Appendix I:

R. v. Kingston (Corporation of the City), (2004) 70 O.R. (3d) 577, (2005) D.L.R. (4th) 734 (Ont. C.A.)

Source: http://www.eprf.ca/ebi/Kingston/Ontario_v_KingstonMay12_2004.html

DATE: 20040512
DOCKET: C38463, C38462
& C38490

COURT OF APPEAL FOR ONTARIO

FELDMAN, SHARPE and GILLESE JJ.A.

BETWEEN:

HER MAJESTY THE QUEEN	Applicant/Appellant
- and -	
THE CORPORATION OF THE CITY OF KINGSTON	Respondent/Respondent
AND BETWEEN:	
HER MAJESTY THE QUEEN	Applicant/Appellant)
- and -	
MIRKA JANUSZKIEWICZ	Respondent/Respondent
AND BETWEEN:	
- and -	
JANET FLETCHER	Applicant/Appellant
- and -	
THE CORPORATION OF THE CITY OF KINGSTON	Respondent/Respondent
- and -	
POLLUTION PROBE	Intervenor

John J. Semenoff and Jerry G. Herlihy for the appellant, Her Majesty the Queen
Robert V. Wright for the appellant, Janet Fletcher
Peter K. Doody for the respondent, City of Kingston

Harry Poch for the respondent, Mirka Januszkiewicz
Paul Muldoon and Theresa A. McClenaghan for the intervenors, Pollution Probe

HEARD: December 2-4, 2003

On appeal from the judgment of Justice David L. McWilliam of the Superior Court of Justice dated June 7, 2002, reported at [2002] O.J. No. 2324.

GILLESE J.A.:

[1] The City of Kingston operated a municipal dump site on the west shore of the Cataraqui River, adjacent to Belle Island, from the early 1950s to the early 1970s. After the dump was closed, the City transformed the site into a recreation area. The City did little to address the environmental problems created by the dump site despite public demands for action and studies that showed that the site was of serious concern.

[2] After testing samples of liquids emanating from the landfill site, Janet Fletcher, an environmentalist, laid charges against the City by means of a private citizen's information. In a separate action, the Ontario Ministry of the Environment laid charges against the City and Mirka Januszkiewicz, the City's Director of Environmental Services and Engineering.

[3] Following a twenty-five day trial, Justice of the Peace Bell convicted the City of all four counts in the private information. He acquitted the City and Ms. Januszkiewicz on the first count in the Ministry's action but convicted them of the other three counts.

[4] On appeal, McWilliam J. of the Superior Court of Justice, allowed the appeals against conviction of the City and Ms. Januszkiewicz and allowed the cross-appeal against acquittal; he ordered a new trial on all counts.

[5] The Crown and Ms. Fletcher appeal on the basis that McWilliam J. erred in his interpretation of s. 36(3) of the Fisheries Act, R.S.C. 1985, c. F-14.

[6] For the reasons that follow, I would allow the appeal, restore the convictions and restore the acquittal.

BACKGROUND

[7] The City of Kingston operated a municipal dump site on the west shore of the Cataraqui River, adjacent to Belle Island, from the early 1950s to the early 1970s. The landfill was created in a marsh in the Cataraqui River and formed a peninsula of garbage. After its closure, the landfill site was transformed into a recreational area but little was done to address the possibility of leachate generation and migration.

[8] Leachate is the term used to describe liquid that emanates from a site after having percolated through it. At a landfill site, leachate is created when rainfall percolates through the site's sandy overburden, dissolving some solids, mixing with liquids and absorbing various gases from the

underlying waste materials. Leachate eventually comes to the surface in seeps and streams. Leachate can also migrate with shallow groundwater.

[9] The charges in the instant case arise from alleged contaminants emanating from the landfill site and entering the Cataraqui River. Ms. Fletcher laid charges by means of a private citizen's information. The Ministry laid separate charges by means of its own information.

[10] On four separate dates, Ms. Fletcher had samples taken of leachate entering the Cataraqui River from the landfill site: December 5, 1996, December 8, 1996, December 14, 1996 and December 17, 1996. These samples were collected from discharges ten to fifteen feet from the bank of the Cataraqui River. The persons collecting Ms. Fletcher's samples did not record the temperature of the leachate at the time the samples were collected.

[11] The Fletcher samples were analysed for "acute lethality" to rainbow trout fingerlings. Rainbow trout is the standard test species for this type of analysis. Acute lethality testing normally involves the placing of test animals in progressively more dilute concentrations of a sample material in order to observe its effect upon them. It is meant to simulate what happens in the field. If the sample material kills a sufficient number of test organisms during an acute lethality test, one can conclude that the sample material is harmful to the environment, fish life or fish habitat.

[12] Ms. Schroeder[1] conducted the acute lethality tests of the Fletcher samples. These tests were performed in accordance with the following Environment Canada protocol: "Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to Rainbow Trout, EPS 1/RM/13". Following this protocol, the samples were aerated and heated to 15ºC plus or minus one degree. Aeration was accomplished by bubbling air through a sample until the sample's oxygen level fell within the accepted range.

[13] The Fletcher samples were tested only at 100% concentration. All of the trout fingerlings that were exposed to the Fletcher samples died within twenty-four hours. Many of these fingerlings died within one hour. Ms. Schroeder testified that the effluent collected in the Fletcher samples was acutely lethal to fish.

[14] As I have already noted, there is no record of the temperature of the Fletcher samples at the time they were collected. However, during the course of the acute lethality testing, the laboratory recorded the temperature and pH[2] of the leachate solutions up to five different times. The temperatures of the samples[3] increased from 11ºC to 14ºC or 15ºC over the course of the testing process. Further, the pH increased from a range of 6.65 to 6.77 (when the samples were received), to a range of 7.23 to 7.27 (when the fish died).

[15] Ms. Schroeder also tested the ammonia levels of the Fletcher samples. She found that those ammonia levels were high enough to account for the mortality of the fish.

[16] After being advised of the analysis results from the testing of the Fletcher samples, the Ministry took its own samples of leachate from the landfill site on four separate dates: February 7, 1997, February 10, 1997, February 19, 1997 and May 6, 1997. Some of the Ministry's samples

were of the leachate discharge as it entered the Cataraqui River and some were of the seep water itself. In addition, upstream samples were taken in order to determine what the "background" readings in the river would have been prior to the ingress of the leachate from the site.

[17] The Ministry leachate samples from February 7, 1997 were taken both from a depressed area right at the river's edge ("sample one") and from an area of open water in the river that was a maximum of two metres from the shore ("sample two").

[18] The Ministry leachate samples from February 10, 1997 were taken at the shoreline where the seepage mixed with the river and at the union of three different rivulets that came out of the ground approximately 1.5 metres from the shoreline. The temperature of the seep water at the point that it entered the river was 4ºC.

[19] The Ministry leachate samples from February 19, 1997 were taken from the same locations as those taken on February 10, 1997. On February 19, 1997, the temperature of the seep water was 5ºC.

[20] The Ministry leachate samples from May 6, 1997 were taken from a seep near a creek about ninety-five paces upstream from where that creek flowed into the Cataraqui River. Its temperature was measured at 6ºC.

[21] The Ministry samples were submitted to a range of tests. The samples from February 10, 1997 and February 19, 1997 were analysed for "acute lethality" to rainbow trout and Daphnia magna, small crustaceans or water fleas used for test purposes. The samples from May 6, 1997 were analysed for "acute lethality" to Daphnia magna only. No acute lethality tests were performed with respect to the Ministry samples from February 7, 1997.

[22] The Ministry's acute lethality tests involving rainbow trout were conducted in accordance with the following Environment Canada protocols: "Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to Rainbow Trout, EPS 1/RM/13" and "Biological Test Method: Acute Lethality Test Using Rainbow Trout, EPS 1/RM/9". The Ministry's acute lethality tests involving Daphnia magna were conducted in accordance with the following Environment Canada protocol: "Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to Daphnia magna, EPS 1/RM/14".

[23] Mr. Lee[4] conducted the Ministry's acute lethality tests involving rainbow trout. In accordance with the rainbow trout protocols, prior to the commencement of each test, the sample under examination was heated to 15ºC and aerated until its oxygen level fell within the accepted range. The samples were tested at a variety of concentrations.

[24] Mr. Lee testified that all rainbow trout exposed to at least a 25% concentration of the leachate samples taken on February 10, 1997 and February 19, 1997 died within twenty-four hours of the test, which was designed to run for four days. All rainbow trout exposed to a 100% concentration of the leachate sample from February 19, 1997 died within three minutes. None of the rainbow trout fingerlings died when placed in the upstream samples. Mr. Lee testified that based on the results from "acute lethality" testing involving rainbow trout of the Ministry

leachate samples from February 10, 1997 and February 19, 1997, there was no doubt in his mind that the leachate was poisonous to aquatic life.

[25] Mr. Poirier[5] conducted the Ministry's acute lethality tests involving Daphnia magna. In accordance with the Daphnia magna protocol, prior to the commencement of each test, Mr. Poirier heated the sample in question to 20ºC. He agitated each sample thoroughly just prior to testing. The samples were tested at a variety of concentrations.

[26] Mr. Poirier testified that based on the acute lethality tests that he conducted on Daphnia magna, he concluded that the Ministry leachate samples from February 10, 1997, February 19, 1997 and May 6, 1997 represented leachate that was deleterious to fish. In addition, Mr. Poirier testified that only two companies have ever submitted an effluent more toxic than the Ministry leachate sample from February 10, 1997.[6] During the test of that sample, 100% of the test organisms placed in that sample died within the first fifteen minutes of the test, which was designed to run for two days. When the leachate was diluted to a 60% concentration (60% effluent and 40% clean water), 92% of the test organisms placed in it were dead within fifteen minutes. When the leachate was diluted to 5% (with 95% clean water), 83% of the test organisms placed in it were dead within forty-three hours.

[27] The Ministry leachate samples were analyzed for chemical parameters including pH and ammonia. According to the chemical analyses of the leachate, the samples from February 7, 1997 were shown to contain 93.8 mg/L of total ammonia and 8.6 mg/L of

total ammonia (samples "one" and "two" respectively), and the sample from May 6, 1997 was shown to contain 31.3 mg/L of total ammonia. By comparison, treated effluent from a sewage treatment plant would contain total ammonia of only 10 to 15 mg/L. Mr. Lee testified that although the acceptable total ammonia concentration for the protection of aquatic life varies with temperature and pH, the very highest number not to be exceeded in any circumstances, according to the guidelines of the Canadian Council of Ministers of the Environment Task Force, is 28.7 mg/L. Mr. Lee testified that the total ammonia values of the Ministry effluent samples from February 7, 1997 and May 6, 1997 were high enough to have been acutely lethal to fish.

[28] The Ministry leachate samples from February 10, 1997 and February 19, 1997 were both shown to contain 127.7 mg/L of total ammonia. Mr. Lee determined that the ammonia concentrations in those two samples were at a level that would cause acute lethality to fish.

[29] All the experts at trial agreed that ammonia was the main toxicant rendering the samples acutely lethal. Ammonia is a naturally occurring substance which, at certain concentration levels, is necessary for life. Ammonia is composed of unionized ammonia (NH_3) and ionized ammonia (NH_4^+). Unionized ammonia is much more toxic than ionized ammonia. The proportion of a solution of total ammonia that is composed of unionized ammonia increases as the temperature and/or pH of the solution increases. Further, the pH of a solution will rise as a result of vigorous shaking and/or aeration.

[30] Some species of fish are more sensitive to unionized ammonia than others. Pink salmon is the species that is most sensitive to unionized ammonia; rainbow trout is the second most

sensitive species. The fact that some species are more sensitive to unionized ammonia than others means that the minimum concentration level of unionized ammonia that will be toxic depends upon the species of fish concerned.

[31] On the Fletcher information, the City was convicted of four counts of unlawfully depositing or permitting the deposit of a deleterious substance in the Cataraqui River, contrary to s. 36(3) of the Fisheries Act, and thereby committing an offence contrary to s. 40(2)(a) of that Act. Each count related to a separate day on which samples of the leachate had been collected.

[32] On the Crown information, the City and Ms. Januszkiewicz were convicted of three of four counts under ss. 36(3) and 40(2)(a) of the Fisheries Act. They were acquitted on the count relating to the Ministry leachate samples collected on February 7, 1997.

[33] On summary conviction appeal, the convictions and the acquittal were set aside and a new trial was ordered. The Crown and Ms. Fletcher appeal from the decision of the appeal judge.

[34] Pollution Probe was granted leave to intervene in this appeal as a friend of the court. Specifically, Pollution Probe was granted intervenor status with respect to the nature, scope and applicability of the precautionary principle as an aid to the interpretation of the Fisheries Act.

THE TRIAL DECISION

[35] The trial judge had no difficulty in finding that the City created and owned the landfill site, was responsible for the site's ongoing operation and maintenance, and had deposited or permitted the deposit of a substance in the Cataraqui River, which was water frequented by fish. As the trial judge noted, the issue that was "hotly contested" was whether the substance in question - the leachate - was deleterious.

[36] In determining whether the leachate was deleterious, the trial judge adopted the test enunciated in R. v. MacMillan Bloedel (Alberni) Ltd. (1979), 47 C.C.C. (2d) 118 (B.C.C.A.), leave to appeal to S.C.C. refused, [1979] 1 S.C.R. xi, holding that the prosecution need only prove that the substance introduced was deleterious or harmful to fish.

[37] The trial judge found that the main toxicant that rendered the samples acutely lethal "was generally agreed to be ammonia" of which "the unionized form was accepted as the most toxic." He found that the samples that had been chemically analysed confirmed the presence of high ammonia concentrations.

[38] At trial, the City and Ms. Januszkiewicz argued that the prosecution had failed to prove that the leachate was deleterious. Among other things, they argued that the pH of the samples had changed between the time the samples were taken and the time they were tested, with the result that the toxicity of the samples had increased when the acute lethality tests were performed. The trial judge rejected this argument on the basis that the testing methodology used by the Crown and Ms. Fletcher had "widespread scientific support", was "fair and impartial" and had been carried out objectively. He characterized the defence argument as "entirely theoretical". The court also noted that the defence had not put forward an in situ sample for analysis.

[39] The trial judge refused to convict on the first count in the Ministry information because of confusion over the date of the chemical analysis of the Ministry sample from February 7, 1997, explaining, "in this confused state, the benefit will go to the Defence."

[40] The court rejected the due diligence defence. Relying on R. v. Sault Ste. Marie (City), [1978] 2 S.C.R. 1299, the trial judge stated that the defence of due diligence involves the characterization of efforts taken to prevent the act or event, including the history of the defendants' efforts for a reasonable period before the charge dates. He found that both the City and Ms. Januszkiewicz were aware that the leachate was flowing into the Cataraqui River and that they chose to ignore the problem.

[41] He concluded:

[T]he Court rejects the defendants' position that they were duly diligent in respect to preventing the discharges. The Court can find no evidence of a comprehensive plan, not even one of effective monitoring of the closed landfill site to detect discharges. Certainly, no effective resources were committed to even dealing with the problems on a haphazard basis.

[42] The court imposed a fine of $30,000 on each of the four privately laid counts and made one half of the fine payable to Ms. Fletcher and one half payable to the Minister of Finance for the Canadian government. The City was given ninety days to pay. Also, the City was ordered to forward to Ms. Fletcher fifteen copies of the final report by Malroz Engineering Inc., an engineering company retained by the City to implement interim seep management measures and conduct a comprehensive environmental site characterization, no later than October 31, 1999 or fifteen days after its presentation to city council, whichever date was sooner.

[43] With regard to the prosecution brought by the Ministry against the City, the court ordered a fine of $10,000 for each of counts two, three and four, totalling $30,000, to be paid within ninety days.

[44] Ms. Januszkiewicz was given a suspended sentence in respect of her convictions on the Ministry information. The sentencing judge reasoned that a suspended sentence was appropriate because other "authors of this misfortune" were not before the court and, although Ms. Januszkiewicz was "not entirely blameless", she was "in the wrong place at the wrong time".

[45] Further, the City was ordered to:

Within three months provide the Ministry with a rationalized long-term site monitoring program indicating whether more or fewer monitoring wells will be required and whether greater or lesser frequency of the sampling will be necessary. The program description should also indicate how future uses of the site may be affected by the presence of contaminants disclosed on sampling and analysis[.]

In addition, the City was ordered to, within twelve months, provide the Ministry with a plan for the capping of the site in accordance with current standards of practice period…. This plan shall involve the evaluation and upgrading of the current cover at the site by the placing of impervious material such as clay to an adequate depth, a site maintenance program involving continuous evaluation of the integrity of the cap, that is, there is a plan for the maintenance program, an inspection program for any seeps, and a contingency plan to deal with any seeps that are found, a surface water management plan addressing both the cap's integrity and the flow quantity and directions of water shed by the cap, and a detailed plan for controlled venting of gases generated by the landfill beneath the impervious cover.

THE SUMMARY CONVICTION APPEAL

[46] The City appealed against conviction and sentence and Ms. Januszkiewicz appealed against conviction. The Crown cross-appealed the acquittal on count one of the Ministry information and appealed the sentence for both the City and Ms. Januszkiewicz.

[47] The appeal judge held that the trial judge erred in applying the test in MacMillan Bloedel to the question of whether the leachate was deleterious. In his opinion, the appropriate test was that set out in R. v. Inco Ltd. (2001), 155 C.C.C. (3d) 383 (Ont. C.A.). He reasoned as follows:

I also see no useful policy reason to find a dichotomy exists between the interpretations given to s. 30(1) of the Ontario Water Resources Act in Inco and s. 36(3) of the Fisheries Act given in MacMillan Bloedel. The "two-tier" test offered by Chief Justice McMurtry in Inco assists in interpreting "a deleterious substance" in s. 36(3) since both the provincial and federal statutes deal, essentially, with "impairing water quality," either per se or those waters "frequented by fish." Consequently unless ammonia was established to be an inherently toxic substance, it would be necessary in my view under s. 36(3) "to consider the quantity and concentration of the discharges as well as the time frame over which the discharge took place." I do not see in the trial judge's reasons that those factors were taken into account in assessing all of the evidence.

[48] The appeal judge concluded that a new trial was necessary. Having allowed the appeal on convictions and concluded that the wrong legal standard had been applied at trial, he held that the Crown ought to succeed in its cross?appeal of the acquittal on count one of the Ministry information.

ISSUES

[49] The main issue to be determined in this appeal is the proper interpretation of s. 36(3) of the Fisheries Act.

[50] In essence, the appellant argues that the offence created by s. 36(3) is made out by proof that a substance discharged into waters frequented by fish is "deleterious" within the meaning of the Act. The appellant Fletcher relies on that argument and, additionally, asks this court to decide whether it is sufficient to show that a substance is acutely lethal to fish to be considered "deleterious" under the Act, whether or not the substance is "inherently toxic".

[51] The respondents, on the other hand, maintain that to make out the offence under s. 36(3), the prosecution must also prove that the substance impairs the receiving water thereby making it deleterious to fish.

[52] In addition, the respondent City submits that the trial judge (1) failed to properly determine whether the appellants had proven beyond a reasonable doubt that the leachate was "toxic" or "deleterious"; (2) failed to consider significant relevant evidence; or (3) erred in holding that the prosecution need not prove that the leachate was deleterious to fish that frequented the Cataraqui River. Further, the respondent Januszkiewicz submits that there was no evidence that the effluent collected in the Ministry sample from May 6, 1997 flowed from the seep where it was collected into the Cataraqui River.

[53] In the event that it is successful on appeal, the Crown asks this court to substitute a conviction with respect to count one of the Ministry information.

THE RELEVANT LEGISLATIVE PROVISIONS

[54] Subsections 34(1) and 36(3) of the Fisheries Act are the key provisions engaged by this appeal. They are set out below. As reference is frequently made to s. 30(1) of the Ontario Water Resources Act, R.S.O. 1990, c. O.40 ("OWRA"), it too is set out below.

[55] Subsection 36(3) of the Fisheries Act is contained within that part of the statute that is headed "Fish Habitat Protection and Pollution Prevention". It provides:

Subject to subsection (4) [deposits authorized by regulation], no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.

[56] Subsection 34(1) defines the term "deleterious substance". The relevant part of s. 34(1) provides:

For the purposes of sections 35 to 43, "deleterious substance" means:

(a) any substance that, if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water[.]

[57] Subsection 30(1) of the OWRA provides that:

Every person that discharges or causes or permits the discharge of any material of any kind into or in any waters or on any shore or bank thereof or into or in any place that may impair the quality of the water of any waters is guilty of an offence.

ANALYSIS

[58] With respect, in my view the appeal judge erred in applying the test set out in Inco to the question of whether the leachate was deleterious for the purposes of s. 36(3) of the Fisheries Act. The Inco test was established in reference to s. 30(1) of the OWRA. As discussed more fully below, the wording of s. 36(3) is markedly different than that of s. 30(1). Moreover, the scope and purposes of the two pieces of legislation is different. Unlike the OWRA, a piece of provincial legislation that focuses on Ontario waters, the Fisheries Act is federal legislation that applies to all waters in the fishing zones of Canada, all waters in the territorial sea of Canada and all internal waters of Canada.

[59] The Supreme Court of Canada has provided clear guidance on the approach to be followed when interpreting legislation: read the words of the provision in context. That is, the words of a provision are to be interpreted by giving them their ordinary and grammatical meaning when read in harmony with the scheme, intent and object of the legislation: see, for example, Re Rizzo & Rizzo Shoes Ltd., [1998] 1 S.C.R. 27 at 40; R. v. Sharpe, [2001] 1 S.C.R. 45 at para. 74 - 5.

[60] Subsection 36(3) of the Fisheries Act, reproduced again below for ease of reference, prohibits persons from (1) depositing or permitting the deposit of (2) a deleterious substance of any type (3) in water frequented by fish or in any place where the deleterious substance may enter such water.

Subject to subsection (4) [deposits authorized by regulation], no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water [emphasis added].

[61] In this case, subsection (4) is not relevant.

[62] In s. 34(1)(a), "deleterious substance" is defined as:

(a) any substance that, if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water.

[63] On an ordinary and plain reading of paragraph (a), a substance is deleterious if, when added to any water, it would alter the quality of the water such that it is likely to render the water deleterious to fish, fish habitat or to the use by man of fish that frequent the water. There is no stipulation in paragraph (a) that the substance must be proven to be deleterious to the receiving water. There is no reference to the receiving water in paragraph (a). On the contrary, the language makes it clear that the substance is deleterious if, when added to any water, it degrades or alters the quality of the water to which it has been added. The "any water" referred to in paragraph (a) is not the receiving water. Rather, it is any water to which the impugned substance is added, after which it can be determined whether the quality of that water is rendered deleterious to fish, fish habitat or the use by man of fish that frequent that water.

[64] I agree with the interpretation of s. 36(3) given by Seaton J.A. in MacMillan Bloedel. As he noted at pp. 121?22: "What is being defined is the substance that is added to the water, rather than the water after the addition of the substance."

[65] The focus of s. 36(3) is on the substance being added to water frequented by fish. It prohibits the deposit of a deleterious substance in such water. It does not prohibit the deposit of a substance that causes the receiving water to become deleterious. It is the substance that is added to water frequented by fish that is defined, not the water after the addition of the substance. A deleterious substance does not have to render the water into which it is introduced poisonous or harmful to fish; it need only be likely to render the water deleterious to fish. The actus reus is the deposit of a deleterious substance into water frequented by fish. There is no requirement in s. 36(3) or paragraph (a) of the definition of the term "deleterious substance" in s. 34(1), of proof that the receiving waters are deleterious to fish.

[66] In R. v. Northwest Falling Contractors Ltd., [1980] 2 S.C.R. 292, the Supreme Court of Canada considered the constitutional validity of s. 33(2) [now s. 36(3)] of the Fisheries Act. In that case, the appellant was charged with violating s. 33(2) as a result of diesel fuel having spilled into tidal waters. In the course of explaining why the provision was constitutionally valid, the Court opined both on the purpose of the legislation and the meaning of s. 33(2). It made the following six pertinent observations at pp. 300?01. (1) Fish, as defined in the legislation, are part of the system that constitutes the fisheries resource. The power to control and regulate that resource must include the authority to protect all those creatures that form part of that system. (2) The legislation is aimed at the protection and preservation of fisheries as a public resource. (3) The provision is concerned with the deposit of deleterious substances in water frequented by fish or in a place where the deleterious substance may enter such water. (4) The definition of a deleterious substance is related to the substance being deleterious to fish. (5) The subsection seeks to protect fisheries by preventing substances deleterious to fish from entering into waters frequented by fish. (6) The provision is restricted to a prohibition of deposits that threaten fish, fish habitat or the use of fish by man.

[67] In my view, the interpretation of s. 36(3) given in MacMillan Bloedel is consonant with the reasoning of the Supreme Court of Canada in Northwest Falling Contractors. Accordingly, I reject the respondents' contention that the Supreme Court of Canada has, by means of its decision in Northwest Falling Contractors, directed the courts to consider the effect of the deposit on the receiving water by means of a consideration of the toxicity of the substance and the circumstances of the discharge.

[68] Those lower courts in Ontario that have followed the reasoning in MacMillan Bloedel, in my opinion, have done so correctly. See, for example, R. v. Cyanamid Canada Inc. (1981), 11 C.E.L.R. 31 at 36?37 (Ont. Prov. Ct. (Crim. Div.)); R. v. Ontario (Ministry of the Environment), [2001] O.J. No. 2581 at paras. 163?71 (Ct. J.); R. v. Jackson (2002), 48 C. E.L.R. (N.S.) 259 at 264 (Ont. Sup. Ct.)

[69] The appellant Fletcher asks this court to determine whether, for the purposes of a prosecution under s. 36(3) under the Fisheries Act, a substance will be considered deleterious if it is shown that the substance is acutely lethal to fish. The question, as phrased, cannot be

answered because it provides insufficient information -- it does not speak to all of the requirements of paragraph (a) of the definition of the term "deleterious substance" in s. 34(1). Paragraph (a) requires proof that the substance, if added to water, alters the quality of the water so that the water is likely to be rendered deleterious to fish. I would add, however, that if a substance, when added to water, alters the water so that the water is acutely lethal to fish, I am of the view that the substance is deleterious.

[70] The respondents argue that although the Crown does not have to prove actual harm or damage to fish or fish habitat when the substance in question is inherently toxic, when the substance is not inherently toxic the Crown must prove that the substance is deleterious at the point it enters the receiving environment. It will be recalled that the trial judge found that ammonia was the main toxicant within the leachate. Ammonia is a naturally occurring substance that can be beneficial and which dissipates quickly in water. This, they argue, necessarily leads to a consideration of the nature and circumstances of the discharge including the length of time over which the discharge occurred and the nature, quality, quantity and concentration of material discharged.

[71] In my view, the essence of the respondents' argument is that the proper test to be applied where the substance is not inherently toxic is that given by this court in Inco.

[72] In Inco, the defendant was alleged to have permitted effluent containing high levels of nickel and iron to be discharged into a river. Charges were laid against the defendant under s. 30(1) of the OWRA. Subsection 30(1) of the OWRA, reproduced again for ease of reference, provides that:

Every person that discharges or causes or permits the discharge of any material of any kind into or in any waters or on any shore or bank thereof or into or in any place that may impair the quality of the water of any waters is guilty of an offence [emphasis added].

[73] As can be seen, s. 30(1) expressly provides that a person who permits the discharge of material into water is guilty of an offence if the discharge "may impair the quality of the water", that is, the water into which the material was discharged.

[74] McMurtry C.J.O., writing for the court in Inco, held that the test established in R. v. Imperial Oil Ltd. (1995), 17 C.E.L.R. (N.S.) 12 (Ont. Ct. J. (Prov. Div.)) should be applied when determining whether an offence under s. 30(1) has been made out. At p. 405, he said this:

Inherently toxic substances will always fail that test, reflecting zero-tolerance for discharging materials that, by their nature, may impair water quality. If the material in the discharge is not inherently toxic, then it will be necessary to consider the quantity and concentration of the discharge as well as the time frame over which the discharge took place. …

Subsection 30(1) prohibits the discharge into water of materials that may impair the quality of any waters [emphasis in original].

[75] In a prosecution pursuant to s. 30(1) of the OWRA, the prosecution must establish that the substance discharged into water has the potential to impair the quality of the water into which it was discharged. In a prosecution pursuant to s. 36(3) of the Fisheries Act, what must be proven is that a substance discharged into water frequented by fish is deleterious. The elements of the two offences are different because the language of the offence?creating provisions is different. In my view, it would be incorrect to apply a test established for prosecutions under s. 30(1) of the OWRA to charges brought pursuant to s. 36(3) of the Fisheries Act.

[76] For this reason, I am of the view that the appeal judge erred not only in making the test under s. 36(3) of the Fisheries Act the same as that under s. 30(1) of the OWRA but also by holding that the trial judge should have made a finding of fact as to whether the leachate was inherently toxic.

[77] Site-specific impairment is not a necessary ingredient of the offence under s. 36(3). Although the second step of the test formulated by this court in Inco relates to substances that are not inherently toxic, the test does not apply to prosecutions under s. 36(3). It applies to prosecutions taken under s. 30(1) of the OWRA, a provision that does focus on impairment of the quality of the receiving water. It may be that one method for proving that a substance, when added to water, renders that water deleterious to fish is through an examination of the nature of the substance and the quantities and concentrations in which it was discharged. However, that does not make such considerations a necessary component of the offence under s. 36(3); rather, it provides a possible form of proof.

[78] Accordingly, in my view, ss. 36(3) and 34(1) cannot be taken as requiring the Crown to prove the nature of the allegedly deleterious substance. The prohibition in s. 36(3) is against the deposit of a deleterious substance "of any type". What must be proven is that the substance, whatever it might be, is a deleterious substance within the meaning of paragraph (a) of the definition of that term in s. 34(1). In this case, it meant that the prosecution had to prove that the leachate, when added to any water, was likely to render the water deleterious to fish or fish habitat or to the use by man of fish that frequent the water. It did not have to prove which component of the leachate was responsible for the degradation or alteration of the quality of the water such that the water was likely to be rendered deleterious to fish. Nor was it obliged to show that fish living in the vicinity of the seep were harmed. It was required only to prove the elements of the offence as set out above.

[79] To the extent that R. v. Pacifica Papers Inc. (2002), 46 C.E.L.R. (N.S.) 93 (B.C. Prov. Ct.), R. v. BHP Diamonds Inc., [2002] N.W.T.J. No. 91 (N.W.T.S.C.) and R. v. Abitibi Consolidated Inc, [2000] N.J. No. 153 (Newf. Prov. Ct.), cases relied upon by the respondents, stand for the proposition that when a substance is not inherently deleterious, the substance's nature and concentration must be proven to be deleterious at the point it enters the receiving environment, I am in respectful disagreement.

APPLICATION TO THE CASE AT BAR

[80] As the appeal judge applied an incorrect legal test when considering the judgment of the trial judge, it falls to this court to determine whether the trial judge erred in concluding that the

elements of the offences alleged under s. 36(3) had been made out. It will be recalled that the elements of the offence to be proven under s. 36(3) are: (1) depositing or permitting the deposit of (2) a deleterious substance (3) in water frequented by fish or where the substance may enter such water.

[81] On the record, there can be no doubt that the trial judge was entirely justified in finding that the respondents had deposited waste in the dump site; that when it rained, some part of the waste or its residue combined with rain water to become leachate; that the leachate seeped into the Cataraqui River; and, that the Cataraqui River is frequented by fish. In the language of s. 36(3), the trial judge was entitled to find that the respondents permitted the deposit of leachate into water frequented by fish.

[82] Did the trial judge err in concluding that the leachate was a deleterious substance within the meaning of the definition of that term in s. 34(1)(a)? That is, did the trial judge err in concluding that the leachate, if added to any water, would alter the quality of that water so that the water was likely rendered deleterious to fish?

[83] The Ministry's acute lethality tests were performed on the Ministry samples at a variety of concentrations. The diluted concentrations were made by adding the leachate to a proportionate amount of water. Given the trial judge's acceptance of the protocols employed and the test results on the diluted Ministry samples, I see no error in his conclusion that the leachate contained in those samples was a deleterious substance within the meaning of paragraph (a) of the definition of that term in s. 34(1).

[84] The tests of the Fletcher samples were performed only on the samples at 100 per cent concentration. In other words, the Fletcher leachate samples were not added to water. The trial judge did not directly address the question of whether the Fletcher samples, if added to water, would have altered the quality of the water thereby rendering it deleterious to fish. The evidence on that point is unclear. On the record before this court, I cannot conclude beyond a reasonable doubt that, had the Fletcher leachate samples been added to water, the water would have been rendered deleterious to fish. As a consequence, the appeal in relation to the Fletcher prosecution must fail.

[85] The intervenor Pollution Probe submits that s. 36(3) must be interpreted in light of the "precautionary principle". It cites 114957 Canada Ltée v. Hudson (Town), [2001] 2 S.C.R. 241 ("114957 Canada") in support of this submission. 114957 Canada concerned the interpretation of s. 410(1) of the Québec Cities and Towns Act, R.S.Q. c. C-19. The Supreme Court held that this provision granted a municipality the authority to adopt a by-law that restricted the use of pesticides within the municipality's territorial limits. L'Heureux-Dubé J., on behalf of the majority of the Court, noted that the Court's interpretation of s. 410(1) was consistent with the "precautionary principle", a principle of international law and policy. L'Heureux-Dubé J. explained at pp. 266-67 that:

The interpretation of By-law 270 contained in these reasons respects international law's "precautionary principle", which is defined as follows at para. 7 of the Bergen Ministerial Declaration on Sustainable Development (1990):

In order to achieve sustainable development, policies must be based on the precautionary principle. Environmental measures must anticipate, prevent and attack the causes of environmental degradation. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

[86] 114957 Canada indicates that the values reflected by the "precautionary principle" may help inform the contextual approach to statutory interpretation. However, the meaning of s. 36(3) of the Fisheries Act is clear and unambiguous. As a consequence, there is no need to resort to the "precautionary principle" as an interpretive guide to the legislative text in question. I note merely that the interpretation of s. 36(3) contained in these reasons is not inconsistent with the "precautionary principle" established under international law.

THE ADDITIONAL ISSUES RAISED BY THE RESPONDENTS

[87] The respondent City raises three additional issues in support of their submission that the appeal should be dismissed. The respondent Januszkiewicz raises a fourth additional issue. I will consider each issue in turn.

A) Reasonable doubt

[88] The respondent City submits that the trial judge erred by failing to determine whether the appellants had proven beyond a reasonable doubt that the leachate contained in the samples was deleterious to fish. I do not accept this submission. Under the heading "THE ACTUS REA OF THE CHARGES", the trial judge explicitly considered whether the leachate contained in the samples was deleterious to fish. He concluded that:

In summary, seven of the eight counts in the charges against the defendants are ruled to be deleterious to fish. The argument made by the defence on these seven charges concerned specifically with this element of the offence are not given credence for the above stated reasons.

[89] The respondents had argued that the results of the acute lethality tests failed to establish that the leachate contained in the samples was deleterious to fish. They argued that the animals used in the acute lethality tests died not as a result of the toxicity of the leachate contained in the samples, but instead as a result of the manner in which the tests were conducted. The trial judge considered this argument and rejected it, concluding that:

By happenstance, in looking at all of the data, the Court does not agree with the Defence's arguments on support of the pH shift as causing the deaths in the bioassays. The argument of the defence is entirely theoretical and scientific experts who wish to overturn accepted science, in this Court's opinion, have to do more than testify in Court.

[90] Under the heading "REASONABLE DOUBT ISSUE", the trial judge cited Cory J.'s statement in R. v. Wholesale Travel Group Inc. (1991), 84 D.L.R. (4th) 161 at 227 that "[t]he Crown must still prove the actus reus of regulatory offences beyond a reasonable doubt." He concluded that:

The Court, after analysing the data presented, considering the arguments put forth by both sides and consulting the relevant case law rejects the reasonable possibilities at issue and has no reasonable doubts as to the commission of the actus reus in seven of the eight charges as outlined above.

[91] Given the trial judge's explicit statements on this element of the offence and the issue of reasonable doubt, it is apparent that the trial judge found that the appellants had proven beyond a reasonable doubt that the leachate contained in the samples was deleterious to fish. The arguments of the respondents concerning the manner in which the acute lethality tests were conducted failed to establish a reasonable doubt. I conclude that the trial judge committed no error of law with respect to this issue.

B) Consideration of significant relevant evidence

[92] The respondent City argues that the trial judge failed to consider significant relevant evidence. Where a trial record, including the reasons for judgment, discloses a lack of appreciation of relevant evidence, an appellate court must intercede: Harper v. The Queen, [1982] 1 S.C.R. 2 at 14. The respondent City claims that there are a number of issues that the trial judge either failed to address or failed to address sufficiently. All of these issues relate to the respondents' argument that the animals that died during the acute lethality tests on the samples died not as a result of the toxicity of the leachate contained in the samples, but instead as a result of the manner in which the acute lethality tests were conducted.

[93] I do not accept this submission. This was a very difficult trial. As the trial judge noted in his reasons:

This was a long trial, twenty-five court days with almost no admitted facts into evidence. Consequently, many witnesses were necessary to establish the legality of a chain of evidence for the samples, the analysis, the charts and exhibits - two hundred and twenty-seven exhibits in all. There were frequent points of law debated. Case law citations numbered over fifty. Ten expert witnesses testified on opposing theories of the key elements of the charges and the Court frequently had to readjust its focus from particular arguments to the overview, that is, the forest was frequently disguised because of the trees.

[94] In spite of these difficulties, the trial judge gave careful consideration to the issue of whether the leachate samples were deleterious to fish. The respondents argued at trial that the samples would not have been found to have been acutely lethal if they had been tested in situ rather than in accordance with Environment Canada protocols on acute lethality testing. The trial found that this argument was "entirely theoretical" and contrary to accepted science. The respondents also argued at trial that the acute lethality tests were not performed in accordance with Environment Canada protocols. The trial judge responded to this claim as follows:

Defence suggested that Drs. Lee and Poirier made errors in their methodology of testing using some quotes from various protocols. However, a careful reading of the whole methodology of the protocols revealed that phrases were taken out of context and the Court was satisfied with the counter arguments and confident that the test methodology was fair and impartial.

A special interpretation of the protocol was proposed by counsellor Doody [counsel for the City] as proof of the unreliability of the Ministry of the Environment laboratory methods. Immediately after the death of the organisms in the effluent, the lab is to conduct temperature and pH measurements. The impracticality and cost of such an interpretation, that is, to have an observer oversee a sample for forty-eight hours to comply with these requests, illustrates a special twist the Defence liked to put on their arguments. The evidence is that all tests are conducted under the same methodology with observations made at timed intervals.

[95] Although the trial judge's reasons are not exhaustive, his reasons nevertheless demonstrate a full understanding of the complex issues of scientific evidence that were before him. I therefore conclude that the record does not disclose a lack of appreciation of relevant evidence.

C) Proof that the leachate was deleterious to fish that frequent the Cataraqui River

[96] The respondent City submits that the trial judge erred in holding that the appellants need not prove that the leachate was deleterious to fish that frequent the Cataraqui River. I do not accept this submission. For the reasons already given, proof that the substance in question is deleterious to the specific species of fish that frequent the water in which the substance is deposited is not an element of the offence in s. 36(3) of the Fisheries Act.

D) The Ministry leachate sample from May 6, 1997

[97] The respondent Januszkiewicz submits that the trial judge erred in convicting the respondents on count four of the Ministry information because there was no evidence that the leachate collected in the Ministry sample from May 6, 1997 flowed from the seep where it was collected into the nearby creek, nor was there evidence that the effluent could have entered the Cataraqui River even if it had reached the creek. This submission is without merit. The trial judge found that:

The Sierra Legal Defence Fund video, which is Exhibit 7, along with evidence of all the samplers characterize the leachate as coming from the ground in the form of seeps or springs running across the ground and into the shore of the river. In some cases where the flow was heavy, channels were cut down to the foreshore to look like small streams. Many of the photographs entered as exhibits also show this situation. Frank Crossley, the Ministry of the Environment's Hydrogeologist, an expert on the movement of ground water through the subsurface, commented that the leachate is formed when the water moves through the soluble materials of the underlying landfill then migrates horizontally in a radial pattern from the high ground to about one metre elevation above the river level. He calculates that the flow from data in the Hill Report as much as twenty tanker loads a day, that's 200,000 litres. Malroz, the company retained by the City of Kingston in March 1997 adopted a remedial action of driving sheet pilings along the periphery to capture the leachate flows and pumping to the sanitary sewer system.

From the massive evidence before the Court, it seems impossible to dispute this element of the offence. The leachate or toxic solution from the landfill site enters the Cataraqui River at the time of these charges.

[98] The Ministry sample from May 6, 1997 contained leachate that was emanating from the dump site. The trial judge found that leachate from the dump site was entering the Cataraqui River at the time this sample was collected. Ms. Januszkiewicz offers no argument that there was any difference between the leachate collected by the Ministry on May 6, 1997 and the "tanker loads" of leachate that flowed into the Cataraqui River on that day. I conclude that the trial judge made no error in this regard.

THE ACQUITTAL ON COUNT ONE OF THE MINISTRY INFORMATION

[99] The appellants maintain that had the appeal judge applied the proper test to count one of the Ministry information, he would have set aside the acquittal and entered a conviction. I disagree.

[100] This court is to defer to findings of fact at first instance absent "a palpable and overriding error": see Housen v. Nikolaisen (2002), 211 D.L.R. (4th) 577 at 582. The trial judge found that the Crown's evidence concerning the Ministry samples from February 7, 1997 - specifically, the date on which the samples were tested - was "in a confused state". On the record before him, he was entitled to make that determination. Having made no palpable and overriding error, I see no reason to interfere with his disposition of count one.

DISPOSITION

[101] Accordingly, I would grant leave to appeal, allow the appeal in part, and set aside that part of the judgment of the Summary Conviction Appeal court that allowed the appeals against conviction of the City and Ms. Januskiewicz in the Ministry's action. The result is to restore the convictions and acquittal at first instance in the Ministry's action. The Crown's sentence appeal is remitted to the Summary Conviction Appeal court to be dealt with accordingly.

RELEASED: 20040512 ("KNF")

"E. E. Gillese J.A."
"I agree K. Feldman J.A."
"I agree Robert J. Sharpe J.A."

---

[1] Ms. Schroeder was qualified as an expert for the private prosecution in the testing of effluent for toxicity in a laboratory.

[2] pH is the measurement of acidity or alkalinity of a sample.

[3] Excepting the sample from December 17, 1996, which had a constant temperature of 14ºC.

[4] Mr. Lee was qualified as a Crown expert witness in the field of aquatic toxicology and impact assessment, including the development and implementation of testing protocols for acute and chronic toxicity to trout.

[5] Mr. Poirier was qualified as a Crown expert witness in aquatic toxicology, including the development and implementation of testing protocols for acute and chronic toxicity.

[6] Mr. Poirier testified that this opinion was based on his review of the data from approximately 15,000 samples.

Appendix II:

Jeremy Moorhouse, "Appendix I — Methodology and Sample Calculations" (Pembina Institute, December 2008)

Appendix 1 – Methodology and Sample Calculations

Jeremy Moorhouse E.I.T.

December 2008

the PEMBINA institute

Sustainable Energy Solutions

About the Pembina Institute

The Pembina Institute creates sustainable energy solutions through research, education, consulting and advocacy. It promotes environmental, social and economic sustainability in the public interest by developing practical solutions for communities, individuals, governments and businesses. The Pembina Institute provides policy research leadership and education on climate change, energy issues, green economics, energy efficiency and conservation, renewable energy and environmental governance. More information about the Pembina Institute is available at http://www.pembina.org or by contacting info@pembina.org.

Appendix 1 – Methodology and Sample Calculations

Table of Contents

List of Tables

List of Figures

1. Data and Detailed Methodology

1.1 Introduction

Environmental Defence contracted Pembina Corporate Consulting (Pembina) to quantify seepage from current and proposed oil sands mining operations. For the purposes of this report seepage is defined as process-affected water that seeps from current and proposed tailings ponds that by-passes proposed mitigation measures. Process-affected water is defined in this report as any water that is contained within external or in pit tailings areas.

Pembina developed five seepage scenarios to understand the range of seepage rates possible using a range of assumptions. The results of one of the more conservative scenarios, scenario 3, are presented in the final report. The methodology, assumptions and data used to develop scenario 3 is discussed in detail in this appendix. A summary of the remaining four scenarios, including key assumptions and a comparison of the results with scenario three is also presented in this document.

For all scenarios Pembina used data from environmental impact assessments whenever possible. However, actual seepage rates that are expected to by pass mitigation measures are not always clear and in some instances do not exist. Table 1 lists the projects included in this assessment, data availability and the estimation technique used.

Table 1: Summary of projects included in assessment and data availability

Project	Data Availability	Estimation Technique
Albian – Muskeg current and expansion	Detailed seepage estimates available in project application	Application values used
Canadian Natural – Horizon Phase 1 and 2	Detailed seepage estimates available in project application.	Application values used
Canadian Natural – Horizon Phase 3 and 4	No publicly available values	Average value used
Imperial – Kearl	Detailed seepage estimates available in project application.	Application values used
Petro-Canada Oil Sands – Fort Hills	Detailed seepage estimates available in project application.	Application values used

Shell Canada Inc. – Jackpine Expansion	Detailed seepage estimates available in project application.	Application values used
Shell Canada Inc. – Jackpine phase 1	Detailed seepage estimates available in project application.	Application values used
Shell Canada Inc. – Pierre River	Detailed seepage estimates available in project application.	Application values used
Suncor - Current	Publicly available records available but not accessible[1]	Average value used
Suncor - Expansions (Voyageur South)	Detailed seepage estimates available but in incompatible format.	Average value used
Syncrude – Announced	No publicly available values	Average value used
Syncrude - Current	Publicly available records available but not accessible	Average value used
Synenco – Northern Lights	Estimates available but not in detail required	Average value used
Total – Deer Creek Announced	No publicly available values	Average value used
Total - Deer Creek Application	Seepage discussed in application but values no provided.	Average value used
UTS/Tek Cominco – Announced	No publicly available values	Average value used

The appendix is divided in to four primary sections. The first section, "Seepage Data from Environmental Impact Assessments" lists reported seepage rates and sources and discusses key assumptions and uncertainties. This section is followed by the "Factor Calculation" sections which illustrates the methodology and calculations used to estimate seepage for projects without publicly-disclosed seepage factors. The third section presents the key assumptions for the other four scenario and compares the results with the third scenario. The final section discusses the limitations associated with the seepage calculations.

[1] Current operations are required to report seepage rates and water quality.

Pembina invite feedback on the data and methodology used. Feedback on the data should be directed towards Jeremy Moorhouse (jeremym@pembina.org, 403-269-3344 ext. 123). The primary goal of this research and report is to determine a realistic and publicly available cumulative value for current and proposed oil sands projects.

1.2 Seepage Data from Environmental Impact Assessments

The following data are used for all scenarios.

1.2.1 Canadian Natural - Horizon

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Canadian Natural – Horizon project are provided in Table 2. The primary assumptions with this data are provided below the table.

Table 2: Seepage lost to deep aquifers

Seepage to Deep Aquifers - Lost		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	0	m3/hr
2011	0	m3/hr
2012	0	m3/hr
2013	0	m3/hr
2014	0	m3/hr
2015	0	m3/hr
2016	0	m3/hr
2017	0	m3/hr
2018	0	m3/hr
2019	0	m3/hr
2020	0	m3/hr
2021	175	m3/hr
2022	346	m3/hr
2023	346	m3/hr
2024	346	m3/hr
2025	346	m3/hr
2026	315	m3/hr
2027	285	m3/hr
2028	284	m3/hr
2029	232	m3/hr
2030	180	m3/hr
2031	180	m3/hr
2032	180	m3/hr
2033	180	m3/hr
2034	500	m3/hr
2035	500	m3/hr

2036	500	m3/hr
2037	500	m3/hr
2038	500	m3/hr
2039	462	m3/hr
2040	347	m3/hr
2041	347	m3/hr
2042	347	m3/hr
2043	347	m3/hr
2044	347	m3/hr
2045	466	m3/hr
2046	466	m3/hr
2047	466	m3/hr
2048	466	m3/hr

Source

Canadian Natural. "Horizon Oil Sands Project: Application for Approval" 2003.

Assumptions:

- Seepage to deep aquifers is assumed to be lost from the mine site and not recoverable by mitigation methods.

1.2.2 Imperial Oil Ventures Ltd. - Kearl

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Imperial Oil Ventures Ltd. – Kearl project are provided in Table 3. The primary assumptions with this data are provided below the table.

Table 3: Seepage lost from site

Seepage Lost to Overburden		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	296.8	m3/hr
2011	1221.5	m3/hr
2012	1929.2	m3/hr
2013	639.3	m3/hr
2014	388.1	m3/hr
2015	285.4	m3/hr
2016	239.7	m3/hr
2017	205.5	m3/hr
2018	205.5	m3/hr
2019	182.6	m3/hr
2020	137.0	m3/hr
2021	91.3	m3/hr
2022	79.9	m3/hr
2023	45.7	m3/hr
2024	45.7	m3/hr
2025	45.7	m3/hr
2026	45.7	m3/hr
2027	45.7	m3/hr
2028	45.7	m3/hr
2029	45.7	m3/hr
2030	34.2	m3/hr
2031	22.8	m3/hr
2032	22.8	m3/hr
2033	11.4	m3/hr
2034	11.4	m3/hr
2035	0	m3/hr
2036	0	m3/hr
2037	0	m3/hr
2038	0	m3/hr

Source

Imperial Oil Resource Ventures Ltd. "Kearl Oil Sands Project - Mine Development: Regulatory Application." 2005. Volume 2, Section 9, Table 5-4

Assumptions:

- Imperial labels seepage as “Seepage to Overburden Sands at ETA”. It is unclear how this seepage escapes the mine site. However, it is assumed to escape as it is included in the outflows of the mine site water balance.
- Imperial assumes no seepage to deep aquifers.

1.2.3 Petro-Canada Oil Sands Inc. – Fort Hills

The data used to estimate seepage lost to the environment associated with the operation of the Canadian Natural – Horizon project are provided in Table 4. The primary assumptions with this data are provided below the table.

Table 4: Seepage lost to deep aquifers

Expected to Pass Interception Wells		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	0	m3/hr
2011	0	m3/hr
2012	0	m3/hr
2013	0	m3/hr
2014	0	m3/hr
2015	0	m3/hr
2016	0	m3/hr
2017	0	m3/hr
2018	0	m3/hr
2019	0	m3/hr
2020	0	m3/hr
2021	574.85	m3/hr
2022	574.85	m3/hr
2023	574.85	m3/hr
2024	574.85	m3/hr
2025	574.85	m3/hr
2026	574.85	m3/hr
2027	574.85	m3/hr
2028	574.85	m3/hr
2029	574.85	m3/hr
2030	574.85	m3/hr
2031	574.85	m3/hr
2032	574.85	m3/hr
2033	574.85	m3/hr
2034	574.85	m3/hr
2035	574.85	m3/hr
2036	574.85	m3/hr
2037	574.85	m3/hr
2038	574.85	m3/hr
2039	574.85	m3/hr
2040	574.85	m3/hr
2041	574.85	m3/hr
2042	574.85	m3/hr
2043	574.85	m3/hr
2044	574.85	m3/hr
2045	574.85	m3/hr
2046	574.85	m3/hr

2047	574.85	m3/hr
2048	574.85	m3/hr
2049	574.85	m3/hr
2050	574.85	m3/hr
2051	574.85	m3/hr
2052	574.85	m3/hr
2053	574.85	m3/hr
2054	574.85	m3/hr
2055	574.85	m3/hr
2056	574.85	m3/hr
2057	574.85	m3/hr
2058	574.85	m3/hr
2059	574.85	m3/hr
2060	574.85	m3/hr
2061	574.85	m3/hr
2062	574.85	m3/hr
2063	574.85	m3/hr
2064	574.85	m3/hr
2065	574.85	m3/hr
2066	574.85	m3/hr
2067	574.85	m3/hr
2068	574.85	m3/hr
2069	574.85	m3/hr
2070	574.85	m3/hr
2071	574.85	m3/hr
2072	574.85	m3/hr
2073	574.85	m3/hr
2074	574.85	m3/hr
2075	574.85	m3/hr
2076	574.85	m3/hr
2077	574.85	m3/hr
2078	574.85	m3/hr
2079	574.85	m3/hr
2080	574.85	m3/hr
2081	574.85	m3/hr

Source

Fort Hills Energy Corporation. "Fort Hills Oil Sands Amendment Application." 2 (2006). Volume 2, Table 8-5 and 8-6 and text.

Assumptions:

- Petro-Canada provided total seepage rates from all ponds that are expected to by pass interception wells.
- This assessment assumes that all seepage that by-passes the interception wells will not be intercepted by other means.

1.2.4 Albian – Muskeg River Mine and Expansion

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Albian – Muskeg River Mine and Expansion project are provided in Table 5. The primary assumptions with this data are provided below the table.

Table 5: Seepage lost to deep aquifers

ETDA Seepage - Basal Aquifer		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	29.17	m3/hr
2011	29.17	m3/hr
2012	29.17	m3/hr
2013	29.17	m3/hr
2014	29.17	m3/hr
2015	29.17	m3/hr
2016	29.17	m3/hr
2017	29.17	m3/hr
2018	29.17	m3/hr
2019	29.17	m3/hr
2020	29.17	m3/hr
2021	29.17	m3/hr
2022	29.17	m3/hr
2023	29.17	m3/hr
2024	29.17	m3/hr
2025	29.17	m3/hr
2026	29.17	m3/hr
2027	29.17	m3/hr
2028	29.17	m3/hr
2029	29.17	m3/hr
2030	29.17	m3/hr
2031	29.17	m3/hr
2032	29.17	m3/hr
2033	29.17	m3/hr
2034	29.17	m3/hr
2035	10.00	m3/hr
2036	10.00	m3/hr
2037	10.00	m3/hr
2038	10.00	m3/hr
2039	10.00	m3/hr
2040	10.00	m3/hr
2041	10.00	m3/hr
2042	10.00	m3/hr
2043	10.00	m3/hr
2044	10.00	m3/hr

2045	10.00	m3/hr
2046	10.00	m3/hr
2047	10.00	m3/hr
2048	10.00	m3/hr
2049	10.00	m3/hr
2050	10.00	m3/hr
2051	10.00	m3/hr
2052	10.00	m3/hr
2053	10.00	m3/hr
2054	10.00	m3/hr
2055	10.00	m3/hr
2056	10.00	m3/hr
2057	10.00	m3/hr
2058	10.00	m3/hr
2059	10.00	m3/hr
2060	10.00	m3/hr
2061	10.00	m3/hr
2062	10.00	m3/hr
2063	10.00	m3/hr
2064	10.00	m3/hr
2065	10.00	m3/hr
2066	10.00	m3/hr
2067	10.00	m3/hr
2068	10.00	m3/hr
2069	10.00	m3/hr
2070	10.00	m3/hr
2071	10.00	m3/hr
2072	10.00	m3/hr
2073	10.00	m3/hr
2074	10.00	m3/hr
2075	10.00	m3/hr
2076	10.00	m3/hr
2077	10.00	m3/hr
2078	10.00	m3/hr
2079	10.00	m3/hr
2080	10.00	m3/hr
2081	10.00	m3/hr

Source

Shell Canada Ltd. "Application for the Approval of the Muskeg River Mine Expansion Project." 2005.

Assumptions:

- External Tailings Disposal Area (ETDA) pit seepage is not intercepted by any method. All other seepage is assumed to be captured by mitigation measures.

- Backfilled pits do not seep.
- The 10 m^3/hr seepage rate continues into the far future

1.2.5 Shell Canada Inc. – Jackpine Mine

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Canadian Natural – Horizon project are provided in Table 6. The primary assumptions with this data are provided below the table.

Table 6: Seepage lost to basal aquifer

ETDA Seepage - Basal Aquifer		
Year	Value	Unit
2007	0	m3/hr
2008	0	m3/hr
2009	282.500	m3/hr
2010	282.500	m3/hr
2011	282.500	m3/hr
2012	282.500	m3/hr
2013	282.500	m3/hr
2014	282.500	m3/hr
2015	282.500	m3/hr
2016	282.500	m3/hr
2017	282.500	m3/hr
2018	282.500	m3/hr
2019	282.500	m3/hr
2020	282.500	m3/hr
2021	282.500	m3/hr
2022	282.500	m3/hr
2023	282.500	m3/hr
2024	282.500	m3/hr
2025	282.500	m3/hr
2026	282.500	m3/hr
2027	282.500	m3/hr
2028	282.500	m3/hr
2029	282.500	m3/hr
2030	282.500	m3/hr
2031	282.500	m3/hr
2032	4.25	m3/hr
2033	4.25	m3/hr
2034	4.25	m3/hr
2035	4.25	m3/hr
2036	4.25	m3/hr
2037	4.25	m3/hr
2038	4.25	m3/hr
2039	4.25	m3/hr
2040	4.25	m3/hr
2041	4.25	m3/hr
2042	4.25	m3/hr
2043	4.25	m3/hr
2044	4.25	m3/hr

2045	4.25	m3/hr
2046	4.25	m3/hr
2047	4.25	m3/hr
2048	4.25	m3/hr
2049	4.25	m3/hr
2050	4.25	m3/hr
2051	4.25	m3/hr
2052	4.25	m3/hr
2053	4.25	m3/hr
2054	4.25	m3/hr
2055	4.25	m3/hr
2056	4.25	m3/hr
2057	4.25	m3/hr
2058	4.25	m3/hr
2059	4.25	m3/hr
2060	4.25	m3/hr
2061	4.25	m3/hr
2062	4.25	m3/hr
2063	4.25	m3/hr
2064	4.25	m3/hr
2065	4.25	m3/hr
2066	4.25	m3/hr
2067	4.25	m3/hr
2068	4.25	m3/hr
2069	4.25	m3/hr
2070	4.25	m3/hr
2071	4.25	m3/hr
2072	4.25	m3/hr
2073	4.25	m3/hr
2074	4.25	m3/hr
2075	4.25	m3/hr
2076	4.25	m3/hr
2077	4.25	m3/hr
2078	4.25	m3/hr
2079	4.25	m3/hr
2080	4.25	m3/hr
2081	4.25	m3/hr

Source:

Shell Canada Ltd. "Application for Approval of the Jackpine Mine - Phase 1." 2002. Volume 3, page 4-49, and Table 4.4-8

Assumptions:

- The seepage rates presented above are assumed to by pass mitigation measures.
- The values above are based on snap shots provided in the EIA

- The seepage rate of 4.25 m^3/hr is assumed to continue into the far future

1.2.6 Shell Canada Inc. – Jackpine Expansion

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Canadian Natural – Horizon project are provided in Table 7. The primary assumptions with this data are provided below the table.

Table 7: Seepage lost to deep aquifers

ETDA Seepage - Seepage to Aquifer from ETDA		
Year	Value	Unit
2007	0	m^3/hr
2008	0	m3/hr
2009	0	m3/hr
2010	0	m3/hr
2011	0	m3/hr
2012	0	m3/hr
2013	0	m3/hr
2014	0	m3/hr
2015	78.767	m3/hr
2016	157.534	m3/hr
2017	264.840	m3/hr
2018	374.429	m3/hr
2019	476.027	m3/hr
2020	583.333	m3/hr
2021	692.922	m3/hr
2022	801.370	m3/hr
2023	864.155	m3/hr
2024	864.155	m3/hr
2025	864.155	m3/hr
2026	0.000	m3/hr
2027	0.000	m3/hr
2028	0.000	m3/hr
2029	0.000	m3/hr
2030	0.000	m3/hr
2031	0.000	m3/hr
2032	0.000	m3/hr
2033	0.000	m3/hr
2034	0.000	m3/hr
2035	0.000	m3/hr
2036	0.000	m3/hr
2037	0.000	m3/hr
2038	0.000	m3/hr
2039	0.000	m3/hr
2040	0.000	m3/hr
2041	0.000	m3/hr
2042	0.000	m3/hr

2043	0.000	m3/hr
2044	0.000	m3/hr
2045	0.000	m3/hr
2046	0.000	m3/hr
2047	0.000	m3/hr
2048	0.000	m3/hr
2049	0.000	m3/hr
2050	0.000	m3/hr
2051	0.000	m3/hr
2052	0.000	m3/hr
2053	0.000	m3/hr
2054	0.000	m3/hr
2055	0.000	m3/hr
2056	0.000	m3/hr
2057	0.000	m3/hr
2058	0.000	m3/hr
2059	0.000	m3/hr
2060	0.000	m3/hr
2061	0.000	m3/hr
2062	0.000	m3/hr
2063	0.000	m3/hr
2064	0.000	m3/hr
2065	0.000	m3/hr
2066	0.000	m3/hr
2067	0.000	m3/hr
2068	0.000	m3/hr
2069	0.000	m3/hr
2070	0.000	m3/hr
2071	0.000	m3/hr
2072	0.000	m3/hr
2073	0.000	m3/hr
2074	0.000	m3/hr
2075	0.000	m3/hr
2076	0.000	m3/hr
2077	0.000	m3/hr
2078	0.000	m3/hr
2079	0.000	m3/hr
2080	0.000	m3/hr
2081	0.000	m3/hr

Source

Shell Canada Limited. "Application for Approval of the Jackpine Mine Expansion & Pierrer River Mine Project - Environmental Impact Assessment." Calgary, 2007. Volume 1 Table 10-2, pg. 10-14

Assumptions:

- Seepage to Aquifer from the external tailings disposal area is the only source of seepage on site.
- Far future seepage is not included in this assessment.

1.2.7 Suncor – Tar Island Dyke

The data used to estimate seepage that escapes mitigation measures associated with the operation of the Suncor – Tar Island Dyke project are provided in Table 8. The primary assumptions with this data are provided below the table.

Table 8: Seepage lost to deep aquifers

Seepage to Deep Aquifers - Lost			Construction Water Seepage		
Year	Value	Unit	Year	Value	Unit
2007	7.2	m3/hr	2007	234	m3/hr
2008	7.2	m3/hr	2008	234	m3/hr
2009	7.2	m3/hr	2009	234	m3/hr
2010	7.2	m3/hr	2010	234	m3/hr
2011	7.2	m3/hr	2011	234	m3/hr
2012	7.2	m3/hr	2012	0	m3/hr
2013	7.2	m3/hr	2013	0	m3/hr
2014	7.2	m3/hr	2014	0	m3/hr
2015	7.2	m3/hr	2015	0	m3/hr
2016	7.2	m3/hr	2016	0	m3/hr
2017	7.2	m3/hr	2017	0	m3/hr
2018	7.2	m3/hr	2018	0	m3/hr
2019	7.2	m3/hr	2019	0	m3/hr
2020	7.2	m3/hr	2020	0	m3/hr
2021	7.2	m3/hr	2021	0	m3/hr
2022	7.2	m3/hr	2022	0	m3/hr
2023	7.2	m3/hr	2023	0	m3/hr
2024	7.2	m3/hr	2024	0	m3/hr
2025	7.2	m3/hr	2025	0	m3/hr
2026	7.2	m3/hr	2026	0	m3/hr
2027	7.2	m3/hr	2027	0	m3/hr
2028	7.2	m3/hr	2028	0	m3/hr
2029	7.2	m3/hr	2029	0	m3/hr
2030	7.2	m3/hr	2030	0	m3/hr
2031	7.2	m3/hr	2031	0	m3/hr
2032	7.2	m3/hr	2032	0	m3/hr
2033	7.2	m3/hr	2033	0	m3/hr
2034	7.2	m3/hr	2034	0	m3/hr
2035	7.2	m3/hr	2035	0	m3/hr
2036	7.2	m3/hr	2036	0	m3/hr
2037	7.2	m3/hr	2037	0	m3/hr
2038	7.2	m3/hr	2038	0	m3/hr
2039	7.2	m3/hr	2039	0	m3/hr
2040	7.2	m3/hr	2040	0	m3/hr
2041	7.2	m3/hr	2041	0	m3/hr
2042	7.2	m3/hr	2042	0	m3/hr
2043	7.2	m3/hr	2043	0	m3/hr

2044	7.2	m3/hr	2044	0	m3/hr
2045	7.2	m3/hr	2045	0	m3/hr
2046	7.2	m3/hr	2046	0	m3/hr
2047	7.2	m3/hr	2047	0	m3/hr
2048	7.2	m3/hr	2048	0	m3/hr

Source

Grace P. Hunter. "Investigation of Groundwater Flow within an Oil Sand Tailings Impoundment and Environmental Implications." University of Waterloo, 2001.

Jim Barker, Dave Rudolph, Trevor Tompkins, Alex Oiffer, Francoise Gervais, . "Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada." Paper presented at the IPEC 2007.

Assumptions:

- Seepage of construction water will reduce to zero m^3/hr over the next five years.
- Seepage through the base of the pond will continue into the far future 2080

1.3 Factor Calculation

1.3.1 Introduction

Several oil sands mines do not have seepage data for a variety of reasons. Proponents of projects in early stages of development have not completed detailed water balances. In other instances projects with impact assessments did not provide detailed information on seepage rates expected to by-pass mitigation measures. Current projects do report seepage rates and seepage water quality to the Government of Alberta. In spite of numerous requests for this information Alberta Environment did not make this information available for this assessment.

The methodology and key assumptions discussed below are for scenario three. The remaining four scenarios used a similar methodology; however, some key assumptions are different. The differences between scenario three and the other four scenarios is discussed in the Other Scenarios section.

1.3.2 Methodology

This assessment estimated seepage for these projects using the following methodology.

The following describes Pembina's methodology to develop seepage rates for current and proposed oil sands mines:

1. Pembina first converted the available seepage rates into production intensity basis (m^3 seepage / m^3 production).
2. Pembina then developed two average seepage factors: one for the beginning of a project (the beginning seepage rate) and the other for the end of project (the end seepage rate). This technique is used to simulate the sealing of ponds overtime.
    a. The beginning seepage rate is based on the average seepage intensity *over the life of the project*. Pembina used the average seepage intensity over the life of the project to make the calculations more conservative. Some of the EIA data project that tailings ponds will seep more at the beginning of operations than at the end. The average seepage rate over the life of a tailings pond is, therefore, lower than the seepage at the beginning of operations. Table 9 contains the calculated average seepage rate based on the data provided for each mine in the section above.

Table 9: Average seepage rates for six proposed oil sands mines

Project	Average Seepage Rate (m^3 Seep / m^3 bitumen produced)
Canadian Natural – Horizon	0.20
Imperial Oil Resources Ventures Limited (Imperial Oil) - Kearl	0.12
Petro-Canada Oil Sands Inc. – Fort Hills	0.46

Albian Sands – Muskeg River Mine (Current and Expansion)[2]	0.04
Shell Canada Ltd. – Jackpine	0.39
Shell Canada Ltd. – Jackpine Expansion and Pierre River	0.37
Average	**0.26**

b. The end seepage rate is based on a seepage reduction factor. Pembina used this method to address sealing in current tailings ponds. For example, a University of Waterloo study found that at Suncor's Pond 1 (Tar Island), "The thick sequence of fine tailings and residual bitumen below the pond, and the unsaturated zone that has developed in the underlying sand tailings, form an effective hydraulic barrier to flow. As a result, drainage flows form the oil sand tailings impoundment are lower and will approach steady state sooner than if pond water were freely flowing into the sand tailings."[3] Projected seepage rates for the Muskeg River Mine Expansion, Jackpine and Jackpine expansion[4] demonstrate this reduced seepage rate. The average seepage reduction rate based on these three projects is 84%. Using the average seepage rate calculated above the end of project seepage rate is 0.04 m^3/m^3 production.

3. Pembina then estimated seepage rates based on bitumen production for current and proposed oil sands mines without seepage data using the two seepage factors (0.26 m^3/m^3 and 0.04 m^3/m^3). The beginning seepage rate is applied during the first 18 years of operations.[5] The end seepage rate is used during the remaining years of operation.
4. Pembina then aggregated the seepage rates to generate total seepage rates per year.

---

[2] The seepage reported by Albian Sands is significantly lower than other projects. Pembina is unclear as to why this value is lower.

[3] Grace P. Hunter (2001). Investigation of Groundwater Flow Within an Oil Sand Tailings Impoundment and Environmental Implications. Earth Sciences, University of Waterloo. **Master of Science:** 363.

[4] The data presented in the data tables for Jackpine Expansion does not demonstrate this reduced seepage rate. However, specific pond seepage rates are discussed in more detail in the project application, see Shell Canada Limited. "Application for Approval of the Jackpine Mine Expansion & Pierrer River Mine Project - Environmental Impact Assessment." Calgary, 2007. ETDA seepage, pg. 6-211 table 6.3-18

[5] Three project clearly projected reduced seepage over time (Muskeg River Mine Expansion, Jackpine and Jackpine expansion). For these three projects the average time period until a reduced seepage rate is projected in a given tailings pond is 18 years.

1.3.3 Example Calculations

The following demonstrates the calculation methodology used for developing estimated seepage values for one proposed mine, Suncor Voyageur South. The expected start up time for Suncor Voyageur South is 2011 with production of 18,216 m^3 bitumen/day.[6]

Where,

BP = Bitumen Production (m^3/d)

SF_b = Beginning seepage factor (m^3 seepage / m^3 production)

SF_e = End seepage factor (m^3 seepage / m^3 production)

S_e = Estimated Seepage (m^3/d)

Then,

$$S_e = SF_b \times BP$$

Given,

BP = 18,216(m^3/day)

SF_b = 0.26 (m^3/m^3)

SF_e = 0.04 (m^3/m^3)

Then seepage for the first 18 years will be calculated using the beginning seepage factor as below,

$$S_e = 18{,}216(m^3 / day) \times 0.26(m^3 / m^3)$$

$$S_e = 4736(m^3 / day)$$

The seepage for the remainder of the project will be calculated using the end seepage factor as below,

$$S_e = 18{,}216(m^3 / day) \times 0.04(m^3 / m^3)$$

$$S_e = 728(m^3 / day)$$

The analysis made similar calculations for all proposed projects.

---

[6] Dunbar, B. (2008). "Existing and Proposed Canadian Commercial Oil Sands Projects." Retrieved November 20, 2008, from http://www.strategywest.com/downloads/StratWest_OSProjects.pdf.

Table 10: Summary of estimated seepage rates per project

Project	Production (m^3/day)	Beginning Seepage Rate (m^3/day)	End Seepage Rate (m^3/day)
Canadian Natural – Horizon Phase 3 and 4	48,800	12,816	2,054
Suncor – Current[7]	46,728[8]	1,968	1,968
Suncor – Expansions (Voyageur South)	19,000	5,016	804
Syncrude Current[9]	64,713	2,724	2,724
Syncrude – Announced	29,568	7,776	1,246
Synenco – Northern Lights	18,206	4,788	765.6
Total – Deer Creek Announced	15,900	4,180	669.6
Total - Deer Creek Application	15,900	4,180	669.6
UTS/Tek Cominco – Announced	33,391	8,784	1,404

1.4 Other Scenarios

Pembina developed 4 other scenarios in order to assess the range of seepage values possible by varying key assumptions in the model. As all scenarios use the same base EIA information (see the Seepage Data from Environmental Impact Assessments section) the differences between the scenarios result from how Pembina used the EIA data to develop generic seepage factors. The seepage factor is the most influential variable on the results of each scenario in Pembina's

[7] Excludes Tar Island. Also, all of Sunco'r current ponds are considered as sealed because they have been in operation for a longer period of time.

[8] Assumed maximum current production. Actual production may be lower.

[9] Production is based on maximum potential production as per Dunbar, B. (2008). "Existing and Proposed Canadian Commercial Oil Sands Projects." Retrieved November 20, 2008, from http://www.strategywest.com/downloads/StratWest_OSProjects.pdf. Actual production may be lower. All Syncrude ponds are assumed to be sealed.

seepage model. These differences are discussed in detail below. This discussion is followed by a comparison of the results for each of the scenarios.

Scenario 3 is the scenario used in the report and is summarized first below, followed by the other scenarios.

1.4.1 Scenario 3 – Report Scenario

There are three main assumptions associated with scenario 3 that are varied for the other assumptions.

1. **Beginning and End Seepage Factor:** Scenario 3 uses two seepage factors. One used to estimate the seepage at the beginning of a project and the other to estimate the seepage near the end of the project. The intent of the two seepage factors is to incorporate the concept of tailings ponds sealing over time.
2. **Seepage Factor Basis:** The beginning seepage factor is based on an average of projected seepage rates available in EIAs (0.26m^3 seepage/m^3 production). The end seepage factor is based on an 85% reduction in this seepage rate (0.04 m^3 seepage / m^3 production). The 85% reduction value is calculated from the projected decrease in seepage from three proposed tailings ponds (see the factor calculation section above for more details).
3. **Sealing:** Scenario 3 assumes all current ponds are sealed and that future ponds will seal after 18 years[10]. Sealed ponds are still assumed to seep but at a much reduced rate (85% lower).

1.4.2 Scenario 1 – Average

Scenario 1 differs in two important ways in comparison with Scenario 3:

1. **Beginning and End Seepage Factor:** Scenario 1 does not disaggregate seepage rates into beginning and end. Only one seepage rate is used over the life of proposed and current projects without seepage data.
2. **Seepage Factor Basis:** As in Scenario 3, Scenario 1 uses a seepage factor based on the average seepage of all projects with EIAs. This seepage factor is 0.26 m^3/m^3 production. However, unlike scenario 3, scenario 1 does not assume ponds seal over time. The average seepage factor is applied over the entire project life.

[10] Three project clearly projected reduced seepage over time (Muskeg River Mine Expansion, Jackpine and Jackpine expansion). For these three projects the average time period until a reduced seepage rate is projected in a given tailings pond is 18 years.

3. **Sealing:** Scenario 1 assumes current tailings ponds have not sealed and applies the average seepage factor to current operations as well.

1.4.3 Scenario 2 – Current Ponds Sealed

Scenario 2 is very similar to scenario 3 but does not apply an end seepage factor. Specific differences and similarities are discussed below.

1. **Beginning and End Seepage Factor:** Scenario 2 uses two seepage factors. One used to estimate the seepage at the beginning of a project and the other to estimate the seepage of current projects. The intent of the two seepage factors is to address the fact that current tailings ponds at Suncor and Syncrude's facilities have likely sealed over time and so seep less then a new tailings pond would.
2. **Seepage Factor Basis:** The beginning seepage factor is based on an average of projected seepage rates available in EIAs (0.26m^3 seepage/m^3 production). This factor is applied to all future projects without seepage data. A different seepage factor is applied to current operation and is calculated in the same way as the end seepage factor is calculated for scenario 3. That is it is 85% lower than the average seepage rate (0.04 m^3 seepage / m^3 production).
3. **Sealing:** Scenario 2 assumes all current ponds are sealed but future ponds will seep at the average rate over their lifetime.

1.4.4 Scenario 4 – Most conservative

Scenario 4 is also very similar to scenario 3; however, it uses the lowest reported seepage rate in place of the average seepage rate used in scenario 3.

4. **Beginning and End Seepage Factor:** Scenario 4 uses the beginning and end seepage factors in the same manner as scenario 3. However, the factors themselves are different.
5. **Seepage Factor Basis:** The beginning seepage factor is based on the lowest reported seepage rate (Albian Sands – Muskeg River Mine Expansion – 0.04 m^3 seepage / m^3 production). The beginning seepage factor is applied during the first 18 years of the projects life. The end seepage factor is 85% lower then this value (0.006 m^3 seepage / m^3 production). The end seepage factor is applied for the remaining years of the project.
6. **Sealing:** Scenario 4 assumes all current ponds are sealed and future ponds will seal after 18 years of operation. Sealed ponds will seep 0.006 m^3 per m^3 of production.

1.4.5 Scenario 5 – Match Profile

Scenario 5 is also very similar to scenario 3; however, it attempts to match the seepage profile of reported seepage rates.

7. **Beginning and End Seepage Factor:** Scenario 5 also uses beginning and end seepage factors; however they are calculated differently than in scenario 1.
8. **Seepage Factor Basis:** The beginning seepage factor is based on the average reported seepage rate of projects with EIAs during their startup period. The seepage value calculated using this methodology is 0.73 m^3 seepage / m^3 production. Similarly an end seepage rate is calculated from reported seepage rates. The seepage value is 0.161 m^3 seepage per m^3 production. The beginning seepage factor is applied during the first 18 years of the projects life (for projects without seepage rates reported in EIAs). The end seepage factor is applied for the remaining years of the project.
9. **Sealing:** Scenario 5 assumes all current ponds are sealed and future ponds will seal after 18 years of operation. Sealed ponds will seep 0.161 m^3 per m^3 of production.

1.4.6 Comparison

Table 11 presents a summary of key assumptions and seepage results for each scenario.

Table 11: Summary of key assumptions and results for each scenario

Scenario	Beginning Seepage Factor (m^3 seepage / m^3 production)	End Seepage Factor (m^3 seepage / m^3 production)	Total Seepage (Mm^3 present – 2080)	Peak Seepage (Mm^3 /yr)	Year of Peak Seepage
1 – Average	0.26	0.26	2293	36	2012
2 – Current Ponds Sealed	0.26	0.04[11]	1587	26	2012
3 – Report	0.26	0.04	945	26	2012
4 – Conservative	0.04	0.006	405	21	2012
5 – Mirror	0.73	0.161	1967	57	2024

Total seepage (the sum of seepage from all projects between now and 2080) is estimated to be between 405 Mm^3 and 2293 Mm^3. Scenario 3, the scenario used in the report, estimates total seepage at 945 Mm^3 which is relatively conservative given the range of seepage values.

Figures 1 to 5 below profile the annual seepage rates per scenario for current projects, projects with applications and proposed projects. Current projects include Suncor, Syncrude and Albian.

[11] Only applied to current ponds

Projects with applications include all approved projects and those with approvals pending but with project applications. Proposed projects include all other projects. A total list of projects included in this assessment is available in Table 1.

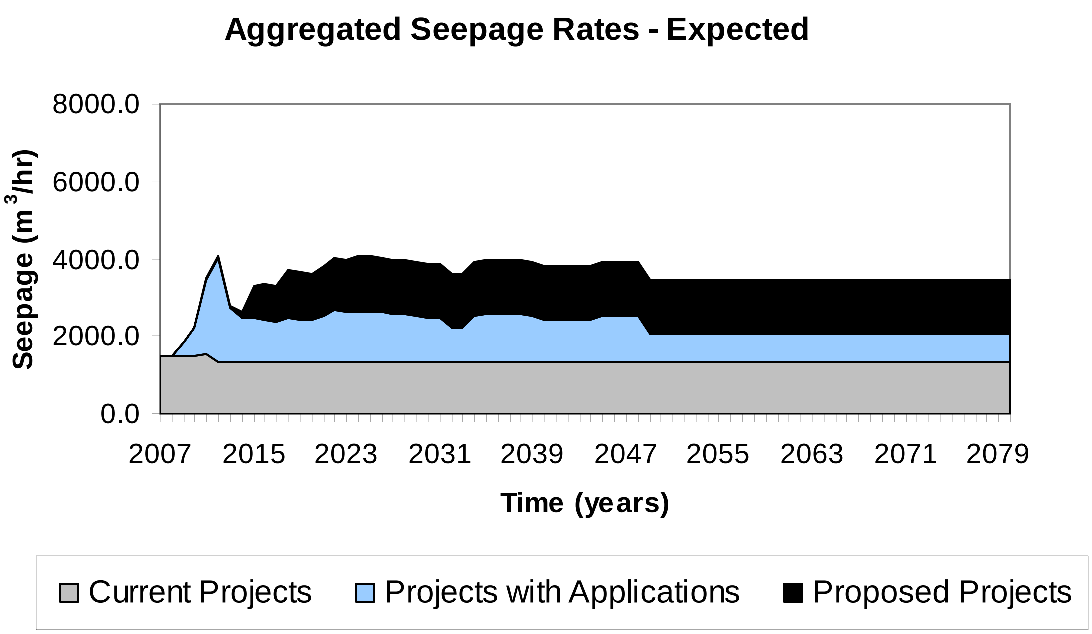


Figure 1: Scenario 1 – Projected seepage rates for current and proposed projects

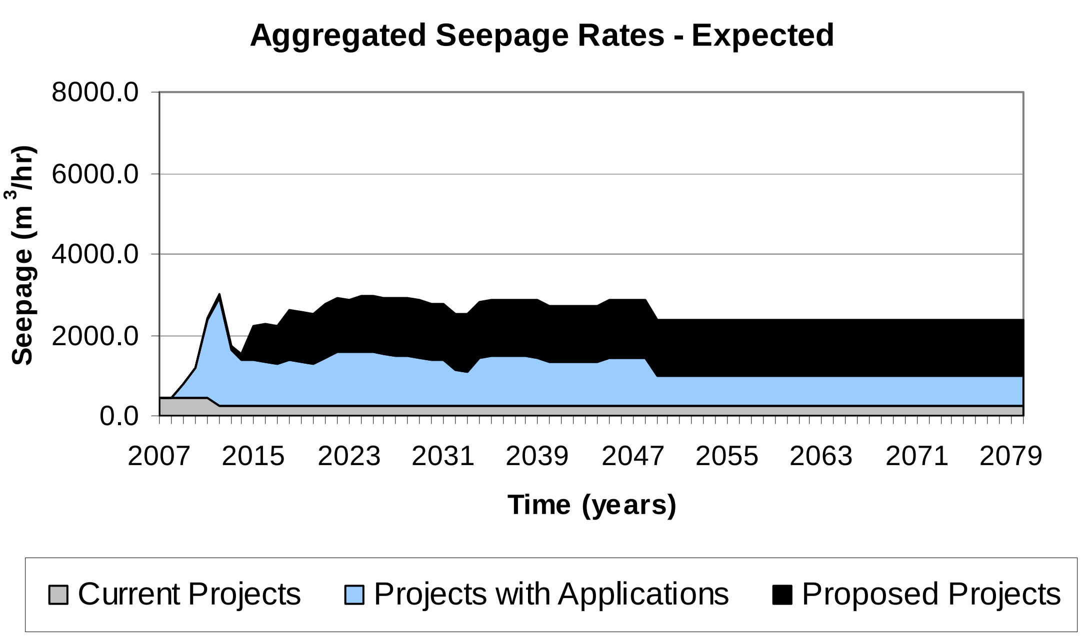


Figure 2: Scenario 2 – Projected seepage rates for current and proposed projects

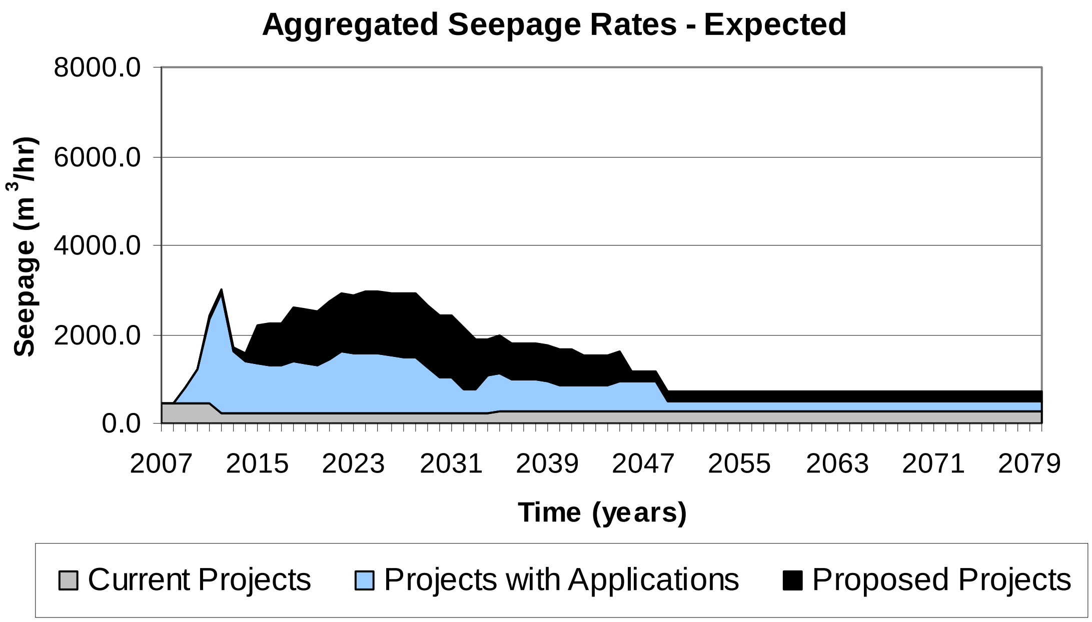


Figure 3: Scenario 3 - Projected seepage rates for current and proposed projects

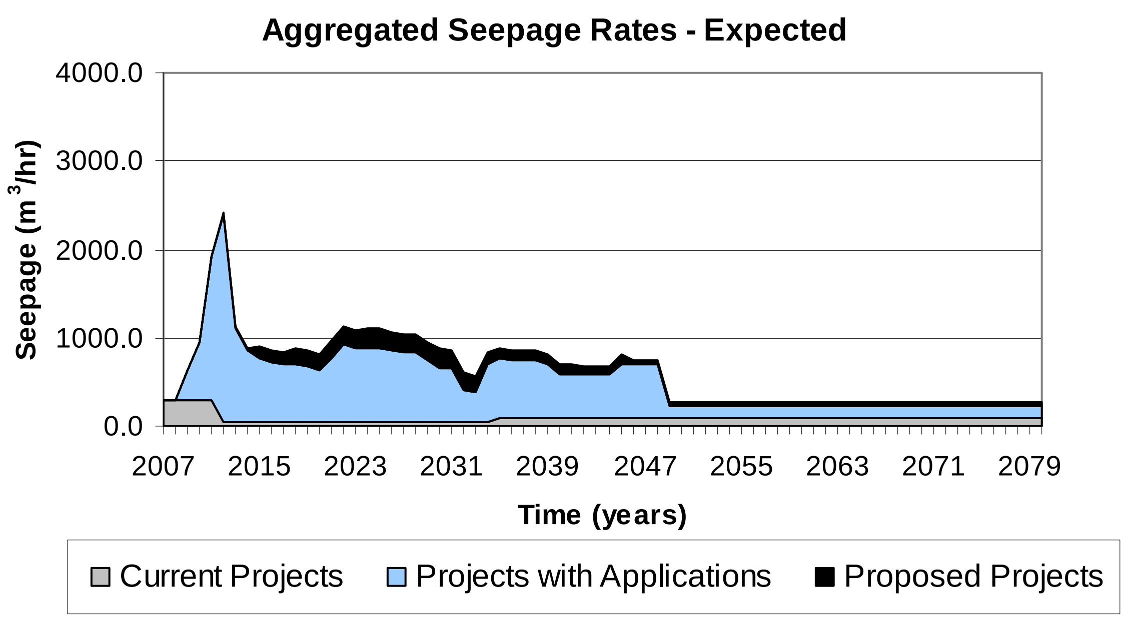


Figure 4: Scenario 4 – Projected seepage rates for current and proposed projects

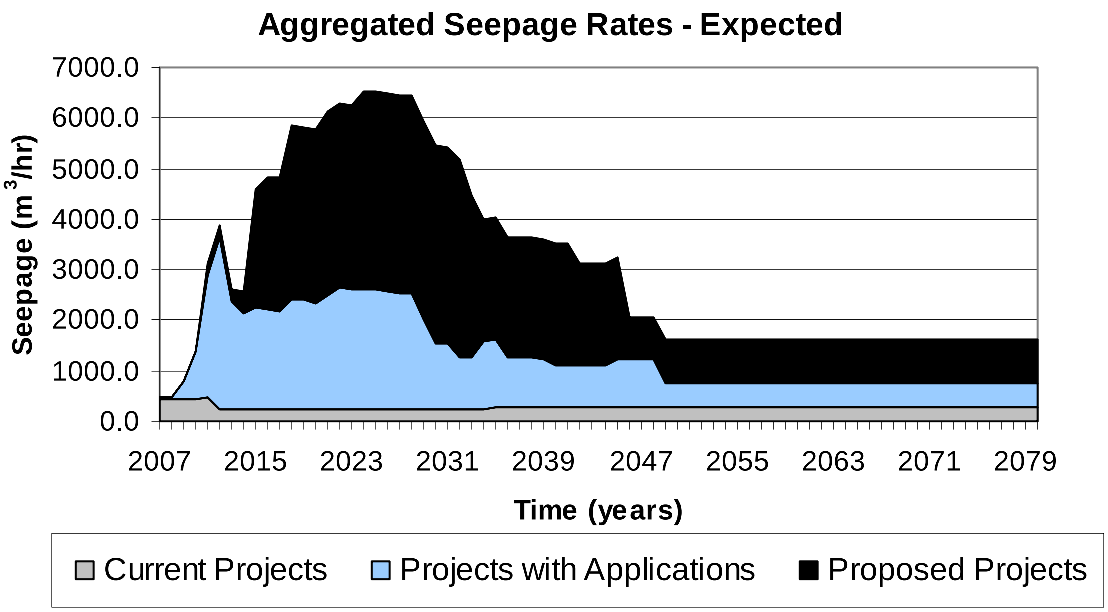


Figure 5: Scenario 5 – Projected seepage rates for current and proposed projects

For information on Pembina's methodology and data used please contact Jeremy Moorhouse at jeremym@pembina.org or at 403-269-3344 ext. 123.

1.5 Limitations

Although the methodology and calculations described and presented above are intended to be conservative estimates of current and proposed seepage rates, there are several limitations in their calculation. These are:

- Slowdown: Changes in project timelines as a result of the current financial uncertainty are not incorporated into this analysis.
- Use of Averages: The analysis used herein to estimate seepage rates for projects without seepage data does not account for the geological characteristics of each individual site. Where information is unavailable at the time of writing, averages are based on information published by the project proponents.
- Fate of the Seepage: This analysis does not attempt to determine the final (receiving water bodies), or even the immediate fate of the seepage (specific receptors such as the basal aquifer). The intent of this analysis is to estimate the rate of process affected seepage that is projected to by-pass mitigation measures.
- The Very Long-Term: Decommissioning a mine includes constructing end pit lakes and incorporating tailings into the landscape. Both end pit lakes and tailings will seep process-affected water into groundwater. This analysis does not attempt to quantify seepage rates for these sources over the very long term (i.e. more than several decades into the future).
- Current Tailings Ponds: Seepage rates for current ponds should be based on reported seepage rates that are publicly available information. Pembina requested these public documents on seepage rates from current tailings facilities from Alberta Environment. However, Alberta Environment did not provide these documents. In the absence of this data Pembina generated estimates as described in the methodology above.

Appendix III:

Matt Price, "1 Million Litres a Day: The Tar Sands' Leaking Legacy" (Environmental Defence, December 2008)

11 MILLION LITRES A DAY

THE TAR SANDS' LEAKING LEGACY

DECEMBER 2008

ENVIRONMENTAL | DEFENCE

ENVIRONMENTAL DEFENCE protects the environment and human health. We research solutions. We educate. We go to court when we have to. All in order to ensure clean air, clean water and thriving ecosystems nationwide, and to bring a halt to Canada's contribution to climate change.

ACKNOWLEDGEMENTS

Author – **Matt Price**

ENVIRONMENTAL DEFENCE would like to thank the people who reviewed the report and provided feedback.

ENVIRONMENTAL DEFENCE would like to thank supporters of its tar sands work, including the **EJLB Foundation** and the **Glasswaters Foundation.**

glasswaters foundation

ENVIRONMENTAL | DEFENCE

317 Adelaide Street West
Suite 705
Toronto, ON M5V 1P9
[t] 416 323-9521
[f] 416 323-9301
[e] info@environmentaldefence.ca
[w] www.environmentaldefence.ca

Printed on 100% post-consumer recycled and FSC certified paper.

Executive Summary

The Government of Alberta is telling the world that it is managing the vast toxic tailings ponds being created by tar sands mining so that toxic leakage from the ponds does not enter the groundwater.

This is untrue.

Virtually everyone close to the tar sands industry knows that all tar sands tailings ponds leak – even the new ones – and that while steps are taken to recapture the leakage, a significant portion of contaminated water still escapes into the environment.

For the first time, this report uses industry information to arrive at a conservative estimate of what the overall leakage from the tar sands tailings ponds is today, and also what it would likely be if proposed projects go ahead.

The results are staggering.

Already, the ponds are leaking over 11 million litres a day of contaminated water into the environment, which is equivalent to over 4 billion litres a year – enough to fill the Toronto Skydome two and a half times.

And, should proposed projects go ahead on schedule, by 2012 this annual leakage rate would increase five-fold to 72 million litres a day, or over 25 billion litres a year – enough to fill the Skydome over 16 times.

LEAKAGE LOST	2007	2012*
Litres Per Hour	465,800	3,006,900
Litres Per Day	11,179,200	72,165,600
Litres Per Month	335,376,000	2,164,968,000
Litres Per Year	4,024,512,000	25,979,616,000

* There have been significant delays in new projects, so timelines may change.

Adding up the annual leakage, the cumulative toxic leakage into the groundwater could reach almost a trillion litres by 2080, and that is without counting the new projects that will inevitably be proposed. This amount would fill Olympic swimming pools placed end to end from St. Johns, Newfoundland to Victoria, BC four times over.

Tar sands tailings water is widely acknowledged to be harmful to human health and the environment. Experiments with this water on fish have shown serious reproductive impacts. Studies on birds have found increased mortality rates, and experiments on plants have shown delayed germination and lower seedling weights. The tailings include naphthenic acids, which are acutely toxic and known to persist for many years, making tailings leakage a long-term contamination problem for the Athabasca watershed, the Mackenzie drainage it runs into, and the Boreal forest.

Tailings ponds leak because they are built on bare ground that conducts water, and their walls are made from the materials dug from the bitumen mining process, which also conduct water. Companies try to capture leaking water using ditches and intercept wells, but a portion escapes into the environment.

There are no public studies about the impacts of the overall toxic leakage today, nor are there public studies about the impacts of a five-fold expansion of this leakage that is projected over a short time span. Tar sands companies self-monitor groundwater contamination and give this information to the Alberta Government, but this is not made public. Monitoring of surface water in the tar sands region is done by an industry dominated body that independent experts have found lacking.

Both the Alberta and federal governments have jurisdiction over the discharge of harmful substances like tailings pond leakage. The Alberta Government is sanctioning the leakage through its permitting system. The federal government is failing to enforce its *Fisheries Act* by deferring to the province. Because Alberta refuses to act, tar sands tailings pond leakage will not end until the Canadian government enforces its own law.

Resumé

Le gouvernement de l'Alberta clame aux quatre horizons qu'il gère les énormes bassins de décantation toxiques qui sont le fruit de l'extraction des sables bitumineux, et que les fuites toxiques s'écoulant des bassins ne pénètrent pas dans l'eau souterraine.

C'est faux.

Pratiquement tous ceux qui vivent près de l'industrie d'extraction des sables bitumineux savent que tous les bassins de décantation ont des fuites – même les plus récents – et que, bien que des mesures soient prises pour récupérer l'eau qui s'échappe, une portion importante de l'eau contaminée réussit à se frayer un chemin dans l'environnement.

Pour la première fois, ce rapport présente, à l'aide des données de l'industrie elle-même, une estimation conservatrice de la quantité d'eau qui s'échappe actuellement des bassins de décantation et de la situation qui prévaudra vraisemblablement si les projets proposés voient le jour.

Les résultats sont bouleversants.

Déjà, plus de 11 millions de litres d'eau contaminée s'échappent chaque jour pour se perdre dans l'environnement, c'est-à-dire plus de 4 milliards de litres par an – de quoi emplir deux fois et demie le Skydome de Toronto...

Et, si les projets proposés vont de l'avant selon l'horaire prévu, d'ici 2012, ce taux de fuites annuelles quintuplerait, pour atteindre 72 millions de litres par jour, ou plus de 25 milliards de litres par an – de quoi emplir le Skydome plus de 16 fois.

FUITES	2007	2012*
Litres par heure	465,800	3,006,900
Litres par jour	11,179,200	72,165,600
Litres par mois	335,376,000	2,164,968,000
Litres par mois	4,024,512,000	25,979,616,000

* Les nouveaux projets connaissent des retards importants; il se peut que les dates diffèrent.

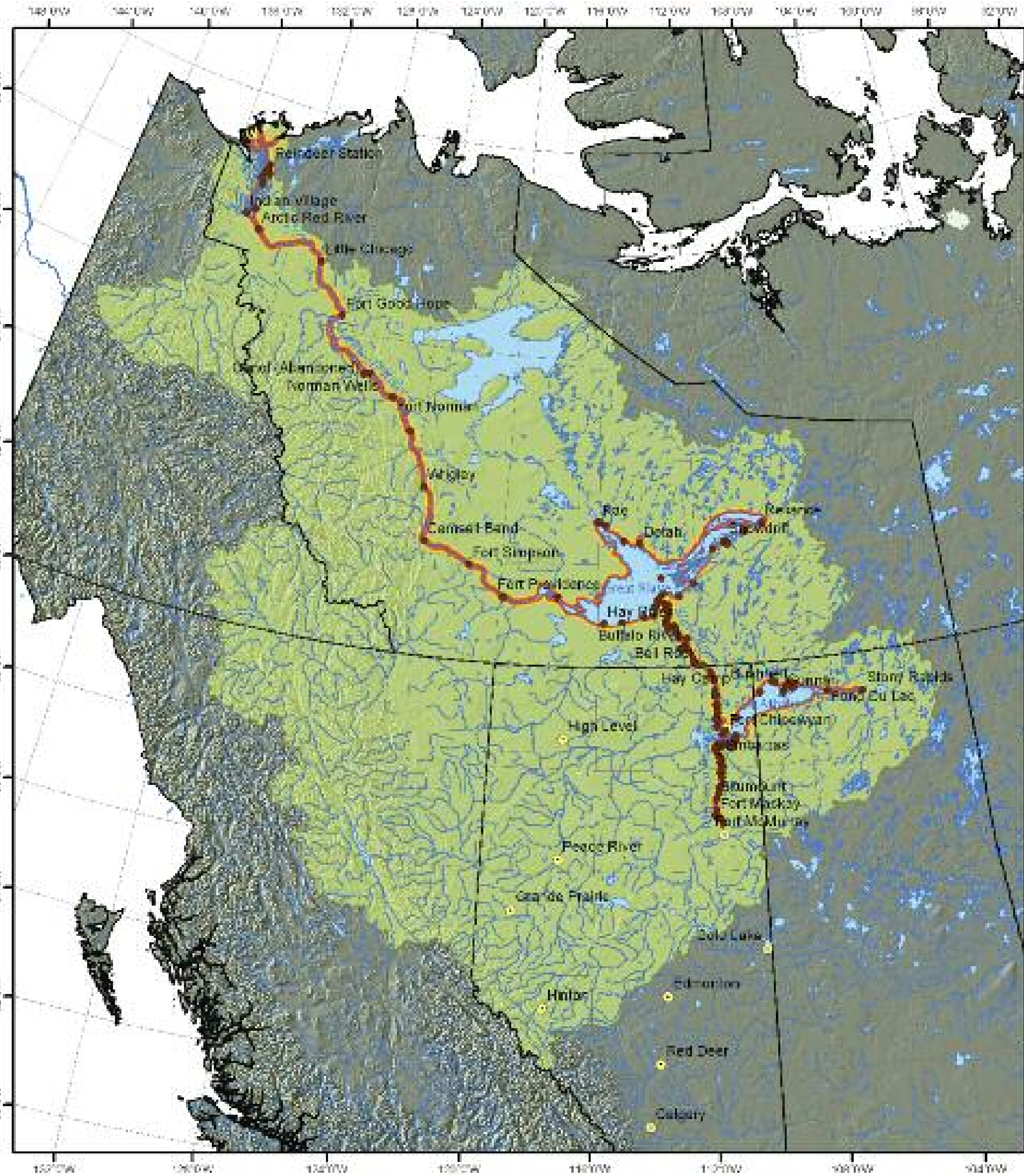
Si l'on additionne les fuites annuelles, la totalité de l'eau toxique qui se retrouve dans l'eau souterraine pourrait atteindre près d'un billion de litres d'ici 2080, et ce, sans même compter les nouveaux projets qui ne manqueront pas d'être mis de l'avant. Avec une telle quantité d'eau, on pourrait remplir des piscines olympiques, placées bout à bout, de St. Johns (Terre-Neuve) jusqu'à Victoria (C.-B) quatre fois.

Il est bien connu que l'eau des bassins de décantation des exploitations de sables bitumineux est néfaste pour la santé et pour l'environnement. Les expériences faites avec cette eau ont montré qu'elle avait des effets très graves sur la reproduction du poisson. Des études portant sur les oiseaux ont révélé des taux de mortalité accrus et les expériences sur les plantes ont montré un retard dans la germination et une taille inférieure de la plante. Les résidus contiennent des acides naphténiques, une matière toxique à effets aigus connue pour sa capacité de persister pendant de nombreuses années, ce qui fait de ces fuites un problème de contamination à long terme pour le bassin hydrographique Athabasca, le réseau hydrographique du Mackenzie dans lequel il se déverse, ainsi que la forêt boréale.

Les bassins de décantation fuient parce qu'ils ont été construits sur le sol dénudé, sur lequel l'eau peut s'écouler, et que les côtés des bassins sont faits de matériel obtenu lors de l'extraction du bitume qui, lui aussi, permet à l'eau de s'écouler. Les sociétés concernées tentent de récupérer les fuites en creusant des fossés et des puits pour les intercepter, mais une partie de ces eaux finit toujours par s'échapper.

Il n'existe actuellement aucune étude publique sur l'impact de toutes ces fuites toxiques, et il n'existe également aucune étude publique sur l'impact qui découlerait de la multiplication par cinq de ces fuites – ainsi que l'on projette de le faire – dans un court laps de temps. Les sociétés qui procèdent à l'extraction des sables bitumineux font elles-mêmes le suivi de la contamination de l'eau souterraine et transmettent ensuite cette information au gouvernement de l'Alberta, mais ces données ne sont pas rendues publiques. Le suivi de l'eau de surface dans la région des sables bitumineux est effectué par un organisme qui relève de l'industrie et que des experts indépendants n'ont pas trouvé à la hauteur de sa tâche.

L'écoulement de substances dangereuses, telles celles provenant des fuites des bassins de décantation, relève du gouvernement de l'Alberta et du gouvernement fédéral. Le gouvernement de l'Alberta approuve ces fuites par le biais de son système de licences. Le gouvernement fédéral évite de faire appliquer sa Loi sur les pêches en s'en remettant à la province. Et parce que l'Alberta refuse d'agir, les bassins de décantation continueront de fuir tant et aussi longtemps que le gouvernement du Canada ne fera pas appliquer sa propre loi.



Downstream Waterbodies from the Bituminous (tar/oil) Sands Area

10 km zone around downstream waterbodies

10 km

0 km

Populated places within 10 km of downstream waterbodies

Mackenzie River basin

Projection: 10 TM
Central Meridian: -115.0
Scale Factor: 0.9992
Origin: 0.0
Linear Unit: Meter
Easting: 500000
Datum: NAD 1983

0 50 100 200 300 400 km

Introduction

This study documents the existence of widespread and increasing leakage – often called "seepage" – of toxic chemicals from tar sands tailings ponds.

As part of its tar sands public relations campaign, the Government of Alberta is circulating a brochure on the tar sands with the claim that measures are taken in the tar sands "to prevent any seepage from entering groundwater systems or waterways."[1]

In the Alberta Legislature, the Alberta Premier and Environment Minister have dismissed evidence of tailings leakage by suggesting that this is only a problem with older tailings ponds, or that leaking water is captured.[2]

These statements contradict what virtually everyone close to the tar sands industry knows: that all tar sands tailings ponds leak, even the new ones, and that while steps are taken to capture this leakage, these steps are imperfect and there is a significant loss of contaminated water into the environment.

We therefore concluded that the truth about tailings ponds leakage would not penetrate until someone calculated *how much* they leak into the environment, so that the debate can progress to discussing the magnitude of the problem, rather than whether such a problem exists.

This study uses industry information to estimate what the overall leakage rate is for tar sands tailings ponds both now and into the future. This information is estimated on a project-specific basis by companies in their project applications, but it has never been publicly put together to come up with an overall leakage rate.

Requests to the Alberta Government regarding what the overall leakage rate is have so far gone unanswered. We welcome a public debate on the magnitude of the tailings ponds leakage problem in the tar sands. Such a debate is critical to the health of the Athabasca watershed, to the people who live there, and indeed to the entire Mackenzie Valley drainage into which the Athabasca empties – an area comprising a fifth the size of Canada and much of Canada's Boreal forest.

"…the principal environmental threats from tailings ponds are the migration of pollutants through the groundwater system and the risk of leaks to the surrounding soil and surface water…the scale of the problem is daunting…" **NATIONAL ENERGY BOARD** [3]

What are Tailings?

Many have seen pictures of the massive toxic tailings "ponds" – a misnomer considering they are now as big as lakes. A bright spotlight was shone on these toxic lakes in April, 2008 after five hundred ducks were killed after landing on one of them.

Tar sands companies want the dense bitumen that's mixed in with sand, silt, and clay. After digging up the mixture, they separate the materials from one another using hot water. Following the recovery of bitumen, there is a large quantity of unwanted water, sand, silt, and clay contaminated with leftover hydrocarbons and other toxic substances.

This waste stream is called "tailings" and is piped into giant pits that the companies build using the materials they dig out of the ground as part of mining. The tailings areas are constructed over the top of bare ground.

The theory is that the solids settle out from the liquids over time, allowing the water to be recycled and the solids to be buried during "reclamation." The reality, however, is that the settling process for the finest tailings has turned out to take much longer than expected – up to 150 years[4] – meaning that these tailings lakes will remain a toxic legacy long after industry has left.

THE PROBLEM IS MASSIVE

It is important to understand the scale of the tailings problem. The industry on average produces about 2,000 to 2,500 litres of tailings per barrel of bitumen, and given levels of production this results in the production of about 1.8 billion litres of tailings every day.[5]

Since mining began in 1968, one study estimates that there are five and a half trillion litres of tailings now on the landscape.[6] These huge toxic tailings lakes now cover an area over 130 square kilometers.[7]

With such massive numbers, there should be no surprise that there is a significant problem with leakage.

TAILINGS ARE TOXIC

Several studies have found tailings pond water to be acutely toxic. An experiment with goldfish in tailings waters found adverse impacts on endocrine functioning.[8] A study of tree swallows on wetlands that used tailings water found that the odds of dying on the sites using the most tailings water were ten times higher than those on the control site.[9] An experiment to assess the impacts of tailings water on plants found that it slows germination in several plant species, and led to reduced weight in seedlings.[10]

These are some of the contaminants of major concern in tailings water:

- **Naphthenic Acids:** Naphthenic acids can be found in tailings ponds at levels over a hundred times those found in nearby rivers.[11] In addition to being acutely toxic, the naphthenic acids associated with the tar sands ponds do not easily break down in the natural environment.[12] The combination of toxicity and slow breakdown rates means water contaminated with naphthenic acids poses a threat to the environment for decades.[13]

- **PAHs:** Polycyclic Aromatic Hydrocarbons (PAHs) are known to be carcinogenic and mutagenic. PAHs are relatively non-soluble, and are therefore known to settle in sediment and to degrade slowly. Exposure of aquatic organisms to PAHs is associated with liver tumours and Environment Canada has concluded that certain PAHs pose a threat to human life or health.[14]

- **Other Contaminants[15]:** Trace metals such as copper, zinc and iron can exist at concentrations that exceed the Canadian water quality guideline for freshwater aquatic life. Tailings have also been found to contain residual bitumen – for example, Suncor's tailings pond contained 9% residual bitumen and diluent.

TAILINGS PONDS ARE ALREADY LEAKING THE EQUIVALENT OF TWO-AND-A-HALF TORONTO SKYDOMES FULL OF CONTAMINATED WATER INTO THE ENVIRONMENT EVERY YEAR.

Tar Island Dyke – a special case

Tar Island Dyke was constructed in mid 1960's by Suncor and has been expanded several times. It is now 92 metres high and stands directly next to the Athabasca River. Tailings are no longer placed in the pond.

The current leakage rate of contaminated water from Tar Island Dyke into the river is estimated to be 67 litres a second or almost 6 million litres a day.[16]

The leakiest tar sands tailings pond gets most of the attention, but it is important to note that while Tar Island Dyke is probably the worst tailings pond for leakage – especially leaking directly into the Athabasca River – all tailings ponds leak, even the new ones.

How do Tailing Ponds leak?

ALL TAILING PONDS LEAK

Tailings ponds leak because they are built directly on ground that conducts water, and the ponds have walls that are built out of the material that tar sands companies take out of the ground, which also conducts water.

This means that contaminated water from the tailings ponds leaks through the base and the sides of the tailings ponds. Leakage through the base can also be more severe depending on the nature of the ground. Suncor's south tailings pond, for example, is built over glacial meltwater channels that provide faster pathways for leaking water.[17]

THE TAR ISLAND DYKE IS NOTORIOUS FOR LEAKING CONTAMINATED WATER DIRECTLY INTO THE ATHABASCA, BUT ALL TAILINGS PONDS LEAK.

STEPS TO SLOW AND RECOVER TAILINGS WATER ARE IMPERFECT

Tar sands companies do try to slow down leakage and to recapture contaminated water that does escape, but they do not get it all. These are some of the ways they do this:

- **Thickeners** – Companies are experimenting with various ways to make the fine tailings settle out faster and thereby reduce the overall amount of tailings available to leak.

- **Drainage Ditches –** Drainage ditches are dug around tailings ponds to collect leaking water, and it is pumped back into the ponds. But these ditches only catch leaking water at relatively shallow depths.[18]

- **Interception Wells –** Interception wells are dug beyond the drainage ditches to try to catch contaminated water before it leaves the company's lease boundary or enters rivers or lakes.

- **Barriers –** When leakage can be transported quickly in underground channels, barriers may be built such as the "grout curtain" installed at Syncrude's Aurora project.

How much leakage do these kinds of efforts catch? That is a hard question to answer since when company estimates do exist, they vary significantly, not just from company to company but also from year to year.

The information provided by CNRL (Horizon) and Shell (Muskeg River Mine) indicates they will capture all "shallow" leakage from their tailings ponds, but not the leakage to deep aquifers, which runs at about a third of the overall rate. PetroCan (Fort Hills) estimates that it will lose about 15 percent of its overall leakage.[19]

It should be noted that there are differences in terrain, meaning that there will be differences in how fast the tailings ponds leak depending on how fast any given piece of ground conducts water. One study suggests that industry is now encountering more shallow sand on new sites,[20] so leakage could speed up.

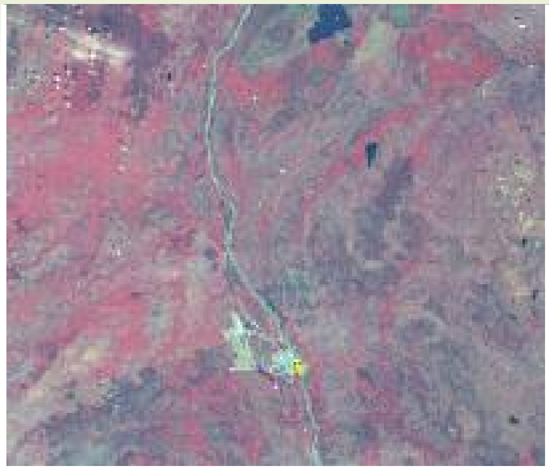
"SELF SEALING"

Industry claims that tailings ponds "self seal" over time. The University of Waterloo has found that leakage declines over time for two reasons. "First, clay and silt sized tailings accumulate at the bottom of the tailings impoundment and act to minimize seepage. Second, permeability is reduced as residual bitumen from the tailings stream forms bitumen mats in the beaches of coarser grained tailings along the edges of the tailings impoundment." [21]

Even though the concept of "self sealing" has not been adequately proven or measured, this study has given the benefit of the doubt to industry on this issue, assuming that this does indeed take place, and has reduced the estimated overall leakage rate accordingly. Industry does not claim, however, that tailings ponds entirely self-seal; they acknowledge there will always be some leakage.

The growth of tar sands mining and tailings ponds is exploding. Tailings ponds now cover 130 square kilometres. This is a sequence of satellite shots from 1974 to 2006, with the final one showing a projection of approved ponds not yet built. The ponds are in yellow.

Credit: Global Forest Watch Canada



1974

1992

THE LONG TERM – CAPPED TOXIC LAKES

Even when the tar sands industry realized it had a problem with the failure of finer tailings to settle out on a timeline to make reclamation possible, it barreled ahead with increased production of both bitumen and tailings, assuming that it could somehow figure things out.

The result is a proposed experiment with the lands and waters of Northern Alberta, putting toxic waste into something called "End Pit Lakes."

The basic idea is that towards the end of a useful bitumen mine, the company would decommission the tailings ponds and transfer the unsettled liquid tailings into the pits from which it has dug the bitumen in the first place. A layer of fresh water would be added over the top of the tailings, the landscape would be built so that water drains in and out of the End Pit Lakes, and then industry would walk away.

At least 25 End Pit Lakes are planned for the tar sands region within the next 60 years despite the fact that nobody really knows how they will perform.[22]

Each year tar sands tailings ponds are already leaking the equivalent of two and a half Toronto Skydomes full of toxic water into the environment, and this could quickly grow to 16 Skydomes.

2002 | 2006 | APPROVED PONDS

What is the overall leakage rate?

METHOD

There has not yet been a public attempt to come up with an estimate of how much tar sands tailings ponds are leaking overall, and what this rate could be if the many new mines go ahead using the same planned approach to tailings.

We therefore contracted Pembina Corporate Consulting to go through the industry proposals to put together this figure. Based on the companies' own data, Pembina produced several scenarios for leakage rates using different assumptions that can be found on the **Environmental Defence** website at **www.environmentaldefence.ca.**

This report has chosen a conservative scenario. This means the leakage problem could be much larger than this report estimates.

This is the method of the scenario we selected:

1. Wherever it exists, Pembina used the specific company information on leakage rates.
2. Where companies did not provide this information, Pembina applied an average leakage rate calculated using the numbers from the companies that did. These averages were applied on the basis of leakage per barrel of bitumen proposed to be produced.
3. Benefit of the doubt was given that tailings ponds largely "self seal" over time, and it was assumed that all ponds largely self seal after 18 years, but that some leakage still occurs. Pembina estimated that sealed ponds leak 85% less than un-sealed ponds.[23]

4. Due to lack of information, it was assumed that existing ponds have largely "self sealed," even though this is probably untrue and therefore under-estimates the current leakage rate. Tar Island Dyke, though, is a special case, and Pembina applied the leakage numbers calculated by the University of Waterloo, but assumed that leakage from Tar Island Dyke would reduce to a long term 'normal' leakage rate after 5 years.
5. The numbers were added together on an annual basis, using start-up dates and production numbers provided by the companies, and therefore arriving at overall leakage rate by year.
6. The final overall leakage rate is what escapes from the ponds after recovery steps have been taken. In other words, this is the leakage that the companies don't catch.

LIMITATIONS

Although the leakage values presented in this report are both rationally developed and conservative, there are several limitations to the calculations used. These are:

- **Slowdown:** With the recent pull back in the price of oil and delays by tar sands companies, the timelines in this analysis may need adjusting, depending on how this reduction in development actually plays out. In any event, a slowdown would not have any affect on calculated current leakage rates.

- **Use of Averages:** Determining leakage rates is a complex task. This analysis does not attempt to develop numbers based on the unique geological characteristics of each site. Where information was unavailable, averages were applied that were calculated from the companies that did provide it.

- **The Very Long-Term:** Mine closure includes the construction of End Pit Lakes (see above) and the burying of tailings into the landscape. Both will continue to leak contaminated water into the environment. This analysis does not attempt to quantify the very long-term – i.e. more than several decades into the future – leakage rates for these sources.

RESULTS – MASSIVE LEAKAGE

Even with a conservative methodology, the estimated cumulative leakage numbers are huge.

In 2007, the tailings ponds were already losing over 11 million litres a day to the environment, or about four billion litres a year.

Four billion litres a year is the equivalent of filling the Toronto Skydome to the roof about two and a half times.[24]

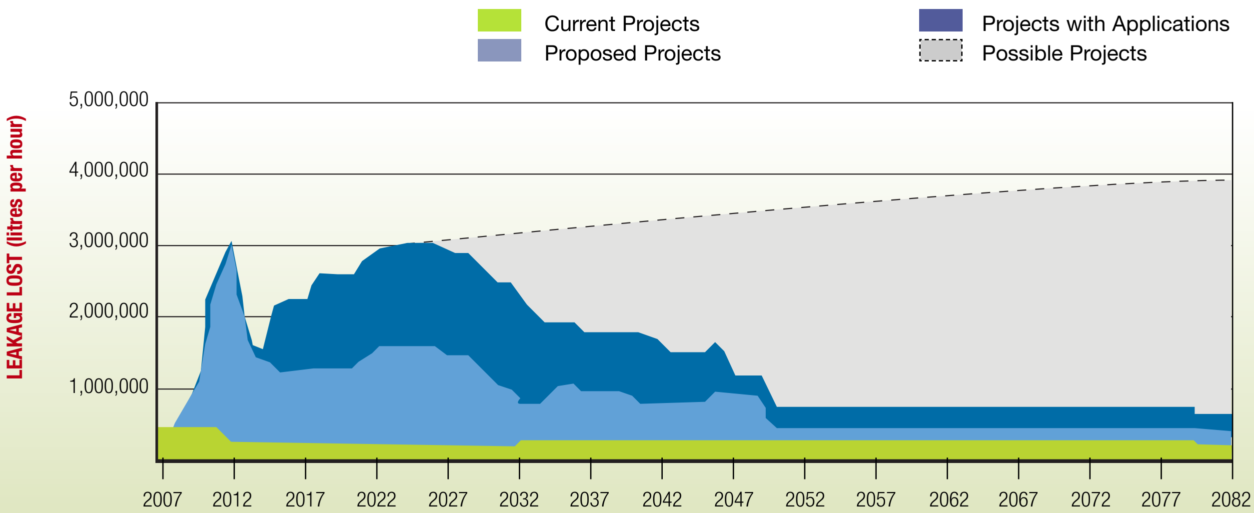
LEAKAGE LOST	2007	2012*
Litres Per Hour	465,800	3,006,900
Litres Per Day	11,179,200	72,165,600
Litres Per Month	335,376,000	2,164,968,000
Litres Per Year	4,024,512,000	25,979,616,000

* There have been significant delays in new projects, so timelines may change.

Estimates of current and proposed projects – and there may indeed be more announced – show leakage rising rapidly. In 2012, overall leakage could grow five fold to about three million litres an hour, or over 25 billion litres a year – enough to fill the Skydome over 16 times.

Adding up the annual leakage, the cumulative toxic leakage into the groundwater could reach almost a trillion litres by 2080, and that is without counting the new projects that will inevitably be proposed. This amount would fill Olympic swimming pools placed end to end from St. Johns, Newfoundland to Victoria, BC four times over.[25]

AGGREGAGED RATE - LEAKAGE LOST TO ENVIRONMENT



This graph shows the estimated overall tailings ponds leakage rate for existing and proposed ponds starting up and "self sealing" at different times. New ponds will likely be proposed though, meaning that the overall rate would keep going up. The timelines in the graph will change due to recent project delays.

Source: Based in part on data from Pembina Corporate Consulting

Impacts

There has not been a public assessment of the existing cumulative contaminated leakage from the tar sands tailings ponds, nor has there been a public assessment of the likely impacts of the vastly increased future toxic leakage.

WHAT THE COMPANIES SAY

To date, the only public information comes from the tar sands companies themselves, who model the impacts of their specific leakage on the groundwater and associated surface waters as part of their project proposal processes. This raises several concerns, including:

- **Independence.** Tar sands companies are trying to get approvals and therefore have an incentive to reach conclusions that minimize concerns.
- **Incrementalism.** Each tar sands company models its own additional impact, but does not model the regional impact several years from now when cumulate leakage will be many times greater than today.
- **Reality.** Modeling of impacts is educated guesswork, and because companies use different models, this creates even greater uncertainty. In reality, groundwater flow is not yet well understood.

Despite these concerns, the project approval process has never rejected a tar sands mine or associated leaking tailings ponds. Some of the evidence presented on leakage during these processes, though, is instructive:

- The Suncor Millenium tailings pond proposal highlighted the existence of underground channels that conduct contaminated water, in this case towards McLean Creek. Suncor outlined how it would have to operate mitigation measures for 60 years after the closure of the pond to prevent contamination from reaching the creek.[26] The Alberta Energy and Utilities Board approved the application despite concluding that the information about groundwater was imperfect, that unknown pathways for the transport of leakage into McLean Creek could exist, and that regional groundwater modeling needed to be done.
- The Shell Jackpine proposal again showed leakage reaching surface water – this time Jackpine Creek.[27] Regarding changes in groundwater quality, Shell indicated "These changes will be long term and irreversible."[28] The joint federal-Alberta panel then went on to call for an initiative to assess the regional impacts on groundwater,[29] but approved the mine and leaking tailings pond anyway.
- The Shell Albian Sands proposal saw Shell disagreeing with Environment Canada's requests to update predictions as new data became available, to include public

reporting, and to include external scientific peer review. Shell also disagreed with recommendations to collect further baseline water and sediment samples from the Muskeg River watershed prior to project initiation.[30]

- The CNRL Horizon proposal predicted that it would exceed several parameters of the provincial water quality guidelines for the protection of aquatic life and/or human health guidelines.[31]
- The Imperial Kearl proposal acknowledged that understanding of groundwater flows was incomplete.[32] Imperial indicated leakage could reach 1,000 litres a second and that measures were needed to prevent this from reaching the Firebag River and its tributaries.[33] The tailings pond was proposed to lie atop permeable deposits.[34]

Overall, the proposals processes show decisions about tailings leakage being made based upon incomplete information, with the regulators repeatedly asking for more analysis but always giving approvals without it.

THE MONITORING MESS

Alberta Environment requires companies to self-monitor tailings pond leakage in groundwater. Companies drill monitoring wells around their leases and send this information to government. Pembina's attempts to access this information have so far been unsuccessful, adding concerns about transparency and accountability to the concern about the conflict of interest inherent in self-monitoring.

Since the basic approach to tailings pond leakage is to hope that it does not show up in surface waters, a key question is how surface water quality is monitored. Both the federal and Alberta governments have delegated much of their responsibility for surface water quality monitoring in the tar sands to the increasingly mischaracterized "multi-stakeholder" body called the Regional Aquatic Management Program (RAMP).

Despite calling RAMP a "multi-stakeholder" body, it is funded and dominated by the tar sands companies, and First Nations and environmental organizations have now distanced themselves from the organization due to concerns over impartiality and competence.[35]

An independent expert review of RAMP in 2004 found "significant concerns" with scientific leadership, effective design, and a failure to incorporate a regional approach.[36] Alberta journalist Andrew Nikiforuk followed up in 2008 to find the outside reviewers lamented the failure to fix the problems, with one noting that industry monitoring efforts such as RAMP often design things to find industrial activity acceptable.[37]

RAMP has so far concluded that surface water quality has not been significantly impacted by tar sands activity.

> "These changes will be long term and irreversible."
>
> — **SHELL** ON IMPACTS TO GROUNDWATER QUALITY

What's At Stake

The people of Fort Chipewyan are living in fear of what tar sands pollution may be doing to their water, the fish and wildlife they depend on, and their health. The predominantly First Nations community sits on Lake Athabasca, about 200 km downstream of the tar sands mines.

Family doctor John O'Connor has become a hero in the community after speaking out about the high incidence of very rare cancers and being persecuted by government authorities as a result.

Dr. O'Connor found that at least three residents and likely two more have died of cholangiocarcinoma, a deadly cancer of the bile duct that occurs in one case for 100,000 people. Fort Chipewyan's population is about 1,000 people.

Alberta Health and Wellness and Health Canada brought misconduct charges against Dr. O'Connor in 2006 with the College of Physicians and Surgeons of Alberta. He has so far been cleared of most of the charges, with one pending.

Credit: Ron Plain

(left) DEFORMED FISH HAVE BEEN SHOWING UP DOWNRIVER FROM THE TAR SANDS. THIS TWO-JAWED FISH WAS CAUGHT IN FORT CHIPEWYAN IN THE SUMMER OF 2008. (right) UNLESS THINGS CHANGE, TOXIC TAILINGS PONDS LEAKAGE COULD INCREASE FIVE-FOLD WITHIN A DECADE.

Regulatory Responsibility

The failure of the relevant regulatory agencies to adequately deal with tailings ponds fits into the overall failure to protect the environment in the tar sands. Because environment is a shared jurisdiction in Canada, this failure belongs to both the Alberta and the federal governments.

EXPOSING THE ALBERTA GOVERNMENT'S "ZERO DISCHARGE" CLAIM

The Alberta Government monitors tailings ponds in two ways. First. the *Energy Resources Conservation Act* sets up the Energy Resources Conservation Board (ERCB) to approve tar sands projects under certain conditions. In June 2008, the ERCB proposed new directives on tailings management, none of which changed anything regarding tailings ponds leaking contaminated water. The ERCB is also responsible for ruling on environmental assessments for tar sands projects.

Second, the *Environmental Protection and Enhancement Act* (EPEA) prohibits the release of harmful substances into the environment, except where allowed by permit.[38] Alberta Environment therefore writes leakage into tar sands permits.

Some believe that because the EPEA prohibits the release of harmful substances that there is a "zero discharge" policy in the tar sands with regards to contaminated water. In fact, the billions of litres of contaminated water leaking from the tailings ponds are sanctioned by the Government of Alberta.

Because the Alberta government is in denial about the environmental impacts of the tar sands, it is unlikely to use its regulatory authority to end leakage from tar sands tailings ponds. Alberta Premier Stelmach called environmental concerns a "myth"[39] and instead ordered a $25 million public relations campaign to improve Alberta's image.[40] As seen above, part of that campaign includes materials saying that toxic leakage is prevented from entering groundwater.

THE FEDERAL GOVERNMENT'S FAILURE TO ENFORCE

The Canadian government has two laws pertaining to the discharge of contaminated tailings pond water into the environment.

First, the *Canadian Environmental Protection Act* (CEPA) is called by the Canadian government "the cornerstone legislation for preventing pollution in order to protect Canada's environment and the health of Canadians." Among the shortcomings of CEPA, however, is a reliance on the discretion of the government to officially name a substance as toxic and then to develop a regulatory response for it. CEPA therefore allows the federal government to regulate toxic tar sands ponds leakage, but does not compel it.

The Canadian *Fisheries Act,* however, has stronger provisions. Section 36(3) says:

> **…no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish** ***or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water*** **(emphasis added)**

Similar to the Alberta EPEA, the *Fisheries Act* allows the regulator to vary the prohibition through permitting or regulation-making activities, but in the case of toxic leakage from tar sands tailings ponds, neither is taking place.

Emphasis is added to the second part of 36(3) above because it is clear the *Fisheries Act* anticipates contaminants entering indirectly into waters frequented by fish. Environment Canada, which overseas enforcement of 36(3), says this about groundwater:

> **Any addition of undesirable substances to groundwater caused by human activities is considered to be contamination. It has often been assumed that contaminants left on or under the ground will stay there. This has been shown to be wishful thinking. Groundwater often spreads the effects of dumps and spills far beyond the site of the original contamination. Groundwater contamination is extremely difficult, and sometimes impossible, to clean up.** [41]

Environment Canada also acknowledges an ominous aspect of the tar sands tailings leakage problem – the impacts of today's groundwater contamination may take years to come to light:

> **Groundwater moves so slowly that problems take a long time to appear. Because of this, and because it is so expensive to clean up a contaminated aquifer (if it can be done at all), it is preferable by far to prevent contamination from happening in the first place.** [42]

Credit: Garth Lenz

TAR SANDS MINES FILL THE TAILINGS PONDS 24/7.

This is part of the reason some have characterized the tar sands as a "slow motion oil spill." It may take years to feel the full impacts of the pollution now taking place.

While there is a Canada-Alberta agreement on coordinating activities on deleterious substances,[43] the existence of a permit that sanctions tar sands tailings ponds leakage under the Alberta EPEA does not relieve the federal government of its responsibilities under s.36(3) of the *Fisheries Act*.

Factors that underline the duty of the federal government to step in on the tailings leakage issue include:

- Expressions of concern from federal officials in tar sands hearings about the weakness of information, modeling, standards, and monitoring with relation to water quality issues; [44]
- The trans-boundary nature of this problem given the proximity of downstream jurisdictions of Saskatchewan and the Northwest Territories;
- The double standard of having specific federal regulation of metals mining and tailings ponds, but not tar sands mining and tailings ponds; and
- The fiduciary duty the federal government has to First Nations, who have heightened concerns regarding water quality and health issues in the tar sands.

Left up to the Government of Alberta, the tailings leakage problem will only magnify. It is time for the Government of Canada to step in and enforce the *Fisheries Act*.

"It has often been assumed that contaminants left on or under the ground will stay there. This has been shown to be wishful thinking."

— ENVIRONMENT CANADA

ENDNOTES

1 "Alberta's Oil Sands. Opportunity. Balance," Government of Alberta, 2008, p. 6.

2 See Alberta Hansard, May 27, May 28, and June 4, 2008.

3 "Canada's Oil Sands: Opportunities and Challenges to 2015," National Energy Board, 2004.

4 "Fact or Fiction: Oil Sand Reclamation," Jennifer Grant et al, Pembina Institute, May 2008, p. 13.

5 "Fact or Fiction," p. 14 and p. 30.

6 Richard Nelson, "Cumulative Fine Tailings Inventory and Pace of Development," Alberta Energy Research Institute presentation at CONRAD 2006 Water Usage Workshop, March 28–29, 2006; cited in "Fact or Fiction," p. 14.

7 Backgrounder to press release, "ERCB releases draft directive on oil sands tailings management and enforcement criteria," June 26, 2008, Energy Resources Conservation Board and Government of Alberta.

8 "Reproductive and stress hormone levels in goldfish (Carassius auratus) exposed to oil sands process-affected water," by A. Lister et al, *Aquatic Toxicology,* January 2008.

9 "Effects of oil sands tailings compounds and harsh weather on mortality rates, growth and detoxification efforts in nestling tree swallows (Tachycineta bicolor)," by Marie-Line Gentes et al, *Environmental Pollution,* September 2005.

10 "Effects of an industrial effluent on plant colonization and on the germination and post-germinative growth of seeds of terrestrial and plant species," by A.U. Crowe et al, *Environmental Pollution*, volume 117, 2002, pp. 179-189.

11 "A Review of the Occurrence and Fate of Naphthenic Acids in Aquatic Environments," John V. Headlye et al, *Journal of Environmental Science and Health,* Vol A39, No. 8, pp. 1989-2010, 2004.

12 See: "Napthenic Acids in Athabasca Oil Sands Tailings Waters Are Less Biodegradable than Commercial Naphthenic Acids," Angela C. Scott et al, *Environ. Sci.Technol.* 2005, 39, 8388-8394.

13 Imperial Oil Resource Ventures Limited: Kearl Oil Sands Project - Mine Development Application and Supplemental Information," Imperial Oil Ltd., 2005, Volume 6.

14 See: http://www.ec.gc.ca/toxics/wood-bois/over/pah_e.htm

15 "Fact or Fiction," p. 36.

16 "Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada," Jim Barker et al, November, 2007, slide 12.

17 "Design of Tailings Dams on Large Pleistocene Channel Deposits: A Case Study – Suncor's South Tailings Pond," by Brett Stephens et al, date unknown.

18 "Integrated Solid Phase, Aqueous Phase and Numerical Investigation of Plume Geochemistry at an Oil Sand Mining Facility" by Alexander Avraham Louis Oiffer, Master Degree Earth Sciences – Thesis: 257, Earth Sciences, University of Waterloo, Section 1.0 Introduction, p. 122.

19 See the sheets for these companies provided in the accompanying scenarios from Pembina. Available at www.environmentaldefence.ca

20 "Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada," by Jim Barker et al, November 2007, slide 20.

21 "Integrated Solid Phase, Aqueous Phase and Numerical Investigation of Plume Geochemistry at an Oil Sand Mining Facility" by Alexander Avraham Louis Oiffer, Master Degree Earth Sciences – Thesis: 257, Earth Sciences, University of Waterloo, Section 1.0 Introduction, p. 4.

22 "Fact or Fiction," p. 31.

[23] Shell projected reduced leakage rates for ponds at their propsed Muskeg River Mine expansion, Jackpine Phase 1 and Jackpine Expansion. The average reduction in leakage rates for tailings ponds at these mine sites is 84% compared with leakage rates during the first 18 years of operation.

[24] This is based on the estimated volume of the Skydome at 1.6 billion litres. See: www.rogerscentre.com/about/facts/index.html

[25] This assumes filling a 50m long Olympic swimming pool requires 2.5 million litres, which divided into a trillion is 400,000 pools worth, laid end to end is 20,000 km worth. St. Johns to Victoria as the crow flies is about 5,000 km.

[26] Decision 2004-113, Suncor Energy Inc., Application for an External Tailings Pond, for the Millennium Mine, Fort McMurray Area, December 30, 2004, p. 17.

[27] Joint Panel EUB Decision 2004-009, Shell Canada Limited, Applications for an Oil Sands Mine, Bitumen Extraction Plant, Cogeneration Plant, and Water Pipeline in the Fort McMurray Area, February 5, 2004, p. 43.

[28] Ibid, p. 44.

[29] Ibid, p. 49.

[30] Joint Panel Report, EUB Decision 2006-128, Albian Sands Energy Inc., Application to Expand the Oil Sands, Mining and Processing Plant Facilities at the Muskeg River Mine, December 17, 2006. p. 43

[31] Joint Panel Report, EUB Decision 2004-005, Canadian Natural Resources Limited, Application for an Oil Sands Mine, Bitumen Extraction Plant, and Bitumen Upgrading Plant in the Fort McMurray Area, January 27, 2004. p. 47.

[32] Joint Panel Report, EUB Decision 2007-013, Imperial Oil Resources Ventures Limited, Application for an Oil Sands Mine and Bitumen Processing Facility (Kearl Oil Sands Project) in the Fort McMurray Area February 27, 2007, p. 37.

[33] Ibid, p. 37.

[34] Ibid, p. 37.

[35] Both the Athabasca Chipewyan First Nation and the Chipewyan Prairie First Nation wrote to RAMP expressing their concern in 2008, and the Pembina Institute has asked RAMP to remove its name from the RAMP website.

[36] "Oil Sands Regional Aquatic Monitoring Program (RAMP), Scientific Peer Review of the Five Year Report (1997-2001), Submitted to: RAMP Steering Committee, February 13, 2004, G. Burton Ayles et al., p.iv.

[37] "Tar Sands: Dirty Oil and the Future of a Continent," by Andrew Nikiforuk, Greystone Books, Vancouver, 2008, p. 72-3.

[38] *Alberta Environmental Protection and Enhancement Act*, Part 5, Division 1, 109.

[39] "Stelmach fights 'dirty' image of oilsands in Washington," Jason Markusoff, Canwest News Service, Wednesday, January 16, 2008.

[40] "Alberta the underdog in oilsands PR battle: Stelmach," Jason Markusoff, edmontonjournal.com, Wednesday, April 30, 2008.

[41] See: http://www.ec.gc.ca/water/en/info/pubs/FS/e_FSa5.htm

[42] See: http://www.ec.gc.ca/water/en/info/pubs/FS/e_FSa5.htm

[43] See: http://www.mb.ec.gc.ca/pollution/e00s62.en.html

[44] See for example: "Submission of the Department of the Environment (Environment Canada), Alberta Energy and Utilities Board, Canadian Environmental Assessment Agency Joint Panel Hearings, Imperial Energy Inc, Kearl Oil Sands Project, EUB Applications 1408771 and 1414891, 2 October 2006, pp. 82-86.

Appendix IV:

Joint Panel Report, EUB Decision 2004-009, Shell Canada Limited, Applications for an Oil Sands Mine, Bitumen Extraction Plant, Cogeneration Plant, and Water Pipeline in the Fort McMurray Area, February 5, 2004, page 43.

Joint Panel Report
EUB Decision 2004-009

Shell Canada Limited

Applications for an Oil Sands Mine, Bitumen Extraction Plant, Cogeneration Plant, and Water Pipeline in the Fort McMurray Area

February 5, 2004

Joint Review Panel Established by the Alberta Energy and Utilities Board and the Government of Canada

REPORT OF THE JOINT REVIEW PANEL ESTABLISHED BY THE ALBERTA ENERGY AND UTILITIES BOARD AND THE GOVERNMENT OF CANADA
Decision 2004-009: Shell Canada Limited, Applications for an Oil Sands Mine, Bitumen Extraction Plant, Cogeneration Plant, and Water Pipeline in the Fort McMurray Area
February 5, 2004

Published by

Alberta Energy and Utilities Board
640 – 5 Avenue SW
Calgary, Alberta T2P 3G4
Telephone: (403) 297-8311
Fax: (403) 297-7040
Web site: www.eub.gov.ab.ca

and

Canadian Environmental Assessment Agency
200 Sacré-Coeur Blvd.
Gatineau, Quebec K1A 0H3
Telephone: (819) 997-1000
Fax: (819) 994-1469
Web site: www.ceaa-acee.gc.ca

CONTENTS

EXECUTIVE SUMMARY

Shell Canada Limited (Shell) filed Applications No. 1271285, 1271307, and 1271383 with the Alberta Energy and Utilities Board (EUB). Application No. 1271285 was made pursuant to Sections 10 and 11 of the Oil Sands Conservation Act for approval of an oil sands mine, a bitumen extraction plant. Application No. 1271307 was made pursuant to Section 11 of the Hydro and Electric Energy Act for approval of a cogeneration plant. Application No. 1271383 was made pursuant to Part 4 of the Pipeline Act for approval of a fresh water pipeline.

The project would be located approximately 70 kilometres north of Fort McMurray and 10 kilometres east of Fort McKay. It is designed to produce 31 800 cubic metres per day of bitumen product.

The project required an environmental assessment under the Canadian Environmental Assessment Act (CEAA). On June 26, 2003, the federal Minister of Fisheries and Oceans referred the environmental assessment of the project to a review panel. On August 18, 2003, Canada and the EUB entered into an agreement to establish a joint environmental assessment panel (the Panel) for the project. Under the agreement, the Panel was charged with fulfilling the review requirements of both CEAA and the Energy Resources Conservation Act (ERCA).

The Panel considered Applications No. 1271285, 1271307, and 1271383 at a public hearing held in Fort McMurray, Alberta, on October 6 through 10 and October 15, 2003. Participants who provided evidence at the hearing included Shell, other oil sands developers, First Nations, local aboriginal groups, local residents, nongovernment environmental groups, a local medical staff association, and representatives from provincial and federal regulatory agencies. While participants raised a number of issues for the Panel's consideration, most of the issues centred on anticipated environmental and socioeconomic impacts of the project.

Having regard for its responsibilities under ERCA and CEAA, the Panel carefully considered all of the evidence pertaining to the applications. The Panel finds that the project is in the public interest, and the Panel is prepared to approve Applications No. 1271307 and 1271383. The Panel is also prepared to approve Application No. 1271285, subject to the approval of the Lieutenant Governor in Council. Furthermore, the Panel concludes that the project is unlikely to result in significant adverse environmental effects, provided that the mitigation measures proposed by Shell and the recommendations of the Panel are implemented.

In approving Application No. 1271285, the Panel set out conditions relating to mining operations, resource conservation, and tailings management. In addition, the Panel also made recommendations to the federal and provincial governments that would aid in the mitigation of the anticipated environmental effects of the project and would address the need for follow-up measures.

This executive summary is provided for the benefit of the reader and does not form part of the report. All persons making use of the executive summary are reminded that the report should be consulted for all purposes relating to the interpretation and application of the Panel's views.

JACKPINE PROJECT JOINT REVIEW PANEL
Calgary Alberta

SHELL CANADA LIMITED
APPLICATIONS FOR AN OIL SANDS MINE,
BITUMEN EXTRACTION PLANT, COGENERATION PLANT, AND WATER PIPELINE
FORT MCMURRAY AREA

Decision 2004-009
Applications No. 1271285, 1271307, and 1271383

1 DECISION AND RECOMMENDATIONS TO CANADA AND ALBERTA

Having regard for its responsibilities under the Energy Resources Conservation Act (ERCA) and the Canadian Environmental Assessment Act (CEAA), the joint Canada and Alberta Energy and Utilities Board (EUB/Board) review panel (the Panel) has carefully considered all of the evidence pertaining to the applications and finds that Shell Canada Limited's (Shell's) Jackpine project, Phase 1, is in the public interest for the reasons set out in this report. Under its mandate through the EUB, the Panel is prepared to approve Applications No. 1271307 (the cogeneration plant) and 1271383 (the pipeline). The Panel is also prepared to approve Application No. 1271285 (oil sands mine and bitumen extraction plant), subject to the approval of the Lieutenant Governor in Council. The Panel's approvals are subject to the conditions listed in Appendix 1. The Panel expects that Shell will adhere to all commitments it made during the consultation process, in the application, and at the hearing to the extent that those commitments do not conflict with the terms of any approval or licence affecting the project or any law, regulation, or similar requirement Shell is bound to observe.

With regard to its responsibilities under CEAA and its terms of reference, the Panel concludes that the project is not likely to cause significant adverse environmental effects, provided that the proposed mitigation measures and the recommendations of the Panel are implemented.

The Panel recommends to Canada that

- the Department of Fisheries and Oceans (DFO) collaborate with Alberta Environment (AENV) in the establishment of instream flow needs (IFN) for the Athabasca River in the event that the Cumulative Environmental Management Association (CEMA) fails to meet its timelines (Section 9.6);
- DFO consider IFN objectives and management approaches in its approvals for the project (Section 11.8);
- DFO, in consultation with AENV, Alberta Sustainable Resource Development (ASRD), Environment Canada (EC), and regional stakeholders, require Shell to develop and implement a comprehensive monitoring program relating to fish and benthic macroinvertebrates (Section 12.5);
- DFO require a report from Shell on its monitoring results relating to the compensation lake and share those findings with other stakeholders in the region (Section 12.5);

- EC provide scientific expertise to CEMA working groups in the selection of appropriate indicators of terrestrial and aquatic ecosystems and in establishing effects-based monitoring systems for regional acid deposition (Section 16.2.9);
- DFO consider conditioning its approval to require Shell to participate in CEMA (Section 21.10); and
- Health Canada (HC), in conjunction with Alberta Health and Wellness (AHW), consider undertaking a regional baseline health study primarily dealing with First Nations, Metis, and other aboriginal groups and consider contributing expertise and funding in support of Wood Buffalo Environmental Association's (WBEA's) efforts to implement an ongoing health-monitoring program consistent with the recommendation of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program (Section 24.6).

The Panel recommends to Alberta that

- in AENV's review of Shell's Water Act application, it consider water allocation based on needs of the different project phases (Section 9.6);
- AENV establish IFN for the Athabasca River in collaboration with DFO in the event that CEMA fails to meet its timelines (Section 9.6);
- AENV review the communications programs in place to ensure that regional water quality and water use information is accessible and understandable to interested parties (Section 9.6);
- AENV include a condition in the Environmental Protection and Enhancement Act (EPEA) approval requiring Shell to develop and implement monitoring programs for sediment and water quality for waters that may be affected by the project (Section 10.9);
- AENV ensure that monitoring plans are designed to ensure early detection of potential water quality changes in groundwater and surface water due to their interactions (Section 10.9);
- AENV condition any EPEA approval for the project to require monitoring of acid deposition on water bodies (Section 10.9);
- AENV consider IFN objectives and management approaches in its approvals for the project (Section 11.8);
- ASRD require Shell to also consider the widths and types of buffer zones for benefits to watershed management when evaluating wildlife corridors (Section 11.8);
- AENV require Shell to conduct or support monitoring of water levels in Kearl Lake to validate the predictions made in the environmental impact assessment (EIA) (Section 11.8);
- AENV and ASRD, in consultation with DFO and EC, require Shell to conduct follow-up studies on potential impacts of fish tainting compounds (Section 12.5);
- AENV consider requesting Shell to provide, prior to construction, additional mitigation plans to limit external tailings disposal area seepage (Section 13.1.6);
- AENV's Dam Safety Branch require Shell to include updated seepage modelling results, Quaternary deposits mapping, monitoring plans, and mitigation measures in the tailings disposal area detailed design report (Section 13.1.6);
- AENV incorporate conditions in its approval requiring Shell, in conjunction with other developers, to define and carry out a regional groundwater study of the Pleistocene Channel

aquifer (PCA) in order to evaluate the regional nature of this groundwater resource (Section 13.1.6);

- AENV and ASRD require Shell to participate in a technical review of wildlife corridors that includes analysis of corridor effectiveness in facilitating wildlife movement (Section 16.1.9).
- AENV and ASRD review with Shell an action plan to maintain other islands or strips of undisturbed native vegetation on the Shell lease in association with wildlife corridors (Section 16.1.9).
- ASRD require Shell to develop a wildlife monitoring program for implementation prior to construction (Section 16.1.9);
- ASRD and AENV identify wetlands research as a priority for CEMA to address and that they consider requiring Shell to support a program to facilitate wetlands restoration (Section 16.2.9);
- AENV and ASRD consider whether additional performance criteria should be developed for progressive reclamation (Section 16.3.4);
- AENV monitor end-pit lake (EPL) development and testing by Shell and other operators (Section 16.4.4);
- AENV consider long-term environmental effects on the Muskeg River in the design of Shell's water monitoring programs (Section 17.6);
- AENV develop management plans and objectives for the Muskeg River basin if Muskeg River Watershed Integrity (MRWI) subgroup timelines are not met (Section 17.6);
- in addition to recommendations on IFN and MRWI, AENV and ASRD consider developing management plans or objectives respecting other environmental issues if CEMA timelines are not met (Section 21.10); and
- AHW, in conjunction with HC, consider undertaking a regional baseline health study primarily dealing with First Nations, Metis, and other aboriginal groups and consider contributing expertise and funding in support of WBEA's efforts to implement an ongoing health-monitoring program consistent with the recommendation of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program (Section 24.6).

2 INTRODUCTION

2.1 Applications

Application No. 1271285 was made by Shell pursuant to Sections 10 and 11 of the Oil Sands Conservation Act (OSCA) for approval of an oil sands mine and bitumen extraction facility in the Fort McMurray area. Shell also applied for approval to receive third-party oil sands for processing and to produce and ship oil sands from the site for third-party processing.

Application No. 1271307 was made by Shell pursuant to Section 11 of the Hydro and Electric Energy Act for a cogeneration plant consisting of one 160 megawatt (MW) gas turbine generator to be located in the southeast portion of Section 10 in Township 95, Range 9, West of the 4th Meridian (SE 10-95-9 W4M.).

Application No. 1271383 was made by Shell pursuant to Part 4 of the Pipeline Act for approval of an 8.5 kilometre (km) fresh water pipeline from legal subdivision (LSD) 02-23-95-10 W4M to LSD 08-16-95-10 W4M.

In support of its proposal and as part of its application to the EUB, Shell also submitted an EIA report to AENV, pursuant to EPEA.

The project would be located approximately 70 km north of Fort McMurray and 10 km east of Fort McKay in Township 95, Ranges 8 and 9, West of the 4th Meridian. The project includes the planning, construction, and operation of the following major oil sands facilities:

- open pit, shovel-truck mine designed to produce 31 800 cubic metres per day (m^3/d) of bitumen for 20 years,
- relocatable crushing and conveying system to size and transport the oil sands to an ore preparation plant,
- three bitumen processing trains that would use a warm (40 to 50°C) water-based, caustic-free ore conditioning and extraction process,
- paraffinic solvent-based bitumen froth treatment process,
- thickeners to thicken thin fine tailings and recycle water,
- cogeneration plant,
- fresh water pipeline connecting the existing Muskeg River Mine (see Figure 1) water withdrawal from the Athabasca River to the project,
- infrastructure associated with the mine and related facilities, and
- tailings management scheme.

The project proposal also includes

- an integrated reclamation plan,
- an integrated water management plan,
- the diversion of 63.5 million (10^6) m^3 per year of water from the Athabasca River, with a maximum instantaneous withdrawal rate equal to the permitted capacity of the intake at 4.17 m^3 per second (s),
- waste management plans,
- initial and ongoing consultation with stakeholders on the social, economic, and environmental impacts of the project, and
- a number of agreements.

Figure 1 shows the project location and other features of the area.

2.2 Joint Panel Review Process

Shell applied to DFO for approval under Section 35(2) of the Fisheries Act for authorization to cause the harmful alteration, disruption, or destruction of fish habitat. Prior to DFO issuing an authorization, an environmental assessment of the project under CEAA was required.

On June 26, 2003, the Honourable Robert Thibeault, Minister of Fisheries and Oceans, referred the environmental assessment of the project to a review panel, pursuant to Section 21(b) of CEAA.

On July 30, 2003, the Canadian Environmental Assessment Agency announced that it was proposing to establish a joint environmental assessment panel for the project. Following a 21-day public comment period, the Honourable David Anderson, Minister of the Environment, and Neil McCrank, Q.C., Chairman of the EUB, signed an agreement (see Appendix 2) to establish the Panel.

Under the Panel agreement, the Panel is charged with fulfilling the review requirements of both CEAA and ERCA. Under ERCA, the Panel must determine whether the project is in the public interest. In making this determination, the Panel is required to consider a range of factors, including resource conservation, safety, and the economic, social, and environmental impacts of the project.

Under CEAA, the Panel is required to submit a report to the Minister of the Environment and to the Minister of Fisheries and Oceans providing the Panel's rationale, conclusions, and recommendations relating to the environmental assessment of the project, including any mitigation measures and follow-up programs.

Under its CEAA mandate, the Panel must assess the environmental effects of the project, including the environmental effects of malfunctions or accidents that may occur in connection with the project and any cumulative environmental effects likely to result from the project in combination with other projects or activities that are existing or planned.

Under its CEAA mandate, the Panel must also determine the significance of the environmental effects of the project. In examining whether any potential adverse effects associated with the project are significant, the Panel must consider the magnitude, geographic extent, duration and frequency, degree to which they are reversible or irreversible, and ecological context of those effects.

Under its CEAA mandate, the Panel must also consider whether there are technically and economically feasible measures that would mitigate any significant adverse environmental effects of the project.

This report sets out the Panel's decision, reasons, rationale, conclusions, and recommendations with respect to its review of the project under ERCA and CEAA and includes a discussion of recommended mitigation measures and follow-up programs. This report also provides a summary of comments received from the public.

2.3 Hearing

The Panel consisted of J. D. Dilay, P.Eng. (chair), R. Houlihan, Ph.D., P.Eng., and G. Kupfer, Ph.D. The Panel considered the applications at a public hearing held in Fort McMurray, Alberta, on October 6 through 10 and October 15, 2003.

Those who appeared at the hearing and the abbreviations used in this report are set out in Appendix 3.

Syncrude Canada Limited (Syncrude) participated in the hearing for the purpose of making final argument. Canadian Natural Resources Limited (CNRL) participated in the hearing for the purpose of questioning. UTS Energy Corp., Suncor Energy Limited, and Imperial Oil Resources and ExxonMobil (ExxonMobil) registered at the hearing but did not question or provide final argument.

3 AGREEMENTS

3.1 OSEC and Shell Agreement

The Oil Sands Environmental Coalition (OSEC) stated that it did not object to the project based on its understanding that Shell would manage and mitigate the adverse effects of the project as outlined in the terms and conditions of its agreement with Shell.

OSEC stated that its agreement addressed issues that OSEC believed were priority issues for the project and the cumulative effects of oil sands development. These issues included species at risk, particulate matter, acid deposition, water withdrawals from the Athabasca River, land disturbance, including loss of wetlands, wildlife movement, and habitat, the creation of EPLs, greenhouse gases (GHGs), and impacts on municipal infrastructure, health, traffic safety, housing, and social services.

OSEC noted that the next steps for Shell and OSEC would be to develop an action plan containing specific tasks and schedules required to meet the agreed-upon objectives.

OSEC requested that the Panel take the agreement into consideration in its deliberations. OSEC also requested that the EUB formally recognize the agreement in any approval it might issue for the project.

3.2 MCFN and Shell Agreement

At the opening of the hearing, the Mikisew Cree First Nation (MCFN) stated that it had reached an agreement with Shell. MCFN stated that it no longer objected to the Shell applications and that many of its specific concerns in relation to the EIA and the project had been addressed.

MCFN said that its main concerns about the project related to impacts of the project on the quantity and quality of water in the Athabasca River. MCFN was also concerned about social, economic, cultural, health, and other impacts of the project on its people and traditional lands. MCFN stated that its concerns were addressed in Shell's Environmental Action Plan. In the plan, Shell committed to provide 30 days of on-site water storage and agreed to involve MCFN in the design, implementation, and review of its monitoring and reclamation plans. An agreement was also reached regarding a number of social, economic, and cultural impacts. The agreement included the possibility of Shell funding a health study in Fort Chipewyan. MCFN stated that it and Shell were committed to developing an action plan to ensure the agreement was met.

MCFN stated that it remained concerned about climate change, long-term flows in the Athabasca River, and CEMA's progress towards defining IFN. MCFN presented evidence on these issues at the hearing.

3.3 ACFN and Shell Agreement

The Athabasca Chipewyan First Nation (ACFN) stated that it did not object to the project, based on its understanding that Shell would mitigate the adverse effects of the project as outlined in the terms of the mitigation agreement between ACFN and Shell.

ACFN stated that water was its main concern and that Shell had addressed this concern by agreeing to limit its withdrawal of water from the Athabasca River and to abide by any approved CEMA recommendations on IFN. Shell also agreed that it would not negatively affect Kearl Lake or McLelland Lake.

ACFN noted that the agreement also included a requirement for an ongoing relationship between ACFN and Shell.

ACFN requested that the Panel consider its agreement with Shell in its deliberations. ACFN also requested that the EUB approval specify the EUB's expectations and requirements in relation to those matters described in ACFN's agreement with Shell.

3.4 Fort McKay and Shell Agreement

Fort McKay First Nations and Metis Local 122 (Fort McKay) stated that it did not object to the project, based on its understanding that Shell would manage and mitigate the adverse effects of the project as outlined in the terms and conditions of Fort McKay's agreement with Shell. Fort McKay requested that the Panel carefully consider the issues and the mitigation identified in the agreement. It hoped that the proposed mitigation would be endorsed and facilitated by the EUB and AENV.

3.5 Non-assertion of Rights Agreement

The Province of Alberta and MCFN advised the Panel that they had entered into a Non-assertion of Rights Agreement, in which MCFN agreed not to assert constitutional rights before the Panel. The Province of Alberta agreed that it would not challenge MCFN's claims of traditional occupation of the project lands before the Panel. The agreement allows the Province of Alberta or MCFN to raise those issues in other forums.

3.6 Views of the Panel

The Panel acknowledges and commends Shell, MCFN, ACFN, Fort McKay, and OSEC on the success of their efforts to enter into agreements. While these agreements will not form part of the EUB approval, the Panel does expect Shell to meet its commitments and continue its consultation and communication efforts throughout the life of the project.

4 ISSUES

The Panel considers the issues respecting the applications to be

- purpose, need, and alternatives to the project,
- resource recovery,
- tailings management,
- environmental effects (water, terrestrial, air),
- health effects,
- measures to enhance beneficial environmental effects,
- need for EIA follow-up,
- regional initiatives,
- regional development,
- social and economic effects,
- public consultation,
- capacity of renewable resources, and
- traditional use and cultural resources.

The following sections of the report summarize the evidence of Shell and the interveners and provide the Panel's assessment of the issues. If Shell or an intervener expressed no views on a particular issue, there is no corresponding section for Shell or that intervener in the report.

5 PURPOSE, NEED, AND ALTERNATIVES TO THE PROJECT

5.1 Purpose and Need for the Project

5.1.1 Views of Shell

Shell indicated that its goal was to continue to supply energy in a responsible manner and to be a responsible member of the communities in which it operated. Shell stated that it must remain viable as a corporation to provide a reasonable return to its shareholders and employment for its employees and to continue to support the communities in which it operated.

Shell acquired Lease 13 in 1956 and spent over $250 million in evaluating its resource potential. In 1999, Shell received approval for the Muskeg River Mine and the Scotford Upgrader and spent about $7 billion on the development of those projects. Shell stated that the project was needed to realize the full benefit of Lease 13 reserves.

Shell indicated that the purpose of the applied-for project was to exploit the resource on Lease 13 further and to provide a supply of bitumen to upgrade, refine, and sell oil to the public. According to Shell, there will be an ongoing demand for transportation fuels and other oil products in North America, which Shell will have the opportunity to meet through the development and use of this resource.

Developments such as the project were integral to Shell's long-term success as a fully integrated petroleum company and responsible member of the communities in which it operated. It stated that oil sands provided a secure domestic source of oil to replace diminishing conventional supplies for North America.

Shell stated that it began testing production methods on Lease 13 in 1955 and first applied to the Alberta government in 1962 for approval of an in situ project. This application was withdrawn as mining methods evolved and the Great Canadian Oil Sands (now Suncor) project advanced.

Shell indicated that to achieve economic production using an in situ recovery method, all of the following conditions would have to be met:

- minimum ore grade,
- suitable cap rock,
- sufficient depth, and
- absence of low-permeability zones in one contiguous area.

Shell did not consider locations within the project area to be economically viable for in situ techniques. Therefore, Shell did not pursue in situ extraction processes as an alternative to the project.

As a result, Shell concluded that there were no viable or realistic alternatives to the project. Shell stated that the need to maximize the value of an asset Shell had owned since 1956 and to obtain a source of bitumen supply for upgrading, refining, and selling to the public could be only achieved through the development of the project.

5.1.2 Views of the Panel

The Panel notes that no interveners argued against Shell's stated need and purpose for carrying out the project. The Panel accepts Shell's stated need and purpose and the criteria that Shell used to evaluate the alternatives it identified. The Panel notes that the purpose and need for the project provide the context for the Panel's consideration of alternatives to the project.

The project, as scoped by the signatories to the Panel agreement, is to construct and operate an oil sands mine, bitumen extraction facility, cogeneration plant, and fresh water pipeline. The Panel, having considered the potential alternatives to the project, concludes that it has sufficient information about the need and purpose of the proposed undertaking and that there are no viable alternatives to the project.

5.2 Alternative Means of Carrying Out the Project

5.2.1 Views of Shell

Shell considered a number of alternative means of carrying out the project. It evaluated the following mining, facility, and infrastructure locations and process methods in detail:

- mine opening sequences and locations,
- external tailings disposal locations,

- plant site locations,
- ore preparation methods,
- ore conditioning and bitumen extraction methods,
- froth treatment methods,
- tailings management methods,
- utility corridor locations,
- access road locations, and
- stream diversions.

Shell evaluated three alternatives for a mine opening location and sequence. Alternative 1 had the mining starting in the area closest to the tailings disposal area and plant site and advancing west to east. Alternative 2 considered mining starting from the north side of the lease, east of the north overburden disposal area. Alternative 3 considered mining starting from the northeast corner of the lease. Shell based the comparison of the three alternatives on development sequences for mining that assessed the initial quantity of overburden, quality of oil sands feed, initial capital costs for ore handling and preparation systems, and the sequencing of reclamation material stockpiles (RMS) and overburden disposal areas. Shell chose Alternative 1 because it was a better choice technically, and it deferred a number of stream disturbances to a later date.

Shell applied for an external tailings disposal area on the southeast corner of Lease 13, after it had evaluated six alternative sites. Shell indicated that because Clearwater clays were under some of the southeast site, it would require additional design features to ensure geotechnical stability. Shell stated that the southeast site was constrained by a number of features limiting its expandability. The applied-for location was Shell's preferred alternative for both economic and environmental reasons.

Shell stated that it required a plant site with enough plot space for a three-train bitumen extraction plant. It reviewed four possible locations, all in areas of low economic oil sands potential but reasonably close to the main ore body. Shell applied for the plant site adjacent to and on the east side of Jackpine Creek (Figure 1). This location was the best-ranked alternative in all of the main categories that Shell used to assess possible locations.

With respect to alternatives for ore preparation, Shell applied for the rotary breaker and slurry box approach, on the basis that it was successful at the Muskeg River Mine. Shell considered the options of feeding ore into a mixbox and or into a cyclofeeder, but was unable to obtain detailed cost and performance data to compare those to its applied-for option.

Shell selected an ore conditioning process that used a noncaustic chemical additive with water between 40 and 50°C, mainly because the environmental benefits were greater when compared to processes that used caustic and/or operated at higher temperatures. The slurry also had to be mechanically conditioned in a pipeline, as rotary drum conditioning had not been scaled up to a suitable commercial use and tank conditioning did not appear to have the technical or economic benefits of pipeline conditioning. Shell stated that it did not consider drum conditioning to be a viable "conditioning only," option based on the data gathered.

Shell concluded from its review that the noncaustic selection would not affect the temperature selection. In addition, the noncaustic and temperature selections would not affect which mechanical conditioning was selected. Shell stated that it selected the Muskeg River Mine extraction and ore conditioning process as its preferred alternative because it was the best economically and technically and was only marginally different from the best environmental case.

Shell assessed four alternative froth treatment processes. One was identical to the existing Muskeg River Mine process design. The three other alternatives considered were use of

- a naphtha-based process diluent,
- inclined plate separators instead of countercurrent gravity separation cells, and
- electrostatic desalting to replace one of the steps in froth cleanup.

Shell stated that its assessments of these alternatives were based on previous proprietary Muskeg River Mine selection studies.

Shell noted that the Muskeg River Mine used a paraffinic froth treatment process because that provided the desired product quality. Shell eliminated three other froth treatment alternatives because they did not provide the required product yield or quality.

All of the tailings streams from the extraction and froth treatment area would be deposited in an external tailings disposal area until there was enough space to deposit the streams in-pit. Shell stated that tailings disposal in external containment required different engineering management than in-pit disposal. It evaluated external and in-pit tailings management options separately. It studied a number of tailings management alternatives for external tailings disposal and in-pit disposal.

The tailings management alternatives for external tailings disposal included

- the use of thickeners,
- no use of thickeners, and
- an alternative that used a thickener, with recovery of thin fine tailings (TFT) in the tailings disposal area for thickening.

Although the third alternative ranked higher than the alternative of not using thickeners, the research data for recovery of TFT from the tailings disposal area was too preliminary for that option to be considered. Shell chose the use of thickeners as its preferred alternative because it resulted in a better tailings management scheme with reduced volumes of TFT.

The tailings management alternatives for in-pit tailings disposal included

- mixing sand and all other tailings streams with gypsum,
- mixing sand and all other tailings streams without gypsum, and
- layering and dewatering.

Using gypsum was Shell's preferred choice, while the layering and dewatering alternative ranked second. Shell's review showed that only the sand and gypsum alternative had the required engineering data to support an application case. Shell said that it would carry out research and development using the Muskeg River Mine streams when it moved that mine's tailings in-pit.

Shell studied three utility corridor alternatives for electrical power and water and three for natural gas. Corridor rankings were unaffected by what the corridor would contain, whether natural gas, solvent, power, or water. Shell evaluated three alternatives for the power and water pipeline corridor and determined the best of the three alternatives. The three possible natural gas pipeline corridors were then ranked against the common power and water pipeline corridor. The preferred approach was a corridor that contained all utilities, power, water, and gas and minimized terrestrial disturbance.

Shell studied seven creek diversion alternatives representing the technically viable options for each creek (see Figure 2). The Khahago, Muskeg, Wesukemina, Shelley, Pemmican, Green Stocking, and Blackfly Creeks would be affected in the project area.

Respecting options for creek diversions, Shell chose the alternative of constructing a low dike and surge facility at the headwaters of Khahago Creek to mitigate the effects of precipitation and runoff, even though it was less attractive economically, because it met the stakeholders' needs.

5.2.2 Views of the Panel

The Panel concludes that Shell has provided adequate information on alternative technologies and alternative construction methods for consideration of these alternative means and their environmental effects. Having regard for Shell's comparisons, the Panel accepts shovel-truck mining, noncaustic bitumen extraction, paraffinic froth treatment, an external tailings disposal area, and in-pit disposal of tailings consolidated with the aid of gypsum as the preferred means of carrying out the project. The Panel accepts that there is a need to divert a number of streams in order to access the reserves. The Panel believes that Shell's mine plan and the location of the plant, tailings disposal area, and infrastructure provides a reasonable balance of good engineering and environmental management practices.

6 MINE PLANNING AND RESOURCE CONSERVATION

6.1 Mine Project Area

6.1.1 Views of Shell

Shell stated that the proposed project area extended from the Muskeg River Mine project area to the boundaries of Lease 13. Shell indicated that development activities for the project would occur east of Jackpine Creek and the Muskeg River (Figure 1). Shell included the area west of Jackpine Creek in the proposed project area because it contained corridors for the road access, utilities, and solvent and product pipelines that had not previously been included in the Muskeg River Mine project area. Shell denoted the area between Jackpine Creek and Muskeg River, referred to as the Sharkbite area, as a potential Muskeg River Mine expansion area. Shell stated that Albian Sands Energy Inc. (Albian Sands) would mine the Muskeg River Mine expansion area.

6.1.2 Views of the Panel

The Panel believes that the project area should allow Shell the opportunity to implement the project. The Panel notes that the corridors described by Shell would extend outside of the proposed project area and would be the subject of other applications. Furthermore, although the Panel notes Shell's assurances that an agreement can be struck between it and Albian Sands, the Panel believes that the project area proposed for the Jackpine Mine may impact Albian Sands's ability to maximize resource recovery in the potential expansion area. The Panel finds that the appropriate project area is the area covering the portion of Lease 13 east of Jackpine Creek and Muskeg River, shown in Figure 1.

6.2 Lease Boundary Mining

6.2.1 Views of Shell

Shell stated that the project would be bordered by the Muskeg River Mine to the west, Syncrude Lease 34 to the north, the Crown lease and ExxonMobil Lease 36 also to the north, and the Syncrude Aurora South project to the east and south. Shell indicated that the oil sands ore body extended beyond the Jackpine Mine lease boundary and into Syncrude Aurora South project, Syncrude Lease 34, ExxonMobil Lease 36, and a Crown lease.

Shell noted that there were a number of options to deal with the lease boundary between Syncrude Aurora South Mine and the Jackpine Mine, each necessitating some amount of resource sterilization. Shell stated that its preferred option was to pursue commercial agreements for swapping reserves to reduce or eliminate loss of mineable ore at the lease boundaries. Shell indicated that it was considering several options for ore swapping, but no agreements had yet been reached.

Shell indicated that although mineable oil sands extended beyond the north boundary into other leases, none of those leases had approved or proposed plans for development that would abut Shell's boundary.

Shell proposed that the Muskeg Creek diversion corridor be a 100 m wide corridor along the north lease boundary, primarily on Shell's lease. The Muskeg Creek diversion corridor was included as fish habitat loss compensation in Shell's No Net Loss Plan (NNLP). However, Shell noted that as part of the cooperation agreement with ExxonMobil, Shell would try to optimize resource recovery and that could impact the location of the Muskeg Creek diversion. Shell proposed to construct the diversion in 2018.

Shell stated that it was committed to working with both Syncrude and ExxonMobil to maximize ore recovery along the lease boundary. Shell agreed to submit, five years prior to commencement of mining, a description of how the resource extending beyond its lease boundary would be mined, including the impact on its mining and tailings plan and any project boundary modifications required.

6.2.2 Views of the Panel

The Panel notes that Shell is committed to continuing discussions with ExxonMobil and Syncrude to develop plans for recovering resource along the common lease boundaries. The

Panel commends Shell's efforts to pursue commercial agreements to exchange ore and thereby reduce lease boundary sterilization. The Panel would welcome agreements that result in optimal resource recovery. The Panel believes there is opportunity for Shell and ExxonMobil to optimize the location of the Muskeg Creek diversion to ensure maximum resource recovery. It will require Shell to address the location of the diversion and any associated oil sands sterilization as part of a lease boundary submission.

The Panel believes that lease boundary plans must be in place well in advance of mining to allow for a workable mine plan, including tree clearing, placement of ditches and dewatering of muskeg, location or relocation of infrastructure, and incorporation of material volumes. The Panel finds that submission of mining details and alternatives at least five years prior to commencement of mining at the lease boundary is a prudent course of action. This would allow time to gather additional information and to evaluate the mining alternatives identified. The five-year submission requirement is further justified in the event that leaseholders cannot reach agreement and EUB intervention is required.

The Panel directs that Shell submit a lease boundary report five years prior to mining activities reaching any common lease boundary. The report must include a comprehensive description of the lease boundary geology and reserves, geotechnical conditions, alternative mining scenarios and impacts, and the costs associated with each, all in accordance with Section 3.1 of EUB *Interim Directive (ID) 2001-7: Operating Criteria—Resource Recovery for Oil Sands Mines and Processing Sites.*

6.3 Road Access, Utility Corridors, and Plant Site

6.3.1 Views of Shell

Shell stated that the Canterra Road would be used to access the project. Shell's proposed utility corridors and the Canterra Road cross the Sharkbite area. Shell agreed that there was mineable oil sands in this area; however, it was not applying for development of the Sharkbite area as part of the Jackpine project applications. Shell said that it saw value in recovering the resource in the Sharkbite area and its intent was to ensure that resource recovery was maximized. Shell indicated that additional resource drilling would be completed in the Sharkbite area during the winters of 2003 and 2004, prior to finalizing the infrastructure routes.

Shell stated that the Canterra Road was a private road with multiple owners and that Shell owned the portion of the road within Lease 13. Shell also stated that it was not responsible for regional alternatives to this road. However, Shell stated that it and Syncrude were looking for an acceptable route from Highway 63 to their respective project areas. Shell stated that this route would be located generally along the south edge of Lease 13. Shell also stated that the results of the discussions between it and Syncrude could change the routing of the Jackpine Mine access route. Beginning in 2007, with the proposed start of full construction of the project, a major realignment of the Canterra Road west and north of the project area would be required to allow for continued access to oil sands developments east of Lease 13. For the longer term, the road would be closed in 2010 when mining activities commenced. Shell stated that the Regional Issues Working Group (RIWG) Transportation Subcommittee was exploring a more permanent eastside access corridor.

A marginal pit expansion area, denoted as SH02-537, would encroach on the plant site footprint. Shell's evaluation indicated that area was not economic to mine (Figure 1). However, Shell stated that it would complete additional resource drilling along the pit limits in the area prior to finalizing the footprint limit of the plant site.

6.3.2 Views of the Panel

The Panel notes that additional drilling in the Sharkbite area will provide further understanding of the mineable oil sands zone. It notes that there is a possibility that the current access route may change as a result of Shell and Syncrude working together to find a suitable access route to the project and the Syncrude Aurora South Mine. The Panel also notes that Shell is participating in RIWG's Transportation Subcommittee, which includes other oil sands developers, Alberta Transportation, and the Regional Municipality of Wood Buffalo (RMWB), to find alternatives to the Canterra Road. The Panel further recognizes that significant changes to the Canterra Road will not occur until 2007. Therefore, the Panel believes that the proposed utility corridor and access route could potentially be modified. Those modifications would need to be considered from a number of aspects, including resource recovery.

The Panel believes that there is sufficient time to acquire the information required to optimize the recovery of mineable oil sands in the Sharkbite area and the location of the access road and utility corridor for the project. The Panel, therefore, directs Shell to submit, for EUB approval, an access road and utility corridor update in its 2006 annual report. The report shall include a resource assessment of the oil sands located in the Sharkbite area and under the modified infrastructure corridor. It shall also include a comparison of alternative access road and utility corridor alignments with respect to resource recovery and other relevant criteria.

The Panel believes that the plant site footprint is sufficient for the proposed project. However, the Panel will require Shell to obtain EUB approval should the plant site area need to be larger. The Panel directs Shell to submit, for EUB approval, a resource assessment of the plant site area two years prior to construction.

6.4 Overburden Disposal Areas and RMS

6.4.1 Views of Shell

Shell outlined a number of disposal areas for overburden and similar waste materials that would be required for the life of the project. Shell indicated that it undertook a review of the geotechnical conditions that affect the disposal areas to identify key geotechnical issues that would be addressed during the mine plan development. Shell also stated that it obtained no new data from the field or laboratory for this analysis; it used a database of geotechnical testing results completed at the Muskeg River Mine, supplemented with Suncor and Syncrude operating information. Shell indicated that it would need to complete further site-specific geotechnical investigations prior to construction.

Shell indicated that it would develop the east overburden disposal area first. This area was divided into two parts to provide a haulage corridor from the mine to the in-pit crusher station. The east disposal area generally conformed to the outline of the PCA (see Section 13). According to Shell, the channel had removed up to 50 m of oil sands along its course, and therefore had significantly decreased the amount of mineable resource. Shell completed drilling core and auger holes in 2001/2002 to improve confidence in the aerial extent and base elevation of the PCA. However, Shell stated that it would complete additional drilling in the mining areas surrounding the east overburden disposal area to further define mineable ore and the location of the final pit wall. Shell stated that the final pit wall would optimize mining costs versus impacts to the PCA due to encroachment. Shell agreed to submit this information to the EUB for review and approval, and stated that it would prefer to submit this as part of the annual mine plan one year prior to placement. Shell indicated that depending on the additional drilling, it would be willing to modify the disposal area footprint to avoid placing overburden on mineable oil sands.

Shell stated that the west overburden disposal area was scheduled to accept material in 2013. It noted that all 24 drillholes located within the footprint had total-volume-to-bitumen-in-place ratios (TV:BIP) greater than 12. The west overburden disposal area would be surrounded by three RMS, denoted as 1, 3, and 4. Shell stated that it would do additional drilling in the mining areas to further delineate the pit limit prior to placing material in the RMS. Referring specifically to RMS 3 and 4, Shell indicated that if drilling showed that there was oil sands in this area, it would not place reclamation material on mineable oil sands. Shell said that it would prefer to submit this information to the EUB for review and approval as part of the annual mine plan.

Shell indicated that the north overburden disposal area would be scheduled to accept material in 2018. Shell noted that it would complete drilling in this area five years prior to overburden placement commencing. Shell agreed to complete further drilling within the footprint of the disposal area and submit a resource assessment of the north overburden disposal area to the EUB two years prior to placing material in this area.

Shell agreed that additional drilling may result in changes to the pit limits and agreed to provide additional ore body characterization. Shell indicated that it was willing to submit an updated ten-year mine plan and material balance by 2008.

6.4.2 Views of the Panel

The Panel finds that the preliminary designs used by Shell for the overburden disposal areas are reasonable, based on the currently available information regarding geotechnical characteristics of the site and materials, and that the use of these designs for long-range planning of waste storage requirements is appropriate. However, the Panel directs Shell to submit, for EUB approval, detailed geotechnical design for all external overburden disposal areas at least six months prior to field preparation in those areas.

The Panel accepts that on the basis of the available data, Shell has optimized the locations of the east and west overburden disposal areas, as well as the RMS, in order to minimize the sterilization of mineable oil sands. However, further drilling in these areas may indicate that the current overburden disposal areas and RMS footprints result in additional sterilization of mineable oil sands. The north overburden disposal area does not have sufficient drilling to warrant approval of the footprint at this time. Shell will be required to complete further drilling in the footprint of the north overburden disposal area. The Panel directs Shell to submit, for EUB approval, a resource assessment of the three waste disposal areas and RMS, two years prior to material placement.

The Panel believes that the resource information for each disposal area must be submitted at least two years prior to material placement, to ensure that there is sufficient time to complete any additional drilling that may be required. This requirement allows sufficient time for at least one full drilling season and an appropriate review period. The information may be submitted as part of the annual mine plan or under separate cover, but it is critical that the timing of the submission be appropriate.

The Panel notes that there is some level of uncertainty in the footprints of all the overburden disposal areas, which could impact the overall disposal capacity. It also notes that Shell intends to complete a significant amount of drilling prior to start-up, which could impact the overall material balance for the project. The Panel finds that while there is sufficient information for Shell to provide an adequate prefeasibility mine plan, an updated ten-year mine plan and material balance are required after the feasibility study has been completed. This will ensure that the project will progress in a way that is in the public interest. Therefore, the Panel directs Shell to submit, for EUB approval, a ten-year mine plan and material balance by the earlier of 2008 or six months prior to pit development.

6.5 Operating Criteria

6.5.1 Views of Shell

Shell stated that it evaluated the Jackpine Mine reserves using the operating criteria established in *ID 2001-7*. It determined final pit limits by using a TV:BIP of 12:1 and considering a number of physical constraints, including lease boundaries, Muskeg River, Jackpine Creek, and the PCA.

Shell stated that the expected bitumen recovery in the extraction process would meet or exceed the bitumen recovery requirements defined in *ID 2001-7* for the average ore grade of 10.7 mass per cent. Shell clarified that 10.7 mass per cent would be the average ore grade over the first 15 years of the mine life. However, Shell expected that situations might arise during operations that could result in these criteria not being met, particularly for lower grade ores. Shell stated that it was committed to filing a report with the EUB at the end of each year explaining overall recoveries achieved for that year and any deviations from *ID 2001-7*. Shell indicated that it would continue to engage in research and development with a view to improving current estimated recoveries.

Shell noted that there were a number of potential plant improvements that could increase bitumen recovery. Shell listed two other factors that would lead to higher ore recoveries: the absence of marine channel or tidal channel transition ore in the early years of mining, and Shell's ability to blend ore from shovels that would be operating at the site.

Shell also stated that it would participate in the review of *ID 2001-7*.

6.5.2 Views of the Panel

The Panel directs Shell to meet the resource recovery requirements specified in *ID 2001-7* for the reasons set out below.

The Panel notes that although Shell indicated that it would meet operating criteria requirements for the first 15 years of the project, Shell has not made the same commitment for the final years of the project. The Panel understands that Shell believes that the lower grade ores the mine may encounter in later years would negatively impact recovery. However, the Panel believes that Shell has sufficient time prior to start-up in 2010 and in the following 15 years of production to optimize its extraction process to increase recovery from the lower grade ores.

The operating criteria concept sets the requirements of resource conservation using a set of four criteria (TV:BIP, selectivity, cutoff grade, and extraction recovery) that are not individually subject to enforcement. It is the overall amount of bitumen recovered annually that Shell must achieve. If Shell's extraction plant recovery is low, it has the opportunity to offset any deficit in bitumen recovery by mining material over TV:BIP of 12, reducing cutoff grade, or altering selectivity. The Panel believes these criteria to be minimum industry standards and it expects operators to design plant facilities and mining operations in order to meet those standards.

The Panel notes that Shell said it would submit a report at the end of each year explaining extraction recovery attained throughout the year and any deviations from *ID 2001-7*. The Panel observes that the operating criteria performance measuring system is an after-the-fact system in that the quantity of bitumen that should have been recovered during a given year is estimated after the year is completed. If there is need for enforcement action, that would occur in the period following the year in which operating criteria are not met. As outlined in *ID 2001-7,* a report issued at the end of the year outlining deviations from the EUB directive would not preclude the EUB from subsequent enforcement action.

Notwithstanding the above, the Panel also understands that many challenges can occur during commissioning of an oil sands project. If Shell believes that it may be unable to meet *ID 2001-7* requirements during commissioning, the Panel expects Shell to submit a detailed plan specifying increased bitumen losses and providing technical and economic justification to the EUB for approval. The plan must be submitted at least three months prior to the processing of oil sands in the extraction plant.

ID 2001-7 requires that the EUB review the operating criteria in 2005, with a view to determining the reasonableness and appropriateness of the criteria. The Panel notes that the project will not be starting up until 2010 and thus would be able to incorporate any changes to the operating criteria that result from this review.

6.6 Mining Setbacks

6.6.1 Views of Shell

Shell noted that it used three criteria to determine the distance mining activity would be set back from the Muskeg River: areas of shrubby swamps, a 100 m undisturbed setback from the edge of the open water channel of the river, and a 400 m wildlife corridor measured from the Muskeg River Mine Miscellaneous Surface Lease (MSL) to the edge of the project disturbance area. Shell stated that it would construct a 100 m wide flood berm and a 65 m road and power line corridor between the setback line and the pit crest. Shell acknowledged that there was potential that mineable ore extended beneath the Muskeg River and indicated that 17.3 10^6 m^3 of bitumen in place, measured from the edge of the MSL to the toe of the proposed pit face, would be left below the Muskeg River, the Muskeg River offset, and associated infrastructure.

Shell stated that a regional wildlife movement corridor study was within the mandate of CEMA. It further stated that it would participate in the appropriate CEMA subgroup and would help fund and design the study.

Shell indicated that mining activity would be set back 100 m from Jackpine Creek. The northernmost section of Jackpine Creek, near the confluence with the Muskeg River, would also require a flood berm.

6.6.2 Views of the Panel

The Panel recognizes that environmental setbacks provide needed wildlife corridors and habitat protection, but notes that mineable oil sands would be sterilized and recovery of the resource would be negatively impacted. The Panel is prepared to accept the proposed setbacks and the associated loss of oil sands resource in order to protect the environment.

The Panel recognizes that a CEMA subgroup is implementing a regional wildlife movement corridor study and that the group's findings may impact the proposed width of the 400 m wildlife corridor. This issue is further addressed in Section 16.1. The Panel also notes that the MRWI subgroup is working towards management objectives for the watershed. The Panel notes that these objectives could also potentially impact the proposed setback from the Muskeg River and are required by Shell and the EUB to make resource management decisions. The Panel observes that the results of further work by CEMA may indicate a need for a larger setback from the Muskeg River. In that case, the amount of resource at risk of being sterilized could increase substantially. The Panel expects that Shell will evaluate the impact of implementing approved results from the CEMA subgroups dealing with the wildlife corridor and MRWI. If there is potential to sterilize additional resources, Shell is required to submit a report for EUB approval containing a comprehensive description of the reserves within the setback, geotechnical conditions, alternative mining scenarios, environmental impacts of each scenario, and associated costs, in accordance with Section 3.1 of *ID 2001-7.*

The Panel supports the disturbance setbacks, provided that the desired protection is achieved, and believes that these setbacks should be maintained, once established. The Panel notes that Shell has proposed multiple criteria to determine the setback from the Muskeg River, including a 100 m setback from the edge of the open water channel. The Panel expects Shell to maintain all the proposed setbacks and will direct that the project area exclude the 100 m setback from the Jackpine Creek and the Muskeg River, as shown in Figure 1. The Panel has adjusted the project area to accommodate the access road and utility corridor, since each would cross the 100 m setback. The Panel believes that the 100 m setback would allow Shell some flexibility within the project area if results from the CEMA committees indicate that the 400 m wildlife corridor could be decreased or if avoiding shrubby swamps is not necessary.

6.7 External Tailings Disposal Area Location and Design

6.7.1 Views of Shell

Shell indicated that it investigated six different external tailings disposal area locations to contain the estimated 571 10^6 m^3 of tailings production. Shell noted that the mining pit, the Khahago surge facility, the Khahago diversion spillway and the south lease boundary, the plant site, and the east overburden disposal area all surround the tailings disposal area. Shell investigated increasing the capacity of the tailings external impoundment by raising the tailings disposal area dikes without changing the footprint.

Shell identified a marginal mining area, denoted as area DH-141, which encroached on the northwest corner of the tailings disposal area, but stated that this area was not economical to mine. Shell stated that while it did not provide the results of combining area DH-141 and SH02-537, work that was completed resulted in a higher combined TV:BIP value than that of either of these pit extensions on their own. SH02-537 was a marginal zone that encroached on the plant site. Shell said that it would complete drilling along the pit limit near the plant site and tailings disposal area prior to finalizing the footprint of either of the sites (Figure 1).

Shell stated that the external tailings disposal area would need to accommodate the tailings production before in-pit storage was possible. The tailings disposal area was designed as a segmented facility divided into a zone for thickened tailings and another zone for a Tailings Solvent Recovery Unit (TSRU) and conventional tailings. Shell indicated that it had not completed any site-specific geotechnical evaluation of the tailings disposal area foundation.

Shell stated that the outside slope of the tailings dike in the southeast corner would be shallower to accommodate the presence of Clearwater clays. In addition to the shallower slope, there was a possibility that a 200 m wide toe berm would be required to stabilize the slope. Shell also proposed to locate the Khahago surge facility in this area. Shell stated that the surge facility would be excavated to a depth of 13 m and could be designed to maintain geotechnical stability of the tailings disposal area.

Shell indicated that it would do further site-specific geotechnical investigation. Shell stated that it would provide the EUB and AENV's Dam Safety Branch with the final tailings disposal area design one year prior to impoundment. Shell also stated that the Khahago surge facility would be constructed earlier than the tailings disposal area and that Shell would provide the design of the facility prior its construction.

In an agreement with MCFN, Shell committed to incorporating additional on-site water storage in the design of the project in the external tailings disposal area, recycle water pond, raw water pond, and Khahago surge facility. Shell indicated that the additional on-site water storage would minimize water withdrawal from the Athabasca River during low-flow periods for up to 30 days. Shell indicated that the 30-day storage commitment would not impact the tailings management plan. Shell did not see any reason to look for off-lease storage solutions.

6.7.2 Views of the Panel

The EUB's responsibility when considering applications for tailings disposal areas is to address their purpose, location, and preliminary engineering design. *Informational Letter (IL) 94-19: The Dam Safety Accord*, specifies that the EUB's role with respect to new external tailings disposal areas is to ensure that structures are located such that resource sterilization is minimized, the facilities are needed and sized to adequately service the proposed project, the site is appropriate, considering logistics as well as environmental acceptability, and the proposed design meets the requirements for worker and public safety and for the integrity of the project.

The Panel believes that the tailings disposal area is sufficient for the prefeasibility planning stage. However, modifications to the tailings management plan or changes to the project layout may negatively impact the tailings disposal area footprint and the proposed capacity. Further, due to the proximity of the plant site, Khahago surge facility and diversion, and the mining pit, there is no additional land available for expansion on Lease 13. There may be an opportunity for Shell to expand south of its lease, but this would require some form of regional cooperation between leaseholders. While Shell indicated that it has the ability to raise the tailings disposal area dikes, the Panel believes that this would increase the capacity by only a small amount.

The Panel believes that the Khahago surge facility may impact tailings disposal area stability. Further geotechnical investigation and a more detailed design may mitigate these concerns. The Panel notes that the Khahago surge facility would be constructed prior to the tailings disposal area and believes that sufficient design work must be completed in parallel with the external tailings disposal area design to ensure that the surge facility will not compromise the tailings disposal area design. The Panel believes that there may be opportunity to change the location of the surge facility in cooperation with neighbouring leaseholders.

Having regard for the above, the Panel will include a condition in the EUB approval for Shell to satisfy the EUB, two years prior to construction of either the Khahago surge facility or the tailings disposal area, that the design of the tailings disposal area, including the surge facility, provides for adequate capacity, stability, and minimization of resource sterilization and environmental impact.

The Panel notes that Shell might use the tailings disposal area to store water for use during low-flow conditions in the Athabasca River. The Panel is concerned that rapid water withdrawal from the tailings disposal area could cause instability in the upstream tailings dike. The Panel expects AENV's Dam Safety Branch to require Shell to address upstream tailings dike stability in the detailed design.

The Panel concludes that the tailings disposal area is unlikely to result in significant adverse environmental effects, provided that the necessary design work is undertaken, submitted, and implemented.

6.8 Project Timing

6.8.1 Views of Shell

Shell stated that its overall development schedule was focused on achieving production of oil beginning in 2010. Site preparation would start in early 2005. In 2001/2002, Shell completed the prefeasibility study and conceptual engineering design of the project. Shell stated that an approval of the project was needed by the end of 2003 to allow for an initial investment decision and start of the feasibility study.

Shell stated that it would be opposed to a sunset clause in its approval. Shell indicated that a number of issues still had to be addressed after regulatory approval before the project would proceed, such as satisfying commitments to stakeholders and managing environmental issues. Shell stated that it had to be confident that it could build this project on time and on budget.

6.8.2 Views of the Panel

The Panel is satisfied that Shell has provided sufficient and adequately detailed information for the Panel to approve the project at this time. The Panel notes that Shell has completed a prefeasibility study and that there may be design changes as new information becomes available. The Panel expects that in the next ten years there will be additional technological development, particularly on tailings management, that may be applied. It also expects environmental management objectives and systems to be developed through CEMA and approved by government, and they may affect the project design. It further notes that Shell has a number of matters to complete prior to the project moving forward. Therefore, to the extent there are changes to the project design, the Panel directs Shell to provide an annual report to the EUB on the status of the project and its development commencing on February 28, 2005, or such other date and frequency the EUB may stipulate.

7 BITUMEN PRODUCTION

7.1 Views of Shell

Shell stated that the proposed bitumen extraction process would meet the operating criteria requirements for average-grade oil sands of 10.7 mass per cent bitumen and higher. Shell committed that it would continue research and development to improve the current estimated recoveries on low-grade ores and to provide the EUB with an update on its progress. It also noted that it would continue to investigate methods to recover bitumen from rejected ore.

Shell indicated that it was doing bench-scale flotation tests to determine the separation characteristics of asphaltenes and solvent in TSRU tailings and the feasibility of recovering the hot water from this stream. It indicated that the solvent was in the asphaltene portion and not the water phase. Shell stated that tests to thicken TSRU tails looked promising, and therefore the water could possibly be recycled back into the process.

Shell noted that the paraffinic froth treatment process would reject asphaltenes with the fine solids in tailings to produce a marketable bitumen product. The estimated asphaltene rejection would vary from 6 to 10 mass per cent. Shell stated that it would accept a condition in its approval limiting asphaltene rejection to 10 mass per cent based on bitumen production.

Shell stated that it had designed the tailings solvent recovery system with three equal-sized trains, of which two could handle the full production, thus providing 50 per cent redundancy. Each TSRU would consist of two stages of solvent recovery to control the losses in tailings prior to discharge to a tailings disposal area. Shell committed to limit its annual average site-wide solvent losses to 4 volumes per 1000 volumes of bitumen production. Shell also committed that it would not discharge untreated froth treatment tailings to the tailings disposal area.

7.2 Views of Alberta

AENV stated that it expected the plant to be designed and operated in a manner that minimized the frequency of odours incidents resulting from emissions of volatile organic compounds (VOCs) and other odorous compounds. AENV also stated that it might include conditions in the EPEA approval that would require Shell to provide 100 per cent TSRU redundancy or to reduce throughput when necessary to ensure that untreated tailings were not sent to the tailings disposal area and consequently that VOC emissions were minimized under all operating conditions.

7.3 Views of the Panel

The Panel encourages oil sands developers to use extraction technology that will maximize resource recovery, reduce energy and water consumption, and minimize fluid fine tailings production. The Panel believes that Shell is attempting to meet these goals by its choice of extraction process and the use of thickeners. The Panel understands that the proposed extraction process is presently being used at the Muskeg River Mine and that Shell will apply knowledge gained to the Jackpine Mine design and operation.

The Panel is prepared to accept Shell's proposed extraction process and expects it to achieve a bitumen recovery that allows it to meet EUB operating criteria. The Panel notes Shell's concern with recoveries from low-grade ores and Shell's commitment to research and development to improve the current estimated recoveries. The Panel directs Shell to provide a report on progress in improving the bitumen extraction recovery in every second annual report to the EUB, starting in 2008, or such other date and frequency the EUB may stipulate.

The Panel understands that Shell is continuing to evaluate TSRU thickeners and that Shell has seen promise in this technology. The Panel directs Shell to continue to evaluate TSRU thickeners technology and report results to the EUB in the 2006 annual report. The report must identify any opportunities to include TSRU thickeners in the project design and construction. The Panel also notes that Shell is testing separation characteristics of asphaltenes contained in TSRU tailings. Therefore, it directs Shell to report on its progress in dealing with separation characteristics of asphaltenes in the TSRU tailings in its annual report to the EUB commencing in 2005, or such other date and frequency the EUB may stipulate.

The Panel notes that Shell would be using a paraffinic solvent extraction process, which would result in asphaltene rejection and disposal with the TSRU tailings. The Panel accepts that higher quality bitumen provides a more marketable product than non-deasphalted bitumen, but is concerned about the rejection of asphaltenes, a potentially usable resource. The Panel directs that on or before February 28 of each year commencing in 2011, Shell shall provide to the EUB a summary of the previous year's operation stating the amount of asphaltene rejected. The Panel also directs that the amount of asphaltenes rejection shall be limited to 10 mass per cent based on bitumen production.

The Panel accepts Shell's commitment to limit annual average solvent losses to 4 volumes of solvent per 1000 volumes of bitumen production to minimize the potential VOC emissions and off-site odour incidents. This calculation shall be based on site-wide losses and shall include losses through vents and TSRU losses during all operating conditions. The Panel also accepts Shell's commitment that it would not discharge untreated froth treatment tailings to the tailings disposal area during normal operations. The Panel notes that these criteria are presently being applied to the Muskeg River Mine. Therefore, the Panel directs that on an annual average basis, Shell must limit site-wide solvent losses to not more than 4 volumes per 1000 volumes of bitumen production under all operating conditions. The Panel also directs Shell not to discharge untreated froth treatment tailings to the tailings disposal area.

The Panel concludes that the proposed extraction process and solvent losses are unlikely to result in significant adverse environmental effects, provided that the proposed mitigation measures and panel recommendations are implemented.

8 TAILINGS MANAGEMENT

8.1 Views of Shell

Shell stated that its objectives for the project tailings management plan were to manage the extraction plant tailings streams economically and in a manner that would minimize the out-of-mine impact. Shell wanted a stable, long-term landscape, consistent with effective reclamation and mine closure planning. The plan would place tailings into the mined-out pits as soon as possible, minimize the size of the external tailings disposal area, and advance reclamation of the mine pits.

Shell stated that the tailings management plan for the project would use an external tailings disposal area for the initial tailings disposal. It stated that it would convert to consolidated tailings (CT), consisting of a mixture of coarse tailings, thickened tailings, and gypsum, in-pit after about six years of operation. It noted that there were no other proven commercial options available to better meet its tailings management objectives.

The project would produce three tailings streams, a coarse slurry stream from the cyclone underflow of the primary separation vessels, a thickened tailings (TT) stream from the thickeners, and a segregating TFT stream from the TSRU into the external tailings disposal area. After about six years, CT would be deposited in the mined-out pits.

Shell estimated that CT would be produced as a nonsegregating mixture 81 per cent of the time. During non-CT operation, segregated sand and TFT would be produced.

Shell stated that all mined-out pits containing CT and the external tailings area would be reclaimed as dry landscapes at mine closure. The TT cell and two in-pit cells would remain as EPLs. Shell noted that the area of these EPLs represented less than 15 per cent of the total tailings disposal area. Shell stated that it would expedite progressive reclamation in the disturbed areas by creating CT with a sand-to-fines ratio of 5:1, allowing reclamation to be completed between three and five years after the end of tailings placement in the CT cells. Shell stated that excess mature fine tails (MFT) would be transferred to the EPLs and capped with water. It noted that the EPLs would eventually be self-sustaining, biologically productive water bodies that provided aquatic habitat. Shell stated that it had tested CT performance over a range of sand-to-fines ratios at the Muskeg River Mine. The tests indicated that it might be possible to allow lower CT sand-to-fines ratios, thereby reducing or eliminating the in-pit water-capped TT cell.

Shell stated that it was pursing other tailings management options through specific research programs, jointly through the Canadian Oil Sands Network for Research and Development (CONRAD), and through performance evaluations from Muskeg River Mine operations. It was committed to continue participating in regional and international research programs related to tailings properties and to ongoing research in the areas of paste pipeline flow studies, stacking, fine tailings mechanical thickening, TSRU tailings heat recovery, and reduction of moisture content of coarse tailings. Shell believed that there were no viable commercial tailings strategies other than those presented in its application.

8.2 Views of the Panel

The Panel believes that appropriate tailings management objectives for oil sands mines should be

- maximizing immediate process water recycle to increase energy efficiency and reduce fresh water import;
- minimizing stored process-affected water volumes on site;
- eliminating or reducing containment of fluid fine tailings in an external tailings disposal area during operations;
- minimizing and eventually eliminating long-term storage of fluid fine tailings in the reclamation landscape; and
- creating a trafficable landscape at the earliest opportunity to facilitate progressive reclamation.

The Panel accepts Shell's proposed tailings management scheme. The Panel believes that the proposed CT scheme takes positive steps towards achieving many of the above objectives.

The Panel recognizes that Shell would consume most of the coarse tailings solids and 60 per cent of the MFT in CT, with the remaining 40 per cent of the MFT transferred to an EPL. This scheme will not meet the objective of eliminating long-term storage of fluid fine tailings in the reclaimed landscape. The Panel notes that Shell will not commence production of CT until six years after start-up. The Panel believes that Shell should investigate opportunities to start CT production earlier so as to consume more of the MFT. The Panel directs Shell to submit a report to the EUB prior to final design or on June 30, 2006, whichever is earlier, on the feasibility of producing CT on commencement of operation in order to reduce the accumulation of TT, TFT, and MFT.

The Panel believes that tailings management is one of the main challenges for the oil sands mining industry. This challenge persists, despite considerable efforts over more than 40 years to develop alternative bitumen extraction and tailings management schemes that do not produce fluid fine tailings. Current tailings management results in tailings having to be impounded indefinitely and prevents reclamation of tailings areas. The challenge is more problematic since there is currently no demonstrated means to reclaim fluid fine tailings. The Panel notes that a reclamation scheme consisting of water capping of fluid fine tailings in an in-pit pond was applied for and endorsed by the EUB subject to a successful demonstration in EUB *Decision 94-5: Syncrude Continuous Improvement and Development Project, Mildred Lake Oil Sands Plant.* This demonstration is a major undertaking and considerable work has already been completed, with more expected to occur over the next 20 years. In the absence of a demonstrated successful case of reclamation of fine tailings by water capping, the EUB has previously directed oil sands mining developers to continue to work on alternative technologies for bitumen extraction or tailings management to ensure that acceptable reclamation of all tailings deposits will be achieved.

Therefore, the Panel expects Shell to continue to work to develop solid tailings technology and to evaluate the feasibility of implementing such technology at the project. The Panel directs Shell to describe its progress on developing solid tailings technology in every second annual report to the EUB commencing on February 28, 2005, or such other date and frequency the EUB may stipulate.

The Panel believes that it is imperative to produce high-quality CT consistently to ensure that the objective of a trafficable landscape that allows rapid progressive reclamation of tailings areas can be met. The Panel notes Shell's overall on-stream factor of 81 per cent and believes that a higher service factor is achievable and necessary to meet this objective. The Panel recognizes that considerable attention to equipment design and operation would be required to achieve a higher service factor and to ensure that the mixture consolidates and remains in a nonsegregated state. Therefore, the Panel directs Shell to submit to the EUB a report summarizing the engineering design and operating plans for the CT system two years prior to planned start-up or on such other date as the EUB may stipulate. The Panel also directs Shell to submit to the EUB on or before February 28 of every year commencing in 2011, or such other date or frequency as the EUB may stipulate, a report summarizing the performance of the tailings management system during the preceding year, including Shell's reasons for any deviations from design.

The Panel believes that Shell's proposed tailings management scheme is reasonable, based on current technology, but that there is need for further development efforts and for the regulators to ensure that Shell and other oil sands developers effectively manage tailings.

The Panel has considered a number of regulatory options to ensure that tailings are managed satisfactorily. In EUB *Decision 2002-089: TrueNorth Energy Corporation*, *Application to Construct and Operate an Oil Sands Mine and Cogeneration Plant in the Fort McMurray Area*, the EUB limited the maximum amount of project disturbance, which had the effect of imposing tailings management performance criteria to some degree. The Panel believes that this work could start by considering the factors that relate to fluid fine tailings consolidation, such as percentage of solids utilization, quality of tailings produced, and tailings system service factor. The Panel does not believe that it has adequate information in these proceedings to establish performance criteria for tailings management. Additionally, the Panel is concerned about potential inconsistencies when criteria are established on a project-by-project basis. The Panel believes that uniform criteria would allow the EUB to regulate more effectively in this area. Ideally, the criteria would be performance based, with the discretion left to operators as to how to meet the requirements. The Panel is not in a position at this time to set such criteria but believes that work should commence without delay to develop these criteria.

The Panel notes that the approval of discard management plans is the regulatory responsibility of the EUB and, therefore, it is appropriate for EUB staff to lead the initiative and consult with mineable oil sands developers. Due to the close linkages between tailings performance and reclamation issues, the Panel believes that this initiative would benefit from the participation of AENV and ASRD, since these departments have reclamation approval responsibilities under EPEA and the Public Lands Act (PLA). Therefore, the Panel will direct EUB staff to work with the mineable oil sands industry, AENV, and ASRD to develop performance criteria for tailings management. The Panel expects this work to result in a recommendation to the Board on the appropriate tailings management performance criteria by June 30, 2005.

The Panel notes that work continues on water capping of fine tailings. The Panel believes that ongoing tailings research will identify alternative means to reclaim fluid fine tailings, perhaps at a higher cost than water capping, if water capping fluid fine tailings proves to be unacceptable.

The Panel believes that close attention to design and operations supported by continued aggressive research by Shell and continued monitoring by EUB and AENV will ensure that Shell's proposed tailings management is unlikely to have significant adverse environmental effects.

9 WATER MANAGEMENT

9.1 Views of Shell

Shell stated that the project would minimize freshwater use by maximizing water recycle in the process. This would be accomplished through the use of tailings thickeners and the use of a noncaustic extraction process that enhanced settling characteristics of tailings and allowed faster release of water for recycle. Shell also stated that it would use surface water and groundwater from the basal aquifer and the PCA to further minimize water withdrawal requirements from the Athabasca River. Shell noted that ambient water quality of the PCA exceeded Canadian drinking water guidelines.

Shell planned to use PCA, basal aquifer, and Athabasca River water for bitumen processing. The addition of Athabasca River water would reduce total dissolved solids (TDS) and maintain overall water quality. Shell could not use the PCA for primary source water for extraction because its water chemistry would impact bitumen recovery.

Shell stated that it would require 15 10^6 m^3 of water storage capacity for pre-start-up in the project external pond disposal area to

- mitigate the peak rate of withdrawal from the Athabasca River during start-up,
- mitigate the quality of supplemental water sources, and
- ensure adequate water for start-up and operations during the early months of peak water demand.

Shell stated that additional water was required for about the first six years of mine start-up and operations while tailings were placed out-of-pit. Shell stated that it would require 4.66 m^3 of fresh water per m^3 of bitumen production, or about 60 10^6 m^3 per year. During steady-state operations when depositing CT in-pit, it would strive for a significant reduction in water use. Shell noted that it would require 2.76 m^3 of fresh water per m^3 of bitumen production, or about 35 10^6 m^3 per year, during steady-state operations. An additional 373 10^6 m^3 of water would be needed at the end of the project life to fill in-pit lakes.

Shell stated that it was requesting a maximum water licence allocation from the Athabasca River of 63.5 10^6 m^3 per year. It was also requesting a maximum instantaneous withdrawal rate of 4.17 m^3/s from the existing Muskeg River Mine water intake structure. First withdrawals from the Athabasca River would not occur until 2010. Shell noted that no increase in the current capacity of the water intake was planned for the project.

Shell recognized that one of the main issues of concern to stakeholders in the region was the future cumulative withdrawal of water from the lower Athabasca River, particularly during the low-flow period from January to March. Shell understood that stakeholders were concerned with the issuance of new water licences by AENV in the absence of a formal IFN management system for the Athabasca River. Shell noted that the maximum water withdrawal from the Athabasca River during extreme low-flow conditions would decrease river levels by less than 1 centimetre and overall flow would decrease by less than 2 per cent. Shell stated that the EIA classified the effects to river flow and water level as nonmeasurable. It committed to verifying the predictions of its EIA and designing a follow-up program to monitor for and adaptively manage the effects of its project.

Shell believed that an IFN management system would be finalized by CEMA in 2005, five years before the operation of the project and Shell's initial water withdrawal. In response to stakeholder interests and in anticipation of potential restriction during low-flow periods, Shell indicated that it was taking a precautionary approach. This included development of additional on-site water storage capacity in the tailings disposal area, recycle water pond, raw water pond, and Khahago surge facility. The additional water storage would allow Shell to minimize its water withdrawal for up to 30 days during low-flow periods.

Shell stated that after six years it could reduce water withdrawal from the Athabasca River for 30 days to a minimum of 0.45 m^3/s required to operate at steady state. Shell indicated that removal of this small volume of Athabasca River water during low-flow periods was still necessary to protect Shell's water supply pipeline from freezing and to feed the boilers.

Shell stated that it supported a phased water licence for the project, provided that similar phased licences were issued to other oil sands projects in the area. Shell said that it had not changed its water licence application to reflect a phased or tiered approach but would be supportive if AENV granted such a water licence. If granted, a licence could include volumes for steady-state operations and higher volumes for short-term water allocation during the first six years of project start-up. However, Shell believed that some flexibility was needed for additional water volumes during steady-state operations and stated that it would apply to AENV for an additional short-term allocation. Shell noted that water licences were typically issued for ten-year terms.

9.2 Views of OSEC

OSEC stated that no new water allocations should be granted until an interim IFN limit was established or the CEMA IFN subgroup determined an IFN management system for the Athabasca River. Either should be in place before Shell needed to withdraw water for the project. OSEC and Shell agreed that AENV Water Act licences should reflect long-term water requirements of the project, allowing Shell to use short-term licences for its start-up period water needs.

OSEC noted that the application before the Panel did not reflect OSEC's agreement with Shell for a minimum water allocation. OSEC understood that it was AENV's decision on how best to allocate water. OSEC believed that AENV could issue a ten-year licence for the base requirements and then issue a supplementary licence for the increased needs during the start-up period.

9.3 Views of MCFN

MCFN stated that it was satisfied with Shell's commitment to stop withdrawal from the Athabasca River if needed and with Shell's plans to have a 30-day water storage as a solution to MCFN's concern about withdrawals during low-flow conditions in the Athabasca River. MCFN also noted that the project was scheduled far enough into the future to set an IFN prior to the project moving forward.

MCFN recommended that the Director under the Water Act ensure that

- any future licences for withdrawal from the Athabasca River for oil sands development include a provision for a cooperative management strategy to restrict water withdrawals during low-flow periods and to accommodate a regulated IFN number;
- the transfer or sale of water withdrawal allocations among oil sands developers be prohibited;
- no exemptions to withdrawal restrictions during low-flow periods be granted;
- licences be tied to a proponent's actual needs and be subject to change depending upon IFN of the Athabasca River; and
- consideration be given to attaching a cost of water to industrial users that reflects the value of the resource.

MCFN made further recommendations to Alberta's Minister of Environment to

- develop a lower Athabasca River Basin water management plan, with AENV taking the lead in the development of this plan and MCFN and other stakeholders being afforded opportunities for participation and input;
- establish a registry to receive and publish water complaints; and
- establish a registry to track the amount of water allocated and used under various water licences in the region.

MCFN further recommended that AENV and Canada immediately set a conservative interim IFN for the Athabasca River and that AENV set 2005 as the firm deadline to establish a consensus-based or regulated IFN without allowing further extensions to CEMA's work schedule.

9.4 Views of WBFN

WBFN expressed concerns about environmental effects on the Peace/Athabasca Delta, effects on wildlife, and the need to determine factors contributing to low water levels in the delta, such as the Bennett Dam and oil sands plants. WBFN stated that until there was resolution of such issues, no more water withdrawal approvals from the Athabasca River should be issued. WBFN expressed a need for an assessment to determine the reasons for the deteriorating condition of the delta before more water licences were issued.

9.5 Views of Alberta

AENV stated that it intended to include conditions in the Water Act licence issued allowing for implementation of management options based on IFN in the Athabasca River. AENV would carefully evaluate the exact amount of water allocation after considering the evidence from the hearing and the Panel's report. AENV acknowledged that all of the existing oil sands Water Act licences had terms and conditions that would allow for the cessation or reduction of water withdrawal should AENV implement a management system for IFN.

AENV said that it accepted on-site water storage as one of the strategies to reduce water withdrawals during low-flow conditions. AENV stated that it was Shell's responsibility to deal with any future limitations on water withdrawals during low-flow periods or any other restrictions on water users.

Alberta stated that the overall annual volume of water available from the Athabasca River was more than sufficient to support Shell's requested allocation. AENV acknowledged that during winter low-flow periods there was potential for cumulative impacts to the Athabasca River. To minimize potential impacts, the timing of low-flow water withdrawals could be managed and withdrawals could be scaled back or managed within IFN objectives without reducing allocations. CEMA was engaged in developing an IFN management system scheduled for completion by the end of 2005. AENV committed to take necessary action should CEMA not be able to advance its IFN recommendation by the end of 2005.

AENV stated that there was provision within the Water Act for water management planning similar to that suggested for the Athabasca River and that this planning function was not exclusive to the Alberta government. AENV referred to the Alberta draft water strategy whereby local or regional groups could participate in basin planning.

9.6 Views of the Panel

The Panel has reviewed Shell's water balance data and water requirements for the project. The Panel understands that Shell's tailings management scheme includes immediate water recycle that will reduce the total make-up water requirements. The Panel notes that 2.76 units of fresh water per unit of bitumen production are required to operate Shell's process on a long-term sustainable basis during steady-state full production. The Panel finds that Shell's water requirement during the initial start-up phase is consistent with the requested allocation from the Athabasca River of 63.5 10^6 m^3 per year. The Panel accepts that water is needed for the project and the most suitable source of water is the Athabasca River.

The Panel therefore recommends that in AENV's review of Shell's Water Act application, it consider water allocation based on needs of the different project phases. The Panel notes that both Shell and interveners were supportive of a phased water licence.

The Panel supports Shell's plan to develop 30-day water storage on site provided that the design can be incorporated into the mine plan without adverse impacts to resource recovery, safety, or the environment.

With respect to IFN, the Panel agrees that there is a need for CEMA and AENV to implement a management system prior to water withdrawals by Shell for the project. The Panel expects CEMA to make its recommendation for an IFN management system to AENV by the end of 2005. The Panel recommends that AENV establish IFN for the Athabasca River in collaboration with DFO in the event that CEMA fails to meet its timelines. The Panel supports AENV amending existing Water Act licences for IFN management, if that becomes necessary.

The Panel does not believe that setting of interim IFN is necessary. In addition, the Panel believes that work to establish interim IFN might result in resources being diverted from the process of determining permanent IFN.

The Panel recognizes that interveners recommended several actions concerning administration of Water Act licences be taken by AENV. The Panel acknowledges that the release of AENV's *Water for Life Strategy* may influence a number of water resource management priorities, with resulting changes to the administration of Water Act licences. The Panel has confidence that in the exercise of its regulatory authority, AENV will address the needs of regional stakeholders, existing licence holders, and applicants seeking new water allocations.

Regarding the recommendation of MCFN to establish a river basin management plan for the lower Athabasca River, the Panel notes that AENV stated that no such activity was presently within the work plan of CEMA. AENV referred to provisions within the Water Act and the *Water for Life Strategy* that would enable stakeholders to initiate and participate in water management plans. The Panel strongly encourages AENV to work cooperatively with regional stakeholders and water licence holders to evaluate a process and establish a water management plan for the lower Athabasca River.

MCFN has recommended public registries to address water quality complaints and the tracking of licensed versus actual water use by regional water licence holders. In the first instance, AENV stated that it does manage a 24-hour telephone hotline for environmental complaints and emergencies throughout the province. The Regional Aquatics Monitoring Program (RAMP) also provides information to local communities about contacts and organizations able to assist citizens with complaints about regional water quality. Additionally, water licence holders report their actual water use to AENV as a regulatory requirement. That information is publicly available. The Panel recommends that AENV review the communications programs in place to ensure that regional water quality and water use information is accessible and understandable to interested parties.

The Panel concludes that significant adverse environmental effects from the proposed water allocation are unlikely to occur, provided that the proposed mitigation measures and the recommendations of the Panel are implemented.

10 SURFACE WATER QUALITY

10.1 Views of Shell

Shell completed an environmental assessment of project activities predicted to alter water quality within the project area, including the release of muskeg drainage and depressurization waters, EPL releases, altered groundwater regimes, disruption of stream channels, tailings seepage, runoff from CT and reclaimed surfaces, and acidifying emissions. Shell predicted that with appropriate mitigation measures, these project activities would have negligible environmental effects on the water quality of the Muskeg River watershed and Shell's EPLs. Shell stated that process-affected surface waters would be contained within a closed water management system and not released off site.

In all cases, whether from project activities or from regional or cumulative effects, Shell concluded that effects on water quality in the Athabasca River or its tributaries would be negligible. Shell also stated that effects of water quality on fish health and fish tainting would similarly be negligible.

Shell observed some instances of degraded water quality in naturally occurring waters of the Muskeg River drainage basin. Shell's EIA also indicated that Athabasca River water exceeded some water quality guidelines and influence EPL water quality. Using the Hydrologic Simulation Program in Fortran (HSPF) model, Shell predicted water quality conditions for the Muskeg River drainage basin from four time intervals during the life of the project. Shell fitted the predicted water quality parameters to frequency distributions of historical water quality data. Shell then compared the data sets to established regulatory criteria and the compliance levels assessed against 99.91 percentile concentrations, as recommended by the U.S. Environmental Protection Agency. Shell gave consideration to ambient concentrations and the observed range of natural variability.

Shell assessed sediments containing chromium, naphthenic acids, and manganese for Jackpine and Muskeg Creeks when screening for exceedances and possible effects on fish health. Shell predicted that the effects of sediment quality on fish health would be negligible. Shell identified surrogate values for naphthenic acid toxicity of sediments, as actual data were not available.

Shell addressed uncertainties in its water quality predictions by providing worst-case scenarios and other measures that overpredicted effects of the project (e.g., no attenuation of in-stream contaminants, simultaneous release of reclamation waters from other projects). Shell adopted regional initiatives such as CEMA and RAMP as a means to reduce uncertainty, manage cumulative environmental effects, and conduct research related to aquatic ecosystems. Shell recognized that mitigation measures were necessary to limit the release of contaminants to receiving waters and to maintain acceptable ratios of process-affected waters to natural runoff flows. Shell's environmental assessment assumed that for mitigation measures to be effective, other oil sands operators would adopt equivalent mitigation measures for the protection of flows and water quality of water bodies.

Shell predicted that air emissions from the project were likely to have moderate to high residual environmental effects upon acidic deposition in the region. As a result, Shell assessed potential effects of those acidic emissions upon ecological receptors, such as regional water bodies and aquatic resources, using lake-specific critical loads (CL) for comparison with potential acid input (PAI) predicted by dispersion modelling. Shell observed that for several regional lakes, acid deposition loadings exceeded CL values under baseline conditions. However, the project emissions contributed only incremental changes to CL exceedances and those incremental changes did not contribute to further exceedances in any other lake. Shell concluded that acidification effects on aquatic water bodies, including spring acid pulses, were negligible. Shell noted that in the future it would address acidification effects by adopting the CEMA acidification management plan. Shell also noted that it would manage potential changes in acidification of water by means of the annual monitoring now conducted by RAMP.

10.2 Views of OSEC

OSEC confirmed in its agreement with Shell that it was satisfied that Shell would comply with the necessary water quality criteria for EPLs. OSEC believed that appropriate water quality criteria would be recommended by CEMA and implemented by Alberta regulators.

10.3 Views of MCFN

MCFN requested that the Panel make recommendations or approval conditions for Shell to address specific environmental requirements of its community. Some of these included requirements for direct involvement of MCFN in the design and review of water quality, EPLs, and wetlands monitoring programs. MCFN requested that the Panel recommend or require Shell to integrate the results of monitoring programs so that Shell's EIA predictions could be validated.

10.4 Views of WBFN

The Wood Buffalo First Nation (WBFN) identified several concerns related to water quality. In relation to the increased water withdrawals of oil sands operations, WBFN said that its members had observed saline and sulphur springs flowing into the Athabasca River. It believed these springs could negatively affect Athabasca River quality during low-flow conditions. WBFN noted historical accounts from its elders of declining water flows and quality in the Peace/Athabasca Delta. The WBFN advised the Panel that more regional water quality data was needed prior to new water licences being granted.

10.5 Views of ACFN

ACFN indicated that its agreement with Shell resolved its issues related to water quality. Shell agreed to ACFN's request for the collection of baseline water quality and quantity data and for yearly monitoring of Kearl Lake and McLelland Lake, which are close to the project area. ACFN asked Shell for commitments that its project would not negatively affect Kearl Lake or McLelland Lake.

ACFN asked to participate in Shell's monitoring programs for surface and groundwaters in both the design of these programs and the development of threshold values and Shell's management action. Shell was asked to support the management system and objectives for maintaining the Muskeg River basin integrity that might be recommended by CEMA and adopted by Alberta regulators. Regarding EPL water quality, ACFN sought commitments from Shell similar to those included in Shell's agreement with OSEC.

10.6 Views of SCC

The Sierra Club of Canada (SCC) was concerned about potential changes to the Athabasca River system as a result of climate change. SCC was concerned that those changes would be exacerbated by increased water withdrawals by oil sands operations and result in increased concentrations of heavy metals and naturally occurring toxics. Other potential changes to water quality might occur from tailings disposal area impoundment failure or flood conditions.

10.7 Views of Canada

EC provided advice to the Panel concerning the water quality of tailings release and EPL waters. EC was concerned that EPLs contained tailings materials that would discharge to fish-bearing waters. EC stated that there was uncertainty regarding the removal of contaminants via EPLs and wetlands and uncertainty about the mobilization of dissolved or adsorbed substances into the food chain. EC recommended that Shell complete a long-term surface water and sediment quality monitoring plan that

- characterizes ongoing conditions in the development area,
- enables comparative analysis between before/after and control/impact conditions,
- tests water and sediment quality predictions, and
- evaluates effectiveness of mitigation measures.

EC advised that predictions of water quality baseline and future conditions used in Shell's environmental assessment sometimes depended on limited historical data. EC stated that most predictions of water quality lacked confidence limits, as Shell had not calculated statistical uncertainties. EC recommended that Shell conduct further baseline and operational water and sediment quality sampling. This would improve scientific knowledge of predisturbance conditions and improve validation of Shell's predicted effects on water and sediment quality during the course of the project. EC recognized the potential for additive or synergistic effects on the Athabasca River based on effluents and water withdrawals. EC recommended to the Panel that more information on potential effects on the Athabasca River be acquired through regional monitoring and research.

DFO identified disturbance or removal of tributary stream channels of the Athabasca River and its tributaries as a cumulative effect upon water quality and fish habitat. To address this concern, DFO recommended that Shell and other regional operators examine incremental changes to streams and their predicted effects at a regional scale. DFO recommended that in combination with existing regional initiatives, new efforts were needed to detect cumulative effects on the regional aquatic environment.

DFO stated that its water quality concerns with respect to the project related to potential tailings disposal area seepage, possible degradation of water quality in Jackpine Creek, and uncertainties of EPL viability.

DFO expressed concern about water quality effects on fish health and fish tainting. DFO noted tailings seepage into the PCA as a concern, but it made no specific recommendations concerning the aquifer or its influence upon surface waters. It also raised uncertainties regarding synergistic or additive effects of interacting water contaminants as a concern. DFO recommended that Shell continue its participation in such organizations as RAMP, CEMA, and CONRAD and implement management strategies and recommendations of those groups. To determine the long-term ecological value of EPLs, DFO recommended the expansion of ongoing research.

To address concerns about cumulative effects on the water quality of the Athabasca River and its tributaries, DFO recommended that Shell participate in a site-specific long-term water quality monitoring program to detect changes in the Athabasca River. DFO supported Shell's continued participation in CEMA, RAMP, and CONRAD regional water quality monitoring and research.

10.8 Views of Alberta

AENV stated that tailings disposal area seepage could require additional monitoring and validation of EIA predictions. It believed that tailings seepage from the out-of-pit tailings disposal area would be limited to Shell's lease area, and seepage effects would be reduced by subsurface permeability conditions, collection ditches, and other mitigations. Groundwater monitoring would detect changes in the subsurface, should they occur. AENV stated that sulphur springs as identified by WBFN contributed relatively small volumes of water to the Athabasca River, so that the water quality of the river was not likely to be affected even under low-flow conditions.

AENV observed that with the exception of natural exceedances of dissolved oxygen and some metals, water quality of the Muskeg River generally complied with Alberta's Surface Water Quality Guidelines. AENV recognized that validation of water quality predictions would be necessary due to future landscape changes and modelling uncertainties related to hydrology and water quality parameters. AENV stated that it might require Shell to monitor surface water quality with some correlation to hydrologic observations. AENV expected Shell to continue its support of CEMA and to maintain work schedules for the development of regional water quality objectives.

10.9 Views of the Panel

The Panel acknowledges that matters related to tailings dike stability or design for flood conditions are subject to approval by AENV. The Panel also notes that Shell will submit detailed engineering designs of the out-of-pit tailings disposal area for technical review and evaluation by AENV for matters of geotechnical stability, hydrology, and public safety.

The Panel understands that water quality predictions of the project are subject to several uncertainties related to modelling assumptions, modelling techniques, baseline data, hydrologic conditions, containment of contaminants, and establishment of closure drainage on reclaimed lands. The Panel recommends that AENV include a condition in the EPEA approval requiring Shell to develop and implement monitoring programs for sediment and water quality for waters that may be affected by the project. The Panel expects Shell to design the program with input from AENV, EC, DFO, and other stakeholders to address such issues as geographic and temporal scope, synergistic effects, scientific precision, and repeatability. The Panel is mindful of the long time frames for tailings seepage water to reach surface waters. Therefore it recommends that AENV ensure that monitoring plans are designed to ensure early detection of potential water quality changes in groundwater and surface water due to their interactions.

The Panel accepts AENV's position that the EPEA licence conditions for the project for the monitoring of surface and groundwater quality and quantity will address potential effects of saline and sulphur springs on the Athabasca River.

The Panel finds that the project has potential to increase the PAI, both locally and to a lesser extent regionally, with possible effects on critical load exceedances of water bodies. Therefore, the Panel recommends that AENV condition any EPEA approval for the project to require monitoring of acid deposition on water bodies. The Panel also expects that Shell will support RAMP and WBEA to ensure monitoring and management of acid deposition effects on ecological receptors in the region.

The Panel concludes that the project is not likely to cause significant adverse environmental effects on surface water quality, provided that the mitigation measures and the recommendations of the Panel are implemented.

11 SURFACE HYDROLOGY

11.1 Views of Shell

Shell assessed environmental changes to surface hydrology in the local and regional study area attributed to such activities as muskeg and mine dewatering, mining, relocation of tributary streams, water withdrawals from the Athabasca River, filling and operation of EPLs, and release of waters from reclaimed land surfaces. It also assessed changes to surface hydrology for potential effects on fish and aquatic organisms and on human health. In all cases, Shell predicted that environmental effects on hydrology as a result of the project would not be significant or adverse to the environment. Shell did not complete a cumulative effects assessment for surface hydrology, since the project effects on hydrology were negligible. Shell's conclusions regarding project effects were contingent upon mitigation measures being successfully implemented by Shell and other operators.

Shell stated that several tributary streams of the Muskeg River would be disturbed or excavated during the course of the project. Figure 2 shows the area of the Muskeg River drainage basin and some tributaries of the Muskeg River. Surface waters from seven tributary streams of the Muskeg River would be affected by mining. A new outlet to Kearl Lake and the Khahago surge facility would be constructed. Jackpine Creek would remain essentially unchanged, as it had high value for fish habitat. At mining closure, three large EPLs were planned, two of which would contain water-capped tailings. The lakes would function for flow attenuation and bioremediation of flows from reclaimed lands.

Shell consulted extensively over two years with a number of the local communities and groups to address environmental concerns, including water resource management, which was of prime importance. Several mitigation measures for reducing environmental effects on water, such as routing of diversions, setback distances, on-site storage of water, and monitoring programs, were addressed through agreements and action plans. Shell identified several initiatives it supported through CEMA and RAMP for the collection of data and management of cumulative effects on water resources. From its recent operating history as a partner in the Albian Sands Muskeg River Mine, Shell submitted additional water resource data to support the project application.

Shell stated that the Muskeg River was one of the most heavily studied rivers of the mineable oil sands region. This benefited Shell by providing a wide assemblage of baseline and EIA data for surface water hydrology. Shell adopted the HSPF to evaluate the study area hydrology and predict flows at key intervals during the life of the project and other existing and planned oil sands projects. Shell used historical records for statistical analyses of Athabasca River discharges and a steady-state model of the Athabasca River in assessing dispersion flows and constituent concentrations. Shell used a mass balance modelling of input and output flows to predict conditions of EPLs.

Shell advanced approaches and mitigation measures for reducing effects of the project upon water resources. These are presented in Section 9: Water Management.

Shell supported the work of CEMA's IFN subgroup in its efforts to develop by 2005 a management system based on ecological, social, and economic values. Shell did not support the development of an interim IFN flow guideline, as advanced by some interveners. Shell submitted evidence of the RAMP (2003) five-year review report, which concluded that between 1957 and 2001 there were no statistically significant trends in the annual maximum flows, minimum flows, or water yields of the Athabasca River.

Shell also addressed issues of existing and planned oil sands mining within the Muskeg River drainage basin and their cumulative effects. It predicted no significant adverse effects to the hydrology of the drainage basin.

Shell predicted that the project would not affect Kearl Lake or McLelland Lake. However, it stated that if effects were attributable to the project, it would implement mitigation measures. It agreed to continue its monitoring efforts through RAMP so that annual monitoring of the lakes would occur. Shell agreed to prepare a monitoring plan for Kearl Lake to collect baseline data during the predevelopment of the project. In its agreement with ACFN, Shell committed to assist ACFN in a plan to restore Richardson Lake (located near Lake Athabasca) for fish spawning.

11.2 Views of MCFN

MCFN stated that its agreement with Shell addressed low flows in the Athabasca River. The agreement required Shell to provide 30 days of on-site water storage to reduce withdrawals from the Athabasca River during low-flow periods. MCFN said that an interim IFN was required for the Athabasca River. MCFN also expressed concerns about cumulative reduction of water quality and quantity in the Athabasca River.

11.3 Views of ACFN

The ACFN agreement with Shell identified several water resource issues. ACFN asked Shell to address the issue of low flows in the Athabasca River and to maintain the river's health, integrity, and sustainability. ACFN recommended to Shell that it involve ACFN members in the design of monitoring programs (e.g., water resources) and development of thresholds for use in Shell's management program. Regarding Kearl Lake and McLelland Lake, ACFN sought assurances from Shell that both lakes would be monitored and that no impacts would occur from the project. ACFN was concerned about the falling water levels of Richardson Lake due to its importance to fish spawning.

11.4 Views of Fort McKay

In closing argument, Fort McKay recommended that the Panel establish timelines for CEMA to develop and recommend interim management guidelines for IFN of the Athabasca River. For protection of the Athabasca River, Fort McKay asked Shell to agree to an AENV licence clause limiting withdrawals for flows below 115 m^3/s. It believed that AENV should have the ability to amend Water Act licences based on the results of CEMA's recommendations regarding IFN. Fort McKay sought assurance from Shell that the project would not impact Kearl Lake. Fort McKay asked Shell to facilitate accelerated work by CEMA and adopt measures to protect the Muskeg River basin before start-up of the project.

11.5 Views of SCC

SCC requested that the Panel suspend decisions for new developments in the Athabasca region, including the Jackpine project, pending a full assessment of the true cumulative effects of those projects. Furthermore, SCC requested that the Panel delay any decisions concerning the project or its water withdrawals until 2005, when results of the CEMA IFN study would be available. According to SCC, Shell's annual water withdrawals and those of other oil sands operations had downstream implications for the Peace-Athabasca Delta and the Mackenzie River Basin Transboundary Master Agreement. Withdrawals from the Athabasca River would negatively affect a river that had already experienced decreased flows from climate change. SCC recommended that Shell be required to re-evaluate its water assumptions for flood protection and tailings management, because it had failed to account for monthly flow variability of the Athabasca and Muskeg Rivers and for a declining flow trend in the past decades.

11.6 Views of Canada

DFO recommended that IFN for the low-flow ice-cover period be established for the lower Athabasca River prior to Shell requiring water withdrawals for the project.

11.7 Views of Alberta

AENV disagreed with interveners that Athabasca River flow had experienced a historical decline. AENV presented a statistical analysis that did not show a statistically significant trend of declining flows. The water allocations Shell was applying for, including all existing, approved, and planned maximum annual water withdrawals, were 6.2 per cent of the river's total annual flow.

11.8 Views of the Panel

The Panel accepts that the project will result in substantial hydrological and landscape change in the project area, and it accepts the key commitments Shell has made to mitigate effects on the environment. In areas such as IFN, watershed management, EPLs, and the compensation lake, the Panel recognizes that a number of uncertainties exist. However, the Panel finds that with current regulatory processes and the efforts of regulators and CEMA to develop leading-edge environmental objectives and management systems, the uncertainties are manageable and acceptable. The Panel does not believe that decisions regarding the project should be deferred. The Panel believes that regulatory requirements, adaptive management processes, monitoring and mitigation measures, and implementation of the Panel's recommendations provide sufficient protection for the environment.

The Panel accepts that within current and future Water Act licences, AENV has authority to amend licence terms and conditions. The Panel supports DFO's recommendation that an IFN management system be established for the lower Athabasca River prior to Shell requiring water withdrawals, and it recommends that DFO and AENV consider IFN objectives and management approaches in its approvals for the project.

The Panel notes that Shell stated that a management system was to be developed for maintaining the Muskeg River drainage basin integrity. This matter is of particular importance and is addressed further in Section 17. The Panel recognizes the efforts of Shell to maintain key tributaries of the Muskeg River, such as Jackpine and Muskeg Creeks, as well as Shell's efforts to maintain the Muskeg River as a key tributary of the Athabasca River. The Panel believes there would be a benefit in evaluating the effectiveness of corridors with respect to wildlife and watershed management. The Panel therefore recommends that ASRD require Shell to also consider the widths and types of buffer zones for benefits to watershed management when evaluating wildlife corridors. This requirement could be met by Shell on its own or in cooperation with other stakeholders.

The Panel is aware of past EUB decisions on oil sands development that expressed concerns about the proliferation of lakes containing water-capped tailings in reclaimed landscapes. As noted in Section 8, the Panel has directed Shell to continue to develop alternative technologies for tailings management. The Panel believes that opportunities will emerge for Shell through such work to optimize the project further by reducing environmental effects on surface waters and the land base.

The Panel notes that Shell stated that Kearl Lake would not be adversely affected by changes to groundwater or alteration of the outlet of Kearl Lake. The Panel recommends that AENV require Shell to conduct or support monitoring of water levels in Kearl Lake to validate the predictions made in the EIA.

The Panel concludes that significant adverse environmental effects from the project on surface water hydrology are unlikely to occur, provided that the mitigation measures and the recommendations of the Panel are implemented.

12 AQUATIC RESOURCES

12.1 Views of Shell

Shell evaluated the effects of the project on fish and fish habitat, fish health, and tainting in conjunction with existing and planned projects. It also examined potential effects of air emissions on water bodies and aquatic resources.

With respect to fish and fish habitat, Shell indicated that the project would result in the removal of a number of creeks. Additionally, Muskeg Creek would be altered and reconstructed over the life of the project. Upon closure of the project, the redesigned Muskeg Creek would discharge to the Muskeg River about 2 km downstream of its existing discharge channel, thereby reducing the flow in that 2 km reach of the Muskeg River. Shell deemed the impacts of the project prior to compensation measures to be long term and of low magnitude for the Muskeg River and to be long term and of moderate to high magnitude for the tributaries of the Muskeg River. However, in accordance with DFO's policy, Shell had developed an NNLP to offset the losses resulting from the project. As a result, Shell predicted that the residual impacts on habitat and subsequently on fish abundance would be negligible after implementation of the proposed compensation strategy outlined in the NNLP. Shell indicated that it would also implement a variety of mitigation measures to alleviate effects on fish habitat in areas not directly impacted by mine development.

Shell proposed a compensation lake as part of the NNLP. Shell proposed to locate the lake on Syncrude's Lease 34. Shell stated that it was presently negotiating an agreement with Syncrude to enable it to start construction of the compensation lake in 2005 in an area that provided an optimum balance between ore sterilization and environmental protection. Shell stated that it did not believe the lake was located on mineable ore, but it would complete additional drilling prior to construction of the lake. If it identified additional oil sands resource, Shell proposed to modify the footprint of the lake or apply to the EUB for approval to sterilize an oil sands resource.

In Shell's examination of the potential effects of predicted water and sediment quality and acidifying emissions on fish health, it concluded that the overall effect of the project on fish health would be negligible. However, one exception was that Shell predicted slightly higher concentrations of naphthenic acids in Jackpine Creek until 2040, at which time the peak and median concentrations would increase more substantially. Although Shell determined that the environmental consequence would be negligible, it acknowledged that there was uncertainty about the level of naphthenic acids that would result in chronic impacts on fish. Therefore, it noted that further follow-up work was needed to establish which naphthenic acids contributed most to toxicity and the concentrations at which this toxicity would occur.

Additionally, Shell assessed the effects of project-related tainting compounds on fish tissue. It concluded that effects would be negligible, but noted that its confidence in the prediction was low due to lack of laboratory studies that used aged or treated process waters.

Shell predicted that the overall effect of the project on benthic communities in water bodies, small streams, and the Muskeg River would be negligible, since the habitat lost to mine development would be recreated to achieve no net loss and the projected changes were relatively small.

12.2 Views of MCFN

MCFN emphasized its reliance on fish and game and noted that some of its members operated as commercial fishers on Lake Athabasca and at the mouth of the Athabasca River.

As part of the MCFN and Shell agreement, Shell committed to review environmental monitoring programs, including the aquatic resources program, with MCFN and to seek its input on the design and implementation of those programs through MCFN Industry Relations Committee representatives.

12.3 Views of Canada

EC noted that the Fisheries Act prohibited the deposit of deleterious substances into fish-bearing waters. It expressed concern regarding the potential of oil sands development to cause the tainting of fish tissue, which was prohibited under the Act. EC noted its participation in the fish tainting committee under CONRAD and commended the progress made by that committee.

Notwithstanding industry's commitment to the fish tainting program, EC acknowledged that it was concerned that the program might not address knowledge gaps, future research, and monitoring adequately. EC suggested that the program should address both project-specific and cumulative effects of oil sands development on fish tainting in the Athabasca River. EC therefore recommended that Shell ensure that the fish tainting program address the knowledge gaps it had identified and make suggestions for future research and monitoring.

DFO was also concerned about the potential of seepage from the tailings disposal area to taint fish or impact fish health. It stated that fish tainting models and the fish health assessment were derived from the results of the HSPF modelling. DFO noted that HSPF modelling used limited real data and, therefore, the level of uncertainty in predictions made by the model was relatively high. DFO recommended that the uncertainties associated with modelling be addressed in the NNLP. Furthermore, with regard to fish tainting, DFO recommended that Shell continue to participate in regional research and water quality monitoring initiatives that addressed the effects of water quality on aquatic resources.

DFO noted its concerns regarding the cumulative environmental effects on fish and fish habitat as a result of the successive elimination of watercourses and cumulative water withdrawals. The lack of baseline data on aquatic resources, coupled with the lack of functioning examples of replacement habitat similar to that proposed by Shell, increased its concerns. Furthermore, it pointed out that the NNLP did not address habitat losses resulting from Shell mining through the floodplain of the Muskeg River. DFO stated that the project would not result in significant adverse environmental effects, provided that the proposed mitigation and compensation measures were undertaken.

DFO believed that Shell had limited opportunity to replace the habitat loss with similar habitat in the same area, given the scale of watershed disturbance proposed. However, DFO stated that it would continue to work with Shell to develop an NNLP that would provide acceptable habitat compensation in the region. DFO would also continue to explore additional alternative compensation options, including off-site works and habitat enhancement projects to ensure no net loss of fish habitat. DFO recommended that all incremental change predictions and concerns be examined on a regional scale and recommended that Shell continue to participate in regional initiatives that facilitated the detection of cumulative effects on the aquatic environment. DFO had no concerns about the compensation lake being located off of Shell's lease. DFO stated that prior to issuing approval of the NNLP, it would require verification from Shell that it had an agreement with Syncrude and that the EUB had approved any oil sands resource sterilization.

DFO asked Shell to continue its participation in the MRWI subgroup and to adopt recommendations that might result from that group's initiative. DFO identified disturbance or removal of tributary stream channels of the Athabasca River and its tributaries as having a cumulative effect on water quality and fish habitat. DFO recommended that AENV and the EUB examine all incremental change predictions at a regional scale. DFO stated that in combination with existing regional initiatives, new efforts were needed to detect cumulative effects on the regional aquatic environment. DFO recommended that Shell participate in existing and new regional initiatives to detect cumulative effects on aquatic resources.

With regard to protecting existing fish habitat, DFO recommended that Shell provide a minimum setback of 100 m along Muskeg Creek upon closure to mitigate the potential impact of mining on riparian habitat and the ecological functioning of the creek. DFO stated that it would be satisfied with a 65 m buffer between the constructed channel and the mine pit, which would allow for the establishment of some riparian area along the diversion channel. A similar buffer of 65 m would be expected for the compensation lake during operations and one of 100 m upon closure.

DFO stated that it did not accept EPLs as compensation for fish habitat. It also noted that there were no functioning examples of EPLs on the landscape with which to verify Shell's prediction that EPLs would eventually be capable of providing aquatic habitat. It recommended that ongoing research into EPLs be continued and expanded to determine their ecological value.

12.4 Views of Alberta

Alberta noted that both water quality and quantity were fundamental to healthy functioning fish habitat. In its view, Shell's predictions of the project-specific and cumulative impacts on fish and fish habitat lacked certainty due to the uncertainties associated with the water quality and quantity models. However, Alberta believed that effects on fish populations and fish habitat would be negligible if Shell could successfully compensate for loss of fish habitat through the NNLP. ASRD noted that responsibility for the NNLP was DFO's and stated that it would continue to provide technical advice on the NNLP. ASRD recommended that monitoring for fish and fish habitat issues continue through groups such as RAMP. When asked whether RAMP was a sufficient monitoring program, AENV responded that the program was currently undergoing a peer review, which would identify any gaps and enable RAMP members to address them. With respect to baseline information, Alberta believed that adequate information pertaining to fish had been collected, but noted that additional information relating to benthic invertebrates would be beneficial.

12.5 Views of the Panel

The Panel acknowledges the concerns expressed by several interveners regarding fish habitat losses and the potential impacts of the project on aquatic resources in the region. The Panel notes DFO's evidence that the impacts on fish and fish habitat can be mitigated through the implementation of mitigation measures, monitoring, and follow-up and by ensuring adequate compensation for habitat losses. The Panel is satisfied that no net loss can be achieved effectively. Nevertheless, the Panel believes that a strong monitoring plan is critical to ensure that fish and fish habitat effects are understood. The Panel recommends that DFO, in consultation with ASRD, AENV, EC, and regional stakeholders, require Shell to develop and implement a comprehensive monitoring program relating to fish and benthic macroinvertebrates.

The Panel notes that Shell's proposed compensation lake would be one of the first of its kind in the oil sands region. The Panel is aware that similar lakes may be proposed in the region to compensate for aquatic habitat lost due to oil sands development. As a result, the Panel recognizes that valuable knowledge could be obtained from this large-scale example of a compensation lake. Therefore, the Panel recommends that DFO require a report from Shell on its monitoring results relating to the compensation lake and share those findings with other stakeholders in the region. DFO should consider requiring Shell to monitor for fish abundance, community structure, and operational results of the compensation lake with regard to hydrological regimes and its responses to high- and low-water events.

The Panel understands that Shell will be completing additional drilling to determine if the proposed compensation lake location would impact oil sands resources. The Panel notes that if drilling indicates a mineable resource, Shell will be required to either relocate the lake or apply to the EUB for resource sterilization.

The Panel notes the lack of information, specifically the uncertainty around naphthenic acids, and the subsequent uncertainty surrounding the issue of fish tainting. The Panel notes Shell's participation in regional initiatives intended to address issues of water quality and fish health, and it is encouraged by the work of the fish tainting committee under CONRAD. It also notes EC's evidence that the CONRAD program may not adequately address knowledge gaps. The Panel is concerned that the information may not be generated in a manner that addresses concerns raised in the proceedings. The Panel notes that the issue of naphthenic acids and their potential impacts on water quality and fish tainting has been known for 20 years. While the Panel recognizes the complexity of this issue, it believes that a higher priority should be placed on understanding it.

The Panel recommends that AENV and ASRD, in consultation with DFO and EC, require Shell to conduct follow-up studies on potential impacts of fish tainting compounds. Furthermore, the Panel encourages DFO and EC to increase their participation in the CONRAD fish tainting program so that the information gaps and research needs identified can be addressed.

The Panel concludes that with the implementation of mitigation measures and the Panel's recommendations, the project is unlikely to result in significant adverse environmental effects on aquatic resources.

13 GROUNDWATER

13.1 Quaternary

13.1.1 Views of Shell

Shell indicated that groundwater from the overburden overlying the mine pits would be removed and released to the surface water drainage system to help mitigate the interception of natural baseflow. Shell predicted that groundwater level in the overburden would recover to very near premining levels and that overburden dewatering activities would not affect groundwater quality. Shell indicated that changes in water levels might affect wetlands and vegetation surrounding the mine pit but that any impacts would be negligible. It stated that it would implement a monitoring program to assess the impacts and validate its conclusions.

Shell indicated that tailings pore water would seep downwards through the tailings disposal area and into the shallow Quaternary deposits. Shell predicted that tailings water seepage would degrade natural groundwater quality, but that the effect of seepage would be limited to the area immediately beneath and adjacent to the tailings disposal area. Shell suggested that certain mechanisms act to reduce solute concentrations in groundwater and thus reduce concentrations and delay breakthrough. Shell stated that it would construct a 6 m deep perimeter ditch to intercept seepage flow from the tailings disposal area, but that some seepage would discharge to the ground surface between the tailings area and Jackpine Creek and that half of this seepage would enter the creek. Shell indicated that some tailings backfill seepage would migrate up from the basal aquifer through the Quaternary deposits into the Muskeg River and through Quaternary deposits into the Muskeg Creek diversion in the far future. Shell stated that with appropriate mitigation, the effects on surface water quality would be negligible. Shell stated that it was planning a groundwater and surface water monitoring program to assess whether there were connections between groundwater and surface water.

Shell indicated that it planned additional drilling in and around the perimeter of the external tailings disposal area for the design of the tailings dike, as well as within the mining area. Shell stated that this information would provide additional information on the Quaternary deposits.

Shell stated that the PCA transected six oil sands leases and had been traced over a length of 77 km. Shell stated that within the project area, the channel was covered with about 10 to 30 m of till, was about 2 km wide, and ranged in depth to more than 50 m. Shell made a number of interpretations regarding groundwater flow within the PCA. In its EIA, Shell stated that based upon the available data, groundwater flow along the channel appeared to be from south to north. Later Shell indicated that groundwater was preferentially funnelled into the PCA from adjacent lower permeability sediments and groundwater flows along the length of the channel, which acted as a conduit for groundwater flow. At the hearing, Shell said that much of the groundwater that entered the PCA in fact passed through it transversely and then back into Quaternary deposits or the McMurray formation on the northwestern flank of the PCA and that the regional flow was generally towards the west and north.

Shell stated that it would use pumping wells to dewater the PCA in the vicinity of pit highwalls in order to stabilize the pit walls and minimize seepage into the mine. Shell predicted that PCA dewatering would affect groundwater levels and flow patterns during mining but that it expected groundwater levels to recover after dewatering ceased. Shell said that it would monitor the effects of dewatering.

Shell stated that the channel was protected by a layer of lower permeability till beneath the tailings disposal area, which would act as a natural liner. Shell predicted that during development, seepage from the external tailing disposal area would migrate downward into the PCA and then toward the dewatering wells. Shell indicated that it expected that initially the affected groundwater would have a chemical composition representing some mixture of the tailings seepage and the natural PCA water chemistry. Shell indicated that once dewatering ceased, the plume of tailings-affected water would remain within the PCA west and east of the tailings disposal area. Shell indicated that tailings seepage water would begin to migrate to the west toward Jackpine Creek and north toward the east EPL. It predicted that the primary areas affected would be limited to within 1 km of the external tailings disposal area. Shell indicated that over time the proportion of tailings seepage would increase until groundwater chemistry in the affected areas approached the same composition as undiluted tailings seepage. It also indicated that changes in groundwater quality would be long term and irreversible, but it did not expect to see significant effects on the PCA due to tailings disposal area seepage. Shell stated that the tailings sand seepage water composition would be within the natural variation of groundwater quality in the PCA and maintained that the water would still be classified as usable. Shell believed that its predictions regarding tailing disposal area seepage were conservative and indicated that it did not foresee any cumulative impacts from tailings seepage into the PCA if other developments in the area proceeded.

Shell stated that while some CT was consolidating, it would express pore water into portions of the PCA and that low-water levels during and shortly after dewatering would increase the tendency for CT pore water to migrate into the PCA. However, Shell indicated that it expected only minor groundwater exchange between the tailings and the PCA. Shell stated that as water levels in the PCA returned to predevelopment levels, seepage from CT cells would decrease to negligible rates.

To minimize the impacts to the PCA, Shell indicated that it had readjusted the mine pit limits to protect the integrity of the channel at the expense of leaving some of the ore in the channel. Shell noted that it would continue to refine and optimize the mine plans to look at the ultimate location of the pit wall and balance mining cost and PCA encroachment. Shell indicated that it would be doing additional work to design a system of depressurization wells and would evaluate its dewatering requirements.

Shell indicated that it had investigated lining the tailings disposal area to limit seepage to the PCA but found that did not provide an environmental benefit; therefore, Shell had not proceeded with a more rigorous evaluation. Shell indicated that a liner might, in fact, force the tailings disposal area seepage waters to the surface sooner and with greater environmental impacts. Shell summarized various adaptive management strategies for project effects on the Quaternary groundwater regime. Shell stated that if certain areas required protection from drawdown as a result of overburden dewatering, it might be possible to install locally a grout wall or low permeability barrier to groundwater flow. Shell indicated that if drawdown as a result of PCA dewatering affected wetlands or surface water bodies, it might consider reinjection of water in sensitive areas, change the sequencing and rates of dewatering, or manage stream diversions to allocate surface water release to sensitive areas. Shell stated that adaptive management strategies to deal with seepage from the tailings disposal area might include the installation of a drain system or a grout curtain, whereas strategies to deal with in-pit tailings might include the installation of a drain system or a reactive wall or the modification of surface drainage patterns to manipulate groundwater recharge and discharge areas and flow patterns.

Shell stated that it had established cooperation agreements with ExxonMobil and Syncrude and that none of the companies had plans to conduct a regional groundwater study of the PCA. Shell also stated that it had completed a conceptual groundwater-monitoring plan and would work with stakeholders to refine the plan. Shell further stated that it would file the revised groundwater-monitoring plan as part of its EPEA approvals. Shell noted that a regional groundwater-monitoring program in the oil sands mining area was not proposed by individual proponents or CEMA. Shell indicated that it could address regional issues through cooperation agreements with adjacent leaseholders.

13.1.2 Views of MCFN

MCFN stated that its agreement with Shell provided for

- MCFN to review and have input on Shell’s proposed groundwater-monitoring program and its implementation,
- MCFN to review the results of monitoring programs to validate the effectiveness of mitigation measures and the correlation between monitoring results and EIA predictions, and

- Shell to collect additional data on groundwater resources and aquifers in the Muskeg River basin.

13.1.3 Views of ACFN

ACFN's agreement with Shell required Shell to

- involve ACFN in the design of monitoring programs,
- determine threshold values that would trigger adaptive management actions, and
- provide ACFN with monitoring results and a comparison with EIA predictions.

13.1.4 Views of Fort McKay

Fort McKay's agreement with Shell provided for the involvement of Fort McKay in the design of the groundwater-monitoring network and in the adaptive management process, including the development of triggers that would result in mitigation actions.

13.1.5 Views of Alberta

AENV stated that it considered seepage from the external tailings disposal area into the PCA to be an impairment of the aquifer. AENV believed that the water within the PCA would be considered a usable groundwater resource even after seepage effects modified its composition. AENV stated that it might include a condition requiring Shell to submit a detailed mitigation plan to limit the lateral extent and water quality effects of seepage prior to the first use of the tailings disposal area. AENV stated that it might also include conditions in any EPEA approval requiring Shell to collect additional data on the aquifer and to confirm Shell's predictions on the effects of tailings disposal area seepage. AENV indicated that long-term effects on the PCA could be minimized and limited to the mine lease boundaries through a comprehensive groundwater monitoring program and effective mitigation process managed through the EPEA process.

With respect to project-specific considerations, AENV indicated that a regional groundwater study on the PCA was not necessary but that the information provided by a regional study might be useful.

AENV indicated that the conceptual groundwater monitoring plan was detailed and addressed several of the aquifers potentially impacted, including those present in the overburden, the PCA, and the basal aquifer. AENV indicated that the monitoring plan included a substantial list of parameters that would be monitored and that the plan was appropriate, although some revisions might be required.

13.1.6 Views of the Panel

The Panel recognizes that tailings seepage will change water quality within the Quaternary aquifers in the Shell lease area. The Panel accepts Shell's and AENV's position that groundwater within these aquifers will remain usable even after seepage water has entered them. The Panel also accepts that Shell has incorporated conservative assumptions into its seepage models. The Panel notes that AENV indicated that long-term effects on the PCA could be managed through the EPEA process. The Panel also notes that AENV stated that it might include a condition in any EPEA approval requiring Shell to submit a detailed additional mitigation plan to limit the lateral extent and water quality effects of seepage prior to the first use of the tailings disposal area. The Panel believes that some mitigation options may be forsaken once construction of the disposal area is complete. Therefore, the Panel recommends that AENV consider requesting Shell to provide, prior to construction, additional mitigation plans to limit external tailings disposal area seepage. The Panel supports AENV's plans to incorporate monitoring and mitigation requirements for tailings seepage effects in any EPEA approval.

The Panel notes Shell's commitment to continue to investigate the Quaternary deposits in the external tailings disposal area and sees this as an opportunity for Shell to continue to refine its seepage effects conclusions. The Panel therefore recommends that AENV's Dam Safety Branch require Shell to include updated seepage modelling results, Quaternary deposits mapping, monitoring plans, and mitigation measures in the tailings disposal area detailed design report.

The Panel notes that Shell has redefined its mine pit limits to protect the integrity of the PCA. The Panel recognizes that the final mine pit limits have not been established and may differ from those currently proposed after additional drilling is completed. Revised pit limits might compromise the integrity of the PCA. While the Panel is prepared to accept that seepage from in-pit tailings will be negligible under the current mine plan, it is conceivable that contamination of the PCA could occur if Shell revises its plans to include mining into the channel. The Panel directs that Shell provide a report, for EUB approval, detailing its mine plans near the PCA five years prior to mining in this area to allow for the consideration of resource recovery issues and environmental impacts. The report shall include the proposed location of the pit limits and their proximity to the PCA, as well as a description of any mitigation that would be completed to minimize the impact of mining near the PCA.

The Panel notes Shell's commitments to involve stakeholders in the design and implementation of its groundwater monitoring program, as well as Shell's commitments to review the results of the monitoring program with these stakeholders in order to assess the validity of its EIA predictions. The Panel recognizes the value of such commitments in ensuring that all parties understand project impacts.

The Panel recognizes that the PCA is a potentially significant groundwater resource of usable water that Shell's and other oil sands developments are likely to impact. The Panel understands that both Shell and AENV believe that a regional groundwater study of the PCA is not necessary for project-specific considerations. The Panel also notes that Shell indicated that it did not foresee any cumulative impacts from tailings seepage into the PCA should other development in the area proceed. However, the Panel believes that there is value in better understanding the nature of this groundwater resource before development begins. The Panel is concerned that the Syncrude and ExxonMobil developments could also impact the PCA. Therefore, the Panel recommends that AENV incorporate conditions in its approval requiring Shell, in conjunction with other developers, to define and carry out a regional groundwater study of the PCA in order to evaluate the regional nature of this groundwater resource. The Panel believes this assessment should be carried out before mining begins in the vicinity of the PCA.

The Panel concludes that with the implementation of mitigation measures and the Panel's recommendations, the project is unlikely to result in significant adverse environmental effects on the Quaternary groundwater regime.

13.2 Basal Aquifer

13.2.1 Views of Shell

Shell stated that a water-saturated basal aquifer was present between the top of the Devonian Formation and the base of the McMurray Formation. Shell indicated that the basal aquifer must be depressurized prior to mining to ensure pit floor and pit wall stability. Shell maintained that the effects of depressurization would extend beyond the immediate vicinity of the mine site. It said that drawdown in the basal aquifer could also produce drawdown in overlying formations, but that depressurization would not significantly affect groundwater elevations in shallow Quaternary deposits. Shell predicted that groundwater discharge to the major rivers in the area would decrease as a result of basal aquifer depressurization, but that the predicted changes represented only small fractions of the respective flows in each stream. Shell indicated that deep seepage beneath the external tailings disposal area would increase as a result of depressurization. Shell also indicated that downward seepage from the tailings disposal area into the basal aquifer might result in a deterioration of groundwater quality in the aquifer in the far future. Shell stated that if depressurization caused unexpected effects, it might adjust the location of dewatering wells or pumping rates to reduce the magnitude of drawdown or it might undertake reinjection of depressurization water back into the basal aquifer.

Shell stated that in-pit tailings backfill would be in direct contact with groundwater in the McMurray Formation and that tailings backfill water would migrate downward through the bottom of mine pits and into the basal aquifer. Shell stated that the resulting deterioration in basal aquifer groundwater quality would be a long-term phenomenon. It suggested that tailings seepage could migrate through the basal aquifer into the west EPL. Shell predicted that in the far future, a plume of tailings-affected water would be present in the basal aquifer, extending from the project to the Athabasca River, and that seepage-affected water would migrate upwards from the basal aquifer through Quaternary sediments into the Muskeg River. Shell indicated that it would conduct groundwater monitoring of the basal aquifer. Shell stated that adaptive management strategies to control seepage flow included the installation of a drain system to capture affected groundwater, the installation of a reactive wall to prevent further migration of affected groundwater, and modifications to the surface drainage pattern to manipulate groundwater recharge areas, flow patterns, and discharge characteristics.

Shell indicated that it would conduct exploration drilling and continue to define the extent of the basal aquifer based on those results. Shell stated that within the mining design effort, it would look at additional information in the areas of basal water quality and depressurization volumes to make sure that the depressurization design was correct. Shell committed to use basal aquifer water in the extraction process regardless of the total dissolved solids (TDS) value of that water.

13.2.2 Views of the Panel

The Panel recognizes that, based on TDS values, water within the basal aquifer could be considered usable groundwater and that TDS values and many chemical parameter concentrations in basal aquifer water exceed the values anticipated for CT and tailings sands pore water seepage. However, certain concentrations anticipated for metals in the CT pore water seepage exceed maximum acceptable concentrations for drinking water quality. The Panel understands that seepage from in-pit tailings would flow into the basal aquifer and form a plume discharging to the Muskeg and Athabasca Rivers in the far future, and potentially to the west EPL. The Panel notes Shell's statement that certain mechanisms act to reduce solute concentrations in groundwater and delay breakthrough. The Panel recognizes that Shell has proposed monitoring programs to validate its groundwater model's predictions and plans on conducting monitoring of basal aquifer water quality in conjunction with its depressurization activities. The Panel notes that Shell has identified adaptive management strategies to deal with any unexpected results.

The Panel expects Shell to meet its commitment to use basal aquifer depressurization water in the extraction process, regardless of TDS.

The Panel notes that a number of groups are collecting data in order to assess the regional impacts of development in the oil sands area on air, surface water, and wildlife, but that no group appears to be assessing the regional impact of development on groundwater. In light of the number of developments in the area, as well as the scale of development, the Panel believes that such an initiative would be valuable in assessing all potential impacts. The Panel recognizes that Shell indicated that it could address regional groundwater issues through cooperation agreements with adjacent leaseholders and that it will undertake monitoring of project-scale impacts on groundwater. The Panel also recognizes that no single leaseholder should be tasked with undertaking a regional groundwater monitoring study. The Panel recognizes that an additional recommendation to regional working groups to undertake such an initiative may not be feasible, given their current workloads. The Panel believes that a regional working group examining groundwater issues should be considered by AENV.

The Panel concludes that with the implementation of any necessary mitigation measures, the project is unlikely to result in significant adverse environmental effects on the basal aquifer groundwater regime or connected surface water bodies.

14 AIR EMISSIONS

14.1 Views of Shell

Shell predicted that the project would increase total regional sulphur dioxide (SO_2) levels by only 0.1 per cent. Shell stated that although the maximum predicted 1-hour ground-level SO_2 concentrations would exceed *Alberta Ambient Air Quality Guidelines* (AAAQG) levels in all emission scenarios (baseline, application, and planned), the predicted differences between maximum SO_2 concentrations for the baseline and application cases were negligible, indicating that the project had little influence on these exceedances.

Shell predicted that the project would increase total regional nitrous oxides (NO_x) emissions from 218 to 241 tonnes per day (t/d). Shell's air quality modelling predicted exceedances of AAAQG for annual nitrogen dioxide (NO_2) in the local and regional study areas for all assessment scenarios. Shell advised that the contribution of the project to the exceedances was small and that predictions of NO_2 tended to be conservative to account for the uncertainty related to predicting ambient NO_2 levels.

Shell committed to develop the project with the following NO_x mitigation measures: a mine fleet that met applicable emission standards at the time of purchase, optimization of travel distances for the mine fleet, effective road and vehicle maintenance programs, use of efficient turbine technology, and low-NO_x technologies for boilers and turbines.

Shell submitted that emissions from the project would not significantly contribute to acidification of soils and water in the region. Shell stated that its analysis was conservative because it had used maximum air emissions for all projects. It maintained that the dispersion model predictions of emissions were founded upon conservative assumptions and that the predicted level of acidifying emissions and PAI values were significantly overstated in the EIA.

Shell noted that there were three tools to manage acidification in the region. One was the acidification management plan presented to CEMA on September 30, 2003. Shell believed that the implementation of this plan would minimize the risk of acidification occurring in the region. The second tool was a comprehensive ambient deposition and environmental effects monitoring program for acidification that was already in place under WBEA. The third tool was an annual monitoring program completed by RAMP to monitor potential changes in alkalinity in water bodies.

Shell predicted that the 24-hour-average concentrations of particulate matter size 2.5 micron ($PM_{2.5}$) would exceed the Canada Wide Standard (CWS) of 30 micrograms per cubic metre ($\mu g/m^3$) in two of the regional communities assessed, Conklin in all emissions scenarios (baseline, application, and planned), and Fort McMurray for the planned scenario. Shell attributed these exceedances in part to community sources of $PM_{2.5}$. Shell believed that its modelling for $PM_{2.5}$ was conservative.

Shell committed to funding a diesel particulate filter project through the Clean Air Strategic Alliance (CASA) and, if it was successful, to explore the feasibility of using the filters on buses in the Fort McMurray area.

Shell stated that it shared the widespread concern that GHGs were leading to changes in the global climate. Shell advised that it supported the commitment by Royal Dutch/Shell Group to cut emissions from GHGs from its global operations by the amount that would meet or exceed Kyoto emissions reduction targets out to the year 2010. Shell noted that it had set voluntary targets for its oil sands unit, with a goal to be less carbon dioxide (CO_2) intensive than the most likely alternative, which was imported crude on a full-cycle basis. It stated that this goal had led to a voluntary reduction target of 50 per cent by 2010 for the Muskeg River Mine. Shell stated that it was presently working with its stakeholders and the Shell Canada Climate Change Advisory Panel to assess voluntary targets for the project, and it further committed to put in place a GHG management plan to reduce emissions over time. Shell also committed to employ the best commercially available technology to minimize GHG emissions. Shell stated that it was committed to meeting the future requirements of Alberta and Canada with respect to GHGs.

14.2 Views of OSEC

OSEC stated that Shell had committed to funding research on a diesel engine after-treatment device and a diesel particulate filter project.

14.3 Views of SCC

SCC was concerned with the EIA results that indicated that the PAI was predicted to exceed critical load for sensitive soils in a significant area, some 288 000 hectares (ha). SCC understood that acidification could lead to problems in forest growth and to acidification of streams and lakes. SCC also stated that acidification in soils could lead to leaching of metals and create other environmental and health problems.

SCC believed that areas in Saskatchewan might be affected by acid deposition, but agreed that the worst air quality effects would be in the local study area (LSA).

SCC stated that it understood that Canada had committed to Kyoto, which called for a 6 per cent reduction of GHGs. It also understood that the Kyoto target was only the first step and that further reductions up to 60 per cent were needed. SCC believed that by approving long-term investment in fossil fuels, such as this project, Canada would have a difficult time meeting its commitments, and therefore it believed the project approval should be denied.

14.4 Views of Canada

EC recommended continuous monitoring of NO_x near the project to validate near-field modelling of baseline and cumulative environmental assessment conditions and agreed that WBEA would be the most appropriate group to implement this recommendation.

EC noted that preliminary total acid deposition modelling indicated that long-range transport into Saskatchewan was likely causing wet and dry acid deposition at levels well below the thresholds for harmful effects. EC recommended that Shell comply with the acidification management plan developed by CEMA.

EC also recommended that regional stakeholders participate in programs to design and implement a more rigorous wet and dry deposition monitoring program, and it believed that the Terrestrial Environmental Effects Monitoring (TEEM) committee would likely implement this recommendation.

EC recommended that regional stakeholders participate in programs to initiate particulate matter and precursor monitoring. EC believed that the Trace Metal Air Contaminants (TMAC) subgroup could design an action plan to fill in the remaining knowledge gaps with respect to particulate matter and that WBEA could implement appropriate long-term monitoring of particulate matter and precursors.

Natural Resources Canada (NRCAN) noted that the oil sands industry reduced its GHG emissions intensity by about 30 per cent and that the industry had forecast that between 1990 and 2010 it would decrease its emission intensity by about 45 per cent. It noted that the oil sands industry had been designated as a large industrial emitter under Canada's Climate Change Action Plan announced in November 2002. EC and NRCAN submitted that Shell would be required to comply with emission intensity targets once established by the Large Industrial Emitters Program under Canada's Climate Change Action Plan.

14.5 Views of Alberta

AENV stated that its policy was to control SO_2 and NO_x emissions to the lowest practicable level through the use of the most appropriate pollution prevention and control technologies. AENV stated that it might include conditions in the EPEA approval requiring Shell to collaborate with WBEA to support an ambient monitoring program that would validate predicted SO_2 and NO_x concentrations.

AENV believed that Shell's modelling results predicting ambient NO_2 emissions indicated that NO_x emissions from the mine mobile equipment should be further studied and emissions further minimized. AENV recommended that Shell and other oil sands mine operators consider an industry undertaking to confirm the source emissions of mobile fleets and review the minimization of emissions from mobile sources. AENV stated that it might include conditions in the EPEA approval requiring Shell to demonstrate that all replacement mine vehicles would meet the latest vehicle emission standards and that they would be equipped with effective emission control technology.

AENV stated that continued ambient monitoring in the region to determine the concentration of acidifying substances in air was a critical component in quantifying and assessing any risk of acidification in regional soils and water bodies. AENV noted that long-term monitoring would be needed to measure more precisely and accurately the effects of wet and dry deposition of sulphur and nitrogen on the environment. AENV stated that it might include conditions in the EPEA approval requiring Shell to participate in ongoing regional environmental management and monitoring initiatives to address acid deposition. It added that it might also include conditions requiring Shell to implement CEMA recommendations for an acidification management framework.

AENV believed that the assumptions Shell used in its $PM_{2.5}$ modelling were conservative and therefore it was unlikely that the CWS would be exceeded. It noted that the modelling results did suggest a need for $PM_{2.5}$ monitoring in communities to confirm Shell's predictions and determine if follow-up management actions were warranted. AENV stated that it might include conditions in the EPEA approval requiring Shell to collaborate with WBEA on enhanced ambient air monitoring for $PM_{2.5}$ in the communities of Conklin and Anzac in order to validate the modelling.

AENV stated that it was committed to reducing GHG emissions and contributing to an effective approach for responding to the risks of climate change. AENV noted that Alberta's action plan provided a framework for reducing GHG emissions while maintaining economic competitiveness.

AENV stated that it might require Shell to submit an annual GHG emissions summary that would include total GHG emissions for the year, emissions intensity, and calculation methodologies used. The GHG summary would describe gross emissions, as well as net emissions, should Shell use offsets to meet any performance targets. AENV indicated that Shell would be required to monitor and report in accordance with provincewide GHG monitoring and reporting requirements once the province established those. Shell would also be required to continue comparing emissions intensity to that indicated by the application and/or to industry-best practices and to describe measures that would be taken to reduce GHG emissions associated with the facility if necessary to achieve predicted performance levels and/or for continuous improvement.

AENV stated that Shell would be required to participate in the development of sectoral agreements applicable to oil sands processing plants, mines, and cogeneration plants. It also stated that Shell would be required to comply with any applicable GHG emissions limits or targets and any other provisions that may be established in a GHG sectoral agreement made applicable to the project.

14.6 Views of the Panel

The Panel notes that SO_2 emissions from the project would contribute only a 0.1 per cent increase in regional emissions. The Panel supports the proposed AENV condition to require Shell to collaborate with WBEA to support an ambient monitoring program that would validate predicted SO_2 and NO_x concentrations, as well as to participate in regional environmental management and monitoring initiatives to address acid deposition.

The Panel recognizes the concerns about NO_x emissions that would result from the project and the potential direct and indirect impacts these emissions would have on the environment on a project-specific and cumulative basis. However, the Panel notes that the conservative nature of the models used to predict ground-level concentrations of NO_x may overstate potential impacts of project emissions. The Panel expects Shell to meet its commitments to minimize NO_x emissions. The Panel also notes that an acidification management framework was tabled at the September 2003 CEMA meeting, and it expects Shell to meet its commitment to work within CEMA to implement this plan as regulators approve it.

The Panel supports AENV's intention to require Shell to demonstrate that all replacement mine vehicles would meet the latest vehicle emission standards and would be equipped with effective emission control technology.

The Panel believes that particulate matter emission and related precursor emissions should be controlled to the lowest practicable level through the use of the most appropriate pollution prevention and control technologies. The Panel accepts AENV's and Shell's position that the $PM_{2.5}$ modelling is conservative. The Panel further supports AENV including requirements in its approvals that Shell collaborate with WBEA on monitoring of $PM_{2.5}$ and PM precursors in the region, including Anzac and Conklin.

The Panel accepts Shell's commitment to use leading technologies to minimize GHG emissions and to develop a GHG management plan for the project. The Panel believes that the issue of GHGs can be dealt with through initiatives and policies developed at the federal and provincial levels. The Panel supports AENV in requiring appropriate GHG emissions and emissions intensity reporting. The Panel expects Shell to participate in the development of sectoral agreements that may be applicable to oil sands facilities and to abide by them.

The Panel believes that there is unlikely to be any significant adverse environmental effects to air quality as a result of the project, provided that the mitigation measures proposed are implemented.

15 CLIMATE CHANGE

15.1 Views of Shell

Shell stated that it had considered the effect of climate change in the EIA. Shell noted that it considered sensitivities of the project to climate parameters that were variable. Shell indicated that the project was designed for highly variable flows in the Athabasca River and it believed that changes to climate over the life of the project could be addressed through an adaptive management approach.

Shell stated that it believed it had incorporated the recommendations contained in *Canada's Working Draft Incorporating Climate Change Considerations in Environmental Assessment, General Guidance for Practitioners, January 8, 2002*. Shell believed that it had completed the requirements for an estimate of emissions, best practices in technology, commitment concerning reduction of emission, consideration of regulatory frameworks, and sensitivities to climate change parameters. Shell said that it was unable to use any climate change models because they had a high degree of uncertainty and variability, particularly for regional predictions.

Shell committed to consider the draft guidelines on climate change in future EIAs.

15.2 Views of MCFN

MCFN cautioned that climate change was a reality and would impact the long-term flows of the Athabasca River. The Fort McMurray region was predicted to increase in temperature by 5°C, becoming similar to the present temperatures of Lethbridge. Increased temperatures would have drying effects upon fens and bogs, with resultant decreases of flows to rivers. MCFN believed that climate change would make ecosystem shifts more probable, and that once ecosystems shifts happened, they would likely affect local climates and the hydrologic cycles. MCFN disagreed with Shell that climate change effects were adequately assessed for the region. MCFN requested that the Panel recommend to Canada and AENV that all future EIAs prepared in compliance with the requirements of CEAA and EPEA specifically consider the effects that climate change may have on the proposed project and cumulatively on the region. MCFN also recommended a water demand and supply study of the Athabasca River drainage basin that included climate change scenarios. MCFN further recommended that an independent agency, perhaps CEMA, complete a cumulative effects analysis that would predict the impacts on ecosystems function and services and would demonstrate whether the regional impact could be mitigated.

MCFN believed that Shell's EIA did not address climate change appropriately, but it stated that its concerns had been alleviated by Shell's commitment to do all it could to address climate change in the near future. MCFN stated that its concerns about climate change had been addressed through Shell's follow-up program to verify the accuracy of its predictions and the effectiveness of the proposed mitigation strategies.

15.3 Views of SCC

SCC believed that any projects in the Athabasca region should be required to follow *Canada's Working Draft Incorporating Climate Change Considerations in Environmental Assessment, General Guidance for Practitioners, January 8, 2002*. SCC argued that Shell had not considered the impact of climate change on the project in the EIA.

SCC stated that it was opposed to further development of the oil sands on the grounds of threats from climate change alone. SCC believed it was bad energy policy to permit projects that would bring fossil fuels on stream for decades when the country needed energy investment in other areas.

15.4 Views of Alberta

AENV stated that climate change and its consideration in EIAs was an emerging issue. AENV noted that the EIA terms of reference did not include climate change.

15.5 Views of the Panel

The Panel notes that the impact of climate change on the project was not part of the EIA terms of reference. When the federal government finalizes its guideline on climate change, the Panel expects all subsequent EIAs to follow those guidelines. The Panel agrees that Shell has considered climate change effects in a reasonable manner in its EIA. It agrees that climate change can be dealt with through an adaptive management approach.

The Panel believes that the impact of climate change on the project can be adaptively managed and therefore concludes that significant adverse effects are unlikely.

16 TERRESTRIAL RESOURCES

16.1 Wildlife

16.1.1 Views of Shell

Shell assessed local and regional effects of the project upon wildlife mortality, habitat loss and fragmentation, and barriers to wildlife movement. Shell used fourteen wildlife species as key indicator resources (KIRs). Shell predicted moderate environmental consequences at the local scale for some KIRs as a result of barriers to wildlife movement and changes to landscape composition and connectivity. Overall, Shell concluded that no significant adverse effects on wildlife would occur within the project area and no significant cumulative effects on wildlife would occur within the region.

Mitigation measures to reduce net effects included reduced surface disturbance and the use of existing rights-of-way. Shell designed the project with a 400 m wide corridor along the Muskeg River to maintain wildlife movements. To avoid critical wildlife periods, Shell stated that it would adopt seasonal timing restrictions in specific areas. Through CEMA, Shell would continue its participation in the development of a regional wildlife management plan. Shell committed to future wildlife monitoring for the project, using CEMA priority species and species of concern.

Shell stated that the conclusions made in the EIA concerning effects on wildlife would not be changed by future implementation of the Species at Risk Act. No species listed by the Committee on Endangered Wildlife in Canada (COSEWIC) had been located in Shell’s LSA.

Shell stated that although different ecosystems would be found on the project site after reclamation, the land would have equivalent capability for most wildlife species. Regarding wildlife health, it did not expect any health concerns to arise from the project. Shell stated that it would implement mitigation measures such as deterrence to manage potential effects on migratory birds from the tailings disposal area. Shell stated that it was not necessary to monitor for toxic effects on migratory birds, since it did not predict adverse water quality effects. Shell responded to EC's recommendation for tissue monitoring of migratory birds by stating that it would consider the need for such monitoring. Shell suggested that the EC recommendation be amended to allow Shell to raise the bird monitoring issue within CEMA and/or WBEA.

16.1.2 Views of OSEC

OSEC was concerned that oil sands development would compromise the integrity of riparian wildlife habitat, wildlife movement corridors, and recreational use along the Muskeg River and Jackpine Creek. OSEC stated that the curved path of the Muskeg River and the boundary of the oil sands lease affected Shell's 400 m corridor next to the river, so that in some places the corridor would be only 100 m wide. OSEC did not believe that this was a sufficiently protective corridor.

16.1.3 Views of MCFN

The agreement between MCFN and Shell included ongoing consultation with MCFN about environmental effects of the project, including impacts on wildlife. Shell agreed with MCFN to undertake environmental monitoring to validate EIA predictions of the project and to review monitoring results and the effectiveness of mitigation measures with them annually. Shell agreed to seek input from MCFN in the design of project monitoring programs, including those dealing with wildlife populations and movement corridors.

16.1.4 Views of ACFN

Shell and ACFN reached an agreement to address concerns related to historic densities and movement of moose in the Muskeg River basin. ACFN and Shell agreed that Shell would consider participating in new organizations, such as a terrestrial monitoring group, that ACFN and a majority of stakeholders might propose.

16.1.5 Views of Fort McKay

The agreement between Shell and Fort McKay addressed key environmental issues, including wildlife species for subsistence hunting, trapper issues, and access management.

16.1.6 Views of SCC

SCC asserted that effects on wildlife would inevitability result from the project. These effects would extend beyond surface disturbance areas due to the diversion of water flows and would act in combination with other regional developments to substantially damage habitat. Other concerns were expressed about loss of biodiversity, nesting areas for migratory birds, and negative effects on wildlife from tailings, oil spills, and air emissions.

16.1.7 Views of Canada

EC was concerned that oil sands development in combination with other anthropogenic changes, such as forest harvesting, pipelines, and other infrastructure, would cause change to and loss of wildlife habitat. As a result, measurable impacts on wildlife, ecosystems, and ecological processes could occur. EC encouraged oil sands developers and all regulators to consider a cumulative and comprehensive approach to impact assessment, monitoring, and mitigation of impacts. EC recommended that interim environmental thresholds and objectives of CEMA be developed and implemented. EC stated that there was a need to assess the effects of each project on wildlife in a regional context and to assess those effects cumulatively with other developments in the region. EC asked that regulators consider the wildlife issues collectively.

EC stated that it was concerned about habitat loss and fragmentation in the boreal forest, as it was expected to lead to a decline of some songbird populations. To reduce disturbances to migratory birds and other wildlife during breeding, nesting, and fledging periods, EC recommended that vegetation clearing for the project not occur between April 1 and August 31.

EC stated that the project would result in the formation of sizeable EPLs to which migratory birds and other wildlife would be attracted. Therefore, EC recommended that Shell conduct long-term monitoring of potential contaminants from EPLs and air emissions and their effects on migratory birds.

EC questioned whether the indicator bird species selected by CEMA's Wildlife and Fish subgroup (WFG) were being monitored. Hence, EC recommended that Shell provide a detailed design and implementation schedule for its LSA for monitoring listed species and priority 1 and 2 indicator species identified by WFG. EC recommended that the information be provided prior to project construction.

In relation to the Species at Risk Act, EC stated that it had not identified any issues for the project. Nevertheless, if threatened or endangered species were discovered in the project area, it maintained that Shell would be expected to prevent the destruction of those species and their habitat.

16.1.8 Views of Alberta

ASRD and AENV agreed that Shell's wildlife mitigations were reasonable and considered a 400 m wide undisturbed corridor as a positive step toward maintaining wildlife habitat values and connectivity along the Muskeg River valley. Nevertheless, due to the increasing level of disturbance and the potential for long-term cumulative impacts on habitat connectivity, ASRD and AENV believed that natural dispersal patterns and seasonal range distributions of some wildlife species might be affected by the project. Consequently, ASRD and AENV requested the EUB to require Shell to undertake and lead a research and monitoring program to examine wildlife responses and effective setback distances for movement corridors in the oil sands area and to examine other potential innovative mitigation and reclamation measures.

16.1.9 Views of the Panel

The Panel recognizes that Shell's assessment of effects on wildlife assumed that the project effects occurred at one time and that predicted effects may be conservative. The fact that project effects on wildlife will likely be compounded during construction and operation of the project emphasizes the importance of successful implementation of Shell's mitigation measures and progressive reclamation. The Panel acknowledges that the EIA indicated moderate environmental effects for some species due to barriers to wildlife movement and for other species due to the removal of large-diameter trees in old growth forest. The Panel recommends that ASRD review with Shell opportunities to further mitigate losses of old growth forest attributed to the project.

The Panel agrees with ASRD and AENV that further research will be needed to evaluate wildlife corridors for effective movement of wildlife species. In establishing optimum features of corridors, such as size and distribution, the Panel believes an integrated approach involving multiple stakeholders and regulatory agencies would be beneficial. The Panel believes there are opportunities during scientific review of wildlife corridor effectiveness by Shell to consider other environmental benefits and mitigations that could contribute synergies or otherwise enhance the value of wildlife corridors. Ecosystem benefits are expected from maintaining limited areas of undisturbed native vegetation within oil sands leases for purposes of wildlife habitat, mitigating losses of old growth forest, biodiversity, reclamation, and watershed management.

The Panel recommends that ASRD and AENV require Shell to participate in a technical review of wildlife corridors that includes analysis of corridor width and effectiveness in facilitating wildlife movement and meets the regulatory needs of both agencies. Furthermore, the Panel recommends that ASRD and AENV review with Shell an action plan to maintain other islands or strips of undisturbed native vegetation on the Shell lease in association with wildlife corridors.

The Panel believes that avoiding vegetation clearing between April 1 and August 31 would mitigate impacts on migratory birds. The Panel expects that ASRD will adopt timing limitations consistent with other oil sands approvals. The Panel recommends that ASRD require Shell to develop a wildlife monitoring program for implementation prior to construction. The Panel expects the monitoring program to address federally and provincially listed species, as well as the priority 1 and 2 indicator species identified by CEMA.

The Panel expects that AENV and ASRD will review the recommendations of EC in view of work that may be implemented independently by Shell or cooperatively within CEMA. For example, the Panel understands that monitoring needs for the environmental effects of tailings and airshed contaminants upon migratory birds may be different in scope and application for regional and project scales. The Panel expects AENV, ASRD, and Shell to discuss appropriate indicators and time frames for Shell to validate its predictions of negligible effects on wildlife health, including that of migratory birds.

The Panel generally supports EC’s recommendation for improved coordinated regional assessment and management of cumulative environmental effects, but believes that further review by EC, including consultation with DFO and AENV, on its feasibility and scope is necessary.

With the potential for listed species of the Species at Risk Act to be discovered in the project area and potential for changes to the COSEWIC species list, the Panel reminds Shell of the necessary vigilance required for ongoing compliance.

The Panel concludes that with the implementation of proposed mitigation measures and the recommendations of the Panel, significant adverse environmental effects on wildlife are unlikely.

16.2 Vegetation, Soils, Wetlands, and Forest Resources

16.2.1 Views of Shell

Shell compared the total disturbance of 8150 ha from the project to the entire area of Alberta's boreal forest natural region and concluded that the small change in total area was not significant. Shell stated that about 5919 ha would be disturbed at any one time during the project. Under baseline conditions, 88 per cent of Shell's regional study area (RSA) was undisturbed. Shell considered the boreal forest to be dynamic and subject to a range of naturally occurring ecosystem changes. Of the total disturbance attributed to the project, 3300 ha of peatlands would be replaced with upland soils and vegetation and 1600 ha would be replaced by open water. In its assessment of the local and regional vegetation resources, Shell compared land cover classes of KIRs that included riparian communities, economic forests, peatlands, old growth forest, rare plant potential, and traditional plant potential.

Shell stated that it ranked effects on vegetation, wetlands, and forest resources according to residual effects following progressive reclamation. Within the LSA, it assessed loss of wetlands and loss of areas containing high rare plant potential with high negative environmental effects. It predicted moderate beneficial environmental effects for terrestrial vegetation, economic forests, and traditional-use plants within the LSA after reclamation. Shell identified a number of project-specific mitigation measures, such as the use of existing disturbances, progressive reclamation and selective use of soil placement, conservation, and replacement of topsoil and organic matter.

Shell stated that it had completed a cumulative effects assessment within the RSA for the two vegetation KIRs, which predicted negative project impacts. It predicted loss of wetlands and loss of areas containing high rare plant potential to have moderate negative environmental effects. This was influenced in part by the inability to reclaim peatlands using current practices. Shell stated that it would continue its participation in the development of regional management systems within CEMA to address cumulative effects on vegetation. Shell acknowledged that some uncertainties existed surrounding the materials and methods of commercial-scale reclamation and committed to ongoing work within CONRAD to improve and develop reclamation techniques. Shell stated that it would monitor soil and vegetation re-establishment as part of its Conservation and Reclamation (C&R) Plan and closure activities.

Shell noted that CEMA's reclamation working group (RWG) had recently held a workshop to review the feasibility of restoring bogs and fens. Shell stated that it would support the restoration of bogs and fens if economically feasible methods were found.

Shell assessed the effects on soils in the LSA using KIRs that included permanent loss of soil units and mineral and organic soil units. It assessed project effects on both the quantity and capability of soil units. Shell assumed, on the basis of monitoring and research, that physical and land capability properties of reclaimed soils were similar to those of natural soils. Shell predicted the negative effects from the permanent loss of soil units to be of moderate consequence for the LSA. It predicted environmental effects of high consequence within the LSA for loss and alteration of organic soil units and for changes in forest capability.

Within the planned development case, Shell predicted that cumulative effects on soils would be negligible for all assessment criteria. Shell's primary mitigation for effects on terrain and soils was progressive reclamation intended to restore equivalent land capability. Shell proposed other project mitigation measures to reduce effects of erosion, compaction, salinity, and admixing. Shell committed to site-specific reclamation monitoring of soil and vegetation.

16.2.2 Views of OSEC

Shell addressed OSEC's concerns by agreeing to a wetlands monitoring program for the project. In addition, Shell agreed to examine opportunities to reduce drawdown of off-lease wetlands and also to work with OSEC to identify a wetland offset project and provide project funding to enhance wetland habitat for migratory birds of the boreal forest.

16.2.3 Views of MCFN

MCFN noted that the agreement with Shell included ongoing consultation with MCFN on vegetation and land use.

16.2.4 Views of ACFN

Shell and ACFN reached an agreement to address ACFN's concerns related to transplanting of plants important to ACFN.

16.2.5 Views of Fort McKay

Shell and Fort McKay reached an agreement that dealt with land disturbance, healing the land, medicinal plants, and access management.

16.2.6 Views of SCC

SCC stated that there would be major impacts on Canada's boreal forest from developments in northern Alberta. Effects could include reduction in the abundance of flora, fauna, and biodiversity, removal of forests, and acidification effects on forest fertility. SCC was concerned about the removal of 54 per cent of the old growth forest from the LSA. SCC challenged Shell's ability to re-establish wetlands. SCC asserted that peat wastage processes could result from hydrologic changes to wetlands and cause irreversible damage. SCC stated that re-establishment of wetlands as proposed by Shell would occur after 2030, and SCC wanted greater certainty for wetlands replacement in the near term.

16.2.7 Views of Canada

EC noted the importance of selecting environmental indicators suitable for detecting ecosystem changes at local, regional, and broader-range scales. In the context of pending implementation of CWS for particulates and ground-level ozone, EC recommended that stakeholders collectively identify suitable indicators for monitoring ecosystem responses to emissions.

16.2.8 Views of Alberta

Citing the report of the Oil Sands Mining End Land Use Committee (July 1998), AENV indicated that it could include approval conditions for Shell to achieve equivalent land capability and meet that committee's objectives for stable landforms with a diversity of forest and wetland ecosystems. AENV expected that soils and ecosystems would be returned to predisturbance capability to support large trees and other native vegetation.

AENV stated that long-term monitoring would be necessary to measure the effects of sulphur and nitrogen deposition on the environment. AENV stated that it might include approval conditions requiring Shell to support research to implement CEMA recommendations for an acidification management framework.

16.2.9 Views of the Panel

The Panel understands that effects of the project upon wetlands and rare plants are for the most part unavoidable and that the loss of some wetlands is likely irreversible. The Panel recognizes that there are uncertainties concerning the performance of reclamation materials for soils and vegetation.

The Panel believes that there are opportunities for Shell and other oil sands operators to evaluate the technical feasibility of engineered wetlands that resemble conditions of peatlands, bogs, and fens and to initiate demonstration research programs. The Panel recommends that ASRD and AENV identify this area of wetlands research as a priority for CEMA to address, and that they consider requiring Shell to support a program to facilitate wetlands restoration.

The Panel recommends that EC provide scientific expertise to CEMA working groups in the selection of appropriate indicators of terrestrial and aquatic ecosystems and in establishing effects-based monitoring systems for regional acid deposition.

The Panel supports AENV requiring Shell to address future implementation of CEMA's acidification management framework with additional research or monitoring of environmental receptors such as soils, vegetation, and water bodies.

The Panel concludes that with the implementation of mitigation measures and the recommendations of the Panel, significant adverse environmental effects on vegetation, soils, forests, and wetlands are unlikely.

16.3 Reclamation

16.3.1 Views of Shell

Shell stated that the project area would be fully reclaimed over time with phased reclamation activities throughout the operating life of the mine. Mining areas would be filled with residual tailings sand, and when the sand had consolidated to a firm landscape, it would be capped with overburden, covered in topsoil, recontoured, and revegetated. Shell stated that the goal was for complete reclamation by the end of the project.

Shell indicated that it defined disturbed lands as the first occurrence of clearing for any project-related activities. Shell stated that it had defined a reclaimed area as one in which the soil cover had been placed on the recontoured landforms and seedlings had been planted or seeds sown. Shell noted that its definition of reclamation would not meet Alberta's requirements for issuing a reclamation certificate.

Shell stated that the project's maximum footprint might change as detailed design progressed. While Shell acknowledged the EUB's desire to regulate a maximum level of project disturbance, Shell believed that it would be more appropriate to work on a series of reclamation milestones throughout the life of its project. It believed that this approach would meet the goal of promoting progressive reclamation. Shell noted that the set of reclamation milestones presented at the hearing might change after the project feasibility study was completed.

Shell stated that it was committed to continuing to conduct detailed reclamation monitoring and to participate in research to refine understanding of reclamation of wetlands and vegetation associated with CT areas. It supported research being done through CONRAD and the EPL subgroup of CEMA. Shell indicated that it would pursue an adaptive management approach to reclamation procedures that were based on research and on new best practices from RWG.

Shell recognized stakeholders' concerns that terrestrial landscapes and water bodies may not be reclaimed in the manner predicted and may not have productive end land uses. Shell believed that extensive ongoing research on tailings management and reclamation would lead to successful reclamation of the oil sands area.

16.3.2 Views of OSEC

OSEC believed that in the absence of an understanding of what the regional environmental thresholds might be, it would be prudent to minimize the amount of disturbance that was occurring. OSEC indicated that it had discussed the feasibility of a disturbance cap, and it agreed with Shell that simply having a cap for the amount of disturbance that a project could impose upon the landscape would do nothing to encourage an operator to minimize disturbance through progressive reclamation. OSEC agreed with Shell that a better approach would be the concept of reclamation milestones, in which an operator is constantly pursuing reclamation and minimizing overall disturbance.

16.3.3 Views of Alberta

ASRD stated that it supported progressive reclamation through either maximum disturbance limits or reclamation milestones. ASRD further indicated that there might be some merit to the milestone approach, since reclamation was not a continuous but a phased process.

ASRD stated that the biggest improvement to progressive reclamation would be to ensure that developers started reclamation immediately when land became available for reclamation, irrespective of budget constraints or other similar issues that might tend to defer reclamation efforts.

AENV stated that it might condition its approvals to ensure that reclamation resulted in a return to equivalent land capability, with integrated landscapes and ecosystems consistent with the report and recommendations of the Oil Sands Mining End Land Use Committee.

16.3.4 Views of the Panel

The Panel believes that reclamation planning and final landscape objectives are important considerations when determining whether an oil sands development is in the public interest.

The Panel is encouraged that Shell is implementing a progressive reclamation approach. The Panel understands progressive reclamation to mean that Shell will reclaim land as soon after disturbance as is reasonably possible and in a manner that is consistent with the closure plan.

The Panel is aware that although some overburden disposal areas have been reclaimed at the existing oil sands mines, none has been certified. Also the Panel notes that no tailings areas have been reclaimed. However, the Panel also notes that the nature of oil sands development inherently requires large areas of disturbance that may remain on the landscape over an extended period of time. The Panel notes that Shell has put a great deal of reliance on its progressive reclamation plans to mitigate the environmental impacts of the project.

In the absence of environmental thresholds or management objectives from CEMA, the Panel believes it is prudent to adopt a precautionary approach on the issue of reclamation. The Panel believes that, to the extent allowed by current technology, the oil sands industry should minimize the overall land disturbance and the maximum amount of land disturbed at any given time and that operators should strive to reclaim disturbed lands as soon as possible. Previously, the EUB has limited the amount of surface disturbance by establishing a maximum area of unreclaimed land within a project area. The Panel notes that Shell indicated that an appropriate number, if the EUB were to limit land disturbance in this case, would be 6309 ha, which is 78 per cent of the total proposed disturbance of 8150 ha.

The Panel acknowledges that Shell has suggested a reclamation milestone approach as an alternative to being regulated to a maximum disturbed area. The Panel believes that the milestone approach may have merit, but it notes that Shell has provided only a limited number of milestones and that it would be revising and finalizing this information after the feasibility study.

Although the Panel agrees with Shell's definitions of disturbed and reclaimed land, it believes that additional information would be needed to determine whether a maximum disturbance or a reclamation milestones approach is more appropriate. The Panel notes that the use of these approaches to regulate tailings management may also be considered in the EUB initiative to develop tailings performance criteria. The Panel recommends that AENV and ASRD consider whether additional performance criteria should be developed for progressive reclamation. These criteria could complement the proposed tailings management criteria described in Section 8 of this report.

The Panel notes that there are opportunities for Shell to revise and improve its reclamation plan as the project progresses and additional knowledge is gained through continued research and development on tailings.

16.4 End-Pit Lakes

16.4.1 Views of Shell

Shell stated that EPLs are permanent features of the project closure landscape. Shell supported the work of CONRAD and the CEMA EPL subgroup in researching the optimum design, operation, and mitigation measures for EPLs. Shell explained that the subgroup was completing literature reviews on EPLs and modelling for physical, biological, and chemical characteristics.

It stated that outside of its five-year plan, the subgroup planned a demonstration project through CONRAD.

Shell committed to validate EPL conclusions in the EIA through participation on the CEMA EPL subgroup and being part of the demonstration project. Shell stated that it would be 30 years until lake waters were discharged, which provided time to incorporate the results of ongoing reclamation research. Shell noted that other oil sands mines' EPLs would be discharging to the environment prior to the project EPL. Shell stated that it would use the knowledge gained from these closures in assessing the development of its EPL towards a productive ecosystem. Shell noted that Syncrude's Base Mine Lake was due to close in 2006, with first releases to the surroundings in about 2016. Shell suggested that this would be a large-scale, end-pit type lake that would be in place prior to the operation of Shell's EPL.

Shell stated that its EPL would have retention times to treat water quality for up to 18 years, and it believed that those waters could be released. Shell indicated that overall EPL water quality should be suitable to support aquatic ecosystems because all EPLs were predicted to be nontoxic when discharges to the environment commenced. Shell also noted that the western EPL would not have tailings at the bottom, which should assist Shell in meeting its water quality objectives more easily.

16.4.2 Views of Canada

DFO noted that there were no functioning examples of EPLs to verify Shell's EIA predictions. DFO stated that in the event that EPLs did not appear to be a viable option, it was imperative that alternative strategies be developed and implemented prior to mine closure.

DFO recommended that ongoing research into EPLs be continued and expanded to determine their ecological value over the long term. DFO further recommended that research be conducted or undertaken on mining and recovery options to reduce or eliminate the need for EPLs.

16.4.3 Views of Alberta

AENV recognized that groups such as RWG and the EPL subgroup were expected to address uncertainties regarding the viability of EPLs, their design and water quality. AENV understood that work plans were in place with appropriate schedules to develop a guidance document and theoretical designs for EPLs. AENV accepted Shell's predictions of functioning EPLs in the closure landscape.

AENV noted that it would be a number of years until the first EPLs were in place and stated that the complexity and uncertainty about their function made it critical that priority continue to be given to ongoing, comprehensive research. AENV stated that the pace of CEMA's work on the model development of EPLs and a guidance document was appropriate.

AENV stated that it expected greater attention to be paid to validation of models by early construction of a physical test case in the oil sands region. AENV indicated that it was not sure if the Syncrude Base Mine Lake would meet its expectations for validating EPL predictions. It explained that once the EPL subgroup completed its initial work, AENV would have a better understanding of what would constitute an appropriate demonstration. AENV stated that it might not be necessary to construct a full-scale EPL to test the physical components of the models being used. It understood Base Mine Lake to be a full test of a “water-capped” lake, but not necessarily of EPLs. AENV indicated that it might require Shell to provide a schedule that included the testing of EPL predictions and design features with a physical test case done in partnership with other oil sands companies.

AENV noted that any discharge from EPLs to natural surface waters would be required to meet Surface Water Quality Guidelines except where exceedances occurred naturally. AENV noted that the viability of EPLs as sustainable ecosystems in the closure drainage landscape for oil sands mines had yet to be conclusively substantiated. Uncertainty in EPL design, functionality, and water quality was identified under the Regional Sustainable Development Strategy (RSDS) as a significant issue. AENV stated that should EPLs not perform as expected, alternative water management measures could be required.

16.4.4 Views of the Panel

The Panel notes that EPLs have not been demonstrated within the oil sands industry. The Panel acknowledges that EPLs have been applied for and endorsed subject to successful demonstration in other oil sands projects and that testing is still proceeding to verify the feasibility of EPLs.

The Panel believes that an EPL demonstration is necessary. It notes that the EPL subgroup has identified that the next phase of its work would involve an EPL test program. The Panel supports AENV’s intentions to require Shell to provide a research schedule that includes the testing of EPL predictions and design features with a physical test case done in partnership with other oil sands companies. The Panel believes that Shell, alone or in cooperation with other stakeholders, should identify a research and development plan to address the design, operation, and ecological viability of EPLs. The Panel expects sufficient work to verify EPL feasibility to be completed in the next 15 years. The Panel notes that this work may include a field demonstration or a full-scale test. The Panel recommends that AENV monitor EPL development and testing by Shell and other operators.

The Panel concludes that with the implementation of the mitigation measures and the recommendations of the Panel, significant adverse environmental effects associated with EPLs are unlikely.

17 MUSKEG RIVER INTEGRITY

17.1 Views of Shell

Shell stated that it considered the effects of the project on the Muskeg River basin water quantity and quality to be negligible, based on its proposed mitigation and water management plans. Shell determined that changes in water levels of Kearl Lake as a result of the project would be negligible. It predicted some water quality exceedances for some parameters in waters of Jackpine Creek, Muskeg Creek, and Muskeg River. Shell noted that predicted values exceeded the threshold value for fish tainting in the Muskeg River. However, because baseline conditions already exceeded the threshold, it deemed these effects to be negligible. See Figure 2 for a map of the Muskeg River drainage basin and main tributary channels.

Shell predicted negligible hydrological effects in its LSA and stated that it therefore did not require a regional assessment of hydrology. Shell also predicted negligible project effects for local water quality and stated that it therefore did not require a regional assessment of water quality. Shell noted that it did provide a planned development assessment for water quality for information purposes.

Shell completed a planned development assessment for effects on aquatic resources that were expected to overlap in time and space with the effects of other regional developments. It predicted a moderate magnitude for tainting of fish tissue in process-affected waters in Jackpine Creek in this case. Local impacts on affected aquatic habitats of the Muskeg River and its tributaries would be compensated for by construction of replacement habitat within a man-made lake.

Other assessments of cumulative effects on soils and vegetation in the RSA did not identify effects that would impair the sustainability of the drainage basin. Shell indicated that it was committed to establishing setbacks along the Muskeg River and Jackpine Creek to ensure the integrity of those streams and watershed. The project had also been designed to minimize surface disturbances and thereby provide a benefit for watershed integrity. Shell assumed in its analysis of the planned development case that other operators would adopt comparable mitigations so that major tributaries and the main channel of the Muskeg River would remain sustainable. Shell concluded that there were no unacceptable long-term environmental effects of the project.

Shell submitted a closure drainage plan to accompany its prefeasibility design of the project. Shell also submitted a Regional Development Update report that identified existing, approved, and future projects in the Muskeg River drainage basin. It included a layout of far future closure drainage features, such as diversion and drainage channels and reclaimed areas, EPLs, and retention ponds across an area of about five townships.

Shell believed that the MRWI subgroup would be identifying the ecological factors that could be at risk due to development and that the MRWI subgroup was developing a management system to ensure sustainability of the watershed. Shell indicated that it would provide leadership and proactively promote the work plan of this subgroup. Other regional initiatives, such as RAMP and the water working group (WWG), supported by Shell also contributed to the understanding and management of cumulative effects related to water resources and aquatic ecosystems. Shell stated that it would meet with regulators to discuss accelerating the work of the MRWI subgroup. Shell agreed in principle to support the management system and objectives for the Muskeg River drainage basin that CEMA might recommend for implementation by Alberta regulators.

17.2 Views of Fort McKay

In its agreement with Shell, Fort McKay requested that Shell address the environmental uncertainties of the impacts on undeveloped parts of the Muskeg River basin. Fort McKay requested that Shell conduct surficial groundwater monitoring and link it to rich fen and bog water level monitoring in order to develop benchmarks of acceptable levels of environmental change and to develop best management practices to minimize impacts in undeveloped parts of the Muskeg River basin.

In closing argument, Fort McKay requested that Shell be required to comply with the objectives and management systems produced by the MRWI subgroup. Fort McKay asked that management systems from the MRWI subgroup be in place prior to 2010, the anticipated opening of the project. Fort McKay asked Shell to proactively advance the work plan of the MRWI subgroup and meet with regulators to discuss the role of regulators in advancing CEMA's work.

17.3 Views of SCC

SCC questioned the accuracy of Shell's information concerning water flows of the Muskeg River, because it had not considered monthly flow variations and flow declines from climate change. This, it contended, would have a potential impact on river water management. SCC stated that it believed that it was necessary to complete a regional environmental assessment of all oil sands projects from the perspective of overall land-use planning.

17.4 Views of Canada

EC stated that there were potential risks of irreversible effects on the Muskeg River watershed from multiple oil sands projects during operations and reclamation. Therefore it recommended that Shell's water and sediment quality monitoring and dewatering monitoring and mitigation programs consider potential synergistic effects upon the Muskeg River and Jackpine Creek from adjacent projects.

DFO recommended that Shell continue its participation in the MRWI subgroup and adopt recommendations that might result.

17.5 Views of Alberta

Alberta stated that its review of the project was guided in part by two planning documents: the Fort McMurray-Athabasca Subregional Integrated Resource Plan (May 1996) and the RSDS (July 1999). In reference to CEMA, AENV understood that the MRWI subgroup was currently developing an environmental management system, with recommendations expected during 2005. AENV stated that it was prepared to take appropriate action if CEMA's work on an MRWI was delayed.

AENV acknowledged Shell's information that operational management of water and the final closure landscape from multiple oil sands projects in the Muskeg River drainage basin could have impacts on the functioning and integrity of the basin. AENV believed that a high degree of integration and cooperation supported by necessary regulatory requirements would be required among industrial users for water management, closure drainage, reclamation, and bitumen recovery to address this issue. AENV stated that it would regulate Shell and other operators by means of EPEA and Water Act approvals and by requiring their participation in CEMA groups, such as the RWG and MRWI subgroup.

17.6 Views of the Panel

The Panel commends Shell for its project design and mitigation measures to address stakeholder concerns related to water flows, water quality, and fish habitats of the Muskeg River basin. The Panel notes that AENV stated there was a need for monitoring programs to validate the EIA predictions of negligible effects upon water quality, hydrology, and groundwater and to address scientific uncertainties.

The Panel is aware of Shell’s statements that its conservative approaches to assessment may in fact overestimate effects, and this would offset some scientific uncertainties in the assessment. The Panel supports the recommendations of EC that Shell complete additional baseline data and monitoring of water quality. It expects that AENV will consider requiring Shell to collect local and regional data, alone or in cooperation with RAMP, to validate Shell’s water quality findings within the Muskeg River basin.

The Panel accepts that Shell has committed to setbacks along the Muskeg River and Jackpine Creek. The Panel recognizes that the potential for long-term effects to surface and groundwater flows entering the Muskeg River from Shell’s mine pit may not be fully mitigated by a 100 m setback distance. The Panel recommends that AENV consider long-term environmental effects on the Muskeg River in the design of Shell’s water monitoring programs.

CEMA has proposed work plans through the MRWI subgroup to develop management objectives and guidelines for the sustainability of the Muskeg River drainage basin. CEMA’s work is expected to contribute a framework for cumulative environmental effects management within the drainage basin, with recommendations expected in 2005. The Panel believes that establishing guidelines and management systems for an area of intensive oil sands development such as the Muskeg River drainage basin should be given high priority so as to enable future development to proceed in an appropriate way. Consequently the Panel urges participants of the MRWI subgroup to accelerate its work so that it meets its objectives to ensure that an integrated drainage basin plan is developed by 2005.

The Panel notes that Shell’s commitments are supportive of this goal. The Panel also notes that Shell’s project schedule has sufficient lead time for adoption of new regulatory standards and guidelines prior to start-up. As a result, the Panel expects Shell to abide by the outcomes of the MRWI subgroup recommendations adopted by regulators. The Panel notes that AENV indicated that it is prepared to take necessary action should the MRWI subgroup fail to meet deadlines for the delivery of recommendations. The Panel believes that this step is necessary to increase regulatory certainty. Therefore, the Panel recommends that AENV develop management plans and objectives for the Muskeg River basin if MRWI subgroup timelines are not met.

18 COOPERATIVE REGIONAL DEVELOPMENT

18.1 Views of Shell

Shell supported the EUB expectation for a broad-based approach to developing all of the leases in the region in a way that will ensure that conservation and environmental objectives are considered and incorporated in the development plan. Shell stated that it was working with all leaseholders whose boundaries adjoined the project. Shell believed that cooperative regional development would allow the interests of one party to be considered by other parties as each developed its respective leases in the area. Shell believed that cooperative development would take into consideration resource conservation, environmental objectives, and public interest issues. Shell noted that it had cooperation agreements with Syncrude and ExxonMobil, which addressed minimization of lease boundary ore sterilization, joint surface water management plans, infrastructure use and routing, closure planning, and sharing of environmental data.

Shell provided a Regional Development Update (March 2003) that outlined opportunities for integration with the Syncrude Aurora South Development, provided the status of Shell's participation in regional initiatives, and provided a summary of the cumulative effects assessment for the project and other regional developments. Shell noted that discussions with Syncrude and ExxonMobil were ongoing. Shell provided examples of conceptual integration opportunities for the Jackpine Mine and the Syncrude Aurora South Development. Potential options for project integration would be subject to ratification by both companies and would also require EUB approval. Shell saw the integration options as "works in progress."

The Regional Development Update reviewed progress with Syncrude in matters of ore exchange along common lease boundaries, water management of flows to Jackpine Creek, Muskeg Creek, Kearl Lake, and the Muskeg River, infrastructure, and closure planning. Shell presented a conceptual closure drainage plan of the Aurora South and the Jackpine Mine developments, as well as options for surface water diversions during mine operations. It also provided a conceptual area development plan of surface disturbances from seven existing and future developments in the Muskeg River drainage basin.

Shell believed that the project would not compromise Syncrude's or Exxon/Mobil's ability to develop their leases. Nevertheless, Shell stated that it had designed the project as a stand-alone development that did not rely on plans of adjacent leaseholders, because adjacent projects were at various stages of development without detailed plans and were less certain than Shell's project.

Shell provided an integrated watershed strategy but noted that such planning was contingent on detailed development plans for developments that were not yet in place. Shell noted that the project had some flexibility to integrate future changes, such as Syncrude stream diversions. Hence, the Jackpine Mine would improve in terms of economic and environmental performance as the regional development process continued.

Shell stated that commingling of surface waters between developers from external tailings areas and the in-pit cells raised a number of practical and legal issues:

- allocation of legal liability for effluent streams of different chemical composition;
- allocation of risk and liability for management of a common tailings pond between and among parties;
- allocation of risk and liability for reclamation and the impact of the different chemical compositions of effluent streams on reclamation; and
- liability for abandonment and reclamation guarantee obligations.

Shell stated that legal liability for contaminants owned or under control of a party prohibited the use of a common tailings disposal area. Shell therefore believed that the commingling of waters, including process-affected waters, from adjacent oil sands facilities faced legal obstacles. However, Shell stated that upon project closure and reclamation, its release water could be commingled with other waters, provided that the released waters complied with AENV Water Quality Guidelines at lease boundaries.

Shell stated that it supported Muskeg River basin planning and integrated development plans to cooperatively achieve objectives of watershed management. Shell did not object to AENV's recommendation that the EUB require Shell to work with other operators and regulators to coordinate management of infrastructure development, reclamation activities, and the mine development. In Shell's view, it was already fulfilling this requirement.

18.2 Views of Syncrude

In closing argument, Syncrude stated that its Aurora project, adjacent to the proposed Jackpine Mine, was approved by the EUB. Therefore the EUB had already determined that the impacts of the Aurora project were acceptable and the project was in the public interest. Syncrude believed that cooperative regional development was a means of optimizing the performance of approved projects. Syncrude noted that it had approval conditions it was required to meet. Syncrude believed that the only parties that needed to be involved in ensuring that the conditions were followed were the approval holder (Syncrude) and the regulators. Syncrude believed that additional public input was not needed at this time, since the EUB would ensure that the public interest was protected as part of its process to ensure that approval conditions were met.

18.3 Views of Alberta

AENV stated that regional resource development required that the coordination of closure planning begin before development occurred. AENV stated that unnecessary environmental impacts might occur unless resource development and integration needs were well understood, with mitigation strategies determined at an early stage. AENV recommended that the Panel require Shell to work with other operators and regulators to coordinate management infrastructure, mine development, land reclamation, closures planning, and water management, as suggested in EUB *Decision 97-13: Application by Syncrude for the Aurora Mine* and *Decision 99-2: Shell Canada Limited Application to Construct and Operate an Oil Sands Mine in the Fort McMurray Area*.

AENV noted that in EPEA and Water Act approvals, it might require Shell to work with other operators to determine acceptable cross-lease boundary closure topography, watershed, wetlands, soil, and vegetation community. AENV also intended to support regional integration of development by requiring operators' continued participation in the RWG and MRWI subgroups.

18.4 Views of the Panel

The Panel acknowledges Shell's commitment to cooperative development and notes the obstacles Shell has faced in attempting to obtain project design information from other operators. The Panel agrees with Shell that cooperative development on lease boundaries, water management plans, infrastructure, closure drainage, and reclamation would improve Shell's project. In other sections of this report, the Panel notes that specific project components, such as the Canterra Road, Khahago surge pond, tailings disposal area location, PCA mapping, Muskeg Creek diversion, lease boundaries, and the compensation lake, would benefit from cooperative regional development and integration.

It appears to the Panel that the project was designed to contain all developments and disturbances to Lease 13 to the fullest extent possible. The Panel believes that such an approach is unlikely to provide the best overall project design or benefit for regional development. The Panel is encouraged by Shell's efforts to negotiate exchanges of portions of Lease 13 for portions of Syncrude's Aurora South lease in the interests of greater resource recovery at the common lease boundary. The Panel believes that there are similar opportunities to improve the project design, and reduce impacts from it by investigating the location of some facilities off Lease 13. For example, the Khahago Creek surge pond, tightly wedged between the tailings disposal area and the lease boundary, may better be located off lease. Additionally the Panel believes that there may be opportunities to optimize stream diversions east of Lease 13 if Shell, Syncrude, and ExxonMobil collaborate more closely.

Sometimes impediments stand in the way of an agreement being structured solely among the companies involved. Legal liability issues, surface rights, the loss of flexibility, and the prospect of higher initial costs are only some of the considerations that could affect a company's willingness or ability to strike agreements that are in the public interest. A properly focused regional initiative, with government participation, could provide a process that overcomes the obstacles preventing oil sands developers from addressing regional issues collectively. The Panel is uncertain whether the MRWI subgroup will address cooperative regional development and project integration issues. However, the Panel believes that the work of the MRWI subgroup, with the participation of multistakeholders, will contribute to the objectives of the EUB and other regulators for cooperative regional development.

The Panel believes that decisive actions to implement cooperative regional development are needed in the Muskeg River basin in order to optimize development in the interests of environmental management and resource recovery. Therefore, the Panel directs Shell to provide an annual report on regional development cooperation to the EUB, starting in 2005. The report should describe guiding principles and activities for cooperative development, opportunities and constraints of collaborative work among developers, specific time frames and implementation steps for all project phases to integrate them with other oil sands projects in the Muskeg River basin, and the means to evaluate outcomes. The Panel expects Syncrude and ExxonMobil to cooperate with Shell on this initiative.

Regarding Syncrude's comments that the only affected parties in respect to the Syncrude Aurora South development and compliance with approvals on it would be Syncrude and the regulators, the Panel believes that regional development opportunities may eventually result in significant changes to Syncrude's and Shell's projects that may require additional applications and amendments to EUB approvals.

19 MEASURES TO ENHANCE BENEFICIAL ENVIRONMENTAL EFFECTS

19.1 Views of Shell

Shell indicated that on a local scale, the environmental benefits of the project were related to new technologies, specifically caustic-free extraction, tailings thickeners, and lower-temperature extraction. On a larger regional scale, Shell had made a commitment to reduce its GHGs emissions from the project to a level less than that associated with imported oil. Shell also stated that additional monitoring and baseline environmental information would be collected as a result of the project. Shell had been working to improve models that apply to the oil sands region. In addition, because of Shell's Historic Resources Impact Assessment (HRIA), there was additional information on historic resources of the region.

Shell stated that the reclaimed site would have a land capability equivalent to that of the predisturbance area, but it would have higher capability for forestry. Shell would be increasing the area of class-2 and class-3 soil capability types. Shell also stated that some First Nations groups might view the compensation lake as a positive development, because there would be increased opportunities for fishing.

19.2 Views of the Panel

The Panel views the technologies that Shell would be using, CO_2 reduction, and the compensation lake as mitigation measures and not environmental benefits. With respect to reclamation activities that may improve land and soil capability, the Panel agrees that there may be an environmental benefit after reclamation is complete. However, the Panel concludes that there are unlikely to be any significant environmental benefits resulting from the project.

20 NEED FOR EIA FOLLOW-UP

20.1 Views of the Panel

Under CEAA, the Panel has a responsibility to conduct an assessment of the environmental effects of the project. In conducting this assessment, the Panel must ensure that all information required for its assessment is obtained and made available to the public.

The Panel has reviewed the EIA and the information brought forward during the hearings and concludes that it has the necessary information to conduct its assessment of the environmental effects of the project. It is satisfied that there is no additional information required to conclude that the project is not likely to cause significant adverse environmental effects, provided that mitigation measures and the recommendations of the Panel are implemented.

The Panel has considered the need for and requirements of follow-up in the environmental assessment of the project. This need has been discussed throughout this report in the appropriate sections. The specific areas of follow-up identified by the Panel include

- tailings management,
- effects on fish and fish habitat,
- effects on surface water quality and quantity,
- effects on groundwater,
- instream flow needs,
- effects on air emissions,
- effects on wildlife, and
- reclamation.

The Panel believes that the specific recommendations in this report should allow Shell to further develop the follow-up programs early in the planning stages of the project. The Panel expects Shell to consult and work with stakeholders who have a specific expertise or are interested in the development of the follow-up programs.

Specific recommendations in this report related to follow-up programs provide a mechanism to ensure that the programs are sufficiently detailed and scientifically rigorous. Shell's follow-up programs should

- contain sufficient baseline information,
- be quantitative in nature and have statistical power,
- include a description of the mitigation to be implemented,
- include detailed descriptions of the monitoring methods, timing, and duration of the study,
- contain reporting and success measurement criteria,
- be developed in consultation with stakeholders having specific expertise,
- ensure that consultation with the regulatory authorities has been carried out, and
- ensure that results are communicated to stakeholders.

21 REGIONAL ENVIRONMENTAL INITIATIVES

21.1 Views of Shell

Shell stated that it was an active member in regional environmental initiatives. It noted that the committees were involved in

- designing management systems for regional environmental issues,
- providing research information on new technologies, and
- collecting baseline, effects monitoring, and research information on aquatic, terrestrial, and air issues to aid in reducing uncertainties.

Shell stated that it was actively involved in CEMA, a registered not-for-profit nongovernment organization established in June 2000. CEMA's mandate was to make recommendations on how best to manage cumulative impacts and protect the environment in the region. Shell stated that CEMA was currently working on priority issues identified through RSDS issued by AENV in July 1999. Shell noted that CEMA consisted of groups working on NO_x/SO_x management, reclamation, TMAC, surface water, and sustainable ecosystem.

Shell also stated that it was actively involved in RAMP, which had been monitoring water and sediment quality, benthic invertebrate communities, and fish populations in the region since 1997. Shell noted that a climate and hydrology program was integrated into RAMP in 2000.

Shell stated that it participated in WBEA, a multistakeholder group with a mandate to conduct air quality, ecosystem, and human health effects monitoring in the region.

Shell stated that one of the reasons the CEMA working group had taken longer than envisioned to do its work was the time needed to establish relationships and trust. Also, CEMA was unique in how it had been addressing issues. Shell noted that CEMA had reorganized in the last few months to increase efficiency and effectiveness, and it believed these measures would help to rectify some concerns. Shell stated that it believed very strongly in CEMA and had a great deal of confidence that CEMA could meet its goals. Shell stated that it had the following suggestions for CEMA:

- CEMA should continue to focus on the issues of priority and those issues of priority should be integrated into a comprehensive work plan.
- All stakeholders should provide adequate resources to ensure that CEMA can meet its mandate.
- All stakeholders need to ensure a long-term commitment of personnel who have the appropriate skills and knowledge to sit on those committees to help the committee move forward.
- All stakeholders need to ensure that there will be continued accountability to meet the milestones at CEMA. Shell noted that CEMA had improved some of its accountability by ensuring that it had permanent staff and a new management committee.
- Industry members should be accountable to the working group.
- Working groups should put their efforts towards their main goal of very strong, comprehensive management systems; the pursuit of interim management objectives could distract them from their long-term goals.

Shell noted that it had eight people working on CEMA and that others needed to make the same kind of commitment to see CEMA succeed. Shell also noted that although a number of CEMA milestones were several years in the future, they were all well before the start of construction of the project.

Shell believed that RSDS and CEMA would continue to play a very important role in managing the cumulative environmental effects in RMWB. Shell believed that the region benefited from the multistakeholder forums and that the consensus-based decision-making process led to sustainable strategies that better addressed the cumulative needs of the RMWB. Shell believed that many of the regional cumulative environmental concerns raised, such as IFN, water quality, wildlife movement corridors, and acidification, were being addressed through the CEMA working groups. Shell further noted that if nonconsensus recommendation reports were produced by CEMA, AENV had the ultimate regulatory responsibility and authority to ensure that regional environmental management systems were developed and implemented.

Shell stated that it would support a condition within its approvals that mandated participation in CEMA and other regional monitoring programs.

21.2 Views of OSEC

OSEC stated that it was concerned about the scope, scale, and rate of regional environmental impacts from oil sands development in the absence of defined environmental limits. OSEC believed that the wisest course of action would be to determine environmental limits and allocate environmental capacity in an informed manner. OSEC also believed that the pace of proposed developments continued to outstrip the ability of CEMA to define environmental objectives and develop an environmental management system. It believed that for any consensus-based multistakeholder initiative, a regulatory backstop was required to ensure that the outcomes of the process were received in a timely manner.

OSEC noted that CASA, upon which CEMA had been modelled, had completed a number of challenging initiatives. It believed that a major reason for this was that AENV set clear end-dates, at which time it would make its decision. If a consensus recommendation was not available, AENV advised that it would make its decision based on available information from recommendations from the individual stakeholders. OSEC believed that this approach served as the impetus for advancing the work as efficiently as possible.

21.3 Views of MCFN

MCFN noted that CEMA work groups had a substantial level of commitment and range of skill level and experience. But it also noted that resources available for various tasks were not consistent. MCFN was concerned about the lack of products from CEMA but stated that it would continue to participate in CEMA so long as CEMA was making progress towards its goals.

21.4 Views of WBFN

WBFN believed that CEMA had good intentions but appeared overloaded. WBFN believed that CEMA should be given additional funds to speed up its work.

21.5 Views of ACFN

In closing argument, ACFN noted that Shell had agreed to limit its withdrawal from the Athabasca River in accordance with any CEMA IFN recommendations. Therefore it was very important to ACFN that an objective was set for IFN as soon as practicable. ACFN was committed to working and solving problems at the CEMA table. ACFN stated that its support and commitment to CEMA were related to CEMA's ability to bring forward meaningful results in a timely manner. ACFN noted that the development of the Muskeg River basin management system was also important.

21.6 Views of Fort McKay

In closing argument, Fort McKay stated that it was a strong supporter and participant in the multistakeholder organizations and would continue to be so as long as they were making progress in meeting their mandates and were not impeded by funding shortfalls. Fort McKay stated that it had significant reservations about CEMA's ability to fulfill its mandate based on recent restrictions on CEMA funding imposed by industry participants. It believed that the pace of granting approvals by regulators had outstripped the ability of CEMA to develop and recommend appropriate regional thresholds for environmental protection. Fort McKay recommended that the Panel endorse timelines for CEMA to develop and recommend an introductory set of environmental management objectives or management systems for NO_x, sulphur oxides (SO_x), IFN, and water quality for the Athabasca River, MRWI, fish tainting, and conservation of terrestrial resources.

21.7 Views of SCC

SCC stated that the CEMA effort was quite laudable and progressive, but it was concerned that CEMA had not delivered on key information pieces, such as IFN. It believed that new developments should not be approved in advance of knowing some of those key pieces of information.

21.8 Views of Canada

EC acknowledged that regional environmental thresholds and objectives were not yet in place. It recommended the development and implementation of interim environmental guidelines by CEMA working groups. This would be consistent with CEMA's own terms of reference and the precautionary principle. EC noted that Shell did not support the pursuit of interim thresholds and objectives. EC further explained that the pursuit of interim thresholds and objectives was not intended to replace or distract from the ongoing CEMA activities. EC noted that a better description of its recommendation would be a staged or phased approach to thresholds similar to what was presented to CEMA as the acidification management plan.

EC stated that it was committed to help prioritize CEMA work and to review timelines. EC stated that it would work towards making sure CEMA reached its timelines.

21.9 Views of Alberta

AENV noted that RSDS was being implemented in partnership with CEMA. Based on identification of priority issues, CEMA working groups were developing recommendations for regional environmental management to be approved by all CEMA members. Recommendations approved by CEMA would be provided to AENV for consideration and, if approved, for implementation.

AENV noted a number of CEMA accomplishments:

- In August 2002, CEMA forwarded to regulators consensus recommendations for managing trace metals in the RMWB, which AENV reviewed and endorsed. These recommendations included a goal, a management objective and actions, research, monitoring activities, and an evaluation period.
- In July 2003, CEMA industry members voluntarily agreed to adopt three management tools to help minimize land disturbance related to industrial development and exploration.
- As of August 2003, CEMA had completed over 28 technical reports, with over 22 other reports in progress, supporting the development of environmental management systems.

AENV stated that it might include conditions in the EPEA or Water Act approvals that required Shell to

- participate in the activities of CEMA,
- support an ongoing research program to implement CEMA recommendations for an acidification management framework,
- support an ongoing research program to develop CEMA recommendations for developing an HFN assessment for the lower Athabasca River,

- support an ongoing research program to develop CEMA recommendations for sustainability of the Muskeg River basin,
- support an ongoing research program to develop CEMA recommendations for EPLs, and
- submit plans demonstrating how the project could be adapted to meet future regional environmental objectives and environmental management systems.

AENV noted that enhanced financial commitment by stakeholders to implement on-the-ground research would be required for successful completion of the deliverables expected under RSDS.

21.10 Views of the Panel

The Panel notes that Shell has identified the importance of regional initiatives to address adverse environmental effects of the project. It has also relied on monitoring, adaptive management, and reclamation activities to mitigate against these effects. In other sections of this report, possible additional monitoring activities are identified for regional initiatives such as RAMP and WBEA.

With regard to CEMA, the Panel believes that CEMA's work is important and that the results will assist the EUB in meeting its regulatory mandate to ensure that energy developments are carried out in an orderly and efficient manner that protects the public interest. The Panel understands that there is good support in general for CEMA but widespread concern about delays in delivery of environmental management objectives and plans. The Panel believes that in light of the delays in producing management objectives and plans, it would be useful to all stakeholders if AENV and ASRD were to review the progress of CEMA and update their expectations of RSDS.

The Panel acknowledges the broad spectrum of regional environmental issues that CEMA is expected to manage as a consensus-based multistakeholder organization. CEMA's diverse membership of industry, First Nations, local aboriginal groups, regulatory agencies, nongovernmental organizations, and other stakeholders presents its own challenges respecting consensus-based decision-making, financial resources, and priority setting.

The Panel heard concerns relating to CEMA's funding and its ability to obtain expert consultants that may have hampered CEMA work process. In addition, the Panel heard that CEMA's recent restructuring and reprioritization would improve its ability to meet critical timelines. The Panel commends CEMA for its efforts to streamline and integrate its goals and organizational structure. Nevertheless, the Panel has concerns that CEMA's effectiveness may also be influenced by the volume and complexity of its work, multiple priorities of stakeholders and funding mechanisms that may not keep pace with CEMA's increased workload. The Panel believes that restructuring and reprioritization are the first steps to ensuring that CEMA meets its goals and the expectations others have of it.

The Panel believes that it is important that CEMA's level of funding and participation is sufficient in light of the increasing level of regional development and capital spending now occurring and planned for the oil sands region. The Panel urges all CEMA participants to re-evaluate their financial support and staff resourcing allocated to CEMA and ensure that they are comparable to the amount of reliance it has put on CEMA to manage cumulative environmental effects in the region. The Panel also urges all CEMA participants to ensure that their staff are accountable for the completion of CEMA deliverables. CEMA participants may want to consider dedicating full-time staff to this initiative, as opposed to the part-time approach. In addition, the Panel supports EC, DFO, AENV, and ASRD in reviewing and optimizing their financial and human resourcing of CEMA to produce meaningful results in an earlier timeframe. The EUB will also examine its financial and human resourcing to the CEMA process and make changes as needed.

The Panel notes that as part of the restructuring initiative, CEMA would provide project managers for the working groups. The Panel believes that assignment of technical experts to the working groups to facilitate dealing with complex scientific issues should also be considered.

The Panel has serious concerns about delays in the issuance of recommendations and the ability of CEMA to meet the proposed timelines. The Panel heard evidence that AENV is prepared to take action should CEMA not meet deadlines for delivery of recommendations for environmental management systems to regulators for approval. The Panel believes this step is necessary to increase regulatory certainty. Therefore, in addition to the recommendations on IFN and MRWI, the Panel recommends that AENV and ASRD consider developing management plans or objectives respecting other environmental issues if CEMA timelines are not met.

The Panel notes that Shell has committed to participate in CEMA and would accept participation as a condition of approval. The Panel supports AENV's intention to condition its approval. It recommends that DFO consider conditioning its approval to require Shell to participate in CEMA.

The Panel notes that recommendations from the MRWI, IFN, and wildlife corridor subgroups are not yet available. As a result, the Panel expects Shell to abide by the outcomes of these working groups and the other regional environmental management initiatives once adopted by the regulators. When CEMA or other regional initiatives have produced substantive results or AENV has acted within its mandate and set management objectives, the EUB will consider the need to review Shell's and other oil sands approvals.

22 SOCIAL AND ECONOMIC IMPACTS

22.1 Macro-Economic Impacts

22.1.1 Views of Shell

Shell stated that the project would bring substantial benefits to Alberta and Canada. It indicated that the overall investment for the project was $2 billion and suggested that the project would be the catalyst for additional investments in pipeline infrastructure and further upgrading facilities in Alberta. Shell estimated that about 10 per cent of the project investment would likely accrue to RMWB residents and companies. It estimated that another 40 per cent would accrue to the rest of Alberta and roughly 10 per cent would accrue to the rest of Canada.

Shell projected that the project would require a peak construction workforce of 2500 and another 970 operations jobs. Shell committed that jobs created by the project would be filled by local residents whenever possible, but strictly on a merit basis.

Shell projected annual operating costs to be about $450 million, of which Shell estimated that 70 per cent would accrue to Alberta workers and companies, with many originating in the Wood Buffalo area.

Shell estimated that the project would pay almost $2 billion in taxes and royalties to the federal and provincial governments by 2036. It estimated property tax payments to the RMWB at roughly $3 million per year, or $83 million over the life of the project.

Shell also indicated that the Wood Buffalo region had already benefited through company donations of over $1.5 million since Shell began its consultation effort in 1996. According to Shell, this included leading donations to the new Technology Centre at Keyano College, to the CT Scanner and medical outreach vehicles at the hospital, and to the redevelopment of the Oil Sands Discovery Centre.

22.1.2 Views of the Panel

The Panel acknowledges the economic benefits to the region, the province, and Canada associated with the project and notes the letter of support for the project from the RMWB. While the taxes and royalties generated by the project will be offset to some degree by the need for government to invest in new infrastructure and expanded public services, the Panel believes that the net benefit from taxes and royalties to Alberta and to Canada will be significant.

The Panel also acknowledges Shell's efforts to support the advancement of education and training locally and its efforts to support the growth and development of local business. The Panel encourages companies to take an active role in supporting initiatives aimed at ensuring that the economic benefits are made available to the broadest possible number of local residents and businesses wanting to participate in the economic opportunities created.

22.2 Public Infrastructure/Services

22.2.1 Views of Shell

Shell acknowledged that the project would contribute to a number of broad social and economic impacts in the region. The impacts identified by Shell related to employment, housing, education, health and emergency services, social services, and transportation infrastructure. Shell suggested that many of these impacts were pre-existing, as a result of previous oil sands development activity in the region, but also recognized that the project would contribute to the cumulative impacts from oil sands developments. Shell indicated it had been working with the Northern Lights Regional Health Authority (RHA), RMWB, and RIWG, as well as the provincial government and other oil sands developers to understand and find solutions to socioeconomic impacts that were cumulative in nature.

Shell stated that it was committed to taking a proactive role in finding solutions to regional socioeconomic issues. However, Shell was also clear on what it perceived its role to be with respect to socioeconomic matters. Specifically, Shell stated that it would

- take direct responsibility for those areas directly under its control,
- facilitate and advocate in areas not under its control, and

- where appropriate, provide resources for identifying and managing impacts.

Shell indicated that it would continue to participate in the Athabasca Resource Development Facilitators Committee to lobby at a senior level within government for resolution of the region's socioeconomic and health care issues.

22.2.2 Views of OSEC

OSEC expressed concern about the cumulative impacts to municipal infrastructure, traffic, health, housing, retail, and nonprofit agencies. OSEC believed that the socioeconomic concerns of Fort McMurray and area residents were not being addressed in a timely or adequate manner to keep pace with the rate of industrial development in the Wood Buffalo region.

OSEC argued that RIWG was not consensus based, did not include the participation of all stakeholders, and approached socioeconomic issues on an ad-hoc basis. OSEC suggested that the development of a new consensus-based multistakeholder group was needed. It believed that this new group should be tasked with identifying and addressing socioeconomic issues and developing recommendations to the appropriate government authorities. OSEC believed that this group could provide a new approach to addressing socioeconomic issues by bringing together a greater understanding of the issues and in turn could be more effective in designing and implementing effective and comprehensive solutions that met the needs of the community.

OSEC noted that its agreement with Shell contained a commitment by Shell to champion the development of an affordable housing subcommittee through RIWG and to provide staff time and funding in support of the subcommittee. In addition, OSEC made reference to a new social indicators subcommittee that was recently formed by RIWG to gather better quantifiable data on social impacts. OSEC was unable to provide additional details about this committee, other than to indicate that the subcommittee was intended to have a monitoring role.

22.2.3 Views of WBFN

WBFN indicated that while oil sands development brought jobs, it also brought increased social problems as a result of alcohol and drug use. WBFN believed that the lifestyle of the aboriginal people living in Fort McMurray had changed drastically over the years due to the rising cost of living and the high cost of housing. WBFN spoke of the need to address the homelessness of some WBFN members.

22.2.4 Views of MCFN

MCFN indicated that its agreement with Shell contained commitments and a process by which Shell would deal with key socioeconomic concerns raised by the MCFN.

22.2.5 Views of ACFN

The ACFN agreement with Shell provided for the establishment a long-term relationship to address socioeconomic issues of ACFN and its members.

22.2.6 Views of Fort McKay

Fort McKay's agreement with Shell dealt with its socioeconomic concerns.

22.2.7 Views of FMMSA

The Fort McMurray Medical Staff Association (FMMSA) stated that it was very concerned about the effects of further oil sands development on an already overstretched health care system and expressed concern for Shell employees of the project who would face limited access to family doctors and to the health care system in general.

FMMSA described the Fort McMurray region as the most underserviced area in Canada in terms of family practice. It also indicated that the region did not have orthopaedic services, a magnetic resonance imager (MRI), or a variety of other diagnostic and visiting specialist services that were needed. FMMSA indicated that there were shortages in air medivac services and that improvements were needed for the rapid response emergency medical system. It described a hospital emergency room (ER) that was routinely operated at capacity and ER facilities that made it physically impossible to increase capacity by having two ER physicians working side by side.

FMMSA asserted that health care was underfunded in the region. Specifically, FMMSA argued that the funding formula was not capable of taking into account the unique situation in the Wood Buffalo region and therefore the health region was being penalized in terms of funding. FMMSA pointed to the rapid population growth that had occurred to meet the labour demands of oil sands developments, the large work camp population and shadow population in the region, the low incidence of elderly remaining in the region due to the high cost of living, and to medical staff recruitment challenges, given the remoteness and the high cost to live and operate a business in Fort McMurray.

FMMSA stated that the demands on the health care system had grown tremendously in recent years and believed that unless the health care system was able to keep pace, there would be an increasing problem with access to health care in Fort McMurray. FMMSA cited a study (referred to as the Cuff Report) undertaken by the RHA and AHW to examine health care funding in the region, but stated that it had been unable to obtain any published results. It also stated that it was aware of a provincial interdepartmental committee that was looking at the infrastructure needs (including health) of the region and that it was also aware of a survey of camp workers and the social indicators subcommittee of RIWG. FMMSA indicated that it had not been able to obtain any of the results from these initiatives and had not been consulted on any of them.

FMMSA requested that the Panel appeal to the Minister for AHW and to the Premier of Alberta for improved health care funding for the region. FMMSA also requested that the Panel recommend to government that a standing policy committee be established to address the unique health care funding needs of rapid-growth areas or, alternatively, recommend that an Order in Council be passed to deal with the disparity and underfunding of health care in remote regions experiencing rapid growth. FMMSA believed that better oversight and monitoring were needed by government to set minimal standards to ensure fair and equitable access to health care for people living in the Wood Buffalo region.

FMMSA acknowledged that Shell could not resolve issues related to health care on its own and could not make up for the lack of RHA funding. However, it did suggest a number of ways Shell could help reduce the strain on the health care system, including by advocating for more health care funding in the region, providing enhanced on-site health services to help relieve pressures on the emergency room (however, it noted that this might also result in increased pressure on the labs and diagnostics at the hospital), emphasizing prevention, maintaining its safety track record, and considering on-site rapid helicopter evacuation available to the whole community so that everybody benefited both during and after work hours.

22.2.8 Views of Alberta

AHW addressed the concerns raised with respect to health services and affordable housing in Fort McMurray. It was the position of AHW that the people served by the RHA had equitable access to first-rate services both in the region and throughout the Capital Health region. It further stated that the issues raised by FMMSA with respect to health services were well known and were much discussed between the RHA and AHW. It emphasized that there were mechanisms in place to deal with issues of health care in the region, and it stated that a world-class funding formula was in place to resource the health authorities.

AHW indicated that it had not raised the issue that lack of affordable housing in Fort McMurray could contribute to adverse human health effects because it was comfortable with the progress made to address affordable housing. It also stated that it took comfort in knowing that the issue of affordable housing was now being looked at within the existing regional groups that addressed socioeconomic issues.

22.2.9 Views of the Panel

The Panel acknowledges that the evidence provided by Shell and interveners indicates that certain public services and infrastructure are struggling to keep pace with the rate of industrial development and population increase in the region. The Panel appreciates that industrial growth does bring about change and it recognizes that extensive industrial development can strain public services and infrastructure. The Panel believes that the benefit to oil sands companies and to the broad public interest derived from a mobile labour force moving into the region to construct a major oil sands project should not come at the expense of an adequate level of public services to long-term Wood Buffalo residents. The Panel can foresee that without proper attention to emerging social and medical issues and without allowing for lead times to invest in new staff, services and facilities, the potential exists for some public infrastructure and services to be severely impacted.

To determine the significance of socioeconomic impacts, the Panel looks to the evidence presented for indications that the appropriate authorities are effectively managing the impacts. The Panel believes that how well a community manages change will ultimately determine the capacity for public services and infrastructure to respond to increasing demands. The Panel did hear evidence suggesting that the appropriate authorities are responding. Reference was made to the work being done by RIWG and the Oil Sands Development Facilitation Committee. There were also references to a survey of camp workers by RIWG, to the Cuff Report, and to a provincial interdepartmental committee reviewing the capital and program delivery needs in the Wood Buffalo region. The Panel also notes the evidence provided by AHW that existing mechanisms are in place to deal with issues relating to health care in the region. Yet, the Panel was given little information beyond assurances that the social impacts are being managed. There was no evidence presented to indicate that the subcommittees of RIWG are effective in achieving the desired results, and information on the survey of camp workers and the Cuff Report or the work of the interdepartmental committee was either not available or not released to the public.

In previous EUB proceedings on major energy facilities in the Wood Buffalo region, the EUB has expressed the view that the responsible government agencies are aware of the impacts and are responding to them. The Panel believes that this is still the case. However, given the expected growth pressures from oil sands developments in the Wood Buffalo region, the Panel perceives there is a need for a reliable source of information on the social and economic challenges (and opportunities) facing the region. The Panel believes that the residents of Wood Buffalo should be provided with information that gives them confidence that adaptive management processes are in place and succeeding with respect to socioeconomic and health matters. A process is needed that provides a coordinated and effective channel through which regional and cumulative socioeconomic impacts can be addressed in a meaningful and demonstrable way. The Panel expects adequate monitoring and verifying of predictions to take place with respect to socioeconomic and health issues and expects this information to be communicated to the residents of Wood Buffalo.

The Panel believes that there is a need for government and the multistakeholder committees addressing socioeconomic issues to better communicate the outcomes (successes and failures) of their work to the residents of Wood Buffalo. The Panel suggests that a formal, coordinated annual compilation of the activities and outcomes from the existing committees and relevant government departments might prove useful. This type of annual progress statement on socioeconomic issues would be reported publicly to provide residents with benchmarks to assess the state of the region and to give them confidence that something is being done. Annual reporting on socioeconomic issues would also serve to provide guidance and focus for the responsible authorities and elected officials working to bring about positive change in the region.

The Panel is encouraged by the efforts of RIWG to establish a social indicators subcommittee. Although no specifics were given on the role of the subcommittee, the Panel believes that establishing indicators and measuring progress is a powerful catalyst for strategic thinking and collaborative action on socioeconomic issues.

While the Panel does recognize that governments and multistakeholder committees are tackling regional socioeconomic issues, it believes better coordination and communication could further enhance these efforts. Some of the interveners suggested that a new consensus-based multistakeholder committee was needed to address socioeconomic issues. The Panel agrees in principle that the process for addressing socioeconomic issues should involve all affected stakeholders, but it does not take a position on how this can best be accomplished (whether through a new committee or accommodated within the existing committees).

The Panel recommends that all levels of government take steps to further enhance the level of planning, communication, and response around socioeconomic and health matters in the Wood Buffalo region. The Panel believes that taking action now on social and health issues will further enhance the region as a place for businesses, workers, and their families to locate and, in turn, will increase the competitiveness of the region to attract and sustain oil sands investment.

Providing a timely and reliable source of information upon which strategic decisions can be made is especially important to this area, given the expected growth pressures it will continue to experience.

23 TRADITIONAL LAND USE

23.1 Views of Shell

Shell stated that it had worked with First Nations, Metis, and other aboriginal groups in the region to integrate traditional environmental knowledge (TEK) into the project EIA and into the regional environmental monitoring and management systems. Shell indicated that TEK was obtained from interviews with nine trappers and traditional land-use studies prepared for other applications, for Fort McKay, and for Lease 13, which was integrated throughout the EIA. In particular, TEK was included in generating the baseline information on resources and resource use and in discussions on ongoing effects of development on aboriginal lifestyles and fish.

Shell stated that First Nations trappers, who would be directly affected by the project, were consulted early in the process and had issues dealt with, and their involvement helped to determine the preferred option for stream diversions.

Shell indicated that its consultation with traditional land users identified a number of key concerns; as well, Shell believed that the various environmental and socioeconomic agreements it had with First Nations and Metis in the region dealt specifically with their unique concerns.

23.2 Views of MCFN

MCFN explained that the hunting, gathering, and trapping activities of its members took them long distances away from their communities, including to traplines they had in the area of Fort McKay. MCFN stressed that one of the most important issues for its members was water, both in terms of quality and quantity in the river system. MCFN explained that elders and members of MCFN used the water to access their traditional lands where they gathered, hunted, fished, and trapped. MCFN stated that it had witnessed a big change in the water system, especially in the Peace Athabasca Delta, and that changes in water quantity were making it harder for them to access their traditional lands and travel to Fort McMurray.

MCFN indicated that oil sands developments should not proceed at the expense of water, land, or the animals that were still hunted and trapped for subsistence by a number of MCFN members.

MCFN acknowledged that Shell committed to provide it with funding for a traditional land-use study.

23.3 Views of WBFN

WBFN expressed interest in participating in traditional land-use studies to help protect and preserve historic sites and gravesites that had relevance to WBFN members.

23.4 Views of ACFN

In closing argument, ACFN stated that water was at the heart of its concerns, as ACFN members had traditionally relied heavily on the Athabasca River for drinking and fishing and as a transportation artery to access lands for hunting and trapping. ACFN stated that the agreement it had with Shell helped to ensure that any adverse impacts of the project were minimized and that the land was safely and fully reclaimed. The agreement also addressed opportunities for ACFN to benefit from the project, which, in its view, would help to ensure the future survival and prosperity of ACFN.

23.5 Views of Fort McKay

In closing argument, Fort McKay stated that the traditional lands of the First Nation and Metis members lay at the heart of oil sands development. Fort McKay indicated that the agreement it signed with Shell was critical to Fort McKay's belief that the adverse impacts of the project would be managed and mitigated in a manner acceptable to the elders and other members of the community of Fort McKay.

23.6 Views of the Panel

The Panel believes that the assessment of traditional land use, as well as the integration of traditional knowledge, has been adequately dealt with by Shell. The Panel notes that the various agreements indicate that Shell is actively working with First Nations and Metis in the region. The Panel also notes that within these agreements, Shell has made commitments to address environmental concerns and to support and promote traditional practices.

The Panel concludes that given Shell's commitments to work with First Nations, Metis, and other aboriginal groups in the area and to take steps to address their concerns, it is unlikely that traditional land use will be significantly affected as a result of the project.

24 HUMAN HEALTH

24.1 Views of Shell

Shell stated that air and water releases from the project were assessed for potential effects on human health in accordance with EPEA, HC, and World Health Organization (WHO) guidelines for health risk assessment. Shell indicated that the assessment predicted no negative health effects for most chemicals of potential concern. In instances where the predicted exposure ratio was greater than the benchmark value of 1.0, Shell stated that given the conservatism built into Shell's modelling, it was unlikely that those exposures would have any health impacts. Shell noted that AHW commented that Shell used an acceptable methodology and concurred with Shell's assessment and conclusions.

Shell noted that MCFN had expressed concerns about the health of its members living downstream of the oil sands plants. In recognition of these concerns, Shell agreed to participate in a baseline health study of the Fort Chipewyan population, as outlined in its agreement with MCFN.

24.2 Views of MCFN

MCFN stated that it had concerns about its members' health. MCFN read from a letter by Dr. J. O'Connor, a family physician in Fort McMurray, with a specific focus on the aboriginal communities surrounding Fort McMurray. The letter expressed concern about an increasing incidence of disease and pathology over the past few years in Fort Chipewyan that was unrelated to lifestyle and suggested there were questions that needed to be answered regarding the health of the residents in this area. MCFN indicated that it shared Dr. O'Connor's concerns.

MCFN's agreement with Shell included a commitment by Shell to contribute funding to a baseline health study of the Fort Chipewyan population, provided that the study was conducted independently and with appropriate scientific rigour and provided that other oil sands developers and/or governments agreed to participate in the funding of the study.

24.3 Views of FMMSA

FMMSA indicated that it was concerned about the high incidence of serious illness in First Nations, Metis, and other aboriginal people. FMMSA expressed a need for more data with respect to community health and recommended that a long-term study of health for the region's population be established. FMMSA suggested that a single snapshot study of community health would be easily dismissed.

24.4 Views of Canada

HC provided background information on WHO and CWS for various air emissions, but it did not comment on the health risk assessment completed for the project.

HC indicated that it had an Environmental Health Officer working in the area who was actively involved with WBEA. HC stated that it supported the efforts of WBEA to implement an ongoing monitoring program and indicated it would participate and contribute money to the program.

24.5 Views of Alberta

AHW stated that an interdepartmental human health review team (lead by Health Surveillance and including representation from HC) reviewed the project EIA. AHW believed that Shell had used an acceptable methodology for its human health risk assessment and the conclusions drawn from the assessment were reasonable. AHW noted that there were predicted air quality guideline exceedances, which, it suggested, were likely the result of highly conservative modelling methods. AHW indicated that validation of the predictions made by Shell would be a logical next step to further address the predicted exceedances. AHW indicated that it would collaborate with AENV to determine what conditions of an EPEA approval might be appropriate to address this issue.

AHW also pointed to the results of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program conducted by AHW and other stakeholders and released in May 2000. AHW indicated that the analysis concluded that air emissions from industrial development produced no measurable negative impact on overall health and no significant differences were found between the population in Fort McMurray and the population of a control group in Lethbridge. AHW indicated that the Fort McKay First Nation also commissioned a Community Exposure and Health Effects Assessment Program for the community of Fort McKay. However, it stated that the findings of this study had not been released to the public.

AHW stated that one of the recommendations made by the Community Exposure and Health Effects Assessment Program was ongoing monitoring of personal exposure levels to contaminants produced by industrial development. AHW stated that it had been working with WBEA over the last two and one-half years to implement the recommendation, but deployment was delayed many times due to funding, issues of science, and the need to recruit volunteers to participate in the ongoing monitoring.

With respect to a baseline health study, AHW commented that a standalone health study for Fort Chipewyan would not provide much value. AHW stated that a program was needed that provided ongoing monitoring of health effects associated with contaminants. This approach would include accessing physicians' claims data and hospitalization data to obtain a baseline perspective on the overall health of the community, which in turn would be linked to the ongoing monitoring program.

AHW offered to assist MCFN in its efforts to establish a baseline for the health of the community and indicated it would continue to work with WBEA to implement an ongoing health-monitoring program that would include many of the First Nations, Metis, and other aboriginal people living in the region.

AHW believed that the health of the public would not be compromised by the construction and operation of the project.

24.6 Views of the Panel

The Panel accepts that the health risk assessment conducted by Shell was appropriate and reasonable. Given the conservatism of the modelling, it also accepts the conclusion that there will be no health risks associated with the construction and operation of the project. The Panel does acknowledge the comments about health and health concerns brought forward by various interveners. In light of the existing and planned industrial development for the area, the Panel agrees that additional baseline health data and ongoing health effects monitoring are warranted. The Panel believes that improved baseline health information is needed, especially for First Nations, Metis, and other aboriginal groups, so that any incremental health effects can be measured and appropriate action taken. This would help validate the modelling results and would serve to improve confidence in the human health risks assessment.

In addressing this issue, the Panel acknowledges that the primary investigative and decision-making responsibilities reside with AHW and HC, and it looks to these departments to validate the need for and to develop a regional health assessment strategy that includes all affected stakeholders. The Panel also notes that both governments have indicated their support for an ongoing health effects monitoring program. With this in mind, the Panel recommends that AHW and HC consider undertaking a regional baseline health study primarily dealing with First Nations, Metis, and other aboriginal groups and consider contributing expertise and funding in support of WBEA's efforts to implement an ongoing health-monitoring program consistent with the recommendation of the Alberta Oil Sands Community Exposure and Health Effects Assessment Program. Further, the Panel expects Shell to meet its commitment to MCFN to fully support and participate in any health assessment program. The Panel believes that the implementation of a health assessment program must include a communications component, so that results of the research are communicated to participants and the public on an ongoing basis.

The Panel concludes that with the implementation of proposed mitigation measures and attention to the Panel's recommendations, the project is unlikely to result in significant adverse human health effects.

25 CULTURAL AND HERITAGE RESOURCES

25.1 Views of Shell

Shell stated that the EIA completed for the project included a historical resources component and a standalone HRIA completed and then reviewed by Alberta Community Development (ACD). The HRIA evaluated the specific resources effects of the first ten years of the project operations and made recommendations with respect to the assessment needs of subsequent stages of project development, as well as mitigation of specific negative effects.

The analysis conducted for the HRIA indicated there would be a moderate to high negative effect until ACD established the required mitigation. However, Shell believed that once the mitigation measures had been implemented, the negative historical resources effects of the project would be negligible.

25.2 Views of the Panel

The Panel is satisfied that the cultural and historical impacts were addressed in a reasonable way and it believes that it is appropriate for Shell to work directly with ACD to establish the remaining historical resources requirements.

The Panel concludes that the project is not likely to have significant adverse effects on cultural and heritage resources provided the proposed mitigation measures ACD approves are implemented.

26 PUBLIC CONSULTATION

26.1 Views of Shell

Shell stated that over the past two years it had consulted extensively with the regulators and key stakeholders on the predicted environmental effects of the project. It stated that its consultation effort included both the individuals and groups that would be directly affected by the project and those that demonstrated an interest in the project, including local communities, First Nations and Metis leaders and organizations, environmental nongovernmental organizations, special interest groups, the RMWB, regulators, government agencies, and industry.

Shell indicated that it had provided information about the project through meetings, workshops, forums, open houses, public documents, information handouts, a toll-free telephone line, speaking engagements, and advertisements. Shell noted that the concerns of its neighbours had been addressed where mutually agreeable solutions could be reached and pointed to the fact that it had environmental partnerships and agreements in place with Fort McKay, ACFN, and OSEC that addressed environmental concerns and provided for further involvement in the development of the project. Shell stated that WBFN had a number of opportunities to participate in the consultation process, but it chose not to participate. Shell stated that WBFN wanted Shell to meet certain conditions prior to any consultation process. Shell did not believe that these conditions were appropriate.

26.2 Views of OSEC

OSEC indicated that it began its review of the EIA in September 2001. OSEC believed that this process enabled it to gain a better understanding of the project and it believed that Shell had gained a better understanding of OSEC's concerns. OSEC stated that it had reached an agreement with Shell.

26.3 Views of MCFN

MCFN stated that it had a long-term relationship with Shell and that it had been working towards an agreement with Shell for a number of months. It pointed out that although it initially had criticisms of the EIA, it believed that Shell remained committed to working toward an agreement with MCFN. In its view, the personal relationship and trust MCFN had with Shell was a key factor in resolving its concerns about the project and coming to an agreement just before the hearing began.

26.4 Views of WBFN

WBFN asserted that it was an aboriginal group that was entitled to be consulted in a meaningful manner. WBFN stated that it had entered into an agreement with Shell that provided a process for WBFN to bring forward any concerns it had with respect to the project. However, WBFN also indicated that it had tried unsuccessfully to reach a separate agreement with Shell that would provide for an ongoing relationship between the two parties. Therefore, WBFN stated that until it reached a meaningful consultation agreement with Shell, it was opposed to the project.

26.5 Views of ACFN

In closing argument, ACFN stated that it enjoyed a positive consultative relationship with Shell and that it looked forward to working with Shell in the future on its agreement.

26.6 Views of Fort McKay

In closing argument, Fort McKay indicated that Shell had been and continued to be a good neighbour to the community of Fort McKay. It stated that Shell had honoured its commitments in relation to the Muskeg River Mine, and it believed that Shell would continue to deal with the community in good faith.

26.7 Views of the Panel

The Panel believes that overall Shell has done an outstanding job of public consultation, involving both those potentially affected and those expressing an interest in the project. The Panel recognizes the proactive approach to participant involvement taken by Shell early in the project development process. Shell demonstrated to the Panel that, where possible, concerns raised by interested parties have been incorporated into the development of the project and into the planned mitigation and monitoring. The Panel also acknowledges the support Shell has provided to regional issues management groups, such as CEMA and its working groups.

The Panel expects all stakeholders in the region to be consulted. The Panel believes that Shell has taken reasonable steps to engage WBFN in the consultation process.

27 CAPACITY OF RENEWABLE RESOURCES

27.1 Views of Shell

Shell's resource use assessment considered several resources and resource uses that could be potentially impacted by the project. Shell evaluated the capability for the use of renewable resources in terms of both availability and accessibility for traditional and nontraditional users.

Shell indicated that road access within the project development area as a result of existing oil sands activities and gas exploration and production operations would have an effect on resource use. Shell stated that site clearing for the mine site and facilities within the project area might reduce resource availability, while changes to the local road system might increase or decrease access to resources. Shell's assessment also considered the increase in the local area workforce and how that might affect resource use. Shell indicated that to use natural resources, the resources themselves must be available and users must have access to them. For each type of resource use, Shell considered relevant government guidelines, available resource use statistics, and important locations in which resources were located in the RSA and LSA. Shell considered three cases in its resource use assessment: a baseline case, an application case, and a planned development case.

Shell indicated that increases in the region's population under both the application case and the planned development case would have implications for all types of resources in the RSA. These effects included increased demand for fishing, hunting, berry picking, and recreation. While effects of these changes were low under the application case, they were considered moderate under the planned development case.

Shell indicated that there were no agricultural activities in the LSA and minimal agricultural activity within the RSA. The agriculture within the RSA was limited to grazing, market gardens, and wild rice operations.

Shell indicated that the effects on forestry as a result of the project would occur due to clearing of forests in the LSA. Shell indicated that trees would be lost from the development footprint for the life of the project and merchantable timber would be salvaged during site clearing. Shell stated that reclamation of the development area was expected to return the area to equivalent or greater capability. Forest regeneration to commercial standards would require 50 years for aspen and 80 to 120 years for coniferous species. Following closure, Shell indicated that the productive forest stands would be restored through reclamation and the regenerated forest would not be available for harvesting for 120 years. As compensation would be provided to the companies affected, Shell concluded that the overall consequence for both resource use and resources users was considered negligible for forestry.

Shell stated the project would result in a temporary loss of wildlife habitat during and in some cases extending several years past the life of the project, as 63 per cent of the LSA would be cleared. Shell stated that access to the area would be replaced through a new access corridor to be determined through multistakeholder consultation. Shell concluded that based on measures of both potential resource use and current resource users, the overall environmental consequence to hunting was negligible.

Shell indicated that the project would result in a temporary loss of furbearer habitat during and in some cases extending several years past the life of the project. This localized habitat loss would have the potential to affect some trappers in the region but was rated by Shell as a negligible environmental consequence. Shell stated that it had met with all affected trappers and it planned to continue to consult with trappers to address their concerns. Shell stated that it was participating with the Sustainable Ecosystems Working Group (SEWG) to understand and manage the cumulative regional effects on wildlife and fish populations, as well as those on hunters, trappers, and fishermen.

Shell assessed berry picking by analyzing the impacts on the berry producing plants. Each vegetation type within the terrestrial LSA that was considered to have berry-producing potential was determined and the effects were evaluated. Compared to the RSA as a whole, the LSA had a relatively small proportion of blueberry habitat and a relatively high proportion of cranberry habitat. Berry-picking activity was limited by restricted road access within both the LSA and RSA. Shell indicated that approximately 1610 ha of berry habitat would be affected by clearing for the project, representing 56 per cent of the potential berry-picking area in the LSA. However, less than 2 per cent of berry harvesters in the region used berry patches in or near the LSA, and the area cleared was 0.25 per cent of the potential berry-picking area in the RSA as a whole. Shell concluded that the environmental consequence to berry picking was therefore negligible. Shell stated that after reclamation occurred, the total amount of potential berry habitat was projected to increase to 4650 ha.

Shell identified that two watercourses had been documented in the LSA as sport fishing locations (the Muskeg River and Jackpine Creek) and one lake was known to support a sportfish population (Kearl Lake). It pointed out that the Muskeg River was accessible by an all-weather road and contained whitefish, perch, northern pike, Arctic grayling, walleye, and mountain whitefish. Shell stated that Jackpine Creek was accessible by road, quad, and snowmobile and had a northern pike population, but was not listed as a fishing location by any potential users. Kearl Lake was accessible by road and had a northern pike population, but had not been listed as a fishing location by any fishers. Shell indicated that no fishing destinations known to support sportfish or fishing areas would be directly affected by site-clearing activities. Shell also indicated that with an increase in upland and lake habitat areas, it was likely that hunting, trapping, and fishing capability after reclamation would also be equivalent or greater than predevelopment levels.

27.2 Views of the Panel

The Panel believes that for each renewable resource that could be affected, Shell has proposed adequate mitigation. The Panel also believes that given the nature of the project, the mitigation measures that will be implemented, and the recommendations of the Panel, the project is not likely to cause significant adverse environmental effects on renewable resources. Accordingly, the Panel concludes that the capacity of those resources to meet the needs of the present and those of the future is not likely to be significantly affected.

28 COGENERATION PLANT AND FRESH WATER PIPELINE (APPLICATIONS NO. 1271207 AND 1271383)

Application No. 1271207 is for approval for an electrical power plant to be located at the project site. Application No. 1271383 is for approval for an 8.5 km fresh water pipeline from LSD 02-23-95-10 W4M to LSD 08-16-95-10 W4M. There were no specific issues raised with respect to these applications.

28.1 Views of Shell

Shell stated that it was applying for a nominal 160 MW cogeneration plant consisting of a single natural gas combustion turbine and generator set and a heat recovery steam generator that would recover heat from the turbine's exhaust gases to produce process steam. Shell stated that it sized the cogeneration plant to meet the mine's electrical requirements and that the plant would provide approximately 40 per cent of the thermal demands for the processing plant. Two natural gas-fired auxiliary boilers would supply additional heat for the process.

Shell projected a maximum peak electric consumption of 170 MW at the start of operations in 2010, increasing to 189 MW in 2013 and to 203 MW in 2018. Therefore, all the plant's electric generation would be consumed within the project. Shell did not anticipate exporting electric energy to the Alberta Electric System from the project. Shell recognized that power exports or changes to the cogeneration plant from what it proposed in the application would have to be approved by the EUB, by way of an amendment to the plant approval. Shell did not expect to change the size or type of plant from what was stated in the application.

Shell indicated in its application that the electrical load not supplied by the proposed cogeneration plant would be supplied from the Alberta Electric System or directly from the existing Muskeg River cogeneration plant via a new 260 kilovolt (kV) transmission line. Shell acknowledged that additional approvals, under Sections 14, 15, and 18 of the Hydro and Electric Energy Act, would be required to construct and operate new transmission facilities and to connect the plant to the Alberta Electric System. Shell also indicated in its application that if it decided to exchange electric energy directly with the Muskeg River Mine and not through the Alberta Electric System, it would have to obtain an Industrial System Designation exception pursuant to Section 4 of the Hydro and Electric Energy Act.

Shell indicated that the fresh water pipeline would be needed to transport Athabasca River water from the Muskeg River Mine site to the proposed plant site. Shell stated that two new pumps would be added to the existing Muskeg River Mine pump house to increase the volume delivered to the Muskeg River Mine site. Shell stated that the existing water intake for the Muskeg River Mine was sufficient to accommodate both projects and therefore no structural changes would be required. Shell noted that arrangements for sharing the common system from the river intake to the Muskeg River Mine would be contained in a written agreement with Albian Sands.

Shell stated that the pipeline would be a butt-welded steel pipe with an outside diameter of 1067 millimetres (mm), a wall thickness of 12.7 mm, and an abrasion-resistant liner. Shell proposed that the pipeline would be buried, except for two portions totaling 120 m where the pipeline would cross the Muskeg River and Jackpine Creek on bridges.

Shell stated that it proposed to start construction of the pipeline in the winter of 2008 and complete construction by early 2010. Shell noted that under Section 13 of the Pipeline Act the EUB had the ability to set the date by which construction of the pipeline should commence.

Shell requested that the EUB issue a pipeline licence that would be in effect concurrently with the other licences issued by the EUB for the project.

28.2 Views of the Panel

The Panel notes that none of the interveners raised any issues regarding the cogeneration plant or the fresh water pipeline.

The Panel notes that Shell is planning on using all the power from the cogeneration plant at the Jackpine Mine, is not anticipating any export of electricity from the project, and is aware that any change in the cogeneration plant from what is proposed in the application would require Shell to apply to amend its approval. The Panel also notes that the power plant is just one of several contributors to total air emissions from the project. The Panel has already addressed air emissions in Section 14.6 and believes that there is unlikely to be any significant adverse environmental effects to air quality as a result of the project provided the mitigation measures are implemented. Therefore, the Panel approves Application No. 1271207 and will issue an approval pursuant to Section 11 of the Hydro and Electric Energy Act in due course.

The Panel also notes that additional approvals would be required to construct and operate the transmission facilities necessary to connect the plant to the Alberta Electric System and to exchange electric energy with the Muskeg River Mine.

The Panel is satisfied with the proposed fresh water pipeline. Therefore, the Panel approves Application No. 1271383 and will issue an approval pursuant to Part 4 of the Pipeline Act in due course. The Panel expects that the pipeline would be constructed prior to 2010 and it will state that the pipeline permit is valid until January 1, 2010. If the pipeline has not been constructed prior to that date, Shell will be required to apply to the EUB for an extension to its pipeline permit.

Dated in Calgary, Alberta, on February 5, 2004.

ALBERTA ENERGY AND UTILITIES BOARD
CANADIAN ENVIRONMENTAL ASSESSMENT AGENCY

<original signed by>

J. D. Dilay, P.Eng.
Panel Chair

<original signed by>

G. Kupfer, Ph.D.
Panel Member

<original signed by>

R. Houlihan, Ph.D., P.Eng.
Panel Member

APPENDIX 1 SUMMARY OF EUB APPROVAL CONDITIONS AND COMMITMENTS

CONDITIONS

- Shell shall submit a lease boundary report five years prior to mining activities reaching any common lease boundary. The report must include a comprehensive description of the lease boundary geology and reserves, geotechnical conditions, alternative mining scenarios and impacts, and the costs associated with each, all in accordance with Section 3.1 of EUB *Interim Directive (ID) 2001-7: Operating Criteria: Resource Recovery for Oil Sands Mines and Processing Sites* (Section 6.2.2).

- Shell shall submit, for EUB approval, an access road and utility corridor update in its 2006 annual report. The report shall include a resource assessment of the oil sands located in the Sharkbite area and under the modified infrastructure corridor. It shall also include a comparison of alternative access road and utility corridor alignments with respect to resource recovery and other relevant criteria (Section 6.3.2).

- Shell shall submit, for EUB approval, a resource assessment of the plant site area two years prior to construction (Section 6.3.2).

- Shell shall submit, for EUB approval, detailed geotechnical design for all external overburden disposal areas at least six months prior to field preparation in those areas (Section 6.4.2).

- Shell shall submit, for EUB approval, a resource assessment of the three waste disposal areas and reclamation material stockpile two years prior to material placement (Section 6.4.2).

- Shell shall submit, for EUB approval, a ten-year mine plan and material balance by the earlier of 2008 or six months prior to pit development (Section 6.4.2).

- Shell must satisfy the EUB, two years prior to construction of either the Khahago surge facility or the tailings disposal area, that the design of the tailings disposal area, including the surge facility, provides for adequate capacity, stability, and minimization of resource sterilization and environmental impact (Section 6.7.2).

- Shell shall provide an annual report to the EUB on the status of the project and its development commencing on February 28, 2005, or such other date and frequency the EUB may stipulate (Section 6.8.2).

- Shell shall provide a report on progress in improving the bitumen extraction recovery in every second annual report to the EUB starting in 2008, or such other date and frequency the EUB may stipulate (Section 7.3).

- Shell shall continue to evaluate tailing solvent recovery unit (TSRU) thickeners technology and report results to the EUB in the 2006 annual report. The report must identify any opportunities to include TSRU thickeners in the project design and construction (Section 7.3).

- Shell shall report on its progress in dealing with separation characteristics of asphaltenes in the TSRU tailings in its annual report to the EUB commencing in 2005, or such other date and frequency the EUB may stipulate (Section 7.3).

- On or before February 28 of each year commencing in 2011, Shell shall provide to the EUB a summary of the previous year's operation stating the amount of asphaltene rejected. The amount of asphaltenes rejection shall be limited to 10 mass per cent based on bitumen production (Section 7.3).

- On an annual average basis, Shell must limit site-wide solvent losses to not more than 4 volumes per 1000 volumes of bitumen production under all operating conditions. Shell shall not discharge untreated froth treatment tailings to the tailings disposal area (Section 7.3).

- Shell shall submit a report to the EUB prior to final design or June 30, 2006, whichever is earlier, on the feasibility of producing consolidated tailings (CT) on commencement of operation in order to reduce the accumulation of thickened tailings, thin fine tails, and mature fine tails (Section 8.2).

- Shell shall describe its progress on developing solid tailings technology in every second annual report to the EUB, commencing on February 28, 2005, or such other date and frequency the EUB may stipulate (Section 8.2).

- Shell shall submit to the EUB a report summarizing the engineering design and operating plans for the CT system two years prior to planned start-up, or such other date the EUB may stipulate (Section 8.2).

- Shell shall submit to the EUB on or before February 28 of every year commencing in 2011, or such other date or frequency the EUB may stipulate, a report summarizing the performance of the tailings management system during the preceding year, including Shell's reasons for any deviations from design (Section 8.2).

- Shell shall provide a report, for EUB approval, detailing its mine plans near the Pleistocene Channel aquifer (PCA) five years prior to mining in this area to allow for the consideration of resource recovery issues and environmental impacts. The report shall include the proposed location of the pit limits and their proximity to the PCA, as well as a description of any mitigation that would be completed to minimize the impact of mining near the PCA (Section 13.1.6).

- Shell shall provide an annual report on regional development cooperation to the EUB starting in 2005. The report shall describe guiding principles and activities for cooperative development, opportunities and constraints of collaborative work among developers, specific time frames and implementation steps for all project phases to integrate them with other oil sands projects in the Muskeg River basin, and the means to evaluate outcomes (Section 18.4).

COMMITMENTS

The Panel notes throughout the report that Shell has undertaken to conduct certain activities in connection with its operations that are not strictly required by EUB, AENV, or DFO regulations or guidelines. These undertakings are described as commitments.

The Panel believes that when a company makes commitments of this nature, it has satisfied itself that these activities will benefit both the project, stakeholders, and the public, and the Panel takes these commitments into account when arriving at its decision. The Panel expects that Shell will adhere to all commitments it made during the consultation process, in the application, and at the hearing, to the extent that those commitments do not conflict with the terms of any approval or licence affecting the project or any law, regulation, or similar requirement Shell is bound to observe. The Panel expects Shell to advise the EUB if, for whatever reasons, it cannot fulfill a commitment. The EUB would then assess whether the circumstances regarding the failed commitment warrant a review of the original approval. The EUB also notes that the affected parties also have the right to request a review of the original approval if commitments made by the applicant remain unfulfilled.

In addition to any commitments it made at the hearing, Shell provided Exhibit No. 12, listing in detail its commitments to stakeholders and regulators in the areas of operational management, environmental management, socioeconomic initiatives, and consultation.

APPENDIX 2 PANEL AGREEMENT

AGREEMENT

To Establish a Joint Review Panel for the Jackpine Mine Project

Between

The Minister of the Environment, Canada

- and -

The Alberta Energy and Utilities Board

PREAMBLE

WHEREAS the Alberta Energy and Utilities Board (the AEUB) has statutory responsibilities pursuant to the *Alberta Energy and Utilities Board Act* and the *Energy Resources Conservation Act*; and

WHEREAS the Minister of the Environment, Canada (the Federal Minister) has statutory responsibilities pursuant to the *Canadian Environmental Assessment Act*; and

WHEREAS the Jackpine Mine Project (the Project) requires a public hearing and approvals from the AEUB pursuant to the *Alberta Energy and Utilities Board Act* and the *Energy Resources Conservation Act* and is subject to an assessment under the *Canadian Environmental Assessment Act*; and

WHEREAS the Minister of Fisheries and Oceans has referred the environmental assessment in respect of the Project to the Federal Minister in accordance with section 21 of the *Canadian Environmental Assessment Act*; and

WHEREAS the Federal Minister has referred the project to a review panel in accordance with section 29 of the *Canadian Environmental Assessment Act*; and

WHEREAS the Government of the Province of Alberta and the Government of Canada established a framework for conducting joint panel reviews through the *Canada-Alberta Agreement for Environmental Assessment Cooperation* signed on June 30, 1999; and

WHEREAS the AEUB and the Federal Minister have determined that a joint panel review of the Project will ensure that the project is evaluated according to the spirit and requirements of their respective authorities while avoiding unnecessary duplication, delays and confusion that could arise from separate reviews by each government; and

WHEREAS the AEUB and the Federal Minister have determined that a joint panel review of the Project should be conducted in a manner consistent with the provisions of the *Subsidiary Agreement on Joint Review Panels*, attached as Appendix 2 of the *Canada-Alberta Agreement for Environmental Assessment Cooperation*; and

WHEREAS the Federal Minister has determined that a joint review panel should be established pursuant to paragraph 40(2) of the *Canadian Environmental Assessment Act* to consider the Project;

THEREFORE, the AEUB and the Federal Minister hereby establish a joint review panel for the Project in accordance with the provisions of this Agreement and the Terms of Reference attached as an Appendix to this Agreement.

1. Definitions

For the purpose of this Agreement and of the Appendix attached to it,

"**Agency**" means the Canadian Environmental Assessment Agency.

“**EIA Report**” means an Environmental Impact Assessment report prepared in accordance with the Terms of Reference issued for the Project by the Director of Alberta Department of the Environment.

"**Environment**" means the components of the Earth, and includes
(a) land, water and air, including all layers of the atmosphere;
(b) all organic and inorganic matter and living organisms; and
(c) the interacting natural systems that include components referred to in (a) and (b)."

"**Environmental Effect**" means, in respect of the Project,
(a) any change that the Project may cause in the Environment, including any change it may cause to a listed wildlife species, its critical habitat or the residence of individuals of that species, as those terms are defined in subsection 2(1) of the *Species at Risk Act*,
(b) any effect of any change referred to in paragraph (a) on
    (i) health and socio-economic conditions
    (ii) physical and cultural heritage
    (iii) the current use of lands and resources for traditional purposes by aboriginal persons
    (iv) any structure, site or thing that is of historical, archeological, paleontological or architectural significance, or
(c) any change to the project that may be caused by the environment

whether any such change or effect occurs within or outside Canada.

“**Federal Authority**” refers to such an authority as defined in the *Canadian Environmental Assessment Act.*

"**Final Report**" is the document produced by the Joint Panel, which contains decisions pursuant to the *Energy Resources Conservation Act* and the Joint Panel's conclusions and recommendations pursuant to the *Canadian Environmental Assessment Act* with respect to the environmental assessment of the Project.

"**Follow-up Program**" means a program for

(a) verifying the accuracy of the environmental assessment of the Project, and

(b) determining the effectiveness of any measures taken to mitigate the adverse environmental effects of the Project.

"**Joint Panel**" refers to the joint panel established by the AEUB and the Federal Minister through this Agreement.

"**Mitigation**" means, in respect of the Project, the elimination, reduction or control of the adverse environmental effects of the project, and includes restitution for any damage to the environment caused by such effects through replacement, restoration, compensation or any other means.

“**Parties**” means the signatories to this Agreement.

"**Responsible Authority**" refers to such an authority as defined in the *Canadian Environmental Assessment Act*.

2. Establishment of the Panel

2.1. A process is hereby established to create a Joint Panel, pursuant to section 22 of the *Energy Resources Conservation Act* with the authorization of the Lieutenant Governor in Council of Alberta, and Sections 40, 41 and 42 of the *Canadian Environmental Assessment Act*, for the purposes of the review of the Project.

2.2. The AEUB and the Agency will make arrangements to coordinate the announcements of a joint review of the Project by both Alberta and Canada.

3. Constitution of the Panel

3.1. The Joint Panel will consist of three members. Two members, including the Joint Panel Chair, will be appointed by the Chair of the AEUB with the approval of the Federal Minister. The third Joint Panel member will be appointed by the Federal Minister in accordance with article 3.2 of this Agreement.

3.2. The Federal Minister will select the third Joint Panel member and recommend the selected candidate as an individual who may serve as a potential acting member of the AEUB. If acceptable to the Lieutenant Governor in Council of Alberta and the Chairman of the AEUB, the Lieutenant Governor in Council of Alberta will nominate this candidate to serve as an acting member of the AEUB and the Chairman of the AEUB will appoint this candidate as a member of the Joint Panel. The selected candidate will then be appointed by the Federal Minister as a member of the Joint Panel.

3.3. The Joint Panel members shall be unbiased and free from any conflict of interest relative to the Project and are to have knowledge or experience relevant to the anticipated Environmental Effects of the Project.

4. Conduct of Assessment by the Panel

4.1. The Joint Panel shall conduct its review in a manner that discharges the responsibilities of the AEUB under the *Alberta Energy and Utilities Board Act* and the *Energy Resources Conservation Act*.

4.2. The Joint Panel shall conduct its review in a manner that discharges the requirements set out in the *Canadian Environmental Assessment Act* and in the Terms of Reference attached as an Appendix to this Agreement.

4.3. All Joint Panel hearings shall be public and the review will provide for public participation.

4.4. The Joint Panel shall have all the powers and duties of a panel described in Section 35 of the *Canadian Environmental Assessment Act* and in Section 10 of the *Alberta Energy and Utilities Board Act*.

5. Secretariat

5.1. Administrative, technical, and procedural support requested by the Joint Panel shall be provided by a Secretariat, which shall be the joint responsibility of the AEUB and the Agency.

5.2. The Secretariat will report to the Joint Panel and will be structured so as to allow the Joint Panel to conduct its review in an efficient and cost-effective manner.

5.3. The AEUB will provide its offices for the conduct of the activities of the Joint Panel and the Secretariat.

- 5 -

6. Record of Joint Review and Final Report

6.1. A public registry will be maintained by the Secretariat during the course of the review in a manner that provides for convenient public access, and for the purposes of compliance with section 55 of the *Canadian Environmental Assessment Act*. This registry will be located in the offices of the AEUB.

6.2. On completion of the assessment of the Project, the Joint Panel will prepare a Final Report.

6.3. Once completed, the Final Report will be conveyed, in both official languages simultaneously, by the Joint Panel to the Government of Alberta, to the Federal Minister, the Minister of Fisheries and Oceans, and to the public.

6.4. Once the Final Report is submitted to the Federal Minister, the responsibility for the maintenance of the public registry will be transferred to the Responsible Authority. The AEUB will continue to maintain records of the proceedings and the Final Report, as per the AEUB Rules of Practice.

7. Other Government Departments

7.1. At the request of the Joint Panel, Federal Authorities and provincial authorities having specialist knowledge with respect to the Project will provide available information and knowledge in a manner acceptable to the Joint Panel.

7.2. Nothing in this agreement will restrict the participation by way of submission to the Joint Panel by other federal or provincial government departments or bodies**,** subject to article 7.1, above, section 12(3) of the *Canadian Environmental Assessment Act* and the AEUB Rules of Practice.

8. Participant Funding

8.1. Decisions regarding participant funding by the Agency under the federal Participant Funding Program, and decisions on intervener funding by the AEUB as provided for in the *Energy Resources Conservation Act*, AEUB Rules of Practice and the AEUB Guidelines for Energy Cost Claims (Guide 31A) will, to the extent practicable, take into account decisions of the other party**.**

9. Cost Sharing

9.1. The AEUB, as lead party, will develop a budget estimate of expenses agreeable to both parties prior to initiation of Joint Panel activities.

- 6 -

9.2. The costs of the review will be apportioned between the AEUB and the Agency in the manner set out in articles 9.3, 9.4 and 9.5.

9.3. The AEUB will be solely responsible for the following costs:

- salaries and benefits of the Joint Panel Chairman and the member of the Joint Panel not appointed in accordance with article 3.2; and
- salaries and benefits of AEUB staff involved in the joint review.

9.4. The Agency will be solely responsible for the following costs:

- per diems of the Joint Panel member appointed in accordance with article 3.2;
- salaries and benefits of Agency staff involved in the joint review;
- all costs associated with the federal Participant Funding Program; and
- French translation requirements.

9.5. The AEUB and the Agency agree to share equally all those costs listed below, incurred as part of the Joint Panel review from the signing of this Agreement to the date the Final Report is issued by the Joint Panel. The shareable costs are as follow:

- travel-related expenses associated with the review incurred by the Joint Panel members, and by AEUB and Agency staff in fulfilling the Secretariat functions;
- per diems and associated expenses of independent/non-government expert consultants or communications specialists retained by the Joint Panel;
- printing of any reports or documents distributed by the Joint Panel necessary for the Joint Panel's work;
- the publication of notices;
- photocopying and postage related to the review;
- production of one electronic and one paper copy of the transcripts prepared by court reporters as required by the Joint Panel;
- rental of hearing and public meeting facilities and equipment;
- sound services at the hearing and public meetings; and
- miscellaneous expenditures up to a maximum of 5 percent of the total budget for the review.

9.6. Shareable costs of the joint review as detailed in article 9.5 will be incurred at the sole discretion of the Joint Panel with due regard to economy and efficiency.

9.7. All expenses not listed above will need prior approval of both parties if they are to be equally shared.

9.8. To facilitate the delivery of payment of per diems of the Joint Panel member appointed in accordance with article 3.2 the AEUB will pay the individual in response to appropriate invoices and will invoice the Agency for the reimbursement of such payments.

10. Amending this Agreement

10.1. The terms and provisions of this agreement may be amended by written memorandum executed by both the Federal Minister and the Chairman of the AEUB. Subject to section 27 of the *Canadian Environmental Assessment Act*, upon completion of the joint review, this Agreement may be terminated at any time by an exchange of letters signed by both parties.

11. Signatures

WHEREAS the parties hereto have put their signatures this 18th day of August 2003.

<original signed by>
____
The Honourable David Anderson
Minister of the Environment

<original signed by>
____
Neil McCrank
Chairman
Alberta Energy and Utilities Board

Appendix
Terms of Reference

Part I - Project Description

Shell Canada Limited is proposing to construct and operate an oil sand mining and extraction facility. The proposed Jackpine Mine is to be located approximately 70 kilometres north of Fort McMurray in Townships 95, Ranges 8 to 9, West of the 4th Meridian. The proposed development includes an open pit, truck and shovel mine, bitumen processing train, a co-generation plant consisting of 170-megawatt gas turbine generator fitted with a heat recovery steam boiler, infrastructure associated with the mine and facility, water and tailing management plans, and an integrated reclamation plan. The Jackpine Mine is designed to produce approximately 31 800 cubic metres per day of bitumen from the McMurray Formation. The Jackpine Mine is expected to have full production in 2010 and last 22 years. Shell is also proposing to construct and operate of a 8.5 km fresh water pipeline from LSD 2-23-95-10 W4M to LSD 08-16-95-09 W4M.

Part II - Scope of the Environmental Assessment

1. The Joint Panel will conduct an assessment of the Environmental Effects of the Project based on the Project Description (Part I).

2. The assessment will include a consideration of the factors listed in subsection 16(1)(a) to (d) and 16(2) of the *Canadian Environmental Assessment Act*, namely:

- **a)** The environmental effects of the Project, including the environmental effects of malfunctions or accidents that may occur in connection with the Project and any cumulative environmental effects that are likely to result from the Project in combination with other projects or activities that have been or will be carried out;
- **b)** The significance of the effects referred to in paragraph a);
- **c)** Comments from the public that are received during the review;
- **d)** Measures that are technically and economically feasible and that would mitigate any significant adverse environmental effects of the Project;
- **e)** The purpose of the Project;
- **f)** Alternative means of carrying out the Project that are technically and economically feasible and the environmental effects of any such alternative means;
- **g)** The need for, and the requirements of, any follow-up program in respect of the Project; and
- **h)** The capacity of renewable resources that are likely to be significantly affected by the Project to meet the needs of the present and those of the future.

3. Pursuant to subsection 16(1)(e) of the CEAA, the assessment by the Joint Panel will also include a consideration of the additional following matters:

a) Need for the Project;
b) Alternatives to the Project; and
c) Measures to enhance any beneficial environmental effects.

4. The Review will consider the Environmental Effects of the proposed Project within spatial and temporal boundaries which encompass the periods and areas during and within which the Project may potentially interact with, and have an effect on, components of the environment. These boundaries may vary with the issues and factors considered, and with the different phases in the life cycle of the project. The boundaries will reflect:

- the natural variation of a population or ecological component;
- the timing of sensitive life cycle phases in relation to the scheduling of the Project;
- the time required for an effect to become evident;
- the time required for a population or ecological component to recover from an effect and return to a pre-effect condition, including the estimated degree of recovery;
- the area affected by the Project; and
- the area within which a population or ecological component functions and within which a Project effect may be felt.

APPENDIX 3 HEARING PARTICIPANTS

Principals and Representatives (Abbreviations used in report)	Witnesses
Shell Canada Limited (Shell) S. Denstedt K. Lozynsky B. Gilmour J. Cartwright	K. Firmin, P.Eng. A. Vanderputten, P.Eng. L. Nehring N. Camarta, P.Eng. R. Seeley, P.Eng. J. Smith, P. Biol. J. Gulley K. Thompson M. Trudell, Ph.D., P.Geol. M. Ingen-Houz M. Rawlings, P.Eng. S. McKenzie, P.Biol. M. Digel F. Ade, Ph.D., P.Eng. A. Beersing, Ph.D., P.Eng.
Oil Sands Environmental Coalition (OSEC) K. Buss	D. Woynillowicz
Athabasca Chipewyan First Nation (ACFN) K. Buss	
Fort McKay First Nation and Metis Local # 122 (Fort McKay) K. Buss	
Fort McMurray Medical Staff Association (FMMSA) M. Sauvé, M.D.	M. Sauvé, M.D.
Sierra Club of Canada (SCC) S. P. Stensil E. May	E. May

(continued)

APPENDIX 3 HEARING PARTICIPANTS (continued)

Principals and Representatives (Abbreviations used in report)	Witnesses
Mikisew Cree First Nations (MCFN) D. Mallon R. Salamucha	Chief A. Waquan W. Courtorielle A. Courtorielle Dr. P. Komers, Ph.D. Dr. E. Dickson Dr. J. Byrne, D.Phil. Dr. S. Kienzle, Ph.D. J. Brownlee, M.E.S. B. Evans V. McKay
Wood Buffalo First Nation (WBFN) J. Malcolm	J. Malcolm R. Woodward W. Castor G. Castor J. Grant
Canadian Natural Resources Limited (CNRL) D. A. Holgate	
Imperial Oil Resources and ExxonMobil Canada (ExxonMobil) K. Sury	
Syncrude Canada Limited (Syncrude) B. Roth D. Bercov	
Suncor Energy Limited (Suncor) S. Lowell	
UTS Energy Corp. (UTS) D. McDonald	

(continued)

APPENDIX 3 HEARING PARTICIPANTS (continued)

Principals and Representatives (Abbreviations used in report)	Witnesses
Government of Canada (Canada) D. Mueller B. Hughson	Department of Fisheries and Oceans (DFO) Panel R. Courtney, P.Biol. D. Majewski B. Makowechi D. Walker J. Shamess A. Thomson, P.Eng.
	Environment Canada (EC) Panel M. Fairbairn L. Bates-Frymel P. Gregoire D. Linderman, Ph.D. B. Brownlee, Ph.D. B. Coutts
	Natural Resources Canada (NRCAN) Panel L. Wells
	Health Canada (HC) Panel L. Liu, Ph.D. O. Vuzi
	Indian and Northern Affairs Canada Panel K. Maksymiec
Her Majesty the Queen in Right of Alberta (Alberta) D. Stepaniuk H. Veale K. Sandstrom	Alberta Environment (AENV) Panel B. Pretula C. de la Chevrotiere, P.Eng. M. Boyd R. Barrett L. Rhude, P.Biol. K. Singh, P.Eng. P. Marriott, P.Eng.
	Alberta Sustainable Resource Development (ASRD) Panel R. Chabaylo, P.Biol. C. Hale, RPF P. McEachern, Ph.D.
	Alberta Health and Wellness (AHW) Panel A. MacKenzie Dr. K. Bodo, Ph.D.

(continued)

APPENDIX 3 HEARING PARTICIPANTS (concluded)

Principals and Representatives (Abbreviations used in report)	Witnesses
Alberta Energy and Utilities Board (EUB) staff G. Perkins, Board Counsel A. Larson, P.Eng. P. Hunt M. Woytiuk M. Dmytriw, R.E.T. C. Brown, P.Biol. W. MacKenzie T. Lemay	
Canadian Environmental Assessment Agency staff S. Chapman	

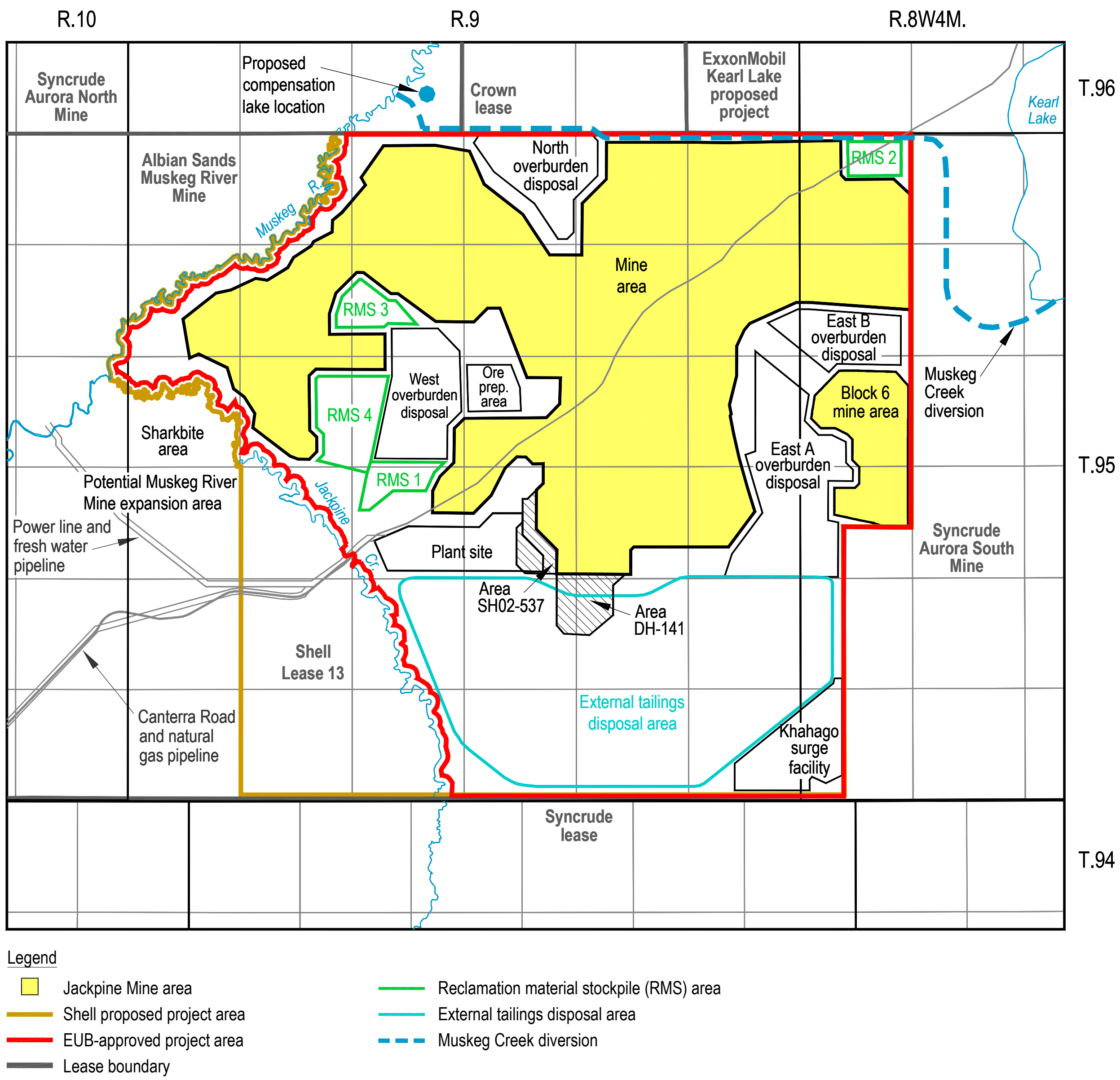


Figure 1. Shell Jackpine Mine and surrounding area

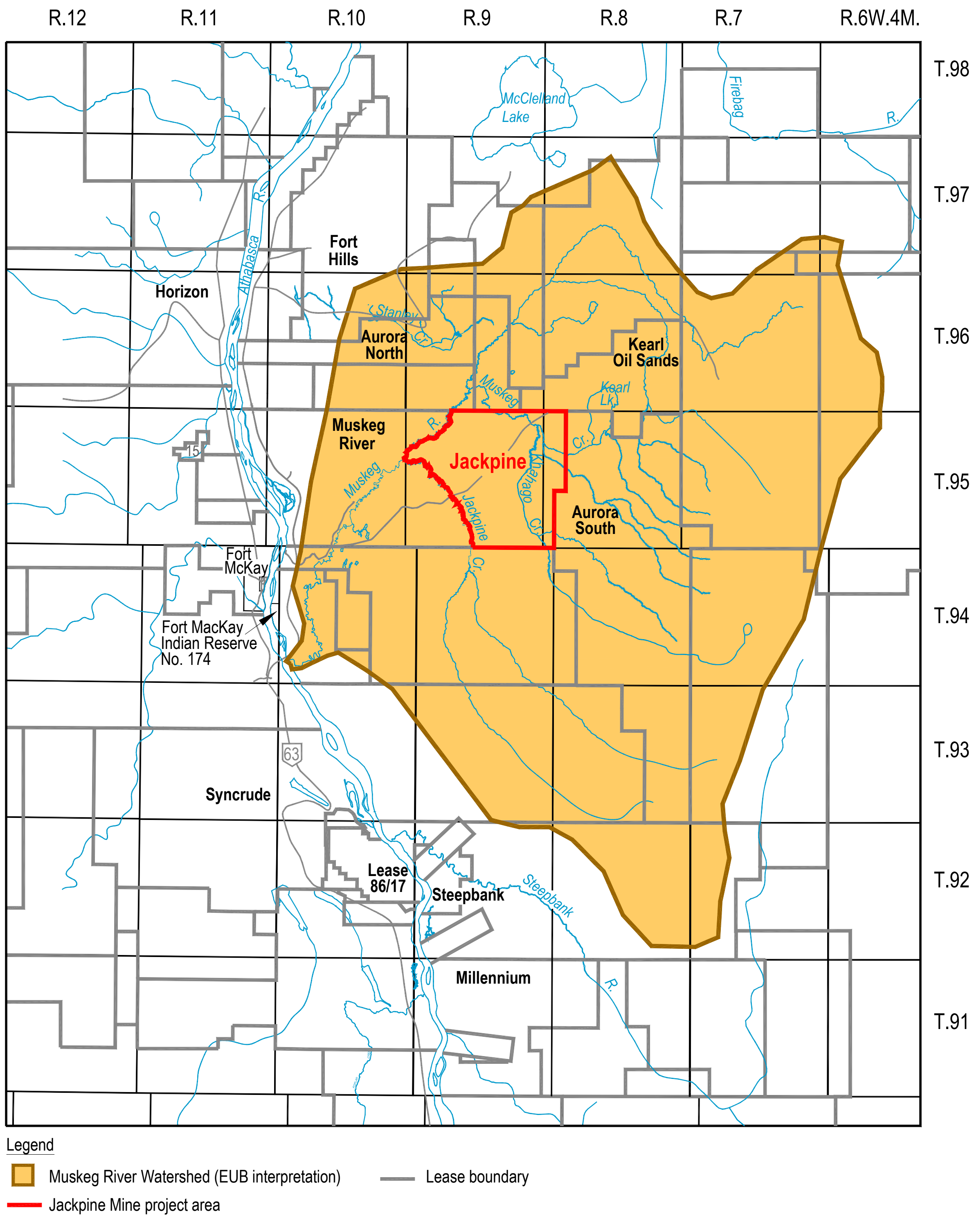


Figure 2. Muskeg River watershed

Appendix V:

Jim Barker et al, "Attenuation of Contaminants in Groundwater Impacted by Surface Mining in Oil Sands, Alberta, Canada" (University of Waterloo) November, 2007

Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada

Jim Barker, Dave Rudolph, Trevor Tompkins
Dept. of Earth & Environmental Sciences
University of Waterloo, Waterloo, ON, Canada
Alex Oiffer, Woley Parsons Komex, Edmonton, AB
Francoise Gervais, Gartner Lee Ltd., Markham, ON
Grace Ferguson, Stantec Consulting Ltd., Kitchener ON

Canada's Oil

- Canada's proven reserves now 179 billion barrels (mainly oil sands)

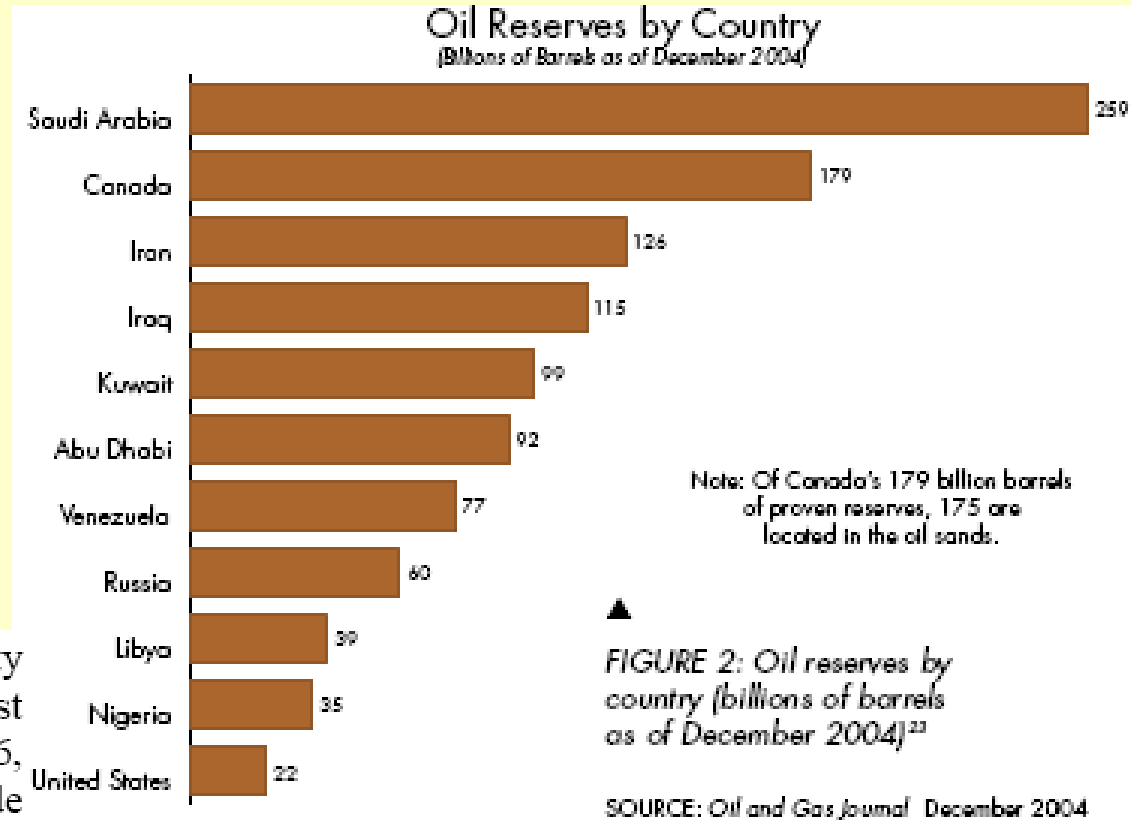


FIGURE 2: Oil reserves by country (billions of barrels as of December 2004)[23]

SOURCE: *Oil and Gas Journal* December 2004

The United States with a refining capacity of over 17 million b/d is Canada's largest market for crude oil exports and, in 2006, Canada was the largest exporter of crude oil supplying almost 12 percent of United States requirements, ahead of both Mexico and Saudi Arabia. In 2006, Canada exported almost 1.6 million b/d and the

IPEC November, 2007

Alberta's Oil Sands

- Oil sands production from surface mining and in situ steam-assisted gravity drainage (SAGD)
  - 2005: mining – 552,000 b/d
    in situ – 438,000 b/d
- Canadian total crude production: 2,000,000 b/d

Oil Sands Mining & Processing

- Current production: 90,000 m^3/d upgraded oil
- Each m^3 of oil requires 2 – 5 m^3 of water
- > 95% of water for extraction is recycled
- 10^6 m^3 of tailings generated annually

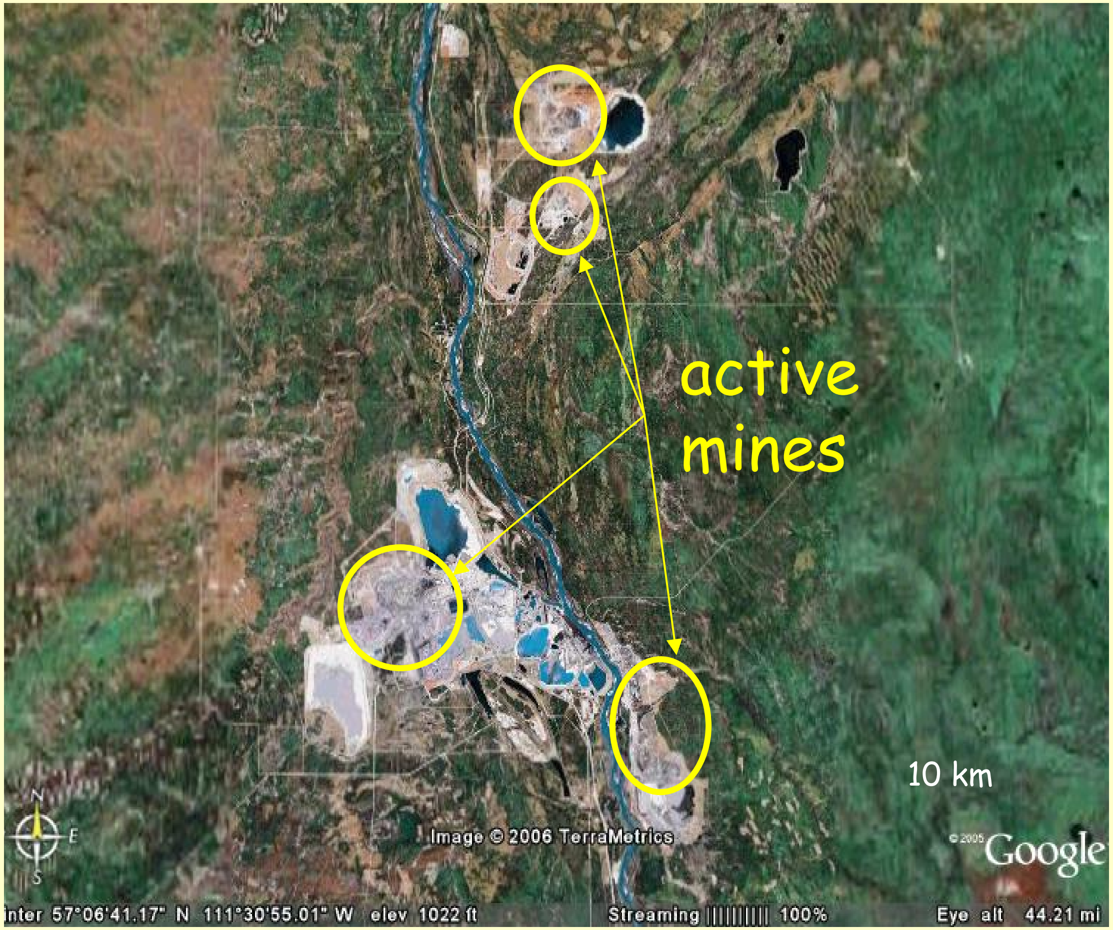
Oil Sands Mining & Processing

- Previous tailings would likely remain fluid for > 500 years; new technologies being employed to generate more rapid consolidation

Tailings being deposited: process water, sand, silt, trace bitumen

Alberta's Oil Sands Mining Area

- Surface mineable deposits cover 2,800 km^2
- Currently over 60 km^2 of tailings ponds



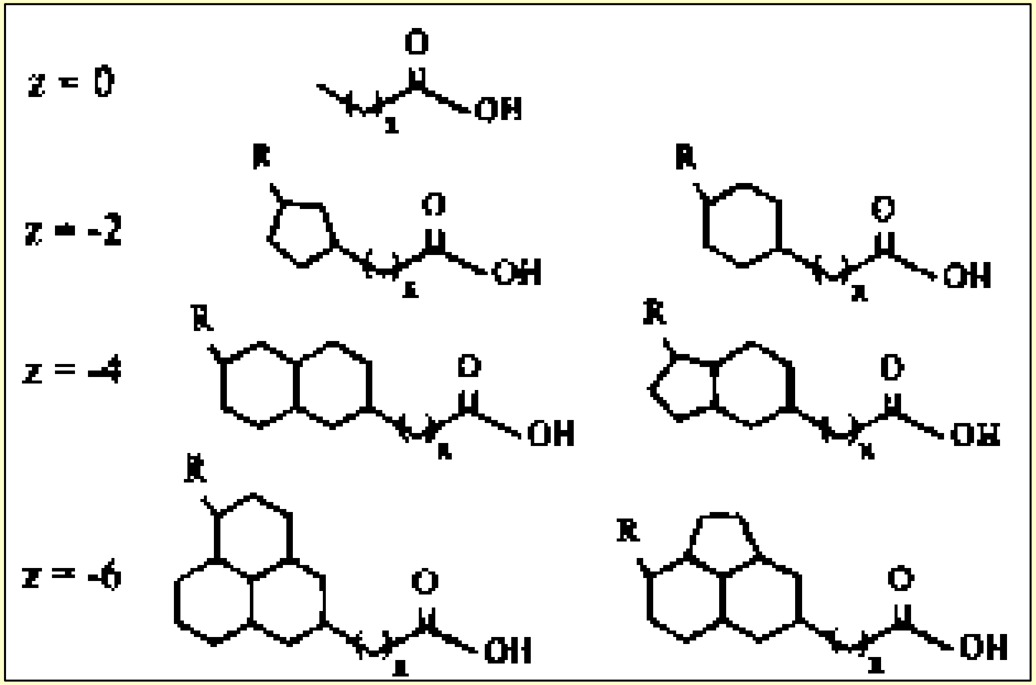
IPEC November, 2007

Groundwater Issues

- The Challenge: tailings fluids are toxic to aquatic organisms
- Naphthenic Acids (NAs) are the major toxicants
  - NAs are constituents of oil sand;
  - a few mg/L are often observed in surrounding surface waters, un-impacted by process water

Groundwater Issues

- Naphthenic Acids (NAs): the major toxicant
  - A complex mixture of acyclic and aliphatic carboxylic acids, with the general chemical formula $C_nH_{2n+z}O_2$, where n refers to the number of carbon atoms and z to the hydrogen atom deficiency caused by ring formation.



Groundwater Issues

- Groundwater is not used for drinking water supply, so aquatic receptors are the focus of concern. Groundwater is a pathway.
- Does (or will) discharge of process-affected groundwater cause significant impacts to aquatic/benthic communities?
- Is aquatic toxicity attenuated by biotransformation during groundwater transport?

Groundwater Issues

- Seepage of tailings water
  - more likely from sand dyke construction than from ponds
  - most seepage is collected and returned to pond
  - current plumes are not affecting aquatic systems (TID is "grandfathered")
  - groundwater may also be a significant pathway in the reclaimed landscape

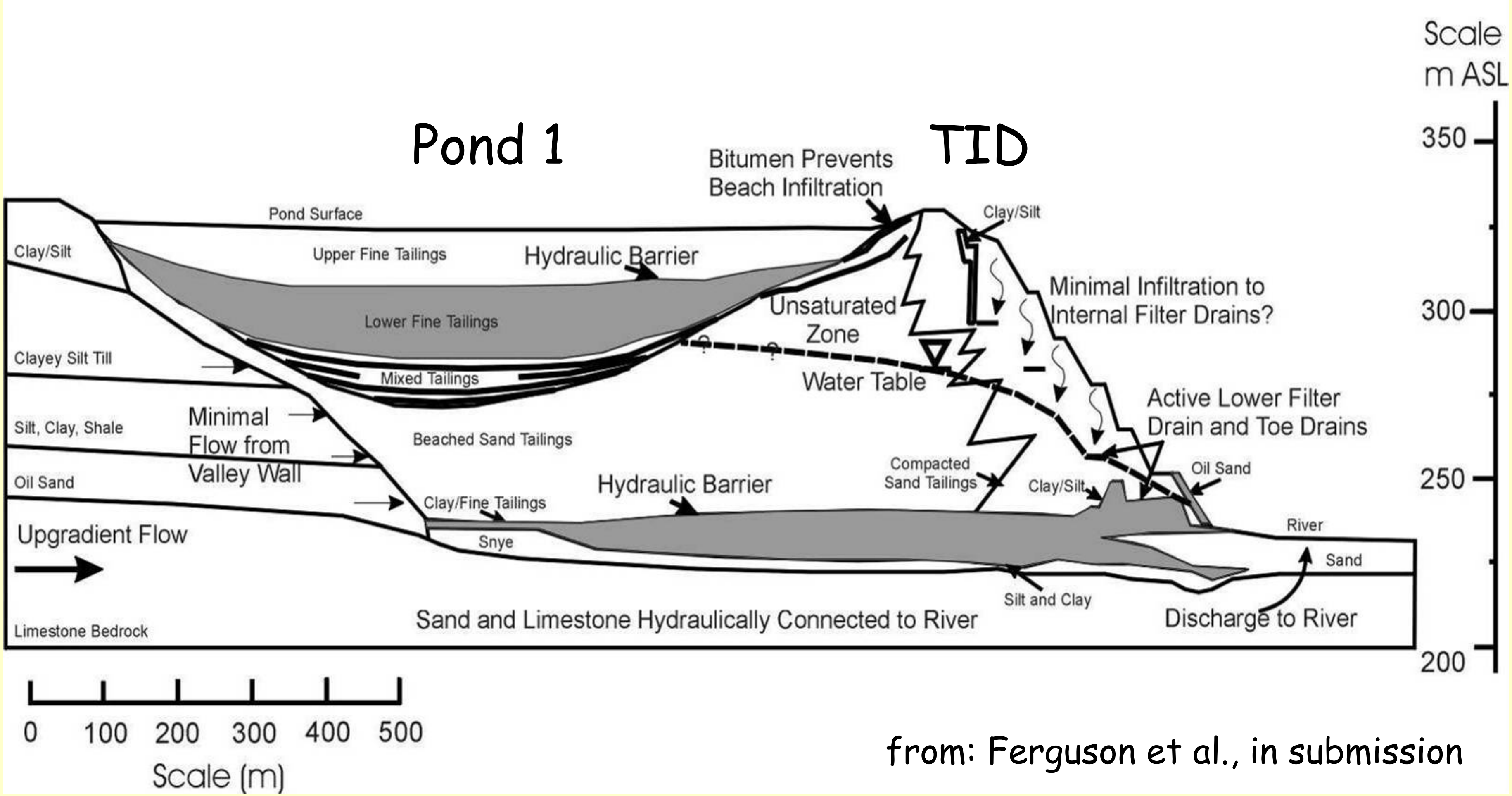
Seepage from Tar Island Dyke

- Initial tailings pond, begun in early 1960's
- Current pond is perched, as fines and tar line the pond
- Seepage to Athabasca River is acknowledged
- No impacts to the aquatic ecosystem have been found
- Ongoing seepage should decline, even without reclamation of the pond

Seepage from Tar Island Dyke

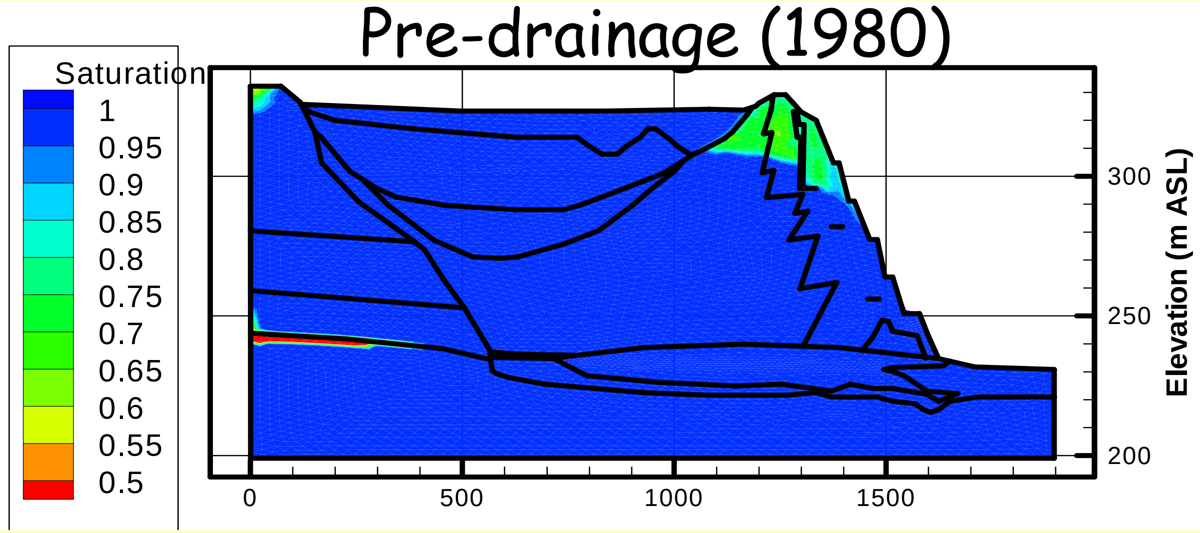
Seepage from Tar Island Dyke

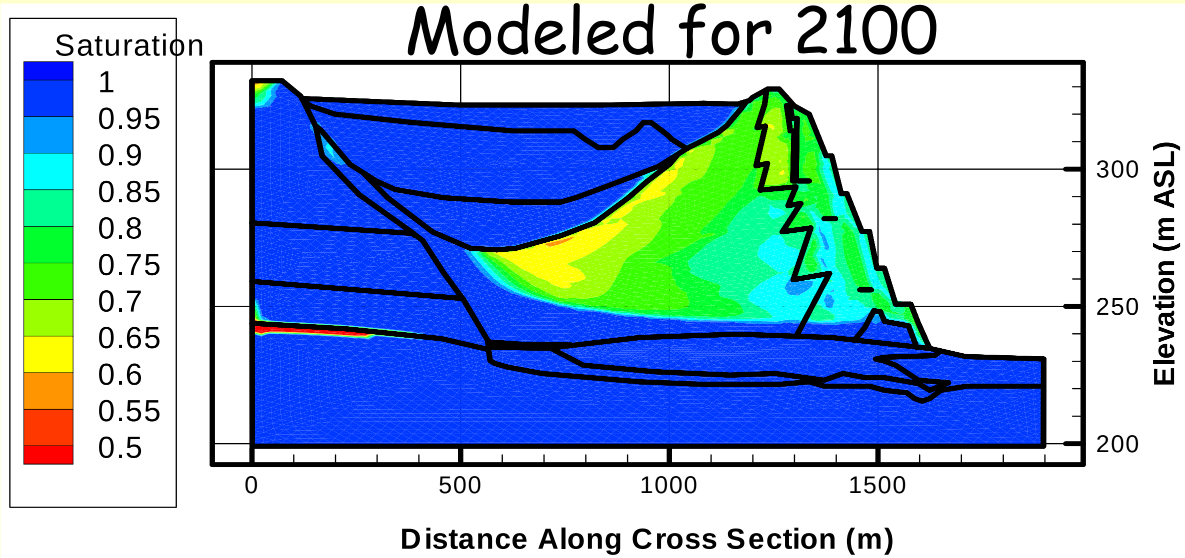
- Conceptual model



from: Ferguson et al., in submission

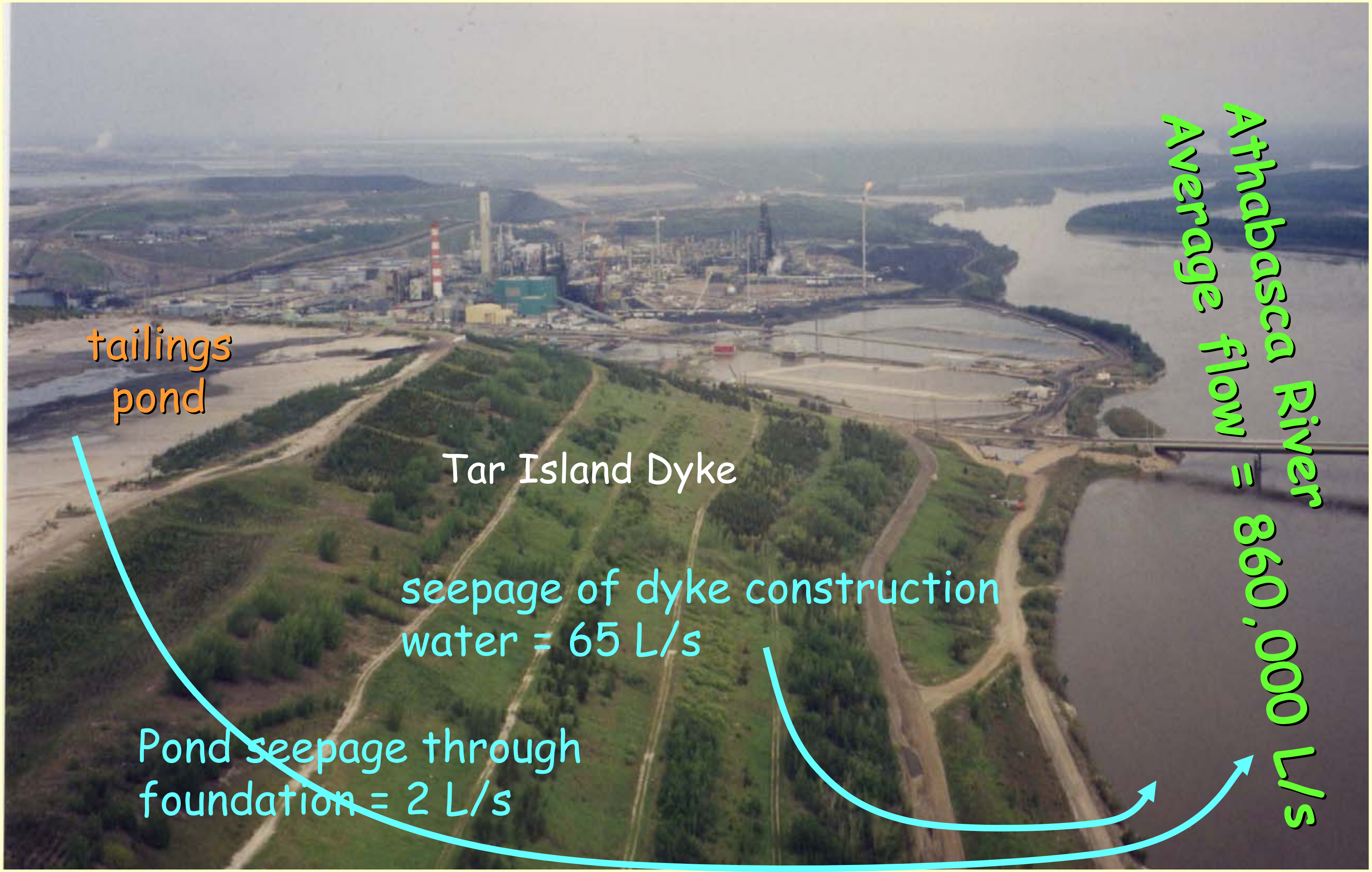
Seepage from Tar Island Dyke



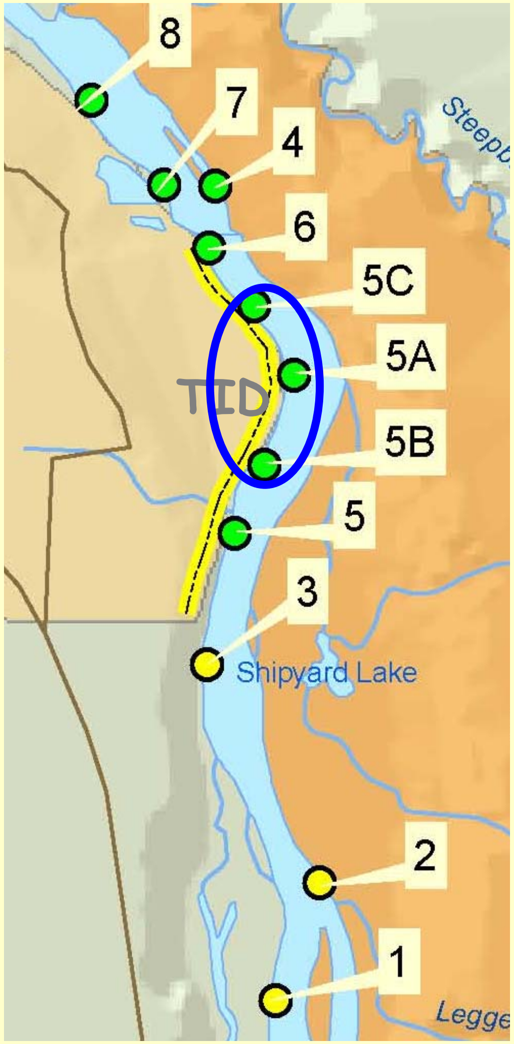


om: Ferguson et
, in submission

Seepage from Tar Island Dyke



Seepage from Tar Island Dyke



- Groundwater under/adjacent to TID

  NAs: 1 - 60 mg/L (PA water > 40 mg/L)

  NH_4^+: 0.4 – 4.7 mg N/L (PA water > 10 mg N/L)

- River sediment pore water

  NAs: ~ bkgd, except 9 mg/L @ 5A

  NH_4^+: > CCME (1 -2 mg N/L) @ 5, 5C, 6

- Benthic invertebrate community

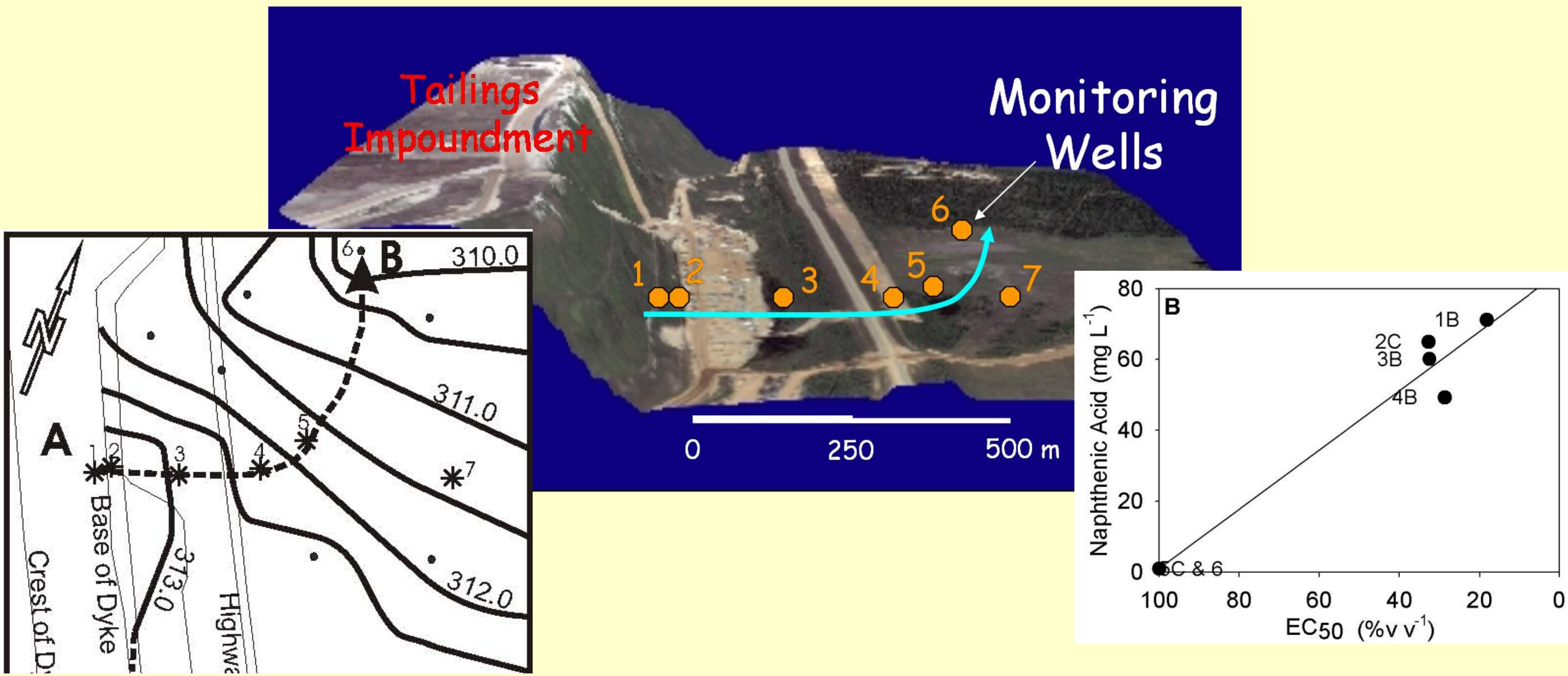
  Larval chironomid midges & tolerant oligochaete worms dominate.

  Similar density, richness, diversity to upstream communities

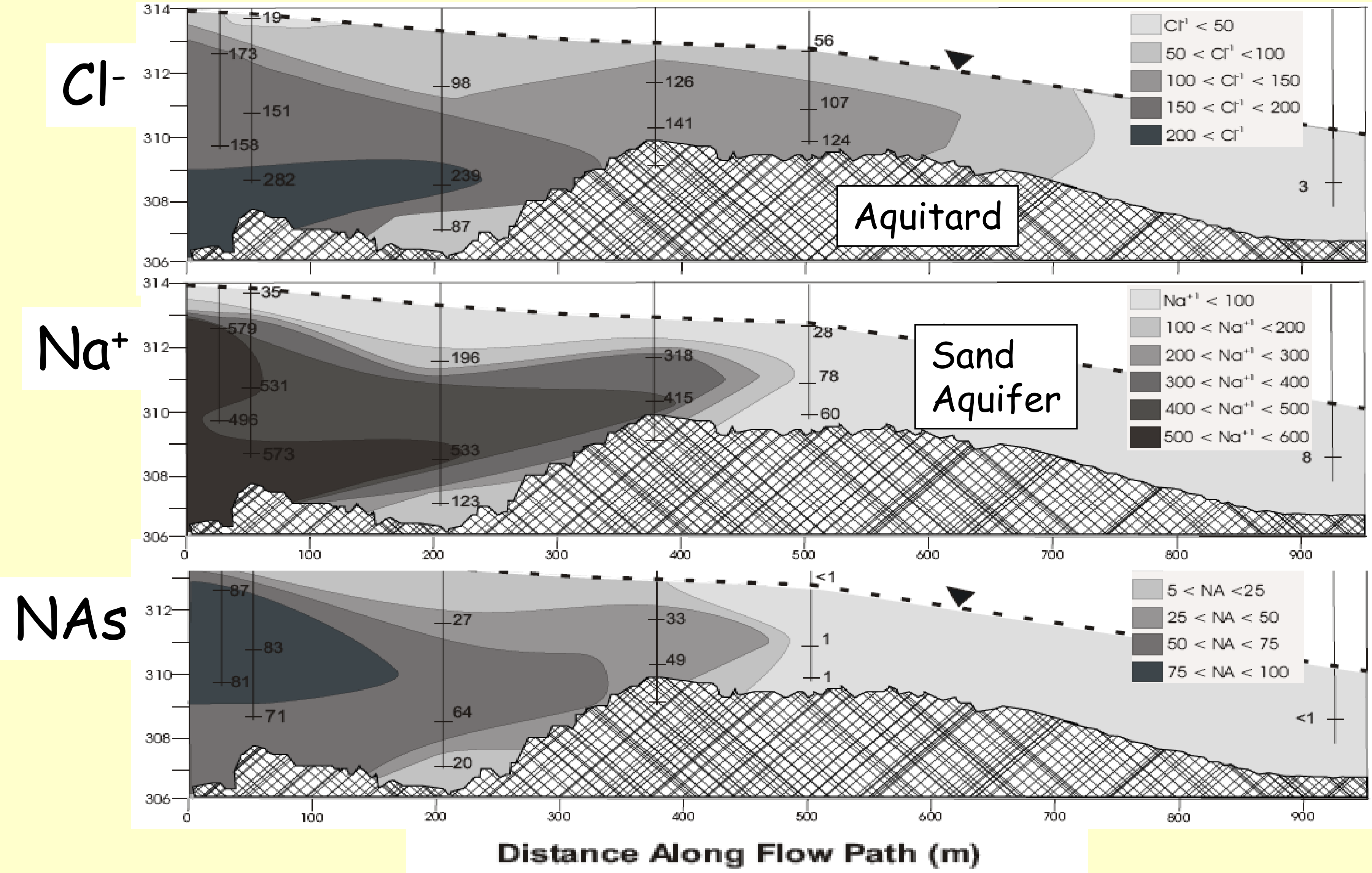
IPEC November, 2007

NAs at a Different Site

- Shallow sand aquifer adjacent to a tailings pond – process-affected water has escaped seepage collection



NAs in a Shallow Sand Aquifer



IPEC November, 2007

NAs in a Shallow Sand Aquifer

- Natural attenuation of Naphthenic Acids:
  - Mobile (perhaps some retardation, as Na^+)
  - Persistent under mildly anoxic aquifer conditions
  - Little attenuation capacity evident

Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada

- Will the seepage of process-affected water become a major problem?
  - improved tailings processing should minimize future tailings pond needs
  - On the other hand, new mines are encountering more shallow sand and so potential for impacts remains

- Ongoing research:
  - controlled release NAs studies underway
  - lab studies of NA biodegradation (U of Alberta)
  - ISCO lab and field trials planned

Attenuation of Contaminants in Groundwater Impacted by Surface Mining of Oil Sands, Alberta, Canada

- Research Support

CANADIAN WATER NETWORK
RÉSEAU CANADIEN DE L'EAU

NSERC
CRSNG

SUNCOR
ENERGY

Albian SANDS

Syncrude
Securing Canada's Energy Future

Canada Foundation for Innovation
Fondation canadienne pour l'innovation

Appendix VI:

Golder Associates, “Final Report: Beaver Creek Profiling System” (Golder Associates, February 2009)

FINAL REPORT

BEAVER CREEK PROFILING PROGRAM
2008 FIELD STUDY

Submitted to:

Syncrude Canada Ltd.
Fort McMurray, Alberta

DISTRIBUTION:

8 Copies	**Syncrude Canada Ltd.** **Fort McMurray, Alberta**
2 Copies	**Golder Associates Ltd.** **Calgary, Alberta**

February 2009 **08-1337-0003**

EXECUTIVE SUMMARY

The year 2007 marked the culmination of a three year monitoring program of Beaver Creek, which was carried out to ensure that risk management conclusions remained the same as those presented in the Beaver Creek Ecological Risk Assessment (ERA) (Golder 2004). The conclusions of the ERA were that there was some evidence for risk to the benthic invertebrate community immediately downstream of the lower seepage dam, but no risks to wildlife populations, fish or amphibians that use Beaver Creek.

Overall, the results of the three year monitoring program indicated that conditions have improved in Beaver Creek and the wastewater control system is working effectively to limit seepage water from the Mildred Lake Settling Basin (MLSB) from entering the creek. No unacceptable ecological risks to Beaver Creek due to the seepage of process water were identified, which supported the overall goal of the original ERA. Consequently the conclusions of the ERA remained valid and additional field studies were deemed not warranted (Golder 2007). However, as part of Syncrude Canada's (Syncrude's) commitment to environmental sustainability, additional monitoring of Beaver Creek was conducted in 2008 to continue to assess and document surface water quality and toxicity within the creek.

The 2008 Beaver Creek Profiling Program was a scaled-down version of the three year ERA monitoring program (2005 to 2007) and was designed to compliment data gathered during that time. Water samples were collected and analyzed for chemistry and toxicity. Sediment samples were analyzed for toxicity.

The objectives of the 2008 study were as follows:

- Objective 1: To confirm that seasonal/annual/spatial trends observed in 2008 were consistent with trends observed during previous years of study.
- Objective 2: To ensure that the conclusions from the three year ERA monitoring program remained valid, i.e., there are no unacceptable ecological risks to Beaver Creek due to the seepage of process water from the MLSB.

Results for Objective 1

Based on the results of the surface water testing, the conclusions for the first study objective were:

1. Surface water concentrations of most parameters were highest in March and decreased by fall. This trend is evident through 2005 to 2008 suggesting that perhaps contributions from spring thaw and surface water runoff are the main

source(s) of inorganic parameters in Beaver Creek, not seepage from the wastewater control system.

2. Surface water COC concentrations were generally highest immediately below the seepage dam at site BC-3 and decreased in a downstream direction toward BC-8.

3. The wastewater control system is operating effectively as surface water concentrations of naphthenic acids, a tracer of process-affected water, have decreased in samples from sites BC-3 and BC-6 since modifications were made to the pumping system below the dam.

Results for Objective 2

Based on the results of the toxicity testing, the conclusions for the second objective were:

1. Water collected from site BC-3 has a statistically significant effect on mortality and malformations in *Xenopus* larvae. This effect does not occur at the sites downstream of BC-3. A growth effect of less than 10% of the control mean growth is observable at all sites downstream of the seepage dam but this does not necessarily confer biological effect.

2. Water collected from BC-5 is not acutely toxic to rainbow trout or fathead minnows. This result has been consistently demonstrated from 2004 to 2008.

3. Significant differences in *Chironomus tentans* survival and growth were detected in sediment from Site BC-6 from Beaver Creek in 2008. This is similar to the 2007 *C. tentans* toxicity test results, when survival and growth were significantly different from controls at site BC-6. However, no differences were detected in growth and survival at Site BC-3 located immediately downstream of the seepage dam. This suggests that the effects detected in sediment samples are unlikely to be related to the toxicity of substances released from the seepage dam. Rather, a localized effect in the vicinity of Site BC-6 may account for the sediment effects observed at this location.

Overall, the results of the 2008 Beaver Creek Profiling Program indicate that conditions have remained stable in Beaver Creek since the culmination of the three year ERA field program and the wastewater control system is working effectively to limit seepage water from entering the creek. There were no substantial changes to COC concentrations in 2008, when compared to the ERA study from 2005 and 2007, indicating that conditions in Beaver Creek are relatively stable. There are no unacceptable ecological risks to Beaver Creek due to seepage of process water, which supports the overall goal of the original ERA.

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF TABLES

LIST OF FIGURES

LIST OF PHOTOGRAPHS

LIST OF APPENDICES

1 INTRODUCTION

The year 2007 marked the culmination of a three year monitoring program of Beaver Creek, which was carried out to ensure that risk management conclusions remained similar to those presented in the Beaver Creek Ecological Risk Assessment (ERA) (Golder 2004). The conclusions of the ERA were that there was some evidence for risk to the benthic invertebrate community immediately downstream of the lower seepage dam, but no risks to wildlife populations, fish or amphibians that use Beaver Creek.

Overall, the results of the three year monitoring program indicated that conditions have improved in Beaver Creek and the wastewater control system is working effectively to limit seepage water from the Mildred Lake Settling Basin (MLSB) from entering the creek. No unacceptable ecological risks to Beaver Creek due to the seepage of process water were identified, which supported the overall goal of the original ERA. Consequently the conclusions of the ERA remained valid and additional field studies were deemed not warranted (Golder 2007).

However, as part of Syncrude Canada's (Syncrude's) commitment to environmental sustainability, it was decided to conduct additional monitoring of Beaver Creek in 2008 to continue to assess and document surface water quality and toxicity within the creek. This report outlines the results of the 2008 Beaver Creek Profiling Program and provides comparison to previous years' data.

1.1 BACKGROUND

1.1.1 Mine Operation and Site Characterization

The Syncrude Mildred Lake site is located in north-eastern Alberta, 40 kilometres (km) north of the city of Fort McMurray. At Syncrude, oil sand is mined and bitumen is extracted and upgraded to synthetic crude oil. The three main by-products of the operation include tailings, sulphur and coke.

The Syncrude site can be divided into three general areas: the mine, the tailings areas, and the plant site. There are two open pit mines, Base Mine and North Mine; and three tailings areas, MLSB, Southwest Sand Storage (SWSS) and In-pit areas which are comprised of the West In-pit (WIP), the Southeast Pond (SEP) and the Northeast Pond (NEP). Other significant features include coke storage cells, overburden dumps, sulphur blocks, sand and gravel pits, sewage treatment facilities, and the Beaver Creek diversion.

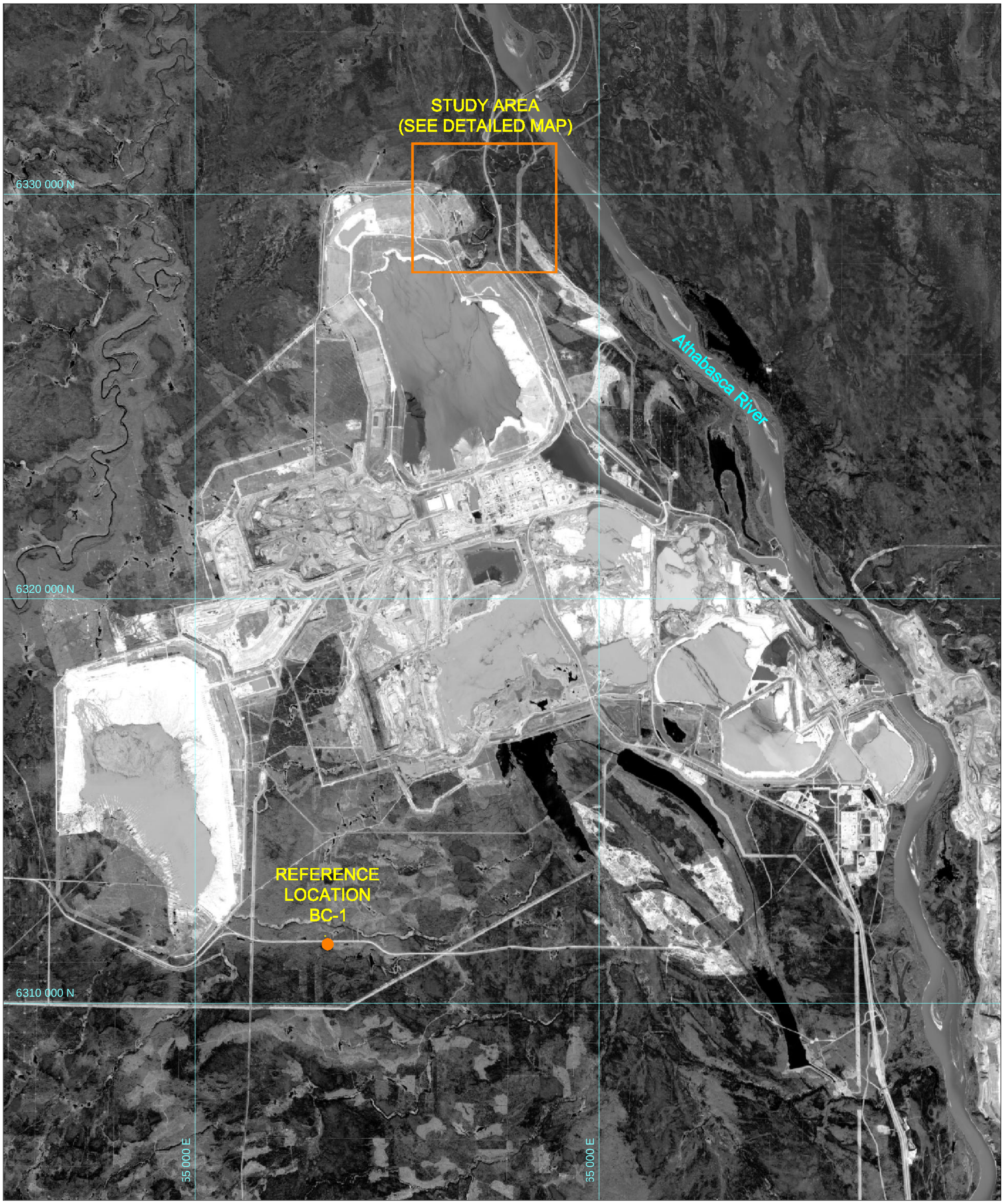
The surface mineable area is associated with the topographic low along the Athabasca River valley. The ore deposit is a bitumen-saturated sedimentary deposit of the Lower Cretaceous McMurray Formation. At the Mildred Lake Site, the open pit excavation reaches an average depth of 65 m and covers an area of approximately 39 square kilometres (km^2). A satellite photograph of the Syncrude Mildred Lake site is shown in Figure 1.1.

Beaver Creek is in a deeply incised valley northeast of the MLSB. During construction of the Mildred Lake Project, the headwaters of Beaver Creek were diverted into Poplar Creek. Therefore, flow within the creek below the MLSB is minimal. In addition, beaver activity in the creek has been extensive, which has changed the morphology of the creek into a series of beaver ponds rather than a free-flowing creek. There is abundant vegetation in the valley which provides habitat for deer, beaver, waterfowl and other birds and amphibians. Due to the low flow and abundant beaver activity, fish habitat is marginal and begins approximately 2 km downstream of the MLSB.

1.1.2 Process Water Seepage

Process water potentially seeping from the Mildred Lake oil sands lease is collected by a series of ditches and returned (by pump) to the MLSB via the seepage control pond. Two dams were constructed in 1999-2000 to retain water and prevent release of process-affected seepage water into Beaver Creek. The lower dam was constructed to increase the capacity of the control pond; ensuring process-affected water is not released to the surrounding environment during flood events. However, there have been contributions of process-affected water detected in Beaver Creek below the dam.

In 2003, work was undertaken to minimize the potential for process-affected water to seep through the lower dam into Beaver Creek. Modifications were made to the pumping system at the lower seepage dam to minimize the gradient across the dam. The modifications included the excavation of a deeper sump and ditching, and periodic operation of a pump to remove ponded water on the upstream side of the dam. Overall, there was less ponding of water in this area in 2004 and 2005. Groundwater monitoring carried out in Beaver Creek and the surrounding area in 2005 indicated that concentrations of major ions had decreased in 2004 and 2005, and remained steady through 2007 as a result of this mitigation.



3 0 3
SCALE KILOMETRES

PROJECT
Syncrude

TITLE

REFERENCE AND STUDY AREA LOCATIONS

Golder Associates
Calgary, Alberta

PROJECT	08.1337.0003.4000	
DESIGN	TD	05/01/08
CADD	YAW	05/01/08
CHECK	TD	02/02/09
REVIEW	RR	02/02/09

FILE No. Reference Loc
SCALE AS SHOWN REV. 0

FIGURE: 1.1

REFERENCES
AIRPHOTO OBTAINED FROM SYNCRUDE CANADA LTD.

L:\2008\1337 Fisheries\08-1337-0003\4000\ Drawing file: Figure 1 Reference -Study area Location.dwg Feb 03, 2009 - 10:23am

1.2 OBJECTIVES

The 2008 Beaver Creek Profiling Program was a scaled-down version of the three year ERA monitoring program (2005 to 2007) and was designed to compliment data gathered during that time. Sample locations remained the same as in previous years, so that results across years were comparable. Previous reports provided results of the 2004 to 2007 sampling programs (Golder 2005; 2006; 2007; 2008).

The objectives of the 2008 study were as follows:

- Objective 1: To confirm that seasonal/annual/spatial trends observed in 2008 were consistent with trends observed during previous years of study.
- Objective 2: To ensure that the conclusions from the three year ERA monitoring program remained valid, i.e., there are no unacceptable ecological risks to Beaver Creek due to the seepage of process water from the MLSB.

To answer the above stated objectives, the following evaluations were completed:

- 2008 water quality, FETAX and chironomid assay data were compared among sites;
- 2008 water quality was compared to water quality measured during previous studies (2004 - 2007); and
- results of the fathead minnow, rainbow trout, chironomid, and FETAX toxicity tests were compared among years (2004 - 2008).

2 METHODS FOR 2008 PROFILING PROGRAM

This section describes the sampling locations and methods for the 2008 Beaver Creek Profiling Program. Fieldwork was completed during two separate field sampling events in 2008, March 17th to 19th and September 8th to 10th. Samples were collected for water quality analysis and toxicity testing on both sampling dates, while sediment samples for the chironomid toxicity assay were collected during the September sampling period only.

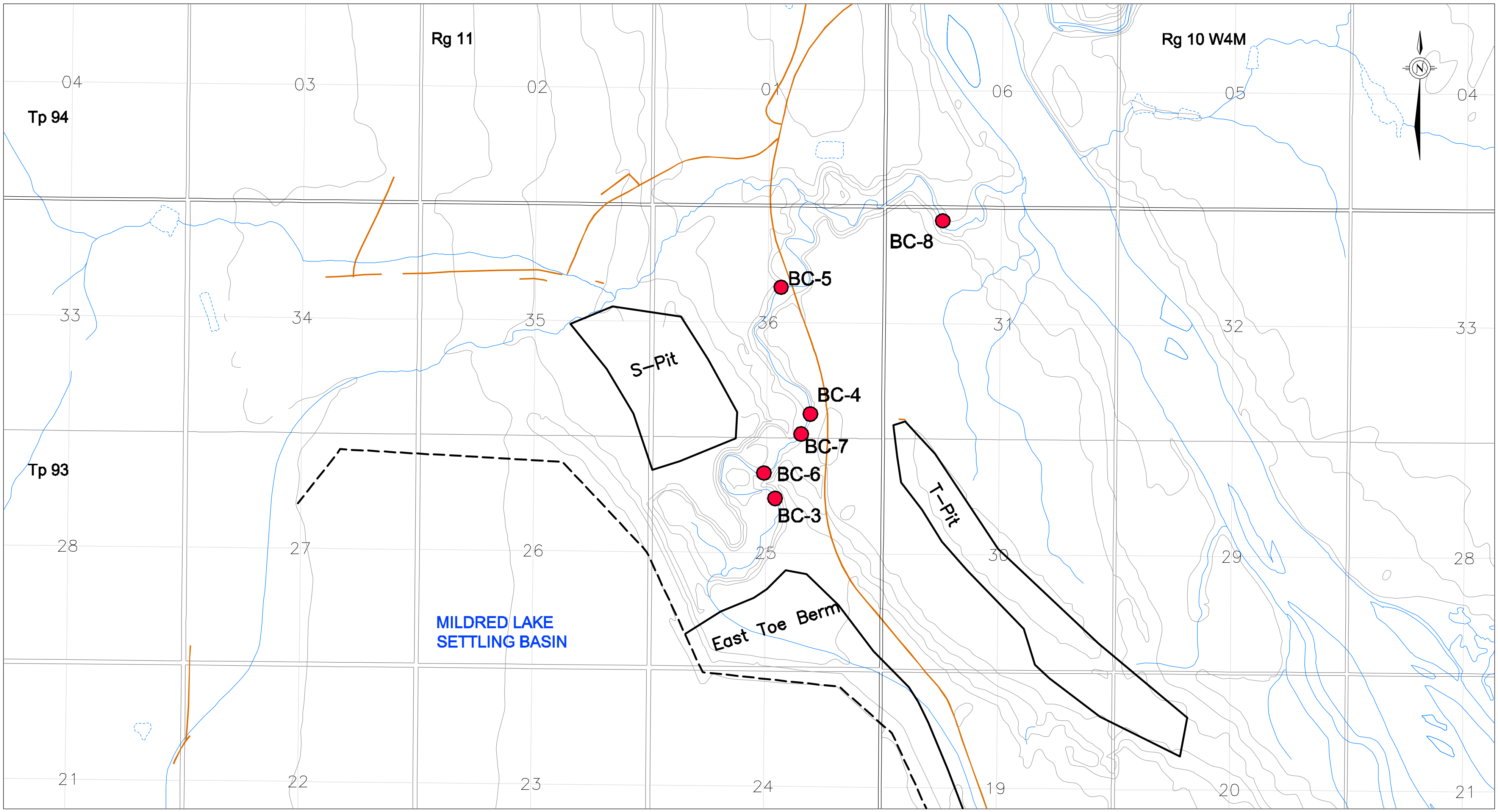
2.1 SAMPLE LOCATIONS

The 2008 Beaver Creek Profiling Program utilized the same sampling sites as those studied in the 2004 to 2007 Beaver Creek ERA monitoring program. The original 2004 sampling regime was designed to evaluate effects along a gradient of exposure in Beaver Creek from immediately downstream of the lower seepage dam (BC-3), to the confluence with the Athabasca River (BC-8). Thus, data were grouped into general geographical areas: upstream reference area (BC-1); immediately downstream of the lower seepage dam (BC-3, BC-6, and BC-7); midway between the dam and Highway 63 (BC-4); at Highway 63 (BC-5) and a downstream reference site at the confluence with the Athabasca River (BC-8). The location of the upstream reference area (BC-1) is shown in Figure 1. Detailed sample site locations are presented in Table 2.1 and Figure 2.1.

Table 2.1 Sampling Dates and Locations for the 2008 Beaver Creek Profiling Program

Sample Site	March 2008			September 2008		
	UTM Coordinate (WGS 84)		Sampling Date	UTM Coordinate (WGS 84)		Sampling Date
	Easting	Northing		Easting	Northing	
BC-1	458223	6311656	17-Mar	458220	6311657	08-Sep
BC-3	461970	6328770	18-Mar	461961	6328762	09-Sep
BC-6	461829	6328934	18-Mar	461869	6329010	09-Sep
BC-7	462194	6329502	19-Mar	462142	632920	10-Sep
BC-4	462091	6329568	19-Mar	462224	6329353	10-Sep
BC-5	462016	6330239	19-Mar	462022	6330241	08-Sep
BC-8	463136	6330688	17-Mar	463140	6330682	08-Sep

L:\2008\1337 Fisheries\08-1337-0003\4000\ Drawing file: Figure 2.1 Sampling Locations.dwg Feb 03, 2009 – 12:17pm



LEGEND

● BC-3 2008 SAMPLE LOCATIONS

SCALE 1 0 1 KILOMETRES

REFERENCE

Alberta Digital Data Obtained From AltaLIS Ltd. (September 2004.) used under license.
Projection: Transverse Mercator Datum: Nad 83 Coordinate System: Utm Zone 12

PROJECT

Syncrude

TITLE

SAMPLING LOCATIONS IN BEAVER CREEK

Golder Associates
Calgary, Alberta

PROJECT	08.1337.0003.4000		FILE No. Sampling Locations
DESIGN	TD	05/01/09	SCALE AS SHOWN REV. 0
CADD	YAW	05/01/09	FIGURE: 2.1
CHECK	TD	02/02/09	
REVIEW	RR	02/02/09	

2.1.1 Site Descriptions

2.1.1.1 BC-1

The Beaver Creek reference site (BC-1) is located about five kilometres south of the Syncrude site (Photo 1). The sample site is located in a lowland area (i.e., grassland and wetland characteristics) with a generally flat topography. The sample site is ephemeral; water flows through the channel during flood events only. Fisher Marten (*Martes pennanti*) tracks, boreal chorus frogs (*Pseudacris maculate)* and moose (*Alces alces*) scat have been observed at this site during previous sampling events.

2.1.1.2 BC-3

Site BC-3 is located approximately 200 m downstream of the Lower Seepage Dam (Photo 2). This area was cleared during construction of the dam and many pioneer species (i.e., shrubs) are present. In this location, the creek has cut through the surrounding topography to form a river valley. Downstream of the sample site, the forest changes from a successional forest to a mature stand of poplar (*Populus spp.*) and spruce (*Picea spp.*). The water is stagnant at this pooled site. In July 2007, boreal chorus frogs and tadpoles (*Pseudacris maculate*) were observed at this site; in September 2007 a wolf (*Canis lupus*) was observed at this site.

Photo 1 BC-1 (September 2008)

Photo 2 BC-3 (September 2008)

2.1.1.3 BC-6

BC-6 is located approximately 1 km downstream of the Lower Seepage Dam in a pooled area between two old beaver dams with little or no water flow (Photo 3). The topography of the surrounding area is generally flat, with a forest composed of a mixture of mature poplar and spruce. A steep cliff rises to the east of the creek at this location. Due to the gentle topography, this area of the creek is composed of either pools, or a slow moving channel. In addition to birds, BC-6 also contains suitable habitat for amphibians and moose; weasel and rabbit activity is evident. Approximately 20% of the water surface is covered by aquatic vegetation. In July 2007, boreal chorus frogs and tadpoles were observed at this site.

2.1.1.4 BC-7

BC-7 is located approximately 1.5 km downstream of the Lower Seepage Dam (Photo 4). The site is the start of the river valley topography which continues throughout the remainder of the downstream sample locations. A steep limestone bank is situated to the east of the site, which has resulted in a landslide of sand into the creek. Water flow is minimal at this site; spruce trees are prevalent along the banks. Approximately 95% of the watercourse is covered with milfoil (*Myriophyllum spp.*) and bladderwort (*Ultricularia spp.*). In July 2007, numerous tadpoles were observed at this site; moose scat was observed at this site in March 2008.

2.1.1.5 BC-4

BC-4 is located 1.7 km downstream of the Lower Seepage Dam (Photo 5). The steep river valley topography continues through this stretch of the creek. BC-4 is a beaver pond, positioned between two beaver dams. The water at this site is clear and flows at a very slow rate. Shrub (willow, *Salix spp.*), grass species, and spruce trees dominate the surrounding riparian vegetation. A shale deposit exists along the banks of the creek. A variety of small bird species have been observed at this site.

2.1.1.6 BC-5

BC-5 is located in a pooled area (i.e., a beaver pond) approximately 3 km downstream of the Lower Seepage Dam (Photo 6). A beaver dam exists to the east side of the pond. The steep river valley topography continues through this stretch of the creek with the rock changing from shale to limestone. The sample site is approximately 100 m west of Highway 63. The area has shallow, slow-moving water with a maximum depth of 40 cm. The banks are composed of grass species and approximately 95% of the water surface is covered with aquatic vegetation. Brook stickleback (*Culaea inconstans*) are commonly observed at this site; Western tanagers (*Piranga ludoviciana)*, spotted sandpipers (*Actitis macularius)* and evening grosbeaks (*Coccothraustes vespertinus)* have been observed at this site.

Photo 3 BC-6 (September 2008)

Photo 4 BC-7 (September 2007)

Photo 5 BC-4 (September 2008)

Photo 6 BC-5 (September 2008)

2.1.1.7 BC-8

BC-8 is located approximately 1 km upstream of the confluence of Beaver Creek with the Athabasca River (Photo 7). Site BC-8 was added to the field study in 2004 since: (1) there were habitat differences between the upstream reference site (BC-1) and the other sites located downstream of the seepage dam (BC-1), and (2) Alberta Environment (AENV) were concerned about potential impacts on the Athabasca River. This area was subjected to a forest fire approximately 10 years ago. The river valley topography noted at BC-4 and BC-5 continues at this site. A pipeline is present in this area and recent construction close to the sample site has resulted in the re-establishment of willow species along the banks of the creek. Water flow in the channel is slow, with abundant woody debris. A maximum water depth to 20 cm was recorded at this site and rust-coloured algae and iron deposits are evident within the creek channel. A variety of small bird species were observed at this site.

Photo 7 BC-8 (September 2008)

2.1.2 Sample Descriptions

Water and sediment samples were collected during the 2008 Profiling Program. The types of samples, analyses and sample locations are presented in Table 2.2.

Table 2.2 Types of Samples, Analyses and Sample Locations for the 2008 Beaver Creek Profiling Program

Media	Type of Analysis	Upstream Reference Location	Downstream Locations					Downstream Reference Location
		BC-1	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
water	Routine Parameters and Ammonia Total Metals Naphthenic Acids Polycyclic Aromatic Hydrocarbons (PAHs) and Alkylated PAHs	x	x	x	x	x	x	x
water	Fathead Minnow and Rainbow Trout toxicity tests						x	
water	Frog Embryo Teratogenicity Assay – *Xenopus* (FETAX)		x[a]	x	x	x	x	x
sediment[b]	Chironomid Assay		x	x	x	x	x	x

[a] Definitive toxicity test. Screening-level FETAX tests at the remaining sample sites.
[b] Chironomid assays in September only.

2.2 WATER SAMPLING METHODS

Prior to sampling at each location, temperature, conductivity, dissolved oxygen and pH were recorded using a Quanta Multiline P4 water quality meter. Samples were collected in appropriate pre-cleaned containers provided by the analytical laboratory. Bottles for metals analyses were triple-rinsed using creek water prior to sampling. Bottles for other types of samples were not rinsed. Grab samples of water were collected by submerging sample bottles approximately 0.15 m under the water surface. Water samples collected for analysis of total metals were preserved according to instructions from the analytical laboratory. Samples were placed on ice, in coolers, and shipped to the laboratory (ALS Laboratory Group, Edmonton, AB) at the end of each sampling day.

Water samples were also collected for conducting toxicity tests on rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*) and frog embryos (*Xenopus laevis*) (FETAX). Water samples for conducting the rainbow trout and fathead minnow toxicity tests were placed on ice, in coolers, and shipped to HydroQual Laboratories (Calgary, AB) at the end of the sampling day. Water samples for conducting FETAX were placed on ice, in coolers, and shipped to Fort Environmental Laboratories Ltd., (Stillwater, Oklahoma, USA) at the end of each sampling day.

2.3 SEDIMENT SAMPLING METHODS

Sediment samples were collected using an Ekman grab. Sediment samples were placed in 5 litre (l) containers provided by HydroQual. Sufficient grabs were taken at each site to fill the containers. Samples were placed on ice, in coolers, and shipped to HydroQual at the end of each day.

2.4 QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

2.4.1 Field Protocol

Water QA samples were collected for the 2008 Profiling Program. These samples were submitted blind (unique sample ID) to the analytical laboratory (ALS) as part of the field quality control procedures. QA/QC samples consisted of field blanks and field duplicates, collected at site BC-3, on both sampling dates.

Field blanks were water samples that consisted of distilled water provided by the analytical laboratory. The water was transferred into sample bottles in the field and treated in the same way as the actual water samples (i.e., preserved, stored and transported). The purpose of the field blanks was to assess potential contamination from sample bottles, field procedures or laboratory error. Field blanks should have values well below the quantified levels in the actual samples and should not have concentrations that are greater than five times the detection limit (US EPA, 1985).

Duplicate samples provide an indication of heterogeneity among samples. The acceptable Relative Percent Difference (RPD) between duplicate samples should be no more than 20% (US EPA, 1985).

2.4.2 Data Analysis

Several QC measures were taken in order to ensure the integrity of data management. Macros were used to organize the data once it was received from the analytical laboratory. This reduced the possibility of transcription errors and highlighted any naming irregularities and redundancies in the original data set.

Ten percent of the water and sediment data in the final database was then cross-checked back to the original data sets in order to capture any possible transcription errors in reported units or values.

2.5 TOXICITY TESTS

Toxicity testing was conducted in 2008 using frog embryos (FETAX), rainbow trout, fathead minnow, and chironomid (*Chironomus tentans*) larvae. All toxicity tests were conducted in accordance with established protocols (Environment Canada 1990, 1992, 1997; ASTM E1439-98). The methodology for each of the above mentioned toxicity tests are outlined in the subsequent sections.

2.5.1 Frog Embryo Toxicity Assay - *Xenopus* (FETAX) Methodology

Xenopus Assay

The 96-hour whole embryo assays (FETAX) were performed by Fort Environmental Laboratories, Stillwater, Oklahoma, using test method ASTM E1439-98, with a modification for increased replicates. Two separate assays were conducted, a screen assay and a definitive assay. For the screen assay, water samples from BC-3, BC-4, BC-5, BC-6, BC-7 and BC-8 were tested at 100% strength. For the definitive assay, a water sample from BC-3 was tested using five concentrations (50%, 75%, 90%, 95% and 100%). All treatments were tested in replicates of four, using test vessels containing 25 *Xenopus laevis* embryos and 200 mL of each test concentration per replicate. Frog embryos were cultured at 24 °C ±2 °C. Dead embryo removal and water changes were performed daily throughout the testing period.

At the end of the 96-hour test period, the number of live larvae in each test concentration was determined. Larvae were then preserved in 3% formalin and the number of malformed larvae was determined using a dissecting microscope. FETAX solution water was used as the laboratory negative control and dilution water, where appropriate, for the assays. Two concentrations (2,500 mg/L and 5.5 mg/L) of the chemical 6-aminonicotinamide (6-AN) were used as positive reference controls to induce embryo-lethality and effect (malformation) in the test culture. The FETAX screen and definitive tests were conducted side by side, with both the negative and positive laboratory controls being shared by both assays. The FETAX data endpoints included mortality, malformation and growth measurements.

Data Analysis

Mortality and malformation frequencies were determined for each test treatment. Head-to-tail lengths of the surviving larvae were measured (cm) as an index of growth (mean sample growth divided by mean control growth, expressed as a percent). Trimmed Spearman-Karber 1.5 (USEPA, Cincinnati, OH) analysis was used to determine the 4-day LC50 and EC50 concentrations. To determine if statistically significant differences existed between the FETAX control solution and the site water treatments, an ANOVA with a Bonferroni t-test ($p<0.05$) and Kruskal Wallace (KW) ANOVA with Dunn's Method ($p<0.05$) were perfomed. Descriptive and ANOVA statistical calculations were performed by Fort Environmental Labs using SigmaStat ® 2.03 statistical software (SPSS ® Inc., Chicago IL).

2.5.2 Rainbow Trout and Fathead Minnow Methodology

Rainbow trout and fathead minnow toxicity tests were performed by HydroQual Laboratories, Calgary, Alberta, on water samples collected from site BC-5. Site BC-5 was chosen as this is the singular site were fish presence has been confirmed (Golder 2004).

Rainbow Trout Assay

96-hour rainbow trout static acute toxicity tests were performed on water collected from site BC-5. One replicate of each treatment was analyzed; treatments consisted of five dilution concentrations (6.25, 12.5, 25, 50, 100% v/v), a positive control (phenol), a whole water sample, and a control treatment (de-chlorinated City of Calgary water). Experimental protocol was followed as outlined in Test method EPS 1/RM/13, with 1996 and 2000 amendments (Environment Canada 1990).

Fathead Minnow Assay

Seven-day fathead minnow larval growth and survival static renewal tests were performed on water collected from site BC-5 in September 2008. Tests were not performed in March as a result of fish supply issues at HydroQual. Four replicates within each treatment were analyzed; treatments consisted of five dilution concentrations (6.25, 12.5, 25, 50, 100% v/v), a positive control (phenol), a whole water sample, and a control treatment (de-chlorinated City of Calgary water). Experimental protocol was followed as outlined in Test method EPS 1/RM/22, amended 1997 (Environment Canada 1992).

Data Analysis

Endpoints for survival (LC_{50}, LC_{25}) and growth (IC_{25}, IC_{50}) were determined by HydroQual for both the rainbow trout and fathead minnow assays.

2.5.3 *Chironomus* Toxicity Methodology

Chironomus Assay

Chironomus sediment toxicity tests were conducted on sediments collected from all sample locations downstream of the MLSB in September. The test species was *Chironomus tentans,* a sediment-dwelling benthic invertebrate that is a common member of the benthic invertebrate community in Beaver Creek.

The chironomid laboratory assay consisted of a 10-day static chironomid survival and growth test. Tests were run on whole sediment samples, each with five laboratory replicates. Treatments also included a laboratory control (silica sand #30 grit and de-chlorinated City of Calgary water) and a positive control (KCl-water only). Test method EPS 1/RM/22, amended 1997 (Environment Canada 1997) was followed for toxicity testing.

An initial assay, set up by HydroQual within the permitted sampling window, failed the testing protocol due to elevated mortality in the control treatments. The test assay was therefore reset with a protocol deviation; samples were outside of the six week holding time by 3 days. Mortality in the control treatments for this test fell within the acceptable limits.

Data Analysis

Chironomid survival and growth data were tested for significant differences from laboratory controls by Golder using a one-way analysis of variance (ANOVA) and Dunnett's test.

3 RESULTS OF 2008 PROFILING PROGRAM

The results of the 2008 Beaver Creek Profiling Program are presented in the following section. Comparison of the 2008 results to previous sample programs, and interpretation of the 2008 results are presented in Section 4.

3.1 WATER QUALITY

3.1.1 Conventional Parameters

Water quality information on conventional parameters, recorded during the two sampling periods in 2008, is presented in Table 3.1. Information is not provided for site BC-1 in March because no water was present at this site at the time of sampling.

The lowest field measured dissolved oxygen (DO) concentrations were recorded in March at sites BC-6 and BC-5. DO concentrations at these two sites were below the Canadian Council of Ministers (CCME) DO guideline of 5.5 mg/L (CCME 1999). DO concentrations increased at these sites during the subsequent sampling event in September and were above the CCME guideline. DO concentrations at all other sites were above the CCME DO guideline on both sampling events.

For sampling periods in both March and September, 2008, specific conductance and alkalinity values were highest at site BC-3 and tended to decrease with distance downstream from the seepage dam (Table 3.1). Water pH values were within the CCME guideline range of 6.5 to 9 for all sites and sampling periods.

Bicarbonate concentrations were highest immediately downstream of the seepage dam (i.e., BC-3) and decreased with distance downstream. Total dissolved solids (TDS) showed a similar trend.

Table 3.1 Conventional Water Quality Parameters at Sites Sampled in Beaver Creek, March and September, 2008

Variable	March							September						
	BC-1	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8	BC-1	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
Field Measured Water Characteristics														
Dissolved Oxygen (mg/L)	-	7.00	5.05	7.58	8.82	2.38	18.39	9.17	13.70	9.56	7.90	6.90	11.64	10.74
Specific Conductance (µS/cm)	-	1,819	1,368	1,012	875	751	866	214	1,044	846	968	954	824	449
pH	-	7.1	7.3	6.7	7.3	7.7	7.5	8.2	8.4	8.2	9.1	9.5	7.7	7.8
Water Temperature (°C)	-	0.01	-0.02	0.14	-0.06	-0.03	0.16	6.97	11.30	10.80	8.96	9.50	8.20	8.00
Laboratory Measured Water Characteristics														
Bicarbonate (mg/L)	-	1,070	808	368	358	410	411	99	536	381	407	378	379	236
Carbonate (mg/L)	-	<5	<5	<5	<5	<5	<5	<5	9	5	<5	<5	<5	<5
Hydroxide (mg/L)	-	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Alkalinity, Total (as $CaCO_3$)(mg/L)	-	877	662	302	294	336	337	81	455	321	333	310	311	194
Total Dissolved Solids (calculated) (mg/L)	-	1,780	1,380	1,370	1,250	928	979	189	875	707	693	686	711	384
Hardness (as $CaCO_3$) (mg/L)	-	543	487	985	882	424	476	124	334	268	362	339	342	213

- = no water present at time of sampling

3.1.2 Concentrations of Chemicals of Concern in Water

To maintain consistency with the previous ERA monitoring program, the Chemicals of Concern (COC) analyzed for the 2008 Profiling Program remained the same as those identified in the 2004 ERA (Golder 2004). For the water matrix, the COCs are as follows:

- aluminum, barium, boron, calcium, chloride, iron, magnesium, manganese, sodium, strontium and napthenic acids.

COC water chemistry results for March and September are summarized in Table 3.2, and are graphically presented below. Water chemistry results are not available for Site BC-1 in March, as water was not present at the site during the sampling period.

COC concentrations are compared to CCME guidelines for the protection of aquatic life, where available (CCME 1999). Complete water chemistry results (raw data) are presented in Appendix I.

Aluminum

Total aluminum concentrations in water samples from all sites in 2008 ranged from 0.02 mg/L at sites BC-7 and BC-8 to 0.65 mg/L at site BC-3 in March, and 0.01 mg/L at sites BC-5 and BC-7 to 0.25 mg/L at site BC-1 in September (Figure 3.1). Aluminum concentrations at sites BC-3 in March, and BC-8 in September were above the CCME guideline of 0.1 mg/L. Surface water aluminum concentrations at BC-1 (upstream reference site) also exceeded the CCME guideline in September when a concentration of 0.25 mg/L was recorded.

Figure 3.1 Beaver Creek Surface Water Aluminum Concentrations for March and September, 2008

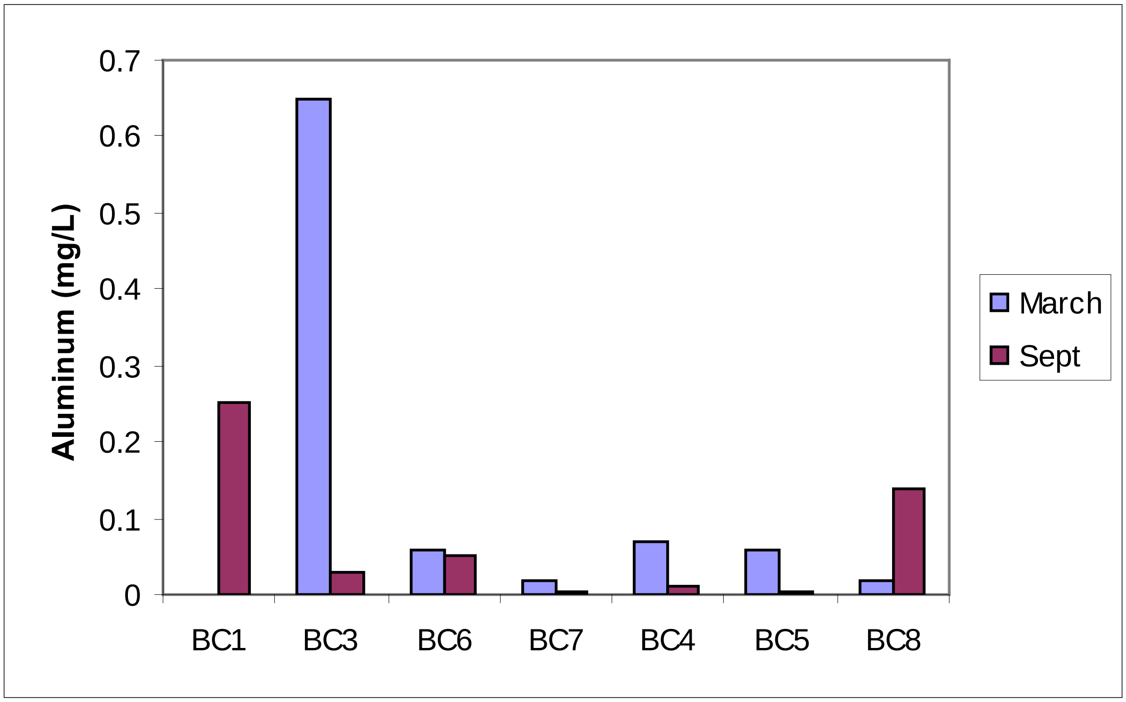


Table 3.2 Summary of Surface Water Concentrations of COC in Beaver Creek; March and September 2008

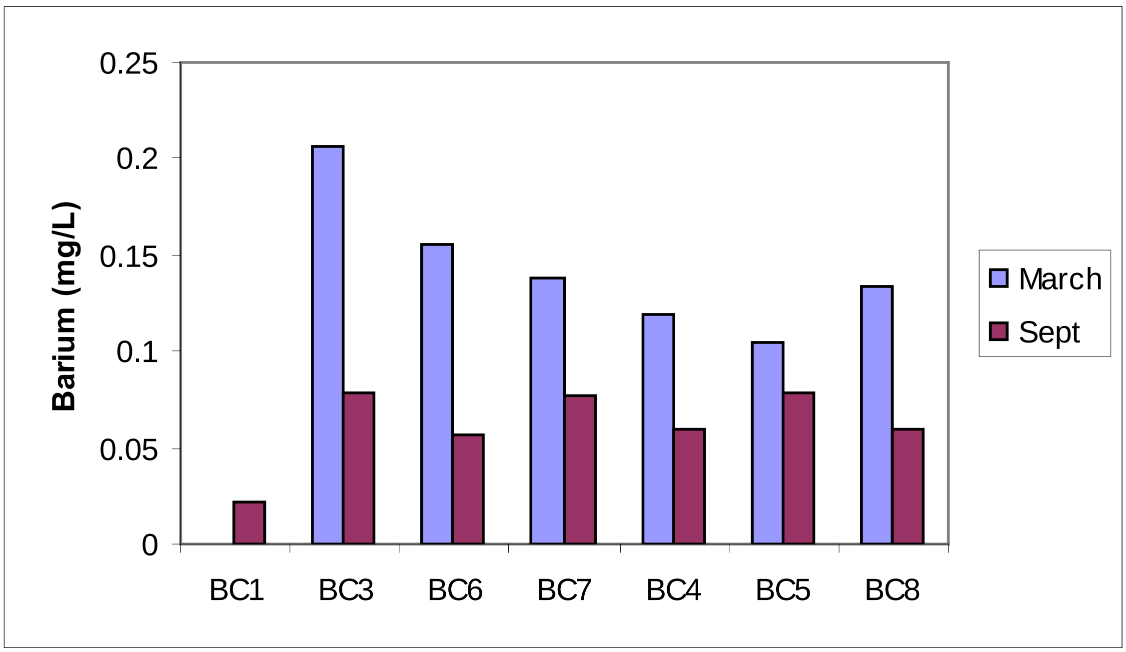
Parameter	BC-1		BC-3		BC-6		BC-7		BC-4		BC-5		BC-8	
	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept	Mar	Sept
Chloride (mg/L)	-	25	518	172	416	143	178	96	178	108	170	118	232	68
Aluminum (mg/L)	-	0.25	0.65	0.03	0.06	0.05	0.02	<1.00	0.07	0.01	0.06	<1.00	0.02	0.14
Barium (mg/L)	-	0.022	0.207	0.079	0.155	0.056	0.138	0.077	0.119	0.060	0.105	0.078	0.133	0.059
Boron (mg/L)	-	<0.05	0.39	0.37	0.39	0.36	0.07	0.24	0.09	0.26	0.17	0.19	0.15	0.12
Calcium (mg/L)	-	30.8	127.0	77.8	82.9	47.5	265.0	87.0	258.0	72.0	112.0	92.8	107.0	58.5
Iron (mg/L)	-	0.655	19.500	0.314	1.720	0.336	9.970	0.534	1.250	0.440	0.606	0.417	3.0	2.59
Magnesium (mg/L)	-	11.2	51.5	35.7	58.3	33.3	61.5	38.1	63.1	37.0	31.2	30.1	31.4	17.3
Manganese (mg/L)	-	0.014	1.450	0.016	0.775	0.064	0.594	0.030	0.434	0.067	0.074	0.020	0.484	0.212
Sodium (mg/L)	-	26	540	215	363	164	95	117	108	128	181	134	165	70
Strontium (mg/L)	-	0.154	0.519	0.324	0.532	0.280	0.470	0.313	0.486	0.291	0.267	0.249	0.48	0.25
Napthenic Acids (mg/L)	-	<1	15	5	9	3	1	2	1	2	3	2	3	<1

- = no water present at time of sampling

Barium

In March, barium concentrations were highest at site BC-3 and gradually decreased with distance downstream (with the exception of site BC-8). This trend was not evident in September. At all sites, barium concentrations were higher in March. Concentrations ranged from 0.11 mg/L at BC-5 to 0.21 mg/L at BC-3 in March, and from 0.02 mg/L at BC-1 to 0.08 mg/L at BC-5 and BC-7 in September (Figure 3.2). There is no CCME guideline for barium.

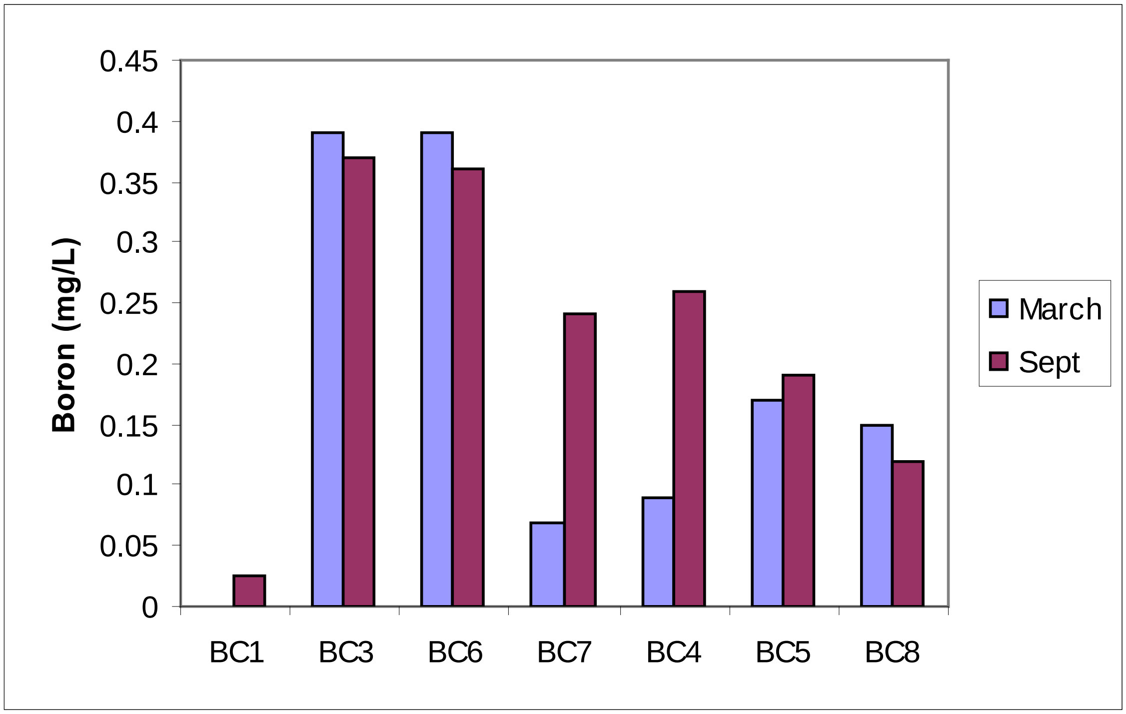
Figure 3.2 Beaver Creek Surface Water Barium Concentrations for March and September, 2008



Boron

Total boron concentrations in water samples ranged from 0.07 mg/L at site BC-7 to 0.39 mg/L at BC-3 and BC-6 in March, and from < 0.05 mg/L at BC-1 to 0.37 mg/L at BC-3 in September (Figure 3.3). For both sample periods, Boron concentrations were highest at sites BC-3 and BC-6. There is no CCME guideline for boron.

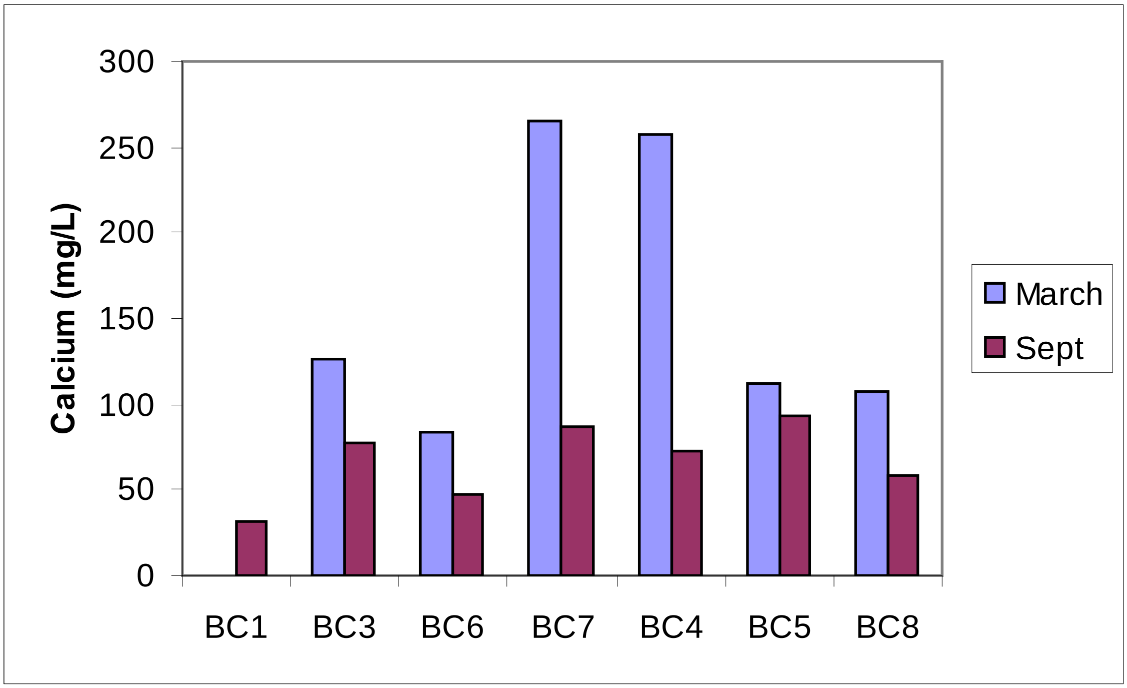
Figure 3.3 Beaver Creek Surface Water Boron Concentrations for March and September, 2008



Calcium

Calcium concentrations were highest at sites BC-7 and BC-4 in March. Concentrations in water samples ranged from 82.9 mg/L at BC-6 to 265 mg/L at BC-7 in March, and from 30.8 mg/L at BC-1 to 92.8 mg/L at BC-5 (Figure 3.4). Calcium concentrations in water collected at BC-1 in September were lower (30.8 mg/L) relative to all other sites (Figure 3.4). There is no CCME guideline for calcium.

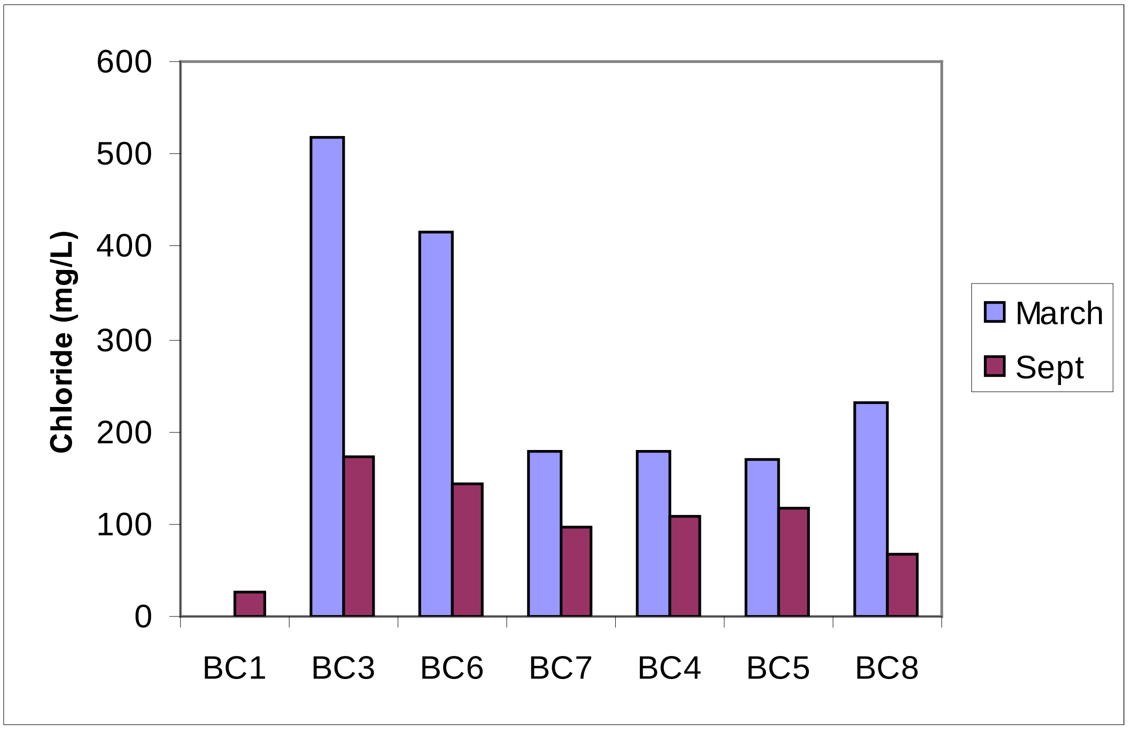
Figure 3.4 Beaver Creek Surface Water Calcium Concentrations for March and September, 2008



Chloride

In March, chloride concentrations were highest at sites BC-3 (518 mg/L) and BC-6 (416 mg/L) (Figure 3.5). Chloride concentrations at these sites were lower in September (172 and 143 mg/L respectively).

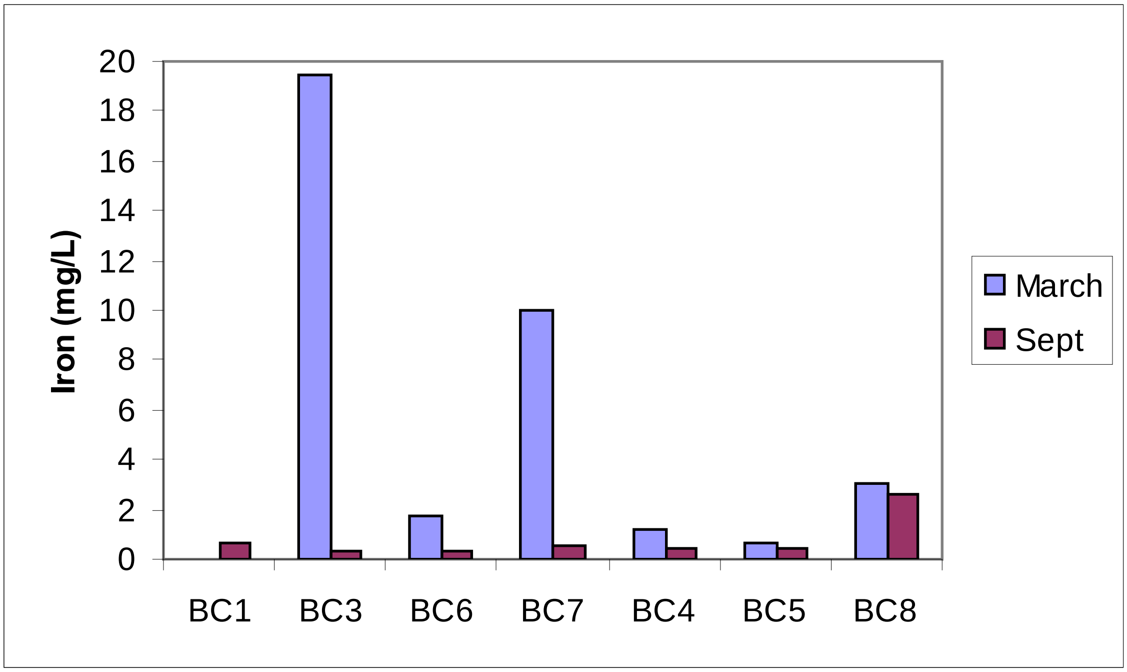
Figure 3.5 Beaver Creek Surface Water Chloride Concentrations for March and September, 2008



Iron

Total iron concentrations ranged from 0.61 mg/L at BC-5 to 19.5 mg/L at BC-3 in March, and from 0.31 mg/L at BC-3 to 2.59 mg/L at BC-8 in September (Figure 3.6). The CCME surface water quality guideline for iron is 0.3 mg/L (CCME 1999). Surface water iron concentrations at BC-1 (upstream reference site) also exceeded the CCME guideline where a value of 0.66 mg/L was recorded.

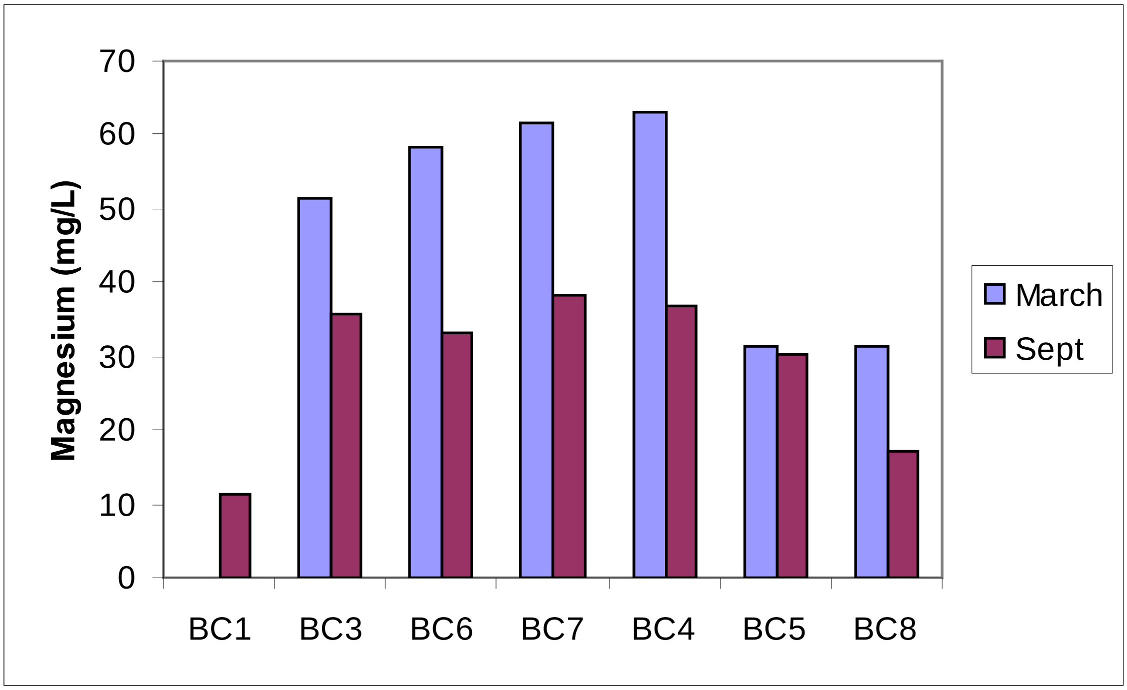
Figure 3.6 Beaver Creek Surface Water Iron Concentrations for March and September, 2008



Magnesium

At all sites downstream of the MLSB magnesium concentrations were higher in March than in September. Concentrations ranged from 31.2 mg/L at BC-5 to 63.1 mg/L at BC-4 in March, and from 11.2 mg/L at BC-1 to 38.1 mg/L at BC-7 in September (Figure 3.7). There is no CCME guideline for magnesium.

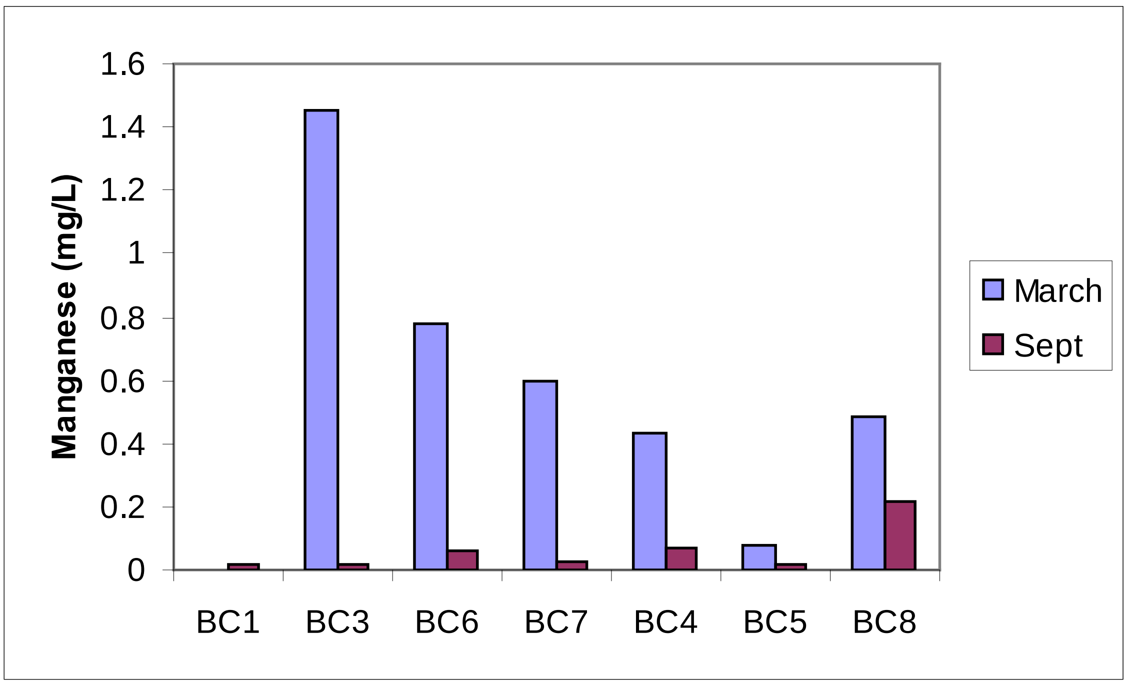
Figure 3.7 Beaver Creek Surface Water Magnesium Concentrations for March and September, 2008



Manganese

In March, manganese concentrations were highest at site BC-3 and gradually decreased with distance downstream (with the exception of site BC-8). Concentrations ranged from 0.074 mg/L at BC-5 to 1.45 mg/L at BC-3 in March, and from 0.014 mg/L at BC-1 to 0.212 mg/L at BC-8 in September (Figure 3.8). There is no CCME guideline for manganese.

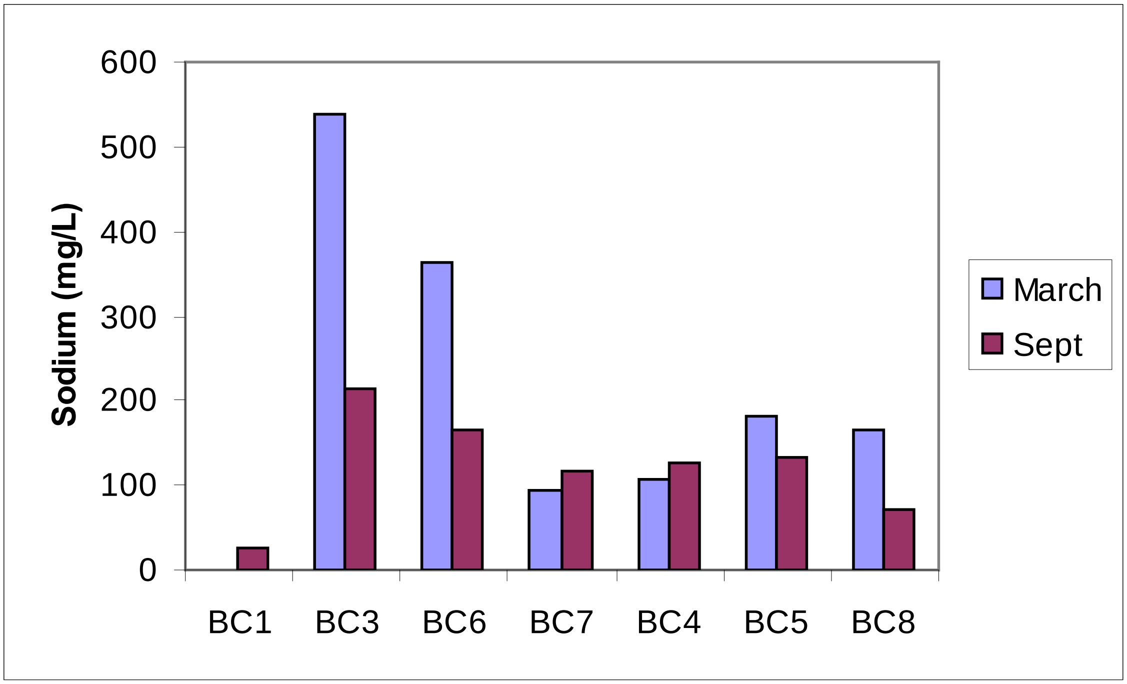
Figure 3.8 Beaver Creek Surface Water Manganese Concentrations for March and September, 2008



Sodium

The highest sodium concentrations were measured at sites BC-3 and BC-6 in March. Concentrations ranged from 95 mg/L at BC-7 to 540 mg/L at BC-3 in March, and from 26 mg/L at BC-1 to 215 mg/L at BC-3 in September (Figure 3.9).

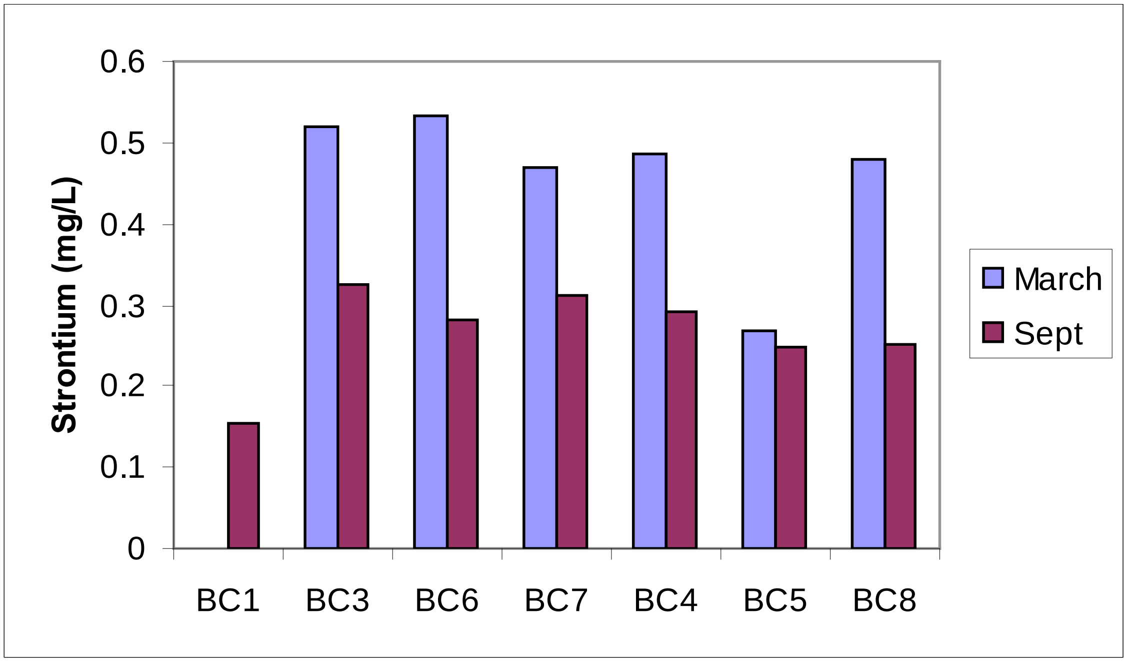
Figure 3.9 Beaver Creek Surface Water Sodium Concentrations for March and September, 2008



Strontium

In March, strontium concentrations were lowest at site BC-5 (0.27 mg/L). Concentrations at all other sites downstream of the MLSB were similar (ranging from 0.53 mg/L at BC-6 to 0.47 mg/L at BC-7). With the exception of site BC-1, total strontium concentrations were also similar among sites in September (Figure 3.10) where concentrations ranged from 0.25 mg/L at sites BC-5 and BC-8 to 0.32 mg/L at site BC-3.

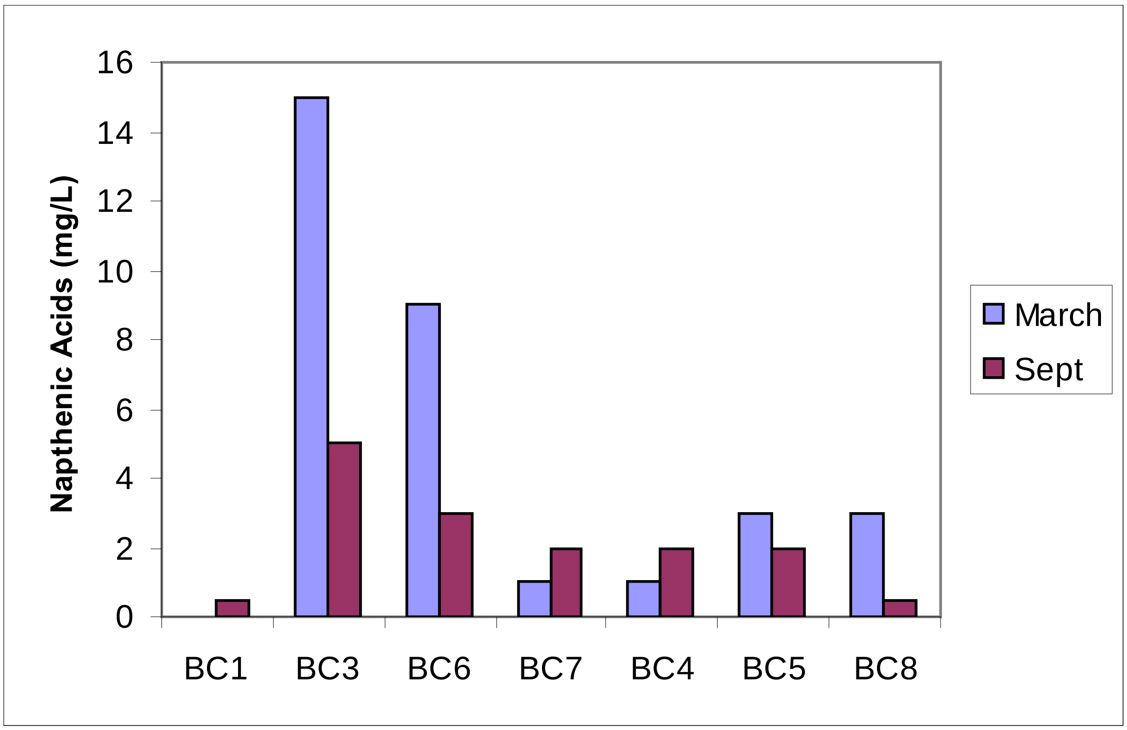
Figure 3.10 Beaver Creek Surface Water Strontium Concentrations for March and September, 2008



Total Naphthenic Acids

Total naphthenic acid concentrations showed a decreasing trend as distance downstream from the seepage dam increased. The highest naphthenic acid concentrations were measured at sites BC-3 and BC-6 in March. Concentrations at these sites were lower in September. Total naphthenic acid concentrations ranged from 1 mg/L at sites BC-4 and BC-6 to 15 mg/L at BC-3 in March, and from <1.0 mg/L at BC-1 and BC-8 to 5 mg/L at BC-3 in September (Figure 3.11).

Figure 3.11 Beaver Creek Surface Water Total Naphthenic Acid Concentrations for March and September, 2008



3.1.3 Quality Assurance/Quality Control (QA/QC)

Duplicate water samples were taken at site BC-3 on each sampling date. With the exception of a reported RPD of >20% for aluminum and barium concentrations in March and manganese in September, the RPDs for all other COC on both sampling occasions were less than 20%.

On both sampling occasions, COC concentrations in the field blank water samples were all below detection limits.

3.2 TOXICITY TESTS

The 2008 results for the 96-hour FETAX, 96-hour rainbow trout, 7-day fathead minnow and 10-day chironomid survival and growth toxicity tests are presented in the following sections.

3.2.1 FETAX Results

FETAX Definitive Test

The results of the March and September 2008 FETAX definitive tests conducted on samples collected at BC-3 are presented in Table 3.3.

In March, the frequency of mortality induced by the five treatment concentrations (50%, 75%, 90%, 95% and 100%) ranged from 7.0% to 35.0% (Table 3.3) and was not significantly different from the laboratory control (100% FETAX solution) treatment ($p=0.063$). Therefore the No Observed Effect Concentration (NOEC) for mortality was 100%. Mean malformation frequencies ranged from 3.1% to 90.5% (Table 3.3). Only the frequency of malformation induced by the 100% treatment was significantly different from the control treatment ($p < 0.001$). Thus, the NOEC value for malformation was determined as 95% while the Lowest Observed Effect Concentration (LOEC) value was 100%. Mean growth across the five treatments ranged from 82.4% to 98.8% of the control (Table 3.3). Significant decreases in growth, when compared to the laboratory control, were detected at the 50% 90%, 95% and 100% concentrations, but not at the 75% concentration. The NOEC for decreased growth was determined to be 75%, while the LOEC was determined as 90%. The LC_{50} and EC_{50} values were determined to be greater than 100% and 96.3% (95% Confidence interval = 95.0% to 97.6%), respectively.

Table 3.3 2008 Results for the Definitive Frog Embryo Teratogenesis Assay - *Xenopus* (FETAX) at Site BC-3

	Positive Control		Laboratory Control (100% FETAX Solution)	100%	95%	90%	75%	50%
	6-AN Reference Toxicant (2,500 mg/L)	6-AN Reference Toxicant (5.5 mg/L)						
March								
mean mortality (%)	100.0	8.0	6.0	35.0	8.0	15.0	7.0	13.0
mean malformations (%)	-	58.7	2.1	90.5[a]	27.8	14.4	3.1	0.0
mean growth[b] (%)	-	-	-	82.4[a]	96.5[a]	96.0[a]	98.8	94.6[a]
September								
mortality (%)	94.0	2.0	2.0	5.0	3.0	3.0	2.0	3.0
malformations (%)	100.0	49.0	2.0	8.3	5.2	3.0	4.1	3.0
mean growth[b] (%)	-	-	-	97.7[a]	96.7[a]	97.0[a]	99.8	98.8

[a] Significantly different from control treatment ($p < 0.05$).

[b] Mean sample length divided by mean FETAX solution control length, expressed as % growth.

- = not available.

In September, the frequencies of mortality induced by the five treatment concentrations ranged from 2.0% to 5.0%, and were not significantly different from the lab control (p=0.749; Table 3.3). Therefore the NOEC for mortality was determined to be 100%. The frequencies of malformation ranged from 3.0% to 8.3%, with no significant differences observed when compared with the lab control (p=0.186; Table 3.3). Thus, the NOEC was determined to be 100% for malformation. The mean growth ranged from 96.7% to 99.8% of laboratory controls (Table 3.3). Significant differences in growth compared to the laboratory control were detected at 90%, 95% and 100% concentrations. The NOEC value was therefore reported at 75% and the LOEC at 90% concentrations. LC_{50} and EC_{50} values could not be determined due to the low frequencies of mortalities and malformation observed in the September FETAX.

FETAX Screen Tests

FETAX screen tests were conducted in March and September of 2008 at all Beaver Creek sampling sites downstream of the seepage dam (BC-3, BC-6, BC-7, BC-4, BC-5, and BC-8).

In March, the six water samples induced frequencies of mortality ranging from 4.0% to 35.0% when tested at 100% concentrations (Table 3.4). Sample BC-3 was the only sample to induce significantly different frequencies of mortality when tested against the control (p = 0.008). Frequencies of malformation ranged from 2.1% to 90.5% (Table 3.4). BC-3 was significantly greater than the control in frequencies of malformation (p=0.015). The mean growth data from the six screening samples ranged from 82.4% to 98.4% of the control. Larval growth in samples from BC-3, BC-6, BC-7, BC-4, and BC-8 were all significantly different from the control treatment (p < 0.001).

Table 3.4 2008 Results for the Screen Frog Embryo Teratogenesis Assay - *Xenopus* (FETAX) at Beaver Creek sampling sites

	Positive Control		Laboratory Control (100% FETAX Solution)	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
	6-AN Reference Toxicant (2,500 mg/L)	6-AN Reference Toxicant (5.5 mg/L)							
March									
mean mortality (%)	100.0	8.0	6.0	35.0[(a)]	12.0	16.0	4.0	5.0	13.0
mean malformations (%)	-	58.7	2.1	90.5[(a)]	2.2	8.7	2.1	3.4	4.6
mean growth[(b)] (%)	-	-	-	82.4*	96.6[(a)]	93.6[(a)]	95.5[(a)]	98.4	92.5[(a)]
September									
mortality (%)	94.0	2.0	2.0	5.0	4.0	7.0	3.0	4.0	2.0
malformations (%)	100.0	49.0	2.0	8.3	4.2	3.1	1.0	2.0	2.1
mean growth[(b)] (%)	-	-	-	97.7*	96.4[(a)]	95.8[(a)]	96.8[(a)]	95.0[(a)]	100.3

[(a)] Significantly different from control treatment (p < 0.05).
[(b)] Mean sample length divided by mean FETAX solution control length, expressed as % growth.
- = no data.

When tested at the 100% concentrations in September 2008, the six water samples induced frequencies of mortality and malformation ranging from 2.0% to 7.0% for mortality and 1.0% to 8.3% for malformation (Table 3.4). There were no significant differences in either the frequency of mortality (p=0.70) or malformation (p=0.08) between the control and the Beaver Creek samples. The mean growth of the six samples ranged from 95.0% to 100.3% of the control (Table 3.4). Larval growth in samples from BC-3, BC-6, BC-7, BC-4 and BC-5 were all significantly different from the control treatment (p<0.001).

3.2.2 Rainbow Trout and Fathead Minnow Results

Fathead minnow toxicity tests were not performed in March as a result of fish supply issues at HydroQual. Results of the 96-hr rainbow trout static acute toxicity test (March and September) and the 7-day fathead minnow survival and growth toxicity test (September only) are presented in Tables 3.5 and 3.6, respectively. There was no mortality in rainbow trout or fathead minnows and no significant difference in fathead minnow growth.

Table 3.5 2008 Results of the 96-hour Rainbow Trout Toxicity Test, Site BC-5

Parameter	March	September
LC_{25}	>100%	>100%
LC_{50}	>100%	>100%
NOEC	100%	100%
LOEC	>100%	>100%

LC_{25} Lethal concentration for 25% of the organisms.
LC_{50} Lethal concentration for 50% of the organisms.
NOEC No observed effects concentration.
LOEC Lowest observed effects concentration.

Table 3.6 2008 Results of the 7-day Fathead Minnow Toxicity Test, Site BC-5

Endpoint	Parameter	March	September
Mortality (%)	LC_{25}	-	>100%
	LC_{50}	-	>100%
	NOEC	-	100%
	LOEC	-	>100%
Growth (mg dry wt)	IC_{25}	-	>100%
	IC_{50}	-	>100%
	NOEC	-	100%
	LOEC	-	>100%

LC_{25} Lethal concentration for 25% of the organisms.
LC_{50} Lethal concentration for 50% of the organisms.
IC_{25} Concentration causing inhibition of growth among 25% of the organisms.
IC_{50} Concentration causing inhibition of growth among 50% of the organisms.
NOEC No observed effects concentration.
LOEC Lowest observed effects concentration.
- = No data available due to laboratory fish supply issues.

3.2.3 *Chironomus* Results

Survival and growth were both significantly lower in sediment from site BC-6 (Dunnett's test, survival: $P < 0.0005$; growth; $P < 0.0001$) when compared to the laboratory controls (Table 3.7). No statistically significant effects on survival and growth were observed in sediments from the other sample locations.

Table 3.7 2008 Results of the 10-day *Chironomus tentans* Static Survival and Growth Test

Site[a]	Survival (Number of Live Organisms)			Growth (mg dry wt./organism)		
	Mean	CV (%)[b]	% of Control	Mean	CV (%)[b]	% of Control
Lab Control	8	14	100	1.97	17	100
BC-3	8	17	93	1.83	18	93
BC-6	5[c]	27	57	0.52[c]	9	26
BC-7	8	17	93	1.78	19	91
BC-4	6	14	76	1.70	12	86
BC-5	7	17	79	2.43	16	123
BC-8	7	19	81	1.44	23	73

(a) Sites are ordered from upstream to downstream.

(b) CV = coefficient of variation.

(c) Significantly different from the laboratory control (one-way ANOVA, $P < 0.05$; Dunnett's test, $P < 0.05$).

4 COMPARISON OF 2008 RESULTS TO PREVIOUS FIELD STUDIES

4.1 CONCENTRATIONS OF COC IN SURFACE WATER

Data comparing maximum concentrations of COC in water samples collected from 2004 to 2008 are presented in Table 3.8. It is important to note that 2004 water chemistry data were collected during a single sampling event in the fall (September) only. For 2005, 2006 and 2007, water chemistry data were collected during four sampling events; March, May, September, and October. In 2008 water chemistry data were collected in March and September only.

Generally, 2008 surface water concentrations of each COC (i.e., aluminum, barium, boron, calcium, chloride, iron, magnesium, manganese, sodium, strontium, and naphthenic acids) were within the range of values reported in previous years (Table 3.8).

Table 3.8 Comparison of Maximum Concentrations (mg/L) of COC in Surface Water Samples Collected from 2004 to 2008

Parameter	BC-1					BC-3					BC-6					BC-7					BC-4					BC-5					BC-8				
	2004	2005	2006	2007	2008[(a)]	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008
Total Metals																																			
Aluminum	0.30	0.40	0.23	0.51	0.25	0.05	1.00	0.86	2.49	0.65	0.03	0.40	0.40	0.08	0.06	0.02	0.20	1.97	0.77	0.02	0.02	0.09	0.18	0.69	0.07	0.06	0.14	0.03	0.10	0.06	0.22	0.65	0.32	0.46	0.14
Barium	0.017	0.021	0.019	0.022	0.022	0.16	0.5	0.243	0.45	0.207	0.07	0.2	0.171	0.2	0.155	0.09	0.13	0.34	0.12	0.138	0.1	0.15	0.137	0.140	0.119	0.098	0.14	0.148	0.13	0.105	0.049	0.14	0.123	0.13	0.133
Boron	0.05	0.05	0.03	0.06	<0.05	0.29	0.34	0.53	0.42	0.39	0.34	0.46	0.45	0.49	0.39	0.24	0.28	0.35	0.28	0.24	0.18	0.2	0.23	0.28	0.26	0.15	0.17	0.22	0.22	0.19	0.10	0.15	0.18	0.23	0.15
Calcium	20.5	25.9	22.2	22.2	30.8	119.0	148.0	146.0	160.0	127.0	47.3	107.0	114.0	92.8	82.9	79.4	147.0	154.0	122.0	265.0	116.0	226.0	259.0	266.0	258.0	81.3	117.0	116.0	118.0	112.0	39.1	120.0	117.0	114.0	107.0
Iron	0.6	0.7	0.39	0.78	0.66	8.46	59.6	31.7	29.4	19.5	0.269	3.34	3.54	0.85	1.72	0.225	1.37	40.9	1.23	9.97	0.225	3.14	1.760	2.64	1.25	0.32	1.230	1.46	1.24	0.606	1.83	3.71	4.1	2.19	3.0
Magnesium	8.0	10.0	9.0	8.1	11.2	41.6	57.8	65.7	73.0	51.5	0.1	72.7	70.6	56.5	58.3	0.0	52.1	55.7	48.2	61.5	40.1	51.5	62.5	64.8	63.1	25.5	32.3	32.1	33.3	31.2	11.9	32.4	34.0	33.7	31.4
Manganese	0.03	0.03	0.011	0.023	0.014	0.82	0.96	1.93	1.91	1.45	0.099	0.79	0.808	1.46	0.775	0.034	0.71	2.03	0.8	0.59	0.01	0.89	1.1	0.717	0.434	0.017	0.19	0.119	0.107	0.074	0.103	0.539	0.435	0.812	0.480
Sodium	19	24	21	22	26	353	642	334	382	540	348	555	336	370	363	224	191	166	166	117	145	207	127	162	128	153	203	185	195	181	58	173	160	242	165
Strontium	0.11	0.13	0.11	0.11	0.15	0.411	0.6	0.581	0.812	0.52	0.255	0.59	0.615	0.559	0.532	0.316	0.52	0.525	0.45	0.47	0.33	0.33	0.499	0.497	0.486	0.213	0.31	0.326	0.318	0.267	0.178	0.519	0.471	0.669	0.480
Major Ions																																			
Chloride	3	19	21	5	25	369	630	318	387	518	449	669	349	395	416	327	274	169	192	178	258	270	184	196	178	173	197	168	181	170	62	224	185	372	232
General Organics																																			
Naphthenic Acids	2	1	1	0.5	<1	19	28	10	12	15	11	19	12	13	9	8	6	4	4	1	4	4.7	2	3	2	5	5	3	3	3	3	4	2	2	3

[(a)] 2008 results are from a single sample collected in September.

Sites ordered from upstream (left) to downstream (right).

2004 results are from a single sample collected in September.

4.1.1 COC Temporal and Spatial Trends

As recommended in the ERA (Golder 2004), and continued in the 2008 Profiling Program, temporal and spatial trends in the concentrations of surface water COC were examined. This was done in an attempt to address the following questions:

1. Do changes in the concentrations of surface water COC follow a distinct seasonal pattern?
2. Are the seasonal patterns consistent among years?
3. Do concentrations of surface water COC increase, decrease, or remain the same annually?
4. Do the concentrations of surface water COC follow a distinct spatial pattern?

4.1.1.1 Temporal Trends

Seasonal Trends

In general, changes in surface water concentrations of each COC follow a consistent seasonal pattern. Previously (from 2005 to 2007), concentrations peaked in March, declined by May, and remained low through to the fall (Figure 4.1). Results from the 2008 Profiling Program were consistent with previous years, in that concentrations were higher in March and had declined significantly by September (with the exception of boron).

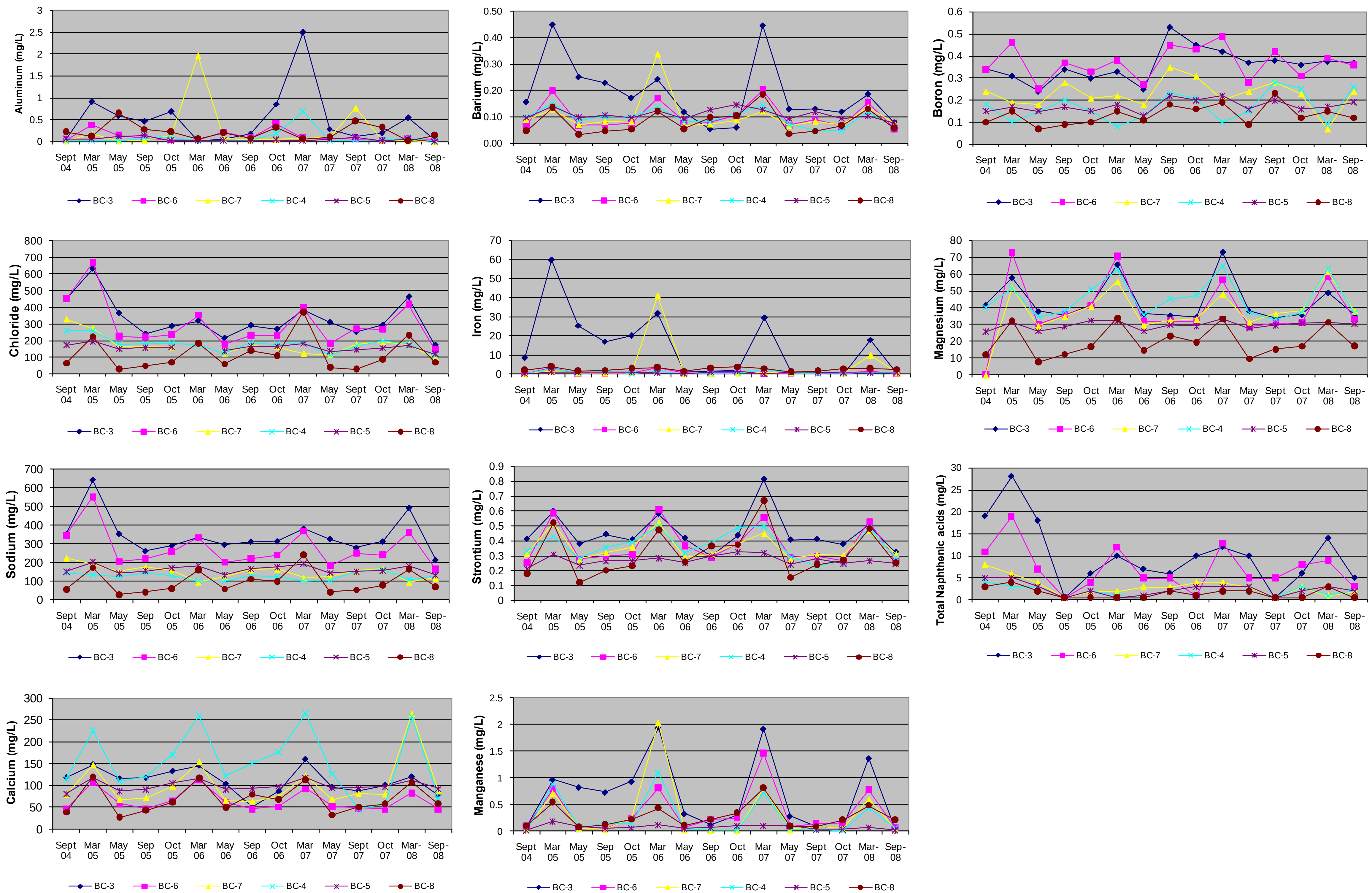
Annual Trends

Concentrations of naphthenic acids, iron, chloride and sodium were highest in 2005 (particularly at sites BC-3 and BC-6) (Figure 4.1). Since 2005, concentrations of these COC have declined from 2005 levels and have remained stable into 2008. Concentrations of the remaining COC (aluminum, barium, boron, magnesium, manganese, strontium and cadmium) have remained relatively stable from 2004 to 2008.

4.1.1.2 Spatial Trends

In general, surface water concentrations of each COC were highest at sites BC-3 and BC-6 and decreased in a downstream direction toward BC-8 (Figure 4.1). However, calcium concentrations were consistently higher at site BC-4, when compared to the other sample sites, from 2004 to 2008.

Figure 4.1 Surface Water Concentrations of COC



4.2 TOXICITY TESTING

4.2.1 FETAX

In 2004 and 2005, FETAX assays for the Beaver Creek ERA monitoring program were conducted by HydroQual laboratories. However, due to husbandry issues, which resulted in increased mortality in some of the control treatments, a decision was made to conduct subsequent testing (from 2006 onwards) at Fort Environmental Laboratories. Therefore, direct comparisons of 2006, 2007 and 2008 FETAX results with previous years' data are not possible.

Fetax Definitive Tests at BC-3

Definitive testing on water samples collected at site BC-3 commenced in October 2006. Prior to this date, only screen tests were performed on water from this site. The general observation that can be made from the results of the definitive test is that the highest concentrations in the dilution series (100% and 95%) produce a significant effect on mortality, malformations and growth in *Xenopus* larvae (Table 4.1). A growth effect can also sometimes be seen in the lower dilution concentrations (90%, 75% and 50%). This trend was not observed however in samples collected in March 2007 and September 2008.

The fact that adult frogs and tadpoles have been observed in Beaver Creek suggests the water at BC-3 is not acutely toxic to local amphibian populations and that local populations are capable of growing and developing into adults and reproducing.

Fetax Screen Tests

In 2006, FETAX screen testing was conducted on water samples from site BC-3 only. In 2007 and 2008 screening tests were conducted on water samples from all sample sites downstream of the seepage dam.

Table 4.2 presents the results of the Fetax screen tests. Data for 2007 and 2008 show that statistically significant differences from the control treatments for malformations are evident in water samples collected from site BC-3 only and occur in water samples collected during the spring months (March and May). This significant result in an increase in malformations is usually not accompanied by an increase in mortality (except in March 2008). Screen test results for BC-3 in 2006 show no significant effects on malformations (except in October), but a significant effect for mortality and growth (Table 4.1).

With the exception of a significant effect on mortality at sites BC-6 and BC-8 in October 2007, Fetax screen results for all other sites downstream of the seepage dam (BC-6, BC-7, BC-4, BC-5 and BC-8) show no significant effect on malformations and mortality. However, a significant effect on growth at all sites downstream of the dam has been evident in 2007 and 2008 (Table 4.2). This growth response, however, is less than 10% of the control mean growth over the test period and does not necessarily confer biological effect.

Table 4.1 Comparison of Results of the Frog Embryo Teratogenesis Assay - *Xenopus* (FETAX) Conducted on Surface Water Samples from BC-3 in 2006, 2007 and 2008

Year	Month	Endpoint	Treatment							
			Positive Control		Laboratory Control (100% FETAX Solution)	100%	95%	90%	75%	50%
			6-AN Reference Toxicant (2,500 mg/L)	6-AN Reference Toxicant (5.5 mg/L)						
2006	March	Mean Mortality (%)	100.0	2.0	2.0	6.0[a]	-	-	-	-
		Mean Malformations[d] (%)	-	53.1	4.1	5.3	-	-	-	-
		Mean Growth[e] (%)	-	-	-	99.8[a]	-	-	-	-
	May	Mean Mortality (%)	100.0	6.0	4.0	15.0[a]	-	-	-	-
		Mean Malformations (%)	-	55.3	1.0	3.5	-	-	-	-
		Mean Growth(%)	-	-	-	91.5[a]	-	-	-	-
	September	Mean Mortality (%)	100.0	4.0	0.0	11.0*	-	-	-	-
		Mean Malformations (%)	-	43.8	2.0	3.4	-	-	-	-
		Mean Growth[f] (%)	-	-	-	93.8[a]	-	-	-	-
	October	Mean Mortality (%)	100.0	80.0	2.0	11[a][b]	7[c]	5.0	5.0	1.0
		Mean Malformations (%)	-	50.0	2.6	3.9[a][c]	3.2	2.1	1.1	1.0
		Mean Growth (%)	-	-	-	90.7[a]	92.2[a]	92.5[a]	94.3[a][b]	98.4[c]
2007	March	Mean Mortality (%)	100.0	2.0	0.0	0.0[c]	0.0	0.0	0.0	0.0
		Mean Malformations (%)	-	55.1	2.0	15.0[c]	5.0	1.0	0.0	0.0
		Mean Growth (%)	-	-	-	98.0[c]	98.0	98.2	98.2	99.6
	May	Mean Mortality (%)	100.0	100.0	3.0	11.0[c]	19.0	16.0	18.0	3.0
		Mean Malformations (%)	-	-	0.0	16.9*	12.3[a][b]	10.7[c]	6.1	0.0
		Mean Growth (%)	-	-	-	91.7*	92.6[a]	92.3[a]	93.1[a]	95.5[a][b]

Table 4.1 Comparison of Results of the Frog Embryo Teratogenesis Assay - *Xenopus* (FETAX) Conducted on Surface Water Samples from BC-3 in 2006, 2007 and 2008 (continued)

Year	Month	Endpoint	Treatment							
			Positive Control		Laboratory Control (100% FETAX Solution)	100%	95%	90%	75%	50%
			6-AN Reference Toxicant (2,500 mg/L)	6-AN Reference Toxicant (5.5 mg/L)						
	September	Mean Mortality (%)	100.0	100.0	8.0	36.0[a][b]	28.0[c]	42.0[a]	26.0	25.0
		Mean Malformations (%)	-	-	2.1	15.8[a][c]	4.9	7.4	2.7	2.7
		Mean Growth (%)	-	-	-	91.1[a]	94.1[a]	91.7[a]	93.9[a]	94.8[a][b]
	October	Mean Mortality (%)	100.0	100.0	5.0	16.0[a]	20.0[a]	19.0[a]	18.0[a]	20.0[a][b]
		Mean Malformations (%)	-	-	2.1	13.2[a][b]	7.6[c]	5.0	4.9	2.6
		Mean Growth (%)	-	-	-	96.6[a][b]	98.7[c]	98.1	97.5[a]	99.5
2008	March	Mean Mortality (%)	100.0	8.0	6.0	35.0	8.0	15.0	7.0	13.0
		Mean Malformations (%)	-	58.7	2.1	90.5[a]	27.8	14.4	3.1	0.0
		Mean Growth (%)	-	-	-	82.4[a]	96.5[a]	96.0[a]	98.8	94.6[a]
	September	Mortality (%)	94.0	2.0	2.0	5.0[c]	3.0	3.0	2.0	3.0
		Malformations (%)	100.0	49.0	2.0	8.3[c]	5.2	3.0	4.1	3.0
		Mean Growth (%)	-	-	-	97.7[a]	96.7	97.0[b]	99.8[c]	98.8

[a] Significantly different from control treatment ($p < 0.05$)
[b] Lowest Observed Effect Concentration (LOEC).
[c] No Observed Effect Concentration (NOEC).
[d] Percent malformations are calculated from the number of malformed larva remaining in surviving populations at the end of the 96 hour test.
[e] Mean sample length divided by mean FETAX solution control length, expressed as % growth.
\- = test not performed.

Table 4.2 Comparison of Results of the Screen Frog Embryo Teratogenesis Assay - *Xenopus* (FETAX) Conducted on Surface Water Samples from Beaver Creek in 2007 and 2008

Year	Month	Endpoint	Positive Control: 6-AN Reference Toxicant (2,500 mg/L)	Positive Control: 6-AN Reference Toxicant (5.5 mg/L)	Laboratory Control (100% FETAX Solution)	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
2007	March	Mean Mortality (%)	100.0	2.0	0.0	0.0	0.0	2.0	4.0	4.0	2.0
		Mean Malformations (%)	-	55.1	2.0	15.0[a]	2.0	6.1	2.1	6.3	7.1
		Mean Growth[d] (%)	-	-	-	98.0	98.1	97.1[a]	96.4[a]	96.1[a]	96.0[a]
	May	Mortality (%)	100.0	100.0	3.0	11.0	5.0	6.0	8.0	6.0	8.0
		Malformations (%)	-	-	0.0	16.9[a]	2.1	3.2	3.3	3.2	8.7[a]
		Mean Growth (%)	-	-	-	91.7[a]	92.0[a]	92.2[a]	94.5[a]	92.2[a]	90.2[a]
	September	Mortality (%)	100.0	100.0	5.0	-	5.0	3.0	6.0	6.0	1.0
		Malformations (%)	-	-	2.1	-	4.2	5.2	1.1	3.1	4.0
		Mean Growth (%)	-	-	-	-	92.6[a]	93.4[a]	99.2	97.8	88.7[a]
	October	Mortality (%)	100.0	100.0	5.0	16.0	35.0[a]	17.0	16.0	10.0	27.0[a]
		Malformations (%)	-	-	2.1	13.2	5.1	3.4	3.5	5.4	5.4
		Mean Growth (%)	-	-	-	96.6[a]	104.2[a]	102.0	99.2	99.8	103.2[a]
2008	March	Mean Mortality (%)	100.0	8.0	6.0	35.0	12.0	16.0	4.0	5.0	13.0
		Mean Malformations (%)	-	58.7	2.1	90.5	2.2	8.7	2.1	3.4	4.6
		Mean Growth (%)	-	-	-	82.4[a]	96.6[a]	93.69[a]	95.5[a]	98.4	92.5[a]
	September	Mortality (%)	94.0	2.0	2.0	5.0	4.0	7.0	3.0	4.0	2.0
		Malformations (%)	100.0	49.0	2.0	8.3	4.2	3.1	1.0	2.0	2.1
		Mean Growth (%)	-	-	-	97.7[a]	96.4[a]	95.8[a]	96.8[a]	95.0[a]	100.3

[a] Significantly different from control treatment ($p < 0.05$).
[b] Lowest Observed Effect Concentration (LOEC).
[c] No Observed Effect Concentration (NOEC).
[d] Percent malformations are calculated from the number of malformed larva remaining in surviving populations at the end of the 96 hour test.
[e] Mean sample length divided by mean FETAX solution control length, expressed as % growth.
- = test not performed.

4.2.2 Rainbow Trout and Fathead Minnow

Results of the 96-hr toxicity tests conducted with rainbow trout from 2004 to 2008 show no mortality during any of the tests (Table 4.3). Similarly, results of the 7-day fathead minnow toxicity tests from 2004 to 2008 did not show mortality or decreased growth during any of the tests (Table 4.4).

These results indicate that water collected from BC-5 is not toxic to rainbow trout or fathead minnows.

4.2.2.1 Chironomus

In 2008, statistically significant differences were detected between the laboratory control and treatments consisting of sediment collected from site BC-6 for both *Chironomus tentans* survival and growth (Table 3.7). Both *C. tentans* survival and growth were significantly lower in sediment from Site BC-6 compared to laboratory controls (Table 3.7). This suggests that sediment from Site BC-6, located downstream of the seepage dam, had a possible effect on the benthic invertebrate community in 2008. This is similar to the 2007 results, when *C. tentans* toxicity tests on sediment from Site BC-6 also detected lower survival and growth compared to laboratory controls (Tables 4.5 and 4.6). This differs from previous years (2004 to 2006) when no statistically significant differences between laboratory controls and field samples were detected in *C. tentans* toxicity test results. However, it is unlikely that this effect was caused by seepage from the dam because no statistical differences were detected in chironomid survival or growth at Site BC-3, which is located immediately downstream of the seepage dam.

Table 4.3 Comparison of Results of the 96-hour Rainbow Trout Toxicity Test Conducted on Surface Water Samples at BC-5 from 2004 to 2008

Parameter	2004	2005				2006				2007				2008	
	September	March	May	September	October	March	May	September	October	March	May	September	October	March	September
LC_{25}	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%
LC_{50}	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%
NOEC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
LOEC	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%

LC25 Lethal concentration for 25% of the organisms.
LC50 Lethal concentration for 50% of the organisms.
NOEC No observed effects concentration.
LOEC Lowest observed effects concentration.

Table 4.4 Comparison of Results of the 7-day Fathead Toxicity Test Conducted on Surface Water Samples at BC-5 from 2004 to 2008.

Endpoint	Parameter	2004	2005				2006				2007				2008	
		Sept	March	May	Sept	Oct	March	May	Sept	Oct	March	May	Sept	Oct	March	Sept
Mortality (%)	LC_{25}	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	-	>100%
	LC_{50}	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	-	>100%
	NOEC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	-	100%
	LOEC	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	-	>100%
Growth (mg dry wt)	IC_{25}	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	-	>100%
	IC_{50}	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	-	>100%
	NOEC	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	-	100%
	LOEC	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	>100%	-	>100%

LC25 Lethal concentration for 25% of the organisms.
LC50 Lethal concentration for 50% of the organisms.
IC25 Concentration causing inhibition of growth among 25% of the organisms.
IC50 Concentration causing inhibition of growth among 50% of the organisms.
NOEC No observed effects concentration.
LOEC Lowest observed effects concentration.
\- = No data available.

Table 4.5 Comparison of 2004 to 2008 Survival Results of Sediment Toxicity Tests Using *Chironomus tentans*

Site[a]	Mean Number of Live Organisms					CV[b] (%)					% of Control				
	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008
Lab Control	10	8	8	8	8	6	5	16	20	14	100	100	100	100	100
BC-1	8	5	-	-	-	25	67	-	-	-	80	63	-	-	-
BC-3	9	5	7	7	8	10	37	27	74	17	90	63	88	93	93
BC-6	9	3	8	3[c]	5[c]	6	92	30	32	27	90	34	102	40	57
BC-7	9	4	4	7	8	9	83	105	72	17	90	54	44	90	93
BC-4	10	5	7	5	6	6	34	46	46	14	100	59	80	58	76
BC-5	6	4	8	5	7	60	68	25	45	17	60	46	98	58	79
BC-8	9	7	8	6	7	10	14	13	64	19	90	80	100	80	81

[a] Sites are ordered from upstream to downstream.

[b] CV = Coefficient of variation.

[c] Significantly different from the laboratory control (one-way ANOVA, $P < 0.05$; Dunnett's test, $P < 0.05$) for 2007 and 2008.

- = not available.

Table 4.6 Comparison of 2004 to 2008 Growth Results of Sediment Toxicity Tests Using *Chironomus tentans*

Site [a]	Mean Dry Weight (mg)					CV[b] (%)					% of Control				
	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008	2004	2005	2006	2007	2008
Lab Control	2.9	1.7	2.2	2.1	2.0	9	12	34	39	17	100	100	100	100	100
BC-1	2.6	3.0	-	-	-	12	41	-	-	-	90	174	-	-	-
BC-3	2.6	2.5	1.6	1.4	1.8	24	24	41	34	18	90	145	75	67	93
BC-6	2.6	3.8	1.9	0.5[c]	0.5[c]	8	22	49	34	9	90	217	88	21	26
BC-7	2.2	4.5	2.0	1.9	1.8	25	13	41	19	19	76	261	92	87	91
BC-4	2.7	3.3	2.0	1.9	1.7	9	9	35	35	12	93	191	94	88	86
BC-5	2.4	4.2	2.7	3.5	2.4	14	20	30	59	16	83	241	126	164	123
BC-8	2.0	4.3	2.1	1.5	1.4	10	32	12	37	23	69	249	95	72	73

[a] Sites are ordered from upstream to downstream.

[b] CV = Coefficient of variation.

[c] Significantly different from the laboratory control (one-way ANOVA, $P < 0.05$; Dunnett's test, $P < 0.05$) for 2007.

- = not available.

5 SUMMARY AND CONCLUSIONS

This study represents a scaled-down version of the three year ERA monitoring program conducted from 2005 to 2007. The purpose of the 2008 Profiling Program was to address the following objectives:

- Objective 1: To confirm that seasonal/annual/spatial trends observed in 2008 were consistent with trends observed during previous years of study.
- Objective 2: To ensure that the conclusions from the three year ERA monitoring program remained valid, i.e., there are no unacceptable ecological risks to Beaver Creek due to the seepage of process water from the MLSB.

Conclusions for Objective 1

Based on the results of the surface water testing, the conclusions for the first study objective were:

1. Surface water concentrations of most parameters were highest in March and decreased by fall. This trend is evident through 2005 to 2008 suggesting that perhaps contributions from spring thaw and surface water runoff are the main source(s) of inorganic parameters in Beaver Creek, not seepage from the wastewater control system.

2. Surface water COC concentrations were generally highest immediately below the seepage dam at site BC-3 and decreased in a downstream direction toward BC-8.

3. The wastewater control system is operating effectively as surface water concentrations of naphthenic acids, a tracer of process-affected water, have decreased in samples from sites BC-3 and BC-6 since modifications were made to the pumping system below the dam.

Conclusions for Objective 2

Based on the results of the toxicity testing, the conclusions for the second objective were:

1. Water collected from site BC-3 has a statistically significant effect on mortality and malformations in *Xenopus* larvae. This effect does not occur at the sites downstream of BC-3. A growth effect of less than 10% of the control mean growth is observable at all sites downstream of the seepage dam but this does not necessarily confer biological effect.

2. Water collected from BC-5 is not acutely toxic to rainbow trout or fathead minnows. This result has been consistently demonstrated from 2004 to 2008.

3. Significant differences in *Chironomus tentans* survival and growth were detected in sediment from Site BC-6 from Beaver Creek in 2008. This is similar to the 2007 *C. tentans* toxicity test results, when survival and growth were significantly different from controls at site BC-6. However, no differences were detected in growth and survival at Site BC-3 located immediately downstream of the seepage dam. This suggests that the effects detected in sediment samples are unlikely to be related to toxicity of substances released from the seepage dam. Rather, a localized effect in the vicinity of Site BC-6 may account for the sediment effects observed at this location.

6 RECOMMENDATIONS

Overall, the results of the 2008 Beaver Creek Profiling Program indicate that conditions have remained stable in Beaver Creek since the culmination of the three year ERA field program and the wastewater control system is working effectively to limit seepage water from entering the creek. There were no substantial changes to COC concentrations in 2008, when compared to the ERA study from 2005 and 2007, indicating that conditions in Beaver Creek are relatively stable. There are no unacceptable ecological risks to Beaver Creek due to seepage of process water, which supports the overall goal of the original ERA.

7 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

Report prepared by:

Tamara Darwish, M.Sc.
Fisheries Biologist

Mary Gregory, B.Sc., Dipl. W.E.M
Aquatic Biologist

André Bachteram, M.Sc.
Aquatic Biologist

Report reviewed by:

Richard D. Robinson, Ph.D.
Principal, Senior Environmental Scientist

Zsolt E. Kovats, M.Sc.
Associate, Senior Aquatic Biologist

8 REFERENCES

ASTM (American Society for Testing and Materials). 1998 (with 2004 revisions). Standard Guide for Conducting the Frog Embryo Teratogenesis Assay – *Xenopus* (FETAX). Designation E 1439-98. Philadelphia, PA: ASTM.

CCME (Canadian Council of Ministers of the Environment). 1999 (with updates to 2003). Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment. Winnipeg, MN.

Environment Canada. 1990. Biological Test Method: Reference Method for Determining Acute Lethality of Effluents to Rainbow Trout, Environmental Technology Centre, Ottawa, Ontario, Report EPS 1/RM/13, (with 1996 and 2000 amendments).

Environment Canada. 1992. Biological Test Method: Test of Larval Growth and Survival Using Fathead Minnows, Environmental Technology Centre, Ottawa, Ontario, Report EPS 1/RM/22, February 1992, Amended in November 1997.

Environment Canada. 1997. Biological Test Method: Test for Survival and Growth in Sediment Using the larvae of Freshwater Midges (*Chironomus tentans* or *Chironomus riparius*), Environmental Technology Centre, Ottawa, Ontario, Report EPS 1/RM/32, December 1997.

Golder (Golder Associates Ltd.). 2004. Ecological Risk Assessment of the Lower Beaver Creek Area. Final report submitted to Syncrude Canada Ltd.

Golder. 2005. Beaver Creek Fall 2004 Monitoring Program. Final report submitted to Syncrude Canada Ltd.

Golder. 2006. Beaver Creek 2005 Monitoring Program. Final report submitted to Syncrude Canada Ltd.

Golder. 2007. Beaver Creek Ecological Risk Assessment: Field Study 2006. Final report submitted to Syncrude Canada Ltd.

Golder. 2008. Beaver Creek Ecological Risk Assessment: Field Study 2007. Final report submitted to Syncrude Canada Ltd.

U.S. EPA (United States Environmental Protection Agency). 1985. National Primary Drinking Water Regulations; Volatile Synthetic Organic Chemicals; Proposed Rule. November 13, 1985. Volume 50. Number 219. Federal Register: 50.

APPENDIX I

RAW WATER CHEMISTRY DATA

Table I-1 March 2008 Water Quality

Parameter	Units	Site					
		BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
Field Measured							
pH		7.1	7.3	6.7	7.3	7.7	7.5
Specific Conductance	µS/cm	1,819	1,368	1,012	875	751	866
Temperature	°C	0.01	-0.02	0.14	-0.06	-0.03	0.16
Dissolved Oxygen	mg/L	7.00	5.05	7.58	8.82	2.38	18.39
Conventional Parameters							
Conductance	µS/cm	3,070	2,400	1,970	1,860	1,530	1,620
Hardness	mg/L	543	487	985	882	424	476
pH		7.8	7.9	7.9	7.8	8.1	8.1
Total Alkalinity	mg/L	877	662	302	294	336	337
Total Dissolved Solids	mg/L	1780	1,380	1,370	1,250	928	979
Major Ions							
Bicarbonate	mg/L	1,070	808	368	358	410	411
Calcium	mg/L	125	88.8	283	246	115	127
Carbonate	mg/L	<5	<5	<5	<5	<5	<5
Chloride	mg/L	518	416	178	178	170	232
Magnesium	mg/L	56	64.5	67.7	65	33.3	38.5
Potassium	mg/L	2.9	2.9	1.6	2.5	1.5	1.9
Sodium	mg/L	492	352	103	106	184	190
Sulphate	mg/L	60.2	61.7	552	481	223	187
Nutrients							
Nitrate + Nitrite	mg/L	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1
Nitrate	mg/L	<0.1	<0.1	< 0.1	< 0.1	< 0.1	<0.1
Nitrite	mg/L	<0.05	<0.05	< 0.05	< 0.05	< 0.05	<0.05
Nitrogen - ammonia	mg/L	0.74	1.23	0.1	0.13	< 0.05	0.17
General Organics							
Naphthenic acids	mg/L	15	9	1	1	3	3
Metals (Total)							
Aluminum (Al)	mg/L	0.65	0.06	0.02	0.07	0.06	0.02
Antimony (Sb)	mg/L	<0.0004	<0.0004	<0.0004	0.0005	<0.0004	<0.0004
Arsenic (As)	mg/L	0.0033	0.0023	0.002	0.0012	0.0009	0.0014
Barium (Ba)	mg/L	0.207	0.155	0.138	0.119	0.105	0.133
Beryllium (Be)	mg/L	< 0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Bismuth (Bi)	mg/L	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Boron (B)	mg/L	0.39	0.39	0.07	0.09	0.17	0.15

Table I-1 March 2008 Water Quality (continued)

Parameter	Units	Site					
		BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
Cadmium (Cd)	mg/L	0.0014	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium (Ca)	mg/L	127	82.9	265	258	112	107
Chromium (Cr)	mg/L	0.0033	0.0051	0.0022	0.0033	0.0038	0.002
Cobalt (Co)	mg/L	0.0025	0.0004	0.0006	0.0005	0.0002	0.0007
Copper (Cu)	mg/L	0.002	<0.001	0.003	0.003	0.004	0.003
Iron (Fe)	mg/L	19.5	1.72	9.97	1.25	0.606	3
Lead (Pb)	mg/L	0.0019	0.0009	<0.0001	0.0002	<0.0001	<0.0001
Magnesium (Mg)	mg/L	51.5	58.3	61.5	63.1	31.2	31.4
Manganese (Mn)	mg/L	1.45	0.775	0.594	0.434	0.074	0.484
Mercury (Hg)	mg/L	-	-	-	-	-	-
Molybdenum (Mo)	mg/L	0.0002	0.0001	0.0001	0.0001	0.0003	0.0002
Nickel (Ni)	mg/L	0.0077	0.0039	0.0064	0.007	0.0038	0.0043
Potassium (K)	mg/L	3.7	3.7	2.1	3	1.8	1.2
Selenium (Se)	mg/L	<0.0004	<0.0004	<0.0004	0.0009	0.0005	0.0007
Silver (Ag)	mg/L	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004
Sodium (Na)	mg/L	540	363	95	108	181	165
Strontium (Sr)	mg/L	0.519	0.532	0.47	0.486	0.267	0.48
Thallium (Tl)	mg/L	0.0012	0.0009	<0.0001	<0.0001	<0.0001	<0.0001
Tin (Sn)	mg/L	<0.0004	<0.0004	0.0017	0.0024	0.0011	0.0053
Titanium (Ti)	mg/L	0.019	<0.005	<0.005	<0.005	<0.005	<0.005
Uranium (U)	mg/L	0.0004	0.0002	0.0007	0.0007	0.0016	0.0005
Vanadium (V)	mg/L	0.0034	0.0019	0.0015	0.0021	0.0018	0.0017
Zinc (Zn)	mg/L	0.037	0.013	0.007	0.032	0.015	0.007
Target PAHs and Alkylated PAHs							
Naphthalene	µg/L	0.06	<0.01	0.19	0.96	<0.01	<0.01
C1 subst'd naphthalenes	µg/L	0.04	<0.01	0.09	0.4	<0.01	<0.01
C2 subst'd naphthalenes	µg/L	0.1	<0.04	0.08	0.25	<0.04	<0.04
C3 subst'd naphthalenes	µg/L	0.07	<0.04	0.05	0.15	<0.04	<0.04
C4 subst'd naphthalenes	µg/L	<0.04	<0.04	<0.04	0.07	<0.04	<0.04
Acenaphthene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C1 subst'd acenaphthene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Acenaphthylene	µg/L	<0.01	<0.01	0.01	0.03	<0.01	<0.01
Anthracene	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dibenzo(a,h) anthracene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a) anthracene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table I-1 March 2008 Water Quality (continued)

Parameter	Units	Site					
		BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
C1 subst'd benzo(a) anthracene / chrysene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
C2 subst'd benzo(a) anthracene / chrysene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
Benzo(a)pyrene	µg/L	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
C1 subst'd benzo(b&k) fluoranthene / benzo(a)pyrene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
C2 subst'd benzo(b&k) fluoranthene / benzo(a)pyrene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
Benzo(b)fluoranthene	µg/L	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
Benzo(k)fluoranthene	µg/L	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
Benzo(j)fluoranthene	µg/L	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
Benzo(g,h,i)perylene	µg/L	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
Biphenyl	µg/L	<0.01	< 0.01	<0.01	0.01	<0.01	<0.01
C1 subst'd biphenyl	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
C2 subst'd biphenyl	µg/L	0.04	< 0.04	<0.04	0.07	<0.04	<0.04
Chrysene	µg/L	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
Dibenzothiophene	µg/L	<0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
C1 subst'd dibenzothiophene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
C2 subst'd dibenzothiophene	µg/L	<0.04	< 0.04	<0.04	< 0.04	<0.04	<0.04
C3 subst'd dibenzothiophene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	< 0.04
C4 subst'd dibenzothiophene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
Fluoranthene	µg/L	< 0.01	< 0.01	<0.01	<0.01	<0.01	<0.01
C1 subst'd fluoranthene / pyrene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
C2 subst'd fluoranthene / pyrene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
C3 subst'd fluoranthene / pyrene	µg/L	<0.04	< 0.04	<0.04	<0.04	<0.04	<0.04
Fluorene	µg/L	<0.01	<0.01	<0.01	0.02	<0.01	<0.01
C1 subst'd fluorene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
C2 subst'd fluorene	µg/L	<0.04	<0.04	<0.04	0.07	<0.04	<0.04
C3 subst'd fluorene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Indeno(c,d-123)pyrene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Table I-1 March 2008 Water Quality (continued)

Parameter	Units	Site					
		BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
Phenanthrene	µg/L	0.02	<0.01	<0.01	0.03	<0.01	<0.01
C1 subst'd phenanthrene / anthracene	µg/L	0.05	<0.04	<0.04	0.05	<0.04	<0.04
C2 subst'd phenanthrene / anthracene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
C3 subst'd phenanthrene / anthracene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
C4 subst'd phenanthrene / anthracene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
1-Methyl-7-isopropyl-phenanthrene (Retene)	µg/L	0.01	<0.01	<0.01	0.01	<0.01	<0.01
Pyrene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Target PANHs							
Quinoline	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acridine	µg/L	0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Note: Site BC-1 not sampled in march since water not present at site.

Table I-2 September 2008 Water Quality

Parameter	Units	Site						
		BC-1	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
Field measured								
pH		8.2	8.4	8.2	9.1	9.5	7.7	7.8
Specific Conductance	µS/cm	214	1,044	846	968	954	824	449
Temperature	°C	6.97	11.30	10.80	8.96	9.50	8.20	8.00
Dissolved Oxygen	mg/L	9.17	13.70	9.56	7.90	6.90	11.64	10.74
Conventional Parameters								
Conductance	µS/cm	332	1,510	1,250	1,200	1,170	1,260	693
Dissolved Organic Carbon	mg/L	-	-	-	-	-	-	-
Hardness	mg/L	124	334	268	362	339	342	213
pH		7.8	8.4	8.4	8.2	8.3	8.3	8.2
Total Alkalinity	mg/L	81	455	321	333	310	311	194
Total Dissolved Solids	mg/L	189	875	707	693	686	711	384
Major Ions								
Bicarbonate	mg/L	99	536	381	407	378	379	236
Calcium	mg/L	30.5	75	48.9	81.5	72.3	88.5	57
Carbonate	mg/L	<5	9	5	<5	<5	<5	< 5
Chloride	mg/L	25	172	143	96	108	118	68
Magnesium	mg/L	11.5	35.6	35.4	38.6	38.5	29.3	17.2
Potassium	mg/L	1.4	0.6	1.3	1.7	1.6	1.4	1
Sodium	mg/L	27	202	167	121	129	124	65
Sulphate	mg/L	45.2	117	119	154	151	163	59.7
Nutrients								
Nitrate + Nitrite	mg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrogen - ammonia	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Nitrogen - Kjeldahl	mg/L	-	-	-	-	-	-	-
Nitrogen - nitrate		<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrogen - nitrite		<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
General Organics								
Naphthenic acids	mg/L	<1	5	3	2	2	2	<1
Metals (Total)								
Aluminum (Al)	mg/L	0.25	0.03	0.05	<0.01	0.01	<0.01	0.14
Barium (Ba)	mg/L	0.022	0.079	0.056	0.077	0.06	0.078	0.059
Beryllium (Be)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Boron (B)	mg/L	<0.05	0.37	0.36	0.24	0.26	0.19	0.12
Cadmium (Cd)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Calcium (Ca)	mg/L	30.8	77.8	47.5	87	72	92.8	58.5
Chromium (Cr)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cobalt (Co)	mg/L	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Table I-2 September 2008 Water Quality (continued)

Parameter	Units	Site						
		BC-1	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
Copper (Cu)	mg/L	0.001	<0.001	<0.001	<0.001	<0.001	0.011	0.001
Iron (Fe)	mg/L	0.655	0.314	0.336	0.534	0.44	0.417	2.59
Lead (Pb)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Magnesium (Mg)	mg/L	11.2	35.7	33.3	38.1	37	30.1	17.3
Manganese (Mn)	mg/L	0.014	0.016	0.064	0.03	0.067	0.02	0.212
Molybdenum (Mo)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nickel (Ni)	mg/L	0.003	0.003	0.002	0.003	0.003	0.003	0.003
Potassium (K)	mg/L	1.6	1.4	2.1	2.5	2.4	1.9	1.4
Selenium (Se)	mg/L	-	-	-	-	-	-	-
Silver (Ag)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sodium (Na)	mg/L	26	215	164	117	128	134	70
Strontium (Sr)	mg/L	0.154	0.324	0.28	0.313	0.291	0.249	0.25
Thallium (Tl)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Tin (Sn)	mg/L	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Titanium (Ti)	mg/L	0.003	0.001	0.001	<0.001	<0.001	<0.001	0.003
Vanadium (V)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc (Zn)	mg/L	0.005	0.006	0.006	0.008	0.007	0.014	0.007
Target PAHs and Alkylated PAHs								
Naphthalene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C1 subst'd naphthalenes	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C2 subst'd naphthalenes	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C3 subst'd naphthalenes	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C4 subst'd naphthalenes	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Acenaphthene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C1 subst'd acenaphthene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Acenaphthylene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
Anthracene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
Dibenzo(a,h) anthracene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
Benzo(a)Anthracene / Chrysene	µg/L	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C1 subst'd benzo(a) anthracene / chrysene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C2 subst'd benzo(a) anthracene / chrysene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Benzo(a)pyrene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03

Table I-2 September 2008 Water Quality (continued)

Parameter	Units	Site						
		BC-1	BC-3	BC-6	BC-7	BC-4	BC-5	BC-8
C1 subst'd benzo(b&k) fluoranthene / benzo(a)pyrene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C2 subst'd benzo(b&k) fluoranthene / benzo(a)pyrene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Benzo(g,h,i)perylene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
Biphenyl	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C1 subst'd biphenyl	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C2 subst'd biphenyl	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Dibenzothiophene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C1 subst'd dibenzothiophene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C2 subst'd dibenzothiophene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C3 subst'd dibenzothiophene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C4 subst'd dibenzothiophene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Fluoranthene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C1 subst'd fluoranthene / pyrene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Fluorene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
C1 subst'd fluorene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C2 subst'd fluorene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Indeno(c,d-123)pyrene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03
Phenanthrene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05
C1 subst'd phenanthrene / anthracene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C2 subst'd phenanthrene / anthracene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C3 subst'd phenanthrene / anthracene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
C4 subst'd phenanthrene / anthracene	µg/L	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.1
Pyrene	µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.03

Appendix VII:

Femi Baiyewun, Syncrude Canada, “2007 Groundwater Monitoring Report, Mildred Lake Site” (March 15, 2008)

March 15, 2008

Alberta Environment
Enforcement and Monitoring Division
11th Floor, Oxbridge Place
9820-106 Street
Edmonton, Alberta
T5K 2J6

Dear Sir/Madam:

RE: 2007 GROUNDWATER MONITORING REPORT – SYNCRUDE MILDRED LAKE SITE

Attached, please find two copies of our Annual Compliance Report for 2007 pursuant to clause 11.9.1 of Approval 26-02-00 under the Environmental Protection and Enhancement Act. We respectfully submit this report in accordance with the terms and conditions of the Environmental Protection and Enhancement Act and amendments, and in accordance with sound engineering and environmental practices.

We trust that the report is satisfactory at this time.

Yours truly,

Nathalie Bérubé

Attachment

Environmental Services and Regulatory Approvals
Syncrude Canada Limited
P.O. Bag 4009, M.D. 4160
Fort McMurray, Alberta, T9H 3L1
Ph: (780) 790-4544 Fax: (780) 790-4105
E-mail: berube.nathalie@syncrude.com

2007
GROUNDWATER MONITORING
REPORT

SYNCRUDE CANADA LTD.
MILDRED LAKE SITE

SUBMITTED TO
ALBERTA ENVIRONMENT

IN COMPLIANCE WITH
APPROVAL 26-02-00, CLAUSE 11.9.1

PREPARED BY: **Femi Baiyewun**
Geotechnical Division, Technical / Operations Support Department

REPORT ISSUED: **March 15, 2008**

Geotechnical Division, Technical / Operations Support Department
Syncrude Canada Ltd.

REPORT DISTRIBUTION:

2 COPIES:	ALBERTA ENVIRONMENT (+ CD)
1 COPY:	JOSEPH MATULA - MANAGER, OPERATIONS SUPPORT
1 COPY:	ALAN BEAVAN - GEOTECHNICAL DIV. / OPERATIONS SUPPORT, TEAM LEADER
1 COPY:	WAYNE MIMURA - ASSOCIATES, GEOTECNICAL ENGINEERING (TAILINGS)
1 COPY:	NATHALIE BERUBE - ENVIRONMENTAL SERVICES
1 COPY:	RON LEWKO - RECLAMATION & CLOSURE (LANDFORM TECH.)
1 COPY:	WILLIAM HUNTER - RECLAMATION & CLOSURE (OPERATIONS)
1 COPY:	GERRALD PRATT – DEWATERING, (TEAM LEADER)
1 COPY:	SYNCRUDE RESEARCH LIBRARY, EDMONTON
1 COPY:	TAILINGS LIBRARY

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1 Introduction

This Syncrude Canada Ltd. report is completed in compliance with Clause 11.9.1 of Approval 26-02-00 under the Environmental Protection and Enhancement Act, which stipulates the requirement to submit an annual groundwater monitoring summary for the Mildred Lake Site to Alberta Environment.

The intent of the groundwater monitoring program is to understand the effects of Syncrude's oil sand mining, bitumen upgrading, and associated operations on the local groundwater quality. Water samples are collected and analyzed from numerous monitoring wells and surface water locations throughout the area. Particular focus is placed on groundwater monitoring in the vicinity of the following facilities:

- Mildred Lake Settling Basin (MLSB) and Mildred Lake East Toe Berm (MLETB)
- Southwest Sand Storage (SWSS)
- Sulphur Block Storage
- In-Pit Tailings Areas
- Proposed Flue Gas Desulphurization (FGD) Landfill Project
- Sewage Lagoons
- Special Waste Interim Storage Area (SWISA)

2 Site Description

The Syncrude Mildred Lake site is located in northeastern Alberta, forty kilometers north of the city of Fort McMurray. At this site oil sand is mined, the bitumen is extracted from the oil sand then upgraded to a synthetic crude oil. The major by-products of this operation include tailings sand, sulphur and coke.

The site can be divided into three general areas: the mine, the tailings areas, and the plant site. There are two open pit mines, Base Mine (presently reclaimed as 400 and 700 dumps) and North Mine, and three tailings areas, Mildred Lake Settling Basin (MLSB), Southwest Sand Storage (SWSS) and In-pit areas which comprised of the West In-pit (WIP), the Southeast Pond (SEP) and the Northeast Pond (NEP). Other significant features include coke storage cells, overburden dumps, sulphur blocks, sand and gravel pits, sewage treatment facilities, and the Beaver Creek Diversion.

The surface mineable area is associated with the topographic low along the Athabasca River valley. The ore deposit is a bitumen-saturated sedimentary deposit of the Lower Cretaceous McMurray Formation. At the Mildred Lake Site, the open pit excavation reaches an average depth of 65 meters and covers an area of approximately 39 km^2. A satellite image of the Syncrude Mildred Lake site is shown in Figure 2.1.

Syncrude has been operating its open pit oil sand mine since 1978. During the first fifteen years or so, mining utilized a combination of draglines, bucket-wheel reclaimers, conveyors, trucks, and shovels. Since 1996 mining has switched to shovels, large haul trucks and pipeline hydro-transport to move the oil sand to the extraction plant. The extraction process involves digestion and conditioning of the oil sand with hot water and caustic soda (NaOH) to facilitate the separation process. Tailings composed of sand, silt and clay with water and small residual amount of bitumen is the primary by-product of the extraction process. These tailings are hydraulically transported to one of the disposal areas. Initially the tailings deposits are saturated with water from the extraction process. In the remainder of the report, such waters will be referred to as process-affected water, and this relates to waters that have been associated with the extraction process.

The bitumen froth product is separated from the sand and converted to a light, sweet, synthetic crude oil, called Syncrude Sweet Blend (SSB). In 2007, Syncrude produced 111.33 million barrels of SSB. By-products of the upgrading process include elemental sulphur and coke.

The focus of the groundwater monitoring program is to assess the impact of process water on groundwater. There are several other facilities on the Syncrude site that pose a potential risk to groundwater quality. These include the sulphur blocks, the SWISA and the sewage lagoons. Since 1993, sulphur has been stored on site in the northwest portion of the plant site. Domestic wastewater produced at Syncrude is treated onsite in sewage lagoons located adjacent to the Athabasca River. All surface water and groundwater monitoring locations are shown on Figure 2.2.

FIGURE 2.1: MILDRED LAKE SITE, SATELLITE PHOTOGRAPH

2.1 Mildred Lake Site and Surrounding Water Users

A search was completed for licensed water wells in the area surrounding the Mildred Lake Site through the Groundwater Information Centre's Web site. An additional search for licensed surface water and groundwater users was completed through the Northeast Boreal Regional office of Alberta Environment. These searches covered the area outlined in Figure 2.1, extending over five kilometres from the Mildred Lake Site. Not all licensed surface water and groundwater wells have coordinates associated with them. In addition, the well identification numbers given for the wells are those obtained from the Groundwater Database. Those that have coordinates provided are shown on Figure 2.1A. Sixty-one well records, mostly for industrial use, were identified within this search area as shown below in Table 2.2. It is not known from the database how many and which wells are still active.

Table 2.1: Search Area for Groundwater Users

					Twp
	0	**17**	**43**	**21**	**94**
	22	**3**	**8**	**0**	**93**
	12	**1**	**44**	**5**	**92**
	2	**0**	**4**	**2**	**91**
Range	**12**	**11**	**10**	**9**	

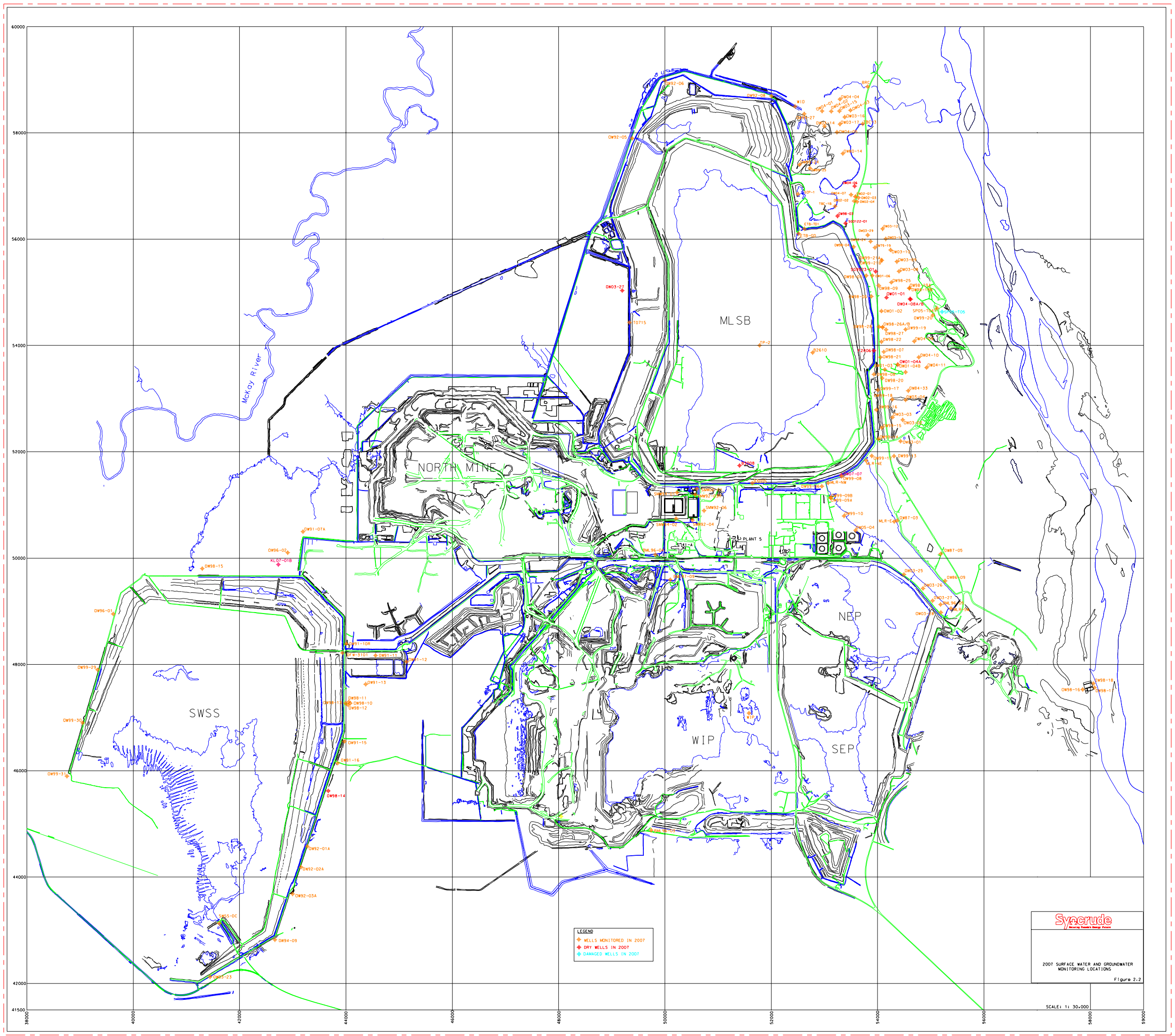
Table 2.2: Summary of Wells Located Around the Mildred Lake Site

Well-ID	Status Date	Owner	Use	1/4 or LSD	SEC	TWP	Range	W of Meridian
0279842	17/11/1987	Kim Lamontagne	Industrial	NE	4	91	10	4
0279843	15/11/1982	Alta Forest Service	Industrial	00	24	91	10	4
0279843	07/11/1977	Poplar Creek Sales	Industrial	07	26	91	10	4
0279845	26/07/1977	Poplar Creek Gravel pit	Industrial	NE	26	91	10	4
0279845	04/05/1987	Can Roxy	Industrial	06	30	91	12	4
0279847	04/05/1987	Can Roxy	Industrial	04	33	91	12	4
0279841	-	Bear Oil Co # Rodeo 2	Industrial	05	17	91	9	4
1270006	11/05/2004	Suncor Energy Inc	Industrial	11	32	91	9	4
0150376	13/03/1990	Carbovan	Industrial	SW	12	92	10	4
0151049	07/05/1990	Carbovan	Industrial	SW	12	92	10	4
1827856	07/04/2005	Alberta Environment	Industrial	SE	14	92	10	4
0296253	18/05/2001	Midstream Joint Venture	Industrial	NE	12	92	10	4
0296250	30/03/2001	Graham Construction & Engng	Industrial	SW	12	92	10	4
0279884	01/10/1971	GCOS # P54	Industrial	09	28	92	10	4
0279882	-	GCOS #K16	Industrial	14	28	92	10	4
0279881	-	GCOS # K15	Industrial	11	28	92	10	4
0279880	-	GCOS # PK18	Industrial	02	28	92	10	4

Table 2.2: Summary of Wells Located Around the Mildred Lake Site (Continued)

Well-ID	Status Date	Owner	Use	1/4 or LSD	SEC	TWP	Range	W of Meridian
0279879	-	GCOS # P58	Industrial	01	28	92	10	4
0279878	07/10/1971	GCOS # P39	Industrial	15	27	92	10	4
0279877	-	GCOS # P57	Industrial	12	27	92	10	4
02798876	-	GCOS # K4	Industrial	03	27	92	10	4
0279875	-	GCOS # K3	Industrial	08	27	92	10	4
0279874	-	Empire Dev	Industrial	00	23	92	10	4
0279873	-	GCOS	Industrial	03	23	92	10	4
0279869	01/10/1971	GCOS	Industrial	15	22	92	10	4
0279866	-	ARC # K17	Industrial	13	22	92	10	4
0279864	01/10/1971	GCOS # P49	Industrial	02	22	92	10	4
0279863	01/10/1971	GCOS # OBS 2	Industrial	14	14	92	10	4
0279860	01/10/1971	GCOS # P19	Industrial	01	5	92	10	4
0040931	15/02/2002	Suncor Energy Inc	Industrial	NE	7	92	10	4
0287976	17/09/1997	Burnco Rock Products	Industrial	SE	19	92	9	4
1500034	09/11/2006	Suncor Energy Inc	Industrial	NE	7	92	9	4
0235766	-	Sun Oil	Industrial	06	3	93	10	4
0235174	-	#74-8 Athabasca Bridge Study	Industrial	NW	29	93	10	4
0235179	-	Bear Oil Co Ltd # Bear Vampire 2	Industrial	04	32	93	10	4
0235182	-	Alta Forest Service	Industrial	00	26	93	11	4
1827859	-	Alta Environment	Industrial	SE	25	93	11	4
0042469	-	PTI Camp Services	Industrial	SW	5	93	11	4
0042470	-	PetroCan #WSW3	Industrial	04	8	93	12	4
0168219	-	AOSTRA UTF Site	Industrial	SE	7	93	12	4
0235187	-	Sinclair Can Oil Co	Industrial	01	8	93	12	4
0235188	-	Sinclair Can #TH20	Industrial	01	9	93	12	4
0235189	-	Sinclair Can #TH20	Industrial	01	16	93	12	4
0235190	-	Sinclair Can #TH20	Industrial	01	17	93	12	4
0235191	-	Sinclair Can #TH20	Industrial	01	19	93	12	4
0286009	-	Gibson Petroleum Co Ltd	Industrial	01	7	93	12	4
0299208	-	PetroCan	Industrial	NW	5	93	12	4
0235209	-	#TH75-95 STN 861+58.5	Industrial	SW	7	93	10	4
0235213	-	#TH75-95 STN 861+58.5	Industrial	06	7	93	10	4
1911642	-	Inland Concrete	Industrial	SE	19	93	10	4
0299207	-	PTI Group Inc	Industrial	NE	32	93	10	4
0235249	-	Home Oil	Industrial	12	26	93	10	4
0235246	-	Home Oil	Industrial	12	25	93	10	4
0233810	-	ARC # 1-457	Industrial	13	12	93	11	4
0233809	-	ARC	Industrial	13	12	93	11	4
0288029	24/02/1998	OSOWN	Industrial	03	28	93	11	4
0235200	11/01/1974	Home Oil	Industrial	12	30	93	9	4
0235202	11/01/1974	Home Oil	Industrial	12	31	93	9	4
0233808	25/03/1975	Home Oil CO #7	Industrial	02	28	93	9	4
0235199	11/01/1974	Home Oil	Industrial	13	29	93	9	4
0235261	21/09/1973	Alta Forestry Ranger Stn.	Industrial	SW	36	93	11	4

Figure 2.2: Surface Water and Groundwater Monitoring Locations



3 Physiography and Geology

3.1 Topography and Drainage

The Mildred Lake site falls within the Saskatchewan Plain division of the Interior Plains physiographic region. Adjacent to the northeast edge of the area is the Athabasca Plain, a subdivision of the major Canadian Shield physiographic region.

The natural topography across the Syncrude site reaches an elevation of 380 meters above mean sea level (mamsl) on the southwest and falls toward the Athabasca River on the east. East of Highway 63, the topography drops rapidly toward the Athabasca River. To the east of the Athabasca River is the Muskeg Mountain, which rises to approximately 610 mamsl.

The dominant drainage feature is the Athabasca River that is located at approximately 2.5 km east of the Mildred Lake site. Mean monthly flows between the years 1958 and 2006 for the "Athabasca River below McMurray" (Environment Canada station #07DA001), are typically highest in July (1,385 m3/s) and lowest in February (161 m3/s).

The MacKay River is the only other major drainage feature. It is located about 9 km west of the Mildred Lake plant site. Mean annual flow between 1972 and 2006 was 13.8 m3/s. The lowest mean monthly flow occurred in February (0.411 m3/s), while the highest mean monthly flows occurred in May (39.7 m3/s). The gauging station is located 5.6 km NW of Fort MacKay (#07DB001), with a drainage area of 5,570 km2. The MacKay River joins the Athabasca River at Fort MacKay

Beaver Creek is an important minor feature because its former upper course traversed the location of the present day Syncrude Mildred Lake Operation. Beaver Creek is now diverted at the south end of the site into Poplar Creek. However, low flow is observed at the northeast end of the Beaver Creek around the Mildred Lake Settling Basing (MLSB).

3.2 Geology

The geology of the Mildred Lake site is illustrated on schematic cross-sections (Figures 3.2, 3.3 and 3.4). The locations of these cross-sections are shown on Figure 3.1.

Devonian Age Deposits

The Upper Devonian Waterways Formation comprises the main unit immediately underlying the Cretaceous sequence. Crickmay (1957) subdivided the Waterways Formation into five members, which are, in ascending order: Firebag, Calumet, Christina, Moberly, and Mildred. The different members of the Waterways Formation form a series of limestone beds with varying proportions of shale. The hydraulic conductivity of the limestone at the Mildred Lake Site is usually very low. In the past, exposures at the base of the mine pit have revealed clay-filled fractures within the limestone.

Cretaceous Age Deposits

<u>McMurray Formation:</u> The deepest Cretaceous strata in the regional study area are the rocks of the McMurray Formation. These strata are separated from the underlying Devonian strata by a major erosional unconformity. The present stream profiles of the lower Athabasca River and Clearwater River are now controlled by the pre-Cretaceous erosion surface. The McMurray Formation has been divided into three stratigraphic units: Lower McMurray (Coastal Plain / Fluvial), Middle McMurray (Estuarine) and Upper McMurray (Near Shore) as described below.

Lower Member (Coastal Plain/Fluvial): Unconformably overlies the erosional surface of the Devonian. Its lowest beds consist of residual clays formed from weathering of the Devonian strata. These beds are overlain by silts and clays of a fluvial origin and by coarse sands, whose thickness is largely controlled by the topography of the unconformity surface on the Devonian sequence. The sand may be either water saturated (the basal aquifer) or bitumen saturated. The basal aquifer is discontinuous throughout Lease 17 and 22.

Middle (Estuarine) and Upper (Near Shore) Members of the McMurray Formation: Consist mainly of a bitumen-saturated quartz sand, interbedded with lenticular beds of micaceous silts, shales, and in places, clays. The Middle Member is characterized by frequent primary sedimentary structures, particularly current bedding, while the Upper Member is more commonly horizontally bedded. The Middle and Upper Members constitute the main ore body being mined in the Athabasca oil sands area (Figure 3.2).

Clearwater Formation: Conformably overlies the McMurray Formation. The deepest beds are glauconitic sandstone and have been termed the Wabiskaw Member. Their distinctive olive green colour makes them useful as an easily identifiable marker horizon throughout the area. The Wabiskaw Member grades up into gray marine shale, which makes up the remainder of this stratigraphic unit. The Clearwater Formation increases in thickness to the west corresponding to the rising topography away from the Athabasca River (Figure 3.2).

Grand Rapids Formation: Likewise, the Grand Rapids Formation only occurs on progressively higher ground southwest of the Mildred Lake Site. It is described as “salt and pepper” sand, generally unconsolidated, and consists of fragments of quartz, feldspar, glauconite, chert, muscovite, and biotite.

Quaternary Age Deposits

The surficial geology of the region consists of deposits of Pleistocene and Holocene age. These surficial deposits include glacio-lacustrine clays, glacial, tills, fluvial deposits and aeolian sand. Syncrude’s classification of overburden geology, which includes the Quaternary deposits and Cretaceous units overlying the McMurray Formation, is shown in the Facies Chart, Table 3.1.

Of particular interest from a hydrogeologic perspective are the glacio-fluvial deposits. Within the current operating portion of Syncrude’s leases 17 and 22, there are two areas with significant glacio-fluvial deposits: east of the MLSB and north of the SWSS. East of the MLSB, glacio-fluvial deposits extend from under the tailings facility east toward the Athabasca River. The sand and gravel deposits overly a silty-sandy till and is capped with a thin layer of Holocene organics. North of the SWSS, the glacio-fluvial deposit is present in the form of a buried Pleistocene channel (G-Pit channel). Five to ten meters of glacial till and glacio-lacustrine clays overlie the G-Pit channel. The channel has been traced to run from near the MacKay River, south under the SWSS, flows north, then turns westward again to the MacKay River (Figure 3.1). The channel has been partially removed by the North Mine, which is currently extending to the north and northwest to the proposed mine limit.

Figure 3.1: Site Plan Showing Location of Cross-Sections

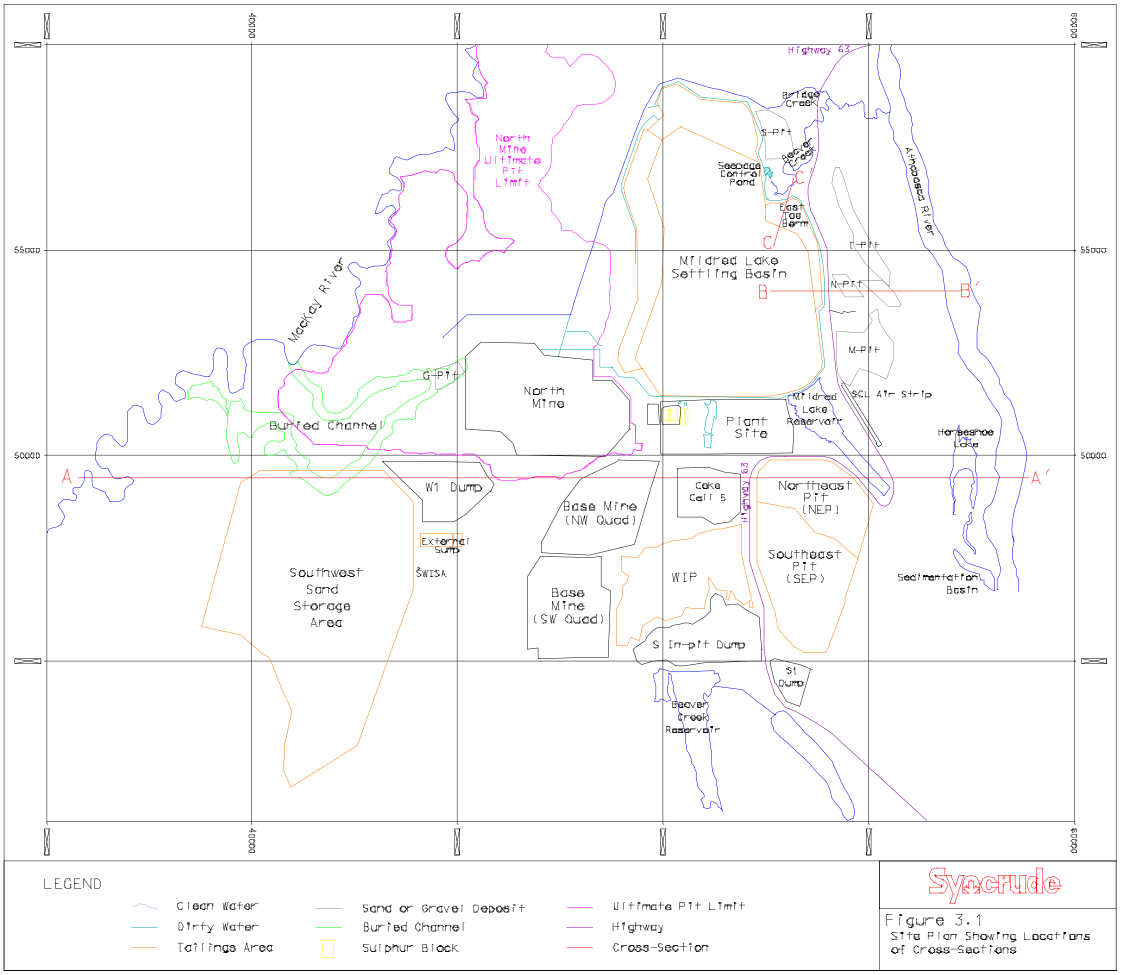


Figure 3.2: Schematic Cross-Section A-A'

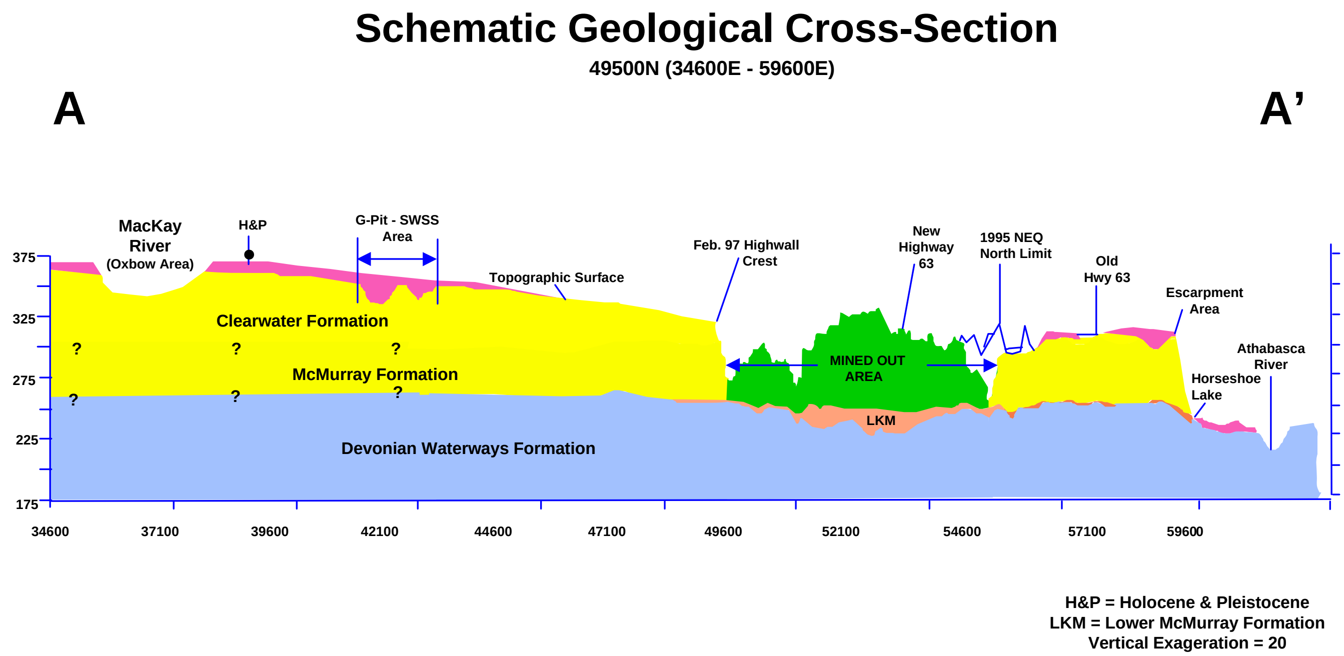


Figure 3.3: Schematic Cross-Section B-B'

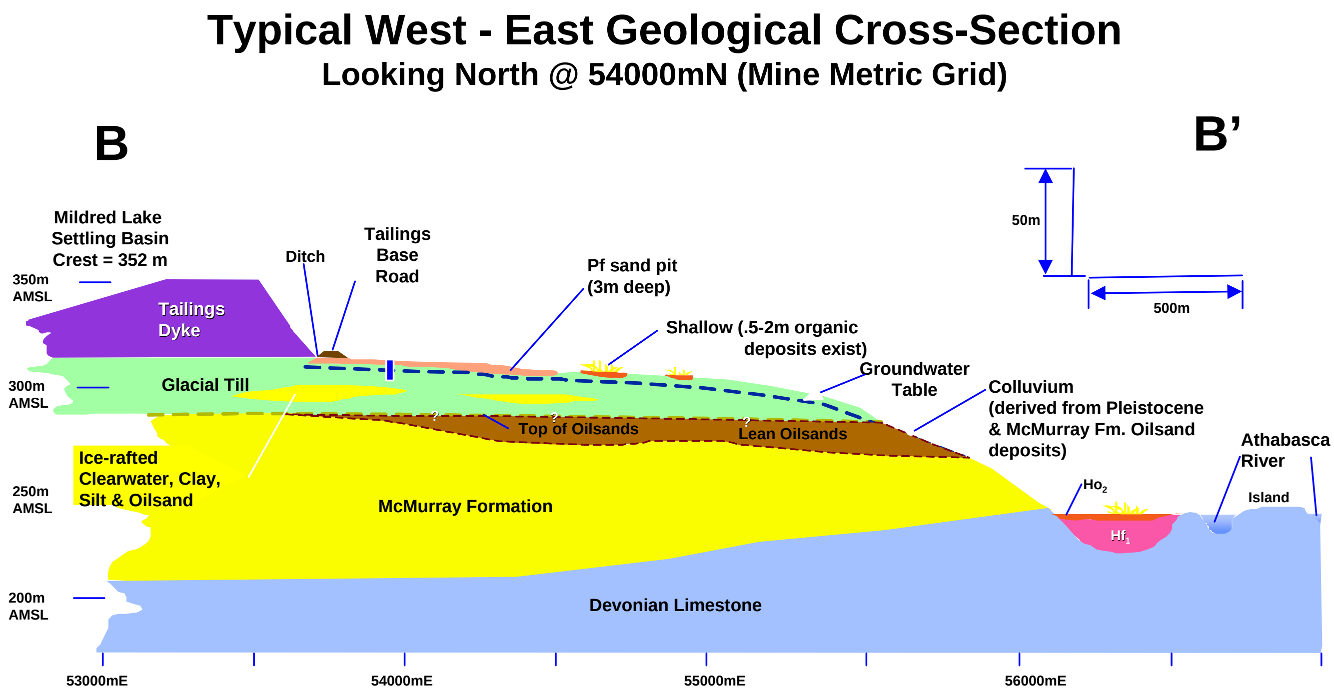


Figure 3.4: Schematic Cross-Section C-C’

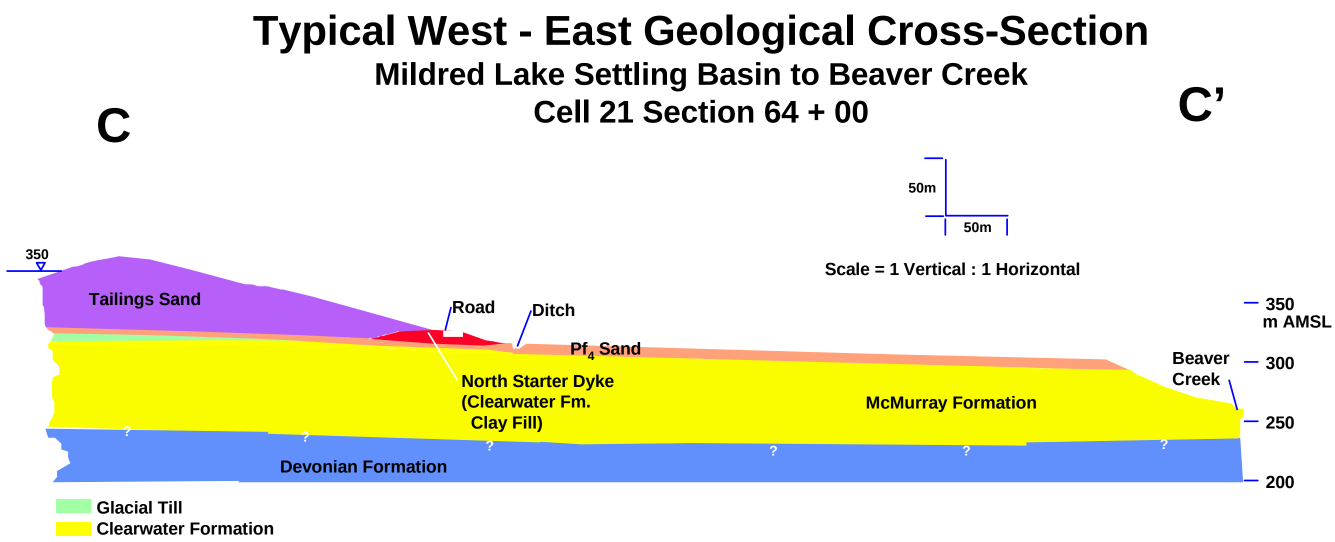


Table 3.1: Overburden Geology Facies Chart

GEOLOGICAL EPOCH		DEPOSITIONAL ENVIRONMENT	GEOLOGIC SYMBOL	UNIFIED SOIL CLASSIFICATION	RANGE OF THICKNESS	LITHOLOGIC DESCRIPTION
	HOLOCENE	Erosional Features & Sediments	He2	Variable	Variable	Slump material; mixed glacial and bedrock materials; variable lithology.
			He1	Variable	Variable	Gully, creek; thin alluvial cover on valley slopes, thin alluvial materials along streams.
		Highly Organic Deposits	Ho2	OL, PT	0.2-6.0 m	Dark brown or black muskeg or peat; primarily mosses & sedges.
			Ho1	OL,OH	Commonly <0.3 m	Brown, grey or black organic mineral soils; mixture of clay, silt, sand & organics.
		Lacustrine (Lakeshore)	Hl2	Variable	0.30 m Commonly <1.5 m	Whitish-grey sand, silt and clay with some gravel, shells and organics.
		Lacustrine (Lake Bottom)	Hl1	CH, OH, MH	0-1.5 m	Whitish-grey silt and clay with shells and organics.
		Alluvial Stream	Hf1	CH, OH	0-3.0 m Commonly 0-1.5 m	Grey bedded sand, silt/clay with brown patches or streaks of organics. Confined to valleys of recent streams.
		Beaver Creek Alluvium	Hf1*	CH, OH Minor SM, SC	0-6.0 m	Silt and clay with some sand lenses and organics confined to Beaver Creek.
		Aeolian Deposits	Hae	SP	0-9.0 m Commonly 0-1.5 m	Light brown to buff fine-grained sand in sheet and dune form; poorly graded.
	PLEISTOCENE	Glacio-Lacustrine (Lakeshore)	Pl3	SM, SC, SW	0-3.0 m Commonly <1.5 m	Sand with minor silt, clay and gravel. Shallow water deposits.
		Glacio-Lacustrine (Mixed)	Pl2	CH, MH, CL, ML	0-6.0 m Commonly <3.0 m	Grey, pink or brown stratified clay, silt & sand interbedded (mm-cm) with gravel or boulder till layers.
		Glacio- Lacustrine (Silt & Clay)	Pl1	CH, MH	0-9.0 m Commonly <3.0 m	Greenish-grey or brown silt and clay with minor sand lenses. Similar to Pl2 but with no gravel content.
		Glacial Outwash (Sand)	Pf4	SW, SP	Variable	Brown, orange, grey or grey-white coarse to fine-grained sand; may contain lenses of black sand.
		Glacial Outwash (Sand & Gravel)	Pf3	GW, GP, GM & GC	Variable	Brown or grey sand and gravel with brightly coloured cobbles and boulders.
		Glacio-Fluvial Meltwater Channel (Coarse)	Pf5b	GM, GC; minor CL	0-6.0 m Commonly <3.0 m	Rust, rusty-brown or brown sandy, silty and clayey gravel with cobbles and boulders.
		Glacio-Fluvial Meltwater Channel (Fine)	Pf5a	SM, SC; minor CL	0-9.0 m Commonly <3.0 m	Brown and grey sand and silty sand; very fine to coarse-grained.
		Glacial Deposits (Ablation Till)	Pg3	SM, SP, SC	0-6.0 m Locally may be thicker	Sand, silt and clay with cobbles and boulders deposited in situ by glacial ablation.
		Glacial Deposits (Lodgement/ Firebag Till)	Pg1	SM, SC	0-12.0 m Commonly 3.0-9.0 m	Brown to grey silty fine-grained sand with gravel and clay. Some cobbles and boulders present. Contains lenses of glaciofluvial deposits. Commonly oil impregnated in basal sands.
		UNCONFORMITY				
	CRETACEOUS	Beach Complex (Grand Rapids Formation)	Kg	No data	0-10.0 m (on SCL)	Buff to light brown sand and sandstone.
		Marine/ Shoreface (Clearwater Formation)	Kcg	No data	0-9.0 m (on SLC)	Fine-grained sand, silt and clay with traces of glauconite.
			Kcf	No data	14.4-19.7 m Mean: 17.1m	Fine to very fine-grained greenish-grey glauconitic sand interbedded with silt and clay.
			Kce	CH, CL	4.0-9.7 m Mean: 6.6 m	Greyish-black silty clay; fissile; minor lenses of fine-grained sand and silt.
			Kcd	SC, SM, SP, SW, CH, CL	7.3-13.7 m Mean:11.4 m	Greenish-grey to grey interbedded very fine to medium-grained glauconitic silty sand, sandy silt and clay.
			Kcc	CH, CL, ML	18.3-26.3 m Mean:23.2 m	Grey-black shales; interbedded clayey silt with clay-rich strata. Low-density black clay at top and base. Bioturbated.
			Kcb	CL, CH	4.0-7.0 m Mean: 5.4 m	Interbedded glauconitic fine-grained sand, clayey silt and silty clay. One thinly laminated, highly montmorillonitic, low density clay in middle,& one near top contact.
			Kca	CH	3.0-6.0 m Mean: 4.5 m	Silty-clay in upper part; clayey silt in lower part; clay-rich with glauconitic silt stringers near basal contact.
			Kcw	SC, SM, ML,CH, CL	0.3-5.5 m Mean: 2.6 m	Interbedded glauconitic fine to medium-grained sandy silt, silt and clayey silt.

4 Groundwater Sampling and Decommissioning Procedures

Well Development

Prior to sampling, wells are purged to remove stagnant water that may not be representative of the formation. Development methods vary slightly depending on the installation and formation being sampled. Where possible, wells are purged by removing three well volumes prior to sampling. Wells installed in lower hydraulic conductivity units are purged by repeatedly removing all water possible, and allowing these wells to recover until sufficient water is available for sampling. Recovery of such wells usually takes a long time and prolongs the sampling time. Purging is completed using either dedicated WaTerra inertial pumps (IP) or Bailer (B).

The specific purging method used for each well is presented in Appendix A, along with the analytical results in Appendix B.

Sampling

Wells are sampled using either a dedicated inertia pump or a bailer. Surface water samples are termed grab samples (G). When required, samples are filtered using a disposable 45-micron in-line filter. The specific device used for each well is identified in Appendix A, along with the analytical results in Appendix B.

Routine Parameters (major ions, pH, EC, TSS, TDS)

A 500-ml polyethylene bottle is rinsed with the well water, then slowly filled to overflowing and immediately sealed. No preservative is required for these analyses.

Dissolved Organic Carbon (DOC)

A 100-ml amber glass bottle is rinsed with filtered water, then filled halfway. A pre-measured volume (1-ml) of 1:1 sulphuric acid (H_2SO_4) is added, and then the remainder of the bottle is filled and immediately sealed.

Phenols

A 100-ml amber glass bottle is rinsed with sampled water, and filled halfway. A pre-measured volume (1-ml) of 1:1 sulphuric acid (H_2SO_4) is added, and then the remainder of the bottle is filled and immediately sealed.

Trace Metals

A 500-ml PETE or HDPE bottle is rinsed with filtered sample water. The bottle is filled halfway with filtered sample water, a pre-measured volume (5-ml) of 20% nitric acid is added, and the remainder of the bottle is filled and immediately sealed.

Field measurements (pH, EC, temperature)

Field measurements of pH, electrical conductivity and temperature are completed after all other samples are collected (provided sufficient water is available). Portable pH and conductivity probes are rinsed with de-ionized water and dried before measurements are taken. The probes are calibrated regularly to ensure accuracy of field measurements.

Sample bottles are labeled and stored in a cooler while sampling is carried out. Samples are sent directly by courier to a contract laboratory for analysis. Chain of custody paperwork accompanies all samples.

In 2007, Golder Associates Ltd. conducted sampling. ALS Laboratory Group (formerly Enviro-Test Laboratories) was contracted to complete analysis of all the surface water and groundwater samples. Syncrude Research collected surface water samples from MLSB (TP-2) and WIP.

Well Abandonment

From time to time, monitoring wells are damaged or abandoned. These monitoring wells are decommissioned in a way that will prevent the migration of contaminants through the well casing.

4.1 Quality Assurance and Control

The contract laboratory uses standard analytical methods and procedures. Standard in-house QA/QC protocols include the analysis of blanks, duplicates and surrogate recoveries for organic analyses, matrix spikes and 10 percent replicates for every sample batch.

Duplicate samples were collected for routine major ions (eight samples), consisting of dissolved metals (three sample), phenols (one sample) and naphthenic acids (four samples). To provide a quantitative measure of the precision of the duplicate analysis, the relative percent difference (RPD) was calculated for those parameters in which the reported concentrations were greater than 4.0 times the detection limit (Tables 4.1 to 4.3).

Most of the duplicate samples were within the accepted standard for groundwater samples (20 percent). Samples exceeding the 20% criterion were phenol, naphthenic acid, zinc and aluminum in six out of eighteen samples. However, the locations of the six samples are at the source points which discharge into the recycle system.

Table 4.1: Phenols - Duplicate Samples

ID	Sample Date	Phenols (mg/l)
OW98-12	27-Jun-07	< 0.001
OW98-12	27-Jun-07	< 0.002
RPD*		**0.00 %**

Table 4.2: Naphthenic Acids - Duplicate Samples

ID	Sample Date	Naphthenic Acids (mg/l)	ID	Sample Date	Naphthenic Acids (mg/l)
DFW-3101	12-Jul-07	22	OW03-11	09-Jul-07	< 1
DFW-3101	12-Jul-07	28	OW03-11	05-Jul-07	< 1
RPD		**24%**	**RPD**		**
OW04-02	20-Jun-07	11	TBC-3	29-Jun-07	2
OW04-02	20-Jun-07	9	TBC-3	29-Jun-07	3
RPD		**20%**	**RPD**		**40 %**

** RPD not calculated as one or both measurements for constituent is not more than 4.0 times the specified detection limit: aluminum = 0.04 mg/l; arsenic = 0.0016 mg/l; zinc = 0.008 mg/l; Phenol = 0.004. Concentrations in mg/l

Table 4.3: Dissolved Metals - Duplicate Samples

ID	TBC-3	TBC-3	RPD	DFW-3101	DFW-3101	RPD	SMW94-01	SMW94-01	RPD
Sample Date	29-Jun-07	29-Jun-07		12-Jul-07	12-Jul-07		07-Jun-07	07-Jun-07	
Fe	0.012	0.011	**8.7 %**	0.014	0.018	**25.0 %**	3.57	3.57	**0 %**
Al	< 0.01	< 0.01	**	< 0.01	0.01	**	0.05	0.04	**22.2 %**
As	0.0011	0.0012	**8.7 %**	0.0053	0.0057	**7.3 %**	0.0005	0.0004	**22.2 %**
B	0.196	0.199	**1.5 %**	2.59	2.67	**3.0 %**	0.402	0.402	**0 %**
Cd	< 0.0001	< 0.0001	**	< 0.0001	< 0.0001	**	< 0.001	< 0.001	**
Cr	0.0015	0.002	**28.6 %**	< 0.005	< 0.005	**	0.0019	0.0012	**45.2 %**
Cu	< 0.0006	< 0.0006	**	0.0009	0.001	**10.5 %**	< 0.0006	< 0.0006	**
Pb	< 0.0001	< 0.0001	**	< 0.0001	0.0001	**	< 0.0001	0.0001	**
Ni	0.0018	0.0019	**5.4 %**	0.0076	0.0072	**5.4 %**	0.0023	0.002	**14.0 %**
Zn	0.003	< 0.002	**0 %**	0.014	0.012	**15.4 %**	< 0.002	< 0.002	**

** RPD not calculated as one or both measurements for constituent is not more than 4.0 times the specified detection limit: aluminum = 0.04 mg/l; arsenic = 0.0016 mg/l; zinc = 0.008 mg/l; Phenol = 0.004. Concentrations in mg/l

5 Monitoring Network

Syncrude maintains a network of surface water sampling points and groundwater monitoring wells (Figure 2.2) to identify any impact that the tailings facilities, sulphur storage, special waste interim storage, proposed FGD landfill and sewage treatment areas may have on groundwater quality. Monitoring is focused on the geologic units with the greatest potential for contaminant transport. The groundwater monitoring network has been divided into eight separate areas based on geology and potential contaminant sources (Figure 5.1). Data gathered on surface water samples from both potential sources and receptor areas are summarized in Section 5.1 and discussed in more detail throughout the text of Section 5, as the results pertain to each area.

To interpret the analytical results, the trend of key parameters over time and the relative concentrations of major ions have been examined. When historical data is not available, current data is compared to background values for the same hydro-stratigraphic unit in that specific area. Chloride and sodium are particularly useful tracers of process water, since they are present in high concentrations in process water relative to groundwater background concentrations. Naphthenic acids have also been used to aid in identifying groundwater influenced by process water. Recent work suggests that natural concentrations of naphthenic acids in the shallow Pleistocene aquifers are low. For specific wells, analysis for naphthenic acids was completed. The change in pH over time is the principal indicator used to identify impact from sulphur storage.

5.1 Surface Water Samples

5.1.1 Background

5.1.1.1 Description

Water samples are collected from various facilities that contain or transport process affected water, including the tailings storage facilities, tailings dyke filter drains, ditches, and the seepage collection pond. These samples provide an indication of the source concentrations of process water and aid in the identification of process-water contamination of groundwater.

Samples are also collected from several natural water bodies around the site. Each of these natural water bodies has undergone significant changes to its flow regime, due to the construction of Syncrude's Mildred Lake Site.

5.1.1.2 **Monitoring Network**

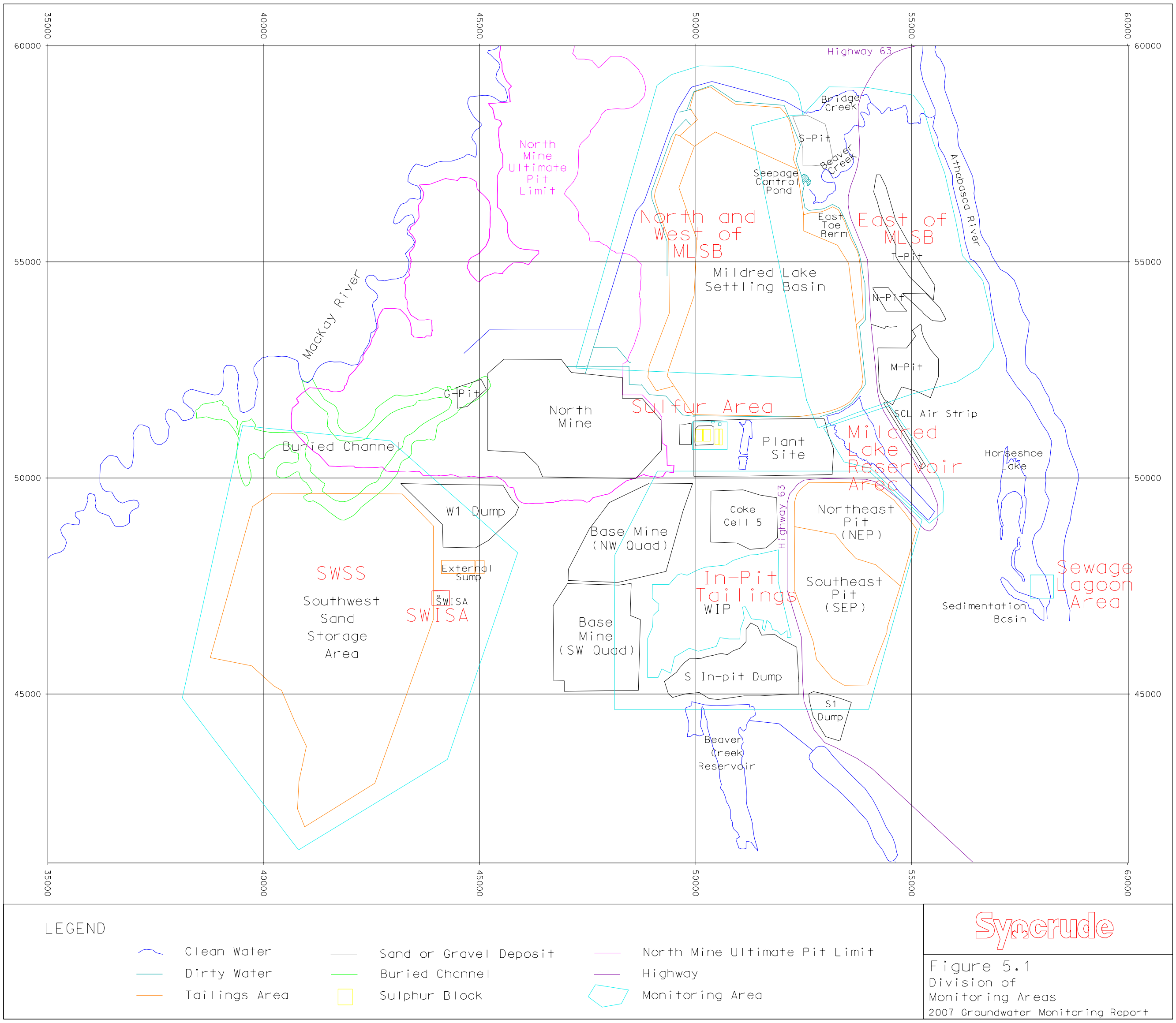
In 2007, there were a total of eight sample locations within the dirty water system, from the MLSB, MLETB, SWSS, and in-pit tailings.

At the MLETB, the surface water sampling points (F2001 – F2501 finger drains) were dry in the last five years and none of these could be sampled in 2007 for there was no flow in these finger drains. However, water samples from ETB-GD and ETB-TD1 were taken from the perimeter ditch-granular drain, which is representative of the expected seepage flow from the MLETB. The monitoring of the finger drain for trickles shall continue in 2008.

The MLSB samples were taken from a central location in the pond and the seepage collection pond to represent the characteristics of the seepage from the dyke. The off-take pipe (B2610) was dry at the time of sampling.

From WIP, samples were collected at the recycle water barge. Sampling at the SWSS comprised of a surface water sample from the decant area (SWSS-DC) and the SWSS – W1 Dump interface filter (DFW-3101).

Figure 5.1: Division of Monitoring Areas



Additional sampling of Beaver Creek was also completed in support of the Beaver Creek Environmental Risk Assessment (ERA) field study to determine the impact of seepage on Beaver Creek. A report on that study will be submitted to AENV in March 2008.
Samples from outside the dirty water system included Beaver Creek, Bridge Creek and Mildred Lake Reservoir (MLR). Samples were collected from two locations along Beaver Creek, just downstream of the lower seepage collection pond (TBC-1B) and at the Highway 63 crossing (TBC-3). The West Interceptor Ditch (WID) was sampled just upstream of the Bridge Creek discharge and Bridge Creek was sampled at Highway 63 while four samples were collected from Mildred Lake Reservoir (MLR) along the shoreline.

Sample locations are listed in Table 5.1 and shown on Figure 5.2.

Table 5.1: Surface Water Sampling Locations

Dirty Water System		
Area	**Location**	**Sample ID**
MLETB	Ditch Granular Drain	ETB-TD1 ETB-GD
MLSB	Pond Off-take pipe Seepage Collection pond	TP-2 T0715 SCP-1
SWSS	Decant (pond water) Filter drain pipe	SWSS-DC DFW-3101
WIP	Pond	WIP
Areas Outside of Dirty Water System		
Area	**Location**	**Sample ID**
Bridge Creek	WID just upstream of discharge to creek At Highway 63	WID BRC
Beaver Creek	Downstream of Lower Seepage Collection dam At Highway 63	TBC-1B TBC-3
Mildred Lake Reservoir	NW corner NE corner E side SW corner	MLR-NW MLR-NE MLR-E MLR-SW

5.1.2 Results and Discussion

The dirty water source areas will be discussed before their respective receiving groundwater or surface water chemistry. Surface areas outside the dirty water system will be discussed along with the receiving environment groundwater chemistry, as it pertains to each area.

The samples collected from within the dirty water system are completed to provide an indication of the process water chemistry within these facilities. At the MLETB, there was no flow from any of the finger drains and we shall continue to watch for trickles in the subsequent year. The trends of the major ion and selected metals concentrations have reduced slightly at ETB-GD except chromium and zinc, while those of the naphthenic acid have slightly increased from 26mg/L (2006) to 29 mg/L (2007), though a reducing trend persisted up to 2006. At SCP-1, TBC-1 and ETB-TD1, the major ions increased slightly this year, which is still within the historical trend while naphthenic acid has been showing a reducing trend in the past years though slightly increased this year from 18mg/L (2006) to 24 mg/L (2007). At TBC-3, a stable flat trend was observed for the major ions, selected metals and naphthenic acid. Other areas such as SWSS-DC, WID and T0715 have the major ions and naphthenic acid on reducing trends. The general trends of the concentrations in the surface water chemistry of the various facilities has remained fairly stable and constant over time despite the re-use and recycling of process water, leaching of salts and organics from the oil-sand, the addition of caustic soda and dumping of other various wastes into the tailings facilities.

The complete analytical results are included in Appendix B, while trend plots are included in Appendix C. A summary of key chemical parameters is provided in Table 5.2.

5.1.3 Recommended Sampling Schedule for 2007

Annual sampling of all existing monitoring locations identified in Table 5.1 will continue in 2008, with the following proposed changes:

- Finger drains sample points shall be observed for trickles or flow from the earliest spring to the start of winter.

Analysis will be conducted in accordance with AENV requirements for the tailings areas in 2008.

The 2007 Beaver Creek Ecological Risk Assessment (ERA) shall be submitted as a separate document by March 2008 as requested.

Figure 5.2: Surface Water Sampling Locations

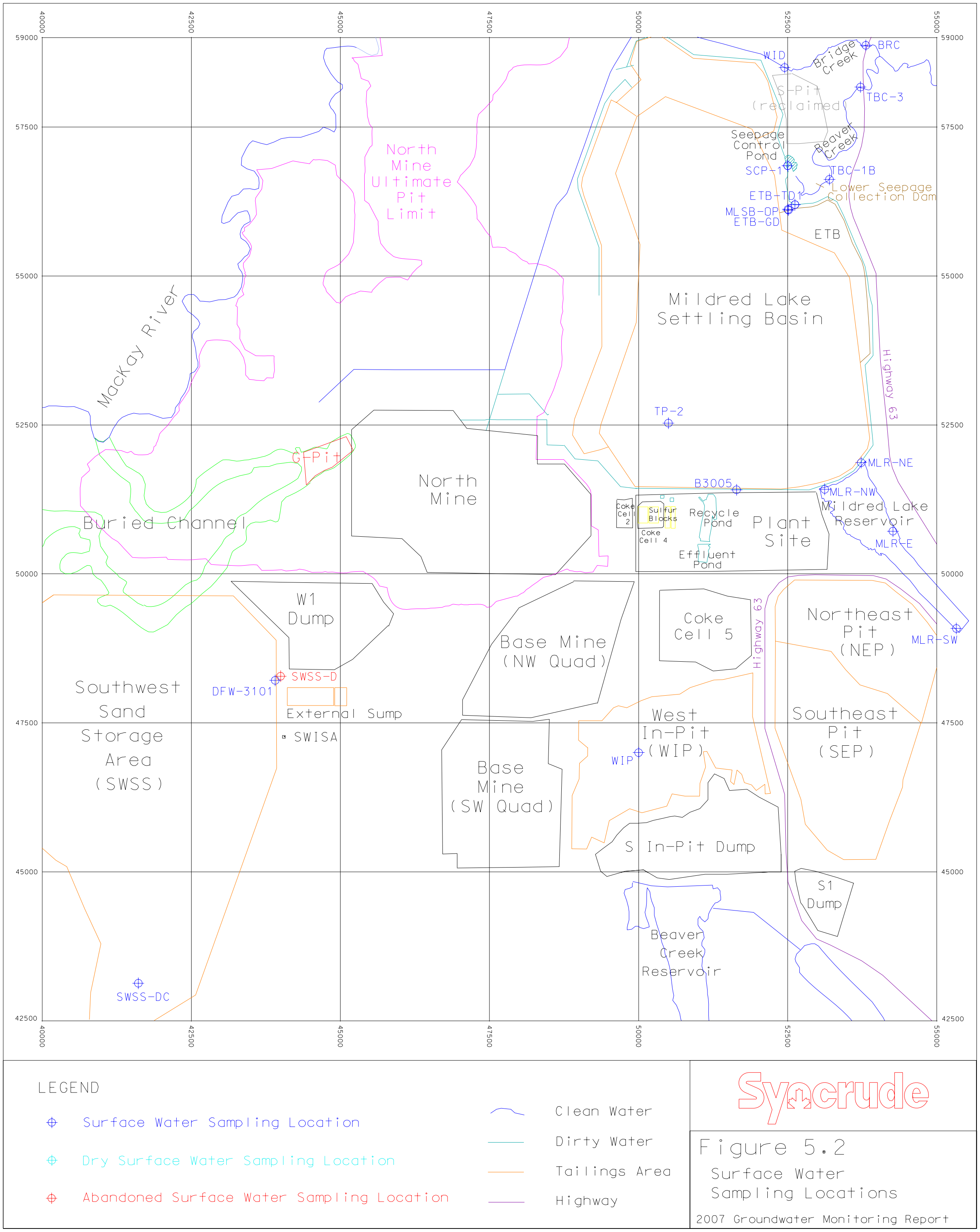


Table 5.2: Summary of Key Chemical Parameters

	Sample ID	Sample Date	Conductivity	pH	HCO_3	Cl_2	SO_4	Ca	Na	TDS	Phenols	Ammonia	DOC	Naphthenic Acids
MLSB	ETB-GD	06-Jun-07	2080	8.1	997	215	18.8	36.7	446	1340	-		65	29
	ETB-TD1	06-Jun-07	2750	8.4	967	381	116	48.7	574	1600	-		60	24
	TP-2	05-Jul-07	2930	7.96	721	350	348	22.8	598	1690	0.027	36.7	45	60.4
	T0715	10-Jul-07	2440	7.6	1060	217	195	51.9	481	1620	-		49	52
	SCP-1	26-Jun-07	2460	8.5	966	275	115	35.1	527	1520			56	21
SWSS	SWSS-DC	12-Jul-07	3570	8.5	723	612	386	14	776	2770	-		78	15
	DFW-3101	12-Jul-07	3900	8.3	1220	521	424	29.3	885	2620			71	22
	DFW-3101*	12-Jul-07	3900	8.3	1210	528	415	30	874	2620	-		86	28
WIP	WIP	05-Jul-07	3290	8.1	803	490	369	17.7	812	2200	0.017	15	51	75.1
Bridge Creek	WID	15-Jul-07	296	8.2	180	7	7.9	31.9	28	270	-		49	< 1
	BRC	29-Jun-07	900	8.1	271	76	130	76.3	88	620	-		32	2
Beaver Creek	TBC-1B	26-Jun-07	2560	7.7	917	382	83	122	401	1570	-		54	6
	TBC-3	26-Jun-07	2560	7.7	344	155	217	96.9	164	860			14	2
	TBC-3 *	26-Jun-07	2560	7.7	344	151	214	96.7	161	880	-		15	3
MLR	MLR-NW	29-Jun-07	329	8.5	144	12	27.4	33.8	23	200	-		12	< 1
	MLR-NE	29-Jun-07	413	8.2	196	18	27.6	37.2	39	260	-		13	2
	MLR-E	29-Jun-07	346	8.2	158	13	28.9	38.1	21	220			11	1
	MLR-SW	29-Jun-07	350	8.1	161	12	27.7	37.5	22	230	-		10	< 1

Abbreviations:

Conductivity (µS/cm), Ca – Calcium (mg/l), Cl_2 – Chloride (mg/l), Na – Sodium (mg/l), SO_4 – Sulfate (mg/l), HCO_3 –Bicarbonate (mg/l), TDS – Total Dissolved Solids (mg/l), Phenols (mg/l), Ammonia (mgN./L), DOC – Dissolved Organic Carbon (mg/l), Naphthenic Acids (mg/l), " - " not analyzed

* Duplicate Sample

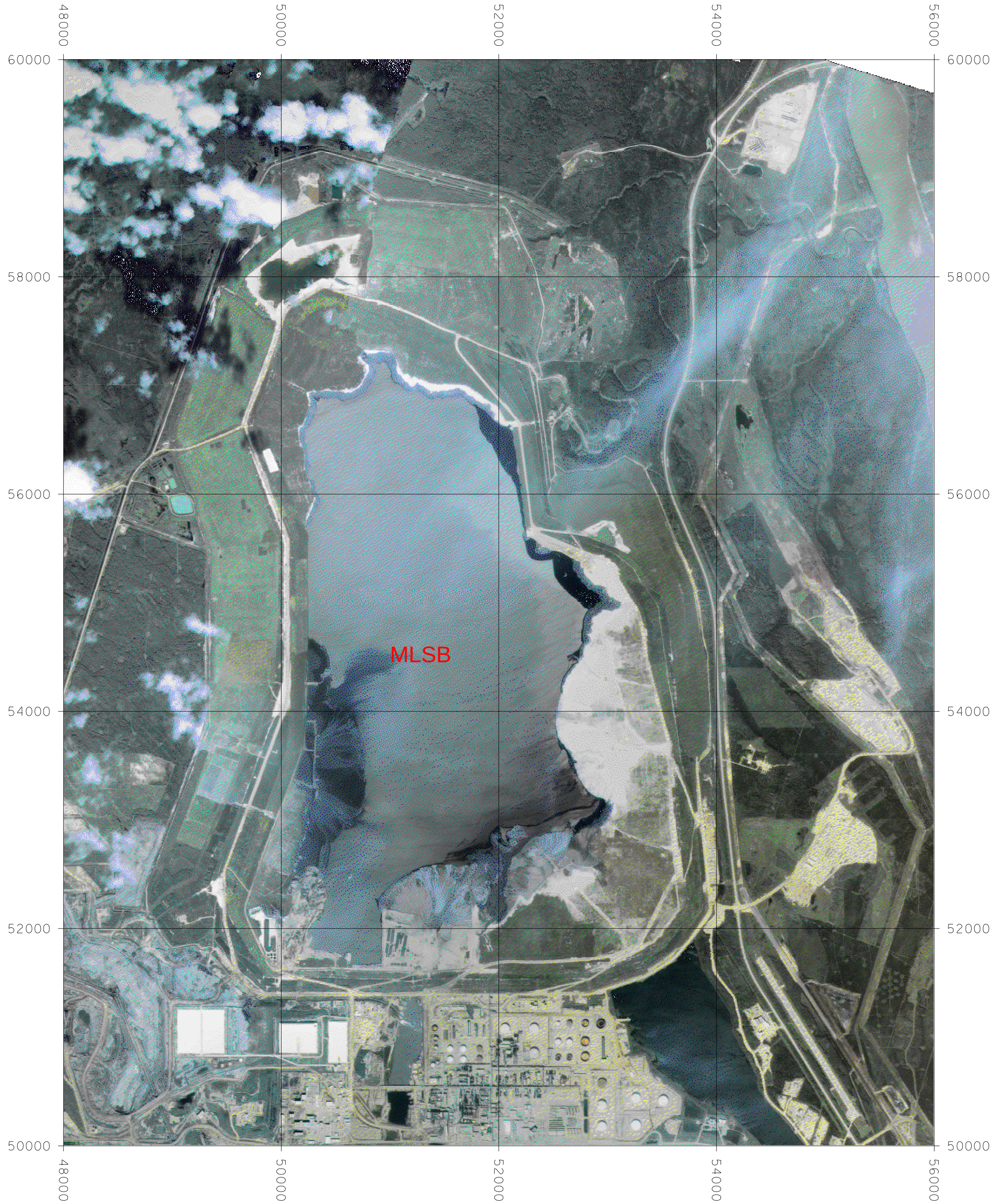
5.2 East of the Mildred Lake Settling Basin

5.2.1 Background

5.2.1.1 Area Description

The Mildred Lake Settling Basin (MLSB) covers an area of approximately 30 square kilometers with significant natural topographic changes to the east of the MLSB. Near the toe of the MLSB, ground elevation is approximately 310 meters. Continuing east, the topography drops to an escarpment in a series of steps to a low of 230 meters, the elevation of the Athabasca River. Two small creeks, Bridge Creek and Beaver Creek, have deeply incised channels that flow easterly through this area. Other features in the area include Highway 63, buried gas and telephone lines, Syncrude's buried Aurora process water pipeline, bitumen pipeline, and power lines. In addition, Syncrude-operated the sand and gravel pit at T-Pit, two undeveloped granular deposits (N-Pit and M-Pit), and the Fort MacKay Ranger Station are located east of the MLSB. Figure 5.3 shows an aerial photograph of this area.

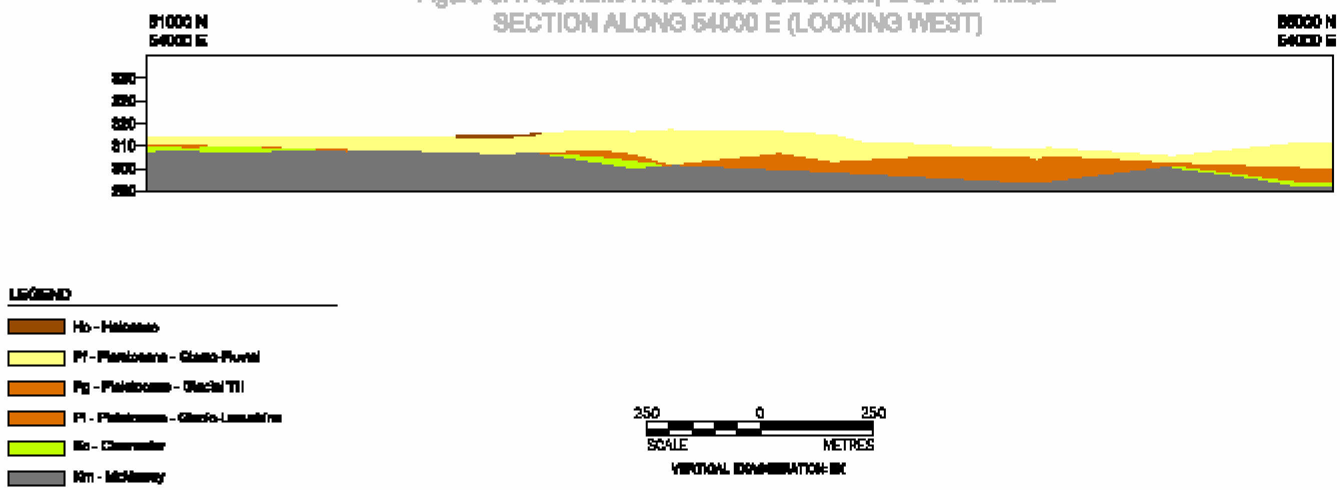
Figure 5.3: Air Photo of the East MLSB Area



5.2.1.2 Geology

The geology east of the MLSB varies significantly from the toe of the tailings structure to the Athabasca River. At the top of the escarpment near the MLSB, glacio-fluvial sands and gravels range in thickness from zero to fifteen meters. This fluvial deposit is generally underlain by glacial till which can be over fifteen meters thick. The Clearwater Formation has been eroded with the exception of localized remnants of the lower members. The McMurray Formation is generally encountered directly under the till. Figure 5.4 shows a north-south schematic cross-section at the top of the escarpment. Within the Athabasca River valley, in the T-Pit area, ten to forty meters of glacio-fluvial sands and gravels lie directly on top of the McMurray Formation or Devonian Limestone.

Figure 5.4: SCHEMATIC CROSS-SECTION, EAST OF MLSB
SECTION ALONG 54000 E (LOOKING WEST)



L:\2006\1346\06-1346-003\3000\Cross-sections\Fig 5-4 Section 54000 East.dwg   Aug 30, 2007 – 2:50pm

The glacio-fluvial deposits are typically heterogeneous, ranging from well to poorly sorted silty fine-grained sand to coarse gravel. Clay lenses are common within the deposit. The till consists of silty sand to sandy silt with light bitumen staining, and is generally quite dense with the exception of the upper few meters. East of T-Pit, little geological information is available. Recent alluvial deposits are believed to cover this area.

5.2.1.3 Surface Water Sources & Receivers

Sources of contamination at the east side of MLSB include the MLSB itself, the Mildred Lake East Toe Berm (MLETB), and the Seepage Control Pond (SCP), which receives seepage water from the MLSB and MLETB filters, off-takes and finger drains (which are now dry), as well as contaminated seepage water pumped from seven wells installed at the toe of the MLETB (which are reporting considerably low flows) and from sumps or water ponds located downstream of the SCP dam.

Potential surface water receivers of process-affected waters from these sources include the SCP, Beaver Creek, Bridge Creek, and Mildred Lake Reservoir.

Monitoring Network

The groundwater monitoring network east of the MLSB consists of eighty-one monitoring wells including one well that was destroyed and another that was damaged in 2007 (which are SP05-T05 and OW99-07 which will be replaced and repaired in 2008 respectively) and one seepage point. No new monitoring wells were installed in 2007 east of MLSB. Current monitoring network was adequate for the description of the groundwater flow paths within the area.

The three dewatering wells in T-Pit area (DW03-013, DW03-017 and DW03-047) installed in 2003 have been abandoned. One of the piezometers, SP05-T047 was sampled while SP05-T05 was destroyed. However, Syncrude intends to replace the destroyed well in 2008.

During 2007, five monitoring wells were dry. These are OW01-01, OW04-04A, OW04-08A, OW04-08B and OW04-06. Seepage areas SG0122-01 was also dry, and therefore was not sampled.

Chemical analyses were completed in accordance with AENV requirements for the tailings areas (Appendix A). Additional analyses for naphthenic acids were completed at several locations.

The location of all monitoring wells and sampling locations are shown on Figure 5.5. The groundwater wells are screened primarily in the Pleistocene sand aquifer (installation details are summarized in Table 5.3).

5.2.2 Results and Discussion

The surficial Pleistocene sand and gravel deposit has the greatest potential for contaminant transport east of the MLSB. This deposit forms a generally continuous unconfined aquifer from the east side of the MLSB to the east side of T-Pit. The aquifer is vertically bound by the underlying till, oil sand or limestone aquitard. Contaminant migration is expected to be limited through the underlying units, due to their low hydraulic conductivity.

Groundwater flow patterns in the surficial Pleistocene sand deposit are complex due to the topographic changes, varying hydraulic conductivity, and the complex geometry of the sand deposit.

In general, the flow direction is to the east, from the MLSB to the Athabasca River escarpment. At the base of the first significant drop in the escarpment (T-Pit area), groundwater flow changes toward the south. This typifies a high hydraulic conductivity sand-gravel deposit and a likelihood of the existence of a terminal buried channel within the T-Pit area. Locally, in the vicinity of Beaver Creek, groundwater flow is toward the creek. General flow directions are shown in Figure 5.5, although local flow directions vary from the overall trends.

The geological conditions east of the MLSB make this area very susceptible to influence from process water. The water chemistry in the wells located east of the MLSB can be grouped into three categories.
(1) Wells with background chemistry, typically low concentrations of dissolved species, low electrical conductivity, and low concentrations of naphthenic acids.
(2) Wells having elevated chloride concentrations, slightly elevated concentration of other major ions, and background concentrations of naphthenic acids geologically.
(3) Wells showing what is interpreted as influenced by Syncrude's process water, typically having elevated concentrations of sodium, chloride, bicarbonate, and naphthenic acids.

However, this classification shall be revised in the 2008 sampling program to adequately reflect the natural geo-chemistry of the areas in the evaluation of the impacted groundwater.

The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. Table 5.4 provides a summary of key chemical parameters.

Table 5.3: Location of Monitoring Wells, East of MLSB

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
OW79-19	55842	53947	269	8.2	9.8	Sand
OW80-14	57610	53343	268.8	2.4	5.2	Sand
OW84-33	53150	54573	314	-	-	Sand
OW98-03	56434	53244	296.3	0.6	2.3	Sand
OW98-04	55853	53550	300.8	3	4.6	Sand
OW98-05	55314	53785	307.4	7.9	9.5	Sand
OW98-06	54922	53882	309.7	6.2	7.8	Sand
OW98-07	53881	54115	316.1	6.5	8.2	Sand
OW98-08	53457	53932	315.7	6.2	7.9	Sand
OW98-09	55129	54022	308.7	10.8	12.5	Sand
OW98-19A	55078	54595	265.9	1.8	3.4	Sand
OW98-19B	55079	54594	265.9	7.6	9.1	Sand
OW98-20	53386	54085	316.7	3.4	6.4	Sand
OW98-21	53781	54053	315.9	5.5	7	Sand
OW98-22	54069	54070	310.5	4	5.5	Sand
OW98-24	55960	53866	273.5	7.6	9.1	Sand
OW98-25	55189	54255	276	12.2	15.2	Sand
OW98-26A	54342	54091	307.8	0.9	2.4	Sand
OW98-26B	54342	54090	307.9	4	5.5	Till
OW98-27	54299	54159	308	2.4	4	Sand
OW98-28	54352	54026	308.7	1.8	3.4	Sand
OW99-05	51399	53023	308.1	7.6	9.1	Sand
OW99-06	51353	52948	306.4	3.1	4.6	Sand
OW99-07	51560	53317	309	4.3	5.8	Sand
OW99-08	51536	53322	309.3	7.3	8.8	Sand
OW99-12	51922	53888	309	0.6	2.1	Oilsand
OW99-13	51918	54308	315.1	5.8	7.3	Sand
OW99-14	52240	54018	313.4	2	2.6	Sand
OW99-15	52455	54077	313.6	2.4	3.1	Sand
OW99-16	52792	53974	313.3	3.1	4.6	Sand
OW99-17	53164	54003	314.3	4.6	6.1	Sand
OW99-18	52983	54276	314.1	2.3	3.8	Sand
OW99-19	54301	54526	305.3	1.2	2.7	Sand
OW99-20	54568	55039	272.9	20.1	21.6	Sand
OW99-21A	55603	54075	267.8	3.7	5.2	Sand
OW99-21B	55601	54075	267.8	8.5	10.1	Sand
OW99-24	57400	52532	276.5	0.9	2.1	Sand
OW99-25	57334	52729	277.1	1.5	3.1	Sand
OW99-27	58355	52620	287.3	3.1	4.6	Sand
OW99-28	58367	52288	285.6	0.3	1.8	Oil sand

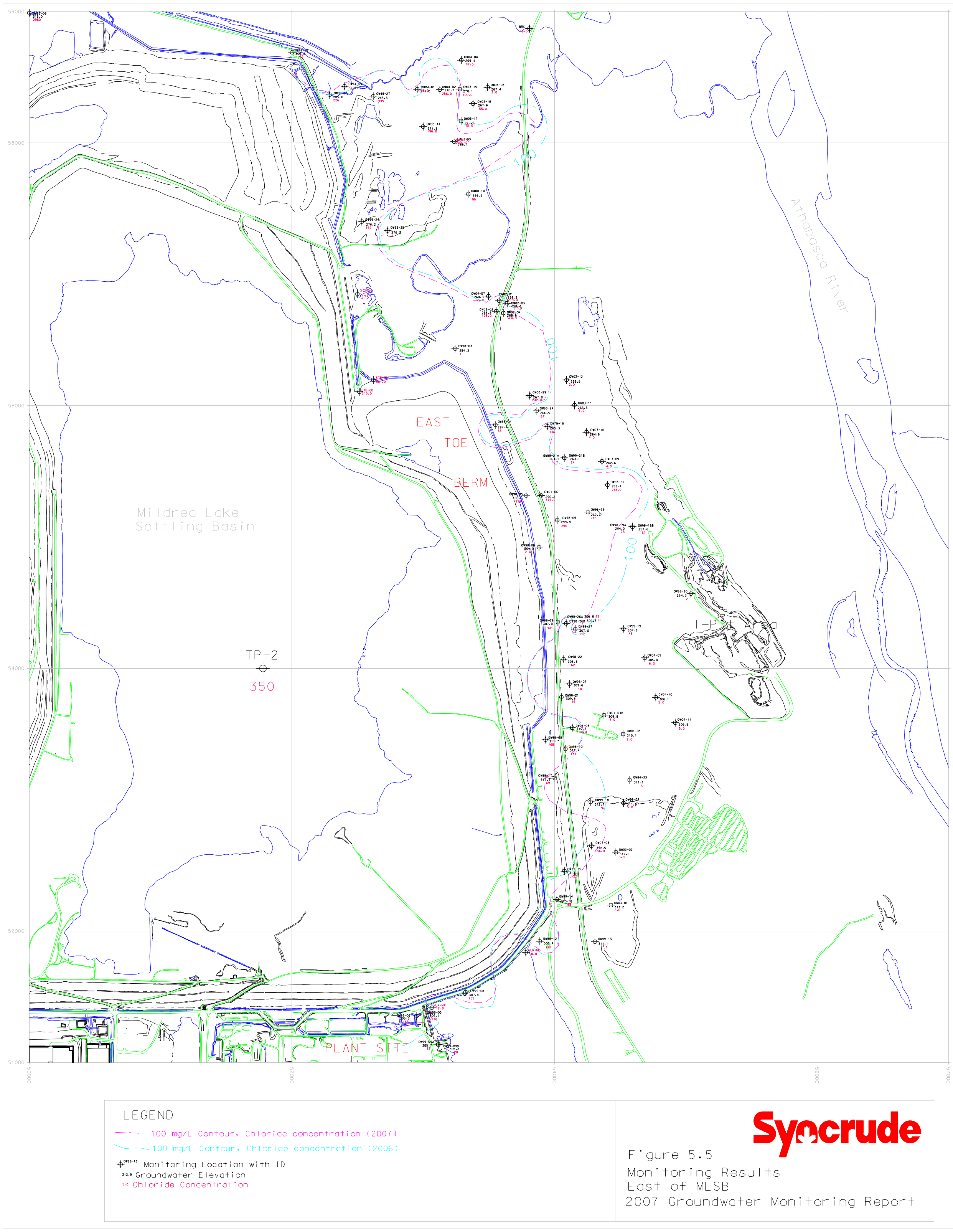
Notes: Sand = Pleistocene sand; Oilsand = Cretaceous McMurray formation; Till = Pleistocene till
Coordinates are in the Syncrude mine metric system
Screen intervals are in meters below ground

Table 5.3: Location of Monitoring Wells, East of MLSB (Continued)

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
OW01-01	54903	54165	310.1	12.8	14.4	Sand
OW01-02	54649	54070	305.2	1.4	3.0	Sand
OW01-03	53549	54136	316.4	5.7	7.2	Sand
OW01-04A	53640	54379	316.6	3.8	5.3	Sand
OW01-04B	53642	54378	316.5	8.3	9.8	Sand
OW01-05	53499	54523	317.3	5.8	7.3	Sand
OW01-06	55316	53900	308.3	13.0	14.5	Sand
OW02-01	56799	53579	271.5	3.0	4.5	Sand
OW02-02	56718	53556	272.2	4.3	5.9	Sand
OW02-03	56799	53579	271.1	2.3	3.8	Sand
OW02-04	56705	53611	271.7	5.7	6.0	Sand
OW03-01	52197	54430	313.9	4.6	6.1	Sand
OW03-02	52600	54469	314.2	2.6	4.2	Sand
OW03-03	52650	54281	314.4	4.4	5.9	Sand
OW03-04	52975	54526	312.4	1.5	2.3	Sand
OW03-08	55396	54404	265.5	13.5	15	Sand
OW03-09	55575	54362	265.9	8.9	10.4	Sand
OW03-10	55797	54244	266.7	2.5	4	Sand
OW03-11	56003	54152	267.1	3.1	4.6	Sand
OW03-12	56196	54092	268.4	1.9	0.3	Sand
OW03-14	58124	53001	277.6	7.6	9.1	Sand
OW03-15	58409	53281	271.0	3.7	5.2	Sand
OW03-16	58299	53380	268.1	3.1	4.6	Sand
OW03-17	58167	53288	270.3	1.4	2.9	Sand
OW03-29	56077	53811	274.8	13.0	14.5	Sand
OW04-01	58408	52955	284.0	15.2	16.8	Sand
OW04-02	58405	53128	273.1	10.7	12.2	Sand
OW04-03	58424	53491	269.2	2.9	4.4	Sand
OW04-04	58630	53290	271.4	2.1	3.7	Sand
OW04-05	58009	53237	271.4	8.2	9.7	Sand
OW04-06	56996	53566	271.8	2.1	3.7	Sand
OW04-07	56833	53497	269.6	1.5	3.0	Sand
OW04-08A	54873	54607	273.2	6.1	7.6	Sand
OW04-08B	54870	54604	273.6	15.8	17.4	Sand
OW04-09	54079	54688	306.9	1.5	2.3	Sand
OW04-10	53779	54772	307.2	3.0	4.6	Sand
OW04-11	53586	54920	307.0	3.0	4.6	Sand
SG9923-01	55390	53962	293.9	Seepage East of Highway 63		
SG0122-01	56300	53396	296	Seepage Northeast of MLETB		

Notes: Sand = Pleistocene sand; Oilsand = Cretaceous McMurray formation; Till = Pleistocene till
Coordinates are in the Syncrude mine metric system
Screen intervals are in meters below ground

Figure 5.5: Monitoring Results, East of MLSB



(1) Wells with Background Chemistry
Twenty-five monitoring wells installed in the Pleistocene aquifer show background values in water chemistry. The wells exhibiting these characteristics are OW80-14, OW84-33, OW98-07, OW98-26B, OW99-13, OW99-14, OW99-19, OW99-20, OW99-25, OW01-04 A & B, OW01-05, OW03-01, OW03-02, OW03-03, OW03-04, OW03-09, OW03-10, OW03-11, OW03-12, OW04-03, OW04-08B, OW04-09, OW04-10 and OW04-11. OW98-26B is installed in till, but the chemistry is interpreted as background for this specific unit.

(2) Wells with Elevated Chloride Concentrations
Twenty monitoring wells installed in the Pleistocene sand aquifer have elevated concentrations of chloride and other major ions. Organic tracers of process water including naphthenic acids and DOC are consistent with background levels. The wells exhibiting these characteristics are OW79-19, OW98-19A & OW98-19B, OW98-21, OW98-22, OW98-24, OW98-26A, OW98-28, OW99-12, OW99-18, OW01-02, OW02-01, OW02-02, OW02-03, OW02-04, OW03-15, OW03-16, OW03-17, OW03-29 and OW04-07.

The observed water chemistry of these wells is not consistent with groundwater historically identified as being influenced by process-affected water. The ratio of sodium to chloride and the low concentrations of organics are not consistent with tailings water. The effect is suspected to be due to the natural geo-chemistry of the soil within the region. These wells are commonly located at the outer edge of areas identified as showing influence from process water.

(3) Wells Influenced by Process-affected Water
Figure 5.5 shows water elevations and chloride concentrations for all current wells in this area. Four zones showing influence from process water have been identified (Figure 5.5). Monitoring results for each zone are discussed in the following paragraphs.

5.2.2.1 Sources

5.2.2.1.1 MLSB: Source to all Groundwater Zones and Surface Waters East and South of Facility
Generally, the input of process water into the MLSB pond from the Extraction Plant has gradually increased since 1998; consequently the concentrations of major ions have also risen considerably. Presently, inflows into the MLSB consist of low flow lines from Plant 6 tailings (delivering fine tails), Stream 73 tailings and coke discharge that tend to seal the pores of the bottom material of the MLSB. A transfer of MFT from the MLSB to the WIP occurs yearly to keep a constant fluid balance in the facility.

Samples from TP-2 located in the tailings pond show a decreasing trend since 2003. Samples from the MLSB off-take pipe T0715 indicate a consistent flat trend in the concentration of process related constituents and are still well below the pond concentrations while naphthenic acid indicated a decreasing trend. The concentrations of process related constituents appear generally stable and the lack of flow in the finger drains located at the east toe of MLSB indicates the effectiveness of the MFT in plugging the pores of the MLSB dyke. This is as a result of the presence of MFT and clays in the bottom of the pond that reduce the hydraulic connection between the pond and the tailings dyke. This low hydraulic conductivity between the pond and the seepage water chemistry is confirmed by the no-flow condition of the off-take pipes. However, this also portrays the continuous flushing of the percolating precipitation in the dyke.

5.2.2.1.2 MLETB: Additional Source to Zone C, Seepage Control Pond and Beaver Creek
The MLETB was constructed with hydraulically placed sand, and so when initially placed, the deposit was fully saturated. Characteristics unique to the MLETB have allowed it to drain and flush significantly faster than Syncrude's other tailings deposits. In particular, the volume of pond water within the MLETB is minimal and has likely been diluted by surface runoff and precipitation over the years. There is therefore no constant or fresh source of process affected water over the entire deposit. The MLETB is also constructed on a foundation having relatively high hydraulic conductivity, and contains a number of finger drains within the foundation of its perimeter.

The evidence indicating that the MLETB has been drained and flushed of contaminants is as follows:

- o The total flow from the finger drains has decreased to zero, indicating that the perimeter of the MLETB has drained, in those locations where the finger drains exist. Currently, all ten finger drains along the north side and the seventeen finger drains along the east side of the MLETB are dry. The only flow from the MLETB is from the toe at ETB-GD (granular drain) section. Flow rates are usually monitored at the finger drains, whereas the ETB drains are only monitored for water level and chemistry. However, the trend of finger drain flow rate from last two years till now has not reported any flow, which is substantiated by the record of no-flow condition from the finger drains this year (Figure 5.6). Syncrude is considering stopping monitoring the finger drains for flow since (the drains are dry) monitoring at the toe is now basically the natural groundwater elevation in the area.
- o The general trend of the standpipes water elevations was slightly lower than previous year and constant in a few locations while the surrounding ditches are virtually dry. Figure 5.7 shows the locations of the standpipes and finger drains, the current elevation of the water table and the original ground elevation in the MLSB relative to the standpipes, finger drains and ditches.
- o The concentration of the major ions sampled from the MLETB appears steady over a five-year period with a slight drop at the later years. This follows a steady state concentration in the MLETB and a subsequent natural attenuation of the contaminant as observed in the declining trend.

With the little or no-flow of process water within the MLETB structure, the flux of water moving beyond the perimeter ditch is expected to decrease, and invariably the potential for influence on the surrounding environment. Provided that the current ditch system is maintained, the flux of contaminated MLETB seepage water reaching the ditch, moving past the ditch and entering Beaver Creek are all expected to decline.

Figure 5.6: MLETB Finger Drain Flows

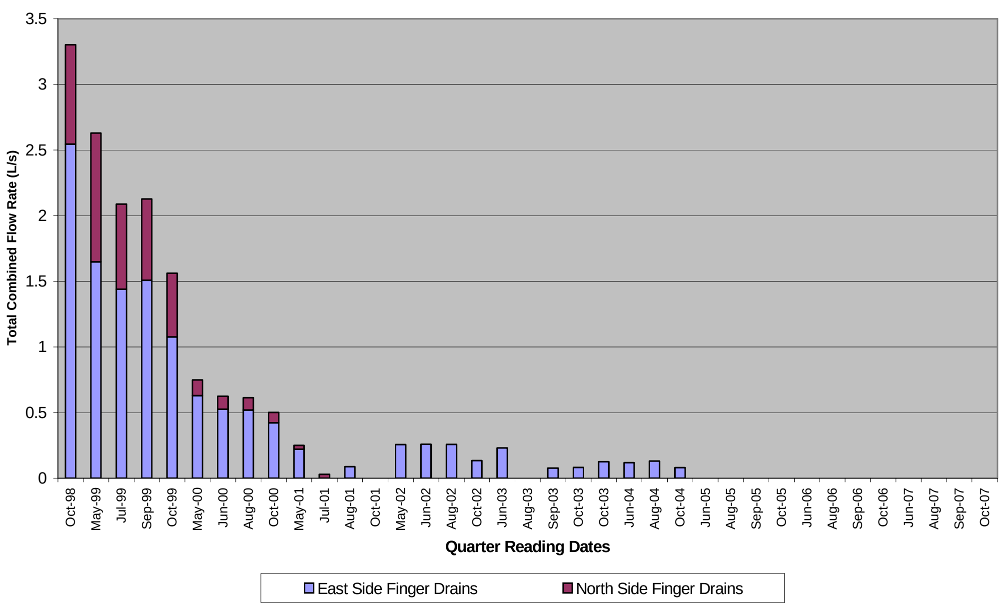


Figure 5.7: MLETB Finger Drains & Standpipes

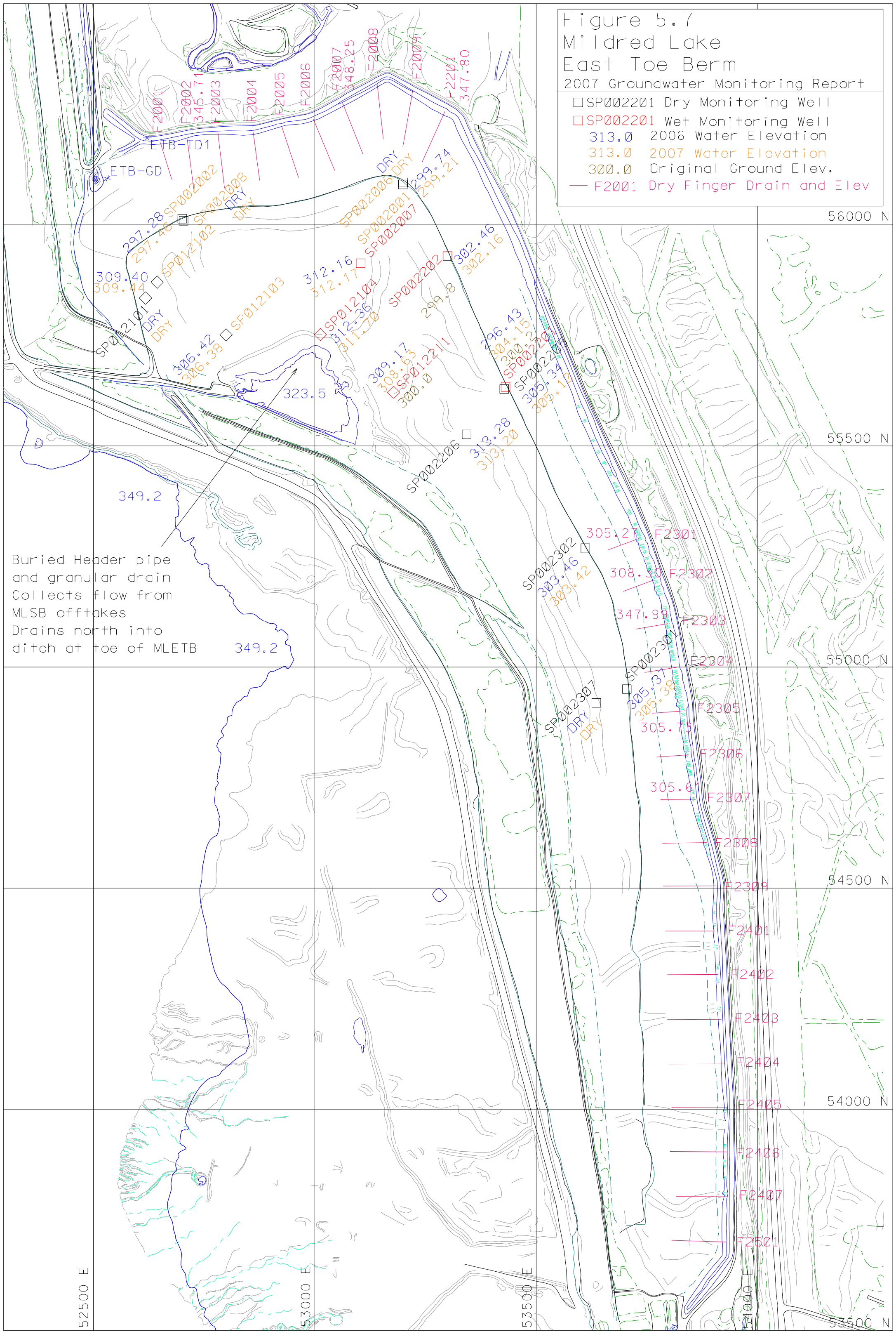


Table 5.4: Summary of Key Chemical Parameters, East of MLSB

Well ID	Sample Date	Conductivity	pH	HCO_3	Cl_2	SO_4	Ca	Na	DOC	Naphthenic Acids
OW79-19	09-Jul-07	949	7.9	291	136	54.9	130	20	5	-
OW84-33	03-Jul-07	535	8.1	325	3	31.4	81.7	9	10	-
OW80-14	29-Nov-07	1060	7.8	411	95	71.1	113	73	12	-
OW98-04	19-Jun-07	835	8.2	269	33	154	90.9	48	5	-
OW98-05	19-Jun-07	2610	8.2	1040	258	151	45.6	515	36	-
OW98-06	19-Jun-07	2200	8.3	931	210	99.4	40.8	435	57	-
OW98-07	21-Jun-07	135	7	11	10	29.5	15.1	3	4	< 1
OW98-08	19-Jun-07	2140	8.2	1080	165	43.6	59.9	422	42	-
OW98-09	25-Jun-07	2300	8.1	983	256	90.9	54.3	489	47	-
OW98-19A	10-Jul-07	698	7.5	247	75	56.7	60	75	19	< 1
OW98-19B	28-Nov-07	1470	7.7	456	167	161	184	82	13	< 1
OW98-20	25-Jun-07	1350	7.9	322	134	168	89.9	172	18	-
OW98-21	25-Jun-07	152	7.1	12	15	18.3	11.7	11	5	-
OW98-22	25-Jun-07	846	7.9	388	62	47.5	86.1	59	14	-
OW98-24	09-Jul-07	678	7.7	226	67	47	93.9	11	6	-
OW98-25	09-Jul-07	1760	7.9	705	215	85.5	89.5	284	20	6
OW98-26A	21-Jun-07	1170	7.9	492	62	173	132	72	13	2
OW98-26B	21-Jun-07	678	8.2	441	11	1	19.5	140	6	-
OW98-27	21-Jun-07	1390	8	610	112	102	67.8	229	22	-
OW98-28	25-Jun-07	1710	7.9	365	341	79.4	132	186	10	-
OW98-28*	25-Jun-07	1710	7.9	365	340	73.9	125	185	8	
OW99-05	19-Jun-07	2270	8.3	1110	178	90.1	38.1	469	63	42
OW99-06	19-Jun-07	2190	8.4	1110	163	30.8	25.8	465	41	53
OW99-08	19-Jun-07	2110	8.4	1070	155	49.8	32.9	450	44	40
OW99-12	04-Jul-07	1490	7.9	552	176	88.4	186	83	18	-
OW99-13	03-Jul-07	547	8.1	325	3	42.1	91.1	4	14	-
OW99-14	21-Jun-07	1020	8	439	88	66.5	112	58	10	-
OW99-15	04-Jul-07	1350	8	683	101	45.3	112	160	23	6
OW99-16	Damaged									
OW99-17	04-Jul-07	2460	8	1100	231	135	93.1	445	62	-

Abbreviations:

Conductivity (µS/cm), Ca – Calcium (mg/l), Cl_2 – Chloride (mg/l), Na – Sodium (mg/l), SO_4 – Sulfate (mg/l), HCO_3 –Bicarbonate (mg/l), DOC – Dissolved Organic Carbon (mg/l), Naphthenic Acids (mg/l), " - " not analyzed

* Duplicate Sample

Table 5.4: Summary of Key Chemical Parameters, East of MLSB (Continued)

Well ID	Sample Date	Conductivity	pH	HCO_3	Cl_2	SO_4	Ca	Na	DOC	Naphthenic Acids
OW99-18	03-Jul-07	928	8.1	258	117	69.7	85.2	91	6	< 1
OW99-19	05-Jul-07	673	8	318	48	24.8	86	34	16	-
OW99-20	05-Jul-07	385	8	214	2	24.9	54.8	4	4	-
OW99-21A	09-Jul-07	272	8.1	162	7	12.7	12.8	48	11	-
OW99-21B	09-Jul-07	715	8	292	24	110	73	57	11	-
OW99-24	18-Jul-07	2730	7.9	1070	352	97.9	49.7	557	41	16
OW99-25	18-Jul-07	561	7.8	284	<1	65.7	87.7	7	7	-
OW99-27	19-Jul-07	2880	8.1	1050	335	207	72.9	506	34	-
OW99-28	19-Jul-07	2810	7.8	784	226	526	169	348	34	-
OW01-01	Dry									
OW01-02	21-Jun-07	1680	7.8	402	297	140	146	147	12	2
OW01-03	21-Jun-07	673	7.6	130	170	54.3	45.8	136	6	2
OW01-04A	Dry									
OW01-04B	21-Jun-07	502	8.1	287	4	37.1	70.3	7	4	-
OW01-05	11-Sep-07	933	7.8	505	2	59.9	167	7	4	-
OW01-06	17-Jul-07	2860	7.9	1200	376	101	51.7	664	61	-
OW02-01	25-Jun-07	1860	7.8	372	274	257	135	223	16	-
OW02-02	25-Jun-07	844	6.8	84	138	114	56.1	72	13	-
OW02-03	25-Jun-07	180	7.6	40	26	12.8	14.1	15	8	-
OW02-03*	25-Jun-07	180	7.6	40	26	13.5	14.5	17	9	
OW02-04	25-Jun-07	1710	7.8	402	324	97.3	192	93	14	-
OW03-01	03-Jul-07	474	7.9	301	2	22.1	78.5	6	20	-
OW03-02	03-Jul-07	667	8	296	5	93.8	106	10	11	-
OW03-03	03-Jul-07	1090	8	304	156	75.2	125	64	9	-
OW03-04	03-Jul-07	567	8.1	328	5	40.5	86.9	7	10	-
OW03-08	09-Jul-07	2120	8	829	258	122	71.5	399	31	10
OW03-09	09-Jul-07	1370	7.5	409	4	467	249	20	12	<1
OW03-10	09-Jul-07	1340	7.4	697	4	249	275	7	8	<1
OW03-10*	09-Jul-07	1340	7.4	690	4	256	283	7	12	
OW03-11	09-Jul-07	1490	7.5	352	6	625	315	3	11	<1
OW03-12	09-Jul-07	608	7.7	296	2	99.3	123	3	9	-
OW03-14	22-Jun-07	1740	7.9	652	196	102	37.1	348	25	3
OW03-15	20-Jun-07	1190	8	450	100	132	112	128	18	4
OW03-16	22-Jun-07	898	7.8	377	55	95.5	95.3	69	11	1
OW03-17	22-Jun-07	1230	7.8	457	75	180	103	156	24	2
OW03-25	28-Nov-07	3560	7.1	218	639	692	370	287	32	-
OW03-28	28-Jun-07	1520	7.8	551	42	378	244	4	20	-

Abbreviations:

Conductivity (µS/cm), Ca – Calcium (mg/l), Cl_2 – Chloride (mg/l), Na – Sodium (mg/l), SO_4 – Sulfate (mg/l), HCO_3 –Bicarbonate (mg/l), DOC – Dissolved Organic Carbon (mg/l), Naphthenic Acids (mg/l), “ - “ not analyzed

* Duplicate Sample

Table 5.4: Summary of Key Chemical Parameters, East of MLSB (Continued)

Well ID	Sample Date	Conductivity	pH	HCO_3	Cl_2	SO_4	Ca	Na	DOC	Naphthenic Acids
OW03-29	09-Jul-07	1280	7.9	310	242	56.8	156	52	8	<1
OW04-01	20-Jun-07	1010	7.7	299	105	124	76.3	107	8	2
OW04-02	20-Jun-07	2240	8	762	256	248	127	334	23	11
OW04-03	20-Jun-07	601	8.1	335	3	54.7	70.8	37	12	<1
OW04-04	20-Jun-07	1140	8	434	92	127	90.1	143	15	1
OW04-05	10-Jul-07	2190	7.9	737	299	194	121	356	25	<1
OW04-07	10-Jul-07	1420	6.6	99	35	652	195	42	17	<1
OW04-09	11-Jul-07	582	7.7	384	6	2.9	97.3	7	22	-
OW04-10	05-Jul-07	587	8	392	5	3.4	99.5	8	23	-
OW04-11	05-Jul-07	747	7.8	423	5	67.2	133	12	29	-

Abbreviations:
Conductivity (µS/cm), Ca – Calcium (mg/l), Cl_2 – Chloride (mg/l), Na – Sodium (mg/l), SO_4 – Sulfate (mg/l), HCO_3 –Bicarbonate (mg/l), DOC – Dissolved Organic Carbon (mg/l), Naphthenic Acids (mg/l), “ - “ not analyzed
* Duplicate Sample

5.2.2.2 Groundwater Receptors

The pumping remediation strategy east of the MLETB was adopted in 2003. The objective is to intercept and retard the migration of contaminant within the source zone. This has resulted in a considerable improvement in the groundwater quality and the impact is better evaluated from the responses at the adjacent receptors.

The possible receptors of groundwater flow external to MLSB area were grouped into zones as follows:

5.2.2.2.1 Zone A

Zone A is located at the southeast corner of the MLSB (Figure 5.5). Results from 2007 sampling program for this area are consistent with results from previous years with three monitoring wells (OW99-05, OW99-06, and OW99-08) showing a stable, flat trend in major ion and selected metals concentrations in groundwater. This resulted in a receding or shrinking trend of the chloride concentration within the area confirms the improvement of the source mitigation-approach. Syncrude is in the process of replacing monitoring well OW99-07 but this will be completed definitely in 2008, while the rest of the damaged wells were replaced this year.

The groundwater will continue to be monitored and the analysis be completed as per AENV requirements for the tailings area.

5.2.2.2.2 Zone B

Zone B is located at the east of the MLSB and generally southeast of the MLETB, between 52000N and 54500N (Figure 5.5). Results from the seven monitoring wells installed in 2003 to 2004 and the concentration of OW01-04B, OW04-10, and OW04-11 at the exterior location in this zone indicated that the background chemistry within the area is still representative of the low historical concentration trend and these areas show no impact from process-affected water while OW01-04A was dry. Another seven wells (OW99-15, OW99-16, OW99-17, OW98-08, OW98-20, OW01-03 and OW98-27) show influence of process-affected water, which is due to their proximity to the MLSB. However, the trend of the concentrations of major ions and selected metals at these wells are flat and stable. Moreover, the chloride concentration is also retarding and shrinking within these areas. Results from another four wells (OW99-12, OW99-18, OW98-21 and OW98-26B) show a steady flat trend in major ions and selected metals while a slight increase of major ions was noticed at two wells due to their proximity to the MLSB, OW98-

22 and OW98-28 consequently the chloride concentration trend within these areas indicated a forward migration. Moreover, groundwater well OW03-03 is also impacted with increased concentration, which is indicative of some variability in the trending. This area shall be closely monitored in the 2008 in order to stabilize the plume.

The perimeter ditch that serves as the seepage control measure in this area had little or no-flow coming into the ditch at this time, which is due to the lack of flow from the MLSB, the finger drains and the seepage mitigation pumping outflow areas.

5.2.2.2.3 Zone C

Zone C is located at the upper east part of the MLETB. A sump and six pumping wells are located around the MLETB to intercept and return water to the MLETB perimeter ditch. This ditch conveys water to the seepage control pond, from which water is eventually recycled into MLSB. This seepage pumping system was established to target this area, where the ditch is ineffective in capturing seepage due to the thickness of the Pleistocene deposits in the area.

Continuous monitoring of the pumping activity occurred throughout the year at all the seepage pumping locations except at well 2 and sump where there were some repair works carried out at the locations. A total of 3,313 cubic meters of contaminated water was intercepted and recycled while the sump located at the northeast end of the MLETB intercepted 2,104 cubic meters. Five pumping locations were not reporting any flow from the aquifer while flows reporting from well 2 and the sump were considerably low. This confirms the very low flow condition prevailing from the MLETB and the adjoining areas. Consequently, a considerable reduction in concentrations is also expected in the down-gradient wells.

Records of flow rates and pumped volumes are documented from the pumps (Table 5.5). The flow is monitored at the pump locations and where a problem arises with the flow meter or pump performance, an estimation of the flow rate is computed by using the annual (2007) volume based on average flow rates measured manually through 2007, multiplied by the pump-run hours. The performance of the pumps have improved considerably and further plan to lower the pump is being considered in 2008 with a view to capture flows in the aquifer.

The concentrations of major ions, selected metals and naphthenic acid reduced at monitoring well locations OW 98-04, OW99-05, OW99-21A, OW99-21B, OW98-05 and OW01-06 while the chloride concentration plume also shrank. This is a considerably evidence of a reduced impact of the process-affected water resulting from the seepage-pumping exercise, which is an improvement on the time-limiting mitigation approach adopted at the MLSB and the MLETB.
At the southern end of zone C, the process-water affected wells OW03-08 and OW98-25 have been reducing naphthenic acid concentrations between 2004 and 2007. This goes to show that the migration of the plume in this area within such close proximity to MLSB have decelerated considerably due to the effect of the seepage pumps and recycling exercise.
The well rehabilitation program has also improved the well performance and continuous monitoring of the pumps has stabilized the plume considerably in 2007.Despite low flows we shall continue the seepage pumping exercise in 2008.

The background chemistry of wells OW03-09, OW03-10, OW03-11and OW03-12 (which were installed on higher terrain, westward of T-Pit), continue to decrease in concentrations of major ions, selected metals and naphthenic acid since 2004-2007. This is am indication a general improvement in the natural geo-chemistry within the environment. Two other wells OW04-08A and OW04-08B were dry.

Table 5.5: 2007 Zone C Pumping Summary

2007 PUMPING SUMMARY					
ID	**Volume since start-up (m^3)**	**2007 Volume (m^3)**	**2007 Percent Run**	**Average Rate m3/hr**	**Time of Year Operated**
Well 1	9,284	-	-	-	Jan-Dec
Well 2	62,856	3,233	-	0.6	Aug.-Dec.
Well 3	3,705	-	-	-	Jan.-Dec.
Well 4	3,064	80	-	0.08	Jan.-Dec.
Well 5	18,703	-	-	-	Jan-Dec
Well 6	5,262	-	-	-	Jan.-Dec.
Well 7	38,936	-	-	-	Jan.-Dec.
Total		**3,313**			
Sump	9,057	2,104	83%	2.1	Aug.-Dec.

* Assumed pumping rate average, used to calculate volumes from pump hours.

At the north end of Zone C, the concentrations of the major ion and selected metals at these three monitoring wells OW02-01, OW02-03 and OW02-04 increased slightly while that of OW02-02 decreased. The locations are close and the variability in concentration appears to be a natural phenomenon. This shall be further investigated in 2008. However, historical trend has been on the decline in the past. Monitoring well OW04-07 installed in 2004 continues to reflect a decline in chloride and major ions concentrations that might be attributed to the improvement of the seepage pumping mitigation exercise while well OW04-06 was dry in 2006 and 2007.

5.2.2.2.4 Zone E

Zone E is located at the northeast corner of the MLSB. This former sand and gravel pit, now reclaimed, forms a topographic low. In 2004, five new monitoring wells were installed in this area to compliment the four wells installed in 2003. Closer delineation of the direction of flow indicates that groundwater initially flows towards the east and alongside Bridge Creek at its northern limits (to E53000) of the area, but then turns south, towards Beaver Creek near N58000 (Figure 5.5). In late 2007 five piezometers were installed to further delineate the flow directions in this area. However, the chloride concentration of OW08-14 increased while the sulphate concentration decreased at the same well location. The on-going is also going to address this effect as the well location.

The chloride concentration and major ions decreased in wells OW04-01, OW04-02 and OW99-09, OW99-27 and increased in wells OW03-14, OW04-04, OW04-05, OW99-04, OW99-24 and OW99-28. Generally the chloride concentration indicated a stable trend and slight increase of other ions were observed. This area is still being studied. There is also an indication that the loading of major ion concentrations from the source of contamination is decreasing further east in the area. This confirms the time-limiting reduction of the concentration that prevails around the MLSB.

5.2.2.2.5 T-Pit Dewatering Wells (Potential Receptor)

The pit development continues at the T-Pit through 2007 and the pit dewatering activity was accomplished through the use of a pit-floor sump in the T-Pit area in order to mine the granular resource in the area. Dewatering wells (DW03-013, DW03-047 & DW03-017) that were installed in 2003 (with two of them having high salinity) were to be properly abandoned. This high salinity water is believed to be connate water that has been trapped at the top of the Devonian low in this area. The Devonian structural pattern of this area confirms this conclusion.

A conductivity survey conducted by Komex in November 2005 on standpipes SP05-T047 and SP05-T05 identified salinities in excess of 10,000mg/L chloride in these wells. This level of chloride concentration is definitely not related to the MLSB water. The depth at which the high salinity water occurs is 15 m below the ground surface in this area.

Throughout 2007, composite samples (of the T-Pit's pumped release water) were taken and reported to AENV quarterly to ensure compliance with discharge criteria. All data on released water should remain within the allowable water quality limits and that the maximum concentration of chloride at 500 mg/l was not exceeded.

For similar reasons stated above, the 2007 groundwater sampling at the T-Pit was taken at piezometer SP05-T047 while SP05-T05 was destroyed and this will be properly abandoned The results of the major ions and the TDS analysis were similar to those calculated from geophysical (conductivity) survey. Both confirmed high salinity content at these locations. The chemistry from these piezometers is similar to chemistry of Devonian Formation wells in the in-pit area (Table 5.6).

Table 5.6: Comparison of Chemistry at T-Pit versus Lower McMurray & Waterways Formation

	T-Pit Wells	**Lower McMurray & Waterways Formation Monitoring Wells**			
ID	**SP05-T047**	**BML96-03**	**BML96-04**	**BML96-05**	**BML96-09**
Ground Elevation	249.6	299.8	311.7	299.8	299.8
Top of Screen	220.8	234.6	244.9	234.6	234.6
Bottom of Screen	217.8	231.5	241.9	231.5	231.5
Water Quality					
Sample Date	22-Aug-07	13-Jul-07	13-Jul-07	13-Jul-07	12-Jul-07
HCO_3	2510	2400	2750	3140	2780
Cl	13100	8380	20000	2040	11700
SO_4	< 0.5	38.4	9.3	1.7	< 0.5
Ca	39.3	70	164	26.9	121
Fe	< 5	4.41	0.71	6.56	9.01
Mg	81.8	152	327	29.5	207
Mn	< 1	0.38	0.12	1.88	0.75
K	34.6	57.3	62.8	14.6	45
Na	8530	6430	12700	2270	8970
Ion Balance	0.92	1.09	0.97	0.94	1.1
pH	7.6	7.9	7.5	7.7	7.6
Conductivity	36400	23200	51400	9490	34600
TDS	23300	14800	35300	6090	21800

Abbreviations:

HCO_3 –Bicarbonate (mg/l), Cl – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Fe – Iron (mg/l), Mg – Magnesium (mg/l), Mn – Manganese (mg/l), K – Potassium (mg/l), Na – Sodium (mg/l), Ion Balance (cations/anions) Conductivity (µS/cm), TDS – Total Dissolved Solids (mg/l), " - " not analyzed

5.2.2.3 Surface Water Receptors

5.2.2.3.1 Seepage Control Pond

The seepage control pond (SCP) is both a receptor of contaminated water, as well as a potential source to its downstream environment. It collects water from the MLETB and MLSB perimeter ditches, as well as water contained upstream of the lower seepage collection dam. The collected water is eventually pumped back into the MLSB.

The concentrations of major ions at OW99-24, which is located north of the SCP-1 (in S-Pit area), have reduced in 2007 except chloride. This relatively indicated an improvement in the water quality in the SCP and other volume handling activities within the area. The concentrations of major ions within are expected to continually improve as we monitor this area in 2008. Low flow from the MLETB may also contribute to the volume and quality reporting at the SCP.

5.2.2.3.2 Bridge Creek

The concentrations of major ions reduced at OW99-27 except for chloride while the surface water quality sample at the west interceptor ditch (WID) indicated a reduced concentrations of major ions, selected metals and naphthenic acid. This reflected a down-stream effect of the low flow from the MLSB (source).

5.2.2.3.3 Beaver Creek

Beaver Creek is routinely sampled at two locations, downstream of the Lower Seepage Dam (TBC-1B) and at Highway 63 (TBC-3). Both locations continue to show a consistent flat and steady trend except for sodium and chloride at TBC-1B. This observation is as a result the reduced actual volume of seepage into Beaver Creek, following the (no-flow) trend from the finger drains, adjacent sampling locations (SG0122-01) and reported low flow in the dyke.

In 2005 Syncrude submitted a 2004 Ecological Risk Assessment (ERA) of the Lower Beaver Creek report on the evaluation of the current seepage conditions and water quality in March 2004, which recommended that the risk assessment does not indicate the need for active immediate risk management that may constitute risk to wildlife, fish and amphibians. The report also recommended a seasonal monitoring to confirm the risk estimate with the exposure scenarios and further monitoring of water quality, toxicity sediment are also proffered on the benthic invertebrate community and the fish habitat for three years. The report was reviewed by AENV in their letter dated December 07, 2005 with comments for clarification by Syncrude. The response was submitted separately and together with the 2005 Ecological Risk Assessment of the Lower Beaver Creek by March 31, 2006. Similarly, response to the comments from the AENV on the 2005 ERA of the Lower Beaver Creek was submitted separately in June 2006. The 2006 ERA report of the Lower Beaver Creek was submitted in March 31, 2007 (together with another copy of the response on the 2005 report) and the comment from AENV was also received. By March 2008, the final report on the 2007 Ecological Risk Assessment of the Lower Beaver Creek will be submitted accordingly.

5.2.2.3.4 Mildred Lake Reservoir

Mildred Lake Reservoir (MLR) is part of Syncrude's water intake system. In 2007, Syncrude imported 35.95 million cubic meters of water from the Athabasca River for use on site. This water is pumped from the river into the lower camp fresh water pond, and then to MLR. Water is taken from the reservoir having a capacity of 7 million cubic meters to supply plant needs.

The chloride and major ions concentrations at the well locations OW99-05, OW99-06 6 and OW99-08 indicated flat trend at all major ions (similar to 2006), except for a slight increase in chloride at OW99-05 and OW99-06. The chloride trend is generally consistent with the 2006 pattern that indicated a stable trend, which is subsequently expected to begin to shrink. This also corroborates the low flow condition at the MLSB.

Recent trend of surface water monitoring (2004-2007) from the sampling locations around the MRL such as MRL-NW, MRL-NE, MRL-E and MRL-SW indicated a stable trend for all the major ions including chloride. Further monitoring and groundwater analysis will be completed as per AENV requirements for the tailings area in 2006.

The capacity of the reservoir is approximately 7 Mm^3 and with the commissioning of the UE-1 project in 2006, the production rates and the turnover of the MLR water has increased to 35 million cubic meters (2007) which continues to give a lower concentration of the chemistry and larger dilution in the MLR. Organic indicators such as naphthenic acid, dissolved organic carbon and phenols are all consistent with the reference locations, which indicate that the effect of the seepage on the overall water quality in the reservoir is minimal.

The Mildred Lake Reservoir will continue to be used as an industrial facility dedicated to supply water to the plant for the foreseeable future. The MLR water will continue to be turned over, as there are no natural upstream or downstream receivers of the waters within. Syncrude will continue to monitor the water quality in the reservoir annually and will perform further evaluations if a significant change in water quality occurs or if the use of this facility changes.

5.2.3 Recommended Sampling Schedule for 2008

Regular scheduled sampling will continue in 2008 for all wells listed in Table 5.3 and analysis will be completed as per AENV requirements for the tailings area.

5.3 North and West of the Mildred Lake Settling Basin

5.3.1 Background

5.3.1.1 Area Description

The northward advancement of mining in the North Mine area will eventually reach the largely undisturbed western area of the MLSB (Figure 5.9). Currently, a dirty-water ditch surrounds the MLSB, carrying seepage water to the recycle water pond at the south and to seepage control pond. The West Interceptor Ditch (WID) intercepts clean water from the area north and west of the MLSB and discharges it into Bridge Creek to the northeast of the MLSB.

5.3.1.2 Geology

Prior to Syncrude's operation, Beaver Creek flowed through the approximate centre of the MLSB. West of the old Beaver Creek channel, the Clearwater Formation is generally continuous and increases in thickness to the west. On the west side of the MLSB, the Clearwater Formation is approximately thirty meters thick. The Clearwater Formation is capped by five to eight meters of glacial till and glacio-lacustrine clay. A thin layer of muskeg is present in some areas. Isolated pockets of glacio-fluvial sands occur as illustrated on the schematic cross-section, Figure 5.8.

5.3.1.3 Monitoring Network

There are currently three monitoring wells located on the north and west sides of the MLSB (Figure 5.9 and Table 5.7). These wells are installed in the Cretaceous Clearwater Formation (Syncrude lithofacies K_{cc}). Chemical analyses of water from these wells were completed in accordance with AENV requirements for the tailings areas (Appendix A).

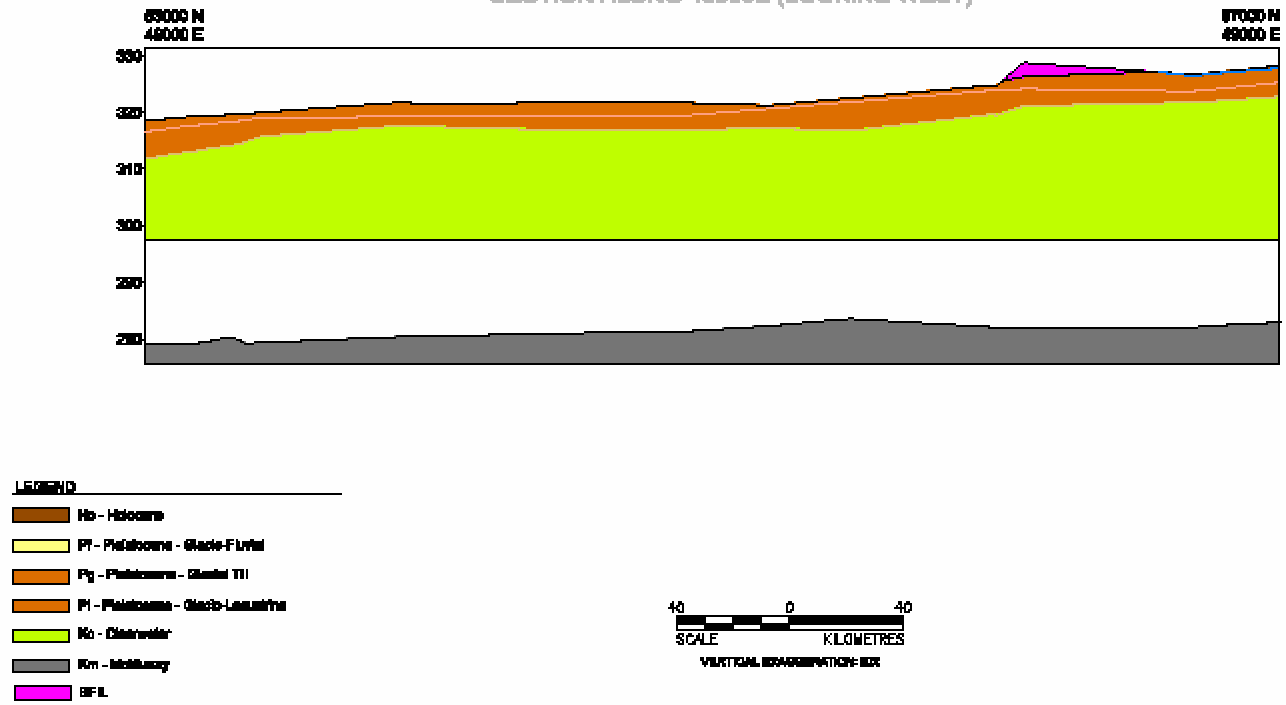
Monitoring west of the MLSB is limited for several reasons. The hydraulic conductivity of the various geologic units is relatively low, thus the risk of significant migration of process water is low. In addition the general hydraulic gradient is from west to east. The area that would experience process-affected water would be limited to the toe of the MLSB. This area will eventually be mined out as the North Mine advances (see final mine limits on Figure 5.9).

Table 5.7: Location of Monitoring Wells, North and West of MLSB

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
OW92-05	57896	49385	326.5	8.5	10.1	KCC
OW92-06	58989	50000	320.3	8.5	10.1	KCC
OW92-08	58690	52002	307.3	8.5	10.0	KCC

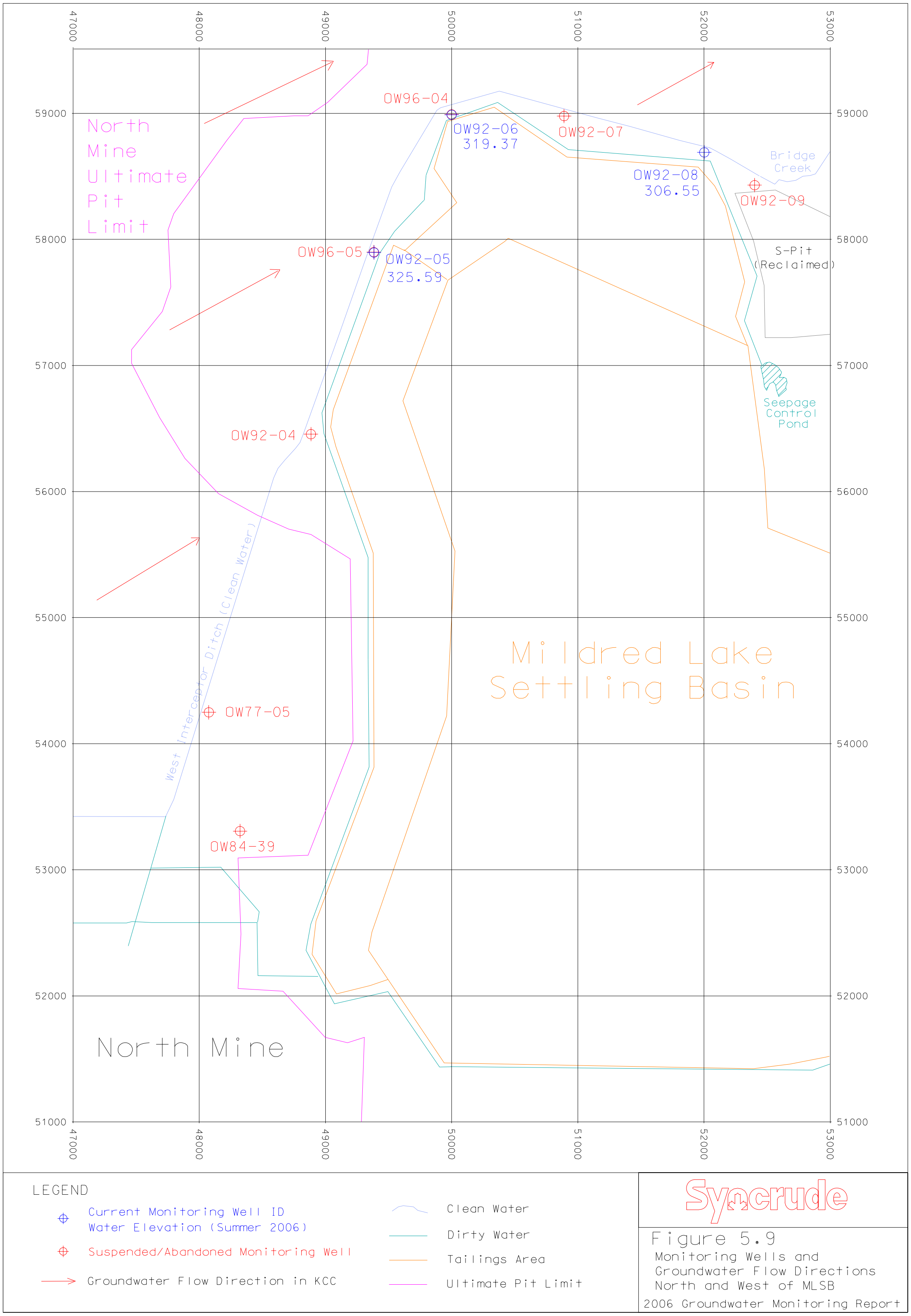
Notes: KCC = Cretaceous Clearwater formation
Screen intervals are in meters below ground
Coordinates are in the Syncrude mine metric system

Figure 5.8: SCHEMATIC CROSS-SECTION, WEST OF MLSB
SECTION ALONG 49000E (LOOKING WEST)



L:\2006\1348\06-1348-003\3000\Cross-sections\Fig 5-8 Section 49000E West (53000N - 57000N).dwg Aug 30, 2007 - 2:51pm

Figure 5.9: Monitoring Wells and Groundwater Flow Directions, North and West of MLSB



5.3.2 Results and Discussion

Major ion concentrations and other key chemical parameters from 2007 sampling program are summarized in Table 5.8. The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included in Appendix C.

Hydrogeologic conditions north and west of the MLSB are dominated by aquitards with hydraulic conductivities estimated to be less or equals $1x10^{-7}$ m/s. Glacio-fluvial sands occur only in isolated pockets. Natural groundwater flow is in a northeasterly direction following the topography of the area. Locally around the MLSB, shallow groundwater flow is expected to be outward from the tailings structure. Seepage ditches are designed to intercept this outward flow.

Detailed interpretations of the groundwater flow directions are not possible with the limited groundwater-monitoring network within this area. Figure 5.9 shows 2007 water elevations and estimated directions of groundwater flow.

The concentrations of major ions, selected metals and naphthenic acid generally indicated a reducing trend in 2007 including total dissolved solids (TDS) at OW92-05, OW92-06 and OW92-08. In general, the concentration of TDS appears to increase with depth in the cretaceous clearwater formation. Moreover, these high concentrations from the natural geo-chemistry appears to contribute to the increased level of concentration experienced towards the tailings area because the groundwater flow direction is from undisturbed areas to the tailings area and the increased trend occurs up-gradient before the tailings area.

Table 5.8: Summary of Key Chemical Parameters, North and West of MLSB

Well ID	Sample Date	Cond.	pH	HCO_3	Cl_2	SO_4	Ca	Na
OW92-05	10-Jul-07	1930	8.1	818	203	117	66.3	317
OW92-06	10-Jul-07	10000	8.1	1270	2980	< 0.5	27.4	2150
OW92-08	10-Jul-07	4780	8	1530	72	1340	68.7	1080

Abbreviations:

Cond – Conductivity (µS/cm), HCO_3 – Bicarbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Na – Sodium (mg/l), “ - “ not analyzed

* – Duplicate Sample

5.3.3 Recommended Sampling Schedule for 2008

There are no changes proposed for this area in 2008. Annual monitoring of OW92-05, OW92-06 and OW92-08 will continue with analysis completed as per AENV requirements for the tailings area.

5.4 Mildred Lake Reservoir Area

5.4.1 Background

5.4.1.1 Area Description

There are several contractors who provide services to Syncrude with their facilities located on the east side of the Mildred Lake Reservoir (MLR). Highway 63 wraps around the southwest and north sides of the reservoir, while Syncrude's airstrip is located east of Highway 63 on its northeast side. The Syncrude plant site and the Northeast Pond (NEP) are situated on the west and south sides of the reservoir that is utilized as a water intake reservoir for the operation. In 2007, 35.95 million cubic meters of water were imported through the reservoir.

5.4.1.2 Geology

A thin layer of Quaternary deposits, generally less than five meters thick, covers the Clearwater Formation around the MLR. The Quaternary deposits consist of glacio-fluvial sand and/or glacial till. A thin layer of muskeg covers the Pleistocene units in some areas. The glacial till is a sandy-silt to a silty-sand. The lower member of the Clearwater Formation (Wabiskaw Member) underlying the till is an interbedded, glauconitic, fine to medium grained, silty, clayey sand.

5.4.1.3 Monitoring Network

The groundwater monitoring network around MLR consists of three wells east of the reservoir and three wells west of the reservoir. Installation details are summarized in Table 5.9 and locations shown on Figure 5.10. The geology of the screen interval for OW87-03 and OW87-05 has been estimated based on water chemistry from these wells, as well as the geology of the surrounding auger holes and test pits. OW87-03 appears to be screened in glacial till, and OW87-05 in glacio-fluvial sand.

Chemical analyses were completed in accordance with AENV requirements for the tailings area (Appendix A).

Table 5.9: Location of Monitoring Wells, MLR Area

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
OW86-09	49571	55271	310.9	4.6	6.1	Till
OW87-03	50707	54368	307.6	4.6	6.1	Till*
OW87-05	50080	55188	316.1	-	-	Sand*
OW99-09A	51134	53116	307.0	2.1	3.7	Sand
OW99-09B	51138	53115	307.1	6.1	7.6	Sand
OW99-10	50794	53368	310.4	4.6	6.1	Sand
OW05-04	50526	53585	309.3	0.6	1.5	Sand

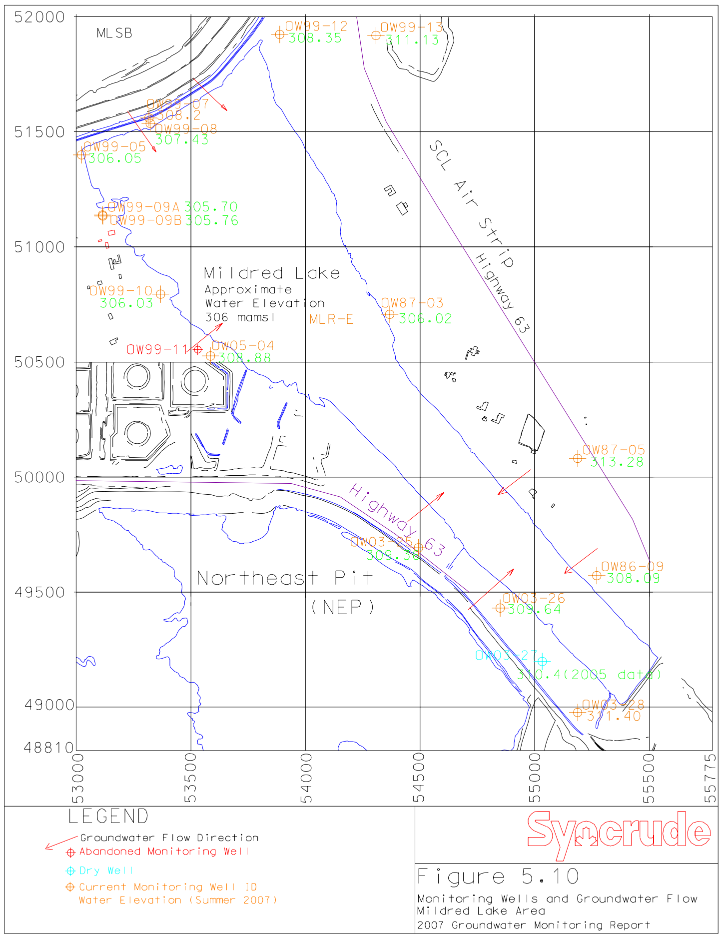
Notes: Sand = Glacio-fluvial sand
Till = Glacial till
Oilsand = Cretaceous McMurray Oilsand
Screen intervals are in meters below ground
Coordinates are in the Syncrude mine metric system
* Lithology estimated based on water chemistry

5.4.2 Results and Discussion

The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. A summary of key parameters is provided in Table 5.10.

The surficial glacio-fluvial sand is the most significant hydrogeologic unit in the area with the greatest potential to allow contaminant transport. This sand is generally thin and not always saturated. The till and underlying Clearwater and McMurray Formations have significantly lower hydraulic conductivity than the sand.

Figure 5.10: Monitoring Wells and Groundwater Flow, Mildred Lake Reservoir Area



The approximate water elevation in the MLR was 306.5 (mamsl) at the time the readings were taken. Water elevations taken at the time of sampling at the monitoring wells around MLR are shown in Table 5.10. Shallow groundwater flow within the glacio-fluvial sand is generally toward the reservoir (Figure 5.10).

Most of the monitoring wells around MLR indicate that groundwater conditions are generally consistent with historical trends. At the southeast end of the reservoir, OW86-09 indicated a reduction in the concentration of major ions and selected metals in 2007 while OW87-05 and OW87-03 increased slightly in concentration of major ions, which may be due to the higher hydraulic conductivity of the sandy aquifer. Monitoring well OW91-12 was damaged and will be replaced in 2008.

On the west side, OW99-10 showed increases in major ions while the naphthenic acid reduced. This is similar to that found in other areas where dewatering activities are occurring, or simply where the water table has been brought below its natural level for a period of time. However, there is a relative reduction when these key parameters are compared to 2004 data. The interaction of the groundwater with the natural geochemistry within the zone might have resulted in the spike of these constituents as the water returns to its natural elevation. The concentration of the key parameters at OW99-09A, OW99-09B and OW05-04 within the same area reduced and this is similar to the historical trend.
The monitoring of these wells will continue in 2008.

Table 5.10: Summary of Key Chemical Parameters, MLR Area

Well ID	Sample Date	Cond.	pH	HCO_3	Cl_2	SO_4	Ca	Na	TDS	Water Elevation*
OW86-09	29-Jun-07	1140	7.8	240	218	62.6	113	56	780	308.09
OW87-03	29-Jun-07	1070	8.2	604	54	35.1	58.6	158	630	306.02
OW87-05	29-Jun-07	2240	8	753	391	64.4	204	117	1410	313.28
OW99-09A	04-Jul-07	494	8	280	12	21.6	67.1	22	310	305.70
OW99-09B	04-Jul-07	577	8	298	20	39	79.2	17	370	305.76
OW99-10	04-Jul-07	2820	7.7	621	363	574	377	166	2070	306.03
OW05-04	04-Jul-07	697	8.1	483	1	4.8	70.5	41	430	307.88

Abbreviations:

Cond – Conductivity (µS/cm), HCO_3 – Bicarbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Na – Sodium (mg/l), TDS – Total Dissolved Solids (mg/l)

* Reservoir elevation approximately 306.5 m

** Resample

5.4.3 Recommended Sampling Schedule for 2008

Sampling will continue for all wells around MLR and the analysis will be completed in accordance to AENV requirements for the tailings area.

5.5 Sulphur Blocks

5.5.1 Background

5.5.1.1 Area Description

The sulphur block area is located in the northwest part of the plant area and south of the MLSB. The Phase I sulphur block facility was constructed immediately west of the tailings road, east of the Coke Cell 4 on a compacted clay pad. The Phase II sulphur block facility is located on top of the Coke Cell 4. Coke Cell 4 was capped with compacted clay fill to isolate the coke from the sulphur block. Shallow ditches around the sulphur blocks carry runoff to the north mine ditch, which flows into the recycle water pond. Peripheral trapezoidal ditches were provided on the circumference of the sulphur blocks. Most sections of the drains are provided with geo-membrane liner, which is placed on a well-compacted clay base.

In 2004, construction of the east half of the Phase III sulphur block pad was completed and it is located to the west of the Coke Cell 4, within the eastern mined-out portion of the North Mine (Figure 5.11). The engineered foundation was constructed of a combination of mine waste, rejects and Clearwater clay in compacted lifts. Pouring on the sulphur block foundation commenced in late 2004, comprising of east and west (phase III) sulphur blocks.

5.5.1.2 Additional Research Initiatives

In May 2004, Syncrude applied to the AENV to begin a second sulphur storage research program designed to refine, gather data and investigate the feasibility of storing sulphur long-term below ground. This research program builds on experience gained from the first sulphur research storage program started in 1999 with the pouring and covering of two smaller blocks adjacent to the northwest corner of MLSB.

Approval for this second research program was obtained in December 2004 to pour 4 pilot blocks, each 23m x 23m x 3m (approximately 3,000 tonnes each). The research sulphur block program commenced in 2005 with the blocks located immediately to the south of the Phase III (Figure 5.11) production sulphur block and both are instrumented with piezometers, standpipes, gas probes, settlement plates, multi-port sampler, lysimeter and thermistors. The pilot four blocks were poured by trucks in the first half of 2005 and then covered with varying thicknesses of soil material. The present research program is being conducted with support from the University of Saskatchewan and monitoring is in progress. A prototype of the buried block was located close to the pilot blocks.

5.5.1.3 Geology

In the sulphur block area for Phases I and II, the Clearwater Formation is thin, covered by glacial till and underlain by McMurray Formation oilsand. Isolated glacio-fluvial sand deposits also occur. Various fills have been placed over the insitu material during the construction of the coke cells, sulphur pads, and roads. Figure 5.12 shows a schematic cross-section through this sulphur block area.

The Clearwater Formation, glacial till and McMurray Formation of the Phase III sulphur block area have been mined out to the limestone elevation. The engineered foundation was then constructed over the base of the mined-out pit using of a combination of mine waste, rejects and Clearwater clay. Lifts were placed in compacted thicknesses of 5m, 2m, 1m and 0.75m to minimize deformation and to provide a low permeability (63m thick) foundation for the sulphur blocks. A veneer of K_{CW} clay and McMurray Formation Marine clay material and liners were included in the upper portion of the foundation. Figure 5.13 shows a schematic cross-section through the Phase III sulphur block area.

5.5.1.4 Monitoring Network

There are six monitoring wells located around the Phase I and II sulphur blocks. Six vibrating wire piezometers (VP's) were also installed in 2003, within local basal muds, watersands and the compacted fill zones of the constructed platform, at three locations to the west of the Phase III sulphur block (Table 5.12 and Figure 5.11). Additional three VP's were installed in 2007 to provide adequate instrumentation for groundwater purposes. So far, these instruments have shown steady and un-saturated conditions since installation, with the exception of one installed below a watersand unit. One vibrating wire piezometer located at the toe of the constructed platform, has the least amount of coverage that reads a partially saturated condition (VP030046-1) where the water table is equivalent to the elevation of the watersand unit (Appendix C).

It is expected that the Phase III instrumentation will continue to indicate dry conditions for an extended period of time, due to the low permeability of compacted fill materials in which the piezometers are installed. This is typical of readings measured in Syncrude's compacted overburden dykes and dumps. It is suggested that observation wells may not be installed in the Phase III area until such time that piezometric levels begin to rise and then the installation of a groundwater monitoring well will be necessary. This will specifically be after water begins to infill the well for sampling, then monitoring of groundwater flow patterns will commence once the piezometric levels have risen.

Existing wells are listed in Table 5.11 and shown in Figure 5.11. The wells are installed in a variety of insitu and fill materials. Chemical analyses were completed on the wells in accordance with AENV requirements for the Phase I and II sulphur areas.

Table 5.11: Location of Monitoring Wells, Sulphur Block Areas

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
SMW92-03R	51193	50566	303.2	2.8	4.3	Muskeg/KM
SMW92-04	50715	50519	305.7	1.4	2.9	Muskeg/Till
SMW92-06	50893	50733	305.7	1.5	4.5	Sandy fill/KM
SMW94-01	51233	50227	308.1	8.5	10	Muskeg/Sand
SMW94-02	50742	50211	305.7	4.6	6.1	Sand
SMW02-01	51303	50601	304.8	7.4	9.0	KM

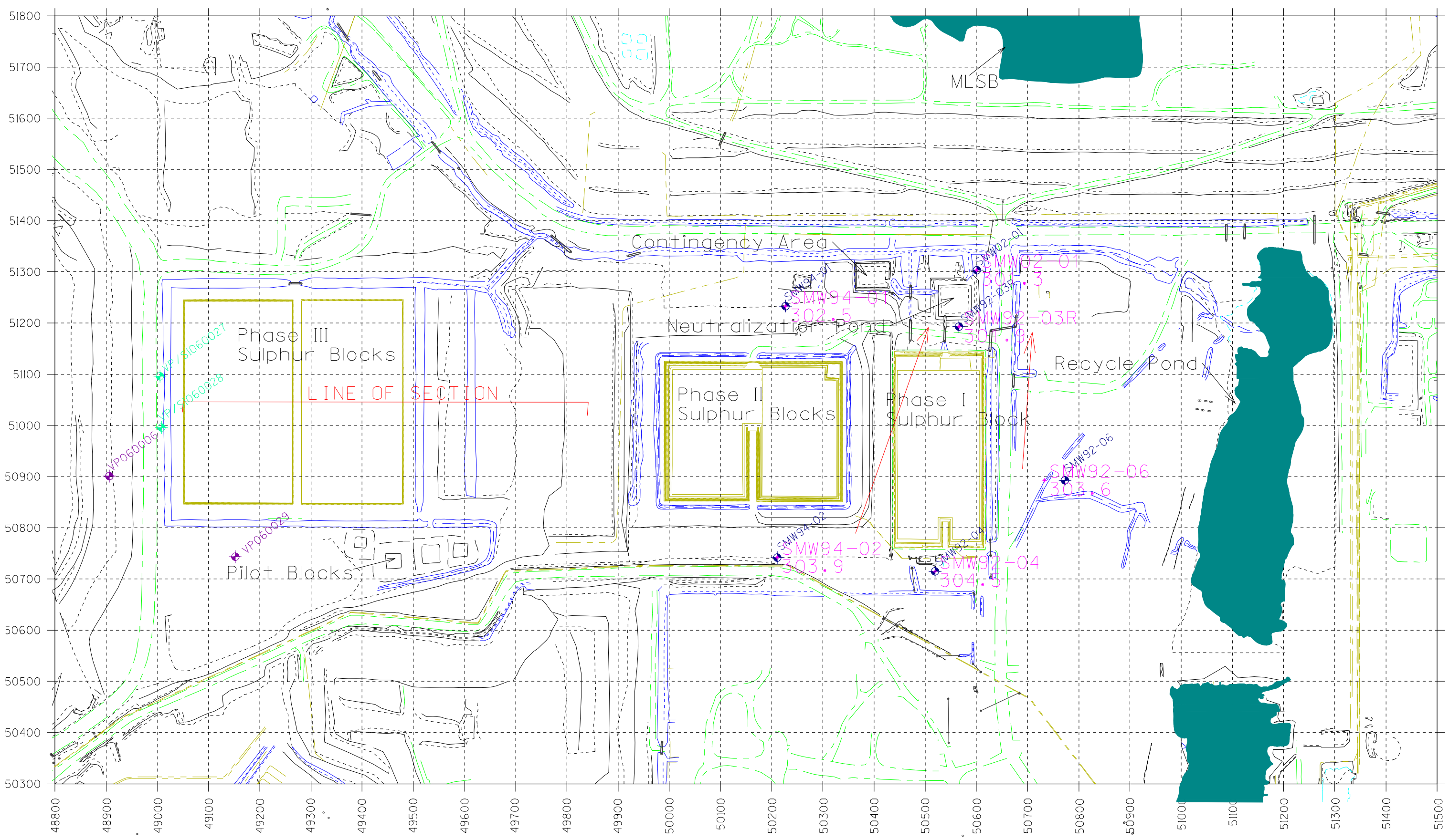
Notes: Sand = Pleistocene sand
KM = Cretaceous McMurray Formation
Till = Pleistocene till
Screen intervals are in meters below ground
Coordinates are in the Syncrude mine metric system

Table 5.12: Location of Vibrating Wire Piezometers, Phase III Sulphur Block Area

Well ID	Northing	Easting	Ground Elevation	Tip Elevation	
				Depth	Lithology
VP030046-1	51299	48137	256.7	10.7	Overbank Mud
VP030047-1	51237	48359	267.4	20.0	Insitu KM
VP030047-2	51237	48359	267.4	13.9	Kc Fill
VP030048-1	50900	48291	266.0	23.1	Basal Watersand
VP030048-2	50900	48291	266.0	17.6	Overbank Mud
VP030048-3	50900	48291	266.0	9.4	KM/Kc Fills contact
VP060006-1	50900.85	48906.13	305.175	16.11	Fill/core
VP060006-2	50900.85	48906.13	305.175	46.12	Fill/core
VP060006-3	50900.85	48906.13	305.175	60.71	Pond Mud
VP060027-1	51096.06	49004.96	316.61	68.3	Pond Mud
VP060027-2	51096.06	49004.96	316.61	71.93	Pond Mud
VP060028-1	50996.0	49007.71	316.19	67.05	Watersand
VP060028-2	50996.0	49007.71	316.19	71.63	Pond mud
VP060029-1	50743.46	49152.02	316.20	3.05	Settlement Liner Lift
VP060029-2	50743.46	49152.02	316.20	7.62	Buffering Liner Lift
VP060029-3	50743.46	49152.02	316.20	23.77	Controlling Liner Lift

Notes: KM = Cretaceous McMurray Formation
Kc = Clearwater clay
Piezometric tip elevations are in metres below ground
Coordinates are in the Syncrude mine metric system

Figure 5.11: Monitoring Wells and Groundwater Flow Directions, Sulphur Block Area



Note:
All Vibrating wire piezometers listed in Table 5.12 are west of the drawing extents near the toe of the platform built to support the Phase III Blocks

LEGEND

SMW92-06 - Monitoring Well with Water Elevation

VP060029 - Vibrating Wire Piezometer; **SI060028** - Slope Indicator Instrument

Figure 5.12: Schematic Cross-Section, Phases I and II Sulphur Block Area

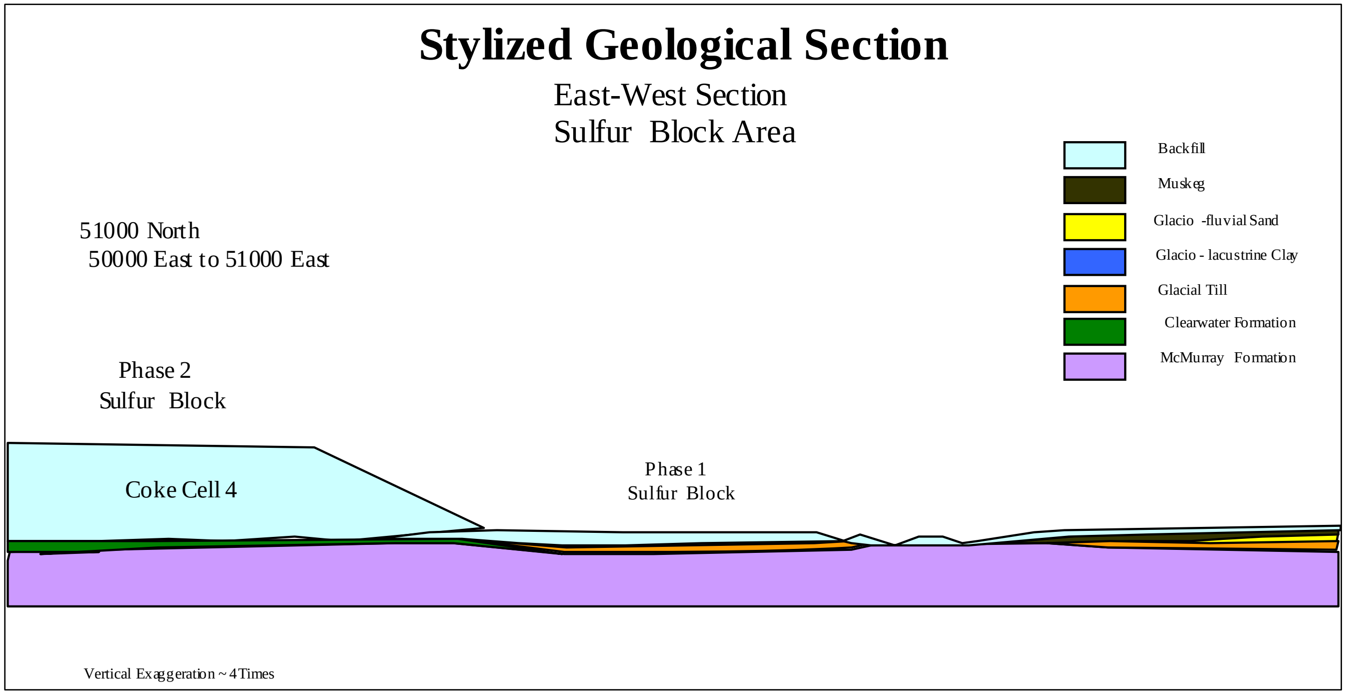
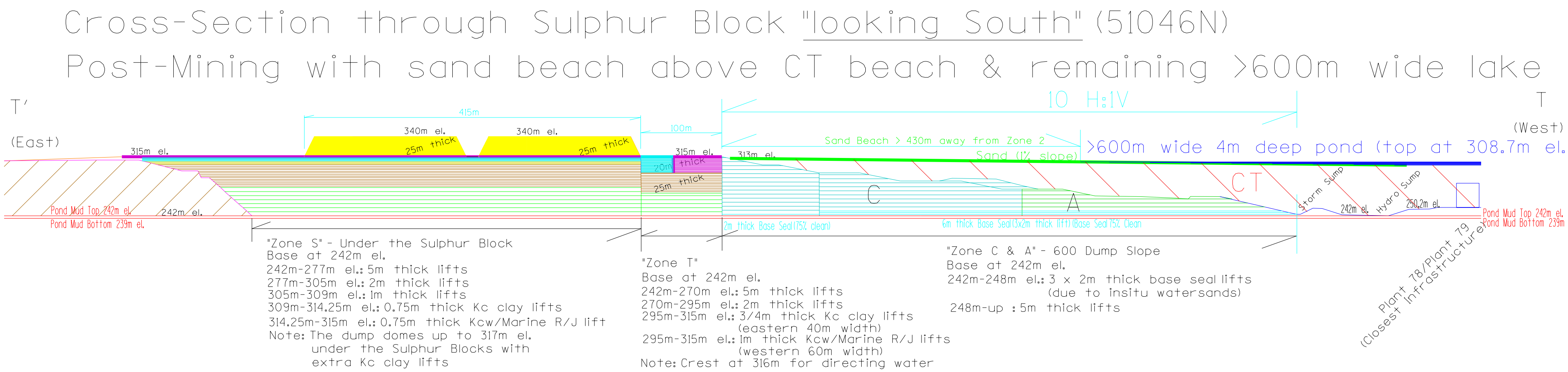


Figure 5.13: Schematic Cross-Section, Phase III Sulphur Block Area



5.5.2 Results and Discussion

The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. A summary of key chemical parameters is provided in Table 5.13.

The various fill materials, ditching, holding ponds, and coke cells complicate the hydrogeological conditions in the sulphur block area. The principal reason for monitoring groundwater in this area is to identify the impacts that the sulphur blocks have on groundwater quality.

Ditching and holding ponds are provided around the Phase I, II and III sulphur blocks and these are linked to a secondary drain that empties to an existing neutralization pond via an existing ditch. The open trapezoidal ditches (drains) are founded on well-compacted (subgrade) clay that maintained a side slope of 3H: 1V. This is overlain with 100mm (PF_4) sand and compacted to 95% standard proctor density. The perimeter drains run along the sides of the sulphur blocks while the drains at Phase III sulphur block were lined with a minimum of 60-millimeter thick geo-membrane and overlain at the bottom-width section of the drain with a non-woven geo-textile material. The flow gradient in the drain is at about 0.5% at most sections. General groundwater flow directions and water elevations from 2007 are shown on Figure 5.11.

The primary risk to groundwater quality around the sulphur storage area is a reduction in pH. To date, there has been no reduction in the pH of the groundwater that would indicate an acidic influence from sulphur storage. In fact, commencing in 2000, the pH began to climb from an average of 6.8, increasing to an average of 7.6 over the past two years in the area. Generally, the pH of the runoff water from the sulphur blocks is very close to neutral pH value in 2006, which indicated a major improvement from 2005 values. If the pH of the groundwater is reduced, there is a potential to mobilize metals that are stable at reduced pH levels. In 2007, almost all the wells are in close to neutral pH except SMW92-03R, which reduced by 0.02 to a pH reading of 7.2. However, the concentration of major ions and the selected metals reduced at this well still confirms the stability of the metals at the well. Also, the concentration of major ions and selected metals at other locations reduced except at SMW92-06, which indicated an increase in sulphate concentration which calls for an increased house keeping within this area. Syncrude have intensified the maintenance of the sulphur block areas and the geo-membrane lined drains, which appear to have attenuated the high sulphate concentration at most section within the sulphur area.

Further comparison of the 2006 and 2007 data continues to improve in concentration from well to well when compared to the trend in the past. Groundwater monitoring well SMW94-02 was repaired in 2007 and read accordingly. The monitoring well SMW94-02 that was damaged will be repaired in 2008.

Table 5.13: Summary of Key Chemical Parameters, Sulphur Block Area

Well ID	Sample Date	Cond.	pH	HCO_3	Cl_2	SO_4	Ca	Na	TDS	As
SMW92-03R	07-Jul-07	6530	7.2	1820	84	2890	615	971	5870	0.0089
SMW92-04	07-Jul-07	1500	7.9	423	44	460	216	98	1110	< 0.0004
SMW92-06	07-Jul-07	1620	7.6	703	73	304	242	48	1130	< 0.0004
SMW94-01	07-Jul-07	1450	7.7	745	94	98.2	113	174	900	0.0005
SMW94-02	29-Nov-07	1500	7.4	737	88	85.1	124	165	941	0.0006
SMW02-01	07-Jul-07	1310	7.9	967	2	2.1	13.6	314	850	< 0.0004

Abbreviations:

Cond – Conductivity (μS/cm), HCO_3 – Bicarbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Na – Sodium (mg/l), TDS – Total Dissolved Solids (mg/l), As – Arsenic (mg/l), " - " not analyzed

5.5.3 Recommended Sampling Schedule for 2008

Annual sampling of all wells listed in Table 5.11 will continue in 2008. All wells will be sampled with analysis completed in accordance to AENV requirements.

5.6 Southwest Sand Storage Facility

5.6.1 Background

5.6.1.1 Area Description

The Southwest Sand Storage Facility (SWSS) footprint covers approximately twenty-six (26) square kilometers. Currently, only one tailings line transports the coarse tailings slurry from the extraction plant to the SWSS. A perimeter road runs along the west, north, and east sides of the SWSS. A dirty water ditch is located between the toe of the SWSS and the perimeter road. Tailings pump-houses are located on the north and east sides of the SWSS along the perimeter access road. The SWSS decant system carries water and fines from the south end of the SWSS through a gravity-flow pipeline to the WIP.

The external sump, located northeast of the SWSS, still holds tailings sand, although it is no longer in use. Syncrude Closure and Reclamation group started to place sand in the small compartment of the external sump in an attempt to cap the MFT material in preparation for future reclamation work. The placement of the sand in the external sump started in late November and is on-going. The western half of this structure has been reclaimed. The AOSTRA Road passes around the south end of the SWSS. The Special Waste Interim Storage Area (SWISA) is located just east of the east perimeter road. The SWISA site is discussed in Section 5.7 of this report. North of the SWSS is the W1-Dump, a disposal area for overburden material being removed in the North Mine. The W1-Dump is expanding and will eventually cover the north portion of the SWSS perimeter road and will butt into the northeast corner of the SWSS tailings dyke.

5.6.1.2 Geology

The geologic sequence found below the SWSS typically consists of muskeg, glacio-lacustrine clay, till, Clearwater Formation clays, and McMurray Formation oilsand. North of the SWSS, a buried glacio-fluvial channel is incised into the Clearwater Formation and underlies the till. An east-west cross-section north of the SWSS is shown in Figure 5.14.

The glacio-fluvial sand and gravel north of the SWSS are heterogeneous. The deposit consists of lenses of well- to poorly-sorted silt, sand, and gravel. The till varies in thickness from one to ten meters across the area. The till is typically a silty-clay, however it may contain lenses of glacio-fluvial sand up to one meter thick. A glacio-lacustrine clay unit overlies the till in most of the area. The clay has a lower sand and gravel content than the underlying till. A thin layer of muskeg covers most of the area with thicker deposits in topographically low areas.

5.6.1.3 Surface Water Source

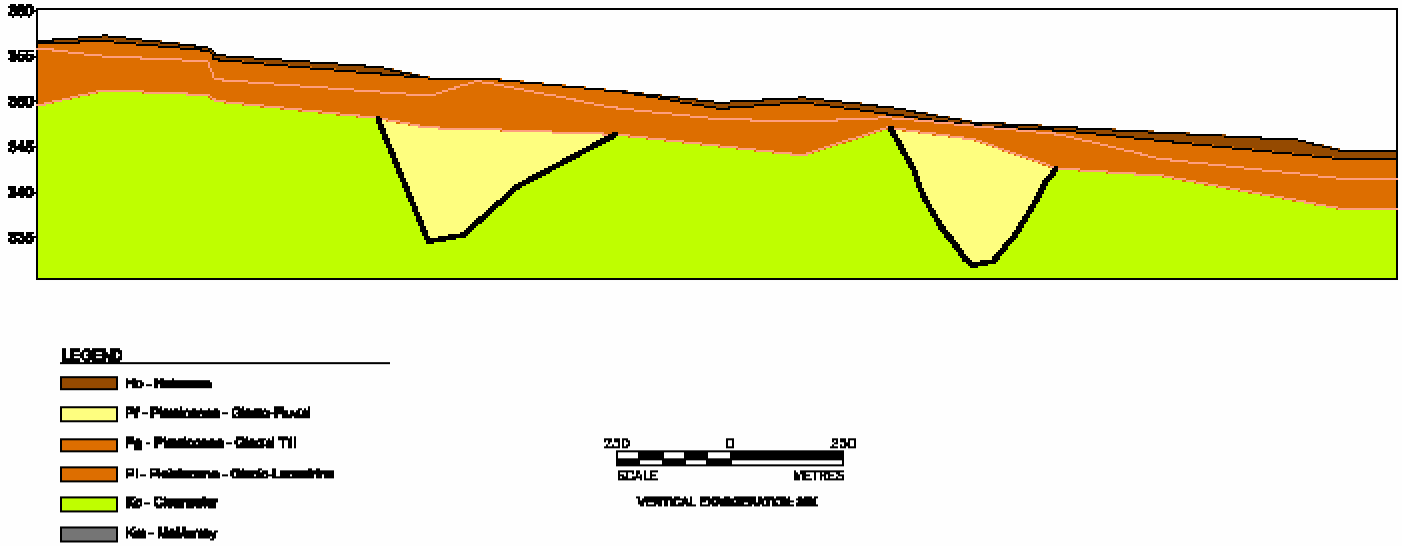
As discussed in Section 5.1, two surface water samples are taken in 2007 from - one from the pond (SWSS-DC) and from the off-take (DFW-3101) both located at the north end of the facility to represent seepage water chemistry coming from the SWSS. The concentrations of the major ion and naphthenic acid decreased at SWSS-DC except for sodium which slightly increased while sodium, chloride and bicarbonate slightly increased at the off-take DFW-3101.However, naphthenic acid concentration decreased at this source.

5.6.1.4

5.6.1.5 Monitoring Network

There are currently twenty active monitoring wells located around the SWSS (Table 5.14). Four additional wells are located around the nearby SWISA, which are discussed in Section 5.7. Chemical analyses were completed in accordance with AENV requirements for the tailings areas (Appendix A).

Figure 5.14: SCHEMATIC CROSS-SECTION, NORTH OF SWSS
SECTION ALONG 51000N (LOOKING NORTH)



L:\2006\1346\06-1346-003\3000\Cross-sections\Fig 5-14 Section 49800 North-20X.dwg Aug 30, 2007 - 2:54pm

Table 5.14: Location of Monitoring Wells, SWSS Area

Well ID	Northing	Easting	Ground Elevation	Screen Interval			Comments
				Top	Bottom	Lithology	
KL89-01B	49881	42730	353.8	5.7	7.2	Sand	
OW91-07A	50499	43193	349.3	6.1	7.6	Till/Sand	
OW91-10R	48387	44006	350.3	8.5	9.8	Till	
OW91-11	48168	44558	345.0	5.5	7	Till	
OW91-12	45142	48049	340.7	4	5.5	Till	
OW91-13	47627	44372	349.7	4.6	6.1	Clay/Till	
OW91-15	46553	43973	352.4	5.5	7	Till	
OW91-16	46145	43847	353.7	7	8.5	Till	
OW92-01A	44577	43272	364.2	4.4	5.9	Till	
OW92-02A	44186	43154	366.4	4.3	5.8	Till	
OW92-03A	43683	42997	370.7	3.3	4.8	Till	
OW94-09	42820	42666	374.1	3.7	5.2	Clay/Till	
OW96-01	48949	39622	370.2	11.3	12.8	Till	
OW96-02	50101	42904	351.7	11.4	12.9	Sand	
OW98-14	45622	43667	356.2	6.4	7.9	Till	Replaced OW91-17
OW98-15	49803	41299	360.5	8.4	9.9	Sand	Replaced OW91-01A
OW99-29	47898	39328	373.6	2.7	4.3	Till	
OW99-30	46901	39050	381.0	3.1	4.6	Till	
OW99-31	45899	38752	390.4	4.6	6.1	Till	
OW03-23	42121	41445	385.5	2.9	4.4	Clay	

Notes: Till = Pleistocene till
Sand = Pleistocene fluvial sand
Clay = Pleistocene lacustrine clay
Screen intervals are in meters below ground
Coordinates are in the Syncrude mine metric system

5.6.2 Results and Discussion

The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. A summary of key chemical parameters for the monitoring wells is provided in Table 5.15.

The glacio-lacustrine clay deposit present in most areas has a low hydraulic conductivity (10^{-8} to 10^{-10} m/s). This minimizes the risk of process water influencing groundwater quality around the SWSS. The hydraulic conductivity of the underlying till has been estimated at 10^{-9} m/s, however this unit has a more variable grain size, consequently higher hydraulic conductivity may be expected at some areas.

The buried Pleistocene channel north of the SWSS is the most significant hydrogeologic feature in this area, having a hydraulic conductivity in the range of 10^{-4} to 10^{-5} m/s. Overall groundwater flow around SWSS is toward the northeast, following the topography. Locally around the SWSS, there may be flow outward from the tailings structure. It is expected that the toe ditch will intercept shallow flow.

Within the buried glacio-fluvial channel, the flow is southeasterly through the western portion, and then it follows the channel toward the northeast, then west. Artesian conditions are present through much of the channel. A portion of the G-Pit channel northeast of the SWSS is currently used as a source of granular material. Dewatering of the channel began in 1999 and it is still on-going, with a view to reduce the pressure within the aquifer. In 2008 Syncrude plans to install 9 dewatering wells and 6 piezometers at the north and south limbs of the G-Pit channel in line with mine plan. Figure 5.15 shows water elevations observed in 2007 and the interpreted groundwater flow directions.

Table 5.15: Summary of Key Chemical Parameters, SWSS Area

Well ID	Sample Date	Cond.	pH	HCO_3	Cl_2	SO_4	Ca	Na	TDS
KL07-01B	09-Nov-07	1920	7.8	844	157	163	170	197	1200
OW91-07A	12-Jul-07	2160	7.9	1140	132	150	145	312	1430
OW91-07B	Damaged								
OW91-10R	27-Jun-07	4130	8.2	1400	299	702	13.6	941	2750
OW91-11	26-Jun-07	1640	8.1	925	32	133	46.2	299	1140
OW91-12	11-Sep-07	3590	7.6	703	208	1270	353	423	2880
OW91-13	26-Nov-07	3030	7.4	1140	13	989	376	160	2600
OW91-15	27-Jun-07	3560	8	1330	156	700	34.7	706	2410
OW91-16	27-Jun-07	3690	8.2	1770	282	245	6.4	838	2410
OW92-01A	27-Jun-07	4440	7.9	655	9	2230	372	621	3840
OW92-02A	02-Aug-07	4970	8	1150	43	1850	65.5	1070	4140
OW92-03A	27-Jun-07	4220	7.9	968	38	1850	273	559	3550
OW94-09	27-Jun-07	2860	8	722	9	1030	231	342	2230
OW96-01	28-Jun-07	3330	8.2	1430	9	710	33.9	803	2340
OW96-02	28-Jun-07	1450	8	865	20	105	106	187	870
OW96-02	28-Jun-07	1450	7.9	863	20	103	105	188	880
OW98-14	Dry								
OW98-15	28-Jun-07	845	7.8	572	2	16.4	117	23	500
OW99-29	28-Jun-07	1630	7.8	725	2	346	143	207	1120
OW99-30	29-Jun-07	3400	7.7	830	10	1360	273	447	2760
OW99-31	28-Jun-07	1200	8.4	738	4	43	2.7	304	750
OW03-23	12-Jul-07	1410	8	908	5	97.5	73.9	203	916

Abbreviations:

Cond – Conductivity (μS/cm), HCO_3 – Bicarbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Na – Sodium (mg/l), TDS – Total Dissolved Solids (mg/l), " - " not analyzed

* Duplicate Sample

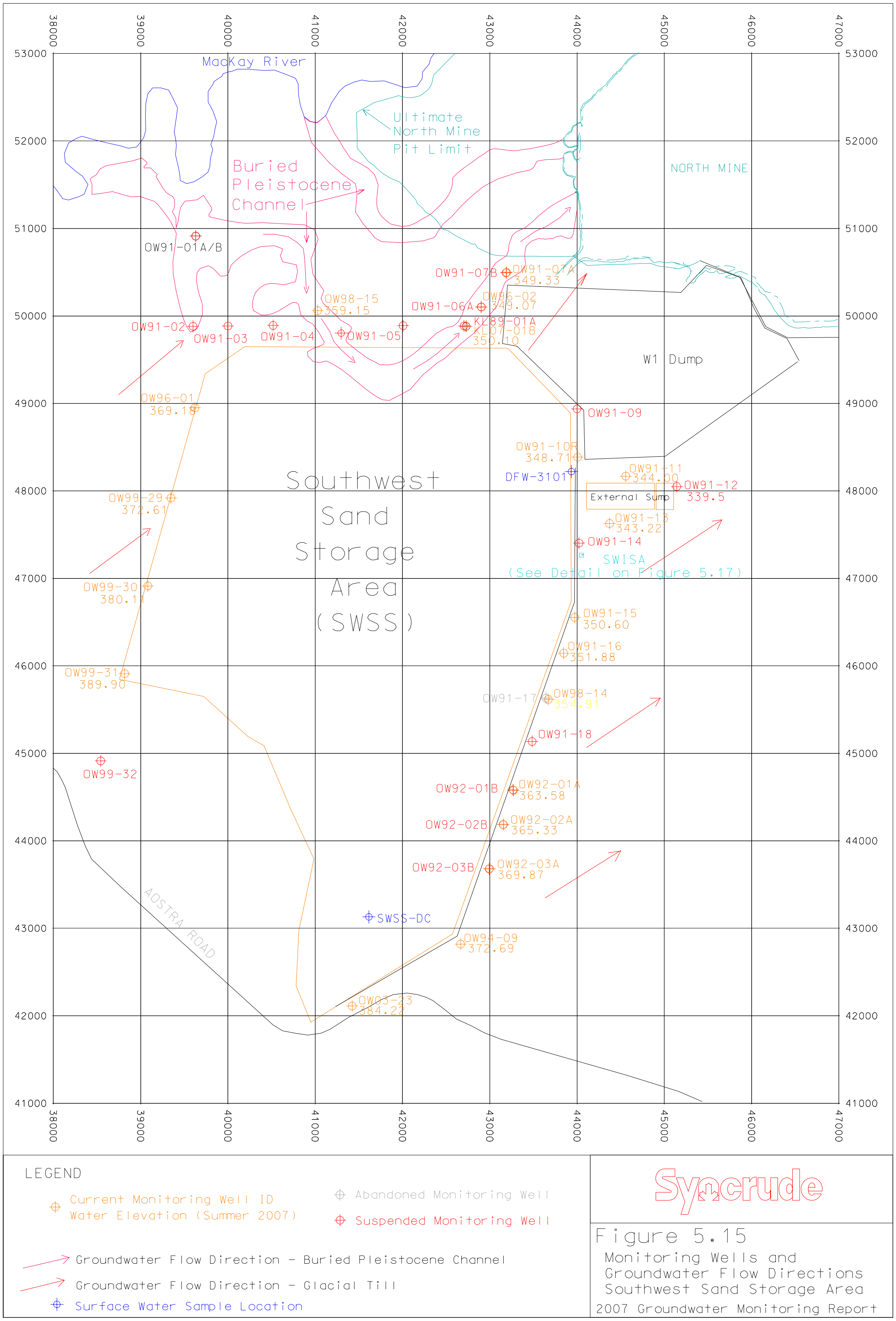
There are three active monitoring wells located within the buried channel northeast of the SWSS. OW96-02 and OW91-07A, OW91-07B and KL07-01B (which replaced KL89-01B). These are located at 600m and 1100m respectively from OW96-02 (northeast of the SWSS). Monitoring wells OW91-07B would be replaced in 2008 due to obstructions within the area.

The concentrations of chloride in the three sampled wells OW96-02, OW91-07A and KL07-01B reduced generally in 2007 and the concentrations of major ions in these wells are below the concentrations the in Syncrude's process water. In addition, any suspected seepage into this channel flows toward the gravel pit, where it is captured by dewatering and retained on site.

As most of the G-Pit channel will be mined out as the North Mine advances west, seepage into the south and north limbs of the buried channel will exhibit an hydraulic gradient towards the opened G-Pit /exposed mine pit area which (naturally flows toward the pit and away from MacKay river) will be dewatered into our dirty water system as dictated by the water quality. Moreover, there is no hydraulic connection between Mackay River and the buried G-Pit (south limb) channel, which can be confirmed from past studies.

Monitoring well OW98-15 is located approximately 150 meters northwest of the SWSS, within the buried channel. This well was installed in 1998 to replace OW91-01A, also located in the buried channel, but further from the SWSS. Results from 2006 and 2007 indicated a reduction of the major metals and this is consistent with the past years. This goes to represent a general water quality in the buried channel since it is an upstream monitoring well that serves as the background quality within the G-Pit area while OW98-15 shows no influence from the SWSS.

Figure 5.15: Monitoring Wells and Groundwater Flow Directions, SWSS



The groundwater well OW99-30 is installed at the upstream to the groundwater flow direction at the southwest location of the SWSS. This well has a high concentration of sulphate while OW99-31 has a lower concentration of major ions in the same vicinity. This confirms that the background groundwater chemistry in glacial till around the SWSS varies significantly, which appears to be the result of the variability in the composition of the till and of the hydraulic conductivity. The monitoring wells in the zones of higher hydraulic conductivity tend to have lower TDS and this is comparable with past trends.

In 2004 well OW91-12 indicated a gradually increase in chloride concentration. It was unclear at that time if the change in chemistry could be linked to seepage of process affected water, as concentrations remained low and the neighboring external sump has not been active for years. Reclamation that commenced in 2005 is on-going at the sump close to the monitoring well OW91-12 and this well has indicated a slight increase in 2007 when compared to 2004. Since this well had started to contain water again, it might be necessary to continue to monitor this trend over some time period in subsequent sampling program. This will indicate the prevailing groundwater quality in the area.

The groundwater chemistry around the SWSS as indicated by other monitoring wells not specifically discussed, are consistent with historical data. These show no indication of influence from process water.

5.6.3 Recommended Sampling Schedule for 2008

Due to the continuing expansion of the W1-Dump, Syncrude has replaced well KL89-01B that was damaged with KL07-01B and OW91-07B will be replaced in 2008.

Annual sampling of all the wells will continue as per AENV requirements for the tailings area.

5.7 Class II Flue Gas Desulphurization (FGD) By-Products Landfill

5.7.1 Background

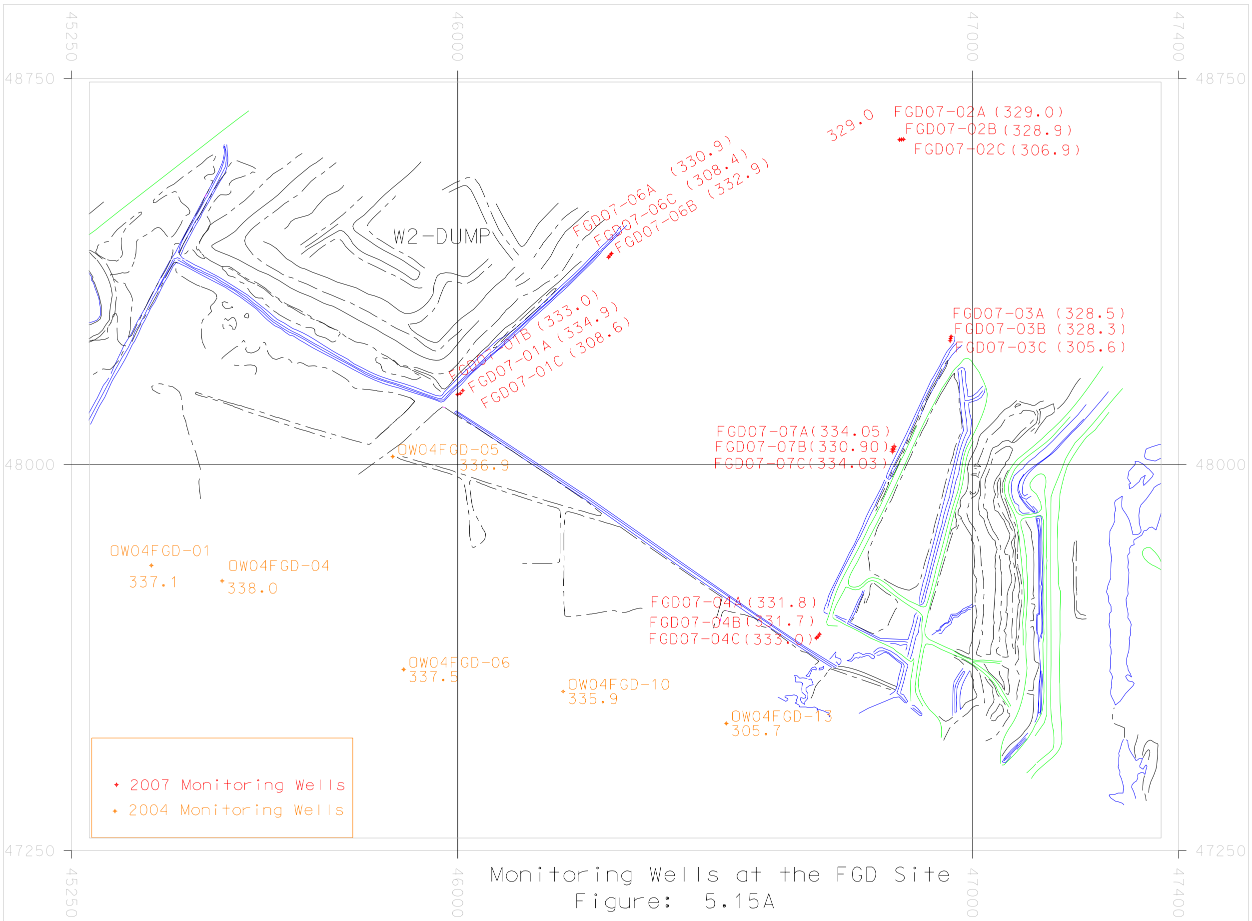
5.7.1.1 Area Description

Syncrude plans to operate a new flue gas de-sulphurization (FGD) project, which is part of its emission reduction project. The FGD by-product consists of moisture-conditioned, silt –sized powdery material that is to be transported and compacted within the proposed landfill site. The by-product will be placed in a proposed landfill (110 hectares) located between eastern side of SWSS (300m away) and the overburden dump W2. The proposed landfill shall be founded on a 3m thick clay liner underlain by another 3m reconstituted native clay, placed and compacted in lifts to prevent contaminant migration. Syncrude would carry out a groundwater monitoring program within this area and include this in the annual groundwater monitoring program when the facility is in operation. However, Syncrude has collected the background groundwater quality of the proposed site for inclusion in this report in 2007.The landfill FGD facility which will have a 25 years lifespan will be completed in 2009.Currently, the project has been phased out starting with one half of the site.

Geology

The proposed landfill site is has a thin Holocene layer underlain by Pleistocene (Pl) deposit with a thickness ranging from 1.5- 4m. This layer is underlain by a glacio- fluvial / till layer ranging in thickness of 0.5m to greater than 6m. Both materials consist of silty clay to clay, having low to high plasticity. The bedrock underlining the glacial till consists of the Clearwater formation (K_{CC}) which mainly clay shale with variable silt and fine sand content, having an average thickness of 26m at the proposed site. Underlying the Clearwater formation is the McMurray formation (K_M). A site layout is shown in Figure 5.15A.

Figure: 5.15A: Flue Gas Desulphurization (FGD) Landfill Site



Surface water Sources

Run-off from the natural areas to the proposed FGD landfill site is not anticipated but perimeter ditches shall be provided around the base of the landfill to intercept surface run-off and upland overland flows. There is also a proposed storm water retention pond that will capture extreme flood flows to be located at the northeast corner of the proposed landfill and supported with sumps, pumps and flow pipelines.

Monitoring Network

The half of the site which has been cleared and completed with monitoring wells in the three stratigraphic units include monitoring wells installed during preliminary investigation design (installed in 2004) and additional background monitoring wells installed in October 2007. The wells are monitored and chemical analyses were completed in accordance with AENV Standards for Landfills in Alberta (May 2004).

The complete result of the analysis, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. A summary of key chemical parameters for the monitoring wells is provided in Table 5.15A.
The shallow and medium depth wells were generally installed in geologic units comprising Pleistocene clays (PL) and Pleistocene glacial tills (PG). The deepest wells were installed in the Wabiskaw member of the Clearwater Formation (Kcw). This unit is glauconitic fine sand that occurs directly above the McMurray Formation at this site. All lithologic descriptions are based on the Syncrude overburden geologic Facies Chart (see Table 5.14A).

5.7.2 Results and Discussion

The concentration of major ions at the groundwater monitoring wells FGD04-01, FGD04-04, FGD04-06, FGD04-05 and FGD04-10, located up-stream of the groundwater flow direction indicated a low range of values which may represent concentrations from natural environment while the concentration of chloride in FGD04-01 was naturally high and this may be from the unit which the well was installed or lenses of high chloride silty-clay soil in pockets of the K_{CC}.

Table 5.16A: Location of Monitoring Wells, FGD Landfill Area

Well ID	Northing	Easting	Ground Elevation	Screen Interval			Comments
				Top	Bottom	Lithology	
FGD04-01	47804.00	45404.90	339.00	16.8	18.3	Screen in Kcc	
FGD04-04	47774.10	45542.60	338.90	3.3	3.8	Screen in PL2	
FGD04-05	48015.50	45873.70	337.20	1	1.5	Screen in PL2	
FGD04-06	47602.00	45895.00	338.10	4.6	6.1	Screen in PG1	
FGD04-10	47559.30	46204.60	336.40	0.91	3.05	Screen in PL2	
FGD07-1A	48143.4	46009.64	336.16	1.2	2.7	Screen in PL2	
FGD07-1B	48136.37	45999.59	336.29	4.2	5.6	Screen in PL2	
FGD07-1C	48138.02	46005	336.29	28.7	30.2	Screen in Kcc	
FGD07-2A	48630.83	46857.98	331.16	1.1	2.8	Screen in PL2	
FGD07-2B	48631.56	46861.86	331.22	1.5	3.0	Screen in PL2	
FGD07-2C	48631.97	46866.03	331.34	27.1	28.6	Screen in Kcc	
FGD07-3A	48248.74	46958.07	330.36	0.6	2.1	Screen in PL2	
FGD07-3B	48244.79	46957.4	330.39	2.1	3.7	Screen in PL2	
FGD07-3C	48240.57	46956.3	330.58	24.4	25.9	Screen in Kcc	
FGD07-4A	47670.64	46702.9	333.52	24.4	25.9	Screen in PL2	
FGD07-4B	47666.83	46699.76	333.52	24.4	25.9	Screen in PL2	
FGD07-4C	47663.28	46696.32	333.6	26.2	28.7	Screen in Kcc	
FGD07-6A	48403.07	46293.1	334.59	0.9	2.4	Screen in PL2	
FGD07-6B	48406.02	46295.3	334.69	2.7	4.3	Screen in PL2	
FGD07-6C	48409.78	46298.28	334.8	27.0	28.5	Screen in Kcc	
FGD07-7A	48026.05	46844.46	333.04	1.8	3.4	Screen in PL2	
FGD07-7B	48030.13	46845.65	333.11	2.7	4.3	Screen in PL2	
FGD07-7C	48035.01	46847.32	333.21	25.2	26.7	Screen in Kcc	

Notes: Till = Pleistocene till
Sand = Pleistocene fluvial sand
Clay = Pleistocene lacustrine clay
Screen intervals are in meters below ground

The other downstream monitoring wells indicated similar low concentration of major ions in the Pleistocene units while those wells in the deeper till units indicated high chloride concentration. The concentrations of major ions, selected metals and naphthenic acid are naturally and generally low including total dissolved solids (TDS) at all the wells installed in the surficial aquifer Pleistocene units.

In general, the concentration of TDS appears to increase with depth in the cretaceous clearwater formation. Moreover, these high concentrations from the natural geo-chemistry appears to contribute to the increased level of concentration experienced towards the proposed landfill area because the groundwater flow direction is from undisturbed areas to the proposed area.

5.7.3 Recommended Sampling Schedule for 2008

Sampling will continue for all wells around proposed landfill in 2008 and the analysis will be completed in accordance to AENV requirements for the landfill area.

Table 5.17A: Summary of Key Chemical Parameters, FGD Landfill Area

Well ID	Sample Date	Cond.	pH	HCO_3	Cl_2	SO_4	Ca	Na	TDS
FGD04-01	26-Jul-07	7490	8.3	2430	1530	69.2	17.1	1840	4970
FGD04-04	26-Jul-07	3900	7.8	765	14	1920	595	410	3750
FGD04-05	26-Jul-07	1060	7.7	710	2	53.9	127	69	665
FGD04-06	26-Jul-07	1290	8.1	839	13	58.2	71.6	231	876
FGD04-10	26-Jul-07	2090	7.8	602	7	778	309	168	1700
FGD07-01A	11-Jan-07	2470	7.6	704	33	883	440	194	2100
FGD07-01B	31-Oct-07	2480	7.9	1280	179	72.9	72.2	516	1640
FGD07-01C	11-Jan-07	9160	7.5	1330	2650	115	54	2000	5300
FGD07-02A	11-Jan-07	1030	7.8	558	17	101	114	87	700
FGD07-02B	11-Jan-07	1330	7.8	659	26	167	91	165	888
FGD07-02C	11-Jan-07	15600	7.6	1520	4920	52.7	72.6	3340	9310
FGD07-03A	31-Oct-07	1570	8.2	527	63	346	110	160	1120
FGD07-03B	30-Oct-07	1440	7.9	526	18	313	82.7	170	1020
FGD07-03C	11-Jul-07	6140	8.1	938	1570	117	26.7	1290	3590
FGD07-04A	30-Oct-07	701	7.8	450	2	25.2	103	16	556
FGD07-04B	30-Oct-07	781	7.9	497	4	31	107	31	540
FGD07-06A	11-Jan-07	1610	7.9	638	9	414	225	108	1210
FGD07-06B	31-Oct-07	2450	7.5	623	6	954	381	188	2040
FGD07-06C	11-Jan-07	8590	7.6	1310	1810	895	63.8	1990	5530
FGD07-07A	31-Oct-07	1020	7.8	531	5	137	132	62	722
FGD07-07B	31-Oct-07	1180	7.9	521	7	225	147	76	944

Abbreviations:

Cond – Conductivity (μS/cm), HCO_3 – Bicarbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Na – Sodium (mg/l), TDS – Total Dissolved Solids (mg/l), " - " not analyzed

* Duplicate Sample

5.8 Special Waste Interim Storage Area

5.8.1 Background

5.8.1.1 Area Description

The Special Waste Interim Storage Area (SWISA) is located east of the SWSS. Hazardous waste is temporarily stored within a secure building at this site prior to being transported off site. An asphalt pad surrounds the storage building. A chain-link fence with barbed wire arming and a locked access gate prevents unauthorized entry into the area.

5.8.1.2 Geology

The geologic sequence underlying the SWISA consists of muskeg, glacio-lacustrine clay, till, Clearwater Formation clays, and McMurray Formation oil sand. A schematic cross-section through the area is shown on Figure 5.16.

5.8.1.3 Monitoring Network

There have been no changes to the monitoring network around the SWISA over the past year. There are four active monitoring wells (Table 5.16 and Figure 5.17). Analysis was completed in accordance with the requirements for the SWISA area.

Table 5.18: Location of Monitoring Wells, SWISA

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
OW98-10	47268	44083	349.4	5.5	7.0	Till
OW98-11	47297	44054	349.6	4.9	6.4	Till
OW98-12	47236	44041	349.7	5.2	6.7	Till
OW98-13	47269	43992	350.6	4.9	7.9	Till

Notes: Till = Pleistocene till
Screen intervals are in meters below ground
Coordinates are in the Syncrude mine metric system

5.8.2 Results and Discussion

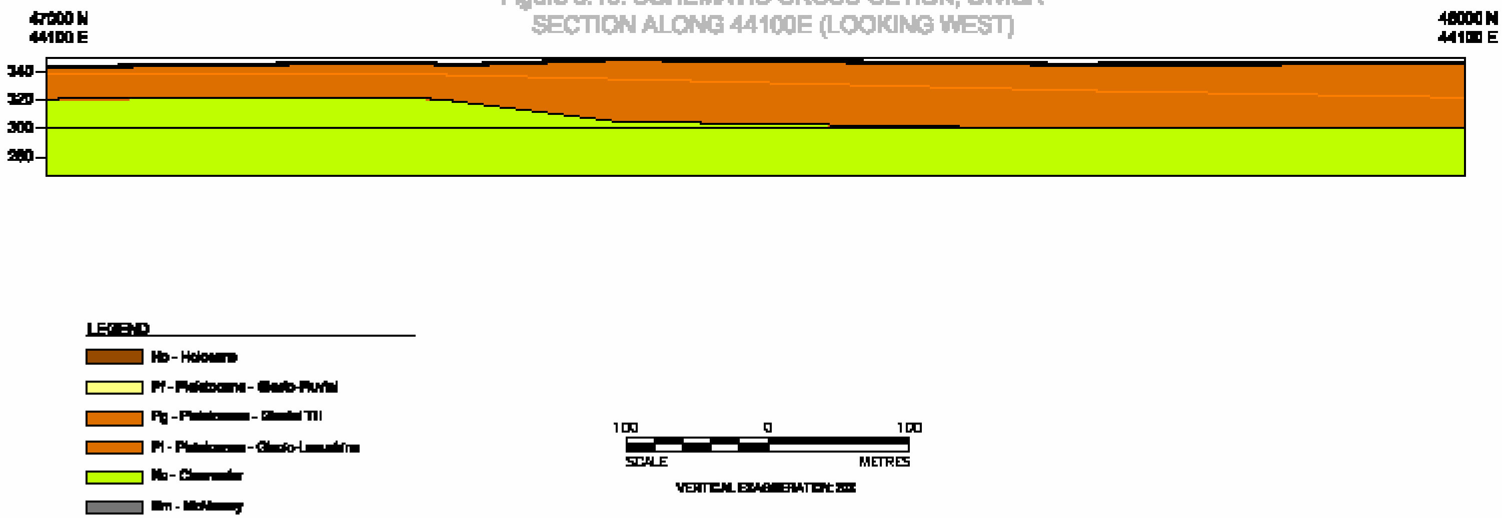
The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. Table 5.17 provides a summary of the chemical parameters in this area.

The surficial glacio-lacustrine clay deposit has a low hydraulic conductivity (10^{-9} to 10^{-10} m/s). The low hydraulic conductivity of the clay and underlying units would provide very good containment in the event of a spill. In surrounding areas, the hydraulic conductivity of the underlying till has been estimated at 10^{-9} m/s. The Clearwater Formation Clays are estimated to have a hydraulic conductivity in the range of 10^{-8} to 10^{-13} m/s.

The direction of groundwater flow in the till is toward the northeast. This is consistent with the topographic slope of the area. The direction of groundwater flow and static water elevations from 2006 are shown on Figure 5.17.

The major ion, selected metals and naphthenic acid concentrations observed in 200 in the monitoring wells around the SWISA site have reduced slightly except chloride which increased slightly at OW98-10, OW98-12 and OW98-13. The general trends of the concentrations have been flat and are generally consistent with historical data. The variability observed in the concentration of sulphur at OW98-11 will be closely monitored in the next sampling season. However, the phenol concentration was virtually constant except at OW98-13.This will also be noted in 2008 sampling program.

Figure 5.18: SCHEMATIC CROSS-SETION, SWSA
SECTION ALONG 44100E (LOOKING WEST)



Aug 30, 2007 - 2:55pm

Figure 5.17: Monitoring Wells and Groundwater Flow Directions, SWISA

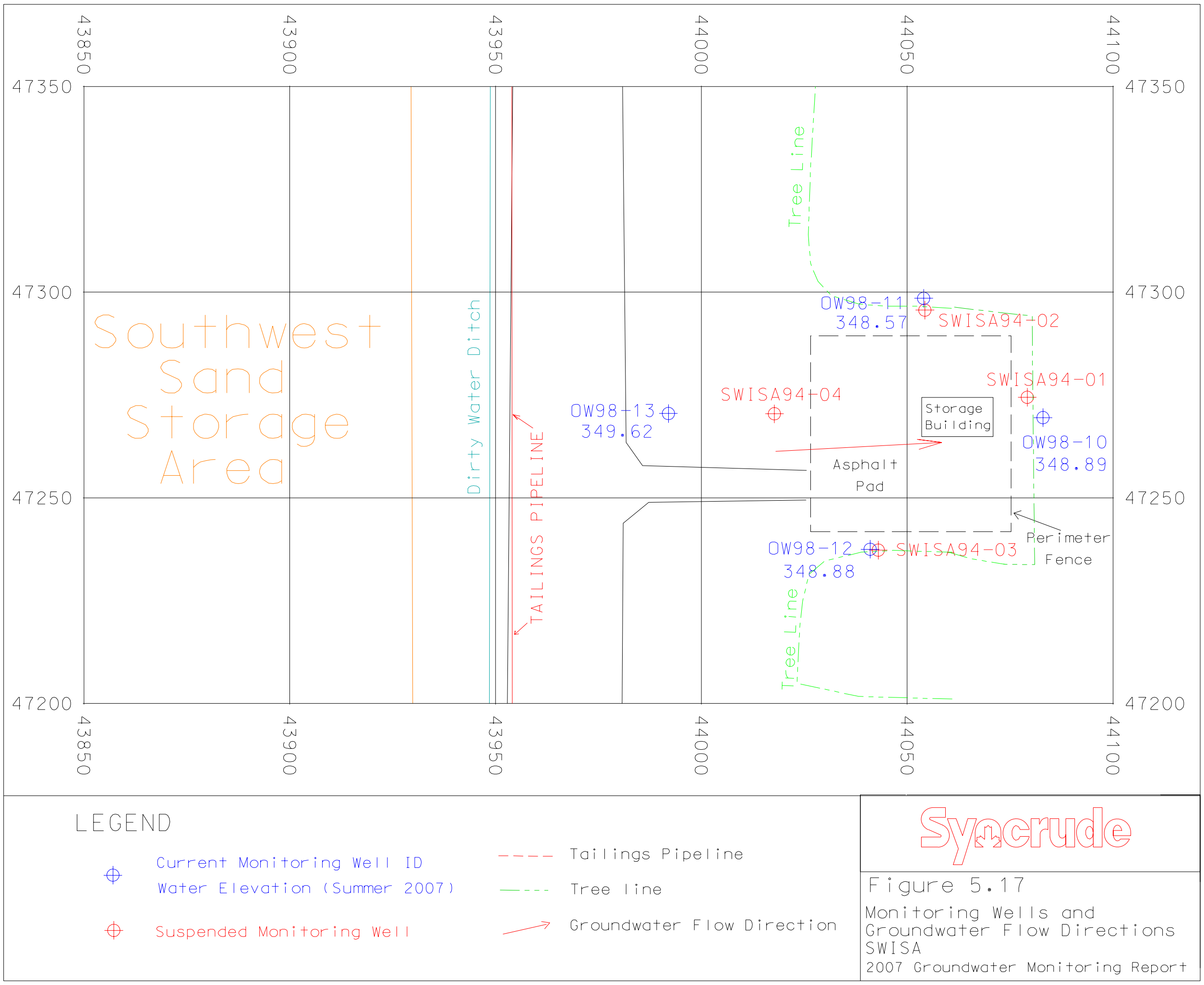


Table 5.19: Summary of Key Chemical Parameters, SWISA

Well ID	Sample Date	Cond.	pH	HCO_3	Cl_2	SO_4	Na	Phenols
OW98-10	27-Jun-07	1610	8.1	859	65	118	249	< 0.001
OW98-11	26-Jun-07	2820	7.8	765	41	964	328	0.001
OW98-12	27-Jun-07	1240	8.1	806	29	14.6	231	< 0.001
OW98-13	26-Jun-07	2840	7.9	1090	75	578	560	0.01

Abbreviations:

Cond – Conductivity (µS/cm), HCO_3 – Bicarbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Na – Sodium (mg/l), Phenols (mg/l)

* Duplicate Sample

5.8.3 Recommended Sampling Schedule for 2008

There are no changes proposed for this area in 2008. Annual sampling of all wells listed in Table 5.16 will continue with analysis completed as per requirements for the SWISA.

5.9 In-Pit Tailings

5.9.1 Background

5.9.1.1 Area Description

Syncrude's original mine pits continue to be used for tailings disposal. The West In-pit (WIP) is located west of Highway 63. The Southeast Pond (SEP) and the Northeast Pond (NEP), both contained within the East In-pit (EIP) are east of Highway 63. These two ponds have now merged. They were initially hydraulically connected through a gravity drainage channel flowing north to south.

There are many facilities and activities surrounding the in-pit tailings areas as shown in Figure 5.18. The WIP is surrounded by reclaimed overburden and muskeg dumps (DW30) to the south, the Highway Berm (current location of Highway 63) to the east, the South West Dam to the west, and Coke Cell 5 to the north. Bordering the EIP are the Highway Berm to the west, the North Closure Dam to the northwest, the highway corridor and plant site to the north, the EIP Boundary Dyke and future northbound Highway 63 corridor to the east (located directly west of the Syncrude/Suncor property line), and a reclaimed overburden dump to the south.

WIP is primarily used as a settling pond for mature fine tailings (MFT) and thin fine tails (TFT) transferred from other tailings areas, including the SWSS, SEP and MLSB. Deposition of coarse tailings and composite tailings into the EIP began in August of 1999 and is ongoing. Sand placement in the NEP will progress till 2010 while placement at the SEP will continue up to 2013.

5.9.1.2 Geology

The geology of the Base Mine typically consists of Devonian limestone underlying the McMurray Formation. The limestone varies from competent limestone to a weathered paleosol. The Lower McMurray Formation is discontinuous, and varies in lithology from pond muds to coarse sands. The sand can be bitumen saturated, but is commonly water saturated. The Middle McMurray member is the main ore body of the mine. These sands are generally well saturated with bitumen and interbedded with clays. The Upper McMurray is continuous, typically composed of fine-grained sand and clays, and the bitumen saturation is highly variable. In most areas, the Upper McMurray averages from five to ten meters in thickness. In areas where the Upper McMurray channels have been cut into Middle McMurray, the Upper member may be over thirty meters thick.

The Clearwater Formation conformably overlies the Upper McMurray. Near the centre of the WIP, the Beaver Creek channel cuts through the Clearwater Formation into the Upper McMurray. West of the Beaver Creek channel, the Clearwater Formation increases in thickness to approximately twenty meters at the west end of the WIP. Anywhere from one to five meters of glacio-lacustrine clay and till overlies the Clearwater clays.

Within the pits, dragline mining (though not in use anymore) typically removed everything above the Devonian, leaving only pockets of pond muds and other uneconomic materials. Waste consisting of clays and rock contaminated ore were cast in-pit by the dragline, forming piles on the pit floor.

Located to the north of the EIP (NEP area) and south of the MLR are the McMurray oilsand units, Clearwater Formation and overlying glacial tills, glacio-fluvial and muskeg materials that remain in-situ. The permeable glacio-fluvial units at surface have variable thickness, but in most areas extend only down to an elevation of 309m, giving an average thickness of 3 meters.

5.9.1.3 Monitoring Network

There are four remaining wells at depth situated around the in-pit areas, and five shallow wells were installed in surficial glacio-fluvial units between the NEP and MLR (Table 5.18). At the time of installation, each of these shallow wells was dry. They are intended for future monitoring, once tailings are deposited above the in-situ oil sand in the NEP (after 2010). These wells will be sampled in 2007 to represent the background data, provided there is sufficient water to sample.

Chemical analyses were completed in accordance with AENV requirements for all the remaining BML wells.

Table 5.20: Location of Monitoring Wells, In-Pit Tailings Areas

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
BML96-03	44882	49741	311.3	54.6	57.6	DW LS
BML96-04	50066	49816	311.9	78.18	81.1	DW LS
BML96-05	49126	55184	311.7	66.8	69.8	DW LS
BML97-09	49592	50100	299.8	65.2	68.3	KM WS
OW03-24*	49856	54324	310.8	0.7	1.6	Sand
OW03-25*	49693	54492	310.7	1.5	2.2	Sand
OW03-26*	49430	54850	311.6	1.7	2.4	Sand
OW03-27*	49198	55033	312.8	1.5	3.1	Sand
OW03-28*	48977	55187	313.6	1.6	3.1	Sand

Notes: KM WS = Cretaceous Lower McMurray Formation – Watersand
DW LS = Devonian Waterways Formation – Limestone
Screen intervals are in meters below ground
Coordinates are in the Syncrude mine metric system
* background chemistry for future monitoring

5.9.2 Results and Discussion

The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. A summary of key chemical parameters for the area is provided in Table 5.19.

The BML wells of the in-pit groundwater monitoring are restricted to deep flow paths (44 to 81 meters) through the Lower McMurray Formation water sand and Devonian Waterways Formation (limestone). Basal water sand is present in isolated pockets around the Base Mine, significantly limiting the potential for migration of process water from the in-pit tailings deposits. Fractures exposed in the mine pit have been clay filled and the hydraulic conductivity of the limestone is appears to be low.

These wells were installed using the conventional rotary-mud drilling technique and then flushed with clean water to remove the drilling mud. Low hydraulic conductivity and depth of the wells has made it very challenging to effectively purge these wells.

Improved purging procedure since 1999 has dramatically improved the quality of the sampling. Consequently, the results since then have been more consistent even in 2007. Analysis for naphthenic acids in the past has indicated that the Lower McMurray Formation and underlying limestone have background naphthenic acid concentrations in the range of 8 to 35 mg/l.

<u>BML96-03</u>
BML96-03 is installed in limestone. The hydraulic conductivity of the limestone at this location is extremely low; the well recovers very slowly and has not reached a static level since it was installed in 1996. In 2004, this well was purged, where it is typically not due to its slow rate of recovery. The water chemistry of this well is considered saline and the 2007 results are consistent with historical data, though there is a slight increase in the major ion concentrations while the concentration of TDS decreased.

BML96-04

BML96-04 is also installed in limestone. This well recovers very slowly, however the static water elevation does not appear to be changing. The water chemistry is considered saline and the 2007 results are consistent with historical data.

The concentration of the major ions reduced considerably and indicated an improvement in the groundwater quality.

BML96-05

BML96-05 is located between the Mildred Lake Reservoir and the northeast mine quadrant. After an initial drop due to neighboring mining activities (ending 1999), the hydraulic head remained relatively consistent (at 286m). Over the past year, the head has increased to 287.7m and is expected to continue climbing given the rapid rate of rise in the NEP over the past couple years and its forecast infilling (head to 310m) by the end of 2010. The water chemistry at this location is also saline and consistent with historical data, though there is a continual reduction in the major ion concentrations and the TDS in 2007.

BML97-09

The hydraulic head of BML97-09 is likely the result of expected in-situ pressures within an isolated watersand unit at the base of mining, after the effect of pit dewatering and mining (from historical mining to the south). The head has been stable for a number of years and does not seem to be influenced at all by the rising WIP pond, or mining to the north. The water chemistry is consistent with historical data.

Two (OW03-25 and OW03-28) out of the three wells in this area actually had sufficient water to sample for chemical analysis while OW03-27 remains dry. Since the hydraulic heads of these wells are higher than both the NEP and the MLR, it is obvious that neither body of water currently influences the head in these wells. The chemistry of these wells is shown below in Table 5.19. These wells do not contain the saline water typical of the basal wells, but they continue to indicate a reduction in their background concentrations.

Table 5.21: Summary of Key Chemical Parameters, In-Pit Tailings Areas

Well ID	Sample Date	Cond.	pH	HCO_3	CO_3	Cl_2	SO_4	Ca	Na	TDS
BML96-03	13-Jul-07	23200	7.9	2400	<5	8280	38.4	70	6430	14800
BML96-04	13-Jul-07	51400	7.5	2750	<5	20000	9.3	164	12700	35300
BML96-05	13-Jul-07	9490	7.7	3140	<5	2040	1.7	26.9	2270	6090
BML97-09	12-Jul-07	34600	7.6	2780	<5	11700	<0.5	121	8970	21800
OW03-25	28-Nov-07	3560	7.1	218	<5	639	692	370	287	2470
OW03-26	28-Jun-07	2410	7.9	443	<5	75	975	378	95	1980
OW03-28	28-Jun-07	1520	7.8	551	<5	42	378	244	4	1140

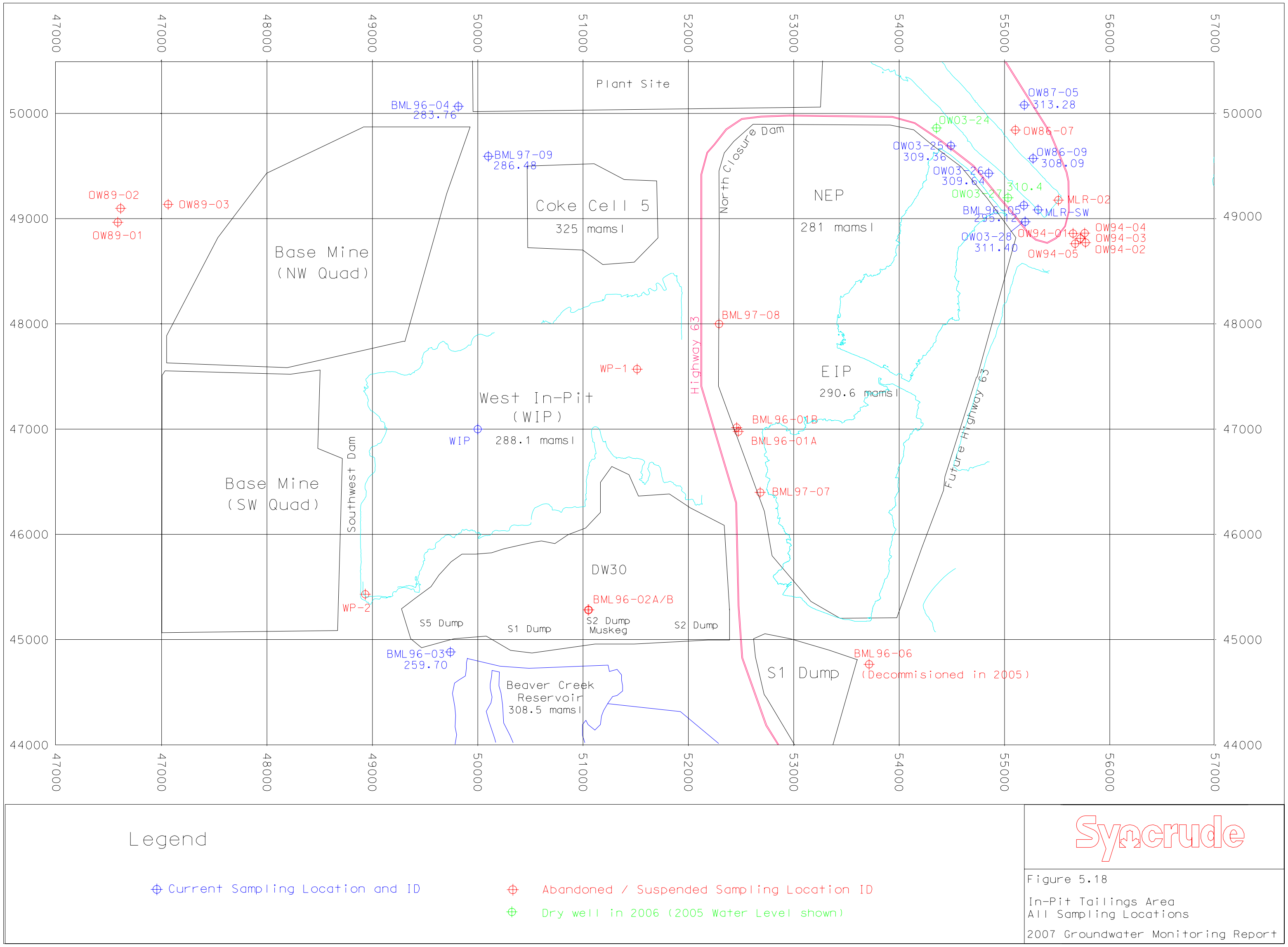
Abbreviations:

Cond – Conductivity (µS/cm), HCO_3 – Bicarbonate (mg/l), CO_3 – Carbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Na – Sodium (mg/l), TDS – Total Dissolved Solids (mg/l) , " - " not analyzed

5.9.3 Recommended Sampling Schedule for 2008

Annual sampling of the wells listed in Table 5.18 will take place in 2008. Analysis will be completed in accordance with AENV requirements for the tailings areas.

Figure 5.18: Monitoring Wells, In-Pit Tailings Areas



5.10 Sewage Lagoons

5.10.1 Background

5.10.1.1 Area Description

Syncrude's sewage lagoons are located in the Athabasca River valley, immediately west of the river and north of Syncrude's fresh water intake sedimentation basin (Figure 5.19). The sewage lagoons were constructed with low permeability liners to minimize the risk of groundwater contamination. After water completes its cycle through the lagoons, it is discharged into the Athabasca River.

5.10.1.2 Geology

In the sewage lagoon area, a sequence of nine to fourteen meters of Holocene alluvial deposits overlay the Devonian limestone. The alluvial deposit consists of interbedded sands, silts, and clays with organic material throughout. The Devonian surface rises from west to east.

5.10.1.3 Monitoring Network

There have been no changes to the monitoring network around the sewage lagoons; it consists of three wells (Figure 5.20). One well is located up-gradient and two are located down-gradient of the lagoons. All the three wells are installed in the recent alluvial deposit. The location and installation details are provided in Table 5.20.
Chemical analyses were completed in accordance with AENV requirements for the sewage area, including analysis for trace metals (Appendix A). Additional analysis for DKN and NH_4 was also completed (see Appendix B).

Table 5.22: Location of Monitoring Wells, Sewage Lagoon Area

Well ID	Northing	Easting	Ground Elevation	Screen Interval		
				Top	Bottom	Lithology
OW98-16	47527	57855	236.1	3.0	6.1	Holocene alluvial
OW98-17	47563	58079	237.9	1.8	4.9	Holocene alluvial
OW98-18	47641	58058	237.4	8.2	9.8	Holocene alluvial

Notes: Screen intervals are in meters below ground
Coordinates are in the Syncrude mine metric system

5.10.2 Results and Discussion

The complete analytical results, water elevations, as well as sampling and purging methods are included in Appendix B, while trend plots are included Appendix C. A summary of key parameters is provided in Table 5.21.

The Holocene alluvial deposit in the Athabasca River valley has a highly variable hydraulic conductivity. The underlying limestone is assumed to have a low hydraulic conductivity. Significant fluctuations in groundwater elevations have been observed around the sewage lagoons. The fluctuations are attributed to changing water levels in the Athabasca River. Groundwater flow is interpreted as being from the southwest to the northeast, however this may be reversed when the river level changes dramatically. Water elevations and the direction of groundwater flow are shown on Figure 5.20.

The upstream nitrogen compounds in the form of TKN (OW98-16) and invariably total nitrogen have reduced in concentration considerably and may appear to reflect the natural nitrogen cycle balance in the environment, which are consistent with the historical data. The current monitoring program has not identified any impact from the sewage lagoons.

Table 5.23: Summary of Key Chemical Parameters, Sewage Lagoon Area

Well ID	Sample Date	Cond.	pH	HCO_3	Cl_2	SO_4	Ca	Fe	TKN	NO_3	NO_2	DOC	Water Elevation
OW98-16	06-Jul-07	1140	7.1	644	77	5.7	134	54.9	13.2	< 0.1	< 0.05	80	234.18
OW98-17	06-Jul-07	1840	7.7	802	69	371	340	4.79	0.5	2.1	< 0.05	10	233.89
OW98-18	06-Jul-07	1340	7.7	749	76	66.8	205	12.5	1.3	< 0.1	< 0.05	19	233.92
OW98-18*	06-Jul-07	1340	7.8	738	76	66.6	2.6	13.6	1	< 0.1	< 0.05	18	

Abbreviations:

Cond – Conductivity (μS/cm), HCO_3 – Bicarbonate (mg/l), Cl_2 – Chloride (mg/l), SO_4 – Sulfate (mg/l), Ca – Calcium (mg/l), Fe – Iron (mg/l), TKN – Dissolved Kjeldahl Nitrogen (mg/l), NO3 – Nitrate (mg/l), NO2 – Nitrite (mg/l), DOC – Dissolved Organic Carbon (mg/l)

* Duplicate Sample

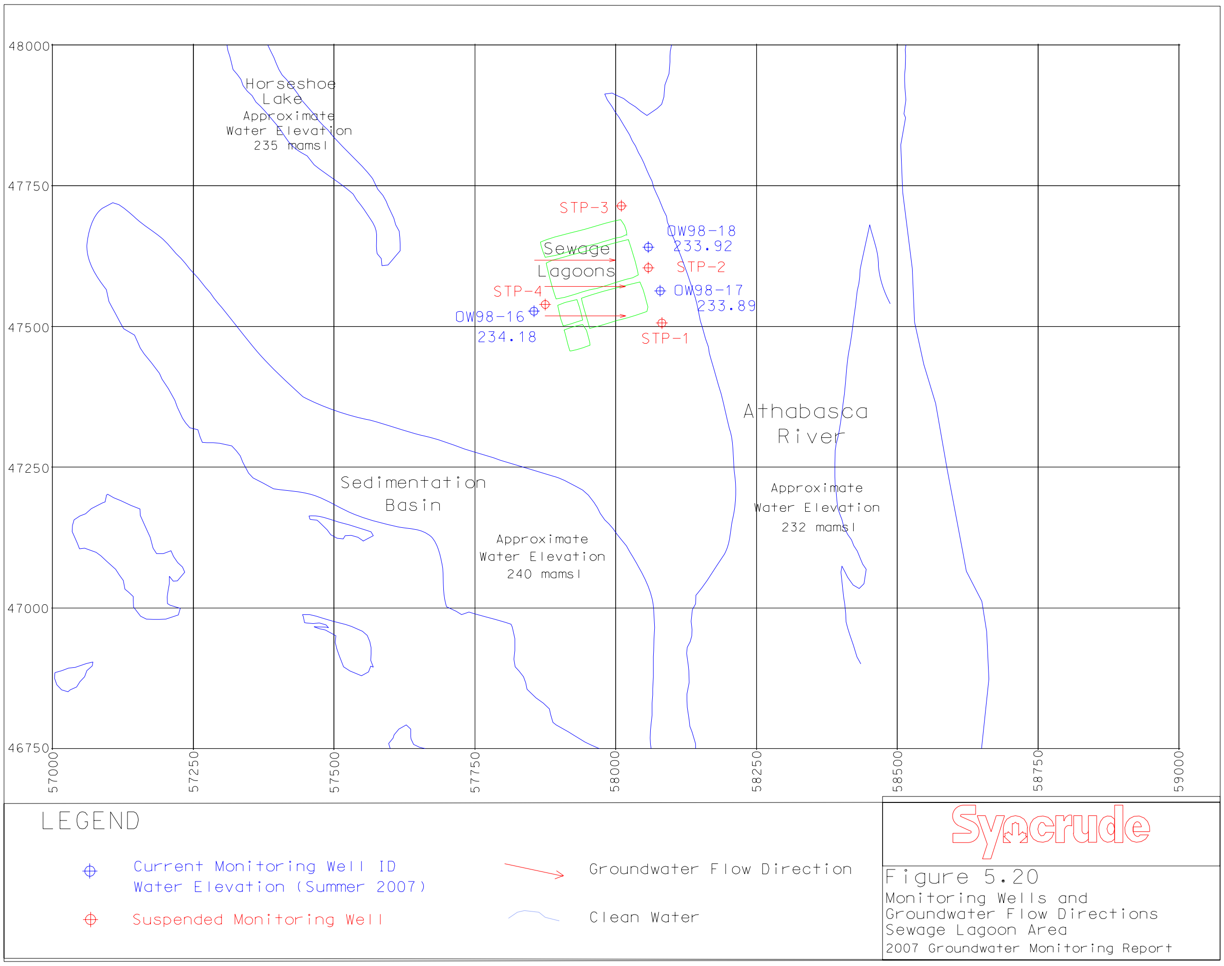
5.10.3 Recommended Sampling Schedule for 2008

Annual monitoring for the three wells in the area will continue with the analysis completed in accordance AENV requirements for the sewage lagoon area in 2008.

Figure 5.19: 2006 Air Photo of the Sewage Lagoon Area

Note:
2007 Photo Mosaic of this area
is not available

Figure 5.20: Monitoring Wells and Groundwater Flow Directions, Sewage Lagoon Area



6 Response to AENV Comments on 2006 Groundwater Report

The following section provides direct responses to or a clear reference to a section of this report that addresses questions raised by AENV to Syncrude's 2006 Groundwater Monitoring Report. AENV question/comments are shown in *italics.*

1.QUALITY ASSURANCE AND CONTROL

- *Pages 12-13 – Relative percent differences (RPD) of greater than the acceptable standard of 20% were observed for some samples without an explanation given.*
  Explain why and how this can be corrected.

Response:

Generally the acceptable RPD should be in the range of 20%. There are two approaches to evaluating field duplicates; the first being the relative percent difference between two sample results and the second approach utilizes the absolute difference between the results. The appropriateness of the two approaches depends on the concentration of the analyte relative to the detection limit for the analyte in the sample (Zeiner, S.T., 1994: Realistic Criteria for the evaluation of field duplicates sample results) (Appendix A). For example, analytes such as Phenols, with very low detection limits generally yield very high RPD values. Syncrude proposes to use the RPD method for those analytes such as major ions with high detection limits and the absolute method for analytes with values below the detection limit. Syncrude has reviewed the sampling protocol in the field, which has reflected a considerable improvement in the RPD of the sample results in 2007. We shall continue to ensure high standards in field sampling protocol in all our monitoring programs.

2. SURFACE WATER SAMPLES

- *Section 5.1 Surface Water Samples- pages 14-19 – As the re-use and recycling of process water continues along with the stripped sour water being directed to the wastewater control system, there is concern over increasing ammonia and naphthenic acid concentrations. Consequently, AENV is recommending that in addition to ammonia and naphthenic acid being analyzed in surface water samples, ammonia and naphthenic acid shall be included as groundwater monitoring parameters for those wells in areas potentially affected by seepage waters containing ammonia and naphthenic acid concentrations (MLSB, WIP, SWSS)*

Response:

Syncrude shall conduct the recommended groundwater sampling analysis at the areas with potential of ammonia and naphthenic acid beginning with the 2008 sampling program.

3. EAST OF MILDRED LAKE SETTLING BASIN (MLSB)

Page 27-Well water chemistry is grouped into three categories: wells with background chemistry; wells with elevated chloride concentrations and wells influenced by the process –affected water. Please detail what is considered elevated in terms of values for chloride and other major ions.

Wells with background chemistry – page 27- Please explain why monitoring wells OW80-14 and OW03-03 clearly show increasing concentrations not reflective of background chemistry.

Wells with elevated chloride concentrations – page 27- Monitoring wells OW79-19, OW98-19B OW01-02, OW02-04 and OW03-29 indicate increasing concentration and if it is not due to process-affected water then what is it due to?

Zone A – Page 32

- *It is our understanding that destroyed monitoring well OW99-07 will be replaced in 2007.*

Zone C – Pages 33-34

- *The pumping system shall continue to be effective in capturing seepage and reducing the migrating plume for Zone C. Syncrude shall address the operating challenges with the pumping system such that it results in better performance. It is imperative that the pumping system operates on a continuous basis.*
- *At the north end of Zone C, monitoring well OW02-04 indicated an increase in concentration not a decrease as indicated on page 34- last paragraph*

Zone E- Page 35

- *Information provided indicates that source mitigation at the MLSB, upper section of Zone E, shall be intensified. Explain in greater detail how beaching activity in 2007n around the north end of Zone E at the MLSB will improve source mitigation. What are Syncrude plans in managing the impacts that have already occurred?*
- *Detail the additional monitoring that will be conducted alongside the beaching improvement. Will additional groundwater monitoring wells be completed or will there be an increased frequency of sampling in the area?*

Response:

The wells that are identified as having elevated chloride concentrations are wells with Chloride slightly over 100 mg/L, which is approximately background in this area. This classification was introduced by Syncrude and was intended to be used as an early warning to identify areas of potential contamination.

Based on this classification, OW80-14 (95 mg/L) is just getting above the 100 mg/L and OW03-03 (78.0 mg/l (2006, and 156 mg/L in 2007) is now showing impact of the advancing plume. In addition, OW79-19, OW98-19B, OW01-02, OW02-04, and OW03-29 show increasing trend. This is because of their proximity to the tailings dyke. This trend will be monitored in future.

The destroyed well OW99-07was planned to be replaced this year in 2007, however, poor access conditions and obstruction within the area required postponing the replacement until 2008.

Going by the 100-mg/L-chloride contour at this zone (Figure 5.5), the beaching activity carried out in 2007 did not make much improvement to the trend of the plume in this zone.
Syncrude has installed more piezometers (zone E) to study the groundwater flow in more detail in this area. This information will be used to formulate a mitigation plan for current situation.

SEEPAGE CONTROL POND

Seepage Control Pond – Pages 36-37

- *In consideration of the continued rise in chloride concentration at OW99-24, explain what source mitigation will be conducted to stem the migration of contaminants downstream.*

Beaver Creek – Page 37

- *AENV will be providing comments regarding the 2006 Beaver Creek Ecological Risk Assessment report and associated groundwater monitoring in a separate letter.*

Response:

The present no-flow and plugging up at the MLSB is expected to indicate a source mitigation improvement in this area, which should reflect in the well OW99-24 with other major ions reducing except chloride. This area shall be monitored more close for consistent trend in 2008.

4. NORTH AND WEST MILDRED LAKE SETTLING BASIN

- *Page 42- OW92-06 – Provide an explanation why the chloride concentration has increased in the monitoring well completed opposite the Clearwater Formation. It would be expected that fairly stable concentration would occur.*

Response:

The high chloride concentration observed at OW92-06 in 2006 is considered anomalous. The 2007 chloride concentration has returned to previous levels. This may be as a result of local flow conditions. Syncrude will continue to monitor this area closely.

5. SULPHUR BLOCKS

- *Syncrude shall continue its 2006- implemented intensified maintenance of the sulphur block areas and the geo-membrane lined drains to ensure quick flow to avert ponding of the surface water in the drains and the potential for increased sulphate concentrations.*
- *Further investigation of monitoring well SMW92-03R results are required to determine the substantial sulphate increase in 2006.*
- *It is our understanding that damaged monitoring well SMW94-02 will be replaced in 2007.*

Response:

Syncrude has intensified the maintenance activity within the sulphur block areas and the monitoring wells in this area are all active including SMW94-02, which was repaired.

6. SOUTHWEST SAND STORAGE (SWSS) AREA

- *Page 58- It is our understanding that damaged monitoring wells KL89-01B and OW91-07B will be replaced. Other wells planned for replacement include OW91-07A and OW91-10R*

Response:

Monitoring well KL89-01B has been replaced with KL07-01B.Monitoring well OW91-07B was not replaced in 2007 due to obstruction within the area (see section 5.6.2). This well will be replaced in 2008.

7. IN-PIT TAILINGS AREA

- *Figure 5.18 shall be updated to match the terminology (DW30, EIP) used in the text to describe the area.*
- *It is our understanding that the five shallow surficial wells installed between the NEP and MLR will be sampled in 2007 to obtain background data provided there is sufficient water.*
- *Explain why OW03-25 has high ion concentration (chloride) as compared to the other two shallow wells (OW03-26 & OW03-28) in the same vicinity.*

Response:

Monitoring wells OW03-25, OW03-26 and OW03-28 are currently active monitoring sites and have been reported since 2004. The concentration of chloride at OW03-25 reduced drastically which is an improvement on the variability of the chemistry within the area.

8. CLASS II FGD BY-PRODUCTS LANDFILL

- *Future groundwater reporting shall include monitoring results associated with the submission of the recently approved landfill location (18 monitoring wells at six sites).*

Response:

Monitoring wells installed in 2004 and 2007are being monitored for background groundwater quality and the results are reported in this Report under Section 5.7.

7 Proposed 2008 Monitoring Program

Proposed changes for each specific monitoring area have been included in the section of the report relating to that area. This section provides a summary and compilation of all proposed changes for the 2008 monitoring program.

A complete list of all sampling locations for 2008 is provided in Table 7.1 while the proposed analytical schedules for 2008 are presented in Table 7.2. Each location will be sampled between May 1 and August 31.If any well installation is damaged; it will be repaired as soon a possible or replaced during the next drilling program.

Syncrude is proposing to continue monitoring the sites that are presented in the 2007 groundwater monitoring report. However, if during the sampling program in 2008 there are wells or off-take pipes that are found to be dry, they will be substituted by the nearest monitoring site and AENV will be notified accordingly.

Table 7.1: 2007 Monitoring Locations by Area

Area (# of locations)	2007 Sampling Locations				
Surface Samples, Dirty Water (9)	ETB-TD1		ETB-GD	TP-2	
	B3005	T0715	SCP-1	SWSS-DC	DFW-3101
	WIP	-	-	-	-
Surface Samples, Clean Water (8)	WID	BRC	TBC-1B	TBC-3	MLR-NW
	MLR-NE	MLR-E	MLR-SW	-	-
East of MLSB (81)	OW79-19	OW80-14	OW84-33	OW98-03	OW98-04
	OW98-05	OW98-06	OW98-07	OW98-08	OW98-09
	OW98-19A	OW98-19B	OW98-20	OW98-21	OW98-22
	OW98-24	OW98-25	OW98-26A	OW98-26B	OW98-27
	OW98-28	OW99-05	OW99-06	OW99-07**	OW99-08
	OW99-12	OW99-13	OW99-14	OW99-15	OW99-16
	OW99-17	OW99-18	OW99-19	OW99-20	OW99-21A
	OW99-21B	OW99-24	OW99-25	OW99-27	OW99-28
	OW01-01	OW01-02	OW01-03	OW01-04A	OW01-04B
	OW01-05	OW01-06	OW02-01	OW02-02	OW02-03
	OW02-04	OW03-01	OW03-02	OW03-03	OW03-04
	OW03-08	OW03-09	OW03-10	OW03-11	OW03-12
	OW03-14	OW03-15	OW03-16	OW03-17	OW03-29
	OW04-01	OW04-02	OW04-03	OW04-04	OW04-05
	OW04-06	OW04-07	OW04-08A	OW04-08B	OW04-09
	OW04-10	OW04-11	SG9923-01	SG0122-01	-
	SP05-T047	SP05-T05	-	-	-
N & W of MLSB (3)	OW92-05	OW92-06	OW92-08	-	-
Mildred Lake Reservoir (7)	OW86-09	OW87-03	OW87-05	OW99-09A	OW99-09B
	OW99-10	OW05-04	-	-	-
Sulphur Blocks (6)***	SMW92-03R	SMW92-04	SMW92-06	SMW94-01	SMW94-02+
	SMW02-01	-	-	-	-
SWSS (20)	KL07-01B^	OW91-07A	OW91-10R	OW91-11	OW91-12+
	OW91-13	OW91-15	OW91-16	OW92-01A	OW92-02A
	OW92-03A	OW94-09	OW96-01	OW96-02	OW98-14
	OW98-15	OW99-29	OW99-30	OW99-31	OW03-23
SWISA (4)	OW98-10	OW98-11	OW98-12	OW98-13	-
In-Pit (9)	BML96-03	BML96-04	BML96-05	BML97-09	OW03-24*
	OW03-25*	OW03-26*	OW03-27*	OW03-28*	-
Sewage Lagoons (3)	OW98-16	OW98-17	OW98-18	-	-

Notes:
* Sampling for background information
** Groundwater monitoring wells to be replaced due to damage or mine activity encroachment
*** Number, location & timing of new installations for Phase III sulphur block are yet to be determined
^ New well replacement
+ Repaired well

Table 0.2: 2007 Analytical Schedule

Areas	Parameters	Frequency
All	Electrical Conductivity, pH	Annually
All	Major Ions (Ca, Cl_2, Mg, Na, K, SO_4, HCO_3, CO_3)	Annually
All	DOC	Annually
All	TDS, TSS	Annually
Tailings/Sewage	Trace Metals (Al, As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Zn)	Once every 3 years (2009)
SWISA/Sulphur	Trace Metals (Al, As, Cd, Cr, Cu, Fe, Pb, Hg, Ni, Zn)	Annually
Sewage	Nitrate, Nitrite	Annually
SWISA	Phenols	Annually

Appendix A: License Requirements and Amendments

Appendix B: Analytical Results and Water Elevations

Appendix C: Historical Trend Plots

Appendix VIII:

"Design of Tailings Dams on Large Pleistocene Channel Deposits, A Case Study – Suncor's South Tailings Pond," by B. Stephens et al, date unknown.

Design of Tailings Dams on Large Pleistocene Channel Deposits A Case Study – Suncor's South Tailings Pond

Brett Stephens – Senior Geotechnical Engineer, Klohn Crippen Berger Ltd, Calgary
Chris Langton – Manager Groundwater, Klohn Crippen Berger Ltd, Calgary
Mike Bowron – Senior Geotechnical Engineer, Suncor Energy Inc, Fort McMurray

ABSTRACT
A number of current and planned tailings facilities in the Athabasca oil sands region are located over large meltwater channel deposits. This paper outlines key design and operational considerations for these facilities, using Suncor's South Tailings Pond (STP) as a case study. Weak foundation conditions associated with Clearwater Formation shales, and management of seepage from the tailings facility into the underlying aquifer required a number of interrelated design elements. Upstream and downstream cross-channel pumping well fields and cut-off walls will be used to intercept seepage. The channel is a confined aquifer for a significant reach of the impoundment and pressures within the channel are predicted to become artesian at the toe of the dykes in response to pond rise. Pressure relief wells will be used to manage these artesian pressures. An observational approach has been adopted for the management of seepage and the pressure relief well system.

RÉSUMÉ
Plusieurs parcs à résidus dans la région des sables bitumineux de l'Athabasca sont situés sur de larges dépôts de sable de l'époque glacière. Cet article expose les principales considérations de design et d'opération de ce type d'aménagements. Le parc à résidus sud (STP) à Suncor est présenté comme étude de cas. La conception des digues a été régie par une combinaison de facteurs dont la faible capacité portante des shales de la Formation de Clearwater et la gestion des écoulements sous les digues. Des réseaux de puits de pompage situés en amont et en aval du dépôt de sable et un mur d'étanchéité seront utilisés pour intercepter les eaux d'écoulement. Le dépôt de sable est un aquifère confiné sous la majeure partie du parc et des pressions artésiennes sont prévues dans l'aquifère sous le pied des digues lorsque le niveau de bassin va monter. Des puits seront installés afin de réduire les pressions artésiennes prévues. Une approche empirique a été adoptée pour la gestion de l'écoulement et le système de puits.

1 INTRODUCTION

A number of current and planned tailings dams within the Athabasca oil sands region are located over large Pleistocene glacial meltwater channel deposits, posing associated design and operational challenges.

Oil sands mine operations require large external tailings dams, typically in excess of 10 km^2 in area, which are needed to store tailings until deposition in mined out pits is feasible. The decision to locate external ponds over these regional scale alluvial deposits is driven by mine economics, land availability and regulations limiting ore sterilization.

The design of Suncor's South Tailings Pond (STP) is presented as a case study to illustrate a number of the above design challenges. This paper outlines the operating requirements, site assessment and the design of the STP.

2 PROJECT DESCRIPTION

The STP is the third external tailings facility to be constructed at Suncor's Millennium mine, located north of Fort McMurray. The existing external ponds include Pond 8A, a tailings storage pond, and Pond 8B, a water clarification pond. The STP is located immediately to the south of Ponds 8A/8B, and occupies an irregular area 4 km by 4.5 km in plan (refer Figure 1). Key features in proximity to the STP include, the Athabasca River, about 2 km west of the site at it nearest point; McLean Creek, which runs southeast-northwest through the site and eventually flows into the Athabasca River; the Steepbank Uplands which forms the eastern boundary of the STP; and Wood Creek and associated wetlands immediately to the north.

The STP is to provide fluid (water and fine tailings) storage for the Millennium Mine until 2013, when in-pit storage for tailings becomes available. The design dyke elevation for the STP is El. 390 m, with a maximum design height of 42 m and a storage capacity of 366 Mm^3 of tailings.

The starter dyke elevation is El 362 m, and has a maximum height of 14 m. The dyke elevation will be raised annually by tailings cell construction of approximately 4 m. Cell construction will commence in 2006 and will be complete in 2013. The design is based on Suncor's established tailings dyke construction methods using cell construction to provide containment, and direct pipeline discharge to beaches. The hydraulic cells are constructed during the summer months, with beaching during the winter period.

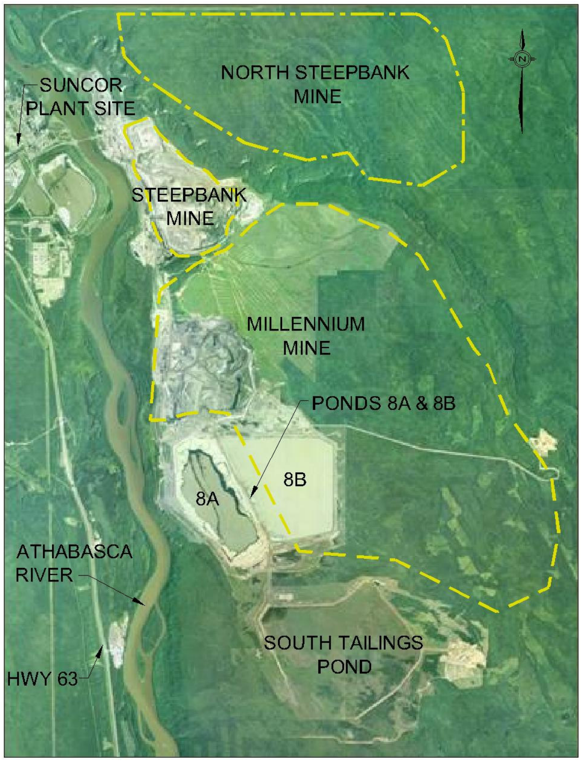


Figure 1 STP Site Location (August, 2005)

The pond will be used to store fine tailings and water from 2013 to 2035. Transfer of fine tailings to in-pit storage will be carried out from 2029 to 2035. Following fluid transfer, the pond will be breached and closure of the facility will commence.

3 FIELD INVESTIGATIONS

An initial scoping level site investigation and design was completed by AMEC in 2002. The 2003 site investigation completed by KCBL comprised 21 drill holes, and a limited number of monitoring wells were constructed. Surface geophysics totalling 12 line km of electrical resistivity tomography (ERT) was completed Worley Parsons Komex. The ERT proved to be a valuable tool in delineating the Wood Creek Sand Channel (WCSC), a Pleistocene meltwater channel and key design feature, trending from southeast to northwest across the site. The success of this application on the STP site is due to the stratigraphy and relative resistivity contrasts between the channel sands and gravels, and the underlying Clearwater Formation.

In 2004, an additional 154 holes were drilled and more than 70 were completed as monitoring wells in the kame, WCSC and the residual STP footprint and surrounding geology. Over 120 slug tests were completed and two pumping wells were established, one in the northwest WCSC and the second in the southeast WCSC segment. Step, constant discharge and recovery tests were carried out to establish WCSC storage and transmissivity characteristics for groundwater modelling during the design process. A further 35 km of ERT profiling were completed to improve the delineation of the WCSC channel morphology and surficial sand deposits.

Additional investigations following design have included:

- A 20 day aquifer test in the northwest WCSC to establish aquifer boundary conditions;
- Additional ERT on selected dyke sections for confirmation of foundation conditions;
- Installation and commissioning of northwest wellfield pumping and monitoring well arrays.
- Test pitting to assess the nature and extent of surficial sand deposits, and completion of a limited drilling program for the southwest WCSC cut-off wall.

Additional investigation of the kame and WCSC interaction is in progress and further ERT work is planned to improve the current understanding of the WCSC morphology in the area of the spill point, which is an area of groundwater discharge from the WCSC into McLean Creek and a key seepage design consideration.

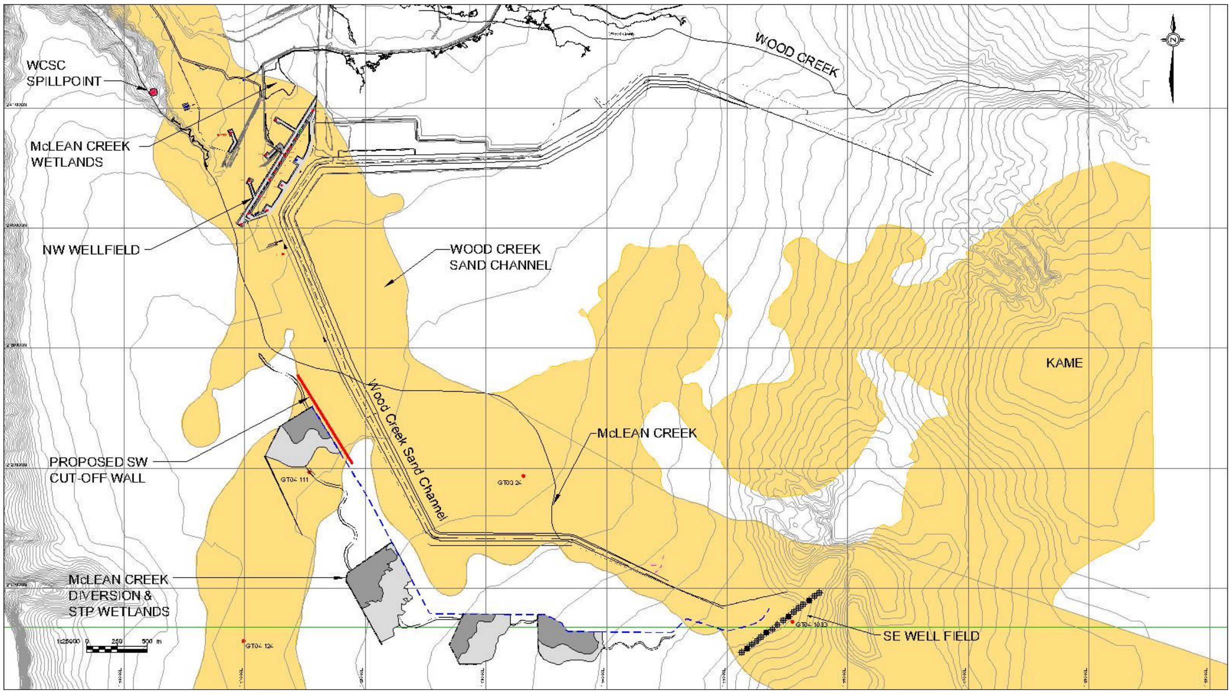


Figure 2 STP General Arrangement (1 km grid shown)

4 SITE GEOLOGY

The general stratigraphic profile at the STP comprises in descending order:

- a surface layer of Holocene organic soil (muskeg);
- Pleistocene glacial till;
- Cretaceous Clearwater Formation clay shales;
- Cretaceous McMurray Formation oil sands; and
- Devonian Waterways Formation limestone.

The Cretaceous McMurray Formation and the underlying Devonian limestone are sufficiently deep that they do not influence the design of the STP, and are not discussed further.

4.1 Holocene and Pleistocene Soils

The soils overlying the Clearwater Formation comprise the following major units listed in descending order:

- **Holocene Soils (Ho):** These soils are muskeg deposits that are generally continuous across the site but are thicker within closed topographic lows where drainage is poor. The muskeg thickness is up to 4 m but is generally 1 m to 2 m thick and is typically comprised of silts, peat, and organic soil containing roots, wood fragments, trace clay, commonly with a fibrous texture, generally ranging in colour from brown to black.
- **Pleistocene Glaciolacustrine Soils (Pl):** These soils are discontinuous lenses of fine sands, silts and clays. The clays are typically of medium to high plasticity, and of firm to stiff consistency and where present, is 1 m to 2 m thick.
- **Pleistocene Glacial Tills (Pg)**: The Pg unit comprises clayey till (Pgtc), silty till (Pgt), sandy till (Pgts) and/or Clearwater-derived till (Pgc), as well as rafted (PgKc) Clearwater, or ice-thrusted (Kcip) Clearwater. The unit underlies muskeg or shallow glaciofluvial sands and gravels. Thickness typically varies up to 26 m. Upper till units are often sandy, and the clay content typically increases with depth. Lower units closely reflect the composition of the underlying parent Clearwater Formation and generally have medium to high plasticity, but plasticity is lower than the underlying Clearwater. Shear zones may be present in discontinuous blocks of transported Clearwater (rafts) that can be present in the glacial till.
- **Pleistocene Glaciofluvial Sands and Gravels (Pfs and Pfg):** These are dense basal sands and gravels within the WCSC that overlie Clearwater Formation. No glacial till was encountered at the base of the WCSC.

4.2 Cretaceous Clearwater Formation

The Clearwater Formation (Kc) underlies the glacial till (Pg) and the WCSC throughout the site, apart from portions of the base on the northwest segment of the WCSC, which can be in contact with McMurray Formation. The contact between these units is an erosional unconformity that rises away from the Athabasca River. The top of the Clearwater varies from approximately El. 323 m in the west to El. 338 m in the east.

The Clearwater is a marine deposit comprised of predominately clay shales with numerous thin carbonate cemented siltstone beds. The Clearwater has been divided by others into eight sub-units for the purpose of stratigraphic correlation in this area. Each of the sub-units is identified on the basis of specific marker beds determined from natural gamma and density geophysical logs as described in Isaac (1982). The oldest sub-unit is the glauconitic Kcw, which conformably overlies the McMurray Formation. The upper sub-units are designated Kca through Kcg. In the vicinity of the STP, the upper, younger Clearwater sub-units have been completely eroded. The youngest sub-unit present at the site is Kcd, which subcrops over the eastern portion of the site. The lower Kcb and Kca sub-units subcrop towards the west as the erosional unconformity drops toward the Athabasca River valley. Kcw underlies the entire site and is overlain by one or more of the younger Kca, Kcb, Kcc and Kcd units.

Core logging identified shear zones in the Clearwater clay shales at this site, characterized by smooth slikensides and striated surfaces, where low angles of shearing resistance are expected. Similar weak shear zones have been observed in Clearwater cores from Dyke 11A which forms part of Pond 8A, and the Mildred Lake Settling Basin (Nicol 1994) at Syncrude. These weak shear zones have caused foundation movements within portions of both dykes.

5 HYDROGEOLOGY

The primary aquifers on the site are the WCSC, and a relatively elevated Kame deposit which forms the eastern boundary of the STP.

5.1 Wood Creek Sand Channel (WCSC)

The WCSC was named following the construction of the Wood Creek Dam, which formed part of Pond 8A, and completely cut off the meltwater aquifer at that location. The WCSC cuts across the STP footprint from southeast to northwest, from where the channel alignment continues to the northwest under tailings Dyke 11A, and through Wood Creek (Figure 2). The channel is typically capped with organics and glacial till, suggesting that the channel was active prior to final glacial retreat in the area, and the channel sediments are dense due to the glacial loading. The channel base typically rests unconformably on Clearwater Formation strata, but in places the channel is incised into McMurray Formation.

Andriashak (1991) considers that the WCSC is an extension of the Clark Channel, a major regional scale buried channel system. This interpretation is further supported by published maps, and air photo interpretation confirmed the presence of surficial sandy material towards the south. For design purposes, these data were collated and the WCSC was interpreted to extend to the southeast of the STP, with a likely connection to the Clark Channel.

Recent site investigation data suggests that extension of the WCSC southeast of the STP is tenuous, and further work is planned to clarify the channel morphology and orientation to the south and east.

Detailed drilling, well installation and aquifer testing programs carried out from 2004 to 2006 in the channel section northwest of the STP have shown that the channel section morphology is variable and sedimentary characteristics vary both vertically through the profile and horizontally across the channel. The channel form represents a combination of two fluvial systems. The lower channel section is interpreted as the original channel thalweg. Sediments in this section of the profile typically comprise coarse grained sands and gravels. Fines content in the units varies, and the presence of relatively high fines contents in some units suggests a proximal source for the sediment. Aquifer potential in the thalweg is typically significant, with permeabilities typically in the range 0.1 to 100 m/day. A general fining upward in the sequence is evident.

The upper channel section is significantly wider and is interpreted as a lower energy fluvial environment with both channel and overbank facies. Extensive sediment reworking is likely to have occurred in a braided and/or meandering fluvial system. Fining upward in the sequence is generally apparent, and hydraulic conductivities vary widely. Typical hydraulic conductivity values for the various Pleistocene units in the STP investigation area are presented in Table 1.

Exploration drilling and aquifer tests have shown that although continuous hydraulic connection in the channel is observed, the lower channel section is the principal aquifer. Delayed response to pumping in the lower section, has been measured in these lower permeability upper channel sediments.

Table 1 Summarized Permeability Results – Strata Specific

Strata	Number of Sites	Number of Tests	Permeability m/day Minimum	Maximum	Median
Slug Testing					
*Glacial Till	29	41	$1.3x10^{-3}$	$7.8x10^{-1}$	$2.1x10^{-2}$
Intertill Sand	9	15	$1.4x10^{-2}$	8.2	0.1
WCSC	32	63	0.6	100	56
Kame	4	7	$7.6x10^{-3}$	8.1	2.0
Pumping Tests					
WCSC	2	3	8	87	36

*= Glacial Till includes silt.

5.2 Kame Deposit

A deposit called the Kame is located on the eastern periphery of the STP in the area of the headwaters of Wood Creek and McLean Creek. This naming convention is based on initial surficial mapping interpretation of the area. Excavation into the unit identified it to be fluvial in nature, fine on the margins and coarse grained at the centre associated with high energy deposition. This original naming convention was retained for record keeping purposes for the STP project.

The base of the deposit rises eastward in the lease area from an elevation of roughly 360 m to 400 m above sea level. Groundwater levels are relatively elevated in the kame and groundwater flow is generally from east to west and follows the topography.

6 STP Design

The key design issues for the STP are:

- Challenging dyke design requirements over weak Clearwater Formation clay shales;
- Reducing artesian pressures at the dyke toe caused by porewater pressures within the WCSC;
- Protection of McLean Creek and off lease regional groundwater systems from process-affected water seepage; and
- Surface water design to maintain a closed circuit system for process affected water, and to divert and reconstruct natural waters systems around the facility.

These elements of the design are discussed in the following sections.

6.1 Clearwater Shale Foundation

The STP is underlain by weak Clearwater Formation clay shales at variable depths. Perimeter slope angles of the STP dykes are controlled by low residual strength shear bedding planes in the Clearwater. Shear strength is further reduced as most of the dyke load is taken up by pore pressure increases in the Clearwater, which will not dissipate over the operational life of the impoundment.

Dyke stability over the pre-sheared Clearwater clay shales relies heavily on the passive shear resistance of the overlying units. In general, the thicker the overlying unit, the steeper the dyke slopes. To develop the passive resistance at the toe, movements along these pre-sheared layers are expected. This mechanism was observed at Syncrude's Mildred Lake Settling Basin and is described in Nicol (1994).

Table 2 summarizes the design criteria adopted for stability assessments of the STP dykes. Material parameters are based on laboratory data from field exploration and Suncor site data. Clearwater shale design strengths are based on back analysis of performance data from Pond 8A dykes.

6.2 Perimeter Dyke Alignment

The perimeter dyke alignment was selected to maximize tailings storage by positioning the dyke toe with deeper Clearwater units where steeper dyke slopes are possible. Along the North Dyke, there was little flexibility as the weak Clearwater Formation is close to the surface. Three stabilizing berms are required in the North Dyke to meet Suncor's operational requirements of tailings dykes slopes no flatter than 10H:1V

Along the South Dyke and West Dyke, the toe was positioned over the alignment of the WCSC and the depth to Clearwater is greater. The thick dense to very dense sands and gravels of the WCSC allow steeper slopes than for shallow Clearwater. The steeper slopes also result in a modest increase in storage capacity for the STP.

Table 2 – Material Strength Parameters

Unit	Cohesion (kPa)	Effective Friction Angle	Pore Pressure (kPa)	Density (kN/m^3)
Dyke Embankment Fill				
- Lean oil sand/dry Tills	0	33°	r_u = 0.25	19.5
- Clearwater shale/wet tills	0	22°	r_u = 0.25	19.0 - 19.5
Tailings Sand				
- Cell	0	34°	Piezometric	19.5
- Sub-aerial beach	0	32°	Piezometric	19.5
- sub aqueous beach	0	28°	Piezometric	18.5
- sub aqueous beach (liquefied strength)	Cu/p'=0.1	-	-	18.5
Foundation				
- Pleistocene Lacustrine	0	26°	$\overline{B}$ = 0.7	20.0
- Glacial Till	0	30°–34°	$\overline{B}$ = 0.4–0.5	21.0
- Glacio-fluvial sand (WCSC)	0	33°–36°	Piezometric	21.0
- Clearwater (cross bedding)	0	17°	$\overline{B}$ = 0.8	21.0
- Clearwater (bedding shear)	0	7.5°	$\overline{B}$ = 0.8	21.0

6.3 Pressure Relief Wells

Pressure relief wells are required to reduce artesian pore water pressures within the WCSC downstream of the perimeter dykes for the STP. Groundwater modelling of the pore water pressures in the WCSC predicted unmitigated artesian pressures in the WCSC of the order of 20 m above existing ground surface levels. The elevated pore water pressures are a result of the rising STP pond, and the WCSC being a confined aquifer. Artesian pressures at the toe of the dyke reduce the passive resistance of soil units above the Clearwater, and may result in boils downstream of the dykes if unrelieved.

Relief wells were selected to manage the artesian pressures at the toe of the STP dykes, as they:

- represent an established technology with documented use in a large number of water supply dykes and flood control levees;
- provide a flexible control measure that can be expanded if the initial system requires modification. In the case of the STP, this flexibility allows for the staged installation of the wells to match the increasing pond elevation, and resultant artesian pressures, during tailings placement;
- can be constructed to penetrate the full thickness of the aquifer to ensure performance is not affected by low permeability lenses present within an aquifer;
- are a passive system which does not rely on power or pumping elements to function; and
- are able to be installed following completion of construction of the STP starter dykes and surface drains.

Middlebrooks (1946) provides a good summary of design and operation of relief wells used for dams and levees.

The preliminary design of the relief well network is based on the method set out by the U.S. Army Corps of Engineers (1992) for the design, construction and maintenance of relief wells. The method provides the well penetration and spacing required to maintain a predetermined average piezometric head down slope of a structure such as a dyke. A maximum average artesian head of 5 m above existing ground surface was adopted for the STP design. The required well spacing is a function of the total head, and well penetration into the aquifer. Full penetration of the WCSC aquifer is required to maximize the spacing between individual wells in the network. For the STP at a final pond elevation of 387 m, a nominal well spacing of 25 m with fully penetrating relief wells is proposed.

The pressure relief well network will be installed in stages, at wider initial spacing to match the rise in pressure. The current schedule for installation of the initial wells affords time for additional monitoring and possible field trials prior to full implementation. The initial installations of wells are programmed for summer 2008. Transient data from the operation of the Northwest Wellfield (refer Section 6.5) will be incorporated into a three-dimensional finite element FEFLOW model. This model will provide a tool for initial design and ongoing assessment of the pressure relief network.

Currently work is in progress to develop procedures for winter operation of the pressure relief wells. This work will include field trials to observe winter operation of relief wells, and required maintenance issues in advance of installation of the pressure relief network.

6.4 Surface Water Management

The surface water management design for the STP includes management of seepage water from the tailings dykes, diversion of natural water courses around the structure, management of pressure relief water and construction of riparian habitat to compensate for the construction of the STP.

All process affected (PA) water from the internal drains within tailings dykes, the relief wells, the outer faces of the STP dykes and any other sources will be collected in perimeter ditches and pumped back to the pond as part of a closed water management system. With time it has been assumed that the groundwater in the WCSC will become process affected and has therefore been included within the closed water circuit for the project.

The McLean Creek alignment flowed through the footprint of the STP. To enable construction of the impoundment, McLean Creek was diverted around the South Dyke and West Dyke of the STP (Figure 1). The STP Wetlands have been constructed within the diversion area to compensate for habitat lost beneath the footprint of the STP and the eventual loss of the existing McLean Creek Wetlands, associated with mining operations to the north of the STP.

6.5 Seepage Management

The STP has been preferentially aligned over the WCSC to take advantage of the sand/gravel foundation as a supporting medium for the pond dykes. However, areas of limited glacial till, exposed sand (WCSC) and kame all provide potential direct recharge pathways for the migration of PA seepage from the STP into the underlying WCSC and the regional groundwater system.

PA seepage from the pond will migrate through two major pathways. The first is through the sand tailings dykes. Seepage will be collected using internal filter drains and will be recycled to the pond in a closed circuit system. The second pathway is vertical seepage through the foundation materials into the WCSC, and lateral flow in the channel, which will predominantly follow current regional channel groundwater flow to the north.

Approximately 50% of the STP (dyke and cell) overlies the WCSC, which provides three potential pathways for seepage of PA water to enter the WCSC and migrate through the channel to the surrounding environment (Figure 2). Potential exit points for seepage are to McLean Creek spill-point to the northwest (NW wellfield), to the regional groundwater system to the southwest (SW cut-off wall), and to the regional groundwater system southeast (SE wellfield). As previously mentioned the northern section of the WCSC was cut-off by the construction of the Wood Creek Dam.

The framework for seepage management is a commitment to the environmental protection of McLean Creek and to the preservation of regional groundwater resources. For McLean Creek this is a commitment to manage seepage flows from the STP, such that concentrations of contaminants (particularly napthenic acids) do not reach concentrations that cause an adverse environmental impact. The commitment in terms of seepage migration in groundwater is that there is to be no movement of contaminants across lease boundaries; and no uncontrolled passage of contaminated groundwater to the surface water bodies.

6.5.1 Seepage Mitigation Design Options

The process of selection for the STP seepage mitigation design was an iterative, consultative process with the client which started in early 2003 and was completed in mid-2004. Throughout the process, mitigation options (and combinations thereof) were raised and ranked based primarily on:

- Achieving low or manageable risk in terms of environment impacts, technical feasibility (of success), flexibility in design, and performance based monitoring facilitating a reasonable response time to changes in the system;
- Minimization of cost, both capital and operating;
- Meeting the STP operational plans with minimal impact to tailings schedules and site layouts; and
- Ready integration into existing mining and tailings operations.

A combination of pumping wells and a cut-off wall were selected as the optimum design solution for seepage control.

Pumping wells in the main aquifer areas carry several advantages to the overall design including a history of successful use, effective cut-off induced across the whole aquifer due to designed interference effects, the ability to quickly expand or decommission the system as monitoring deems necessary, and this option represents proven technology in the oil sands and other industries across Canada.

6.5.2 Seepage Design Elements

A groundwater model was established and calibrated to steady state to assist in the seepage management design.

In the northwest, to protect aquatic resources against adverse environmental impact in McLean Creek, STP seepage will be managed using a system of interception pumping wells. The wells were installed in February 2006 and a commissioning trail was initiated in May. A comprehensive monitoring program is in place to monitor the development of draw-down in the channel. The design intent is to reverse the current groundwater flow gradient in this portion of the channel, such that any seepage is intercepted by the pumping wells, and a reversal in groundwater gradient is established between the pumping wells and the spill point in McLean Creek (Figure 2). System performance to date is in accordance with the design.

In the southwest channel of the WCSC, a cut-off wall will be constructed in 2007 to intercept PA seepage. This design may require a limited number of pumping wells upstream of the wall to manage pore pressure build up in this area. Instrumentation and a monitoring program will be in place prior to commissioning, to measure pore pressures, groundwater quality, and to assess performance of the cut-off wall.

In the southeast segment of the channel, relatively reduced pond head and channel hydrogeological conditions combine to limit the anticipated extent of a PA migration and unmitigated seepage is unlikely to move beyond the lease boundary. Groundwater gradients in the WCSC channel in this area are to the north, mitigating against seepage travelling southeast in the channel. Interception pumping wells are currently included as the seepage mitigation design option. The requirement for the wells will be assessed and based on performance monitoring data, once the STP is in operation.

Groundwater gradients naturally mitigate against STP seepage to the east. However, investigations are currently in progress, building on the initial investigations to date, to characterize the kame deposit and optimize seepage design elements, prior to inundation of the eastern STP area in 2008 when pond elevation reaches the base of the kame deposit at approximately 375 m elevation.

The current groundwater model will be revised in due course based on the 2005 and 2006 investigation data and operational monitoring data. Transient calibration will allow use of the model as predictive tool for ongoing seepage design optimization, and as a closure planning tool. An academic research program has been commissioned to determine actual pond seepage rates and to assess natural contaminant attenuation potentials of the foundation sediments and the WCSC. These data will be then be available for further model refinement and ultimately closure design.

7 CONCLUSIONS

The location of tailings facilities over major Pleistocene meltwater channel deposits can pose significant design challenges. For the STP, this required an integrated approach to engineering of dyke slopes, PA seepage and pore pressure management in the aquifer. For these projects an integrated project team comprising geotechnical, hydrology, environmental and hydrogeology disciplines are needed.

Management of seepage into the meltwater channels is the key design consideration for STP in terms of dyke stability and environmental compliance. The STP seepage management system is large and requires a long term commitment to operation and maintenance.

An observational approach to the design and operation of the STP has been adopted and approved. This approach recognizes the scale of the project, uncertainties within the available data, and provides flexibility and contingency for the operation and development of the tailings impoundment. A commitment to a high level of operational monitoring and maintenance of dyke stability and seepage management systems is implicit in this approach.

8 ACKNOWLEDGMENTS

We wish to thank Suncor Energy Inc. for permission to publish this work. We also wish to acknowledge the assistance of those colleagues who helped prepare and review this manuscript.

9 REFERENCES

Andriashek, L.D. and Meeks, J., 1991. “Bedrock topography, drift thickness and buried channels, Northeast Alberta”. EUB Alberta Geological Survey.

Isaac, B.A. et al, 1982. “Characterization of the Lower Cretaceous Overburden for oil sands surface mining within Syncrude Canada Ltd. Leases. Northeast Alberta, Canada.” Proceedings 4th International Conference of the International Association of Engineering Geology, New Delhi, India.

Klohn Crippen Consultants Ltd, 2004. “Millennium Mine, Design of the South Tailings Pond”, November 18, 2004.

Middlebrooks, T.A. and Jervis, W. H. 1946. “Relief Wells for Dams and Levees”. ASCE Transactions Paper No. 2327, June 1946.

Nicol, D. 1994. The Syncrude Mildred Lake tailings dyke redesign. Proceedings of 18th ICOLD, Q.70, R.12, pp 145-184.

US Army Corps of Engineers, 1992. Design, construction, maintenance of relief wells. EM 1110-2-1914.

Appendix IX:

“The sustainable management of groundwater in Canada,” Expert Panel on Groundwater, May 2009

The Sustainable Management of Groundwater in Canada

The Expert Panel on Groundwater

Council of Canadian Academies
Conseil des académies canadiennes

Science Advice in the Public Interest

THE SUSTAINABLE MANAGEMENT OF GROUNDWATER IN CANADA

Report of the Expert Panel on Groundwater

THE COUNCIL OF CANADIAN ACADEMIES
180 Elgin Street, Ottawa, ON Canada K2P 2K3

Notice: The project that is the subject of this report was undertaken with the approval of the Board of Governors of the Council of Canadian Academies. Board members are drawn from the RSC: The Academies of Arts, Humanities and Sciences of Canada, the Canadian Academy of Engineering (CAE) and the Canadian Academy of Health Sciences (CAHS), as well as from the general public. The members of the expert panel responsible for the report were selected by the Council for their special competences and with regard for appropriate balance.

This report was prepared for the Government of Canada in response to a request from Natural Resources Canada via the Minister of Industry. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the authors – the Expert Panel on Groundwater.

Library and Archives Canada Cataloguing in Publication

The sustainable management of groundwater in Canada [electronic resource] / Expert Panel on Groundwater

Issued also in French under title: La gestion durable des eaux souterraines au Canada. Includes bibliographical references. Issued also in print format

ISBN 978-1-926558-11-0

1. Groundwater--Canada--Management. 2. Groundwater-- Government policy--Canada. 3. Groundwater ecology--Canada. 4. Water quality management--Canada. I. Council of Canadian Academies. Expert Panel on Groundwater

GB1029.S88 2009a 333.91'040971 C2009-900066-0

Images: Select interior graphics designed and/or re-produced by Richard Franklin. Cover photo courtesy of Environmental Agency (UK).

Translation: This report was translated from English to French by Benoît Thouin (TETRACOMM inc.), certified translator En-Fr (Canada). The French version was edited by René Therrien (expert panel member), Claire Breton-Pachla and Mary-Christine Thouin (TETRACOMM inc.).

Council of Canadian Academies
Conseil des académies canadiennes

Printed in Ottawa, Canada, June 2009

Canada

This assessment was made possible with the support of the Government of Canada.

The Council of Canadian Academies

SCIENCE ADVICE IN THE PUBLIC INTEREST

The mandate of the **Council of Canadian Academies** (the Council) is to perform independent, expert assessments of the science that is relevant to important public issues. Here "science" is interpreted broadly to encompass any knowledge-generating discipline, including the natural, social and health sciences, engineering and the humanities. The Council's assessments are performed by independent panels of qualified experts from Canada and abroad.

Operating at arm's length from government, but with 10-year funding of $30 million provided in 2005 by the Government of Canada, the Council carries out studies of subjects proposed by the Government, and eventually, by non-governmental and private-sector organizations. The Council is governed by a 12-member board, a majority of whom are appointed directly or indirectly by the Council's three member Academies – the Canadian Academy of Health Sciences, the Canadian Academy of Engineering and the RSC: The Academies of Arts, Humanities and Sciences of Canada. A 16-member scientific advisory committee, composed of eminent representatives of the broad science community, advises the Council's Board with respect to assessment topic selection, terms of reference, selection of expert panels and external report review. The founding members of the Council are:

RSC: The Academies of Arts, Humanities and Sciences of Canada is the senior national body of distinguished Canadian scientists, scholars and artists. The RSC consists of approximately 1,800 Fellows: men and women from across the country who are selected by their peers for outstanding contributions to the natural and social sciences and to the arts and humanities. The RSC is a charitable organization incorporated by an Act of Parliament in 1883.

The **Canadian Academy of Engineering** comprises many of the country's most accomplished engineers, who have expressed their dedication to the application of science and engineering principles in the interests of the country and its enterprises. The Academy is an independent, self-governing and non-profit organization established in 1987 to serve the nation in matters of engineering concern. The approximately 440 Fellows of the Academy represent all disciplines of engineering and are drawn from industry, government and academe.

The **Canadian Academy of Health Sciences** encompasses the full breadth of academic health sciences including all of the medical and allied health sciences, ranging from fundamental science to social science and population health. The approximately 300 Fellows are recognized for their leadership, creativity, distinctive competencies and commitment to the advancement of academic health science and for having made significant lifetime contributions to the health of Canadian society.

www.scienceadvice.ca

Publications of the Council of Canadian Academies

THE REPORTS LISTED BELOW ARE ACCESSIBLE THROUGH THE COUNCIL'S WEBSITE (www.scienceadvice.ca):

The State of Science and Technology in Canada

Influenza and the Role of Personal Protective Respiratory Equipment: An Assessment of the Evidence

Small is Different: A Science Perspective on the Regulatory Challenges of the Nanoscale

Energy from Gas Hydrates: Assessing the Opportunities and Challenges for Canada

Vision for the Canadian Arctic Research Initiative: Assessing the Opportunities

Innovation and Business Strategy: Why Canada Falls Short

The Sustainable Management of Groundwater in Canada

Better Research for Better Business

THE REPORTS LISTED BELOW ARE IN THE PROCESS OF EXPERT PANEL DELIBERATION:

Assessment on Risk Assessment Techniques in Animal Health

Assessment on the Integrated Testing of Pesticides

The Expert Panel on Groundwater

James P. Bruce, O.C., FRSC, Chair, Environmental Consultant, Climate and Water (Ottawa, ON)

William Cunningham, Assistant Chief, Office of Ground Water, U.S. Geological Survey (Reston, VA, U.S.A.)

Allan Freeze, FRSC, Former Professor and Director in the Geological Engineering Program, University of British Columbia (Surrey, BC)

Robert Gillham, C.M., FRSC, Distinguished Professor Emeritus, Department of Earth and Environmental Sciences, University of Waterloo (Waterloo, ON)

Sue Gordon, Research Hydrogeologist & Leader, Integrated Water Management Program, Alberta Research Council (Calgary, AB)

Steve Holysh, Senior Hydrogeologist, Conservation Authorities Moraine Coalition (Toronto, ON)

Steve Hrudey, FRSC, Professor Emeritus, Environmental and Analytical Toxicology, University of Alberta (Edmonton, AB)

William Logan, Deputy Director, International Center for Integrated Water Resources Management, US Army Corp. of Engineers (Alexandria, VA, U.S.A.)

Kerry MacQuarrie, Professor & Canada Research Chair in Groundwater-Surface Water Interactions, Department of Civil Engineering & Canadian Rivers Institute, University of New Brunswick (Fredericton, NB)

Paul Muldoon, Environmental Lawyer (Toronto, ON)

Linda Nowlan, Faculty Research Associate, Program on Water Governance, Institute for Resources, the Environment and Sustainability and the Department of Geography, University of British Columbia (Vancouver, BC)

John Pomeroy, Canada Research Chair in Water Resources and Climate Change; Director, Centre for Hydrology; Professor, Department of Geography and Planning, University of Saskatchewan (Saskatoon, SK)

Steven Renzetti, Professor, Department of Economics, Brock University (St. Catharines, ON)

Barbara Sherwood Lollar, FRSC, Professor and Director, Stable Isotope Laboratory, Department of Geology, University of Toronto (Toronto, ON)

René Therrien, Professor, Department of Geology and Geological Engineering, Université Laval (Québec City, QC)

Project Staff of the Council of Canadian Academies

PROGRAM DIRECTORS:

Katherine Levitt

Trina Foster

Maria Trainer

WITH ASSISTANCE FROM (IN ALPHABETICAL ORDER):

Michelle Campbell (Consultant)

David Cashaback (Senior Analyst)

Jennifer Chandler (Consultant)

Alison Crone (Program Assistant)

Laurence Davidson (Consultant)

Marc Saner (Director of Assessments)

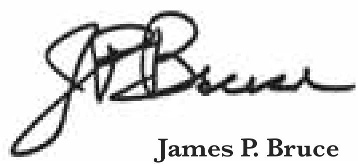
Christina Stachulak (Program Director)

Acknowledgements

The Expert Panel on Groundwater was established in response to a request from the Minister of Natural Resources Canada asking the Council of Canadian Academies to assess what is needed to achieve sustainable management of Canada's groundwater resources, from a science perspective.

During the course of its deliberations, the panel sought assistance from many people and organizations that provided valuable advice and information for consideration. A special thank you is extended to the provincial agencies, scientific organizations and individual experts who made valuable submissions in response to our Public Call for Evidence. The work of the expert reviewers was also critical to improving the final report and their efforts are greatly appreciated.

The panel also wishes to recognize the assistance received from the sponsors of the study and the staff of the federal agencies consulted. Furthermore, the production of this report would not have been possible without the active support provided by the staff and contractors of the Council of Canadian Academies.



James P. Bruce
Chair, Expert Panel on Groundwater

Report Review

This report was reviewed in draft form by the individuals listed below — a group of reviewers selected by the Council of Canadian Academies for their diverse perspectives, areas of expertise and broad representation of academic, industrial, policy and non-governmental organizations.

The reviewers assessed the objectivity and quality of the report. Their submissions — which will remain confidential — were considered fully by the panel, and most of their suggestions were incorporated into the report. They were not asked to endorse the conclusions nor did they see the final draft of the report before its release. Responsibility for the final content of this report rests entirely with the authoring panel and the Council.

The Council wishes to thank the following individuals for their review of this report:

Diana Allen, Professor, Department of Earth Sciences, Simon Fraser University (Burnaby, BC)

William Alley, Chief, Office of Ground Water, US Geological Survey (San Diego, CA, USA)

R.N. Betcher, Manager, Groundwater Management Section, Manitoba Water Stewardship (Winnipeg, MB)

François Bregha, Senior Associate, Stratos Inc. (Ottawa, ON)

John Cherry, FRSC, Distinguished Professor Emeritus, Department of Earth Sciences, University of Waterloo and Adjunct Professor, School of Engineering, University of Guelph (Waterloo & Guelph, ON)

Rob de Loë, Professor and University Research Chair in Water Policy and Governance, Department of Environment and Resource Studies, University of Waterloo (Waterloo, ON)

Mary Griffiths, Former Senior Policy Analyst, the Pembina Institute (Edmonton, AB)

Terry W. Hennigar, President, Water Consulting (Wolfville, NS)

R. Anthony Hodge, President, International Council on Mining and Metals and Professor of Mining and Sustainability, Queen's University (Victoria, BC)

Theodore Horbulyk, Associate Professor, Department of Economics, University of Calgary (Calgary, AB)

Charles Lamontagne, Hydrogeological Engineer, Water Policy Directorate of the Ministry of Sustainable Development, Environment and Parks, Government of Quebéc (Québec City, QC)

René Lefebvre, Professor, Institut national de la recherche scientifique, Centre - Eau Terre Environnement (Québec City, QC)

Harm Maathuis, Hydrogeologist (Saskatoon, SK)

Ralph Pentland, President, Ralbet Enterprises Inc. (Ottawa, ON)

David Rudolph, Professor, Department of Earth Sciences and Member, Waterloo Institute for Groundwater Research, University of Waterloo (Waterloo, ON)

J. Owen Saunders, Executive Director, Canadian Institute of Resources Law, University of Calgary Faculty of Law (Calgary, AB)

Marios Sophocleous, Senior Scientist, Geohydrology Section, Kansas Geological Survey, The University of Kansas (Lawrence, KS, U.S.A.)

Harry Swain, Senior Research Associate, Centre for Global Studies, University of Victoria (Victoria, BC)

The report review procedure was monitored on behalf of the Council's Board and Scientific Advisory Committee (SAC) by **Ms. Elizabeth Dowdeswell**. The role of the report review monitor is to ensure that the panel gives full and fair consideration to the submissions of the report reviewers. The Board of the Council authorizes public release of an expert panel report only after the report review monitor confirms that the Council's report review requirements have been satisfied. The Council thanks Ms. Dowdeswell for her diligent contribution as review monitor.

Peter J. Nicholson, President
Council of Canadian Academies

TABLE OF CONTENTS

Preface

In September 2006, the federal government, through Natural Resources Canada, asked the Council of Canadian Academies to appoint an expert panel to answer the question "What is needed to achieve sustainable management of Canada's groundwater resources, from a science perspective?" The charge to the panel was further specified in a series of sub-questions:

- *What current knowledge gaps limit our ability to evaluate the quantity of the resource, its locations and the uncertainties associated with these evaluations?*
- *What do we need to understand in order to protect the quality of groundwater supply – for health protection and safeguarding other uses?*
- *For groundwater supply and quality monitoring purposes, what techniques and information are needed? What is the current state of the art and state of practice, and what needs to be developed in Canada?*
- *What other scientific and socio-economic knowledge is needed to sustainably manage aquifers in Canada and aquifers shared with the United States?*

The Council assembled a diverse group of leaders in the science of groundwater, as well as experts in the sociological, economic and legal aspects surrounding sustainable groundwater management. The panel met numerous times over the past seventeen months to consider the existing body of literature in order to answer the above questions. In addition, the panel initiated a call for evidence in July 2007 that solicited the input of a wide variety of stakeholder groups. The panel reviewed the results of this consultation and incorporated that information into its deliberations and conclusions. A compilation of these responses is presented in Appendix 2 of this report.

The report is organised as follows. Chapter 1 provides context, beginning with some highlights of the importance and value of groundwater in Canada, as well as some basic facts about groundwater, presented from the perspective of the charge to the panel. Chapter 2 examines the concept of sustainable management of groundwater based on the five goals identified by the panel. These goals lay out sustainability considerations relative to quantity, quality, ecosystem support, socio-economic benefit, and good governance. Chapter 3 highlights a number of trends and emerging critical issues for groundwater, and thus establishes an agenda of challenges that are urgently in need of management based on sustainability principles. In Chapter 4, the goals presented in Chapter 2 are used as an analytical construct to identify the science and engineering needed to underpin sustainable groundwater management. Particular emphasis is placed on the data and knowledge required for effective decision-making. Chapter 5 then addresses groundwater management and decision-making in Canada — encompassing jurisdiction, policy and regulation, and economic instruments — in order to assess the degree to which the current governance of groundwater reflects principles of sustainability. Chapter 6 presents a number of case studies to test and illustrate the goals of sustainable groundwater management in concrete, practical circumstances. The report concludes, in Chapter 7, with an overview of the key findings from this report and a summary response to the questions posed in the original charge to the panel. Supplementary material is provided in three appendices. Appendix 1 provides the reader with a primer on the basics of groundwater science; Appendix 2 documents the highlights from the Public Call for Evidence; and Appendix 3 is a compilation of excerpts of recommendations from major reports in Canada on the subject of groundwater.

1 Introduction

1.1 OVERLOOKED AND UNDERVALUED: GROUNDWATER SUSTAINABILITY IN CANADA

Canadians and their industries use enormous quantities of water, second only to the United States in *per capita* terms and more than double the European average (OECD, 1999). Groundwater is a key component of this overall consumption. Nearly 30 per cent of Canada's population (almost 10 million Canadians) depends on groundwater to supply its drinking water, and more than 80 per cent of the country's rural population relies on groundwater for its entire water supply (Environment Canada, 2004b; Nowlan, 2005). Groundwater, a critical resource that Canadians often treat as 'out of sight, out of mind,' is now gaining visibility due to contamination, over-use and conflicts. Groundwater quality and quantity problems incur enormous costs for society.

Headlines from the past year alone illustrate some of groundwater's effects on Canadians' health, environment and economy (Box 1.1). The most tragic groundwater news stories date back to the Walkerton, Ontario, contamination in May of 2000. It was the worst documented outbreak of pathogenic *E. coli* poisoning caused by municipal tap water and led to seven deaths and sickened more than 2,300 with severe gastrointestinal illness (O'Connor, 2002a; O'Connor, 2002b).

Box 1.1: Groundwater in the Headlines

February 17, 2008. Walkerton *E. coli* payout tops $65M but angry businesses feel shut out: More than $65 million has been paid so far to the victims of Canada's worst-ever *E. coli* tragedy, but businesses hit hard by the crisis say they have seen little of the promised compensation — and some blame crass politics for their plight (*Western Star*).

April 7, 2008. More than 1,700 Canadian boil-water advisories in effect: There were 1,766 boil-water advisories in place across Canada as of the end of February 2008, not including an additional 93 advisories in First Nations communities, according to an investigative report published in the Canadian Medical Association Journal (*Globe and Mail*).

April 18, 2008. Ontario renews Nestlé permit to extract groundwater for sale: Application for the permit prompted thousands of letters of complaint (*Globe and Mail*).

May 23, 2008. Cameco testing for uranium leak in Lake Ontario: World's largest uranium producer says computer modelling shows that "small amounts of contaminated groundwater" may be coming from its Port Hope processing plant (*Globe and Mail*).

June 24, 2008. PCBs, fuel leaking into St. Lawrence River, pollution watchdog says: North America's environmental watchdog says up to eight million litres of diesel fuel and up to two tonnes of dangerous PCBs have contaminated Montréal's Technoparc and are leaking into the nearby St. Lawrence River. The watchdog, the Commission for Environmental Cooperation, released its five-year investigation into the site yesterday (CBC).

July 1, 2008. Water expert raises alarm about coal-bed mining in salmon rivers: Dr. Stockner is now raising alarms about the threat coal-bed methane mining holds for salmon rivers in northern B.C.… Effluents once in the ground then entering groundwater and eventually, surface flows, can severely impact the physico-chemical balances of rivers and streams for several decades... Shell's project is in the early exploratory stages, but the plans call for more than 1,000 wells to be dug to extract methane (*Globe and Mail*).

July 9, 2008. Québec towns near border fear tainting of water supply: Elgin Mayor Jean-Pierre Proulx said he's concerned the dump will contaminate the groundwater that ends up in wells used by his 480 residents (Montreal's *The Gazette*).

July 27, 2008. Oilsands threaten groundwater: Conservation specialist warns steam blowout could contaminate massive Athabasca aquifer near Fort McMurray (*Edmonton Journal*).

July 31, 2008. Nitrates killed thousands of PEI fish, officials say: Environment officials are blaming nitrates for recent fish kills in several Prince Edward Island waterways. Thousands of dead fish were discovered late last week along the Wheatley and Cardigan rivers. The nitrates that have leached into streams and rivers from agricultural applications encourage the growth of underwater plant material and algae (*Globe and Mail*).

Despite the economic and ecological value of groundwater, Canada's legislative framework and institutional capacity for groundwater management have yet to fully mature. The application of the scientific knowledge required for a sustainable management of groundwater remains, with some notable exceptions, under-developed (Mitchell, 2004). This is not an acceptable state of affairs, particularly in view of current or emerging stresses on Canada's groundwater resources due to:

- Population growth and its increasing concentration in urban areas, with major implications for land-use planning and watershed protection;
- Intensification of agriculture, resulting in greater demands on groundwater and the ever-present risk of contamination by nitrates and other residues and pathogens;
- Increased exploitation of hydrocarbons and other mineral resources in response to global demand, creating new and growing pressures on the quantity and quality of adjacent water resources — both surface water and groundwater;
- The presence of contaminated sites and the continuing need for remediation;
- The growing concern for groundwater source protection as a consequence of some or all of the foregoing;
- Threats to aquatic ecosystems and fish due to the low flow of streams that are fed by groundwater during dry periods;
- Transboundary water challenges and the ongoing need for cooperative management of water resources that straddle or cross the Canada-US border; and
- The impact of climate change and its resultant changes in the demands placed on, and availability of, our linked groundwater and surface-water resources. The ultimate effects of climate change on the distribution of water in Canada are highly uncertain, but are potentially of great significance for some regions and for economic activity.

Many of these stresses are already established; others are emerging and demand our foresight and pre-emptive action. All point to the need for Canadians to pay greater heed to this country's precious water resources, both above and below the ground. Water is "the driver of nature"[1] and it is therefore imperative that Canada's hydrosphere be managed sustainably.

While there are no widespread cases as yet of Canadian "water follies," such as the catastrophic over-pumping documented in the United States (Glennon, 2005), individual examples of unsustainable groundwater management are on the rise across Canada. Because many surface-water bodies such as rivers and lakes are already heavily used, groundwater sources are likely to be relied on increasingly for water supply by an expanding population that already uses far greater *per capita* amounts of water than citizens in most other countries. The coming conflicts are foreshadowed in recent journal articles such as, for example, "A Gathering Storm: Water Conflict in Alberta" (Block and Forrest, 2005) and "The Processes, Patterns and Impacts of Low Flows Across Canada" (Burn *et al.*, 2008).

An evaluation of the current situation in Canada reveals that we have not yet experienced a catastrophic over-usage of our groundwater resources.

1 Leonardo da Vinci, quoted in World Bank Doc. 456, Groundwater, Legal and Policy Perspectives.

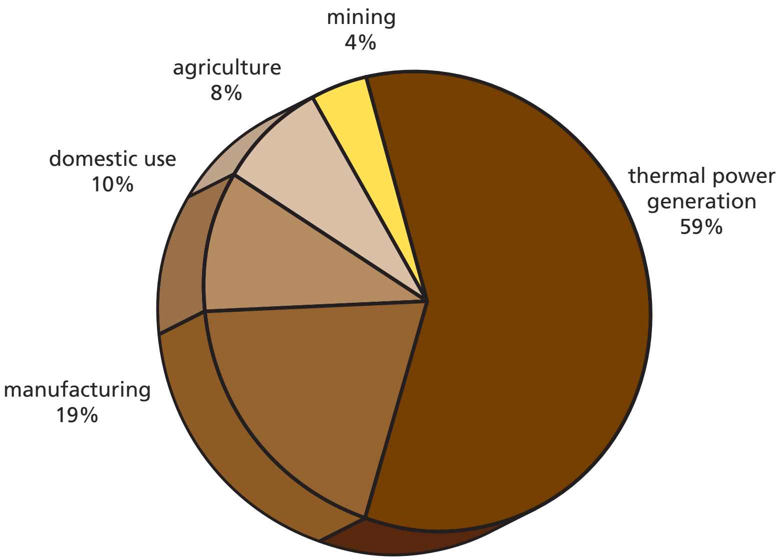
While there have been individual cases where local problems have arisen, nothing could be viewed as a national crisis. This begs the question: why worry about Canada's groundwater? And why now? The answer is that Canada is in the enviable position of being able to put in place proactively, the policies and management practices that can prevent potential calamities in the future — calamities that have been experienced all too often in other parts of the world.

Quantity and Usage

Canada is fortunate to have enormous resources of freshwater; almost 900 000 km^2 or 8 per cent of the nation's total area is covered with fresh surface water (Environment Canada, 2004b). In most of the ways that people and ecosystems are affected, it is the spatial distribution of water flow that matters, not the overall store of water. From this perspective, the North and much of the Prairies are quite arid, with near-desert conditions in the high Arctic; the southern coastal areas, particularly along the Pacific Ocean, are very wet; while the regions bordering the St. Lawrence River and Great Lakes, much of the Atlantic Provinces, and the Rockies enjoy ample, but not excessive, precipitation. Consequently, any consideration of water resources in Canada will have a prominent regional dimension.

The first sub-question of the charge asks: *"What current knowledge gaps limit our ability to evaluate the quantity of the resource, its locations and the uncertainties associated with these evaluations?"* The panel was not able to identify any accurate estimate of the volume of groundwater in Canada — a deficiency acknowledged by the Geological Survey of Canada (GSC) in their statement that "the amount of groundwater stored in Canadian aquifers and their sustainable yield and role in ecosystem functioning are virtually unknown" (Nowlan, 2005; Rivera, 2005). Chapter 4 will consider the scientific and engineering methods and data needed to quantify groundwater resources in Canada.

Total annual freshwater use in Canada for all purposes (industrial, agricultural, domestic, and in connection with thermal power generation) is estimated to be about 45 cubic kilometres (km^3) or very roughly 1,500 cubic metres (m^3) *per capita*, distributed as illustrated in Figure 1.1; this includes both surface water and groundwater. Normal household use, at about 330 litres per person per day (or 120 m^3 per person per year on average) accounts for less than 10 per cent of total use (Environment Canada, 2007). Thermal electric generating industries use approximately 60 per cent of the total as cooling water, virtually all of which is returned to its source without degradation, other than a small increase in temperature (Shinnan, 2008).



(Data Source: Environment Canada, 2007)

Figure 1.1
Average freshwater use in Canada.

Data on the uses of groundwater, within the use of freshwater overall, are limited and dated. Based on estimates for 1995 (OECD, 1995), groundwater accounted for only a little more than four per cent of total freshwater use in Canada, but this was roughly double the amount of annual groundwater use estimated between 1980 and 1990. The United States uses vastly more groundwater than Canada, even on a population-adjusted basis. Groundwater use in the United States in 1995 was 106 km^3, accounting for about 22 per cent of its total freshwater abstraction in that year (OECD, 2004).

The primary use of groundwater in Canada varies regionally, from municipal purposes in Ontario, Prince Edward Island, New Brunswick and the Yukon, to livestock watering in Alberta, Saskatchewan and Manitoba, to largely industrial purposes in British Columbia, Québec and the Northwest Territories, and to domestic wells in Newfoundland and Nova Scotia. Within each province there is variability in the spatial distribution of groundwater use, depending on local aquifer properties and surface-water availability (Environment Canada, 2007). The dependence of provincial populations on groundwater for domestic needs ranges from 100 per cent in Prince Edward Island to about 23 per cent in Alberta. This wide variation illustrates the highly regional nature of dependence on groundwater.

In developing policies regarding groundwater management, regulators will need to know both the current and the projected consumption of the resource.

Record-keeping with respect to groundwater withdrawals varies across the country. All provinces except Québec and British Columbia report having databases of the allocations made to larger groundwater users; however, only Alberta and Saskatchewan record the amount of water actually taken by these users. Ontario and Manitoba are in transition, moving from a system where only allocations are recorded to a system where measurement of actual takings must be reported by users. Record-keeping of extractions is one area where Canadians could and should have certainty. If decisions for additional allocations from a basin are to be in the best interest of the basin's socio-economy and ecosystems, there should be no uncertainty about the volumes that permitted users are already removing, how the water is being used, and the extent and location of the return flows.

Obtaining data on groundwater use is surprisingly difficult. Environment Canada operates a national voluntary survey to collect data from over 2,500 municipalities encompassing over 90 per cent of the Canadian population. The Municipal Water and Wastewater Survey[2] (Environment Canada, 2007) compiles water-use data, including how much groundwater is extracted and the number of residents supplied by domestic wells. It is currently the best source of national data on groundwater extraction for domestic and municipal purposes, but due to a poor response rate from many small municipalities (more than half of municipalities fail to respond), it is incomplete over large sections of the country. To better document groundwater use in Canada, initiatives are necessary to improve the response rate by assisting municipalities with the survey and supporting the collected data with available provincial information on municipal waterworks.

It is apparent from the foregoing that there is a critical lack of data on groundwater allocations, including municipal, industrial and agricultural allocations; on actual withdrawals of groundwater; and on volumes discharged or reused. Groundwater cannot be managed effectively, at any scale, without these data, and the agencies responsible should assign a high priority to securing it.

Quality and Monitoring

Groundwater management in Canada will require more than just the assurance of sufficient quantity. It will also require that the available resources meet the necessary quality standards for human and ecosystem protection. In order to answer the second sub-question, *"What do we need to understand in order to protect the quality of groundwater supply and, thereby, protect public health and generally ensure groundwater is safe to use?"* regulators will need to be able to analyse the existing level of groundwater quality as well as monitor and predict changes. While the provinces currently collect

2 The survey used to be known as the Municipal Water Use and Pricing survey (MUD/MUP); it has been conducted once every two or three years, starting in 1983.

some groundwater quality data, there is no national assessment of trends in groundwater quality, though the National Water Research Institute (NWRI) and the Geological Survey of Canada (GSC) are now collaborating on collecting this information. The research priorities of the NWRI include a national synthesis of groundwater-quality data and the GSC's priorities include a synthesis of physical aquifer data, including aquifer mapping, recharge and vulnerability (Lawrence, 2007). Chapter 3 describes specific instances of the groundwater quality issue while later chapters seek to outline the science that is required to protect the quality of groundwater resources in Canada.

The third sub-question of the charge to the panel asks: *"For groundwater supply and quality monitoring purposes, what techniques and information are needed? What is the current state of the art and state of practice, and what needs to be developed in Canada?"* The scales at which groundwater is monitored include regional monitoring of background water quality and site-specific monitoring of known or suspected groundwater contamination. Regional monitoring focuses on naturally occurring compounds such as arsenic, fluoride and, possibly, dispersed agricultural pollutants, such as nitrate, that have health implications. Regional monitoring is largely the responsibility of provincial agencies. Site-specific monitoring programs focus on anthropogenic contaminants, such as solvents or hydrocarbons from leaking waste-disposal facilities, and are designed to quantify the presence and extent of contamination and aid in the selection of appropriate remedial action. They are usually undertaken by private contractors, hired by site owners, and operated under the scrutiny of provincial regulators.

Value

The fourth sub-question of the charge asks: *"What other scientific and socio-economic knowledge is needed to sustainably manage aquifers in Canada and aquifers shared with the United States?"* While numerous factors will enter into the socio-economic equation for the management of groundwater in Canada, a significant consideration for regulators when developing groundwater policies will be the "value" that groundwater represents to the country. The value of groundwater has both an indirect component (e.g., ecosystem protection, quality of life) as well as a direct component in the form of economic impact. Despite the availability of empirical estimation techniques and the efforts undertaken in other countries to value their water resources (Kondouri, 2004; Young, 2005), relatively little research has been carried out in Canada regarding the value of water (Renzetti and Dupont, 2007). There is consequently very limited information regarding the valuation by Canadian users of water and effectively no current information on valuation by users of groundwater. Chapter 5 of the report addresses the knowledge required to understand the interconnected socio-economic factors and their role in groundwater management.

1.2 THE BASICS OF GROUNDWATER SCIENCE

Water exists as a solid (ice), liquid, or gas (water vapour). Oceans, rivers, clouds, and rain all contain water, and all are in a continuous state of change. Surface water evaporates, cloud water precipitates, and rainfall infiltrates the ground. Despite its various dynamic states, the total volume of water on earth has remained virtually unchanged for the last three billion years, at roughly 1.4 billion km^3 (Powell, 1997; Shiklomanov, 2000). Of course, the distribution of water on earth varies; some locations have an abundance while others have very little. Of the total volume of water, about 97.5 per cent is saline; of the remaining 2.5 per cent, about two-thirds is isolated in polar ice and glaciers, and almost all of the remaining one-third is buried underground. The remaining surface-water fraction, which is our traditional source of freshwater, amounts to only about 0.3 per cent of the planet's freshwater (Gleick, 1996). The circulation and conservation of the Earth's water is called the 'hydrological cycle' (Box 1.2).

The basic concepts and terminology of groundwater science, as used in this report, are summarised in Appendix 1. They include: hydrogeological environments, porosity, hydraulic head, groundwater flow, aquifers and aquitards, groundwater-flow systems, groundwater-surface-water interactions, well yield, aquifer yield and basin yield, groundwater quality and groundwater-related hazards

Box 1.2: The Hydrological Cycle

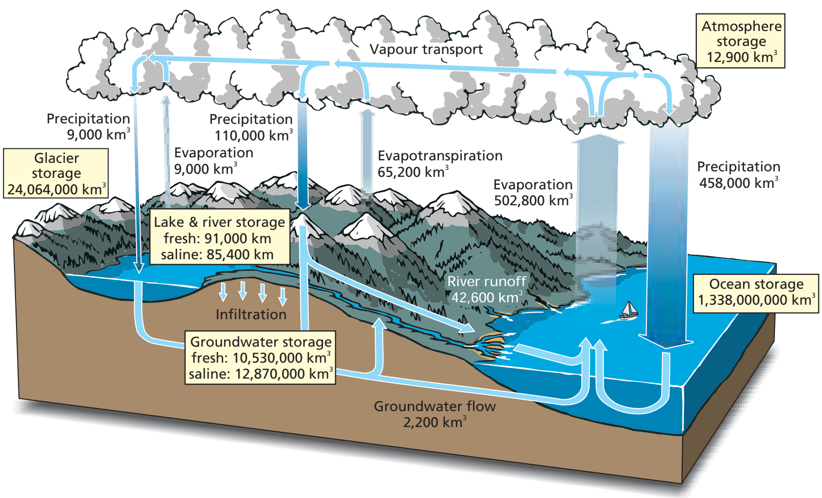
Solar energy continuously transfers water among the hydrosphere, biosphere, lithosphere, cryosphere and atmosphere in a process that is governed by a water balance (see Figure 1.2). The water balance is an accounting of the water flowing in and out of a defined area in a given time. The area could be an urban garden or the St. Lawrence River watershed.

Although at any given moment all the water in the global water balance must add up to the 1.4 billion km^3 total, some segments of the cycle are moving very slowly, specifically deeper groundwater and glaciers. They are considered 'stored water' as their volumes are replaced only over very long time frames. Other segments of the cycle, precipitation and rivers for example, are considered 'flowing water' because they are replenished almost on a daily basis.

Evaporation of surface water by the warmth of the sun drives the cycle. Surface-water features such as oceans, lakes, and rivers provide approximately 90 per cent of the moisture in the atmosphere via solar evaporation; the remaining 10 per cent is evaporated by plants through transpiration. Evaporation is controlled by the energy supply of the environment and is expected to increase with climate change where water supply permits. At any given time, it is estimated that almost 13,000 km^3 of water is present in the atmosphere, or roughly 0.001 per cent of the earth's total volume of water. Precipitation occurs as water vapour cools and eventually condenses, usually on tiny particles of dust in the atmosphere. It is estimated that approximately 45,000 km^3 of precipitation falls on the global landmass each year.

Rainfall or snowmelt in excess of evapotranspiration and infiltration produces runoff to wetlands, streams and lakes. A fraction of the precipitation water infiltrates into the ground. The rate of infiltration depends on soil type, soil moisture content, slope steepness and the presence of cracks or fractures in the ground. The rate of infiltration and the runoff and evaporation patterns determine, on a local basis, the fraction of water applied to the surface that moves through the soil to become groundwater. Thus groundwater is the residual from precipitation, after evapotranspiration and runoff have been accounted for.

Groundwater represents the largest stock of freshwater in the global water cycle, although it is estimated that somewhat less than half of this volume is freshwater, the rest being in deeper saline aquifers. Only about three per cent of total groundwater is active in the hydrological cycle on an annual basis (Gleick, 1996).



(Adapted and reproduced with permission from United Nations Environment Programme, 2002)

Figure 1.2

The hydrological cycle.

REVIEW OF KEY POINTS

- Nearly 30 per cent of Canada's population (almost 10 million Canadians) depends on groundwater to supply drinking water, and more than 80 per cent of the country's rural population relies on groundwater for its entire water supply.
- Groundwater and surface water are inextricably interconnected within the hydrological cycle. There is really just one store of available freshwater.
- There are very significant current and emerging stresses on Canada's groundwater including population growth and urbanisation; agricultural intensification; impacts related to hydrocarbon production; and the growing impact of climate change.
- In most of the ways that people and ecosystems are affected, it is the local-scale flow of water that matters; the store of water is secondary. This is particularly relevant to groundwater, which flows very slowly. Consequently, any consideration of water in Canada will have a strong regional dimension.
- Canada has not yet experienced widespread over-usage of groundwater. There have been individual cases where severe local problems have arisen, but this has not yet occurred on a national scale.
- Canada is in the enviable position of being able to put in place proactively, the policies and management practices that can prevent such crises from occurring.
- Despite the economic and ecological value of groundwater, Canada's legislative framework and institutional capacity for groundwater management have yet to evolve sufficiently to respond to groundwater challenges.
- There is very limited information regarding the valuation of water in Canada and effectively no current information on valuation by users of groundwater.
- There is a critical lack of data on: groundwater allocations, actual withdrawals of groundwater, and volumes discharged or reused. Groundwater cannot be managed effectively without these data, and the agencies responsible should assign a high priority to their collection.

2 Sustainability in the Groundwater Context

The preceding chapter identified a set of key issues to be considered when developing strategies regarding the management of groundwater: quantity, quality, monitoring, usage and value. This chapter addresses what is meant by sustainable management and proposes a set of goals for the sustainable management of groundwater.

2.1 INTERNATIONAL DEVELOPMENT OF THE SUSTAINABILITY CONCEPT IN RELATION TO WATER

The concept of environmental sustainability was first broached at the Stockholm Conference on the Human Environment, sponsored by the United Nations in 1972. Since then, numerous international conferences have been held to develop definitions of sustainability for a variety of circumstances (Table 2.1), including international meetings devoted solely to water. The first major water conference was at Mar del Plata, Argentina, in 1977, and in the 1990s international water meetings began to proliferate. The first of the triennial World Water Forums happened in Marrakech in 1997, followed by The Hague in 2000, Kyoto in 2003, Mexico City in 2006, and Istanbul in 2009. World Water Week also occurs annually in Stockholm; it focuses on the implementation of international processes and programs in water and development. Despite the prevalence of such meetings, critics continue to point out that they have not measurably advanced water sustainability (Gleick, 2007).

At the World Summit on Sustainable Development in Johannesburg in 2002, participating nations agreed to a number of water actions focused first on halving, by the year 2015, both the proportion of people who are unable to reach or afford safe drinking water and the proportion without access to basic sanitation. This Plan of Action also committed the nations to, among other measures, mitigate the effects of groundwater contamination and develop and implement strategies with regard to integrated drainage basin and groundwater management (WSSD, 2002).

Various international agencies have looked at ways to promote groundwater sustainability. The United Nations Environment Programme produced "Groundwater and its Susceptibility to Degradation: A Global Assessment of the Problem and Options for Management," which documented how over-exploited aquifers, falling water tables, and seawater contamination threaten the world's natural underground reservoirs, upon which two billion people depend for drinking water and irrigation (UNEP, 2003). UNESCO has a large groundwater program, including the Internationally Shared Aquifer Resources Management Initiative, and has also compiled a global report on indicators used to measure groundwater sustainability (UNESCO, 2006). The Food and Agriculture Organisation of the United Nations (FAO) has reported on groundwater and international law (Burchi and Mechlem, 2005). The World Bank's Groundwater Management Advisory Team program assists developing nations with groundwater management and has produced a useful series of Groundwater Briefing Notes (GW MATE, 2006).

Table 2.1
International Initiatives to Define 'Sustainability'

Year	Event	Sustainability Definition
1987	Brundtland Commission (World Commission on Environment and Development)	"…development which meets the needs and aspirations of the present generation without compromising the ability of future generations to meet their own needs." It also stated: "…at a minimum…must not endanger the natural systems that support life: the atmosphere, the waters, the soils and living beings."
1992	United Nations Conference on Environment and Development (also known as the Rio Earth Summit)	"The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet, while preserving the hydrological, biological and chemical functions of ecosystems."
1992	Dublin Water Principles Affirm Principle 1 in Lead Follow-up to the Rio Earth Summit	"Since water sustains life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems. Effective management links land and water uses across the whole of a catchment area or groundwater aquifer."

2.2 CANADIAN DEVELOPMENT OF THE SUSTAINABILITY CONCEPT IN RELATION TO WATER

There are many examples in Canada of increased emphasis on sustainability in water management. Recent Canadian legislation contains sustainability commitments, such as the *Auditor General Act* (Government of Canada, 1985a), which requires 25 federal departments to develop and update sustainability strategies, and the *Canadian Environmental Protection Act* (Government of Canada, 1999), whose primary purpose is to "contribute to sustainable development through pollution prevention".

No Canadian law at the federal level refers specifically to groundwater sustainability; however, two federal policies on water do make this link. The 1987 Federal

Water Policy states that its overall objective "…is to encourage the use of freshwater in an efficient and equitable manner consistent with the social, economic and environmental needs of present and future generations" (Environment Canada, 1987). The Federal Water Framework, put together in 2004 by a committee representing 19 departments, established the federal goal of "Clean, safe, and secure water for people and ecosystems". This goal is to be achieved by "sustainable development through integrated water-resources management within the federal government and within national and international contexts" (Government of Canada, 2004). The vision of the Canadian Framework for Collaboration on Groundwater is "To ensure a healthy and sustained groundwater resource for all Canadians" (Rivera *et al.*, 2003).

Provincial water laws and policies are increasingly based on sustainability principles. For example, the *Ontario Water Resources Act* states that: "The purpose of this Act is to provide for the conservation, protection and management of Ontario's waters and for their efficient and sustainable use, in order to promote Ontario's long-term environmental, social, and economic well-being" (Government of Ontario, 1990). Similarly, the *Preamble to Québec's Water Preservation Act* states that "Québec's water resources are essential to the economic, social and environmental well-being of Québec; and whereas it is necessary to provide for the sustainable use of water resources..." (Parliament of Québec, 1999). Other provincial water laws are also guided by sustainability principles.

Non-government bodies have also focused on water and sustainability. The Canadian Water Resources Association produced "Sustainability Principles for Water Management in Canada" (CWRA, 1994), and NGOs lead public education, awareness building, and policy programs across the country.

2.3 THE PANEL'S GROUNDWATER SUSTAINABILITY GOALS

Bearing in mind the foregoing, the panel sought to develop a conceptual framework to help identify what science is needed to underpin sustainable management of groundwater in Canada. The panel recognises that in the context of assessing the scientific requirements for the sustainable management of groundwater in Canada, science should be interpreted broadly to include not only the physical sciences and engineering but also social science and law. While this report focuses primarily on the physical sciences, it also considers the economic, social and legal aspects of a sustainable groundwater management regime.

The panel believes that groundwater management must be a shared undertaking among all orders of government in Canada, and that all governments (federal, provincial, territorial, and local) therefore have important roles to play in developing the physical science basis for the management of the resource. It is envisaged that a framework for the synchronised, cooperative, and coordinated application of physical science in all regions of the nation would be a substantial step towards a cooperative framework that would extend into the long-term management of Canada's groundwater resources.

Based on the sub-questions in the charge, the panel considered the following:

- *Quantity and Usage:* What is required to ensure sufficient groundwater resources on an ongoing basis in Canada and what science is needed to be able to monitor and evaluate the supply of groundwater?
- *Quality and Monitoring:* What is required to ensure groundwater quality from human-health and ecosystem points of view and what science is needed to be able to monitor and evaluate the quality of groundwater?
- *Value:* What socio-economic factors need to be considered in the decision-making processes surrounding groundwater management?

Having regard for these questions, as well as for the various definitions of sustainability used in international and national documents, the panel believes that the concept of groundwater sustainability should encompass five interrelated goals: three that involve primarily the physical sciences and engineering domain, and two that are mainly socio-economic in nature (Figure 2.1). The five sustainability goals are the following:

(1) *Protection of groundwater supplies from depletion:* Sustainability requires that withdrawals can be maintained indefinitely without creating significant long-term declines in regional water levels.

(2) *Protection of groundwater quality from contamination:* Sustainability requires that groundwater quality is not compromised by significant degradation of its chemical or biological character.

(3) *Protection of ecosystem viability:* Sustainability requires that withdrawals do not significantly impinge on the contribution of groundwater to surface water supplies and the support of ecosystems. Human users will inevitably have some impact on pristine ecosystems.

The use of the term 'significant' in the three foregoing goals implies a notion of what may be acceptable to society in terms of permissible degradation or depletion of the resource. The mechanisms by which society determines what is acceptable are encompassed in the following two goals:

(4) *Achievement of economic and social well-being:* Sustainability requires that allocation of groundwater maximises its potential contribution to social well-being (interpreted to reflect both economic and non-economic values).

(5) *Application of good governance:* Sustainability requires that decisions as to groundwater use are made transparently through informed public participation and with full account taken of ecosystem needs, intergenerational equity, and the precautionary principle.[4]

(Council of Canadian Academies, 2009)

Figure 2.1
Groundwater sustainability pentagon.

4 The precautionary principle seeks to encourage those undertaking projects to consider and address harm to the public or the environment even if the scientific consensus that harm will occur is unclear. The precautionary approach is innovative in that it changes the role of scientific data. It requires that once environmental damage is threatened, action should be taken to control or abate possible environmental interference even though there may still be scientific uncertainty as to the effects of the activity (Birnie and Boyle, 2002). The basic elements are the need for a decision, a risk of serious or irreversible harm, and a lack of full scientific certainty. In the past 10 years, the precautionary approach has become an integrated part of both environmental and health-based Canadian regulatory measures (Government of Canada, 1992; Government of Canada, 1999).

Most previous attempts to define sustainable groundwater use (Alley *et al.*, 1999; Devlin and Sophocleous, 2005; Sophocleous, 1997; Sophocleous, 2007) acknowledge that the question of what constitutes sustainability involves judgment and is ultimately a societal decision that should be informed by scientific knowledge and sustainability principles, including the precautionary principle. This is reflected explicitly in the fifth goal, application of good governance. The panel sees the goals as interrelated (Figure 2.1). For example, decisions regarding volumes withdrawn from groundwater resources may also have an important impact on the viability of ecosystems (Box 2.1). More generally, sustainability requires that groundwater and surface water be characterised and managed as an integrated system within a drainage basin or groundwater basin. Groundwater and surface water are both inherent components of basin-wide water budgets, and they are inextricably interconnected as components of the hydrological cycle. Furthermore, withdrawal limits set by groundwater management policies need to consider the societal and economic impact on the surrounding area. In other words, each of these five goals is necessary and no one in itself is sufficient. The overall achievement of sustainability will rely on a careful analysis and balancing of the five goals.

The implementation of policies that are jointly beneficial to the environment and to social and economic well-being requires interdisciplinary understanding and cooperation that challenges our traditional administrative systems at all levels. The systems approach to assessing the sustainability of water-resource development requires consideration of all the components of the hydrological cycle and not of any one component in isolation.

It appears that no authority in Canada at any level (local, provincial, or national) has assessed the sustainability of groundwater use under its jurisdiction or established a sustainable-management strategy in a way that fully meets the above-stated goals. It is not the intent of the panel that these goals should be adopted as writ for the purposes of decision-making. Rather, they are an interpretive tool that was used to guide panel deliberations. Furthermore, since each of these goals addresses the various aspects of the original charge (quantity, quality, monitoring, usage, and value), they can be used to guide data gathering, groundwater modelling, groundwater management, and economic decision-making. The following section serves to elaborate on the role of each of the five goals.

Box 2.1: Water Budgets and Sustainability

Water-budget calculations that attempt to estimate the rates and volumes of groundwater recharge and discharge for a groundwater basin and relate them to precipitation, surface runoff, and the other components of the hydrological cycle are a useful and informative component of many basin-wide groundwater studies. Several of the case histories in Chapter 6 utilise such calculations in their assessments of groundwater conditions in various parts of Canada. However, naïve usage of the recharge calculation from a water budget (or some percentage of it) as a direct estimate of sustainable groundwater yield is not recommended.

An early and simplistic approach to water-resource engineering set the maximum sustainable yield of an aquifer equal to the amount of water that recharges the aquifer under natural, predevelopment conditions. This is widely dubbed "the water budget myth" (Alley *et al.*, 1999; Bredehoeft *et al.*, 1982; Devlin and Sophocleous, 2005). The use of this concept could lead to calculations of sustainable yield that are too high or too low, depending on the hydrogeological circumstances.

The water that is withdrawn has only three possible sources: groundwater storage, induced recharge, and captured discharge. Pumping produces a transient change in the aquifer's water budget, initially taking water from storage, but eventually leading to a new equilibrium with either increased recharge or decreased discharge (Alley *et al.*, 1999; Freeze and Cherry, 1979). In either case, groundwater pumpage takes water from the surface water component of the hydrological cycle, even though the time-lags might be considerable. Induced increases in groundwater recharge rates reduce the amounts of overland flow to streams from upland recharge areas, while decreases in groundwater discharge rates reduce the baseflow to valley streams.

If the positioning of wells in an aquifer increases the recharge, and if the resulting reduction in water available for overland flow is acceptable, then estimates of sustainable groundwater yields based on predevelopment recharge rates may be too low. If the positioning of the wells captures water that would otherwise leave the aquifer as discharge to streams and wetlands, and if this reduction in discharge is not acceptable, then estimates of sustainable yield based on predevelopment recharge rates may be too high. The latter case is more common than the former.

Furthermore, not all the water that is pumped from groundwater is necessarily consumed. Some portion of applied irrigation water, for example, ends up back in the subsurface as so-called 'return flow,' although the 'return flow' might be to an aquifer other than the one from which it was extracted. In the case of domestic and industrial water use, some of it becomes wastewater that is treated and returned to the groundwater or surface water bodies of the hydrological system.

2.4 INTERPRETING THE PANEL'S GROUNDWATER SUSTAINABILITY GOALS

Protection of Groundwater Supplies from Depletion

Sustainable groundwater management must seek to prevent continuous, long-term declines in groundwater levels (Box 2.2). Water-table elevations that reach a new equilibrium position are generally acceptable, provided the third goal, namely protecting ecosystem viability, has been adequately respected. However, if pumping leads to declining water tables that never equilibrate, then the use is unsustainable because the groundwater in storage eventually becomes depleted to a degree that does not allow continued use. (An example of a long-term decline in groundwater levels is provided in the case study of the Denver Basin in Chapter 6.)

Box 2.2: Water-Level Declines in the United States

Groundwater is the principal source of drinking water for about 50 per cent of the United States population, providing approximately 98 per cent of the water used for rural domestic supplies and 37 per cent of the water used for public supplies. In addition, more than 42 per cent of the water used for irrigation is withdrawn from wells. The total groundwater use in the United States was 315 million m^3 per day in 2000 (Hutson *et al.*, 2004).

Because of this reliance on pumped groundwater, the volume of groundwater in storage has declined in many areas of the United States. Among the consequences of groundwater-level declines are increased pumping costs, deterioration of water quality, reduced discharge of water to streams and lakes, and land subsidence. Such negative effects, while variable, happen to some degree with any groundwater use. As with other natural resources, society must weigh the benefits gained by the use of this natural resource against the consequences of such use.

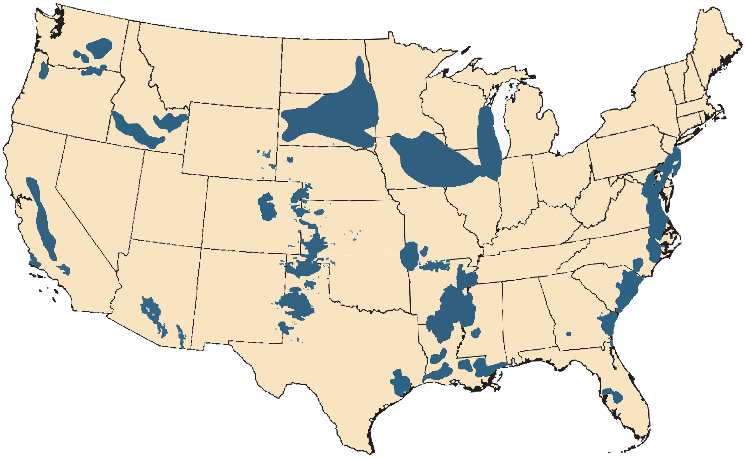
The United States Geological Survey (USGS) compiled a map (see Figure 2.2) depicting areas of water-level decline in excess of about 12.2 metres in at least one confined aquifer since predevelopment, and areas of water-level decline in excess of 7.6 metres in an unconfined aquifer since predevelopment. The areal extent of the water-level decline must be approximately 1,300 km^2 or larger to be included on the compilation map (Reilly *et al.*, 2008). As shown in the figure below, water-level declines may occur over large geographic areas as a result of groundwater pumping.

Although the USGS database contains groundwater information from every state, it is not a comprehensive database of all groundwater monitoring activity across the United States. Thus the map is not a comprehensive evaluation of water-level declines in all areas. United States knowledge is incomplete, in some cases because there are not enough water-level data, and in other cases because data have not been compiled nationally. A national effort is ongoing in the United States to organise available federal, state, and local information on changes in groundwater levels.

Groundwater systems change in response to development and should be monitored and evaluated on a regular basis to quantify the amount of water available for use and the ramifications of using the resource. Each regional groundwater system is unique in terms of climate, hydrogeological framework, and boundary conditions (both type and location), and each system responds differently to stresses from human development and climate.

The USGS is undertaking a broad-scale assessment of the nation's groundwater resources that is adaptable over time and that provides quantitative regional analyses of major areas of groundwater use. The program builds on past federal efforts and a long history of partnerships among the USGS and other federal agencies, states, tribes, and local governments to collect groundwater data and undertake investigative studies of groundwater systems. Products of the program include current estimates and historic trends in groundwater use, storage, recharge, and discharge (water-budget analysis); computer models of regional groundwater systems; region-wide estimates of aquifer properties for major aquifers; evaluation of existing networks for monitoring groundwater availability; and testing and evaluation of new approaches for analysis of regional aquifers.

The program is designed to allow both 'scaling up' to a national synthesis and 'scaling down' to provide information relevant to issues of more local concern. Groundwater management decisions in the United States are made by states, municipalities, and special districts formed for groundwater management. Thus, regional studies are partnered, where possible, with interested agencies and organisations to enhance their relevance to local concerns, and information and models provided at the regional scale are designed to provide a regional framework for more detailed studies and models by individuals who make management decisions at the local level (Reilly *et al.*, 2008).



(Adapted and reproduced with permission from Reilly *et al.*, 2008)

Figure 2.2

Areas of water-level decline in the United States.

To date, there are few examples of excessive groundwater depletion on a large scale in Canada, though localised examples do exist. The Estevan Valley aquifer in southern Saskatchewan saw a substantial decline due to extraction for electricity generation. Pumping was halted in 1994, and estimates suggest the water level in the aquifer will take up to 20 years to recover (Rivera, 2005).

There can be serious economic consequences from excessive depletion. For example, greater costs are expected for pumping and possibly for treatment if groundwater has to be extracted from ever-deeper aquifers because of increasing water-level declines. Alternative water sources via pipelines, tanker water and bottled water (Township of Langley, 2008; Region of Waterloo, 2007b) are often far costlier than local groundwater use. Furthermore, the costs of addressing issues such as land subsidence caused by groundwater over-pumping can be huge. Several instances of costly land subsidence have occurred in the United States (Galloway *et al.*, 1999). Declining storage levels also reduce the buffer provided to municipal and agricultural users during droughts.

Protection of Groundwater Quality from Contamination

Sustainability requires that groundwater quality is not compromised by a significant degradation of its chemical or biological character. The effects of reduced quality in groundwater supplies can affect both human health and ecosystem health. For illustrative purposes, the following discussion is restricted primarily to the protection of drinking-water quality.

While poor groundwater quality may stem from naturally occurring constituents in the aquifer matrix, it is commonly human-induced and a reflection of the local land use. In rural and agricultural settings, groundwater contamination may come from a variety of sources, including manure storage and application, septic systems, accidental spills and pesticide application (CEC and Government of Canada, 2006). In urban settings, large-scale industrial activities, transportation networks, and small-scale commercial operations may contribute. In coastal settings, groundwater management must account for the protection of aquifers from seawater intrusion.

Water-borne disease is a potentially serious problem associated with degraded water quality. The recent tragic example of groundwater contamination in Walkerton, Ontario, claimed seven lives, caused many hundreds of illnesses, and led to the Walkerton Commission of Inquiry, which resulted in a complete overhaul of Ontario's drinking-water management system. Other provinces followed suit in examining the adequacy of their drinking-water protection systems. While nationwide figures for waterborne disease outbreaks are not readily available, the numbers appear to be significant. For example, between 1980 and 2004, British Columbia had 29 confirmed outbreaks of water-borne disease that affected tens of thousands of people (Government of BC, 2007). At Walkerton, the costs of investigating the problem and putting a new system in place were very high. For example, the Commission itself had a budget of approximately $10 million, and $65 million was paid in compensation to victims and their families (WCWC, 2007).

The Walkerton case is an extreme example of contamination, but it is not an isolated one. As of March 31, 2008, there were 1,859 boil-water advisories in effect in Canada as reported by the Canadian Medical Association. Ontario led the country with 679 orders, and British Columbia was next with 530. These alarmingly high numbers were not segregated by water source, so the number of advisories attributable to groundwater is unknown.

In addition to human health impacts and costs, groundwater quality problems have other substantial costs to society. Agricultural and industrial contamination is far costlier to clean up than to prevent in the first place. For example, the Ontario Ministry of the Environment spent approximately $22 million between 1984 and 1993 remediating surficial soils at a polychlorinated biphenyls (PCB) storage facility near Smithville, plus an additional $3 million to replace the town's water-supply well with a pipeline from Grimsby, about 10 kilometres to the north. It is estimated that up to 40,000 litres of PCB still remain in the fractured bedrock aquifer, and the recovery of PCB and remediation of the aquifer are deemed too complex and expensive. The Ministry therefore spends $0.5 million annually to maintain a pump and treat system to control the off-site movement of contaminants (Government of Ontario, 2002a).

Sustainable groundwater management must seek to prevent groundwater contamination caused by human activities and remediate and restore contaminated groundwater. Protecting municipal users of groundwater from the health risks associated with contaminated water can be met (i) by preventing pollution through effective wellhead and source-water protection programs and effective regulation and enforcement systems, (ii) by ensuring that pumped wells do not have the potential to draw in contaminated groundwater that cannot be readily treated, (iii) by installing peripheral monitoring wells for early detection of potential contaminants, and (iv) by installing appropriate wellhead or water distribution treatment systems (users of private wells rely primarily on pollution prevention measures, although wellhead treatment for naturally occurring chemical and biological constituents is increasingly common in some areas).

It is emphasised that impacts on groundwater from risky land-use practices or over-exploitation may take many years or even decades to appear. Once the impact is observed, it may take an extremely long time or be impossible to repair. This is a unique aspect of groundwater that requires management techniques different from those used for surface water.

Protection of Ecosystem Viability

Groundwater discharge to streams is responsible for maintaining stream baseflow and thus plays a key role in supporting essential ecosystem functions, such as providing habitat for aquatic plants and animals, moderating the impact of cycles of drought, sustaining wetlands, assimilating waste, and transporting nutrients. To illustrate, for brook trout (and, to a lesser extent, rainbow and brown trout), it is not only the flow of groundwater into headwater streams that is important, but also a stable temperature and the dissolved oxygen necessary for egg survival and development (Meisner *et al.*, 1988). How much change can these fish tolerate before their reproduction is unsuccessful? This question continues to be a field of research. No figures exist to show exactly how freshwater species depend on groundwater or how to calculate the amount of groundwater that can be removed from a discharge zone before affecting the health of the river to which it is linked (Gartner Lee Ltd., 2002; Rivera, 2005). Therefore, the water requirements of groundwater-dependent ecosystems and aquatic ecosystems are not yet easily quantified, although these topics are receiving an increasing amount of attention from scientists (IAH, 2007), regulators (USDA, 2007), the European Union in implementing its Water Framework Directive (see Box 5.1), and NGOs and research institutes (WDGF, 2005; Program on Water Governance, 2008; Nature Conservancy, 2008).

Both the quantity and quality of groundwater influence ecosystem viability. One of the most egregious examples of impact on quality comes from Prince Edward Island, where a recent independent commission found that the discharge of nitrate-contaminated groundwater resulted in the degradation of environmental conditions in watercourses and estuaries with the ‘costs’ including: fish kills, economic losses to commercial and recreational fishing and shellfish harvesting, and reduced real-estate values for shoreline properties (Government of PEI, 2008). This issue is more thoroughly addressed in the Prince Edward Island case study in Chapter 6.

Groundwater extraction will alter, to varying degrees, the natural predevelopment water budget. There is invariably a trade-off between the socio-economic benefits of increased water supply for consumption and the ecological benefits of stable outflow to groundwater discharge areas. Determining the trade-offs is a central goal of sustainable groundwater management. Adequate discharge from the flow system must be maintained to keep major springs viable, to maintain the health of wetlands, to provide sufficient baseflow to streams, to maintain lake levels at acceptable elevations, and to provide the necessary freshwater contributions to estuarial shorelines. Groundwater withdrawals should not lead to a reduction in the diversity of flora and fauna that populate such habitats.

Understanding the temporal variability of a groundwater-flow system and its interaction with surface water is important. An assessment of groundwater discharge requirements for ecosystem viability must ensure that relevant surface-water features are incorporated into the groundwater understanding when estimating the discharge of groundwater to surface-water bodies, and that the needs and vulnerabilities of the aquatic ecosystem are understood. Both of these tasks are technically difficult, making the determination of an acceptable change in groundwater level a major conceptual and measurement challenge (Farber, 2002).

Governance processes, discussed below in the context of the fifth goal of sustainable management, seek to balance the human benefits of groundwater extraction with the ecosystem benefits incurred by maintaining adequate stream baseflow and wetland habitats. However, while methods to value the human benefits are readily available and well understood, the mechanisms to assign value to the ecosystem benefits are poorly understood and incomplete. Governance is therefore at risk of favouring human benefits.

Achievement of Economic and Social Well-being

Canadians use groundwater for drinking water and for many other purposes. Managing groundwater according to sustainability principles would ensure that residents have stable and good quality supplies. Furthermore, sustainable management policies that maintain water levels, stream baseflow rates, and wetland habitats provide direct economic benefit to tourism, small-craft navigation, the hunting and fishing community, and many others. Groundwater also has value far beyond dollars. Water has spiritual, cultural and aesthetic value. Springs, for example, are often places of scenic and spiritual significance. The panel recognises the importance of sustainably managing groundwater to respect these important values.

From an economic viewpoint, one would ideally seek to maximise the net benefit society derives from using groundwater, including the benefits incurred simply by leaving the groundwater in place. The benefit incurred due to withdrawal of groundwater at any particular time must be considered in the context of two associated costs imposed on society: (i) the sum of the current-period costs experienced by the user, plus costs to any neighbouring users affected by the withdrawal, together with the cost of ecological impacts, and (ii) the cost associated with foregone potential net benefits that might have been enjoyed by future users. Inclusion of this second cost is necessary to ensure that groundwater use is allocated across users and across time periods so as to maximise its sustained value to society, consistent with the notion of intergenerational equity as a premise of sustainability (NRC, 1997).[5]

This reasoning can have important implications. In the case of a deep aquifer, for example, where head drawdowns due to pumping might not impact surface water supplies for a very long time, the objective of maximum value to society, which involves some discounting of costs and benefits in the future, could validate a program of extensive pumping. Any plan to use such an aquifer in this way is inherently unsustainable according to the first goal — the protection of groundwater from depletion. But the fourth goal, promotion of economic and social well-being, might nevertheless justify such a decision. This could be argued if the loss in value associated with the drawdown in the aquifer were offset with a related increase in value arising from an expansion of human-created capital such as infrastructure, businesses, or investment in alternative water supply technologies. The practical application of such a rationale is illustrated in the Denver Basin case study in Chapter 6. This position is not without its critics, and it illustrates the challenge of defining and operationalising a concept of strict 'quantity' sustainability while taking into account the goal of maximising social and economic well-being over an extended time (Schiffler, 1998; UNESCO, 2006).

The economic and social benefits from the industries that rely on groundwater are enormous but virtually impossible to quantify with the available data. Current industries directly reliant on groundwater include the oil and gas industry and agriculture, especially livestock operations. Failure to manage groundwater sustainably could eventually harm these sectors. The lack of empirically based knowledge about the value of water to the health and well-being of Canadians and their ecosystems may impede the ability of governments to manage groundwater sustainably. Reliable estimates of economic value could promote more efficient decision-making regarding water allocations, water-related infrastructure, expenditures for source water protection, and remediation of contaminated waters.

Regardless of society's best intentions for the long term, there will always be pressure to use groundwater to maintain current socio-economic prosperity. That is why a

---

5 In technical terms, a value-maximising plan for groundwater use must be such that (i) the marginal benefit of the last unit of groundwater should be equal to the sum of the marginal costs of extraction and the marginal user-cost in each time period. The last term measures the foregone net benefit arising from current-period withdrawals; and (ii) the present value of the net marginal benefit (marginal benefit minus marginal cost) in each time period must be equal across the planning horizon. This second condition must be met if groundwater use is to be allocated across time periods in a way that maximises society's benefit from groundwater use. It is also important to note that the definition of marginal cost here is more complex than that found in static (i.e., one time period) economic optimisation problems.

proper governance process is necessary to establish groundwater allocations and achieve, over the long-term, the five goals of sustainability. Lasting frameworks that identify and protect aquifers and groundwater flows vital to both humans and ecosystems (now and in the near future) are thus needed. These frameworks will require a risk-management approach that seeks to direct potentially unsustainable uses of groundwater to aquifers with reduced ecological value. Arguably, this logic is already being applied informally in many parts of Canada as managers seek to accommodate new demands within the allowances of their drainage basin's ecosystems. In Alberta, for example, petroleum companies are required to look for a saline water source before applying for a licence to remove non-saline water for enhanced oil recovery.

Application of Good Governance

Water governance is the range of political, organisational and administrative processes through which interests are articulated, input is received, decisions are made and implemented, and decision-makers are held accountable. It is distinct from water management, which is the operational, on-the-ground activity of regulating water and imposing conditions on its use. Governance involves more than the activities of any particular 'government,' and extends to public, private, and civil-society actors.

Different groups define different criteria for good water governance (Bakker and Cameron, 2002), but common criteria include: inclusiveness, participation, transparency, predictability, accountability, and the rule of law. Providing relevant information in a form that is accessible to the public is a prerequisite for a fair and transparent decision-making process. Most jurisdictions provide access to some information about groundwater. For example, some provinces make available maps of relevant geology and wellhead-protection areas. Most provinces also maintain public databases of water-use permits and licences, although they are sometimes difficult to interpret.

Inclusiveness is a key component of drainage-basin planning processes in which governments seek to improve management by involving a wide range of government, public, and private stakeholders in the decision-making process. Providing opportunities for conflict resolution is another important part of governance. Opportunities to participate in groundwater licensing decisions vary from province to province. Ontario's Environmental Bill of Rights and associated public registry is one example of a legal public notice and comment opportunity. Another crucial element of good governance is the rule of law. In terms of groundwater management, respecting the rule of law refers to topics such as compliance with licence conditions, enforcement of reporting requirements, respecting and accounting for First Nations' title rights, treaty rights, and ultimate access to the legal system in the event of unresolved conflicts. Indeed, weak governance structures may lead to greater conflicts over groundwater use:

- Opposition to new proposed legislation in Manitoba designed to better protect groundwater and regulate the hog industry is so strong that hog producers have joined together to create an 'Unfriendly Manitoba' website expressing their opposition to the government's activities. The issue of intensive livestock operations is particularly divisive in a number of provinces.
- Opposition to water-bottling plants withdrawing from groundwater sources has also sprung up across the country, and can involve long and costly disputes (Nowlan, 2005). Uncertainties about how groundwater regulations affect water-bottling operations are a common concern (for example, see the case study in Chapter 6 on Basses-Laurentides).
- Conflicts over groundwater management and use arise in numerous other settings such as land development, golf courses and pipelines.
- Failure to include all affected groups in decision-making procedures can lead to litigation, such as several lawsuits involving First Nations now underway in Alberta.[6]
- Litigation can also arise over failure to assess the cumulative impact of projects, with costly delays for industry, as the recent court case involving the revocation of a water permit for the Kearl oil sands project demonstrates.

Participatory decision-making at the early stages of groundwater development can sometimes, but not always, help to avoid later conflicts. When citizens have access to information and rights to participate in decision-making, they may be less likely to resort to lawsuits (Nowlan and Bakker, 2007). Groundwater laws will be more effective if developed and implemented with a high degree of user participation (Tuinhof, 2001).

Groundwater sustainability can be enhanced when multiple government agencies, citizens groups and scientific researchers work together. For example, H_2O Chelsea — a collaborative project involving a Québec municipality, a research institute, and a citizen-based NGO — works to protect groundwater resources in this small low-density development built on the Canadian Shield in the Gatineau Hills. The municipality now has a policy requiring developers to conduct pumping tests to demonstrate that

6 A number of lawsuits are underway related to First Nations rights and resource and water management. A claim by the Beaver Lake Cree in Alberta seeks to invalidate authorisations for thousands of petroleum projects on the band's core territory (Sandborn, 2008). The Chipewyan Prairie First Nation has made a similar claim (Lillebuen, 2005). The Tsuu T'ina Nation and Samson Cree Nation are asking the Court of Queen's Bench to overturn the Alberta government's decision to close nearly every river, lake and stream in southern Alberta, arguing that the plan doesn't effectively protect the environment (D'Aliesio, 2008).

there is an adequate water supply to support proposed new developments (Nowlan and Bakker, 2007). The consistent application of good governance criteria is likely not only to increase legitimacy but also to improve the quality of decision-making and thus avoid the need to resort to formal conflict-resolution mechanisms such as environmental appeal boards and the courts.

Finally, to ensure that the governance process equitably balances ecosystem needs with socio-economic needs, comparable accounting procedures are necessary in both domains to quantify the value of water. Failure to use economic criteria in decision-making regarding groundwater allocation and groundwater quality means that these decisions are likely to be economically inefficient in the long term, and failure to fully account for the value of ecosystem functions means that the governance process will likely favour socio-economic interests over ecosystem interests.

2.5 REPORTING ON SUSTAINABILITY TARGETS

Performance monitoring is an integral part of implementing sustainable resource management. The data so obtained are best interpreted in terms of clearly defined targets that indicate success or failure with respect to stated goals. Owing to the multiple goals outlined above, and to the complexity of groundwater behaviour, the assessment of sustainability will usually require several independent indicators. Ideally, they must be measurable and representative and should be easily retrievable from program databases. They should be directly related to the sustainability goals and readily compared with sustainability targets, reference values, ranges or thresholds and therefore be able to serve as triggers for action when indicated (Hodge *et al.*, 1995). Representative indicators might include water levels in select water-table wells and deeper piezometer nests, water-quality determinations from potentially vulnerable contaminant locations, spring flow rates, wetland health, streamflow measurements, and estimates of stream baseflow rates. In more complex cases, indicators might be needed to assess the extent of seawater intrusion, land subsidence, or the potential for transboundary impacts. Socio-economic indicators could be based on identified costs and benefits of the approved groundwater development program and on more qualitative measures of social well-being.

It is apparent that techniques for acquiring and applying sustainability indicators to improve management need further development. To provide focus for this ongoing task, the federal government, in cooperation with the provinces, should be encouraged to report on the current state of groundwater quantity and quality in Canada and on progress towards sustainable management. Such a report should be updated at regular intervals, possibly every five years.

REVIEW OF KEY POINTS

- The rising worldwide attention being paid to 'sustainability' reflects a change in human attitudes — one that tempers the traditional focus on the short term and seeks to take fully into account how the actions of today might affect the future.
- The panel formulated five interrelated goals to help address the sustainability dimension of groundwater science and management:
  - Protection of groundwater supplies from depletion
  - Protection of groundwater quality from contamination
  - Protection of ecosystem viability
  - Achievement of economic and social well-being
  - Application of good governance
- It appears that no authority at any level in Canada has assessed the sustainability of groundwater use under its jurisdiction or established a sustainable-management strategy in a way that fully meets these five goals.
- Sustainability requires that groundwater and surface water be characterised and managed as an integrated system within the context of the hydrological cycle in a drainage basin or groundwater basin.
- Impacts on groundwater from land-use practices or over-exploitation may take many years or even decades to appear. Likewise, repair may take an extremely long time, is generally very expensive, and may even be impossible.
- Mechanisms to assign value to groundwater uses and, in particular, the ecosystem benefits of groundwater are poorly understood and incomplete. Governance is therefore at risk of favouring human benefits.
- The assessment of sustainability will usually require several independent indicators. It is evident that techniques for defining and applying sustainability indicators need further development.

3 Current and Emerging Issues for Groundwater Sustainability

New stresses on Canada's groundwater, together with the intensification of several existing pressures, will challenge the sustainable management of groundwater. The trends and emerging issues outlined below form the context within which sustainable groundwater management must go forward and, taken together, constitute an agenda of priorities for groundwater managers and for the science needed to inform their decisions.

3.1 POPULATION GROWTH AND URBANISATION

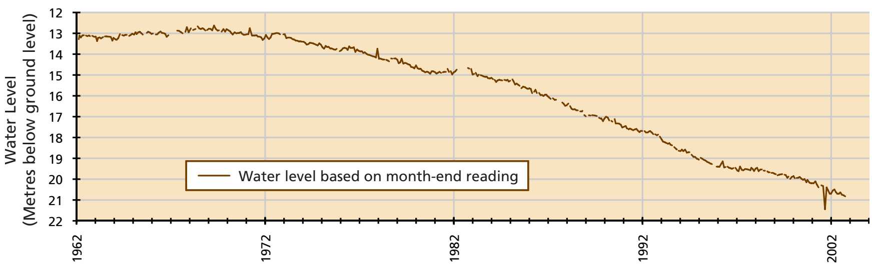
Canada's population of 33 million is projected to be between 36 and 42 million in 2031 and between 36 and 50 million in 2056 (Statistics Canada, 2005). Meanwhile, the concentration of population in urban areas is forecast to increase from 80 per cent of Canadians today (Statistics Canada, 2007) to 87 per cent of a larger population by 2030 (Globalis Canada, 2005). What are the implications for groundwater resources? The question involves many variables, including the proximity and availability of groundwater resources, the natural vulnerability of groundwater systems, the coherence and comprehensiveness of current governance regimes, the nature of existing stresses, and climate change impacts, all weighted according to the local setting of each basin. In general though, we can expect increased demand for groundwater.

Increased Demand for Groundwater

Increased demand for groundwater will be especially strong where surface water is unavailable due to, for example, poorer quality or higher cost. Intensive and increased groundwater withdrawals may require drilling into deeper aquifers with the risks of lower water tables, decline in well yield, greater lift costs and, in isolated cases, saline intrusion or land subsidence.

The Township of Langley, near Vancouver, British Columbia, is an example of a rapidly urbanising agricultural community (its 2008 population of 100,000 is forecast to reach 165,000 by 2023) that has experienced substantial groundwater declines and is taking steps to reverse them. Ongoing monitoring indicates declining water levels in the more intensively used aquifers (Figure 3.1). In some cases, this trend has occurred for nearly 40 years. An analysis of the data indicates that the declines are not due to changes in precipitation but are the result of groundwater overuse (Township of Langley, 2008). Instituting water-demand management to conserve groundwater can result in significant savings. The Township estimates that meeting the goals of its proposed water management plans would result in a 30 per cent reduction in overall water use with a savings of approximately $800,000 in 2007 (Township of Langley, 2007).

Population growth and urbanisation usually lead to encroachment of residential, commercial and industrial development on rural and semi-rural areas. The combination of extensive hardened surfaces and increased groundwater withdrawals may reduce the potential for groundwater recharge and diminish the ability to sustain current streamflow rates in low-flow periods. Meanwhile, an increased demand for groundwater may drive efforts to recharge aquifers artificially.



(Data Source: British Columbia Ministry of Environment, 2007)

Figure 3.1

Hydrograph showing water level in Langley municipal water supply well no. 7.

Groundwater Contamination from Pollutants

Growing local populations and urban concentration increase the risk of contamination of groundwater, including:

- Threat of chemical contamination from urban wastewater (via sanitary-sewer leaks), industrial chemicals (spillage, ground disposal) and solid waste disposal (landfills); road de-icing chemicals and dust suppressants; fertilisers and pesticides; leaking underground storage tanks; and leachate from operating and decommissioned landfills, among others.
- Threat of microbial contamination from surface sources since upper-aquifer and shallow groundwater supplies in urban areas are particularly vulnerable to such contamination.
- As urban boundaries expand, potable water may still be supplied through private wells, and homes and businesses may remain on septic systems. The intensity of use would thus amplify any issues pertaining to groundwater quality.

Trend Away from Groundwater to Piped or Treated Surface Water

As water demands increase with population growth, often compounded by greater regulatory scrutiny of water supplies, areas with limited groundwater resources (or, in some cases, limited understanding of their groundwater resources) will seek supplemental water, often in the form of surface water piped from larger lakes. This is increasingly the case in southern Ontario, where the Great Lakes provide an adjacent alternative to groundwater. These responses create other challenges related to sewage assimilation and the regulatory implications of inter-basin water transfers, not to mention that the pipeline-related costs (environmental assessments, public consultation, construction, etc.) are quite often much greater than those associated with local groundwater supplies.

Failure to Enhance Regulatory and Governance Regimes

A key challenge in any environmental issue is the ability of public authorities to respond effectively and in a timely manner. Laws and policies governing land use, agricultural activities, chemical use and spill prevention, waste management and the like, have historically been extremely complex and difficult to strengthen. Some provincial water laws, such as New Brunswick's, provide for the protection of groundwater recharge zones. If the provincial water law does not address protection of recharge zones, it is left to local governments to protect these zones through land-use plans. Coordination between provincial and local governments is vital because the stresses from urban growth and the associated infrastructure needs are felt directly at the local level, while regulatory authority is shared between both levels of government.

3.2 IMPACT OF AGRICULTURE

Agriculture is a major user of water in Canada, with an approximate annual consumption of 3.6 billion m^3 (Environment Canada, 2007). Supplementary irrigation is by far the largest component, accounting for about 85 per cent of the total, while water for raising livestock accounts for approximately 10 per cent. Water use for irrigated agriculture is greatest in the southern regions of western Canada. Although the study of Kulshreshtha and Grant (2007) could not differentiate between the water sources (groundwater or surface water), a major resource in this region is the large rivers that are fed by mountain snowpack, rainfall and groundwater. These rivers are experiencing the impact of climate change (e.g., Demuth and Pietroniro, 2003), like those in the western United States, where it has been suggested that the reduced reliability of surface water supplies because of climate change may result in a growing reliance on groundwater (Scanlon *et al.*, 2005). This may foreshadow a significantly increased demand in western Canada for groundwater for irrigation. Indeed Kassem *et al.,* (2005) have noted that, for the South Saskatchewan River Basin, better representation of groundwater resources in integrated water-supply and planning models will be required in the future because the demands on groundwater resources are expected to increase due to the limited surface-water supplies. Going forward, it will also be critical to closely monitor the allocated and actual groundwater use by all sectors.

There has been a general intensification and industrialisation of Canadian agriculture resulting in greater farm size and specialisation to capture economies of scale. Interest in the environmental sustainability of agriculture has prompted Agriculture and Agri-Food Canada (AAFC) to develop a set of agri-environmental indicators to track the sector's progress toward meeting environmental objectives (Lefebvre *et al.*, 2005). Within the framework of these indicators, the importance of groundwater is recognised in the context of irrigation, soil salinity, and water contamination by nitrogen compounds and pathogens.

Nitrate Contamination

Although several indicators relevant to groundwater are still under development, the risk of water contamination by nitrogen compounds has already been assessed by Agriculture and Agri-Food Canada. Lefebvre *et al.* (2005) found that, nationally, the nitrate concentration in water leaching from agricultural land (as determined at the Soil Landscape of Canada scale), from residual soil nitrogen and from water-balance estimates, was 24 per cent higher in 2001 (7.3 mg of nitrate per litre) than in 1981. The risk of water contamination by nitrate is likely to have increased due to several factors, including regional increases in fertiliser use, livestock numbers, and legume crop acreages. Low precipitation in 2001 was also cited by Lefebvre *et al.* (2005) as potentially reducing crop yields and nitrogen uptake by crops. While the risk of nitrate contamination of groundwater has increased during the past two decades, there are mature federal-provincial programs in place, such as the National Farm Stewardship Program, that are intended to minimise contamination of water. Best Management Practices for minimising contamination of groundwater are not yet as widely adopted by agricultural producers as they could be. Additional monitoring, research and enforcement are required to ensure agricultural practices achieve desired goals (see case studies on Prince Edward Island and Abbotsford-Sumas aquifer in Chapter 6).

Biofuel Production

A second trend in the agricultural sector is the growing use of feedstocks such as grain and cellulose for the production of biofuels. In the United States there has already been a dramatic expansion in corn-ethanol production. This is forecast to continue for at least another decade (NRC, 2008). Recent assessments of water-quality impacts point to the fact that, compared with soybeans and mixed-species grasses, corn production has the largest application rates of fertilisers and pesticides. Thus, all else being equal, corn-based ethanol production will likely lead to an increase in application rates of nitrogen-based fertilisers, especially if corn is produced on a continuous basis instead of being grown in rotation with other crops (NRC, 2008). This could be an important consideration in corn-growing regions of Canada (e.g., southern Ontario). The groundwater resources that would be most at risk would be those contained in shallow aquifers that receive relatively high recharge. The net assessment of how biofuel production may affect groundwater availability and quality is dependent on a number of factors, including what crop type is replaced by biofuel corn, regional differences in climate, and whether previously uncropped areas are developed for biofuel production (NRC, 2008).

3.3 RURAL GROUNDWATER QUALITY

It is estimated that more than four million Canadians, mostly in rural or suburban areas, rely on private water supplies that are mostly sourced from groundwater (Corkal *et al.*, 2004). Unlike municipalities, private water users usually do not have the economic ability or geographic opportunities to choose their water-supply source.

Groundwater contamination in rural areas may come from a variety of sources, including manure storage and application, septic systems, accidental spills, and pesticide application. Testing of water quality from private wells in Canada, which is mandatory only for new or re-drilled wells in Québec and New Brunswick, typically reveals a situation that would be unacceptable for a regulated municipal water supply.

There is no national program for tracking how many private wells have water treatment or disinfection systems and how many are subject to contamination. However, according to various surveys, nitrates and bacteria represent by far the most common well-water contaminants in Canada. It is estimated that 20 per cent to 40 per cent of all rural wells have nitrate concentrations or coliform bacteria occurrences in excess of drinking-water guidelines (Van der Kamp and Grove, 2001). Specifically, studies in Saskatchewan and Ontario have found that roughly 30 per cent to 35 per cent of surveyed wells exceeded drinking-water guidelines for bacteria, while approximately eight per cent of wells in Alberta exceeded the guidelines (Fitzgerald *et al.*, 1997; Rudolph and Goss, 1993; Sketchell and Shaheen, 2000). Ninety-two per cent of private wells in Alberta and 99 per cent in Saskatchewan exceeded Canadian guidelines for one or more health and aesthetic parameters (i.e., qualities that affect taste or odour, stain clothes, or encrust or damage plumbing) (Corkal *et al.*, 2004; CEC Government of Canada, 2006).

A 1991–1992 survey in Ontario (Goss *et al.*, 1998) found that of 1,292 farm wells sampled and compared with Ontario drinking-water quality objectives, 14 per cent exceeded the nitrate guideline, 34 per cent exceeded the fecal coliform guideline, and six wells exceeded guidelines for pesticides. A recent expert review of water wells in Ontario (Novokowski *et al.*, 2006) recommended that a comprehensive province-wide water quality survey of all types of private wells should be undertaken immediately and that such surveys should be repeated at least every 10 years to track water quality changes.

A recent study on nitrate contamination of water wells in central Saskatchewan (Hilliard, 2007) found that 25 per cent of the 109 wells identified exceeded the health guideline for nitrate. Of these, two-thirds had at least one of the following characteristics: close proximity to land receiving nitrogen fertiliser application; near a corral; or within 100 metres of a septic field. Most were shallow wells. Other examples of localised contamination from natural sources exist in Canada. For example, in Halifax County, Nova Scotia, Meranger *et al.* (1984) reported that 66 of 94 private residential wells exceeded the Canadian drinking-water guideline for arsenic.

Table 3.1 provides another relatively recent summary of well-water quality studies in Canada. The lower values adopted recently for arsenic, trichloroethylene (TCE) and total coliforms mean that the fraction of tested wells that failed to satisfy the Canadian Drinking Water Guidelines (CDWG) at the time of the above studies will now be larger.

Table 3.1
Summary of Well-water Quality in Canada

Contaminant	Canadian Drinking Water Guideline (CDWG)	Well Coverage	Percentage of wells exceeding CDWG	Estimated population using wells
Arsenic[7]	25 µg/l	all	3 to 8	300,000
TCE and PCE[8]	30 to 50 µg/l	municipal	0.2 to 0.6	70,000
Pesticides	2 to 200 µg/l	rural	0.0 to 0.5	10,000
Nitrate	45 mg/l	rural	5 to 17	400,000
Bacteria[9]	0 *E. coli* / 100 ml < 5 or 10 coliform/100 ml	rural	10 to 36	1,000,000

(Data Source: Canada Council for Ministers of the Environment, 2002)

7 CDWG for arsenic is 10 µg/l effective 2006.
8 CDWG for TCE is 5 µg/l effective 2006.
9 CDWG for total coliforms is 0/100 ml effective 2006.

Considering the currently poor situation of many rural wells, the fact that most source-water protection initiatives are focused on municipal supply wells, and the prospect of further intensification of agriculture, it is apparent that rural groundwater quality requires increased attention. Mandatory testing of new wells and public education initiatives should be expanded and strongly supported. Examples of such initiatives are New Brunswick's Know Your H_2O program, which offered free microbiological testing to private well owners during 2006–2007; the "Mon puits, ma responsabilité" initiative from the Union des Producteurs Agricoles in Québec, which included public-awareness talks on groundwater, the distribution of signs used by farmers to visually identify more than 6,000 rural wells and promote awareness among farmers to keep minimum distances between their operations and wells; and, in Alberta, the recently established Working Well program held 19 workshops that reached more than 900 well owners in 2008, with plans to provide web access to fact sheets on groundwater.

3.4 IMPACT OF ENERGY AND MINING ACTIVITY

Canada is the world leader in the production of uranium and potash and is among the five leading countries for the production of about a dozen other minerals and metals. Canada is also likely to remain among the world's largest producers and exporters of energy, based largely on reserves in the oil sands. The rapid modernisation of China and India, among other countries, will greatly increase world demand for energy, metals and minerals, and thus production in Canada is very likely to increase. This will put greater demands on water and is likely to generate increasing volumes of extraction-related wastes.

The Energy Connection

Energy sustainability and security are closely linked to both surface water and groundwater. This is especially evident in the case study on oil sands development in Chapter 6. However, water from either surface or groundwater sources is also essential for other energy-extraction activities, for hydroelectric power development, for refining, for growing of crops and processing for biofuels, and for cooling purposes in thermal and nuclear electricity production. Indeed, the United States Department of Energy is beginning to link energy security to water security.

Oil Sands and Coalbed Methane: The potential environmental impacts of extraction of bitumen from the oil sands in Alberta will likely remain a controversial issue because of the extremely large area affected, the large volumes of groundwater and surface water being pumped, and the plans to continue extraction for several decades. While some oil sands are accessed through mining operations, much of the resource will be obtained through *in situ* operations. The long-term impact on groundwater is still insufficiently understood, given the likely magnitude of the impact, but it is likely to be greatest for *in situ* operations, since they cover a much larger area and, at a majority of sites, use non-saline and saline groundwater to provide steam for their operations (Griffiths *et al.*, 2006). As noted in the oil sands case study (Chapter 6), there is a wide range of water use in various surface-mining oil sands projects, ranging from an average of about three barrels of water per barrel of crude oil for open-pit mining operations, to an average of less than half a barrel for *in situ* operations (Griffiths *et al.*, 2006).

Plans for the large-scale extraction of methane from coal seams (coalbed methane or CBM) in Alberta and British Columbia have been identified as a concern for groundwater resources. Methane is captured by drilling wells in target geological formations and depressurising the formations by extracting the groundwater to release the methane gas. The extracted groundwater and any associated brine would have to be disposed of to avoid contaminating surface water and other groundwater supplies.

Geothermal Energy: The objective of curbing greenhouse gas emissions is focusing attention on the potential of geothermal energy, the production of which is very likely to increase in Canada. Energy derived from heat in the Earth's interior can be exploited to generate electricity, in the case of high-temperature geothermal reservoirs, or to heat and cool buildings, in the case of low-temperature reservoirs. With today's very efficient heat pumps, almost any geological formation in Canada can be used as a low-temperature geothermal reservoir. (High-temperature geothermal reservoirs are generally located in tectonically active zones and are therefore much less common than low-temperature reservoirs.) Geothermal heating and cooling requires drilling boreholes in geological formations in one of two configurations: (i) a closed loop, where a cooling fluid is circulated in the tubing installed in the borehole, but where there is no groundwater extraction or injection; and (ii) an open loop, where groundwater is pumped from the geological formation via a well and injected back into the formation via another well after having travelled through a heat exchanger located at ground surface. There is some concern that geothermal systems can potentially degrade groundwater quality as a result of coolant fluid leaking underground from a closed-loop system or as a result of the water injected back into the geological formations from an open-loop system.

Mine Impacts

The main environmental problem associated with mining operations is the generation of effluents from waste rock and tailings which, if allowed to migrate freely, degrade the quality of surface water and groundwater. Current legislation ensures that acid mine drainage is controlled at active mines, but it is not always controlled at abandoned or orphaned mines. These sites will likely remain an issue for several decades. Additional problems arise from chemical-leach operations, by which effluent waters are often contaminated with metals such as arsenic and require long-term retention in tailings ponds. Water table declines can also occur due to dewatering operations.

Impacts in the North

The increase of energy and mining production will affect northern communities, as exploration and exploitation of natural resources continue to migrate further north. Northern communities are already often faced with groundwater quality and quantity problems, and the impact on groundwater of increased energy and mining production in northern regions is largely unknown.

3.5 CLIMATE CHANGE

Observations of the warming climate and the results of predictive climate models concur that there will be continued warming of the lower atmosphere due to the increased net energy build-up (IPCC, 2007). "Consideration of climate can be a key, but under-emphasised, factor in ensuring the sustainability and proper management of groundwater resources"(Alley *et al.*, 1999).

The most recent report of the Intergovernmental Panel on Climate Change (IPCC) (Meehl *et al.*, 2007) dealing with global climate projections concludes that the intensity of precipitation events around the globe is likely to increase, and such a trend has already been observed in parts of Canada. High-intensity rainfalls, especially in spring, have been shown to be related to many water-borne infectious disease outbreaks in Canada from 1974 to 2001 (Schuster *et al.*, 2005). These outbreaks stem from surface waters or shallow wells with insecure wellheads, but the proportion of each has not been documented. There is a projected tendency for drying of the mid-continental areas during summers through increased evaporation, indicating a greater risk of droughts in those regions. Projected mean-temperature increases vary by region across Canada, from 2ºC to greater than 6ºC in the high Arctic, accompanied, in general, by less snow accumulation in winter, seasonal changes in river flow, greater evaporation rates, melting glaciers and thawing permafrost.

Unfortunately, owing to a lack of definitive studies, there are no specific groundwater conclusions in the IPCC report for the north temperate zones. The first linkages of this nature have just been developed but they have not been applied to climate change problems yet. The IPCC conclusions on surface hydrology nevertheless have important implications for groundwater recharge and withdrawal and are consistent with observations in some regions of Canada. The longer snow-free season will produce greater seasonal evaporation, leaving less water to replenish the groundwater systems. This situation may be problematic for ecosystems dependent on the baseflow discharge of groundwater, and it may deplete groundwater supplies with strong surface water connections.

Implications of Climate Change for the Groundwater Cycle

Impact on Recharge: Groundwater recharge can occur from water stored in lakes, ponds, and wetlands or from soil water in porous materials. Both soil water and surface water storage are sensitive to a changing climate; indeed, surface storage is very sensitive to snowmelt and intense rainfall events. Larger snowmelt or intensive rainfall events will have greater likelihood of forming runoff from the catchment to surface water storage areas and thus likely result in less recharge. The March snowpack that feeds the spring melt in most of southern Canada has declined in recent decades (NRCan, 2008). Models project this to continue in future decades with more rain and less snow in winter months (NRCan, 2008). This often results in more river flow in winter, but lower flows in the critical summer and autumn months. Thus, contributions to low flows from groundwater will become increasingly important to protect watercourses and ecosystems in seasons of greatest demand. However, during periods of severe drought in the western Prairies (e.g., 2001–2002), which are expected to become more frequent, even deep groundwater levels have been observed to decline (e.g., SWA, 2008).

While snowmelt runoff is expected to decline, intense rainfall events may increase in many regions. Rising temperatures will have important implications for surface and ground temperature. Evaporation, which depletes both surface water and soil water storage, is expected to increase over Canada as climate change progresses. In all areas of Canada except the Prairies, evaporation has already increased since 1960 (Fernandes *et al.*, 2007). On the other hand, increases in ground temperature may lead to a decline in the occurrence of frozen soils in spring, which may lead to greater infiltration of snowmelt water.

In summary, a number of processes suggest that the spring recharge of groundwater from snowmelt might decline, except where frozen soils thaw due to warmer winters. Episodic summer recharges from intense rainfall events are likely to compensate only partially for this since such events contribute mainly to runoff. There is strong evidence that evaporation will increase further where water supplies are sufficient to support it. The combination of the changes in these hydrological processes will likely mean reduced groundwater recharge across Canada under climate change. This is consistent with observed trends, such as those examined by Rivard *et al.* (2003), who suggested decreasing groundwater recharge in eastern Canada. Furthermore, rising sea levels will pose an increasing threat of salt water intrusion into groundwater along coastal areas. A complete analysis of the potential effects of climate change on groundwater recharge has not been accomplished for Canada.

Impact on Withdrawals: Groundwater withdrawals for watering gardens, irrigating crops and supplying water for ethanol plants from which biofuels are produced are likely to increase under climate change. Withdrawals will be largest in periods of drought, which may increase in length and spatial extent. Only a few studies "have focused on water supply and allocation schemes under climate change scenarios on regional and provincial scales" (de Loë *et al.*, 2007).

Impact on Baseflow: Since groundwater discharge to streams is generally considered proportional to recharge rates, it is expected that this discharge will decline as water tables drop. This discharge is important for maintaining low flows in many rivers and streams. A recent analysis by Ehsanzadeh and Adamowski (2007) suggests that climate change will bring declining low flows in many rivers across Canada, with modified trends from the Ottawa Valley eastward, in southern British Columbia and in southwest Alberta, and upward trends in the northwest, with little change on the Prairies and in southern Ontario.

Impact of Climate Change on Permafrost

Thawing of permafrost is having increasingly profound effects on watercourses, groundwater, land subsidence, and water infrastructure (Cohen, 1997). Areas most susceptible to landslides include ice-rich, fine-grain sediments on slopes close to bodies of water. Peat bogs are subsiding in the Mackenzie Basin as the underlying frozen soils thaw. While there is evidence from comparative aerial photographs of the decline in the peat plateau in the southern Northwest Territories (Bill Quinton, personal communication), the full impact of recent warming on thermokarst[10] development, as the permafrost degrades and ablates, has not been assessed. Rising groundwater temperatures in the discontinuous permafrost zone in northern parts of the western provinces indicate greater warming than the 1-to-2°C rise in air temperature since 1970 (Cohen, 1997). Thawing, and the accompanying land deformation, can disrupt surface and groundwater-flow systems. In some cases, water pipelines and fuel storage facilities can be disturbed (Cohen, 1997).

Warming at high northern latitudes in climate-model simulations is also associated with large increases in simulated thaw depth over much of the permafrost regions. A poleward movement of the southern extent of permafrost and a 30 per cent to 40 per cent increase in active-layer thickness is projected for most of the permafrost area in Canada, with the largest relative increases concentrated in the northernmost locations. Initially, soil moisture would increase during the summer (NRCan, 2008).

10 Thermokarst refers to a land surface that forms as ice-rich permafrost melts.

By late this century, when the thaw depth will have increased substantially, a reduction in summer soil moisture will likely occur.

In conclusion, both reduced recharge in much of southern Canada and increased water demand in a warming climate will affect groundwater levels in the coming decades. Much more research on this issue is urgently needed to ensure sustainability of supplies and to assess impacts on ecosystems. It is therefore appreciated that a recent report from Natural Resources Canada examines the preliminary scientific data on the likely impacts of climate change on water and other resources in Canada (NRCan, 2008).

3.6 SOURCE-WATER PROTECTION

Over the past two decades there has been a considerable effort, both in research and policy-making, to develop and implement preventative methods for limiting contaminants in groundwater. Although wellhead protection practices evolved earlier in the United States (typically through the 1990s), most Canadian provinces, with New Brunswick being a key exception, were less active (Nowlan, 2005). In Canada, groundwater management activities were being carried out sporadically at a local level, generally by municipalities that were interested in maintaining high-quality groundwater supplies so as to avoid the costly expenditures of addressing contaminated municipal supply wells, such as those incurred at Smithville and Elmira in Ontario. The situation changed in 2000 following the tragedy in Walkerton, Ontario, which led to a report calling for a revamping of water management in Ontario, with considerable focus on groundwater (O'Connor, 2002b). This prompted Ontario to develop a comprehensive *Clean Water Act*. Other provinces implemented similar programs, such as Alberta's Water for Life program, Québec's Water Policy update, Manitoba's Water Stewardship program, British Columbia's new water strategy program, and Saskatchewan's Watershed Authority.

Our technical ability to map capture zones and time-of-travel zones necessary for source water protection plans is still developing, and there is a tendency to err on the conservative side when delineating these zones. There have been remarkably few tests worldwide of the ability to accurately predict capture zones, and few predictions would claim accuracy greater than a factor of two, even in relatively simple hydrogeological environments. Because corrective action, including land purchases, may be required in protection zones where significant threats are identified, the size of capture zones can have major economic implications for municipalities and landowners. Since land-use decisions are contentious, often with large financial implications, methods to minimise the uncertainty in delineating municipal wellhead protection zones will be a priority (Box 3.1). Basin managers must decide on the right balance between, on the one hand, additional expenditures to acquire new data to better confirm subsurface conditions and, on the other, coping with the risk associated with using uncertain modelling analysis results.

Box 3.1: Transference of Technical Information to Decision-Making

A key outcome of effective groundwater management is land-use decisions that adequately consider impacts on the groundwater system.

A present-day concern in Ontario is that municipalities continue to spend significant funds in modelling groundwater systems only to have the final consultant reports stress the uncertainties associated with the understanding of the groundwater-flow system. This is, of course, appropriate from the consultant's perspective, since they wish to ensure that the uncertainty is properly conveyed so that decisions are taken with full knowledge of the limitations of the analysis. However, from the municipality's perspective, there is a desire for reliable knowledge subject to few, if any, technical caveats that are hard for non-experts to evaluate. The solution lies in the clear need for technical expertise at the municipal level to take the information derived from such studies and to translate it into an effective risk management framework so that the municipality's decisions benefit from the scientific analysis, including the inevitable uncertainty, that has been undertaken.

Consider the following situation that was submitted from Don MacIver, Mayor of the Township of Amaranth, Ontario:

"In our municipality, we have three groundwater studies by eminent hydrogeologists, all using exactly the same wellhead data sources from the Province of Ontario and the same models. After hundreds of thousands of dollars were spent for each study, three radically different maps were generated for various hydrogeological issues, especially the mapping of areas of contamination related to recharge areas."

"We intended to use these maps to restrict the spreading of biosolids and other developments on sensitive agricultural land. With three different sets of maps produced by experts, it was clearly apparent that the hydrogeology mapping of groundwater that we intended to select would not withstand the challenges to our proposed bylaws in court. Obviously the developers or biosolid spreaders would use the other sets of groundwater maps to support their case."

"Legal challenges would, as is the case in subdivision disputes, become nothing more than two hydrogeologists arguing in court at public expense. Therefore, we turned to the Conservation Authority and their hydrogeologists to resolve the three different studies and produce one set of values and maps that would withstand legal challenges, with their hydrogeology expert defending their analysis. The Municipality needs this type of technical and expert support that will withstand legal challenges in court."

(Source: Personal Communication, January 2008)

Groundwater presents a particular challenge as source water for First Nations communities because it is not clear, in the current absence of any regulatory structure addressing the safety of drinking water for First Nations (Swain *et al.*, 2006), who is responsible for assessing the quality of drinking water from wells that are used as individual water supplies on First Nations reserves. In addition, as is also the case for surface water, First Nations reserves generally lack the capability to influence source water protection in up-gradient areas located off-reserve. The practice of on-reserve source-water protection is only beginning to receive attention.

3.7 ECOSYSTEM PROTECTION

The intricate linkage between groundwater systems and surface streams requires further study. Many cold water streams receive at least half of their total flow from groundwater (Winter *et al.*, 1998). The research and work needed to ascertain groundwater contributions to the instream-flow needs of aquatic species are in their infancy. Hydrogeologists will need to work in partnership with fisheries biologists and other aquatic scientists to better understand the role of groundwater resources in maintaining aquatic ecosystem viability and integrity. The definition of instream-flow needs requires intensive research and agreement on procedures.

Since aquatic species have diverse requirements for cool water and other aspects of habitat, and require a sufficient streamflow during groundwater-fed low-flow periods, determining the groundwater contributions required to protect ecosystems is complex. There is often an attempt to express these requirements as instream-flow needs (IFNs). Several jurisdictions across Canada have different ways of calculating IFNs. Indeed, it has been estimated that there are currently more than 200 methodologies in use (Tharme, 2003). A concerted effort needs to be made to narrow the range of approaches to the problem if useful guidance is to be provided to groundwater managers to address this aspect of groundwater sustainability (Sophocleous, 2007). The provinces, notably Alberta and Ontario, have undertaken studies of this issue, but for the sake of developing nationally agreed-upon procedures, it would be desirable for the federal Department of Fisheries and Oceans to work with the provinces.

3.8 TRANSBOUNDARY WATER CHALLENGES

Disputes about water bodies that span or cross the Canada-US border can challenge sustainable groundwater management. Recent disputes involving surface water illustrate the variety of issues that might arise, such as the introduction of alien species in the Garrison Diversion project and the Devils Lake disputes between Manitoba and North Dakota; the transboundary pollution in the Flathead River originating from a proposed coal mine in British Columbia and flowing into

Montana; the mine and energy development proposals that threaten wilderness areas in the Taku and Iskut-Stikine watersheds in British Columbia and Alaska; and the continuing pollution and water-level problems in the Great Lakes (IJC, 2008).

To date, transboundary groundwater tensions have been rarer than surface water disputes in Canada-US relations. This is in sharp contrast with the complex and pressing issues of groundwater sharing along the more populous and arid United States-Mexico border, involving at least 17 shared groundwater basins (Hall, 2004). The case study on the Abbotsford-Sumas aquifer (Chapter 6) is one example of a groundwater issue that has generated considerable attention but has so far not abated the nitrate contamination that migrates from Canadian sources to American wells. Pressure on aquifers in the Great Lakes basin will also gain prominence in the coming years as climate change affects lake levels and recharge patterns (see also Chapter 6).

Institutional Mechanisms

The existing institutions involved in transboundary water management have not historically focused on groundwater, although there are signs that groundwater is gaining prominence as an issue that needs attention. The International Joint Commission (IJC) is expected to issue a comprehensive report on groundwater in the Great Lakes region in 2009. The Great Lakes Charter Annex and accompanying set of agreements between two Canadian provinces and eight American states addresses groundwater extraction through its general prohibition on large-scale diversions from the Great Lakes basin.

In most cases, transboundary Canada-US water disputes are resolved through cooperative mechanisms and information sharing through action bodies such as the Abbotsford-Sumas International Aquifer Task Force, the Great Lakes Council of Governors, and the extensive bi-national cooperative framework of the IJC. However, unilateral state action has prevailed over a negotiated diplomatic solution in the case of the Devils Lake discharges into the Red River basin. (After initial overtures to Canada were not accepted, the United States refused to allow the dispute to be submitted by a reference to the IJC.[11]) There are other cases in recent years in which provincial and state governments have taken a lead. This trend is illustrated by the Great Lakes Annex Agreement, where the national governments allowed the adjacent states and provinces to negotiate an agreement. For the upcoming renegotiation of the Columbia Basin Treaty, the Government of British

11 The United States and Canada have a practice of referring matters to the IJC only through joint referral, and never through a unilateral reference, though the Boundary Waters Treaty provides that disputes over transborder water pollution may be referred to the IJC either unilaterally (Article IX) or jointly (Article X).

Columbia, rather than the Government of Canada, has been building public understanding concerning the issues at stake and has established the Columbia Basin Trust to promote the applicable science and public education.

Bulk Exports of Water

There continues to be public uncertainty about the adequacy of Canadian laws to protect water from bulk exports. Although all the provinces, with the exception of New Brunswick, have passed legislation that forbids the bulk export of water, and although federal law prevents exports from boundary waters, laws might nevertheless be changed by a future legislature. Some experts have therefore proposed a new federal 'Model Act' to address the perceived deficiencies in the Canadian legal framework that governs water exports (CWIC, 2008). While the debates and bulk-export proposals usually involve surface sources (e.g., Gisborne Lake in Newfoundland and Labrador), groundwater is, in principle, not immune from diversion and bulk removal.

3.9 CONTAMINATED SITES AND REMEDIATION

Contaminated sites are areas that have been polluted as a result of human activity to a degree that creates a risk to health or the environment. The issue of contaminated site clean-up illustrates the complexity of sustainable groundwater management and the extent of coordination required among different jurisdictions.

It has been estimated that there are over 100,000 sites in the United States contaminated with chlorinated solvents (Box 3.2). In Canada, less effort has been put into identifying contaminated sites, although current estimates indicate that there are approximately 5,000 sites on land owned or controlled by the federal government and 28,000 sites on non-federal properties (ECO Canada, 2008). While national attention has been focused on a few of these, such as the Valcartier military base in Québec and the Elmira and Smithville sites in Ontario, they are only symptoms of a much greater problem. In 2000, the City of Barrie, as a precautionary measure, removed one of 12 supply wells from service because its trichloroethelyne (TCE) concentration had reached 23 μg per litre, approximately half of the maximum allowable levels for drinking water. The source of the TCE remains uncertain (City of Barrie, 2003).

The problem is exacerbated by the fact that drinking-water limits for many industrial chemicals are very low, of the order of five μg per litre for several chlorinated solvents, for example, and thus relatively small discharges can contaminate very large volumes of water. In addition, because of the relatively low solubility of many of these chemicals, small sources can persist for long periods of time. Thus, a small release by a single dry-cleaning establishment or gas station could result in a major groundwater contamination problem. With the growing awareness of the problem and the potential liability, commercial operations have become much more conscientious in their use of hazardous chemicals, and thus the incidence of releases to the environment has decreased substantially. Nevertheless, the thousands of legacy sites that remain represent a continuing threat to groundwater quality.

Management of contaminated sites in Canada is risk-based, with standards and practices varying from province to province. It is required that wellhead protection zones be mapped, that potential sources of contamination within these zones be identified, and that the level of risk to the water supply be determined. Where significant risk is identified, corrective action is required. The process presents considerable challenges to municipalities. First is the uncertainty associated with the mapping of wellhead protection zones. Second, historical records of chemical use are far from complete and, recognising that small historical sources can still cause major problems, it is likely that attempts to identify potential sources of contamination will also be far from complete. Managing the risk presents a further challenge. The obvious choices are: to select a replacement supply, such as surface water; to move the municipal well to a different aquifer or location; to remediate the source and associated contaminant plume, should one exist; or to treat appropriately at the wellhead the water drawn from the supply wells. Methods for remediating contamination by industrial chemicals, particularly chlorinated solvents, after they have entered the subsurface, are costly. Wellhead treatment can provide an engineered, though often complex, solution, but it is often politically unpopular and is costly in its own right. In some cases, the only cost-effective solution is to find an alternative water supply.

Deterioration of groundwater quality as a consequence of yet-unidentified contaminants is an emerging issue. Over the past few decades, the soluble constituents of petroleum products and chlorinated solvents (and other industrial organic compounds) have been identified as contaminants, followed more recently by MTBE (an additive to gasoline, replacing lead) and perchlorate. While MTBE has been a significant issue in the United States, it has had only minor use in Canada, and a recent survey by Environment Canada indicates that perchlorate is not a significant problem in Canadian groundwater (Environment Canada, in preparation). Based on the record of the past thirty years, it must be anticipated that as-yet-unidentified chemicals will emerge as significant threats to water quality.

Box 3.2: Contaminated Site Clean-up

There is no overall federal law that requires sites with contaminated groundwater and soil to be remediated. Different federal agencies and coordinating bodies work on the issue of contaminated sites. The chief regulatory requirements are found in provincial laws. The main qualification for including a site in the federal inventory of contaminated sites is that there is a concentration of a substance in the soil or groundwater (usually a petroleum product or a metal) that is higher than 'expected' for that region of Canada. In 1996, the federal Office of the Auditor General estimated that there were approximately 5,000 contaminated federal sites in Canada, and the 2004 federal budget updated this number to approximately 6,000 sites, with an associated clean-up cost in excess of $3.5 billion.

Provincial laws require the clean-up of contaminated sites that are not on federal land. Usually the statute provides that provincial environmental officials may order investigation and clean-up of contaminated sites where statutory triggers occur, such as discovery of an adverse effect or off-site migration of contaminants. These laws vary significantly, as noted in a report on federal, provincial, and territorial standards, guidelines, and regulations used to establish remediation limits for key contaminants (NB DoE, 2005).

One consequence of the lack of national coordination is that records of contaminated sites and remediation activities across Canada are not easily accessible. One common practice is to extrapolate statistics on these issues from United States sources to create estimates of the Canadian situation. It is estimated, for example, that over 100,000 sites in the United States are contaminated with chlorinated solvents (USEPA, 1999). Furthermore, considering all hazardous-waste sites, the United States National Academy of Sciences (NRC, 1994) estimated that there could be between 200,000 and 300,000 hazardous-waste sites in the United States and that costs of remediation could be of the order of $750 billion. There are likely thousands of chlorinated-solvent sites in Canada as well, but records are not readily available, and specific breakdowns for nuclear, military, and landfill sites are also lacking.

There are several key differences in the regulatory and remediation situation in Canada, compared with the United States. Large American environmental restoration programs such as Superfund, and remediation research and technology development programs on the scale of, for instance, the Strategic Environmental Research and Development Program, do not have equivalents in Canada. Regulatory powers, as well as the consequences of non-compliance, are significantly greater in the United States. Finally, the approach in Canada can be broadly described as a risk-based approach, rather than an approach based on prescribed numerical standards for groundwater contaminants. While standards and practices vary from province to province, the key feature of the Canadian risk-based approach is that remediation or treatment is triggered only if there is an identifiable on-site or off-site risk. In this context, risk refers to the likelihood of exposure of a hypothetical human or ecological receptor to specific contaminants at levels exceeding maximum acceptable concentrations. Sites are typically assessed in a phased approach with an initial option of remediation to generic criteria based on projected land use or to site-specific criteria that are based on a more detailed site-specific risk assessment. In short, even if contamination at a given site exceeds a specific standard level, if there is no risk to a receptor or end-user and no migration off-site, resources are focused instead on sites that pose more significant risks. Furthermore, site remediation in Canada is typically triggered by a change in use, such as the offer of a property for sale or an application for rezoning.

Pharmaceuticals and personal care products have lately become an issue of concern, particularly in surface water (Kolpin *et al.*, 2002). The primary source of pharmaceuticals in the environment appears to be treated sewage effluent discharged to surface water. Potential pathways to groundwater could include recharge from surface water bodies, artificial recharge and septic systems. Though still in the early stages of investigation, the only reported occurrences of pharmaceuticals in Canadian groundwater have been associated with septic system effluents (Carrara *et al.*, 2008). Currently, little is known concerning the fate and transport of these chemicals in subsurface environments.

Waste Management Practices

Recognising that contaminated sites represent the consequences of past waste management practices, current disposal procedures are relevant to long-term groundwater sustainability. There is an increased awareness about the health and ecosystem impacts of municipal and industrial wastes, and the provincial, federal, and international legislation controlling the procurement, ownership, transportation, and disposal of these substances has been effective in reducing releases to the environment. Continuing efforts are nevertheless required to ensure that contaminants remain well-regulated, that emerging contaminants are identified, and that disposal sites are judiciously located to minimise damage to groundwater regimes and constructed and maintained in compliance with a high standard.

Emerging waste streams include carbon sequestration and radioactive waste. Carbon sequestration captures carbon dioxide and pumps it underground for long-term storage as a measure to mitigate the atmospheric build-up of greenhouse gases. Potential groundwater risks include the gradual migration of carbon dioxide into shallow aquifers and resulting changes in the groundwater chemistry and overall water quality, as well as the displacement of deeper native brine and the triggering of changes in shallow groundwater-flow regimes (IPCC, 2005). Groundwater-flow patterns are important to siting and designing radioactive-waste disposal facilities in a way that ensures the longest possible travel time for potential radionuclide emissions from containment structures to possible receptors.

3.10 CHANGING PUBLIC ATTITUDES

Management policies that ensure long-term sustainable groundwater use in Canada will have to be robust, not only with respect to the emerging issues that have been highlighted in this chapter, but also in the face of possible changes in public attitudes that may accompany future developments. The following is a brief enumeration of relevant issues where public attitudes are particularly important and which, if attitudes were to change significantly, could enhance or undermine future political support for more sustainable groundwater management.

The Sustainability Ethic: The current public discourse on sustainable development is taking place during a period of increasing political support for careful stewardship of our natural resources. However, the continued prevalence of a strong environmental ethic cannot be taken for granted. There have been many swings of the pendulum in the past, and there will likely be more in the future. Support for environmental protection tends to wax and wane, being stronger in good economic times than in bad, and during periods of social activism rather than more laissez-faire periods. The boom and bust of the economic cycle has a very significant impact on public psychology and therefore makes it difficult to maintain stable long-term policies in support of sustainable development (Homer-Dixon, 2001).

Public Funding Priorities: Attitudes toward public spending are particularly important, whether driven by the economic cycle or not. One of the clearest messages the panel received from individuals who responded to the call for evidence was a demand for more funding for hydrogeological studies. Respondents from both the public and private sectors thought that government support for research, regulation, and public education on groundwater sustainability matters was inadequate. Of course, more funding for sustainability-oriented environmental policies would ultimately lead to one of two outcomes: either less funding for other government programs or higher levels of taxation. Increased taxation is never popular with either taxpayers or legislators; therefore, policies designed to ensure sustainable use of groundwater will always be at risk of fluctuations in the level of financial support from the public sector.

Evidence-informed Decision Making: Policies designed to encourage sustainable use of groundwater ought to be based on sound scientific principles and should foster the use of the most up-to-date and innovative technical and socio-economic instruments to meet policy goals. Therefore, any erosion of public trust in the methods of science and evidence-based policy analysis could undermine sustainable-use objectives.

The Security Imperative: The rise of international terrorism has led many to fear for the safety of drinking-water systems and other vulnerable infrastructure such as dams and levies. These fears could lead to huge public expenditures to improve system security, a priority that would far eclipse attention to the studies needed to assess groundwater sustainability. At the same time, lack of faith in public water systems could lead to greater reliance on personal supply systems based on locally controlled groundwater pumpage, thus increasing withdrawals that are hardest to assess and control.

Management of Conflict: It is possible that groundwater sustainability policies could lead to limitations on use that cause conflicts between competing water consumers, or between consumers divided on the issue of ensuring the maintenance of groundwater discharges for the protection of the ecosphere. It is likely that there will be considerable political pressure from all sides on this front in future years, and managing such conflict is one of the most difficult challenges facing resource-use decision-makers. The key to successful management of conflict is creating dispute-resolution mechanisms that come into play before conflicts erupt.

REVIEW OF KEY POINTS

Population Growth and Urbanisation

- Coordination between provincial and local governments is vital because the stresses from urban growth and associated infrastructure needs are felt directly at the local level, while regulatory authority is shared between both levels of government.

Impact of Agriculture

- While best management practices for minimising contamination of groundwater could be more widely adopted by agricultural producers, there are grounds for optimism that the risk of nitrate contamination could be reduced, although success to date has been limited.

Rural Groundwater Quality

- Considering the currently poor quality of the water in many rural wells, the inadequate monitoring programs and inconsistent educational programs that promote and assure rural well-water quality, the fact that most source-water protection initiatives are focused on municipal wells, and the prospect for further intensification of agriculture, it is apparent that rural groundwater quality requires increased attention, including community-based outreach programs on water wells and aquifers.

Impact of Energy and Mining Activity

- Energy sustainability and security are closely linked to both surface water and groundwater. More specifically, the long-term cumulative impact on groundwater of oil sands development is still insufficiently understood, given the likely magnitude of the impact, but it is likely to be greatest for *in situ* operations, since they cover a much larger area and, at most sites, use groundwater (either saline or non-saline) to provide steam for their operations.

Climate Change

- Climate change will affect groundwater levels in coming decades through reduced recharge in much of southern Canada, increased water demand in a warming climate, decreased synchronicity of recharge and withdrawal timings, and increased decadal variability of recharge and withdrawal as drought cycles intensify. Much more research is urgently needed to ensure sustainability of supplies and to assess impacts on ecosystems.

Source Water Protection

- The technical ability to map capture zones and time-of-travel zones necessary for source water protection plans is still developing. The tendency to err on the conservative side when delineating capture zones increases their size, and this can have major economic implications for municipalities and landowners.

Ecosystem Protection

- The research needed to ascertain the groundwater discharge requirements for aquatic species is in its infancy. The definition of instream-flow needs from groundwater requires intensive research and agreement on the procedures for establishing these needs.

Transboundary Water Challenges

- The existing institutions involved in Canada-US transboundary water management have traditionally not focused on groundwater, although there are signs that groundwater is gaining prominence as an issue that needs attention (e.g., the pending report of the IJC on groundwater in the Great Lakes region).

Contaminated Sites and Remediation

- Commercial operations have become much more conscientious in their use of hazardous chemicals, and thus the incidence of releases to the environment has decreased substantially. Nevertheless, the thousands of contaminated legacy sites that remain pose a continuing threat to groundwater quality.
- Deterioration of groundwater quality due to unidentified contaminants is an emerging issue. For example, little is known concerning the fate and transport of pharmaceuticals from treated sewage effluent into subsurface environments. It must be anticipated that as-yet-unidentified chemicals will emerge as significant threats to water quality.

Changing Public Attitudes

- Long-term management of groundwater resources may have to take into consideration possible changes in public funding priorities, waxing and waning of the sustainability ethic, swings in the level of public trust in science and government, and public concerns over water security and the management of water-based conflicts.

4 Scientific Knowledge for the Sustainable Management of Groundwater

This chapter addresses the fundamental understanding needed to inform the management of groundwater for sustainability. The focus here is on the behaviour of the groundwater system in response to natural and human-induced influences. This knowledge is required for any science-based approach to sustainable management that has the goals of protecting the quantity and quality of groundwater as well as its contribution to the viability of ecosystems.

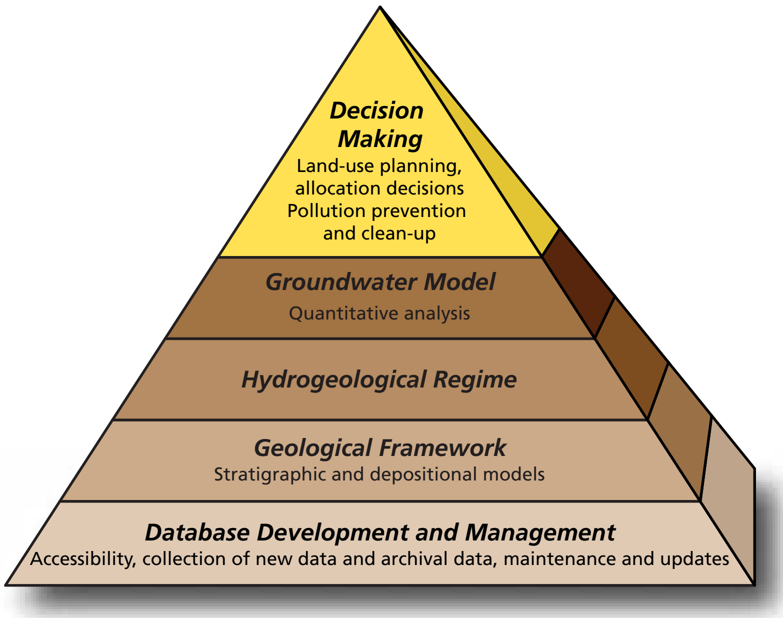
4.1 THE ANALYSIS OF GROUNDWATER-FLOW SYSTEMS

Groundwater studies can occur at many scales, ranging from site-specific to regional; therefore, it is necessary to establish the appropriate scale for sustainable management and to tailor the science to that scale. While it is convenient to suggest that studies be conducted at the watershed scale, boundaries of watersheds and groundwater-flow systems may not fully coincide. Groundwater studies must therefore aim to address the flow system, from area of recharge to area of discharge. This flow-system scale, which is often referred to as the groundwater catchment scale or groundwatershed, forms the backdrop to this discussion.

Flow-system analysis is based on the effective use of a suite of conceptual and quantitative tools and methods, with the forecasting of long-term impacts generally being the goal. There are four investigative components that, when managed in an integrated manner, should lead to credible and defensible interpretations of groundwater-flow systems. This, in turn, will enable decision-making on issues pertaining to groundwater and land use that contribute to the sustainable utilisation of the resource. The four components listed below form a scientific framework for the sustainable management of groundwater. The Oak Ridges Moraine, Region of Waterloo, and Big River case studies in Chapter 6 illustrate the application of this four-component framework:

- A comprehensive geological, hydrogeological, and hydrological database that supports the following components of the framework;
- An understanding of the geological framework through which the groundwater flows;
- A quantitative description of the hydrogeological regime; and
- An appropriate groundwater model.

The components of the framework are illustrated in Figure 4.1, shown as a pyramid to emphasise their connection to the decision-making process (Kassenaar and Wexler, 2006; Sharpe and Russell, 2006). The foundation of this framework is a comprehensive base of data that describes the relevant geological environment, as well as the hydrogeological parameters and dynamic elements (e.g., precipitation and evaporation; surface water measurement; withdrawals; and land-use changes) that determine groundwater behaviour. A discussion of data collection and management issues is deferred to Section 4.4. The following discussion focuses on the other three components of the framework. Particular emphasis is placed on the fourth component, groundwater modelling, of which the other three components constitute integral parts.



(Council of Canadian Academies, 2009)

Figure 4.1
Science requirements for groundwater sustainability.

The Geological Framework

The development of a sound understanding of the subsurface geology is one of the most critical steps in managing groundwater (Sharpe and Russell, 2006). This involves understanding the geological processes responsible for the original deposition of the rock or sediment framework. Secondary processes that can influence groundwater movement through this framework — such as tectonic activity and metamorphism that might, for example, fracture the geological framework or reduce the permeability — must also be considered. This understanding of the geology enables groundwater managers to estimate aquifer configuration and extents, thereby providing guidance for more effective characterisation efforts and enabling improved input to groundwater models and improved predictions of groundwater flow-system dynamics. Since drilling is expensive and information cannot be collected everywhere, and because parameters that control groundwater movement can vary considerably over short distances, an understanding of the geological setting provides a defensible and cost-effective means of interpolating hydrogeological measurements across broad areas. Geophysical methods (e.g., seismic reflection, electromagnetic ground-penetrating radar, etc.) are increasingly being used to assist in characterising the subsurface geological framework and, where conditions are suitable, have proven to be a cost-effective alternative to more costly drilling programs.

The Hydrogeological Regime

The next requirement is to develop an understanding of the groundwater-flow system through analyses of hydraulic head measurements, pumping test results, and other relevant hydrogeological data. These types of studies allow for the quantification of the hydrogeological environment and enable hydrogeologists to define, for example, aquifer extents and thicknesses, confining-layer extents and thicknesses, porosity and hydraulic conductivity distributions, and other elements of the hydrogeological regime. With these quantitative estimates in hand, calculations can be made of hydrogeologically important entities such as flow velocities, bulk-flow rates, water budget components, and discharge rate to streams.

Groundwater Models

The final element of the four-component framework is the construction and use of an appropriate hydrogeological model. Groundwater flow and transport models are useful tools for supporting decision-making because they allow hydrogeologists to probe the potential impacts of land-use and pumping changes on the overall groundwater-flow system. Furthermore, the very development of these models necessitates the systematic interpretation of information from a variety of sources in order to develop an integrated understanding of groundwater systems. Within this framework, groundwater-flow modelling plays an integrative role; when model predictions are tested, the results frequently lead to re-evaluation, reconsideration, and quantitative adjustments of the understanding of the hydrogeological regime. Through an interactive process among the four components of the study framework, a calibrated model is developed in which results, such as hydraulic head patterns and subsurface flow rates, are consistent with measured values in both space and time. Once calibrated, the model can then used to forecast the effect of imposed, cumulative stresses, such as increased pumping from wells, on the overall groundwater-flow system.

Groundwater models have benefits that extend beyond simply predicting groundwater movement and contaminant transport. Properly calibrated models help to prioritise data-collection activities and provide a method for forecasting future conditions under alternative development scenarios. They provide the most sophisticated available method to evaluate the cumulative impacts that arise when there are many pumping sites or land developments.

Hydrogeological models are mathematical solutions to the equations that describe groundwater flow and contaminant transport. Several types of models exist, ranging from very simple to very complex. Some simple models are based on analytical solutions that require many simplifying assumptions. Another type of simplified model involves drawing a flownet for an aquifer, which is a graphical solution to the groundwater-flow equation. Simple models can be useful, but the most commonly used models for prediction are based on numerical solutions of the flow or transport equation, and it is this type of model that is under discussion here.

Depending on the scope of the investigation, the model may consider only the groundwater-flow system, or it may attempt to predict a more comprehensive response that integrates groundwater and surface water, or even atmospheric conditions. These latter approaches can be particularly important in ecological studies where there is a strong connection between groundwater and surface water, or where the goal is to assess the effects of climate variability and long-term change. Once a reasonable understanding of the physical hydrogeological system has been achieved, it is also possible to superimpose quality issues, with concentration and transport parameters as input to contaminant-transport models.

Contaminant Transport Models

Contaminant transport modelling is frequently undertaken to determine the time of arrival of known contaminants at sensitive receptors; to assist in the design and management of groundwater remediation activities; to help anticipate quality changes that could result from proposed changes in land use; and, increasingly, to delineate capture zones and time-of-travel zones around pumping wells.

While groundwater-flow models are the basis for both regional flow modelling and contaminant-transport modelling, there are major differences in their approaches. In regional flow modelling, the important output is usually quantity, with only minor regard for the source or the path followed. In this case, parameters such as hydraulic conductivity, averaged over a substantial volume of the subsurface, may be sufficient. For example, although a particular aquifer may be known to be heterogeneous with hydraulic conductivity values varying over two or three orders of magnitude, it may well be sufficient to assign a single ‘average’ hydraulic conductivity to the entire aquifer, such as that which might be determined from a large-scale pumping test.

On the other hand, for the purpose of contaminant transport modelling, the primary output from flow modelling is the velocity field, from which estimates of time-of-travel can be derived. From the foregoing example, and assuming that the velocity is roughly proportional to the hydraulic conductivity, velocities within the aquifer could vary by a factor of 100 to 1,000 and locally could be orders of magnitude different from the velocity that one would be calculated on the basis of a spatially uniform hydraulic conductivity. Thus, for contaminant-transport modelling, very detailed stratigraphic information is required, paying particular attention to the high-permeability zones and their interconnectedness.

Transport models superimpose various processes on the velocity field, depending upon the contaminant of concern. For non-reactive contaminants such as chloride, this would be limited to hydrodynamic dispersion; however, for reactive or biodegradable solutes, reactive processes of increasing and considerable complexity have been incorporated. It is important to recognise that for each process included in the transport model, the geologic materials must be characterised with respect to at least one additional transport parameter. This can add substantially to the efforts required for site characterisation, to the computational requirements, and ultimately to the level of uncertainty in the results.

Verification and calibration can present further difficulties in contaminant-transport models. In regional flow models, there are various measurable quantities against which simulated results can be compared; water levels and groundwater discharges to streams are the most common. The normal outputs from contaminant-transport models are concentration distributions. Should contaminants or contaminant plumes already be present, there is a basis for testing model results. In many applications however (particularly models of the future effects of changing land use or delineation of capture zones and time-of-travel zones), contaminants are not present initially and thus there is no reasonable basis for model calibration; this leads to considerable uncertainty in predicted results, or to a cautiously large delineation of the capture zones.

We turn now to a more thorough discussion of the role of models in groundwater management and decision-making. This will be followed by an extensive assessment of the data inputs that exist and the data still required to enable more effective groundwater management.

4.2 THE ROLE OF MODELS IN GROUNDWATER MANAGEMENT

Models are important tools for groundwater management, but are generally under-utilised in Canadian jurisdictions; however, it must be recognised that not all hydrogeological issues require a complex modelling solution. The first question to be considered in any hydrogeological investigation is whether a model is appropriate to address the issues under consideration, and whether there is sufficient understanding of the system to justify the use of a model. Model complexity should be scaled to the demands of the catchment. In simple situations, a conceptual model coupled with reliable data may be sufficient for managing groundwater sustainably. In larger or more-complex basins, numerical modelling will undoubtedly be necessary. Numerical models are almost always needed to fully quantify the cumulative impacts of multiple wells or sources of contaminant loading. Proper assessment and accounting of cumulative impacts is a prerequisite to the sustainable use of the resource.

Models don't make decisions, people do. When used appropriately, groundwater models can be useful tools to assist in making decisions in support of sustainable groundwater management. However, both the input and the output from a model must be subject to analysis before a final decision is made. In addition, it is essential that groundwater modellers have a suitable level of training and experience in order to effectively develop and run the model and interpret its results in the context of the particular catchment and the issues being analysed (Gerber and Holysh, 2007).

Model-Use in Management Decision-Making

As noted in Section 3.6, jurisdictions in Canada now clearly recognise the need for source water protection as the first barrier to protecting drinking-water quality. More generally, the land-use planning process must consider the long-term availability and vulnerability of local groundwater resources and the potential for cumulative impacts. Where they are available and in use, the products of hydrogeological studies — including aquifer mapping, characterisation, and modelling — have been effective in integrating groundwater concerns into the land-use management process, provided that the groundwater investigations precede the land-use development. The groundwater studies necessary to provide this knowledge are best undertaken on a catchment-scale and with a flow-systems approach that requires detailed knowledge of recharge, sustainable yield and discharge conditions. Wellhead and source-water protection plans are common applications of this approach.

Where conflicts over water use develop, modelling of alternative allocations can often help to clarify the future scenario that optimises social well-being and ecological health. An example of this approach is provided in the Big River basin case study in Chapter 6. This case study demonstrates how the existence of a well-defined model, built on clear assumptions and fully documented hydrogeological interpretations, can aid in creating a trustworthy and transparent base of evidence for conflict resolution.

Models in the Public Sector

Looking forward, as provincial authorities increasingly seek sustainable groundwater allocation strategies, their modelling capacity must improve in order to develop, understand and operate authoritative catchment-scale groundwater management models. These catchment-scale models should ideally integrate and support ongoing local-scale private sector groundwater studies.

The use of models by provincial regulatory agencies varies from province to province; in most provinces it lags behind state-of-the-art application. In Ontario, under the new *Clean Water Act*, the use of groundwater models is progressing very rapidly, and frequently seems to take place without the time necessary to fully develop and use the critical thinking that must be an inherent part of hydrogeological modelling analysis. It is important in such cases, where tight timelines are a key factor, that the documentation of the uncertainties in the modelling results be at the forefront so that decision-makers can weigh all the evidence.

The panel strongly endorses the development of effective modelling platforms by government agencies to aid in their assessments of groundwater sustainability. Situations that lead to the most effective uses of numerical groundwater models are situations in which the requirement of the model to provide sound hydrogeological input to decision-makers is successfully balanced with the need to provide transparent documentation of details of the model that highlight both its strengths and its weaknesses.

In reviewing the responses from public agencies to the Call for Evidence, it is clear that jurisdictions vary widely in their scientific approach to groundwater sustainability assessment. In jurisdictions where the appropriate agencies have apparently not instituted the four-component approach recommended here, or its equivalent, the roadblocks appear to fall into four categories: (i) lack of a mandate from above, (ii) lack of sufficient funding to carry out such a program, (iii) lack of people or expertise to design and carry out the necessary field measurement programs, hydrogeological interpretations, and computer modelling exercises, and (iv) lack of sufficient available data.

Documentation

Given the amount of data and geological understanding that typically are used to develop a groundwater-flow model, rigorous documentation of the model development process is critical. Such documentation should include the data used to populate the key parameters across the model domain, as well as any changes made to these parameters as the model evolves. Transparency in the modelling process is needed to allow different practitioners to readily run the model. Documentation of the lessons learned in the model journey also needs to be carefully set down so that future modellers can build on any insight developed. This also allows for a prioritisation of the key datasets needed to improve the overall hydrogeological understanding.

Uncertainty and Risk Management

Numerical models do not provide unequivocal answers to issues in groundwater management; rather they provide simulated results that must then be further considered in the context of providing practical solutions to the problem at hand. It is therefore imperative that model output uncertainty be carefully explained by modellers to decision-makers.

The routinely used groundwater-flow and contaminant-transport models generally provide theoretically accurate representations of the fundamental physical and chemical processes that are active in most hydrogeological situations. However, the confidence in the geological and hydrogeological understanding on which predictions are based depends on the availability of the data in the area of interest, and on the interpretations of this data. There may be issues with respect to the quality and density of data points, and also with the types of data; for example, data on the geologic material, groundwater levels and precipitation are necessary across the area being modelled, and streamflow data are necessary at key junctures within the study area.

In practice, the accuracy of models can be affected by a number of sources of error and uncertainty, largely stemming from the fact that groundwater is hidden from sight and its behaviour is less observable and more uncertain than is the case for surface water. In particular, the accuracy of modelled predictions is affected by the following:

- Errors, gaps, and uncertainties in the conceptual geological or hydrogeological understanding that is developed for the groundwater system under study. Such uncertainties include, for example, the continuity and effectiveness of aquitards as barriers to flow; the connectivity of multiple aquifers; the influence of facies changes on the extent of aquifers and aquitards; and the hydraulic role of joints and faults in fractured rocks and in solution channels in carbonate rocks. Incomplete data can often be interpreted in a number of equally plausible yet conflicting ways.
- Errors and gaps in the data used to develop a quantitative understanding of the hydrogeology. For example, uncertainty in the three-dimensional configuration of hydrogeological parameters, such as hydraulic conductivity, will be greatest in areas where logged drill holes are sparse, and other types of geological and geophysical mapping have not been carried out.
- Errors in calibrating the groundwater model to the flow system in question, perhaps due to a paucity of hydraulic-head data, spatially, vertically or temporally.

- Uncertainty surrounding the applicability to the study area of the fundamental groundwater-flow and transport equations underpinning the computer models, perhaps due to the presence of fractured or solutioned rocks rather than porous sediments.

As a consequence of uncertainty, modelling needs to be viewed not as a one-time effort but as an ongoing process. As additional field data are collected and as understanding is gained over time about the conceptual and quantitative nature of the hydrogeological regime, the model needs to be periodically adjusted and recalibrated. In all cases where reliable field-based observations are available, these measurements should supersede numerical-model-simulated output and the model must be amended to reflect the field data. As the information base improves, the uncertainty in model predictions will be concomitantly reduced. Furthermore, the model results can be used to highlight the parameters and areas of greatest uncertainty and thus guide the location and details for new drilling and monitoring. This reduction in prediction uncertainties, as data and experience accumulate, gives rise to a 'living model' approach that is well suited to an adaptive management philosophy. Lessened uncertainty in hydrogeological prediction leads to less risk in the making of groundwater management decisions. Early decisions will thus reflect a precautionary approach, but as uncertainty narrows, management decisions can be made with greater levels of confidence. When decisions must be made, the most recent modelling results are used to inform such decisions. If uncertainty is high, it is likely that a risk-averse course of action will be selected. If uncertainty is low, a more cost-effective path forward may be possible. This 'living model' concept is similar to that used for municipal official plans. Such plans are generally reviewed and updated on a five-year cycle, but they can usually be amended at any time if new or additional information merits. However, on any given day the current plan is still used as the basis for making decisions.

There is no general criterion to define how accurate a prediction should be or, equivalently, how small the uncertainty needs to be before it is considered acceptable. From a decision-making standpoint, this is an economic issue. Additional data should be collected until such time as the cost of collecting them exceeds the benefits that could be realised from a better or less-costly decision. For example, the level of uncertainty that is acceptable for a groundwater allocation decision might be unacceptable for a contaminant remediation decision. Defining the acceptable level of uncertainty should therefore relate to the context of sustainability for a given situation, and the uncertainty in science must be captured in all subsequent decisions with a formalised risk-management process. Establishing procedures and standards in this respect may facilitate the contracting and administration of risk-management and modelling expertise by local agencies.

4.3 THE FRONTIERS OF MODEL DEVELOPMENT

The multiple goals of sustainable groundwater management may require sophisticated models that can (i) better capture the interaction between groundwater and surface water; (ii) integrate hydrogeological phenomena with economic variables; or (iii) provide a detailed account of contaminant transport. The development and refinement of such models are active areas of research in which Canadians continue to make significant contributions.

Integrated Groundwater-Surface-Water Models

Numerical models used in hydrogeology have generally focused on groundwater only and neglect or greatly simplify interactions with surface water. Renewed interest in the simulation of all components of the water cycle has recently led to the development of numerical models for integrated surface-water and groundwater flow. These models are more complex than groundwater-only models and they will likely play a bigger role in the future in predicting groundwater availability. In order to take advantage of this developing class of models, agencies undertaking monitoring activities should seek integrated hydrological monitoring systems that capture and integrate climate, surface water, groundwater, and extraction or consumption data.

Contaminant Transport Models

There is ongoing research and development in contaminant-transport modelling. One area of research concerns multispecies contaminant-transport models with reaction networks. These transport models are designed to provide more accurate representations of potentially very complex chemical and biological reactions that occur in groundwater, and that affect a multitude of contaminants. Models are also currently being developed to simulate contaminant transport coupled with other physical processes, such as variations in fluid density or fluid temperature. The simulation of multiphase flow processes and their impact on contaminant migration and remediation also remains an active area of research.

Hydrogeological Land-Economic Model Integration

Much of the discussion in Chapter 5 suggests that the integration of economic models (that incorporate user demand for groundwater) with hydrogeological models (that describe groundwater dynamics) would provide managers with a powerful tool to promote sustainable groundwater use. A number of such integrated computer models have been developed and used to examine the linkages between economic activity and surface water, for example, Environment Canada's Water Use Analysis Model (Kassem *et al.*, 1994).

Models reflecting links between economic activity and groundwater are less common and have tended to be devoted primarily to the use of groundwater by the agriculture sector. An early example is Kelso (Kelso *et al.*, 1973). More recently, researchers at the University of California have developed CALVIN,[12] an integrated economic-engineering model that links the surface and groundwater supplies of California with the state's major water-using sectors (Jenkins *et al.*, 2004). The application of such models, especially complex, linked, hydrogeological-economic models, if developed with care and caution, could also be valuable in the Canadian milieu.

In addition, the integration of models that address land use and management components with hydrogeological and economic features is an emerging need in Canada. The linking of these models will provide a means by which to compute and analyse a range of indicators relevant to evaluating ecological, social, and economic performance within a groundwater sustainability context. For example, the 5th EU Framework Programme funded the creation of OpenMI[13] as a technology platform for linking different models. As part of the 6th EU Framework Programme, OpenMI has been used and further expanded to encompass models that facilitate integrated analysis of policy questions across land, water, social, and economic outcomes.[14] The existence of such tools in a Canadian context would be of great utility not only for improving groundwater management, but also in managing cumulative impacts across media in cost-effective ways.

Ongoing Research

Canadian researchers have contributed significantly to groundwater modelling methods and software and these developments are reflected in the generally wide usage of models in the domestic consulting industry, although applied primarily at local scales to address issues relating to landfills, contaminated sites, and the capture zones of large supply wells. Box 4.1 provides a short summary of ongoing research directions in Canada.

We now turn to the final element of the four-component framework for sustainable management of groundwater flow-system analysis: the base of data that is needed to support the other three components.

4.4 DATA REQUIREMENTS FOR SUSTAINABLE GROUNDWATER MANAGEMENT

Groundwater data, whether from borehole drilling, geophysical surveying, or larger scale pumping tests, are expensive to obtain. It is therefore surprising to find that these data, once obtained, are commonly not preserved in an efficient or accessible format.

12 For more information on CALVIN, please see: http://cee.engr.ucdavis.edu/faculty/lund/CALVIN.
13 http://www.openmi.org/.
14 http://www.seamless-ip.org/; http://www.sensor-ip.org/.

For example, in current practice in Ontario, especially for larger watershed-management studies, one of the biggest allocations of project funds and time (often well over 50 per cent) is for collecting and managing existing data because no structured, comprehensive, water-related databases are maintained by public agencies. Over the course of many years, groundwater-related data have been lost or over-looked because of the lack of a readily accessible database. A recurring theme with consultant-led projects across the country is that, given the major effort required for collecting and managing existing data, there is insufficient time and budget remaining for the optimal data analyses required to develop innovative solutions to hydrogeological problems. Although budgets may be insufficient to begin with, and should be revised to reflect the work necessary to undertake the project, certainly one of the first steps in remedying this issue should be to optimise the management of data at the appropriate public sector agency and to provide ready consultant access to the data so that the task of amassing the needed data is not repeatedly duplicated over the years.

Box 4.1: Groundwater Research in Canada

Much of the current hydrogeological research in Canada is focused on groundwater quality, although increasing attention is being paid to sustainability, integrated groundwater-surface-water studies and aquifer characterisation. A partial list of current research topics or areas includes:

- Aquifer characterisation and development of improved methods for characterisation;
- Integrated groundwater-surface-water studies (at watershed scale in some cases);
- Fate and transport of a wide range of potential and known contaminants, including both organic and inorganic and emerging contaminants, such as endocrine disruptors and personal care products;
- Behaviour of non-aqueous liquids in the subsurface (industrial solvents and petroleum products in particular);
- Occurrence and mobility of pathogens;
- Industrial contributions to groundwater contamination including agriculture, manufacturing, and the natural resource and energy sectors;
- Remediation of contaminated groundwater; and
- Mathematical models of increasingly complex chemical and physical phenomena.

Comprehensive figures on the amounts and sources of funding for groundwater research in Canada do not exist. In 2006–2007, the Natural Sciences and Engineering Research Council of Canada (NSERC) provided $5 million to support groundwater research undertaken by university faculty (personal communication, March 31, 2008). In addition, the Canadian Water Network (CWN), one of the 21 national Networks of

Centres of Excellence, has annual funding that averages $5 million. The CWN involves 125 researchers from 38 universities across Canada and addresses a broad range of issues affecting both surface water and groundwater. Research is conducted in collaboration with the diverse community of end-users of water research across Canada.

Some data, publicly available from the Department of Earth and Environmental Sciences at the University of Waterloo, provide a snapshot of the support for what is likely the best-funded academically based groundwater research program in Canada. Total water-related research funding in 2005–2006 was about $6.7 million.[15] This includes work on both groundwater and surface water. About 57 per cent consisted of research grants with the remainder primarily from contracts. Approximately one third of the funds ($2.2 million) came from the federal government, about $1.5 million of which was from NSERC programs. Provincial sources accounted for about seven per cent of the total, with the remaining 60 per cent from industry, primarily from the United States and other international sources (personal communication, March 26, 2008). While likely to be of practical relevance and beneficial to Canada, as well as to the sponsoring industry, this latter research will not necessarily be consistent with provincial and national groundwater priorities.

Natural Resources Canada (NRCan) and Environment Canada both have active groundwater science and technology programs, although their financial resources are limited. The primary focus of NRCan is currently directed to the mapping and characterisation of major Canadian aquifers, while the focus of Environment Canada concerns the occurrence, fate and transport of contaminants of national concern. Several provinces also have active aquifer mapping and characterisation programs that have been ongoing for many years. Although there are numerous examples of collaboration among federal, provincial and university researchers, the federal departments have very limited resources in support of extramural research. These departments are consequently constrained in their ability to encourage university researchers to address topics of national priority.

Given the poor record of groundwater data management across the country, it is critical that the collection, maintenance, and management of existing and newly collected groundwater-related data, coupled with ready access to these data, be viewed as a priority for action across the country.

In general, the level of resources dedicated to systematic water-related data collection has failed to keep pace with the demands of land development, and in some cases has declined over the past 20 years, as illustrated by the number of stream gauges in Canada declining from 3,600 to about 2,900 (Statistics Canada, 2003).

15 Based on an assumption that 85 per cent of research funding going to the Department of Earth and Environmental Sciences was water-related.

Some proactive provincial programs have nevertheless emerged, including the 2001 Ontario Provincial Groundwater Monitoring Network (PGMN) and the *Ontario Clean Water Act*. The latter requires watershed-focused water budgets with particular requirements for collecting and interpreting streamflow measurements.

When assessing data needs, a first consideration is the scale of the investigation and the questions that need to be answered. For example, projects to assess the transport of specific contaminants in the groundwater system need localised subsurface data that typically must be obtained from on-site drilling, sampling, and monitoring. On the other hand, projects to assess groundwater availability within a catchment are more regional in scale. While there is a need for similar types of information for both types of studies, in the case of basin-scale studies, the subsurface geological framework is typically conceptualised on a regional scale and local data might not be as significant.

The problem being addressed also influences the type of data needed. For questions of allocation — for example, recharge and discharge rates, as well as climate and streamflow data — would be critical to evaluate the flow of water through the system and make appropriate allocation decisions. In this regard, it is important to have these data collected at the same location, which is generally not the case in Canada. In assessing contaminant plumes and designing treatment programs to minimise impact to groundwater quality, localised data on aquifer hydraulic conductivity and geochemical processes would be more critical.

The data required for effective groundwater management fall under the following general headings:

- Geological data (includes elements such as borehole logs, sediment grain size and compositional analyses, geophysical survey results, and mapping products);
- Hydrogeological data (includes elements such as aquifer or aquitard parameters and water levels);
- Climate data;
- Groundwater quality data;
- Groundwater withdrawal data; and
- Surface water data.

Geological Data

Geological information to support an understanding of groundwater flow can be extracted from various geological mapping programs undertaken by provincial geological surveys, the Geological Survey of Canada, or studies undertaken by university researchers and consultants. Hydrogeologists rely largely on borehole data as the fundamental tool in characterising the subsurface geology and hydrogeology, although as noted earlier, geophysical methods for subsurface characterisation can be effective in many settings (for example, see Pullan *et al.*, 2004). At a broader scale, information from water well records can also be used to support the conceptualisation of the regional geological setting.

Surface mapping has typically been undertaken throughout Canada at various scales and is used extensively by the hydrogeological community to support the estimation of recharge rates and to further decipher the subsurface geological environment. Many of these provincial maps are not available in a digital format and are therefore of limited value to current Geographic Information System (GIS) methods of analysis. Programs to make available high-definition surface-geology maps should be supported. The raw data used to derive various geological maps consists typically of outcrop descriptions or the geological logging of boreholes and are generally available in hard copy only.

(Courtesy of the Oak Ridges Moraine Groundwater Program)

Figure 4.2
Installing a Groundwater-Monitoring well.

In a similar vein, aquifer maps that are derived from various raw hydrogeological data can also be considered as a data source. In this regard, only British Columbia, Manitoba, and New Brunswick indicate that a systematic delineation of provincial aquifers has been undertaken. Alberta and Saskatchewan have a comprehensive suite of hydrogeological maps that provide information on groundwater availability and quality; these are interpreted by some hydrogeologists to be equivalent to aquifer maps. There have also been many provincial studies that have comprehensively characterised various aquifers in many of the provinces. Several recent studies, led by the Geological Survey of Canada (GSC), of the Oak Ridges Moraine, Châteauguay River Watershed, and Annapolis-Cornwallis Valley Aquifer, among others, have also provided insight into sedimentary geological processes and have considerably advanced the conceptual geological understanding in the areas investigated.

The last comprehensive assessment of Canada's groundwater resources was published in 1967 (Brown, 1967). Currently, efforts are underway to establish a National Groundwater Inventory and, in that regard, the Groundwater Mapping Program managed by the GSC has undertaken to assess 30 key regional aquifers (Rivera, 2005). The collaborative assessments are intended to broaden knowledge on recharge; discharge; estimation of sustainable yield; quantification of aquifer vulnerability at a regional scale; and to provide provincial and local groundwater managers with the data and information needed to make informed land-use and groundwater-allocation decisions. (See, for example, the case studies of Basses-Laurentides and Oak Ridges Moraine in Chapter 6.) With funding of roughly $3 million per year, nine of the 30 aquifers had been assessed by 2006. At current rates, however, it is expected the mapping will not be complete for almost another two decades. In view of the importance of better hydrogeological knowledge as input for models, and for better groundwater management generally, a more rapid pace of aquifer mapping is necessary.

Given the relatively immature status of aquifer mapping across the country, there appears to be a need to develop a method of categorising aquifers at different scales (provincial, regional, or local). This is a difficult task, especially in glaciated terrains where stratigraphy can vary over short distances, or in fractured rock environments where fracture networks create the aquifers. Nevertheless, the development of such a framework would help local studies link to provincial objectives of further understanding groundwater-flow systems. The existing Intergovernmental Geoscience Accord (NGSC, 2007) should be used to guide the respective roles of the GSC and the Provincial surveys with respect to this mapping initiative.

Hydrogeological Data

There are several programs that capture data on aquifer transmissivity, hydraulic conductivity and storage values. Nova Scotia, New Brunswick, and British Columbia report having a provincial database that includes this information, and Manitoba is in the early stages with paper records currently available. This exemplifies a recurring theme; although many data are collected, there are few systematic efforts to assemble them into a collective database to improve future understanding and management of the resource. In the meantime, hydrogeologists must rely on their knowledge of reports and maps on file with local agencies, or if the data have not been made public, repeat the field investigations to acquire the necessary data.

Well Data: Provincial water-well record datasets are relied upon to provide an important source of data to the groundwater industry and decision-makers across the country. Although there is no systematic national database of wells or groundwater levels across Canada, the datasets provide good spatial coverage across many parts of the country. While the geological data may be rudimentary for many of the wells, a regional understanding of subsurface aquifers can usually be determined. A shortcoming of the datasets is that they typically contain records of water wells and fail to capture the more detailed geological data obtained from boreholes drilled by technical consultants for hydrogeological or geotechnical investigations. Water wells are usually drilled using mud or air rotary techniques that provide only an approximate representation of the subsurface geology (Russell *et al.*, 1998). Depending on the aquifer sequences, water well records can reveal more aquitard information than aquifer information owing to the fact that once a suitable aquifer is encountered, the well is stopped and screened without necessarily defining the base of the aquifer. Shallow dug wells and older drilled wells are also missing from the databases and the position coordinates of many wells are only accurate to several hundred metres at best.

The panel surveyed all provinces to identify current programs and the types of groundwater information collected and to determine whether the data are readily available to the public (Table 4.1).

In Ontario, a new regulation calls for the capture of all consultant-drilled boreholes and the entry of this higher-quality geological data into the database. Saskatchewan and Alberta have, at times, maintained programs to geophysically log wells when they are drilled; Manitoba collects geophysical data from selected wells and has developed an inventory of geophysical data that is being linked to the water well record database (Box 4.2). Integration of digital data facilitates management tasks, including the interpolation of aquifers over large distances, thus reducing the long-term costs of groundwater exploration. British Columbia's water well record management program is currently voluntary, although it is understood that well logs will be mandatory in the future. Many drilled wells in that province are not in the database.

Table 4.1
Summary of Provincial Water Well Databases (August, 2007)

Province	Does the province maintain a database of water well records?	Are the data readily accessible and available to the public?
Newfoundland and Labrador	Yes	Yes — $50 charge for CD of wells drilled between 1950 and 2002 (~15,500 records)
Prince Edward Island	Yes	Yes — no charge for records; planning for web access to records
Nova Scotia	Yes	Yes — $100 charge for entire database of wells drilled between 1940 and 2004 (97,000 records)
New Brunswick	Yes	Yes — no charge for records
Québec	Yes	Yes — well records are searchable on a website at no cost
Ontario	Yes	Yes — $20 charge for individual well records; more data available by request; moving to web access (~550,000 records)
Manitoba	Yes	Yes — data available by request ~110,000 records in database from 1970 onward
Saskatchewan	Yes	Yes — no charge for records
Alberta	Yes	Yes — well records are searchable on a website at no cost
British Columbia	Yes	Yes — no charge for records

(Courtesy of William Cunningham)

Figure 4.3
Monitoring well with satellite telemetry equipment.

Box 4.2: Manitoba's Water Well Monitoring System

The mandate of the Water Stewardship Branch is to manage the province's surface water and groundwater resources to provide for the social, cultural, and economic well-being and the health and safety of present and future generations of Manitobans. The Groundwater Management Section focuses on the evaluation, monitoring and protection of groundwater. The group administers the provincial *Ground Water and Water Well Act*, undertakes studies to map aquifers, collects long-term temporal data and maintains databases of hydrogeological conditions, all with the aim of assessing the sustainability of major aquifers.

Monitoring of groundwater levels was first undertaken in the 1960s in support of the Red River Floodway. The network has grown progressively to approximately 550 monitoring wells. The 2007 program also included 250 water-quality samples and the monitoring of 35 rainfall gauges. These data were added to the database to develop a regional-scale understanding of water levels and quality. From a sustainability perspective, major aquifers have been mapped and their hydraulic properties defined through borehole geophysics and pumping tests to facilitate sustainable yield estimates.

The Province is currently undertaking a well-by-well evaluation of the network to see what value is being derived from each well and to better develop the Province's overall monitoring philosophy. This evaluation will be used to assess whether each monitoring well needs to be maintained in the network or if it is duplicating responses obtained by other wells. The evaluation process involves an analysis of the hydrographs, borehole geophysical logging, conducting a pumping test, and water sampling of all active and inactive wells if that information does not already exist. Eleven wells were decommissioned in 2006–2007 as a result of the program.

In 2006–2007, the groundwater management section operated on a budget of about $1.4 million with a staff of 14 (Government of Manitoba, 2007).

Water-Level Data: Water level information is the other key dataset that is derived from the water well records. It is impractical to develop an understanding of longer-term trends in water levels from water well records because they generally contain only one water level measurement at each well. It is obviously necessary to measure water levels over a longer time period to see trends that can lead to an understanding of how aquifers respond to drought, rainfall or snowmelt. In addition to more general day-to-day monitoring linked to water takings or other land use-changes, the requirements of which vary on a case-by-case basis and from province to province, the provinces all have active regional ambient groundwater-level monitoring networks with the number of observation wells ranging from fewer than 25 to over 500 (Table 4.2). A recent summary of the provincial groundwater monitoring networks is available from the Saskatchewan Research Council (Maathuis, 2005). In every province, except Newfoundland and Labrador and Ontario, the data are available publicly either by request or via a website. British Columbia has one internet site for real-time data where two to four days of current data are available, and a separate site where all of the data can be accessed.[16] Figure 4.3 illustrates a monitoring well equipped with telemetry equipment to provide real-time data to users. It is important that the water-level data, once collected, also be reviewed and analysed to look for long-term trends and other relevant details about the groundwater system. It is unclear how well the provinces are doing in this regard.

Climate Data

Precipitation and temperature data, in particular, are essential components of regional groundwater investigations, allowing for the estimation of evapotranspiration, groundwater recharge and runoff. Environment Canada maintains a database of climate stations, with some temperature and precipitation data from more than 11,000 stations across the country.[17] A selection of approximately 200 stations have up-to-date weather data posted hourly online while another set of stations has climate normals calculated and available. Many of the 11,000 stations are historical and no current climate information is collected. Unfortunately, it is only once the data are downloaded that one can determine how long the climate station has been active and the extent of missing data. For example, of the approximately 11,000 climate stations, only about 1,500 have climate normals; i.e., sufficient data is available to cover 15 years of activity between 1971 and 2000.[18]

16 The following websites provide data on water level monitoring programs in various provinces. In British Columbia, see http://www.env.gov.bc.ca/rfc/river_forecast/grwater.html for real-time data and http://srmapps.gov.bc.ca/apps/gwl/disclaimerInit.do for long-term data. In Alberta, see http://www.telusgeomatics.com/tgpub/ag_water/; in Saskatchewan, see http://www.swa.ca/WaterManagement/Groundwater.asp?type=ObservationWells#; in Nova Scotia see http://www.gov.ns.ca/enla/water/welldatabase.asp; and in Prince Edward Island see http://web3.gov.pe.ca/waterdata/tool.php3.

17 The complete database is available at the Environment Canada website (http://climate.weatheroffice.ec.gc.ca/Welcome_e.html) and is easily accessible.

18 To improve the service, Environment Canada could, for each climate station, provide the years of record on a map and differentiate, using different colours, the stations that are currently active versus those that are no longer monitored or maintained.

Table 4.2
Summary of Aquifer Mapping and Groundwater Monitoring Programs (August, 2007)

Province	Does the province have an inventory of aquifers?	Does the province have a program to measure groundwater levels in a monitoring network?
Newfoundland and Labrador	No	Yes — up to 25 wells in the network; the data are not accessible to the public.
Prince Edward Island	No (only one main aquifer)[19]	Yes — 13 wells are monitored in a partnership agreement with the federal government; data are accessible over the web.
Nova Scotia	No	Yes — 24 wells are monitored; data are available on a public website.
New Brunswick	Yes	Yes — up to 25 wells are monitored; the data are available by request.
Québec	No	Yes — 25 to 50 wells are currently monitored with plans to expand to between 200 and 500 wells; data are available on a public website.
Ontario	Partially — a series of consultant-led studies were undertaken in the vicinity of the municipal supply wells and the studies contain some aquifer information. There is no systematic program to develop this further.	Yes — about 460 wells are monitored in a partnership with watershed authorities; data are available only to the watershed authorities via a password-protected website.
Manitoba	Yes — at a regional scale since most of the aquifers are bedrock-related. In areas dominated by glacial sediment aquifers, there are maps that address the likelihood of finding a suitable aquifer.	Yes — 550 wells are monitored regularly, mostly in areas of groundwater withdrawals; data are available by request; the intent is to put data on the web.
Saskatchewan	Groundwater maps address the likelihood of finding groundwater supplies.	Yes — 50 to 100 wells are monitored; long-term data are available on a website.
Alberta	Groundwater maps address the likelihood of finding groundwater supplies.	Yes — over 197 Groundwater Observation Wells are monitored; data are available on a website.
British Columbia	Yes — inventory of some 900 aquifers — not necessary to delineate the full extent of the aquifer (e.g., could be delineated on the basis of a number of wells using same unit).	Yes — 163 wells are monitored; data are available on a website.

19 In Prince Edward Island, since there is a single sandstone aquifer covering the province, further aquifer mapping is unnecessary from a geological perspective.

Table 4.3 shows the extent to which each province maintains climate data in addition to the data maintained by Environment Canada. While most provinces tend to rely on Environment Canada, many report data from additional meteorological stations, although these stations are typically operated intermittently as part of a localised research project, or for some other specific purpose. The stations are inadequate for providing a year-round accounting of precipitation or temperature for the purposes of groundwater management. In the case of three provinces (Newfoundland and Labrador, Manitoba and British Columbia), programs to collect some climate data are in place, but only for part of the year. Ontario does not maintain climate stations of its own, but for source-water protection initiatives, the province has regenerated missing data from Environment Canada's stations in order to make the data more useful for ongoing source-water protection work.

Only three provinces, New Brunswick, Québec, and Alberta, have programs to supplement the Environment Canada data. With regard to public access to data, Québec allows for a web-based search of their stations to see what types of data are collected at each station.[20] Specific data requests can be made directly to the province. Alberta allows real-time data (on both precipitation and streamflow) to be viewed through a web portal.[21] Historical data do not appear on the website and access requires a direct inquiry to the province. New Brunswick's website only allows for the searching, by month and year, of a summary of the precipitation, streamflows and groundwater-level data.[22]

Table 4.3
Provincial Climate Data Collection (August, 2007)

Province	Does the province have a program to collect climate data?	If yes, are the data readily accessible and available to the public?
Newfoundland and Labrador	Yes — for winter road conditions	
Prince Edward Island	No	
Nova Scotia	No	
New Brunswick	Yes — no specific information provided	Yes
Québec	Yes — 155 stations run by Province	Yes
Ontario	No	
Manitoba	Yes — but only operated in growing season	Yes
Saskatchewan	No	
Alberta	Yes	Yes
British Columbia	Yes — for snowpack in mountains	

20 For more information on Québec's online climate data, see Surveillance du climat website at: http://www.mddep.gouv.qc.ca/climat/surveillance/index.asp.

21 For more information on Alberta's online climate data, see Alberta's River Basins website at: http://environment.alberta.ca/apps/basins/default.aspx.

22 For more information on New Brunswick's online climate data, see New Brunswick's Water Quantity Information website at: http://www.gnb.ca/0009/0371/0007/0006-e.asp.

Surface Water Data

Streamflow, or the amount of water that flows from a watershed, is an important component of the water budget and can significantly contribute to an understanding of subsurface hydrogeological conditions. In cases where the groundwater-flow system generally reflects the surface-water divide, streamflow data can better constrain estimates of recharge to the groundwater system.

Environment Canada, in cooperation with the provinces, some municipalities and industries, jointly operates a network of streamflow gauges, generally known as the HYDAT network.[23] There are currently 2,844 stations in operation, of which roughly half transmit data in real-time, but data from 5,577 inactive stations remain available in the database (WSC, 2006). The database is available through the Environment Canada website and allows for querying historical data by station and year.

Most provinces rely on the HYDAT network for all of their surface-water flow needs. Table 4.4 summarises the streamflow data collection initiatives of the provinces. Only Québec and Alberta have gauged stream locations above and beyond the HYDAT network. Alberta's River Basins web site, which incorporates more than just the HYDAT stations, is a particularly useful source of real-time data in a tabular format.[24] HYDAT gauging station locations are selected based on the needs of the funding partner and serve a number of specific purposes ranging from flood control to hydroelectric power generation to municipal water supply. From a groundwater perspective, this means that there are numerous watersheds, especially in the northern parts of the country, but also in the south, where no public streamflow measurements have been taken or where gauges are located higher up in a watershed and do not permit determination of how much water is actually leaving the lower reaches of a watershed. Furthermore, it is rare that climate, streamflow and groundwater levels are all measured at the same location within the basin, making correlation of some data difficult.

23 HYDAT stands for Hydroclimatological Data Retrieval Program. Environment Canada has a website (http://www.wsc.ec.gc.ca/index_e.cfm) where the data can be downloaded on an annual basis since 1991 (previous data are available in hard copy) for a fee of $100.

24 For more information on Alberta's online streamflow data, see Alberta's River Basins website at: http://environment.alberta.ca/apps/basins/default.aspx.

Table 4.4
Provincial Streamflow Data Collection (August, 2007)

Province	In addition to Environment Canada's HYDAT data, does the province have a program to collect streamflow data?	If yes, are the data readily accessible and available to the public?
Newfoundland and Labrador	No	
Prince Edward Island	No	
Nova Scotia	No	
New Brunswick	No	
Québec	Yes — 158 stations run by province.	Yes — by request, although an increasing number are online.
Ontario	Partially — Some conservation authorities have programs to collect additional streamflow data but this is not mandated by the province and the data are not collated at a provincial level.	
Manitoba	No	
Saskatchewan	No	
Alberta	Yes	Yes — real-time available on website; historical data by request.
British Columbia	No	

Groundwater Quality

There is considerable disparity in the requirement for, and the thoroughness of, groundwater quality monitoring across the country. In Alberta, for example, water-well drillers are required only to submit the drill logs to Alberta Environment. They may advise that the well owner should have groundwater quality analysed, but there is no requirement for conducting the analysis. The only sample likely to be collected may be for bacteria or coliform. (There are groundwater testing requirements related to the drilling of shallow coalbed-methane (CBM) wells, but they target a specific subset of domestic-water wells within a 0.6-kilometre radius of a CBM well (ERCB, 2006). Requirements vary from province to province with respect to water-quality data for newly drilled domestic wells, but typically only bacteria or coliform testing is required.

Mandatory testing for water quality of all newly constructed or re-drilled water wells in New Brunswick was introduced under the Potable Water Regulation in 1994

(Government of NB, 1989; Government of NB, 1993). Before work begins on a well, a licensed drilling contractor collects the testing fee from the well owner. The well owner must then submit the voucher and a water sample from the well after it has been subject to normal usage. The water sample is tested at a provincially operated laboratory for total coliform and *E. coli,* as well as a range of inorganic parameters such as calcium, chloride, iron, fluoride, and arsenic. The well owner is notified of the results and the Department of Environment maintains the data in a province-wide groundwater database, along with the "Water Well Drillers Report". Under the Potable Water Regulation, the testing results are treated as confidential and may be released only with the permission of the well owner, or in an aggregate format that does not identify the individual well from which the sample was retrieved. During the 2006–2007 fiscal year, the Department of Environment analysed samples from 1,356 new or re-drilled wells, which represented a redemption rate of 66 per cent for the testing vouchers. During the same time period, water-well information, including water quality, was provided in response to over 750 requests from professional consultants conducting a variety of assessments (NB DoE, 2007).

Assessments of groundwater monitoring must distinguish between regional monitoring of background water quality and site-specific monitoring of known or suspected groundwater contamination. Regional background monitoring usually focuses on the potential exceedances of naturally occurring contaminants such as arsenic or fluoride, and possibly, non-point agricultural pollutants such as nitrate. It is often carried out by provincial agencies in their regional monitoring-well networks in concert with water-level measurement programs (although chemical samples do not need to be taken nearly as often as water-level measurements, given the unlikelihood of any rapid changes in regional water quality).

Site-specific monitoring programs are designed to detect the occurrence of anthropogenic contaminants, like solvents or hydrocarbons, arising from point sources such as leaking waste-disposal facilities or industrial spills. They usually require many monitoring wells, perhaps even including some with sophisticated multi-depth sampling points. Such monitoring networks are designed to quantify the presence and extent of contamination and aid in the selection of appropriate remedial action. They are usually installed by private contractors, hired by site owners, and operated under the scrutiny of provincial regulators.

The design of monitoring-well networks that are effective and cost-efficient for either purpose is a difficult task and further research is needed in this area. Furthermore, the design and installation of individual monitoring wells requires great care in order to avoid the introduction of spurious chemicals into the subsurface environment. Proper protocols have been developed in recent years (Nielsen, 2006), but are time-consuming and expensive. Monitoring groundwater quality is much more difficult than it would appear, and reliable data are not easy to come by.

It is the panel's opinion that while there is a need for improved groundwater-quality data across the country, particularly with respect to benchmarking baseline conditions so that long-term changes can be properly documented, it is recognised that specific monitoring initiatives can be very costly without direct corresponding benefits. Water-quality monitoring programs are probably best developed on a case-by-case basis by individual provinces and local agencies, although coordination of effort at a limited number of sites is needed to permit assessments of national or large-scale regional trends. There may be a need for a sparse monitoring network, coordinated on a national scale, to detect any large-scale trends in groundwater quality due to changes in the chemical composition of global or regional precipitation.

Groundwater Withdrawals

As discussed in Chapter 1, the collection of data on groundwater withdrawals is spotty across the country and many major users of groundwater are not required to regularly report their extractions. This is information that is essential for groundwater management, and the costs of collecting such information could largely be borne by the users with only minor implications for public sector budgets.

4.5 MANAGING THE COLLECTION AND SHARING OF DATA

Managing the collection and sharing of Canada's groundwater monitoring data, including water levels and quality, requires substantial improvements, particularly with respect to ambient background conditions and trends. As documented in the preceding sections, all provinces and local agencies have ongoing water level monitoring programs. But the number of observation points is generally insufficient and water-quality data are not a priority of these programs. Systematic analyses of these data are not done in many cases and no mechanism exists to identify new and emerging potential threats or to evaluate the need for action to monitor or remediate, except in a reactive mode.

An important objective of data acquisition and management is to bridge agency and disciplinary boundaries and to compile an integrated, comprehensive database covering geology, groundwater, surface water and climate-related information across the catchment area. This broad scope recognises that water management cannot stop at municipal boundaries and that a broad range of data sources needs to be tapped to establish the foundation for credible groundwater decision-making and effective long-term resource management. Management of the database should also seek to capture high-quality data collected by technical consultants that would otherwise be lost in archived paper reports. In Ontario, for example, the same data have been found to be repeatedly collected at the same location, sometimes several decades apart, simply because there is no formal database to house such information.

Water management in Canada, as in many countries, crosses multiple levels of government and several departments within each government. Approaches used in the United States and elsewhere to address this inherent fragmentation contain relevant lessons for groundwater data and information management across Canada. One promising approach would be to provide access to groundwater-related data through a database system similar to the National Water Information System of the United States Geological Survey (Box 4.3). This requires a common database structure, shared among water resource departments, that would facilitate a common portal to publicly disseminate the data, minimise staff support needed to maintain groundwater databases and remove duplication of effort to assemble and maintain the data. Ongoing Canadian initiatives in this regard are outlined in the following paragraphs.

Groundwater Information Network: A group of federal, provincial and watershed agencies is working in partnership with the national GeoConnections[25] program to develop a Groundwater Information Network (GIN). The GIN is developing standards for data management to facilitate sharing of information. Groundwater monitoring at all levels must be more strongly supported and a platform for sharing data, such as the GIN, needs to be developed through federal-provincial cooperation. Universities and technical consultants who undertake data-collection field activities, but generally do not contribute to public groundwater databases, are encouraged to do so.

Water Well Mapping and Analysis System: This project is an initial component of GIN and seeks to add 'depth' to the Canadian Geospatial Data Infrastructure (CGDI) by making well log records available from several major groundwater data providers. The stimulus for this project came from the Canadian Framework for Collaboration on Groundwater (Rivera *et al.*, 2003). Ontario, Manitoba, Alberta, British Columbia and Nova Scotia have agreed to participate with Natural Resources Canada (NRCan) in the project by sharing their well water information.

---

25 GeoConnections is a federal initiative to leverage the power of the internet to access terrain science data compiled by federal departments, primarily in the form of maps and satellite imagery. The program is founded on the Canadian Geospatial Data Infrastructure that provides for storage and access to virtually any form of location-based information.

By developing a web-based standard data structure for drill logs (called Groundwater Markup Language)[26] and following CGDI data access protocols, the project enables online access to existing well log databases located in the partnering provinces. It is envisaged that, over time, partners to the project will expand beyond the provinces to include other groups and agencies with significant well log holdings. In addition to enabling access to groundwater information, the project will also provide web-based tools to visualise, analyse, and integrate the well log records. This is facilitated by third-party software developers who leverage the common data standards.

Box 4.3: Groundwater Data Management & Access in the US

The United States does not have a comprehensive national groundwater database. Rather, data on groundwater quality and level are collected and stored by federal water agencies, most state agencies, and some local entities. Much of the data collected by states is publicly available on the internet. Extensive amounts of groundwater-related data are also made available online through mission-based national programs led by both the United States Environmental Protection Agency (EPA) and the United States Geological Survey (USGS). In addition, a web portal is under development by the Consortium of Universities for the Advancement of Hydrological Science.

The EPA maintains two data management systems containing water-quality information: the Legacy Data Center and STORET. These are primarily surface-water quality systems, but groundwater quality data from approximately 75,000 wells are also available.[27]

The USGS monitors the quantity and quality of water in the nation's rivers and aquifers, assesses the sources and fate of contaminants in aquatic systems, develops tools to improve the application of hydrological information, and ensures that its information and tools are available to all potential users. This diverse mission cannot be accomplished effectively without the contributions of the Cooperative Water Program (CWP) (USGS, 2008b). For more than 100 years, the CWP has been a highly successful cost-sharing partnership between the USGS and water-resource agencies at the state, local, and tribal levels. The CWP has contributed significantly to meeting USGS mission requirements and keeping the agency focused on real-world problems. The linkage to local and state water-resource needs also ensures that the program responds quickly to emerging issues.

26 Groundwater Markup Language (GWML) is being developed mainly in Canada with the input of international collaborators in the United States, Europe and Australia. It is still in development and not yet in use.

27 For more information on the Legacy Data Center and STORET, see http://www.epa.gov/storet.

The USGS and Cooperators jointly plan the scientific work performed within the CWP. The result is a national program with broad relevance and widespread use of its products. Because rivers and aquifers cross jurisdictional lines, studies and data collected in one county or state have great value in adjacent jurisdictions. Through the CWP, the USGS ensures that the information can be shared and is comparable from one jurisdiction to the next.

Cooperators choose to work with the USGS because of the agency's broad technical expertise, its long-standing record of performing high-quality measurements and assessments, and its commitment to providing public access to data collected under the CWP. Because the USGS is a scientific, non-regulatory body, parties in many types of regulatory and jurisdictional disputes accept its data and analyses as impartial and valid.

Within the Cooperative Water Program, about half of the funds (which totalled $215 million USD in 2004, almost two-thirds of which was provided by the Cooperators) are used to support data-collection activities, the remainder being used for interpretive studies. The USGS compiles and analyses information resulting from these activities into regional and national synthesis products.

The National Water Information System (NWIS) supports the acquisition, processing, and dissemination of information about water quantity and quality collected at over 1.5 million sites around the United States. The NWISWeb system[28] is a publicly accessible, aggregated compilation of data (from 48 local NWIS systems) that contains water levels from about 800,000 wells and water-quality data from more than 300,000 wells. The NWIS is both a work-flow application and a long-term database. It contains not only groundwater quality and levels, but also surface water data (e.g., quality, flow, stage, and discharge). The NWIS provides continuous access to data collected over the last 100 years, as well as telemetered surface water, groundwater, and water quality data. The real-time data processing feature enables data transmitted via satellite or other telemetry to be processed and made publicly available on the web site within 5 to 10 minutes after transmission. Currently, more than 1,000 wells have real-time groundwater level instrumentation. Data from these wells are used to assist with many State and local programs such as drought designation, salinity monitoring and well-field management. To help sift through the data, management tools are made available through web-based systems to provide 'at-a-glance' reporting on the location of wells and the status of the most recent measurements. A variety of national networks have been designed based on data in the NWISWeb system.

There is an effort underway in the United States to create a more comprehensive, national source of water monitoring data. The Advisory Committee on Water Information

28 For more information on the NWISWeb system, see http://waterdata.usgs.gov/nwis/gw.

(ACWI) represents the interests of water information users and professionals in advising the federal government on water-information programs (USGS, 2008a). In January 2007, ACWI established a Subcommittee on Ground Water (SOGW), consisting of federal, state, business and academic volunteers, to encourage implementation of a nationwide, long-term groundwater quantity and quality monitoring framework. The effort is analogous to the recent European groundwater initiative under the European Community Water Framework Directive. A report from the SOGW, released in 2009, provides a framework for a 'network of networks' among state and federal agency groundwater monitoring networks.

The SOGW is reviewing various models for an information portal, including the Hydrological Information System (HIS) of the Consortium of Universities for the Advancement of Hydrological Science (CUAHSI). CUAHSI, which represents more than 100 United States universities, receives funding from the National Science Foundation to develop infrastructure and services for the advancement of hydrological science and education in the United States, and has specifically been funded to develop the HIS.[29] The HIS portal intends to make the nation's water information universally accessible, while also providing access to the original data sources. The portal will transparently access a geographically distributed network of hydrological data sources using web services. The HIS user will be able to see the locations of data sources from various agencies, identify all of the data of interest, and obtain these data with a single request.

National Groundwater Database (NGD): The NGD is an established and growing groundwater database with two roles: (i) it is the database engine and structure behind GIN; and (ii) it is the information management vehicle for the GSC groundwater mapping program. As part of its internal information management strategy, the management of the NGD proposes to establish standard types of data, which will be publicly disseminated, for the various projects of the groundwater mapping program. NRCan projects will be responsible for adding to these standard layers as part of their project activities.

National Land and Water Information Service: Agriculture Canada is investing $100 million over four years to establish a national web-based source of information of agricultural and environmental data on land use, soil, water, climate, and biodiversity to primarily assist agricultural land-use decision-makers (AAFC, 2009).

29 For more information on the CUAHSI Hydrological Information System, see http://www.cuahsi.org/his.html.

National Atlas: The Atlas of Canada intends to integrate groundwater maps from NRCan with other social, environmental and economic themes at national, continental and global scales. This will provide the geographical context to help explain the significance of the science knowledge collected by the groundwater program. A variety of groundwater-related maps will be included, initially at a national scale.

National Water Atlas: The Atlas of Canada is teaming up with Environment Canada, Agriculture and Agri-Food Canada, and Statistics Canada to create a web-based Water Atlas to provide an up-to-date and reliable accounting of Canada's water at a national scale. The maps are intended to provide a scientific and general overview of the state of the quality and quantity of water in Canada. Initial plans suggest it will be hosted by the Atlas of Canada, with a tentative completion date of 2010.

REVIEW OF KEY POINTS

Groundwater Knowledge and Science for Sustainable Management

- Four investigative components, when managed in an integrated manner, can inform decisions as to the sustainable use of groundwater: (i) a comprehensive water database, (ii) an understanding of the geological framework, (iii) a quantitative description of the hydrogeological regime, and (iv) an appropriate groundwater model.
- Hydrogeological studies, including aquifer mapping and characterisation, have been effective in integrating groundwater concerns into the land-use management process, provided, of course, that the groundwater investigations precede the land-use development.

Groundwater Modelling in Practice

- In most provinces, the use of models by regulatory agencies lags behind state-of-the-art application. Thus, as governmental authorities increasingly seek sustainable groundwater allocation strategies, there is a need to improve their capacity to employ catchment-scale groundwater management models.
- To be most effective, numerical groundwater models must provide sound hydrogeological input to decision-makers, together with transparent documentation that highlights both the strengths and weaknesses of the model. In particular, it is imperative that model output uncertainty be explained by modellers to decision-makers.
- Modelling needs to be viewed as an ongoing process. As additional field data are collected, the model needs to be adjusted and recalibrated periodically. This 'living model' approach is well suited to an adaptive management philosophy.

State of Knowledge

- Models that couple atmosphere, land surface, hydrology and groundwater need development to enable better assessment of the impacts of land-use change and of climate change and variability.
- Models reflecting links between economic activity and groundwater are not common and have tended to be devoted primarily to the use of groundwater by the agriculture sector.
- Much of the current hydrogeological research in Canada is focused on groundwater quality, although increasing attention is being paid to sustainability, integrated groundwater-surface-water studies and aquifer characterisation.

Aquifer Mapping and Characterisation

- The last comprehensive assessment of Canada's groundwater resources was published in 1967. The Groundwater Mapping Program managed by the GSC aims to assess 30 key regional aquifers; only nine assessments have been completed.

At current rates, it is expected that the mapping will not be complete for almost two decades. In view of the importance of better hydrogeological knowledge as input for models and for better groundwater management generally, a more rapid pace of aquifer mapping is necessary.

Groundwater Quality Monitoring

- There is considerable disparity in the requirement for, and the thoroughness of, groundwater-quality monitoring across the country. Specific groundwater-quality monitoring can be very costly without direct commensurate benefits. Monitoring programs are best developed on a case-by-case basis by individual provinces and local agencies, although coordination of effort at a limited number of sites is needed to permit assessments of national or large-scale regional trends.

Groundwater Data Collection and Integration

- In general, the level of resources dedicated to systematic water-related data collection has failed to keep pace with the demands of land development and in some cases has declined over the past 20 years. Moreover, systematic efforts to assemble groundwater-related data into a readily accessible pan-Canadian information management system have been limited. The collection, maintenance, and management of existing and newly collected groundwater-related data, and ready access to these data, should be viewed as a priority for action across the country.
- Approaches used in the United States and elsewhere to address the fragmentation of groundwater data and information management contain relevant lessons for Canada (for example, the National Water Information System of the United States Geological Survey).

5 Groundwater Management and Decision-Making

This chapter addresses primarily the remaining goals of sustainable groundwater management, namely the achievement of socio-economic well-being and the application of good governance. A description of the jurisdictional environment in Canada provides context. Issues related to the good governance of groundwater are illustrated in Section 5.2, primarily through examples and a discussion of current provincial and local practices, including the technical and legislative aspects of drinking-water standards. The achievement of socio-economic well-being is addressed in Section 5.3, with particular emphasis on the potential for the broader application of economic instruments to encourage the sustainable use of groundwater in Canada.

5.1 GROUNDWATER JURISDICTION IN CANADA

The Constitution of Canada distributes among the federal and provincial governments the powers to make laws and to own and manage property. Water is not specifically mentioned as a constitutional head of power for either of these orders of government. The provinces have the primary legal jurisdiction through their powers of ownership over public land.

Primary Provincial Role

Legislative powers derived from the Constitution give the provinces the primary role in water management, including jurisdiction to regulate:

- management and sale of public lands;
- property and civil rights;
- local works and undertakings;
- municipal institutions; and
- generally all matters of a local or private nature.

The provinces, as the primary regulators of groundwater, map and monitor the resource; assess its recharge and discharge; evaluate sustainable yield; develop and maintain models; assess groundwater extraction impacts on streamflows and groundwater-surface-water interactions; collect and compile groundwater information; and generally manage groundwater resources. Provincial regulations also set well construction and closure standards, establish licensing or registration systems for well drillers, and specify water testing and chemical analysis requirements for new and altered wells.

To carry out these essential roles, each province has staff and resources dedicated to groundwater management. Provinces take different approaches to their management responsibilities, and the various provincial legal frameworks vary accordingly (Nowlan, 2005). New Brunswick's approach, for example, has generally been viewed as successful. Its Wellfield Protected Area Designation Order gives regulators the authority to identify and protect the entire recharge area associated with and surrounding a wellfield by setting out three subzones. Each subzone has specific restrictions on permitted land uses and activities to account for the differences among contaminants that persist in the environment for different time frames, move at different rates, and pose different health risks. Similar approaches are used in other provinces. Saskatchewan uses aquifer management plans. Since 2006, Ontario requires source-protection plans for drinking-water sources, and Québec protects groundwater catchments under the *Règlement sur le captage des eaux souterraines*.

Significant Federal Role

The federal government also has legislative and proprietary powers to manage groundwater on federal lands, including national parks and military bases. The main constitutional powers of the federal government related to water, though not always relevant to groundwater, include jurisdiction over:

- boundary and transboundary waters shared with the United States;
- sea-coast and inland fisheries (including fish habitat);
- interprovincial watercourses (shared with provinces);
- international or interprovincial 'works and undertakings' (which the courts have interpreted to cover pipelines);
- federal works and undertakings;
- canals, harbours, rivers, and lake improvements;
- national parks; and
- Indians and lands reserved for Indians. (Canada's aboriginal population is much broader than the group covered by the *Indian Act* and includes Inuit, non-status Indians, Métis, and status Indians not resident on reserves — persons for whom the federal government does not have formal water responsibilities.)

The federal Parliament also has wide powers over the environment stemming from the constitutional responsibility for the "peace, order, and good government" of Canada; the criminal law, which may be used to protect public safety or health; the power to negotiate and implement international treaties,[30] but only if the subject matter of the treaty falls within federal jurisdiction; and, perhaps of most relevance to water, spending power.

30 The federal government also has the constitutional authority to implement Empire treaties, i.e., treaties originally concluded by the British Empire on Canada's behalf. The Boundary Waters Treaty is the most important example of this type of treaty with respect to water.

Water Agreements with the United States: Boundary water is the subject of the 1909 International Boundary Waters Treaty (BWT) with the United States, one of Canada's oldest resource treaties.[31] The treaty includes, among several provisions, the obligation not to cause pollution that will injure health or property in the boundary waters of the other party. The scope of the treaty is limited to the lakes and rivers along the Canada-US border and thus excludes groundwater. The institution that implements this treaty is the International Joint Commission (IJC). While traditionally focusing on shared surface waters, it has also had to examine groundwater as part of its mission. The IJC has recommended that the Canadian and United States governments take an ecosystem approach to managing the US-Canadian international watersheds, including the creation of joint watershed boards, which would presumably also affect groundwater management.

Other Canada-US water agreements include the 1961 Columbia River Treaty, the 1972 Great Lakes Water Quality Agreement, and a remarkably large number of additional formal and informal agreements, in place mostly within the framework of the BWT. With respect to the Great Lakes, an agreement was reached in December 2005 among the eight states that border the lakes and the provinces of Ontario and Québec. It has now been approved by all jurisdictions, including the United States Congress.

This agreement aims to limit and regulate transfers of water out of the basin and will affect groundwater in the basin. Ontario recently passed the *Safeguarding and Sustaining Ontario's Water Act* (Government of Ontario, 2007) that also seeks to implement the provisions of the 2005 Agreement. A case study on groundwater in the Great Lakes is presented in Chapter 6.

Multinational Agreements: National rules are influenced by international law. International treaties on biodiversity and climate change, for example, affect Canada's freshwater management responsibilities. Recent rules on transboundary aquifers have been proposed by the Drafting Committee of the United Nations International Law Commission, but are not yet legally binding.[32] Canada has

31 Boundary waters are bodies of water, such as the Great Lakes, that form part of the international boundary. For the purpose of this treaty, boundary waters are defined as the waters from main shore to main shore of the lakes and rivers and connecting waterways, or the portions thereof, along which the international boundary between the United States and the Dominion of Canada passes, including all bays, arms, and inlets thereof, but not including tributary waters which in their natural channels would flow into such lakes, rivers, and waterways, or waters flowing from such lakes, rivers, and waterways, or the waters of rivers flowing across the boundary.

32 The UN International Law Commission's Draft Articles on the *Law of Transboundary Aquifers* were adopted on first reading in 2006 and were submitted to governments for comments and observations on January 1, 2008 (United Nations, 2008).

Box 5.1: The European Union's Water Framework Directive

The European Union's Water Framework Directive (WFD) was adopted in October 2000 to guide national-level action aimed at restoring water quality and managing quantity sustainably (EU, 2000). Key themes of the WFD are action on a basin scale, requiring cooperation among basin states, and a focus on water quality, whereby states are to assess and rank basin-water quality and deliver 'good' water status by 2015.

By focusing on basins, the WFD provides for the integrated management of groundwater and surface water for the first time at a pan-European level. In addition, groundwater quantity is specifically addressed in the directive, with abstraction limited to that portion of the overall recharge not needed by the ecology of the watershed.

From a quality perspective, the directive adopts a 'precautionary approach' and prohibits the outright discharge of contaminants to groundwater and requires monitoring to document possible indirect discharges. The premise of this approach is that, as a stock resource, groundwater should not be polluted at all. It is noted that nitrates and pesticides, as non-point sources, are controlled by chemical quality standards.

Further direction was provided in a 2006 Groundwater Directive which, *inter alia*, requires member states to:

- define and categorise groundwater bodies within basins on the basis of the pressures and impacts of human activity on the quality of groundwater (this was completed in 2004 and 2005);
- establish registers of protected areas within basins for groundwater habitats and species directly dependent on water (the registers must include all bodies of water used for the extraction of drinking water and all protected areas);
- establish groundwater monitoring networks based on the results of the classification analysis so as to provide a comprehensive overview of groundwater chemical and quantitative status;
- set up a river-basin management plan for each basin to include a summary of pressures and impacts of human activity on groundwater status, a monitoring of results, an economic analysis of water use, a protection program and control or remediation measures;
- by 2010, take into account the principle of cost recovery for water services, including environmental and resource costs, in accordance with the 'polluter pays' principle; and
- establish, by the end of 2009, a program of measures for achieving WFD environmental objectives — namely abstraction control and pollution control measures that would be operational by the end of 2012.

entered into significant free-trade agreements that may have implications for water management; however, this remains an unresolved issue.[33]

In some parts of the world, effective management coordination has been achieved in spite of complex jurisdictional issues. A notable example is the European Union Water Framework Directive (Box 5.1).

Shared Responsibility Over Water

The Constitution gives formal, shared, water-management responsibilities to both the federal and provincial governments in relation to agriculture. In practice, these two orders of government also share responsibility for interprovincial water issues and health, among other issues.

The *Canada Water Act* (Government of Canada, 1985b), originally passed in 1970, but seldom used in recent years, enables the federal government to enter into agreements with the provinces and territories to undertake comprehensive river-basin studies; to monitor, collect data and establish inventories; and to designate water quality management agencies. The Act also gives the federal government the power to act unilaterally, a power it has not used. Other federal water laws relevant to groundwater are: the *Fisheries Act* (Government of Canada, 1985c), which prohibits damage to fish habitat and the deposit of deleterious substances in fish-bearing waters and which may be useful to protect groundwater essential to fish habitat; the *Canadian Environmental Protection Act* (Government of Canada, 1999), which controls toxic substances and prevents pollution; the *Canadian Environmental Assessment Act* (Government of Canada, 1992); and the *Species at Risk Act* (Government of Canada, 2002).

In the 1987 Federal Water Policy (Environment Canada, 1987), the Government of Canada committed to a number of actions, such as developing national guidelines for groundwater assessment and protection, and measures to achieve appropriate groundwater quality in transboundary waters. The policy presents the federal government's philosophy and goals as to how water should be managed in Canada in the best interest of Canadians, now and in the future, under a joint and cooperative management approach with the provinces. The policy remains largely unimplemented and remains in the public domain for information purposes only (Box 5.2).

33 See Joseph Cumming, "NAFTA Chapter XI and Canada's environmental sovereignty: investment flows, article 1110 and Alberta's *Water Act*" (Cumming and Foroehlich, 2007). This article addresses the potential effect of Chapter XI of the North American Free Trade Agreement (NAFTA) on Canada's ability to effectively protect its natural resources through regulation. Specifically, the article discusses a Case Study involving Alberta's *Water Act* and how its objectives could be undermined by Article 1110 of NAFTA.

Box 5.2: 1987 Federal Water Policy

The Federal Water Policy was formulated in the aftermath of a public inquiry on water management led by University of British Columbia Professor, Peter Pearse. The "Pearse Inquiry" marked a paradigm shift in Canada (which also occurred in many other countries) from water policies employed as vehicles for economic development to water policies for the effective long-term management of the resource itself.

Under a joint and cooperative management approach with the provinces, the policy was based on two goals: (i) to protect and enhance the quality of the resource, and (ii) to promote the wise and efficient management and use of the resource. Five strategies were recommended to aid in the implementation of the goals:

- water pricing to reflect the full value of the resource and to serve as a means of controlling demand;
- science leadership to encourage research into current and emerging issues and further develop the data structures to improve the knowledge base available to decision-makers;
- integrated planning on a watershed basis, recognised as the best scale for water management and also the scale most conducive to joint federal, provincial and municipal cooperation;
- legislation renewal to address water challenges, including inter-jurisdictional issues and the control of toxic chemicals in the water cycle; and
- public awareness programs to communicate to Canadians the pressures on their water resources (and the consequences for themselves) so as to encourage the uptake of policy initiatives.

Individual policy statements addressed the many facets of water use and value, including groundwater contamination, safe drinking water, climate change, and data and information needs, among others.

In 2005, the Report of the Commissioner of the Environment and Sustainable Development criticised the government for its "stagnant federal water policy" (CESD, 2005).

Municipal Regulation

Municipalities derive their powers from the provinces. Areas of delegated municipal jurisdiction typically include the power to make land-use and local environmental bylaws. A Supreme Court of Canada decision in 2001 affirmed the right of municipalities to pass bylaws to protect the health of their citizens and the environment (SCC, 2001). Local governments supply water to users on a central system.

They do not issue permits for water takings or allocations. In fact, local governments require a permit from the province for water takings to supply their own systems. Local governments are directly involved in groundwater management in cases where groundwater is a source of municipal water supply, and indirectly through land-use decisions that have the potential to contaminate groundwater.

There is an increasing trend for provinces to delegate groundwater management responsibilities to local governments and multi-stakeholder bodies. This effort is likely to be most successful where the provinces have ensured that delegation is supported by sufficient financial and human resources and where there is a requirement to take action and report back on progress.

In the view of the panel, management of groundwater and land use should be fully integrated. Some integration is beginning to occur through source-water and wellhead protection plans. At a broader scale, aquifer vulnerability maps are increasingly used as tools to guide municipal land-use decisions. Integration is, however, still often incomplete due to:

- inadequate data for assessing the impact of land-use change on recharge and runoff;
- little capacity of municipal governments to effectively implement provincial policy statements as land-use changes are approved;
- little enforcement of best management practices that are recommended, or even mandated, as part of an approved land-use change or in farm land management; and
- prevalence of local political pressure to ensure that new tax-paying land-use changes are smoothly approved.

Aboriginal and Treaty Rights to Water

Though there has been no specific judicial consideration of an Aboriginal right to the use of water, it is reasonable to assume the existence of a right to use water for traditional purposes such as fishing and transportation (Bartlett, 1988). Both federal and provincial governments have a duty to consult aboriginal groups when resource and land-use decisions may affect their rights. The provision of clean drinking water in aboriginal communities across Canada is an ongoing problem that these communities and the federal government are attempting to resolve. (Exact figures on the number of Aboriginal communities reliant on groundwater for drinking water are not available.)

Although a number of federal laws govern water and wastewater on reserve lands, no one law regulates this issue, and the 2006 report of the Expert Panel on Safe Drinking Water for First Nations noted the ‘considerable disadvantage’ of the patchwork of federal laws, and the numerous advantages of new federal legislation on this topic, i.e., a bridge to self-government, improving capacity of First Nations to deal with water issues, uniform standards for all First Nations, and greater accountability (Government of Canada, 2006a; Government of Canada, 2006b).

Groundwater jurisdiction is also complicated by unresolved Aboriginal water interests, which include legally recognised rights, such as treaty rights, and unresolved claims of Aboriginal rights and title.[34] Recent Supreme Court of Canada (SCC) cases have affirmed the significant leverage that Aboriginal peoples have on the environmental regulatory process and a new confluence between Aboriginal and environmental law (Cassidy and Findlay, 2007). The Haida (SCC, 2004a) and Taku River (SCC, 2004b) cases both arose in the context of environmental regulations related to forestry, mining and environmental assessment. In decisions jointly released in 2004, the SCC held that the government had a duty to consult and accommodate Aboriginal interests before Aboriginal rights and title were finally determined. A subsequent case involving the Mikisew Cree and Treaty held that the duties of consultation and accommodation also applied in a treaty context (SCC, 2005).

Jurisdictional Fragmentation and Coordinating Mechanisms

The different spheres of responsibility for groundwater management overlap and therefore sometimes conflict. The problem is not so much complexity as fragmentation, often intra-jurisdictional, with a lack of coordination. For example, permit allocations made by provincial regulators may diminish baseflows to streams critical for fish habitat and biodiversity maintenance, two areas of federal responsibility (Saunders and Wenig, 2006). Another example occurs when provincially managed groundwater violates health guidelines for drinking water, affecting a municipality's ability to use that source for municipal supply. This is complicated further where groundwater migrates across the Canada-US border, which impacts on American consumers and farmers, as in the case of the Abbotsford-Sumas aquifer discussed in Chapter 6. Resolving these overlaps and conflicts is an essential prerequisite for sustainable groundwater management.

Coordinating mechanisms that involve the federal, provincial and territorial governments and that are relevant to groundwater include: the Canadian Council of Ministers of the Environment (CCME), which has a forthcoming initiative on groundwater; the Federal-Provincial-Territorial Committee on Drinking Water,

34 Aboriginal rights are rights held by Aboriginal peoples that relate to activities that are an element of a practice, custom or tradition, integral to that Aboriginal group's distinctive culture. Aboriginal title is a separate Aboriginal right to the land.

which establishes the Guidelines for Canadian Drinking Water Quality; and Federal-Provincial/Territorial Environmental Assessment Cooperation Agreements. Coordination is also required with local governments, local water users and community and environmental groups.

Interprovincial coordinating agreements on water involving the federal government include agreements related to the Prairie Provinces Water Board (PPWB, 2006), the Mackenzie River Basin Master Agreement (MRBB, 1997), and the Canada-Ontario agreement on Great Lakes water quality (Canada-Ontario Agreement, 2007). Coordination also involves Aboriginal peoples, as Aboriginal rights to water are complex, contested and an as-yet unresolved issue that affects water governance and water management in a number of ways (Woodward, 1994).

Working groups have emerged in recent years that span the federal, provincial and municipal orders of government in the interest of coordinated groundwater strategies. In 2003, a National Ad-Hoc Committee on Groundwater composed of stakeholders from federal and many, but not all, provincial groundwater agencies, as well as a few representatives of the academic and private sectors, issued the Canadian Framework for Collaboration on Groundwater (NRCan, 2003). The goals of this document were to acquire groundwater information and knowledge, improve collaboration among agencies and organisations, establish linkages among groundwater information systems, and provide a resource base accessible to all levels of government for the development of a groundwater management policy. Some of the collaborations envisioned in the report are ongoing; others have been slow to start. A meeting of Canadian government hydrogeologists in October 2007 under the auspices of the Canadian Chapter of the International Association of Hydrogeologists is further evidence of emerging cooperation at the working level, but there is still a need for a more clear-cut, formally stated division of duties among the various levels of government.

Coordination of groundwater management with local governments is also required, as many provinces are delegating an increasing number of water management responsibilities, such as watershed planning, to municipal governments or to multi-jurisdictional governance bodies. Alberta's Watershed Planning and Advisory Councils, Ontario's source-protection committees to protect sources of drinking water in Ontario's *Clean Water Act*, and Québec's Basin Organisations are three examples (Nowlan and Bakker, 2007).

The amount of decision-making authority delegated to these types of bodies varies. Most perform an advisory, rather than a regulatory, function. Delegation may be justified on the basis of the principle of subsidiarity, which has been endorsed by the Supreme Court of Canada as "the proposition that law-making and implementation are often best achieved at a level of government that is not only effective, but closest to the citizens affected and thus most responsive to their needs, local distinctiveness and population diversity" (SCC, 2001).

Overlapping jurisdiction may become a greater challenge to both surface-water and groundwater management owing to the growing interest in the watershed planning approach. Implementation of sustainable groundwater initiatives will require even greater coordination in the future to overcome the administrative divisions in Canadian water-resource management institutions. Such divisions are common between those who deal with water quantity and those who deal with water quality; between experts in groundwater and surface water; and between those responsible for water science and for water policy.

5.2 THE GOVERNANCE AND MANAGEMENT OF GROUNDWATER IN CANADA

Certain uses of groundwater are unregulated. For example, private domestic use is usually exempt from provincial licensing requirements, and most provinces do not require a permit to be obtained until a certain threshold amount of water will be used. (The threshold varies substantially from province to province.) Wells on private land are generally not regulated after commissioning. Small septic systems are regulated locally at the time of installation but subject to only limited monitoring after installation. Federally regulated lands (First Nations reserves,[35] national parks, military bases, prisons) and entities (airlines, banks, and railways) have no specific water regulations.

Policy Tools for Achieving Sustainability

A number of policy instruments exist to help achieve the sustainable management of groundwater. Regulations on groundwater allocation and prevention of contamination are one group of tools, but they vary widely from province to province. Economic instruments are also created by regulation, and they seek to shape the economic environment in which users make decisions regarding their water use and discharges. Common law remedies may also be used to protect the environment. Voluntary codes of practice and nonbinding standards, including the Canadian Drinking Water Guidelines, constitute another group of tools. Agricultural waste and well construction may be controlled by either codes of practice or regulations in different parts of Canada.

35 The recent Report of the Expert Panel on Safe Drinking Water for First Nations considered the options for regulating safe drinking water on reserves and recommended three potential options (Government of Canada, 2006a).

Efforts to regulate groundwater allocation and the prevention of contamination are challenged by informational deficiencies. Private groundwater withdrawals are often not measured, and the impacts of these withdrawals on groundwater levels and quality may not be well understood. In the words of one analyst, "very few (if any) commodities possess as many idiosyncratic characteristics as groundwater" (Kondouri, 2004). Perhaps as a result, water-related policies and regulations have typically been concerned with influencing the 'quantity' of water used, or the 'quality' of water, but rarely both together. Unfortunately, much of the research literature reflects this artificial separation. Policies aimed at influencing the allocation of specific quantities of water are considered in isolation from policies aimed at achieving a specified level of water quality or from policies resulting in groundwater quality changes as a consequence of excessive abstraction. Sustainable water management clearly involves both quantity and quality as acknowledged in the framework of the five interrelated goals introduced in Chapter 2. The legal framework nevertheless treats quantity and quality separately. Water laws regulate access, allocation, and water quantity; health, environmental and sector-specific laws regulate water quality.

Overview of Provincial Regulation of Groundwater

All provinces manage groundwater through regulations for well construction, maintenance and abandonment, as well as licensing and registration requirements for well drillers. Many provincial laws envision that groundwater will be included in water or watershed plans, though the degree to which this occurs varies from province to province. Ontario passed a *Clean Water Act* (Government of Ontario, 2006) in October 2006 that is anticipated to have positive implications for groundwater protection. The focus of the legislation is to protect present sources and existing future sources of drinking water through (i) assessment of threats to both surface and groundwater in vulnerable areas; (ii) formation of multi-stakeholder source-water protection committees that develop plans to address source-water threats; and (iii) adoption and implementation of plans by municipalities once approved by the Ontario Minister of Environment. These plans may supersede municipal official plans and zoning bylaws if there is an inconsistency. In contrast, Alberta's South Saskatchewan River Basin water management plan (approved in 2006) excluded from the planning process groundwater that was not hydraulically connected to the relevant surface water (Alberta Environment, 2006).

In addition to explicit water laws, a wide range of provincial laws on health, energy development, and pollution prevention and control serve to regulate groundwater extraction, allocation, protection and use. One British Columbia survey listed 39 provincial statutes relevant to watershed planning (WCEL, 2004). A few provinces have passed specific legislation that prescribes a separate land management regime for a designated area with a particular groundwater issue or focus, such as the Oak Ridges Moraine in Ontario, discussed in Chapter 6.

Many provinces require an environmental assessment of projects with significant groundwater impacts, and procedures invariably allow public participation. The federal government also requires assessments. For example, a project requires a comprehensive study under the *Canadian Environmental Assessment Act* (Government of Canada, 1992) if it involves "the proposed construction, decommissioning or abandonment of a facility for the extraction of 200,000 m^3 per year or more of groundwater, or an expansion of such a facility that would result in an increase in production capacity of more than 35 per cent," or if a federal proponent is involved. Projects that meet both federal and provincial thresholds will be subject to a joint assessment. Even if a formal environmental assessment process is not triggered, many provinces and territories require permit applicants to notify the public of their application and to conduct a public consultation.[36]

Many provinces have also developed non-regulatory strategies for water, such as Québec's water policy, Our Life, Our Future; Alberta's Water for Life strategy; and British Columbia's Living Water Smart strategy. There are also sectoral policies specific to groundwater, such as Alberta's Groundwater Allocation Policy for Oilfield Injection Purposes. Nevertheless, few provinces have developed a comprehensive groundwater strategy, although Alberta is in the process of developing one (Eckert, 2007).

Regulation of Groundwater Withdrawals

Provincial water laws and regulations prescribe who is entitled to a groundwater-use right, such as a permit or licence; how to allocate water between competing water users; and when to remove or curtail rights. In all the provinces except British Columbia, groundwater and surface water are part of the same licensing regime. British Columbia remains the sole jurisdiction in Canada that has no general licensing requirement for groundwater extraction above a defined threshold level. A submission made by British Columbia to the panel identified the lack of a legal framework as a challenge. This submission noted that there

36 Many provinces have an administrative agency that hears appeals of licences or permits. For example, Ontario has an Environmental Review Tribunal; British Columbia and Alberta have Environmental Appeal Boards; and Québec has the Tribunal administratif du Québec. Other administrative tribunals also make decisions on key groundwater issues. For example, in Alberta, the Energy and Utilities Board plays the pivotal role in approving projects that have an impact on groundwater and surface water, including coal-fired power plants and associated mines, oil sands, oil and gas wells, and the use of water for enhanced hydrocarbon recovery.

is generally a lack of understanding and awareness that other provincial agencies and local governments, who make decisions that potentially impact groundwater, need to manage or protect groundwater as part of their business. In 2008, the Government of British Columbia released its Living Water Smart report (Government of BC, 2008) which promises to correct some of the gaps that exist in the current regulatory framework by 2012–2014. The lack of a province-wide mandate for the implementation of this vision nevertheless remains an issue.

Licensing systems that establish rules for priority of use, based on criteria such as the date the licence was obtained (prior allocation), or on set categories such as municipal supply, agricultural, industrial, and power generation, are used in eight of the thirteen jurisdictions (all but British Columbia, Saskatchewan, Québec, New Brunswick and Prince Edward Island) (Nowlan, 2005). Most provinces and territories recognise essential human needs — usually called 'domestic uses' in the statutes — as the highest of priorities. The criteria for issuing a groundwater permit vary from province to province, though notably, no province uses information on the economic value of the water's proposed use as a criterion for decision. In addition, where there is a price for permits to take water, the charges are used only to defray administrative costs and do not provide an incentive for conservation. Data are summarised in Table 5.1.

A common way for regulators to limit the environmental impact of groundwater withdrawals is through the design of criteria for issuing a groundwater licence or permit. These criteria, however, may reflect only a limited consideration of cumulative impacts and ecosystem protection. The oil sands case study in Chapter 6 illustrates this lack of cumulative impact assessment. Another example relates to the lack of cumulative impact assessment by the province of Ontario (this is being done on a more local basis; see case study in Chapter 6) for a number of golf course developments in the Oak Ridges Moraine area in Ontario (Garfinkel *et al.*, 2008). There is, to date, no standard methodology for incorporating instream-flow protection into laws and regulations, although a number of provinces are examining ways to address this gap (Box 5.3). Environmental assessments and approvals for industrial activities also incorporate ecological requirements, as the oil sands and other case studies in Chapter 6 demonstrate. Provinces may use moratoria to restrict groundwater extraction when conditions such as over-allocation so dictate. For example, Prince Edward Island currently has a moratorium, in effect since 2001, on issuing permits for new irrigation wells, as outlined in the Prince Edward Island case study in Chapter 6.

Table 5.1

Provincial Groundwater Allocation Fee Structures (June 2005)

Question / Jurisdiction	Is groundwater ownership explicitly vested in the public?	Price charged for groundwater use (if so, price variables)	Classes of usage subject to or exempt from fees	Administrative cost recovery	Verification of quantity use is universally required (e.g., metering)	Environmental concerns addressed in decision-making process
Alberta	Yes	No	N/A	Yes, through licence fees	No	Discretionary
British Columbia	Yes	No	N/A	N/A	No	No
Manitoba	Yes	Yes, costs range from $1.00 to $2.00 per 1 million litres	All uses except industrial are exempt	Yes, through licence fees	Yes, though not required by regulation, administrative practice requires metering as a condition of licences	Mandatory
New Brunswick	Yes	No	N/A	Yes, well driller fees	No	No
Newfoundland and Labrador	Yes	No	N/A	Yes, through licence fees	Yes, where licence is in place	Mandatory
Northwest Territories	Yes	Yes, costs range from $1.50 to $2.00 per 1 million litres	Fees payable where water is used pursuant to licence (eight types of undertakings require licence)	Yes, through licence fees	Generally a condition of water licensing	Mandatory
Nova Scotia	Yes	Yes, $0.35 to $0.43 per 1 million litres	Fees payable where water is used pursuant to licence (use over 23,000 litres per day)	Yes, through licence fees and annual fees	Yes, where licence is in place	Mandatory
Nunavut	Yes	Yes, costs range from $1.50 to $2.00 per 1 million litres	All water users pay fees, except domestic and emergency	Yes, through licence fees	Generally a condition of water licensing	Mandatory
Ontario*	No	Forthcoming	N/A	Yes, through well drilling and permit fees — use over 50,000 litres per day	No	Mandatory
Prince Edward Island	No	No	N/A	Yes, well driller fees	Yes	Mandatory
Québec**	Yes	Forthcoming	N/A	Yes, through licence fees	No	Discretionary
Saskatchewan	Yes	Yes, costs range from $0 to $12.53 per 1 million litres	All uses except industrial are exempt	Yes, through licence fees	Yes, where licence is in place	Discretionary
Yukon Territory	Yes	Yes, costs range from $1.50 to $2.00 per 1 million litres	Water use under 100 m^3 per day is exempt	Yes, through licence fees	Generally a condition of water licensing	Mandatory

* The charge of $3.71 per million litres of water applies to commercial and industrial water users who withdraw more than 50,000 litres per day from groundwater, starting January 1, 2009. ** Québec is considering a royalty system.

Source: (Nowlan, 2005)

Box 5.3: Water Licensing in Ontario and Québec

Criteria for issuing a water permit in Ontario and Québec apply to both groundwater and surface water and require consideration of the protection of the natural functions of the ecosystem, water availability, water use (including the impact or potential impact of the water on water balance and sustainable aquifer yield), and other issues, including the interests of anyone who has an interest in the water-taking (Government of Ontario, 2004).

In Ontario, the regulation allows an application to be refused if the proposed water-taking is in a high-use watershed as shown on the Average Annual Flow Map, and if the water taking is for certain defined uses such as water bottling and aggregate processing, unless certain conditions are met. Ontario's obligations under the Great Lakes Charter must also be considered when issuing a permit.

In Québec, hydrogeological studies and quantification of the impacts on ecosystems and other local users must accompany an application (Parliament of Québec, 2002).

Regulation of Groundwater Quality

Groundwater quality is protected through drinking-water and aquatic-health protection laws as well as environmental assessment approvals at both the provincial and federal levels, and approvals for activities such as well drilling, geothermal and energy development, and contaminated site remediation. Despite programs at all levels of government, management and regulatory actions to remedy contamination and prevent further degradation remain inadequate for sustainable groundwater management. The sustainability goal of protecting groundwater from contamination, including the remediation of already impacted groundwater, requires action on several fronts.

Groundwater quality is also protected by provincial environmental laws, which usually require companies that emit contaminants into the air or water, or dispose of waste, to obtain permits from the relevant provincial department or ministry of the environment. These laws do not distinguish between pollution of groundwater or surface water. While different legal approaches are used to limit water pollution, a common approach in Canada is known as the 'end-of-pipe' regulation, which limits the concentration or amount of a particular chemical being deposited in a water body by a particular source. Although provincial schemes typically provide for extensive investigation, inspection, contravention, and penalty provisions, in practice they are infrequently used. By contrast, the United States *Clean Water Act* (US Government, 1972) uses the 'total maximum daily load' approach, which determines the maximum quantity of a pollutant that a receiving body can tolerate in a day, and limits total deposition by all sources to less than this.

Threats to groundwater arise from concentrated point sources of pollution such as discharge of wastewater from industrial sources, as well as from diffuse non-point sources such as urban runoff and agricultural contamination. Elevated nitrate concentrations, mainly from dispersed agricultural sources, continue to persist in groundwater in a number of important aquifers across the country. Despite widespread awareness of the problem, there has been little success through a Best Management Practices approach in reducing nitrate loadings and their concentration in our groundwater resources. Voluntary control measures for agricultural runoff, even when supported by incentives, have been unsuccessful. Innovative stormwater controls show promise for groundwater recharge, but their impacts on groundwater quality are not well understood.

Groundwater Used for Drinking Water

The primary relationship between groundwater quality and human health arises from the use of groundwater as a source for drinking water. If adequately regulated, groundwater has some inherent and beneficial characteristics, including:

- accessibility in locations where reasonable quantities of high-quality surface water are not available;
- consistency of composition — i.e., groundwater quality is generally much slower to change than surface water, allowing more time to adjust water treatment responses to changing water quality characteristics (although the corollary is also true that once it is contaminated, considerable time and expense are necessary to remediate it); and
- long groundwater flow paths and natural filtration through subsoil media, which achieves some, and often substantial, pathogen removal.

For private supplies, availability of any quality of water will be the key driver of source selection because surface-water alternatives are commonly not available. When poor-quality groundwater is the only option for a private water supply, point-of-entry or point-of-use water treatment technology will be necessary.[37] For community water supplies, both the quantity and quality of available groundwater are key determinants relative to any surface-water supply alternatives. The technologies used in point-of-entry or point-of-use devices are often substantially more expensive at the scale of a community water system than conventional water treatment technology.[38]

37 Point-of-entry devices treat all the water entering a building. Point-of-use devices treat only the water at a particular outlet, such as a kitchen tap.

38 Conventional water treatment technology is usually considered to be chemical coagulation, rapid dual media filtration and chlorination for disinfection.

Box 5.4: Regulation of Drinking-Water Quality in Canada

The Federal-Provincial-Territorial Committee on Drinking Water refers to a "multi-barrier" approach to ensure the safe delivery of drinking water to the consumer's tap. This approach evaluates and implements means for ensuring high-quality drinking water within every component of the water-supply system, from the broad natural environment to the supply aquifer or reservoir, to the water treatment plant and, finally, to the water distribution system. The multi-barrier approach is not consistently applied across the country.

One key element of this approach is the Guidelines for Canadian Drinking Water Quality, published by Health Canada since 1968, which set Maximum Acceptable Concentrations (MAC) of certain contaminants after water treatment. These Guidelines are not binding and are not mandated by a national law regulating drinking water, but instead are incorporated into provincial laws in different ways.[39] Provincial laws require water suppliers to ensure that the water they supply is potable by meeting minimum water treatment and quality standards. The laws also require monitoring and water-quality testing, construction approvals, operator and laboratory certification, and public notification of water-quality problems.

A second element of the multi-barrier approach is source-water protection. To protect groundwater drinking-water sources, provincial laws may require a water management plan, such as a source-protection plan that can, among other things, set water-taking limits. Each province has different forms of water planning provisions. Ontario's new *Clean Water Act*, for example, is to date the only law in Canada that requires drinking-water source-protection plans to be prepared for most of the province.

All provinces regulate wells primarily to guard water quality, by protecting the zones around wells, but also to conserve groundwater, by controlling and sometimes limiting the rate of extraction. For example, well owners may be obligated to stop or control artesian flows.

Bottled water is considered a food and is regulated under Division 12 of the Food and Drug Regulations. Bottling facilities were subject to inspection by the Canadian Food Inspection Agency, including some analysis of water quality (Health Canada, 2007). However, the Agency indicated it will discontinue inspection of water bottling facilities in 2005 due to improved compliance.[40]

39 Environment Canada's Freshwater website provides links to water-related policy and legislation in Canada's provinces and territories. See http://www.ec.gc.ca/WATER/en/policy/prov/e_prov.htm for more information. A recent (2006) listing or comparison of provincial and territorial regulatory regimes for drinking water is available as Appendix C of the Report of the Expert Panel on Safe Drinking Water for First Nations (Government of Canada, 2006a).

40 See Table 2.5, DPR 2004-05, available at http://www.tbs-sct.gc.ca/rma/dpr1/04-05/CFIA-ACIA/CFIA-ACIAd4502_e.asp.

All provinces have requirements for regular water sampling from municipal drinking-water wells and, while most sampling is focused on the treated water, raw water sampling is usually necessary. Water-quality analyses must comply in some provinces with the Guidelines for Canadian Drinking Water Quality promulgated by Health Canada (Box 5.4). In cases where capture-zone or source-protection plans are in place for such wells, the plans usually include the installation of monitoring wells that are sampled regularly to ensure that there has not been any encroachment of contaminated groundwater into the protected area.

Because of strong municipal management and collaborative provincial oversight, and the role of the Federal-Provincial-Territorial Committee on Drinking Water, the quality of groundwater-based municipal drinking water is generally excellent across Canada. However, the frequent occurrence of microbial contamination in private and small community wells, including First Nations wells, remains unacceptable and undermines the health of a number of Canadians. A stronger regulatory environment for Canadian drinking water is necessary.

For regulatory purposes, groundwater is classified into one of two major groupings: (i) groundwater under the direct influence of surface water contamination (GUDI);[41] and (ii) 'secure' groundwater (which allows for reduced treatment requirements). Drinking-water supplies from GUDI sources are generally required to meet the same treatment requirements as surface water sources. More 'secure' groundwater sources are often exempted from expensive filtration requirements.

There are currently 67 microbiological, chemical or physical parameters (plus 78 radionuclides) listed with Maximum Acceptable Concentrations (MAC) in the Guidelines for Canadian Drinking Water Quality (Health Canada, 2008). Most parameters are listed for precautionary reasons; i.e., if present at concentrations substantially exceeding the MAC, they could pose a health risk to consumers. There is a much shorter list of contaminants that are known to have caused adverse health outcomes through exposure to drinking water and that may pose a pervasive threat to drinking-water safety. Among the major drinking-water contaminants with demonstrated health risks to humans are microbial pathogens (including viruses, bacteria and protozoa), arsenic, nitrate and fluoride (WHO, 2007).

---

41 Various definitions of GUDI are used, but the concept is illustrated by one regulatory guidance document: "any water beneath the surface of the ground with: i) significant occurrence of insects or other macro-organisms, algae, organic debris, or large-diameter pathogens such as *Giardia lamblia* or *Cryptosporidium*; or ii) significant and relatively rapid shifts in water characteristics such as turbidity, temperature, conductivity, or pH which closely correlate to climatological or surface water conditions" (Nova Scotia Environment and Labour, 2002).

Microbial Pathogens: These have always been the most pervasive health risks associated with drinking-water consumption.[42] Of all the microbial pathogens (viruses, bacteria and protozoa), viruses are the smallest and most likely to pass through granular media, thereby potentially posing a greater risk for groundwater contamination. Viruses are not routinely monitored in groundwater, but enteric viruses have been occasionally detected in Canadian municipal drinking-water wells by recent research funded by the Canadian Water Network (Locas *et al.*, 2007; Locas *et al.*, 2008; see also the Great Lakes Basin case study in Chapter 6).

Fortunately, fatalities caused by water contaminated by microbial pathogens are now rare in Canada. A tragic exception was the outbreak in Walkerton in May 2000, where mismanagement of the municipal water-treatment system allowed pathogen-contaminated groundwater, arising from cattle manure, to enter the drinking-water supply, making more than 2,300 individuals ill, of whom seven died (see Box 5.5). Microbial pathogens causing water-borne outbreaks usually arise from fecal wastes originating, in order of likelihood, from humans, livestock, and wildlife. Where microbial contamination is discovered, the main emergency response tool available to public health authorities is to issue a boil-water advisory (or order, in the case of commercial facilities serving the public). An investigative news story for the Canadian Medical Association Journal (CMAJ) reported a total of 1,766 boil-water advisories in effect in Canada as of March 31, 2008 (Eggertson, 2008b). These were in addition to those in place in First Nations communities, which totalled 93 in February 2006 (Eggertson, 2008a). No breakdown was available for what proportion of these situations involved groundwater sources, and the high totals reflected the reality that some provinces, like Ontario (679 boil-water advisories), included facilities like trailer parks, campgrounds, seasonal camps and gas stations, while other provinces like Alberta (13 boil-water advisories) did not report for the whole province, nor were very small systems included. British Columbia has a large number of very small community systems (more than 3,500) resulting in a disproportionate number of boil-water advisories (530) for its population, as is the case with Newfoundland (228). Many boil-water advisories have been in place for years, indicating that they are being used as an alternative to providing adequate treatment or source protection, a problem that is tied to a widespread reliance on very small systems lacking adequate means to ensure the competence necessary to consistently deliver safe drinking water (Hrudey, 2008a; Hrudey, 2008b).

42 The World Health Organization estimates that currently "1.8 million people die every year from diarrheal diseases (including cholera); 90 per cent of these are children under five, mostly in developing countries and 88 per cent of diarrheal disease is attributed to unsafe water supply, inadequate sanitation and hygiene" (WHO, 2004).

Arsenic: While arsenic may be a byproduct of many industrial processes, the most common source of arsenic contamination of drinking water is the natural minerals in geologic materials. Arsenic is abundant in the earth's crust, and groundwater at many locations in Canada has elevated levels of the element. Instances of high arsenic concentrations in drinking water around the world originate primarily from natural sources in groundwater (well water). Surface water in general contains concentrations of arsenic below the World Health Organization and Health Canada guideline levels of 10 micrograms (μg) per litre. Data from all Canadian water utilities show arsenic concentrations below the 10 μg per litre guideline level. Nevertheless, several localised areas in Canada, including Halifax and Guysborough Counties in Nova Scotia, exhibit arsenic concentrations in private well water above 10 μg per litre.

Nitrogen: Nitrogen compounds, whether from natural sources, fertiliser application or improper septic-field operation, can lead to increased nitrate and nitrite levels in groundwater because nitrogen compounds are readily oxidised to nitrite and nitrate. These ions are highly soluble in water and are easily transported through soil materials and aquifers. Elevated nitrite levels in the blood can be caused by exposure to elevated nitrate levels in drinking water, leading possibly to a disorder caused by a reduction in haemoglobin capacity of blood to transport oxygen (methaemoglobinaemia). Bottle-fed infants are particularly at risk. Groundwater can exhibit elevated nitrate concentrations in response to local land use and hydrogeological conditions.

Fluoride: The excess ingestion of fluoride can cause fluorosis, a condition that first affects the teeth. At higher exposure levels, it affects bones, leading to skeletal fluorosis, which can be a debilitating disorder. In much of Canada, fluoride is added to drinking water in carefully controlled amounts as a public health measure to strengthen dental enamel and prevent tooth decay. These levels are not harmful to health. However, fluoride can be naturally elevated in groundwater to levels that exceed those that cause the beneficial effect on dental health and cause the adverse effects of fluorosis (WHO, 2008).

Other Contaminants: There are many potential drinking-water contaminants intrinsically capable of causing adverse human health effects at sufficiently high doses, even if they have not caused documented disease outbreaks through drinking-water exposure. These contaminants require attention to ensure that they do not become a public health problem. For groundwater, some of the more common contaminants of precautionary concern include: radionuclides (from natural or human activity); uranium, for chemical toxicity to kidney function (from natural or human activity); pesticides; semi-soluble hydrocarbons (from human activity); halogenated solvents, including trichloroethylene and perchloroethylene (from human activity); and mixed contaminant sources such as leachate from landfill and waste-disposal activities. These contaminants are difficult to treat and have the potential to cause the shutdown of municipal well fields. Proactive measures are necessary to identify contaminants of natural and human origin that may render groundwater unsafe for consumption, and to inform residents of their presence. Reconnaissance surveys and publication of information, coupled with mandatory testing of private wells in suspect areas, are necessary to protect the health of rural residents.

Finally, there can be aesthetic or nuisance factors associated with poor water quality that are related, for example, to smell, taste, excessive hardness, or appearance. Although these are not usually direct causes of adverse health effects, the noxious nature of such water sources can lead users to seek more aesthetically pleasing, but less safe, water sources. A case in point arising from the Walkerton experience is that the vulnerable shallow that caused the outbreak when it became contaminated with microbial pathogens, was commissioned and maintained by the town because its water was much softer than the deeper, more secure wells which otherwise served the town.

Looking forward, the use of large-scale water treatment technology as a means of polishing groundwater to drinking-water standards is expected to become increasingly cost-effective and will assist municipalities in maintaining the use of groundwater as a drinking-water source in urban settings. The Regional Municipality of Waterloo is already moving forward in this regard in order to re-institute one of their high production wells in Waterloo (personal communication, 2008).

Box 5.5: Walkerton — Events of May 2000

In May 2000, Walkerton, Ontario, experienced an outbreak of water-borne disease that killed seven people and caused serious illness in more than 2,000 others. This event gripped the nation's attention because of the human tragedy that unfolded and the shock that a community water supply could cause the death and illness of consumers in Canada's largest province at the start of the 21st century. Ontario called a public inquiry, headed by Justice Dennis O'Connor, which produced two detailed reports: Part 1 dealt with what happened in Walkerton (O'Connor, 2002a) and Part 2 dealt with what steps Ontario should take to prevent such failures from happening again (O'Connor, 2002b). Despite the clarity and detail of these reports, many Canadians, including professionals with an interest in water, adopted selective accounts from the mass media coverage and much misinformation about this tragedy remains.

Walkerton was served by three wells in May 2000. The well ultimately determined to be responsible for the outbreak was designated as Well 5. It was drilled in 1978 and completed in fractured limestone with the water-producing zone ranging from 5.5 metres to 7.4 metres in depth. The outbreak occurred after a heavy spring rainfall (a one-in-60-year storm) resulted in Well 5 becoming contaminated by pathogens traced to manure produced on an adjacent farm. The exact means by which the pathogens travelled from the farm manure to enter Well 5 was never established with certainty, but the karst conditions (i.e., conduits caused by dissolution of the carbonate bedrock) of the shallow aquifer allowed rapid transport of contamination once it reached the aquifer. The operator of the farm was following exemplary farm practices and was exonerated by the Inquiry. When Well 5 was commissioned in 1978, the pump test showed fecal coliform contamination after 24 hours. The hydrogeologist's report warned of the contamination risks, specified the need for chlorination, and recommended that the town purchase a buffer zone to protect Well 5, but no action was ever taken on the land-use recommendation. Microbiological and turbidity monitoring over subsequent years confirmed that Well 5 was subject to surface contamination.

The only treatment barrier required by the Ontario Ministry of Environment was chlorination to achieve a residual of 0.5 mg per litre after a 15-minute contact. If that single requirement had been continuously met, more than 99 per cent of the pathogens would have been inactivated. Although the system supervisor was supposed to measure the chlorine residual once a day, the Inquiry found that chlorine residuals were not measured on most days and that fictitious entries for residuals were usually entered on daily operating sheets.

The failure to measure chlorine residuals was critical, because the contamination most likely entered Well 5 on May 12, one week before illness became evident in the community. When asked on May 19 and 20 whether there were any problems with the drinking-water quality, the general manager of the system assured the local health authorities that the water was satisfactory, despite having received adverse microbiological monitoring results for the Walkerton distribution system on May 17. A boil-water advisory was not issued until May 21, when health authorities had concluded the water must be involved. The first victim died on May 22. At least eight days without valid chlorine residual monitoring had passed between the contamination influx and the boil-water advisory, after illness was already widespread.

The organic loading from the manure contamination would have overwhelmed the inadequate, fixed chlorine dose, leaving no chlorine residual or disinfection capacity to inactivate the pathogens entering the distribution system. Measuring the chlorine residual would have identified the problem immediately, but none was measured during this critical period.

The Inquiry revealed failures at many levels, including: ineffective regulatory oversight, reductions in funding of provincial water monitoring, inadequate watershed protection, poor system management and operations (water treatment and monitoring of the barriers for the risks facing this vulnerable groundwater system), and inadequate operator training.

Some of the prevalent misconceptions about Walkerton have ranged from the extremes of assigning all the blame on the operators to assigning all the blame on the regulatory system. The misdeeds of the operators included lying and falsifying records and were certainly inexcusable, but the Inquiry found that these operators had no idea of the risks they were bringing upon their neighbours. They continued to drink the water themselves during the outbreak. The operators were charged under the Criminal Code, but in accepting their guilty pleas the Crown accepted a statement of facts claiming that there was nothing the operators could have done once the system had become contaminated. That erroneous claim misses the critical issue that performing the chlorine residual monitoring that was required would have revealed, in real-time, that Walkerton's water was contaminated. The system could have been shut down, and a boil-water advisory called within 24 hours, rather than allowing residents to consume heavily contaminated water for eight more days as ultimately happened. This was particularly tragic because the local hospital recommended parents have their children with diarrhea drink more fluids, thereby increasing their exposure to the contaminated water during this period.

The Walkerton disaster provides a strong case for the multiple-barrier approach to assuring safe drinking water. This disaster does not demonstrate that groundwater is inherently unsafe for drinking-water supplies. Well 5 was recognised from the outset as a vulnerable shallow well (groundwater under the direct influence of surface water) and evidence demonstrated consistently that it was subject to contamination, so this vulnerable, thoroughly mismanaged scenario must not be generalised to all groundwater supplies. Because outbreaks of disease caused by drinking water remain comparatively rare in Canada, particularly in contrast with the developing world, complacency about the dangers of water-borne pathogens has become common. Yet, the source of water-borne disease in the form of microbial pathogens is an ever-present risk because these pathogens are found in human fecal waste and in fecal wastes from livestock, pets and wildlife, making any drinking-water source at risk of contamination before or even after treatment (if a bacterial source was to be introduced after treatment).

Enforcement

The foregoing has described the framework of existing regulations in respect of protecting both the quantity and quality of groundwater, but even the best rules will not be effective if not adequately enforced. The panel believes that stronger enforcement of existing regulations and controls would improve sustainable groundwater management. Among the enforcement options most in need of improvement are accurate and timely reporting of all licensed groundwater withdrawals; adherence to water-quality monitoring requirements; provision of complete documentation of geology and well construction and well abandonment details; and timely adherence to contaminated site clean-up and restoration.

5.3 ALTERNATIVE GROUNDWATER REGULATORY APPROACHES

The discussion to this point outlines what might be called the 'regulatory paradigm' that has been used to manage groundwater to date in Canada. Taken as a whole, the regulatory decisions of governments form the framework within which decisions by private agents such as farmers, households, and firms are taken. For the most part, this regulatory paradigm has set quantitative limits on water withdrawals or the deposition of wastes or, less commonly, set technological standards that have to be met. Thus, one important feature of this framework concerns the incentives or signals it provides to decision-makers regarding their water use or waste disposal. For the most part, these quantitative limits have provided relatively weak incentives for decision-makers to innovate, to conserve on water use or to consider explicitly the costs that their actions (in terms of aquifer draw-downs) may have imposed on others.

Furthermore, notwithstanding the existing regulatory framework, there are several reasons to expect private decision-making in respect of groundwater use to be inefficient and possibly unsustainable. Many of these reasons are related to groundwater in some cases having the characteristics of 'common property' as described in Box 5.6. It is nevertheless the case that economic efficiency in groundwater management is seldom a consideration in the Canadian context. Current groundwater allocation methods do not use market-based incentives such as fees, subsidies and trading systems to shift allocation to high-value uses and generally promote conservation. By introducing appropriate incentives, it may be possible to bring user decisions closer to efficient and sustainable groundwater use. The implementation of economic instruments will require determination of royalty rate structure, integration of the instruments with existing regulations, and collection of the local-scale information necessary to design and implement the instruments.

Efficiency is a term used by economists to describe an allocation of productive resources where social welfare is maximised; i.e., society is doing the best it can with its limited resources. The concept of efficient use is more commonly understood in the context of minimisation of waste. In that regard, there is great scope for broader application of available technology and further research to improve the efficiency of water use in many industrial and domestic sectors, the oil sands developments being one prime example. Economic incentives, and in some cases regulations, may also need to be considered.

The conditions needed to achieve efficiency, in the welfare-maximising sense used by economists, have received considerable attention; nowhere more so than in the use of natural resources such as groundwater (Griffin, 2006; Kondouri, 2004). Efficient withdrawal of groundwater requires that users be aware of the full costs and benefits of personal actions. The challenge lies in defining and measuring the relevant concepts and developing a regulatory environment in which the user of groundwater is made

Box 5.6: Tragedy of the Commons

Aquifers may cross property boundaries and even political boundaries. This feature, combined with the fact that it is often difficult to monitor withdrawals from an aquifer, suggests that the exploitation of aquifers may suffer from the problems often associated with other common property resources such as communal grazing areas, near-shore fisheries and wilderness areas. Withdrawals from an aquifer by a user in one time period have the potential to impose costs on others both in the same and future time periods. Costs may be imposed in the current period when one user's withdrawals lower the water level of the aquifer and thereby increase pumping costs for others, or when one user's withdrawals reduce water quality in the aquifer and thereby reduce its value to others. Furthermore, costs may be imposed on future water users because a unit of groundwater removed in the current period may be unavailable for use in future periods. Finally, in the case of shallow groundwater resources, there may be hydrological interactions between surface and groundwater resources with the effect that withdrawals from groundwater sources may reduce surface-water flows and thus impose additional costs on users of surface water and have negative implications for local ecosystems. A discussion of recent empirical studies is found in Kondouri, 2004.

In the absence of regulations compelling each user to take all current and future costs and benefits related to groundwater use into account, there are strong reasons to believe groundwater withdrawals will not be efficient or sustainable. Typically, a user is fully aware of the benefits of personal water use but only partially aware of the costs (perhaps knowing one's pumping costs but not knowing the costs being imposed on others). This results in the user overestimating the net benefits (benefits minus cost) and thus withdrawing too much water from the aquifer. Since all users tend to make the same error, a damaging depletion may result from the collective over-exploitation of the common property resource — in this case, a shared aquifer.

The actual magnitude of the inefficiency and its implications for sustainability will depend on a number of real-world parameters such as the physical character of the aquifer as well as the magnitude of the costs being imposed on others, relative to the benefits being enjoyed by the user.

aware of them. These observations have led some analysts to investigate alternative regulatory paradigms that might provide stronger incentives for innovation and conservation (Kolstad and Freeman, 2007). One alternative paradigm in particular relies more heavily on altering the economic landscape facing water users through the introduction of prices for water or the establishment of markets for water. These approaches have historically been eschewed by Canadian governments (with some recent exceptions, notably Alberta) and, thus, it may be valuable to consider briefly what is known regarding the potential efficacy of these 'economic instruments'.

There are very few empirical studies of Canadian water demands, and of these, almost none specifically consider the users' demand for groundwater (Renzetti and Dupont, 2007). As a result, what we currently know about the economic characteristics of the demand for groundwater in Canada must be inferred from existing studies of the demand for surface water in Canada or from empirical studies of groundwater demands from other jurisdictions (Box 5.7).

Box 5.7: What Determines the Demand for Water?

The socio-economic and climatic similarities between Canadian and American cities allow some inferences to be drawn from empirical studies of the United States. In a recent meta-analysis of 124 estimates of the residential price elasticity of demand, Espey *et al.* (1997) calculate an average price elasticity value of -0.5*. Furthermore, residential water demands have been found to be positively correlated, as might be expected, with income, number of family members, size of home, size of lawn and summer temperature (Griffin, 2006; Renzetti, 2002). There is some evidence that the water demands of Canadian households are positively related to the quality and reliability of municipal water supplies (Adamowicz *et al.*, 2007; Rollins *et al.*, 1997).

Industrial water use has been found to be sensitive to a variety of economic factors such as the price of water, the prices of other inputs and the level of the firm's output. Dupont and Renzetti (2001), for example, apply an econometric cost-function model to Environment Canada's Industrial Water Use Survey data for the manufacturing sector and conclude that the average price elasticity of demand for intake water is -0.8. Furthermore, water intake demand has been found to be positively related to the level of firm output and to the price of internal water recirculation (de Gispert, 2004). This last finding indicates that many manufacturing firms view intake water and water recirculation as substitutes. A portion of fluid effluent from industrial facilities and municipal sewage treatment plants may be deposited in aquifers. The economic characteristics of these activities are particularly ill-understood. However, there is limited empirical evidence that economic instruments (such as effluent charges) and environmental regulations induce both manufacturing plants and municipal governments to reduce their waste flows (Dupont and Renzetti, 2001; Renzetti, 1999).

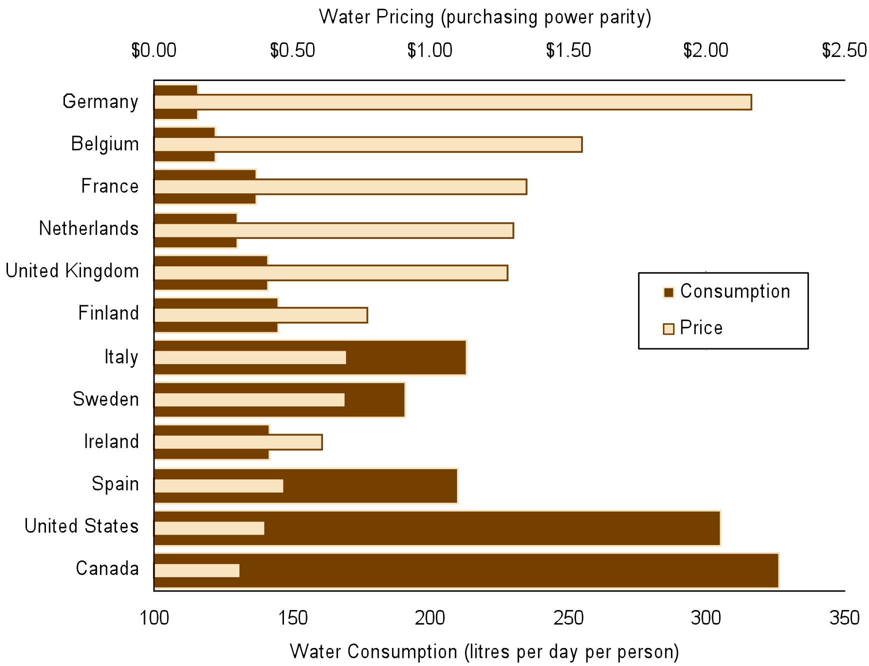
Evidence from American studies suggests that irrigation-water demands from agriculture are less sensitive to prices than industrial- or residential-water demands. Conversely, they have been found to be positively correlated with the value of the crop and evapotranspiration levels (Griffin, 2006). In the cases where farmers have access to both groundwater and surface-water supplies, there is evidence that farmers may treat groundwater as a buffer against uncertain surface-water supplies.

*A price elasticity value of -0.5 indicates that a household's water demand is predicted to fall by 0.5 per cent in response to a one per cent increase in the price of water (holding all other factors fixed).

Setting a Price for Groundwater

There are two levels of jurisdiction at which a price could be set for groundwater. The first is at the municipal level, where some water agencies rely in whole or in part on groundwater supplies to provide potable water to their customers. The second is at the provincial level, where provinces could set prices for direct abstractions by farms, industrial facilities, water utilities and other large users of groundwater.

Municipal Pricing: Municipal water prices can be designed to promote sustainable groundwater use (Figure 5.1). An important first step is that a local water agency's cost accounting must fully record all of the costs of providing drinking water. Historically, this has not been done, with water agencies typically recording operating costs and a portion of capital costs (Renzetti and Kushner, 2004), thus providing water users with an implicit subsidy and an incentive to use water unsustainably. However, recently introduced legislation in Ontario (Government of Ontario, 2002b; Government of Ontario, 2006) will require local water providers to account for all operating, capital and source-protection costs that they incur and to recover these through appropriately designed prices. While these initiatives may not have defined the 'full costs' of water supply



(Data Source: Environment Canada, 2008c; OECD, 1999)

Figure 5.1

Municipal water consumption and pricing.

as the European Union's Water Framework Directive (in which environmental costs are also included, as discussed in Box 5.1), they are an important step towards promoting the principles of demand-side management and thus of sustainable groundwater use.

Provincial Pricing: The second level for pricing groundwater is provincial.[43] The available empirical evidence on the economic features of water demand suggests that levying a groundwater abstraction royalty or tax will result in reduced withdrawals. Several European countries have levied such charges, and there is some evidence that, in addition to raising revenues to support environmental programs, the royalties have prompted industrial firms and other users of groundwater to innovate and use less groundwater (Speck, 2005).

The significant challenge in levying these charges is the difficulty of determining the appropriate rate for the royalty (see Dupont and Renzetti, 1999 for an example of such an assessment using Canadian data). In principle, the fee should reflect the marginal public cost of the groundwater use; this, in turn, would depend on a large number of hydrological, ecosystem and economic parameters (Kondouri, 2004). In order to promote efficient and sustainable use of groundwater, these charges, in theory, should be specific to the place and time of the withdrawal.

In principle, the pricing of direct abstractions of groundwater could be extended to address activities that result in changes in groundwater quality. For example, a 'pollution tax' could be levied against activities, including farming or industrial operations such as factories, that bring pollutants into aquifers. The tax would be designed to discourage such activities and to complement other environmental regulations. (This presumes that a certain amount of specified pollutants can be safely assimilated by the water system in question.[44]) The task of setting a price for point sources of groundwater pollution is similar, in principle, to that of regulating withdrawals of groundwater. However, the informational requirements for setting a price on groundwater pollution would be quite challenging because they would require an understanding of the current and future impacts of the polluting activity and the economic damages associated with them. Agricultural water pollution exhibits several particularly problematic characteristics for regulators. These include uncertainties regarding the source of emissions, the quantity of emissions from each source, the relationship between actions of polluters and emissions, and the relationship between emissions and ambient environmental quality of both surface water and groundwater. In addition, because of the crucial importance of

43 Several provinces already levy administrative fees for water abstraction permits. The basis for these fees and their impacts on users are unclear. See the Sierra Fund report (Nowlan, 2005).

44 In the United States, for example, there are a limited number of economic instruments based on allocation of 'total maximum daily load' of certain pollutants in surface water systems (Hoag and Hughes-Popp, 1997; Keplinger, 2003).

physical conditions (e.g., local soil types, groundwater-surface-water interactions and weather conditions), the analysis of non-point-source pollution, and the design of policies aimed at controlling it in a least-cost fashion, are likely to be case-specific.

Creating a Market for Groundwater

An alternative economic instrument relies on the creation of a legal and market framework, within which private agents trade their rights to water use. There is now considerable literature (summarised in Griffin, 2006) that demonstrates that well-designed water markets can improve the efficiency of the allocation of surface-water resources, although there are continuing concerns about unintended negative impacts on instream flows and third parties affected by water trades. Horbulyk and Lo (1998) and Mahan *et al.* (2002) carry out useful simulations of the workings of surface water markets under the prior appropriation regime of southern Alberta. The numerical results show a significant improvement in the efficiency of water allocation (relative to current allocations) as a result of water trades. The *Alberta Water Act* (1999) authorises transfers of an allocation of water under a licence, if approved by a Director of the provincial government. A number of transfers of surface-water licences have occurred, chiefly in southern Alberta, with more transfers expected in the future. To date there have been no transfers of licences for groundwater use, although legislation does allow the transfer of groundwater allocated under these licences.

Reallocation of groundwater licences through the introduction of markets could, in principle, be part of a framework to trade in-surface water rights or could exist on its own. Creation of a market for groundwater abstraction rights, however, presents considerable challenges (Garduno *et al.*, 2003; Griffin, 2006; Kemper *et al.*, 2003). Griffin enumerates a number of reasons why groundwater markets may have difficulty achieving the same efficiency gains that have been experienced with surface-water markets. Paramount among these is the set of external effects that one agent's groundwater use may have on current and future users (Box 5.7). For example, increased rates of pumping by one user (that might follow from purchasing or leasing groundwater rights) may increase the pumping and treatment costs of other contemporaneous users and may reduce aquifer levels for future users.

Just as the pricing of groundwater could be extended to account for users' impacts on water quality, so too could groundwater markets be employed to address water quality concerns. In fact, researchers have considered the application of tradable permits to the control of non-point-source pollution. For example, farmers within a watershed could be allotted or sold permits for the application of phosphorous or nitrogen on their crops. A trading system to limit phosphorous discharges to the South Nation River in Ontario has been implemented (Sawyer *et al.*, 2005). Farmers who are able to reduce their use of the regulated substance will find themselves with extra permits that can be sold to farmers, municipalities and businesses facing higher costs of abatement. The challenge in implementing trading schemes for non-point pollution is two-fold. First, the damage caused by a given quantity of emissions will depend on a variety of factors. As a result, regulators will not, in general, be indifferent to the time, location and manner that the nitrogen or phosphorus is applied. These concerns may narrow the range of possible trades and, as a result, restrict the potential efficiency gains of trading. Second, it must be possible for regulators to monitor and measure nitrogen or phosphorus use to ensure that farmers are not employing more than they are allotted.

In summary, a considerable body of evidence suggests that greater use of economic instruments such as water prices, abstraction fees and tradable permits has the potential to promote sustainable groundwater use. The principal challenges facing their implementation include the lack of experience of governments in Canada with these policy instruments; a lack of understanding regarding the economic characteristics of users' groundwater demands; and the need to coordinate the introduction of market-based instruments with existing regulatory frameworks.

5.4 ALLOCATION OF RESOURCES TO GROUNDWATER MANAGEMENT

Many aspects of groundwater management are best carried out at a local level where knowledge of local conditions can be used to make day-to-day land-use decisions and satisfy long-term planning needs. However, the advanced technical expertise required to investigate complex aquifer systems and develop and calibrate the model simulation systems is costly and requires considerable skill. Allocation of staff and funding to groundwater management has not kept pace with the increasing demands placed on the resource, leaving many Canadian basins with insufficient groundwater management expertise and capacity. Several examples suggest that cooperative efforts involving the three orders of government have generated positive outcomes by combining available resources into a single, geographically focused, vertically integrated management approach (see the case studies in Chapter 6 on Basses-Laurentides and Oak Ridges Moraine).

There currently is a shortage of hydrogeologists in Canada and there will be an increasing demand for groundwater science and management skills as more rigour is applied to managing the resource. University and college programs that focus on groundwater as a resource within a framework of integrated hydrological sciences and ecosystem sustainability, watershed management, water resources economics and water law will be increasingly in demand (see Box 5.8).

Box 5.8: Training in Hydrogeological Skills in Canada

Groundwater professionals usually are registered engineers or geoscientists, but hydrogeology, in its own right, is not a registered profession in Canada. This makes it difficult to gauge the number of groundwater professionals working in Canada. Indeed, groundwater expertise can be acquired through various disciplines such as geological, civil and environmental engineering; environmental sciences; physical geography; and perhaps others. Nevertheless, hydrogeology is most commonly considered a sub-discipline of the geosciences. Furthermore, acceptance as a hydrogeologist generally requires an advanced degree (M.Sc. or PhD) with specialised training in the hydrogeological sciences.

Of the 36 Canadian universities that offer programs in the geosciences, almost half offer advanced degrees with specialised training in hydrogeology. There is a considerable range in the size and scope of the various programs, although most offer courses in the basics of physical hydrogeology, environmental geochemistry and mathematical modelling. Relevant training is also available through one or two introductory courses at the undergraduate level at several additional universities, and through environmental programs at several colleges. Though relevant, the breadth and intensity of undergraduate and college training is generally not sufficient for graduates to be considered groundwater professionals. Additional training is available through seminars and short courses offered by industry and universities or through professional associations such as the Canadian Chapter of the International Association of Hydrogeologists and the Canadian Geotechnical Society.

Given the rapid emergence of groundwater quality as a major environmental concern at the time when many of the groundwater programs were being established (about 30 years ago), university-based teaching and research has had a strong orientation towards contaminant hydrogeology. More recently, however (and possibly in response to greater awareness of global water shortages, climate change and the need for a more integrated approach to water management), greater emphasis is being put on groundwater resource development.

Estimates gleaned from membership in professional associations suggest that there could be between 700 and 1,000 groundwater professionals practising in Canada, with the largest single number employed by private consulting firms. Anecdotal information obtained from conversations with the principals of consulting firms suggests that there is currently a serious shortage of groundwater specialists (one medium-sized company indicated that it wished to hire 40 hydrogeologists over the next two years). Though incomplete, and only partially relevant to the current topic, a recent report (ECO Canada, 2008) provides a useful snapshot of the human-resource situation in one component of the environmental market, namely the investigation and remediation of contaminated sites. The report indicates that there will be 11,500 vacancies over the next 12 months and that geologists and hydrogeologists are among the most difficult to recruit. The shortage of human resources has caused some companies to turn down contract opportunities, has slowed the pace of cleanup, and has slowed the development of this sector of the economy. Some industries facing groundwater problems (the petroleum industry, for example) are hiring staff hydrogeologists and, in response to legislation such as the *Clean Water Act* in Ontario, it is inevitable that there will be an increased demand for hydrogeologists from provincial agencies, municipalities, conservation authorities and consulting firms. Thus, while there is currently a shortage of hydrogeologists, there is reason to believe that the demand will continue to outpace the supply. Though Canada has numerous universities that train hydrogeologists, training is generally at the post-graduate level and thus the number of graduates per year is relatively small. If the current and future demand for hydrogeologists is to be met, then clearly greater resources are required to increase the capacity of our training programs.

To address the five goals of sustainability, specialised training in several disciplines is needed, including hydrogeology, hydrology, environmental chemistry, freshwater ecology, resource management, economics, planning, environmental law and perhaps others. Indeed, meeting the goals of sustainable management of groundwater is a highly interdisciplinary challenge. While specialists in the respective disciplines are clearly needed, there is also a great need for individuals with more general backgrounds who can bridge the technical and communication gaps between the respective disciplines, and particularly between the physical and social sciences. Hydrogeologists need training and experience in communicating their science to regulators, decision-making tribunals and the public in order to make sure that what the science can tell us is properly incorporated into water-management decisions.

REVIEW OF KEY POINTS

Jurisdiction for Groundwater Management

- The provinces, as resource owners, have the primary legal jurisdiction as regulators of groundwater. The federal government has legislative and proprietary powers to manage groundwater on federal lands and has many areas of policy and spending authority that can affect groundwater sustainability. There are several relevant areas, such as agriculture and environment, where responsibility is shared between the Government of Canada and the provinces.
- The *Canada Water Act*, originally passed in 1970, enables the federal government to enter into agreements with the provinces and territories to undertake comprehensive river-basin studies; to monitor, collect data and establish inventories; and to designate water quality management agencies.
- The 1987 Federal Water Policy committed to a number of actions, such as developing national guidelines for groundwater assessment and protection, and measures to achieve appropriate groundwater quality in transboundary waters. The policy remains largely unimplemented.
- The *Canadian Framework for Collaboration on Groundwater*, issued in 2003 by an *ad hoc* committee of stakeholders, has encouraged cooperation at the working level, but there is still a need for a more clear-cut, formally stated division of duties among the various levels of government.

Local Management

- Since many aspects of groundwater management are best carried out at a local level, there is an increasing trend for provinces to delegate groundwater management responsibilities to local governments and multi-stakeholder bodies. This effort is likely to be most successful when accompanied by sufficient financial and human resources, together with a requirement to take action and report back on progress.
- There currently is a shortage of hydrogeologists in Canada and there will be increasing demand for groundwater science and management skills as more rigour is applied to managing the resource.

Groundwater Management Practices

- Water-related policies and regulations have typically been concerned with influencing the *quantity* of water used, or the *quality* of water, but rarely both together.
- Criteria for issuing a groundwater licence or permit may reflect only a limited consideration of *cumulative* impacts and ecosystem preservation. Furthermore, there is to date no standard methodology for incorporating instream-flow protection into laws and regulations, although a number of provinces are examining ways to address this gap.
- No province uses information on the economic value of the proposed use as a criterion for issuing a groundwater permit. Where there is a price for permits to

take water, the charges are used only to defray administrative costs, rather than as an incentive for conservation.

Management of Groundwater Quality

- Groundwater quality is protected through drinking-water and aquatic-health protection laws as well as environmental assessment approvals at both the provincial and federal levels. Despite programs at all levels of government, management and regulatory actions to remedy contamination and prevent further degradation remain inadequate for sustainable groundwater management.
- Regulators have made progress towards limiting point-source pollution from industries such as pulp and paper. In contrast, best management practices to control non-point-source pollution from agriculture or urban run-off have had limited success, and strengthened regulations or new technical approaches should be explored.
- Because of strong municipal management and collaborative provincial oversight, and the role of the Federal-Provincial-Territorial Committee on Drinking Water, the quality of groundwater-supplied *municipal* drinking water is generally excellent across Canada. However, the frequent occurrence of microbial contamination in private and small community wells, including the First Nations wells, remains unacceptable. More effective management of drinking-water safety for individual, small, and remote systems is therefore necessary.
- Fatalities caused by water contaminated with microbial pathogens are now rare in Canada. A tragic exception was the outbreak in Walkerton in May 2000. That disaster provides a strong case for the multiple-barrier approach to assuring safe drinking water. The Walkerton tragedy does *not* demonstrate that groundwater is inherently unsafe for drinking-water supplies. It shows that this systemic breakdown of governance can occur with water supplies from any source, whether groundwater or surface water.

The Importance of Enforcement

- Stronger enforcement of existing regulations and controls would improve sustainable groundwater management. Most in need of improvement are: accurate and timely reporting of all licensed groundwater withdrawals; adherence to water-quality monitoring requirements; provision of complete documentation of geology and well construction and well abandonment details; and timely adherence to contaminated site clean-up and restoration.

Potential and Challenge of Market-based Instruments

- Current water prices at the municipal and provincial levels do not reflect the costs of water use and thus promote over-consumption and inhibit innovation and conservation. In this regard, Canada significantly lags behind international best practice.
- Current groundwater allocation methods in Canada rarely use market-based

incentives despite considerable evidence suggesting that greater use of economic instruments such as water prices, abstraction fees and tradable permits has the potential to promote sustainable groundwater use. The principal challenges facing their implementation include the lack of experience of governments in Canada with these instruments; a lack of data and understanding regarding the economic characteristics of users' groundwater demands and their impacts on others over time; and the need to coordinate the introduction of market-based instruments with existing regulatory frameworks.

Allocation of Resources to Groundwater Management

- Allocation of staff and funding to groundwater management has not kept pace with the increasing demands placed on the resource, leaving many Canadian basins with insufficient groundwater management expertise and capacity. Several examples suggest that cooperative efforts involving the three orders of government have generated positive outcomes by combining available resources into a single, geographically focused, vertically integrated management approach.

6 Assessing Groundwater Sustainability — Case Studies

Given the large area of the country and the tremendous variability in hydrogeological settings, it would be a formidable task to perform a comprehensive national assessment of groundwater sustainability in Canada. The task would be further complicated by the fragmented jurisdictional and regulatory environment; spatially and temporally inconsistent groundwater data collection and archiving; and the uneven level of understanding of groundwater-flow systems that exist nationally. To provide a snapshot of the Canadian situation, and to briefly compare it to examples from the United States, the panel has instead chosen to present a number of case studies. The locations of the case studies are shown in Figure 6.1.

(Council of Canadian Academies, 2009)

Figure 6.1
Case study locations.

Taken as a group, the case studies illustrate most of the sustainability issues that have been discussed in previous chapters; however, each case study has a different focus and these span the scientific, regulatory, and legal aspects of groundwater management. The studies demonstrate that progress has been made towards each of the five sustainability goals, with the possible exception of Goal 4 (socio-economic). There are no cases where all five sustainability goals have been addressed.

Case studies have been selected from regions of the country that have a relatively well-developed groundwater knowledge base, and thus they may not be reflective of the national situation. In many of the case studies a high level of knowledge and management has been attained only after conflicts have arisen; in others, the knowledge base is still relatively poor and sustainability goals have not been reached. Issues that are dealt with include agricultural impacts on groundwater quality, energy extraction, urban development, management at the watershed scale, and transboundary groundwaters.

6.1 PRINCE EDWARD ISLAND: IMPLICATIONS OF AGRICULTURAL NUTRIENT LOADINGS FOR GROUNDWATER AND RELATED ECOSYSTEMS

The Prince Edward Island case study (Figure 6.2) was selected to demonstrate the quantity and quality issues associated with groundwater extraction and streamflow, and nutrient loadings from agriculture. In particular:

- A moratorium on new high-capacity irrigation wells has been implemented by the provincial government until a better understanding of the potential impacts on aquatic ecosystems is established.
- Despite crop rotation requirements and agricultural best management practices, groundwater quality in many parts of the province continues to be impacted by nutrients from agricultural activities.
- Groundwater transport of nitrate to streams and estuaries has triggered environmental degradation in shallow estuaries, with consequences to shellfish harvesting, and water-based recreation and tourism.
- Because of province-wide concern, an independent commission, representing various interests, was appointed to establish a plan to deal with nitrate contamination of groundwater.

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.2
Prince Edward Island.

Background

Prince Edward Island (PEI) is the only province that depends on groundwater for essentially all freshwater supply. Approximately 45 per cent of the population of 136,000 receives water from groundwater-sourced municipal distribution systems, while the remainder is served by individual domestic wells. The streams and rivers of the province typically receive about 70 per cent of their flow on an average annual basis as groundwater baseflow (Randall *et al.*, 1988). This dependence of the population and aquatic ecosystems on groundwater coexists within a largely agricultural economy (see Figure 6.3).

PEI is essentially one aquifer (5,680 km^2) composed of sedimentary rock formations dominated by sandstone. The volume of groundwater used on a provincial basis is a small fraction of the annual recharge. It is estimated that only one to three per cent of annual recharge is extracted from the PEI aquifer (Jiang *et al.*, 2004); on a regional scale, water-table levels on PEI have not experienced significant declines because of pumping. The PEI aquifer has inherent characteristics that make it vulnerable to contamination, including: relatively high annual recharge rates; cool groundwater temperatures (~ 10°C) that inhibit microbial and chemical degradation processes; and relatively high bulk hydraulic conductivity in the surficial deposits and shallow, fractured rock. These factors, combined with significant agricultural land use, have led to relatively widespread impacts on groundwater quality (e.g., Savard and Somers, 2007).

(Courtesy of Kerry MacQuarrie)

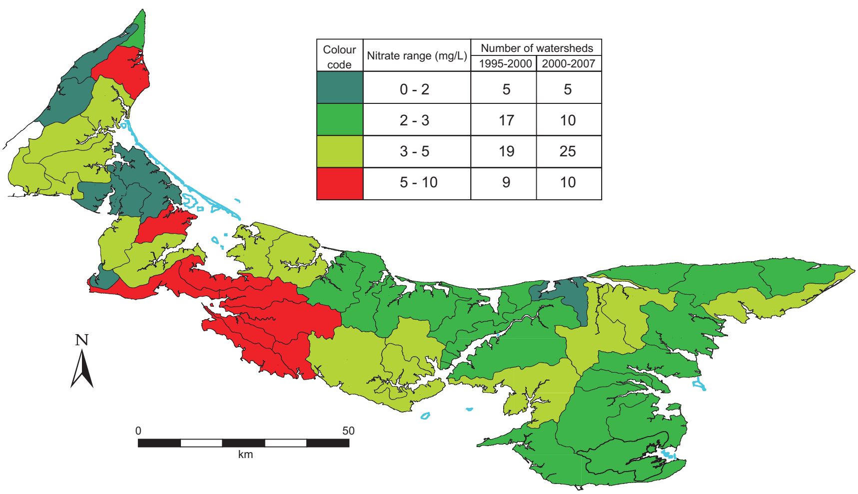
Figure 6.3
A view of the landscape in an agricultural area of central Prince Edward Island.

Sustainability Considerations

Groundwater Quantity: Traditionally, the extraction of groundwater has only been regulated for wells pumped at rates greater than 330 m^3 per day (Government of PEI, 2007a). An allocation permit is granted by the provincial government once it has been demonstrated that the proposed extraction does not cause undesirable impacts on other groundwater users and the environment. Allocations were assessed based on the average annual recharge to the catchment, with cumulative groundwater extractions limited to a maximum of 50 per cent of the annual recharge (Jiang *et al.*, 2004).

In response to concerns about increased groundwater extraction for irrigation, which typically has its highest demand during the dry (low streamflow) periods of the year, the provincial government imposed a moratorium on permits for high-capacity irrigation wells (CBCL Limited, 2003). The moratorium was, in effect, an application of the precautionary principle that provided the time required for more-comprehensive hydrogeological assessments of the long-term cumulative impacts on stream baseflow. Groundwater-flow models were developed for several representative catchments, calibrated with existing groundwater data and stream baseflow records (Jiang *et al.*, 2004) and used to test extraction scenarios. Even with these more-detailed hydrogeological studies, the moratorium on high-capacity irrigation wells remains in effect because there is currently insufficient information to determine the instream flow requirements for aquatic ecosystem viability and integrity (Prince Edward Island Department of Environment, Energy and Forestry, personal communication).

Groundwater Quality: Current potato production practices on PEI have been linked to elevated nitrate concentrations (greater than 3 mg N per litre) in groundwater (Benson *et al.*, 2006). Nitrate in groundwater may pose a human health risk when concentrations exceed the maximum acceptable concentration (MAC) of 10 mg N per litre (Health Canada, 1995). In some catchments (Figure 6.4), as many as 20 per cent of the wells exceed the MAC for nitrate (Savard and Somers, 2007) and studies have attempted to determine the human health effects (Bukowski *et al.*, 2001).



Colour code	Nitrate range (mg/L)	Number of watersheds	
		1995-2000	2000-2007
	0 - 2	5	5
	2 - 3	17	10
	3 - 5	19	25
	5 - 10	9	10

(Adapted and reproduced with permission from Savard and Somers, 2007)

Figure 6.4
Mean nitrate concentration in groundwater based on domestic water well data.

Nitrate concentrations in several rivers that receive a significant component of baseflow increased at a rate of approximately 0.5 mg N per litre per decade during the 1980s and 1990s (Somers *et al.*, 1999). These streams, as well as direct groundwater discharge, deliver dissolved nitrogen to the many small estuaries around the coastline of PEI, and this has contributed to an increasing frequency of anoxia, obnoxious smells, and excessive algal growth in numerous estuaries along the northern coastline of PEI (Prince Edward Island Department of Environment, Energy and Forestry, personal communication).

The province has recently appointed an independent Commission on Nitrates in Groundwater to develop a strategy to reduce nitrate concentrations in groundwater and surface water (Government of PEI, 2008). The strategy is to ensure that:

- nitrate contamination in surface and groundwater will be brought to acceptable levels as soon as possible;
- residents will be able to rely on high-quality natural drinking water; and
- streams, rivers, ponds and estuaries will support a healthy variety of aquatic life.

The fracture network that exists in the rocks of PEI also increases the susceptibility of the aquifer to contamination from microbial pathogens; however, very limited data were available to assess the current situation. Although bacterial contamination of surface waters is a concern, Somers *et al.* (1999) noted in their work that an adequate assessment of bacterial contamination of groundwater could not be made because of the complications of sparse sampling points and site-specific factors such as unknown well integrity. Data presented by Fairchild *et al.* (2000) indicate that five of 42 wells (presumably domestic) tested positive for total coliforms; however, the data reported was collected in 1990 and 1991.

Socio-Economic Implications: The Commission on Nitrates in Groundwater (Government of PEI, 2008) identified the following socio-economic impacts resulting from nutrient loadings to aquatic systems:

- economic losses to commercial and recreational fishing and shellfish harvesting;
- reduced opportunities for water-based recreation and tourism;
- significant costs associated with the remediation of damaged habitats; and
- reduced real estate values.

No valuation is available, however, to indicate the economic magnitude of these impacts.

Approaches to Improving the Sustainable Use of Groundwater

All sectors are in agreement that nitrate leaching to groundwater must be reduced while maintaining a viable agricultural base (Government of PEI, 2007b). Possible strategies include optimised fertiliser management, such as using controlled-release fertiliser products, or a modification of the cropping systems in the rotation to more effectively manage nitrate (Agriculture and Agri-Food Canada, personal communication). These strategies are still being researched in the context of potato production in PEI.

Crop rotation legislation was enacted in the province in 2002, but it is unclear how widely it is practiced or enforced. In 2001, 40 per cent of the potato acreage was in a rotation of less than the minimum recommendation of three years and, therefore, potentially not in compliance. The high percentage of land that was not managed in a three-year rotation was attributed to increasing pressure during the 1990s to produce high-yield crops on a limited agricultural land base (Government of PEI, 2003).

One of the stated purposes of the *Agricultural Crop Rotation Act* is "to maintain and improve groundwater quality" (Government of PEI, 2004a). Because the Act specifically identifies potatoes as a "regulated crop," it is clear that crop rotation in potato production is intended to reduce leaching of nutrients to groundwater. Indeed, the Commission on Nitrates in Groundwater (Government of PEI, 2008) recently made a strong recommendation that the provincial government should "implement a mandatory three-year crop rotation in fields under regulated crop cultivation, with no exemptions". Although other contributors of nitrate were identified by the Commission, including septic systems and cosmetic use of fertilisers, the most significant of the Commission's 30 recommendations relate to reducing nitrate leaching from agricultural crops, and specifically potatoes.

Municipal well-field protection plans are to be developed based on the concept of capture zones for pumping wells, the identification of potential sources of contamination within these capture zones, and proposed control measures that may include zoning bylaws, legally binding agreements with landowners, or the purchase or lease of sensitive lands for the purpose of preventing groundwater contamination within capture zones (Government of PEI, 2004b). The capture zones for all municipal supplies in the province have been modelled by provincial government hydrogeologists and the results have been provided to municipal governments. The municipalities are at various stages of developing plans and schedules for implementing well-field protection (Prince Edward Island Department of Environment, Energy and Forestry, personal communication).

Lessons Learned

Long-term declines in regional groundwater levels are not currently an issue on PEI, i.e., the panel's first sustainability goal is being met, and the recent flow-systems analyses that have been conducted on a catchment scale represent an important advance in groundwater management. On the other hand, the panel considers the current situation of widespread nitrate contamination and the resulting impacts on aquatic ecosystems to be unsustainable from a groundwater quality and ecosystem viability perspective (goals 2 and 3). The relatively unrestricted land-use changes that have resulted in the expansion or intensification of agriculture in many catchments point to the pitfalls of non-integrated land and groundwater resource management. Because of the long transport times of contaminants in groundwater-flow systems, it has taken decades for the effects of past land-use changes to manifest themselves in surface waters and deeper groundwater supplies. Unfortunately, similar time frames may be required for remedial actions to yield environmental benefits.

Solving these long-term groundwater quality issues will likely require multi-institutional collaboration, as exemplified by recent studies on climate change and groundwater nitrate concentrations (e.g., Savard and Somers, 2007; Somers *et al.*, 2007; Vigneault *et al.*, 2007). Current efforts to develop integrated catchment management plans, led by local stakeholder committees with support from provincial and federal agencies, appear to be a good start toward addressing the relatively widespread impacts of current land use practices. However, even with the application of the best science and a long shopping list of well-intended recommendations (e.g., Government of PEI, 2008), Canadian attempts to reduce large-scale nitrate contamination of groundwater to date have not been particularly successful (see further discussion of this in the Abbotsford-Sumas case study).

The continuing moratorium on high-capacity irrigation wells highlights the current gaps in understanding the linkages between groundwater-flow systems and the surface-water ecological systems that depend on, or are influenced by, groundwater discharge. Determining instream-flow needs and acceptable nutrient loads to estuaries are two science-based problems that place groundwater science at the interface with ecology and that will ultimately bring society to some difficult sustainability questions. Management actions with regard to instream flows may need to be iterative; that is, initially allowing a partial allocation of a proposed groundwater extraction, with follow-up ecological monitoring and evaluation before making modifications to the management decision, consistent with adaptive management principles. This would better account for the slow response time for some groundwater systems and the uncertainty in isolating ecological responses.

The relatively non-fragmented jurisdictional environment that exists within PEI, where essentially one layer of government oversees water resources, should provide a good test case within Canada for better integration of groundwater and surface water.

6.2 REGIONAL MUNICIPALITY OF WATERLOO, ONTARIO: APPLYING GROUNDWATER POLICIES AT THE MUNICIPAL LEVEL

The Waterloo case study was selected to demonstrate the challenges faced by municipalities in managing groundwater sustainably in the face of anticipated growth, more stringent regulations, and relic contaminants from historical industrial operations.

Background

The Regional Municipality of Waterloo is the largest user of groundwater for municipal supply in Ontario. It includes the municipalities of Cambridge, Kitchener and Waterloo and the Townships of North Dumfries, Wellesley, Wilmot and Woolwich.

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.5
Region of Waterloo.

The area of the region is approximately 1,380 km^2, of which approximately one-third is urban. The population of about 507,000 is expected to grow by more than 40 per cent to 729,000 by 2031 (Region of Waterloo, 2008).

Current municipal water use is 260,000 m^3 per day and is projected to increase to 300,000 m^3 per day by 2041. About 25 per cent of the water is taken from the Grand River, and the remaining 75 per cent (approximately 200,000 m^3 per day) from local groundwater resources. A highly integrated supply system has evolved, including more than 120 wells and one surface-water intake (Region of Waterloo, 2008).

The region is located in the central portion of the Grand River watershed. Topographically, it is dominated by glacial moraine features, characterised by permeable sand and gravel deposits and a rolling-to-hummocky relief. These moraine deposits provide numerous high-yielding overburden aquifers. The hummocky topography and permeable soils also provide areas of high groundwater recharge. The moraine deposits are highly complex, with inter-layering of sands and gravel and aquitard materials making the aquifers difficult to map and characterise. Bedrock aquifers are associated with the Guelph and Amabel formations, both limestone deposits, and serve as an excellent groundwater supply for the City of Cambridge (Region of Waterloo, 2007a).

Sustainability Considerations

Groundwater Quantity: Based on the 2008 water budget calculations, it is estimated that groundwater extraction accounts for about 25 per cent of the recharge across the region, though in local areas this could be considerably higher, possibly as much as 50 per cent (Region of Waterloo, 2007a). The region experiences water shortages during dry summer months, often necessitating watering restrictions. While supply infrastructure is a factor, seasonal declines in water levels in the supply wells are often the cause, although, with few exceptions, long-term monitoring of water levels in pumping wells and observation wells indicates that water levels have stabilised (Region of Waterloo, 2007a).

Sustainability within the broader context of ecosystem viability, and in view of rapidly increasing demand, is less certain. The Regional Municipality recognises the requirement to maintain adequate groundwater discharge to streams and wetlands; however, the effects of current withdrawals are uncertain and the scientific criteria for maintaining ecosystem viability and integrity are poorly developed.

Groundwater Quality: The region is faced with the common array of contamination issues, primarily anthropogenic. These include nitrate contamination, particularly in rural areas with permeable soils; road salt; and, on a local basis, landfill leachate, petroleum products, chlorinated solvents and other industrial chemicals.

Approaches to Improving the Sustainable Use of Groundwater

Because of the complexity of the aquifer systems, diversity of land use, high water demand and growing population, the region faces a range of groundwater issues of both a technical and management nature. Seven staff hydrogeologists ensure a constructive and informed interaction with higher levels of government, maintain a high technical standard in investigative work contracted to consultants, and ensure strong technical reviews of development proposals seeking land or water-use changes in the region.

The Regional Municipality administers a public education and conservation program, including incentives such as rebates for installation of low-volume toilets. The goal of the program is to achieve water savings of 14,000 m^3 per day (about five per cent of current municipal use) by 2015. Nevertheless, it is anticipated that an additional 40,000 m^3 per day will be required by 2041 (Region of Waterloo, 2007a), provided through:

- aquifer storage and recovery; i.e., pump from the Grand River during periods of high flow and store in aquifer, then recover during periods of low flow;
- additional groundwater wells; and
- a pipeline to Lake Huron or Lake Erie by 2035.[45]

In the wake of the identification of N-Nitrosodimethylamine in production wells in the Elmira area in 1989, the Regional Municipality implemented risk reduction programs to better manage capture zones within the historical distribution of point-source industrial contaminants (Region of Waterloo, 2007a). A reconnaissance survey of potentially contaminated sites, based largely on provincial and municipal databases, was completed in 1996 and is periodically updated. The results of the survey have been used to characterise contaminated and potentially contaminated sites within each wellhead protection area. Levels of risk to groundwater supplies are determined through an indexing procedure that considers the number of potential contaminant sources, the size and severity of the particular source, the vulnerability of the particular aquifer, and the proximity of the contaminant sources to the well field. Delineation of the protection areas has relied heavily on three-dimensional numerical models to determine capture zones and boundaries of the two-year and 10-year time-of-travel zones around each well (Region of Waterloo, 2007a).

To address non-point sources, the Regional Municipality provides financial incentives for farmers to reduce nitrogen fertiliser application and encourages best management practices; it also has programs to reduce the application of road salt (Region of Waterloo, 2007a). In spite of these efforts, contamination of groundwater by nitrate and road salt will remain a sustainability issue for many years.

Lessons Learned

The accuracy of the risk associated with past land use is limited by the quality and completeness of the historical data. Land transfer records frequently do not include

---

45 At first glance, the notion of building a pipeline from somewhere like Lake Erie or Lake Huron to service a groundwater-dependent community seems to be an obvious solution. However, such pipelines have some significant implications, such as:

i) Since the water is being transported, possibly over a considerable distance, through different municipalities, there are often issues of determining appropriate and fair allocation of the costs of the infrastructure for water delivery, treatment and maintenance, and thus pricing of water; it may be argued that piping of water may foster development in areas where, due to water unavailability, development should be limited or constrained;

ii) The pipeline route from the source of water to the community it seeks to serve may become a major issue since the communities that can gain access to the pipeline will have more security for growth while communities more distant from the route may be disadvantaged, all of which leads to the thorny issue of determining which communities should have access to the water pipeline and which ones will not;

iii) As water pipelines become more commonplace, the impact on the lakes supplying water may be overlooked or underestimated, even though many consider the Great Lakes to be a finite water resource;

iv) Similarly, as communities develop in areas supplied with piped water, issues will arise concerning appropriate waste water treatment; and

v) When a municipality realises that water supplies are an issue, it often further legitimates efforts to instil conservation measures, thus raising acute awareness among the community of the value of water. Such efforts may be thwarted where water is imported from a distant source in a manner giving the impression that water supply is not an issue.

the full range of chemicals that have been used at a particular property. In the absence of an effective means for the Regional Municipality to monitor or limit the use of chemicals, there continues to be uncertainty regarding the risk of current and future practices. The possible consequences of as-yet-unidentified legacy sites continue to be a source of uncertainty and concern.

Establishing wellhead protection zones to protect water quality has a high level of uncertainty, particularly in hydrogeologically complex areas such as those encountered in the region. Risk reduction often involves either land-use restrictions or the outright purchase of property, both of which have substantial economic consequences. Application of the precautionary principal under these circumstances could result in very costly requirements that may, in fact, be impractical.

Because of the geological complexity of the aquifers, projections of sustainable yield are uncertain; thus the degree to which the potential yield of new wells can be realised is equally uncertain. Development pressures in recharge areas, and the possible effects on recharge stemming from the change in land use, add to the difficulties of predicting future groundwater availability. Finally, the effects of current withdrawals on ecosystem health are uncertain, and the scientific criteria for maintaining ecosystem viability and integrity are poorly developed.

6.3 OAK RIDGES MORAINE, ONTARIO: COLLABORATIVE REGIONAL GROUNDWATER MANAGEMENT

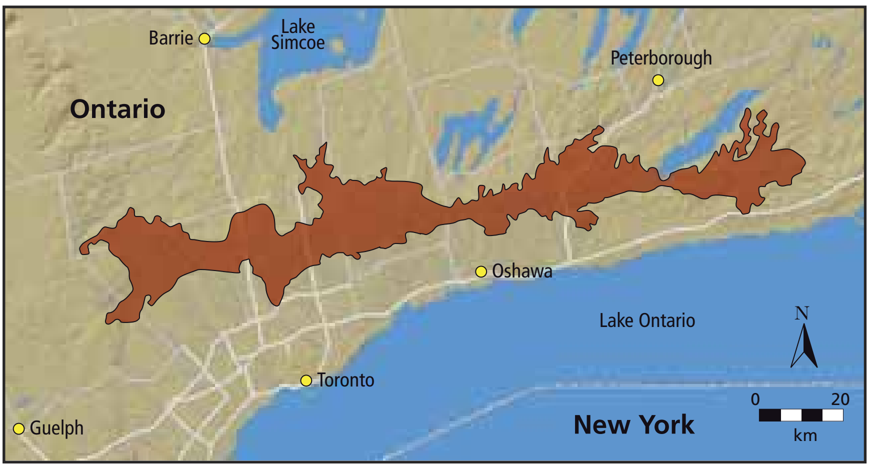
The Oak Ridges Moraine case study was selected to demonstrate the merits of a collaborative and integrated approach to groundwater management over a regional cluster of hydraulically and ecologically similar basins. In particular:

- Municipalities and conservation authority agencies in the Toronto area formed a partnership and pooled their resources for a common regional scientific approach to their collective groundwater resources.
- The characterisation program developed and maintains a data management system, a comprehensive geological understanding of the moraine, and numerical groundwater flow-modelling simulations. These tools are frequently updated and are effectively ‘living’.
- The program maintains a strong linkage to the partner planners to imbed groundwater opportunities and vulnerabilities in land-use decisions.
- The program made use of scientific contributions from all three levels of government.

Background

The Oak Ridges Moraine stretches some 160 kilometres across southern Ontario, from the vicinity of Trenton in the east to the Niagara Escarpment in the west (Figure 6.6). The moraine is the height of land separating southward-flowing drainage towards Lake Ontario from northward-flowing drainage into Lake Simcoe and other northern Kawartha Lakes. The moraine is recognised as a regional groundwater recharge area, providing the groundwater source to municipally developed aquifers and to the numerous streams with headwaters on the flanks of the moraine (Howard *et al.*, 1995).

The groundwater-flow systems are typically shallow and are strongly linked to local surface-water streams in reflection of subdued topography and the humid climate. Many surface-water streams are dependent on groundwater discharge to sustain baseflow during a significant part of the year, and the aquatic ecosystems within the streams are dependent on the quality and quantity of groundwater that discharges into the stream (Bradford, 2008).



(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.6
Oak Ridges Moraine, Ontario.

Sustainability Considerations

From a groundwater perspective, the moraine has long been the focus of significant attention by municipalities, conservation authorities and the Government of Ontario, as well as by the public owing to:

- the recognition of the moraine as a naturalised area where hydrological processes are seen as an important part of Ontario's natural heritage, including the numerous groundwater-dependent, cold-water streams emerging from the moraine flanks;

- the extensive use of groundwater in the area for municipal purposes (e.g., Newmarket, Aurora, Caledon, Uxbridge), domestic purposes (approximately 65,000 private domestic wells in York, Peel and Durham Regions alone), other industrial uses (e.g., aggregate washing), and recreational uses, e.g., some 38 golf courses are on the Oak Ridges Moraine (Garfinkel *et al.*, 2008); and
- pressing development, encroaching onto the moraine, from the rapidly growing communities surrounding Toronto, which has the effect of reducing groundwater recharge and degrading groundwater quality.

Public attention to these factors led to the passage of the 2001 provincial *Oak Ridges Moraine Conservation Act* and the accompanying Oak Ridges Moraine Conservation Plan. These documents aim to better manage land development on the Oak Ridges Moraine, require the use of modelling to develop water budgets for watersheds originating on the moraine and, for the first time in Ontario, put in place provincial land-use restrictions in wellhead protection areas.

Approaches to Improving the Sustainable Use of Groundwater

Since 2000, the municipalities of York, Peel, Durham and Toronto (YPDT) and the nine conservation authorities with jurisdiction on the Oak Ridges Moraine (collectively known as the Conservation Authorities Moraine Coalition or CAMC) formed a partnership for the purpose of establishing a groundwater management program on the moraine (see the YPDT-CAMC website). Given that most of the land-use decisions that affect groundwater resources are carried out at the local level by municipal governments and conservation authorities, it is at this level where decision-making with respect to groundwater resources must be implemented. Both the provincial and federal governments provided support of a technical or financial nature.

The central focus of this partnership (Holysh *et al.*, 2003) has been the understanding of flow systems of both groundwater and surface water. Whether related to nutrient management, water-taking permit issuance, development approvals, landfill or road salt impacts, or any other land-use decisions affecting groundwater resources, the key to making appropriate land-use development decisions is a comprehensive understanding of how water moves through watersheds and how proposed development may affect this movement or the quality of the water.

The program has produced three key products: (i) a water-related database; (ii) a geological model (Kassenaar *et al.*, 2003); and (iii) a numerical groundwater-flow model (Wexler *et al.*, 2003). These products are being used by the partner agencies to plan and assess development, and they continue to be refined to meet the growing needs of the partnership. However, for effective groundwater management, the technical understanding derived from the science must translate into meaningful policies and decisions. The program therefore established strong links to the planners within the partner agencies. For example, a recent study investigated the best means of translating findings from the technical watershed and hydrogeological studies into Official Plan policies that guide land-use decisions across the area (Ogilvie and Usher, 2005).

The operating costs, shared among the partner agencies, are $400,000 per year, or about eight cents *per capita*, supplemented with one-time provincial grants of about $2 million.

Comprehensive Water-Related Database: One of the first YPDT-CAMC projects was to assemble a comprehensive digital database that would not only support groundwater-flow model construction, but also form the foundation for long-term groundwater management.

An important objective was to bridge both agency and disciplinary boundaries by compiling an integrated, comprehensive database covering geology, groundwater, surface water, and climate-related information across a wide regional area. This broad scope recognises that water management cannot stop at municipal boundaries and that a wide range of data sources needs to be tapped to establish the foundation for credible groundwater decision-making and effective long-term resource management. As one example of the ongoing database updating, data logger files of water levels from numerous monitoring locations are being routinely added to the database.[46]

Management of the database also seeks to overcome a common failing of data collection processes in which high-quality data are collected by skilled consultants at considerable cost, reported through various studies, and then simply lost in archived paper reports within the various agencies.

Conceptual Understanding and Detailed Geological Model: The Geological Survey of Canada (GSC) undertook a multi-year investigation of the Oak Ridges Moraine through the 1990s and, among other things, highlighted the need for an understanding of the regional sedimentology in groundwater investigations (e.g., Russell *et al.*, 2001).

The second major product from the YPDT-CAMC program has been to build on the work of the GSC and complete the construction of digital geological layering at a regional scale to represent subsurface geological and hydrogeological units.

46 The database contains information on approximately 300,000 wells, 4,500 surface-water gauging stations and 580 climate stations, as well as descriptions of outcrops and details of water-taking permits. In addition, close to 50 million temporal readings of water levels, water quality, pumping rates, climate data, and streamflows are linked to their point of measurement.

The glacial sediments laid down across south-central Ontario constitute the primary aquifers in the area, and an understanding of their morphology is critical to understanding groundwater-flow patterns on a number of scales (Barnett *et al.*, 1998).

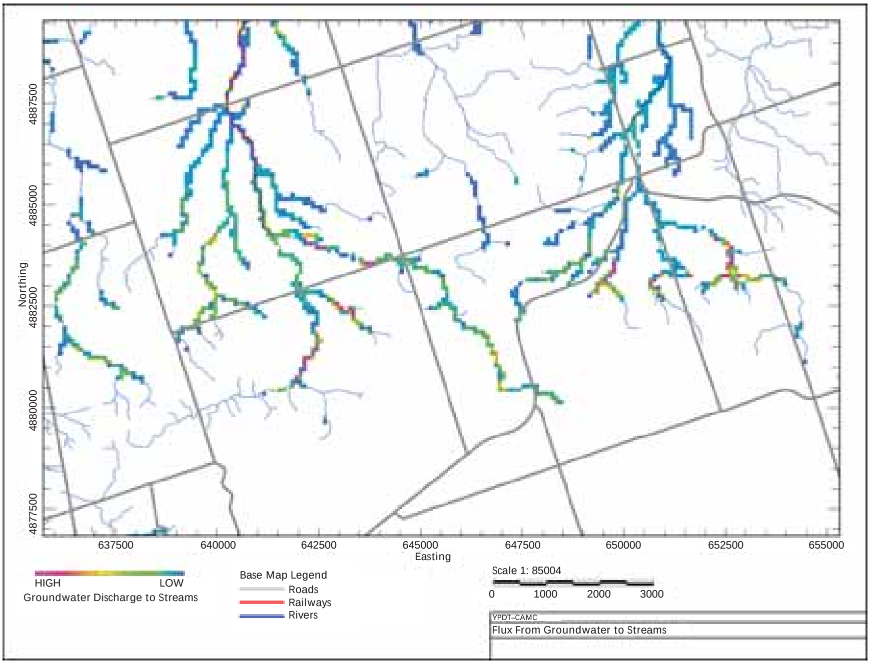
Numerical Groundwater Modelling: The third objective of the YPDT-CAMC program was to use the database and geological layering to develop numerical groundwater-flow models to assist in water management decision-making. Regional modelling of the entire Oak Ridges Moraine was undertaken based on a five-layer model consisting of about 3.3 million cells, each 240 metres by 240 metres square. The model demonstrated that regional groundwater models can be effective groundwater management tools (Kassenaar and Wexler, 2006).

Given that headwater streams on the moraine are particularly sensitive to changes in groundwater levels, gauging the full effects of development demanded simulation of the interaction between groundwater and the moraine's numerous headwater streams. Local modelling (centred on the Toronto and York Regions) was therefore undertaken, requiring eight layers with 7.1 million cells measuring 100 metres by 100 metres (Kassenaar and Wexler, 2006). The smaller cell size was necessary to better represent stream-aquifer interaction and assess drawdowns around municipal wells. However, the size of the model has posed technical difficulties, including computer memory optimization, incorporation of hundreds of kilometres of streams, addressing unconfined units, and assigning hydraulic conductivity values across such a broad area with sparse pumping-test data.

Figure 6.7 shows the predicted discharge (colour-coded) to each of the 100-metre cells along headwater tributaries within a portion of the model area under baseline conditions. Simulated discharge to streams under different land-use and pumping conditions can be compared on a cell-by-cell basis to produce maps of predicted change in the groundwater discharge to streams. Only by incorporating all streams into the model and calibrating to observed baseflows is consideration of this level of stream impact evaluation possible. This type of analysis can be used by municipalities and conservation authorities to target specific tributaries or reaches of streams for further investigation, monitoring and sensitivity analyses to assist in determining the significance of predicted groundwater level changes on streamflows.

Lessons Learned

It is believed that the local level — where data, information and tools are needed on a day-to-day basis for water management-related decision-making — is the most appropriate level for the activities carried out under the Oak Ridges Moraine program. Knowledge of the data, and being able to credibly comment, comes from the intimate knowledge gained from analyses and studies in support of day-to-day decision-making.



(Reproduced with permission from Kassenaar and Wexler, 2006)

Figure 6.7
Local model results showing the groundwater flux to the moraine's headwater streams.

Technical Lessons

- A focus on understanding subsurface depositional processes is important in developing a conceptual model and building geological layers for groundwater-flow modelling.
- Building a groundwater-flow model that incorporates the stream network in detail allowed for estimations to be made of the possible impact of groundwater level changes on surface flows.
- Even if done on a one-time basis at irregular intervals, the measurement of streamflows not influenced by precipitation or snowmelt events can provide important clues about the interconnectedness of groundwater and surface water systems. Program funds have been well spent on filling in data gaps with such measurements.
- Carefully conveying the results of groundwater-flow models and the uncertainty inherent in such results is critical to achieving support for using complex modelling approaches to address groundwater issues.

Management Lessons

- In urban groundwater-dependent areas, municipal expertise is the key to sustainable groundwater management.

- Integration and ready access to data aid considerably in typical local-level investigations and decision-making. For example, in responding to water-well complaints, the use of the YPDT-CAMC program database to quickly depict groundwater levels from nearby wells and precipitation records from nearby climate stations on the same graph allows managers to evaluate whether or not drought is a factor to be considered.
- However, while the overall objectives and outcomes of a regional database are invaluable, coordinating the incoming data streams from the partner agencies is burdensome. In addition, disseminating the data is often hampered by confidentiality requirements for some segments of the data, particularly data that may affect property value.
- Over the life of the program, researchers have advanced differing geological models that demand changes in the conceptual geological understanding, with cascading implications on all aspects of the program.
- An important aspect of the program is that the groundwater-flow model is managed as a 'living model' and updated on a regular basis. Nevertheless, the model has, at times, been inappropriately applied by consultants working for the partner agencies, with results misinterpreted in the absence of a complete understanding of the model or the uncertainties in the results.
- Linking the science and understanding gained through the program to the planning process provides credibility and support to the program since it helps to ensure the relevance of any initiatives undertaken.
- To facilitate the process, technical staff must have a passion for understanding water movement through the surface and subsurface environments; the capacity to ask effective questions of the data, interpretation and numerical model; and the ability to synthesise the information to answer the questions, and present and discuss the significance with effective communication skills. These and other staff with skills in quaternary geology, regional groundwater flow systems and numerical modelling are difficult to find.

6.4 ATHABASCA OIL SANDS: CHALLENGES FOR SUSTAINABLE GROUNDWATER MANAGEMENT OF MEGA-DEVELOPMENTS

The Athabasca case study was selected to demonstrate the challenges encountered when ensuring that enforceable regulations and management objectives, based on a scientific understanding of the groundwater resource on a regional scale, are in place in advance of a rapidly expanding mega-development. As the case study demonstrates, and in light of the sustainability criteria advanced in this report, the cost and success of a protracted regulatory response are uncertain at best, and sustainable groundwater management is unachievable to date. This case study reflects the body of material available in August 2007.

Background

Alberta contains the second-largest proven concentration of oil in the world, the vast majority of which is found in oil sands deposits. Oil sands are contained in three major areas of northern Alberta covering approximately 140,000 km^2. Oil sands production from all three deposits is expected to triple from the 2005 level of one million barrels per day to three million by 2020, and possibly to five million by 2030 (Alberta Energy, 2008). The Athabasca oil sands region, located near Fort McMurray, is the largest reservoir of crude bitumen in the world, covering an area of over 40,000 km^2 (Figure 6.8) (OSDC, 2008b). It is estimated to contain between 1.7 and 2.5 trillion barrels of bitumen, with approximately 10 per cent recoverable at the current price-technology mix (OSDC, 2008a). For bitumen processing, typically 2.0 to 4.5 m^3 of water, mostly from the Athabasca River, are required to produce 1 m^3 of synthetic crude oil (Griffiths *et al.*, 2006), despite efforts to recycle water.

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.8
Athabasca oil sands region.

The Athabasca deposit is the only large oil sands reservoir in the world that is suitable for large-scale surface mining, although most of it can be produced using only the more recently developed *in situ* technology. With approximately 500 km^2 of land already disturbed by oil sands surface-mining activity, there have been serious disruptions to the more local groundwater systems as a result of the removal of up to 75 metres of overburden and the creation of large pits. These pits end up as tailings ponds filled with wastewater, sandy-to-clayey material, and bitumen generated from the mining and bitumen processing. Tailings ponds already cover an area of over 50 km^2 and are some of the largest human-made structures on the planet (Peachey, 2005).

In situ recovery methods are used to extract the bitumen at depths typically greater than 75 metres. The most common extraction technique involves steam injection (steam-assisted gravity drainage (SAGD)). A mix of non-saline and saline groundwater is most commonly used for generating the steam. Although 90 to 95 per cent of the water used for steam is reused, 1 m^3 of bitumen produced still requires about 0.2 m^3 of additional groundwater (NEB, 2008). Eventually, most of the groundwater used for steam injection or processing ends up either being deep-well injected or stored in tailings ponds. This groundwater is considered lost as a resource for consumptive use.

Hydrogeological Setting

The land cover in the Athabasca oil sands area is primarily wetlands and boreal forest. These are underlain by varying thicknesses of overburden, comprising a range of coarse materials in buried valleys or glacial deposits and modern organic deposits sitting atop thick clay tills and sandy tills. The overburden is vertically punctuated by downcutting glacial and post-glacial meltwater channels and modern stream courses (Parks, 2004).

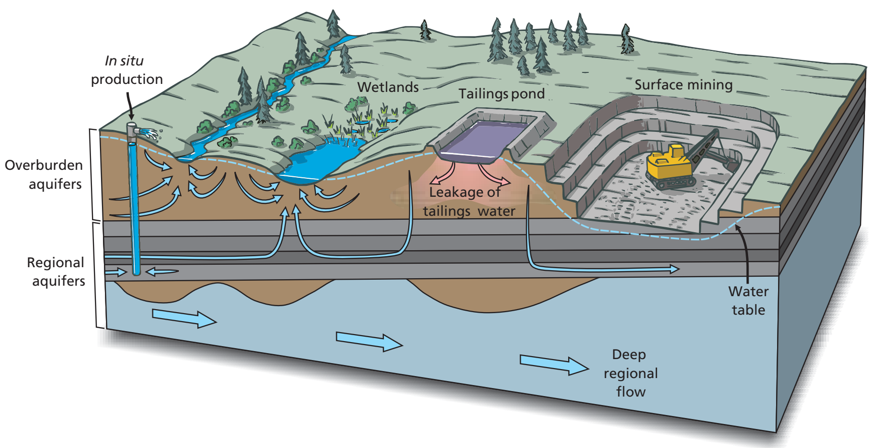
The Athabasca oil sands sit predominantly in the Cretaceous McMurray Formation of the Mannville Group. A typical hydrostratigraphic section through the Mannville Group can be subdivided into four aquifers separated by three intervening aquitards. The intervening aquitards are the bitumen-saturated middle and upper McMurray sandstone and the Wabiskaw and Clearwater shales (Barson *et al.*, 2001).

North of Fort McMurray, the oil sands are exposed near the banks of the Athabasca River, whereas they occur at greater depths in the south, down to approximately 400 metres below ground. The oil sands deposits, which are poorly cemented sandstones, can be as much as 80 to 85 metres thick in some areas. The oil sands behave as aquitards because they are highly saturated with viscous bitumen.

Several hydrogeological units are used or have the potential to be used as a groundwater resource. A key unit is the brackish basal sand aquifer within the McMurray Formation, in areas where the bitumen content is low. It is used for *in situ* production, although at shallower occurrences it will be dewatered during mining operations. Buried preglacial valley aquifers, such as the Wiau Valley aquifer, with cumulative flows of almost 8,000 m^3 per day at springs measured along the Athabasca River (Stewart, 2002), and glacial channel aquifers also have the potential to be significant sources of groundwater.

Sustainability Considerations

The scale and rate of growth of oil sands operations has created significant changes to the groundwater resources in the area. Key groundwater issues are shown schematically in Figure 6.9. These issues are discussed in terms of the sustainability criteria developed earlier in this report.



(Adapted and reproduced with permission from Alberta Research Council, 2007)

Figure 6.9
Schematic diagram of key groundwater issues in the Athabasca oil sands region.

Groundwater Quantity: Large and extensive disturbances of the natural landscape have resulted from surface mining, where up to 75 metres of overburden is removed, followed by the pumping of groundwater to prevent flooding of the open pit, and resulting in the creation of new shallow groundwater-flow systems. Critical field data for understanding these changes in flow systems are difficult to obtain close to the mining operations because monitoring and pumping wells commonly have a limited life expectancy as a result of the advance of the mine face. In addition, pumping tests to determine aquifer characteristics are not completed away from the mine because the discharge water is saline, and it can only be discharged where proper facilities exist (Baxter, 2002).

Approximately 80 per cent of the area with oil sands is at depths that require *in situ* methods designed to increase the mobility of the viscous bitumen so that it can be captured by production wells, commonly achieved using the SAGD process.

When water is recycled, the net requirement for this process is about 0.2 m^3 per m^3 of bitumen produced (NEB, 2008). Since more than four-fifths of the total bitumen reserves in Alberta are accessible only by *in situ* methods, the demand for groundwater for *in situ* production could be as great as, or greater than the demand for surface water for oil sands mining, unless new extraction processes are adopted (Griffiths *et al.*, 2006).

A regional understanding and conceptual hydrogeological model for the area remains incomplete in the absence of coordinated and focused studies. The preglacial buried aquifers and the glacial channel aquifers, although potential sources of freshwater, only have rough estimates of regional-scale groundwater-surface-water interactions, despite over three decades of hydrogeological attention (Parks, 2004). The emphasis in existing assessments of regional hydrogeology in both the published descriptions, as well as in industry reports, has focused mostly on bedrock aquifers at the expense of the shallow but variable Quaternary aquifers that, although difficult to describe, are subject to many of the impacts. Knowledge is lacking as to whether the aquifers in the Athabasca oil sands region can sustain these groundwater demands and losses.

Compounding the challenge is the fact that, while public, the information collected for regulatory requirements is not available in a consistent, integrated format. Thus, it is difficult for stakeholders to integrate studies, build on previous work, share data and generally ensure that sufficient research is integrated within the regulatory process that leads to management decisions. Similarly, in the absence of a common and integrated groundwater database, modelling the effects of supply wells on surface water features is limited by the availability of data to characterise the various regional aquifer units.

Groundwater Quality: Roughly two tonnes of oil sands are excavated to produce one barrel of oil, and the sand and associated process water is discharged to large tailings ponds. The tailings-pond dams may be constructed out of some of this processed sand. There is a concern that this has resulted in more-permeable zones in the dams that may leak and act as migration pathways for the contaminants in the tailings water. Of particular concern is the proximity of the tailings ponds to the Athabasca River, with a potential to detrimentally affect both human and aquatic ecosystem health downstream.

A thorough understanding of the hydraulic controls on SAGD operations, critical for constraining the injection and production fluids and preventing cross-formational migration and contamination of productive aquifers, is absent. The key parameters that control the extent of leakage, the confining pressures in the overlying layers, the integrity of the aquitards and the presence of downward gradients are generally difficult to measure comprehensively and therefore are not well characterised. Away from the bitumen, the degree of hydraulic connectivity to down-cut and often buried glacial scours and to modern river courses needs to be better understood before more underground injection sites are approved (Barson *et al.*, 2001; Baxter, 2002). The SAGD operations that are more vulnerable to leakage across formations are those located in discharge areas close to river valleys. Poorly cemented and improperly completed or abandoned *in situ* wells, which could potentially lead to the upward migration of injection or production fluids, are another risk. Hydraulic connection could also be established between the deeper zones after the amount of bitumen is reduced, which can result in downward migration from shallower zones (Barson *et al.*, 2001).

Ecosystem Impacts: The Alberta government does not require operators to restore the land to 'original condition' but only to 'equivalent land capability'; i.e., it must support a range of activities similar to its previous use before oil sands development. However, when reclaimed, the surface-mined sites are expected to have less wetland, more lakes, and almost no peatlands (NEB, 2006). Also, as noted above, the aquatic ecosystems are vulnerable to leakage from tailings ponds located near the Athabasca River.

Governance: Alberta Environment and the Energy Resources Conservation Board (formerly the Alberta Energy Utilities Board) are the two main provincial government regulators for groundwater-related issues in the Athabasca oil sands. Two main regulatory tools are the Environmental Impact Assessments (EIAs) and various approvals to develop, divert, operate and reclaim or remediate. The Federal Department of Fisheries and Oceans also has a regulatory role, primarily through the *Canadian Environmental Assessment Act* (CEAA). Joint panel reviews (provincial and federal) have been undertaken for oil sands applications under a combined EIA and CEAA process.

Alberta's environmental risk management approach to energy development proposals could be interpreted to tolerate adverse impacts on aquifers if no end user exists, e.g., if no water wells are installed. This interpretation occurred in the joint panel review comments on the Algar project (80 kilometres south of Fort McMurray), where effects on the aquifer from pumping were considered to be not 'relevant' as there were no identified users within the study area, other than another oil sands development (Millennium EMS, 2007).

Groundwater is currently allocated with reference to the estimated sustainable well yield, rather than on a basis of acceptable diversion rates from an aquifer. Barson *et al.* (2001) report that "finding and sustaining the large volumes of fresh (non-saline) (ground)water necessary for steam production, without jeopardizing groundwater resources in the area, is a challenge that could limit the large-scale commercial development of the oil sands resource". The current permitting process based on EIAS focuses on Regional Study Areas that do not extend much beyond lease boundaries, rather than on regional flow systems.

The Surface Water Working Group of the Cumulative Environmental Management Association (CEMA), a multi-stakeholder organization established to provide effective regional environmental guidelines, objectives, and thresholds noted that "there are currently no collaborative water-related research projects being undertaken by the industry." There are concerns that CEMA struggles to match the pace of development in the oil sands (e.g., Kennett, 2007), and was unable to include groundwater in its initial scope of work. Environmental groups have withdrawn from this organization because some 'consensus' recommendations have not been accepted by the industry.

Industry operators hire consultants to undertake studies, the subjects of which include the demands and impacts on groundwater, the results of which are submitted to the appropriate regulator and are publicly available. There are uncertainties as to whether these organizations have the staff with the requisite hydrogeological expertise and the freedom to evaluate whether the environmental reports and ongoing monitoring are adequate to ensure sustainable groundwater management.

Approaches to Improving the Sustainable Management of Groundwater Resources

The following key questions, which address the key issues critical to sustainable management of groundwater resources, remain largely unanswered (modified from Alberta Research Council, 2007):

- How do low-flow levels in the Athabasca River affect shallow groundwater, and how does aquifer dewatering in the mining activities affect surface water systems?
- What are the effects of increased mining activities, changing land cover, or diversion of groundwater out of mined areas on groundwater recharge?
- Will increased oil sands operations dewater or reduce non-saline aquifer supplies as well as depressurise or dewater saline aquifers?
- How will changes in water quality, resulting from aquifer disturbance and tailings-pond leakage, affect the quality of groundwater and surface water resources?
- What data are required to assess the claim that deep injection of steam and waste does not negatively impact the regional and local aquifer systems, and are these data available?
- What are the regional threshold objectives to ensure sustainable groundwater management?
- Do planned developments have adverse impacts on water in adjoining jurisdictions (e.g., Northwest Territories or Saskatchewan) and downstream ecosystems?

To overcome the governance and research gaps and address the hydrogeological data and knowledge challenges outlined above, detailed scientific studies structured under a regional management framework could be used (Kennett, 2007). This framework would have specific groundwater sustainability objectives, defined on a regional basis, with consideration of cumulative effects, and would be established prior to issuing oil sands project approvals. Establishment of regional planning tools based on cumulative impacts was acknowledged in the Alberta government's Oil Sands Ministerial Strategy Committee (2006). Adopting this approach would change the government's EIA project-by-project approval process.

Several new initiatives from both government and industry indicate a growing recognition of the critical consequences of the rate and scale of growth of the oil sands for the sustainability of groundwater resources in the Athabasca oil sands region. These include:

- Alberta Environment's Athabasca Oil Sands (AOS) Groundwater Quality Study and Regional Groundwater Quality Monitoring Network — Phase 1 Design of Monitoring Program;
- proposed new policy legislation: Cumulative Effects Management from Alberta Environment and an Integrated Land Management Framework from Alberta Sustainable Resources Development (Alberta Environment, 2007; Alberta Environment, 2005);
- SAGD Regional Groundwater Modelling Initiative;
- pooling of data by individual operators for larger-scale interpretations; and
- groundwater studies (beyond regulatory requirements) being undertaken by individual operators.

A critical next step would be the development of a strategic framework to identify and evaluate the areas of research and the knowledge and technology needed to respond to future issues of groundwater sustainability in the Athabasca oil sands. One key requirement is a delineation of what is needed for long-term sustainability — including an examination of cumulative regional effects — and what is needed for the more short-term, current, and local issues.

Finally, the question remains as to who should be involved to ensure that implementation is based on sound science. A high demand exists in Alberta for experienced hydrogeological experts, which challenges the ability of regulators to recruit experienced hydrogeologists. The Alberta Water Research Institute has been mandated to increase its number of researchers, and it is hoped that this number will include hydrogeologists.

Lessons Learned

There continue to be uncertainties about the capacity of the groundwater resources in the Athabasca oil sands region to supply the needs of the oil sands operators and about the impacts of the operations on groundwater, interconnected surface waters and aquatic environments. These uncertainties highlight the need for improved knowledge and governance of the groundwater resources on both local and regional scales and for inclusion of cumulative effects.

The definition of clear groundwater objectives (allocation, required quality) prior to the approval of the oil sands projects is critical. These objectives need to be based on (i) adequate knowledge of current hydrogeological systems and their linkages to land use and surface-water environments and (ii) accurate and updated predictions of future, cumulative effects on these systems. This approach would improve the ability of stakeholders to determine the acceptability of the proposed developments.

For the developments that are already approved, the efforts to mitigate groundwater impacts require the collaboration of numerous stakeholders and adequate numbers of skilled hydrogeologists in various levels of government, research institutes, and industry or consultants.

6.5 ABBOTSFORD-SUMAS AQUIFER, BRITISH COLUMBIA AND WASHINGTON: EXPLORING MEANS OF REDUCING AGRICULTURAL LOADINGS

The Abbotsford-Sumas aquifer case study was selected to demonstrate that there can be international dimensions to the management of local groundwater resources and to emphasise the importance of vertical integration in our management regimes and governance structures. In particular, the Abbotsford-Sumas aquifer highlights the complexities of addressing contamination that crosses international borders, and the role of fairness in protecting groundwater from further deterioration.

Background

The Abbotsford-Sumas aquifer covers an area of approximately 200 km^2 under British Columbia and Washington State. It is an important source of water for domestic, municipal, agricultural, and industrial uses on both sides of the border, supplying approximately 110,000 people in Canada and the United States, and is the sole source of supply for communities such as Clearbrook, British Columbia.

The aquifer is shallow, comprised of a thin layer of largely unconfined permeable glacial outwash sands and gravels. The water table is close to the surface and susceptible to contamination from land-use practices, primarily agriculture, which

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.10
Abbotsford-Sumas aquifer.

is the dominant land use on both sides of the border. Groundwater generally flows from north to south, with the result that land-use practices in British Columbia impinge on drinking-water quality in the adjacent area in Washington State.

Contamination of the aquifer has been a concern since the 1950s (with regular groundwater sampling carried out since the mid-1970s and intensified since the mid-1990s), despite the introduction of a number of regulatory and voluntary initiatives on both sides of the border during the past fifteen years. Raspberry production and waste-management practices associated with poultry production (16 million birds producing approximately 600,000 m^3 of manure per year) are the two land uses primarily associated with the nitrate contamination of the aquifer (ASASF, 2007). Nitrate leaches easily into the soil and groundwater as it is soluble in water and mobile in the soil.

Washington State counties and the state government are concerned that nitrate from the Canadian side of the border has reached the capture zones of their drinking-water wells. The aquifer is identified as one of the "most severely contaminated aquifers" in the state (ASASF, 2007). Transboundary water agreements include the 1909 Boundary Waters Treaty and a 1996 Memorandum of Understanding between the Province of British Columbia and the State of Washington on referral of water-rights applications, in order to provide for timely prior consultation on water quantity allocation permits related to the aquifer.

Sustainability Considerations

Groundwater Quality: Well sampling identified an increase in surplus nitrogen compounds from 1971 to 1991, attributed to a shift away from dairy production and towards poultry production and crops requiring more nitrogen. Approximately 70 per cent of water samples between 1991 and 2007 exceeded the 10 mg nitrate as nitrogen per litre drinking-water guideline, with individual values as high as 91.9 mg per litre (Environment Canada, 2004a). Elevated nitrate concentrations occurred more frequently in areas where agriculture was the primary land-use activity and where the water table was close to the surface (Hii *et al.*, 2006).

In 1995, a nitrogen isotope study indicated that the nitrate was coming mainly from poultry manure being used to fertilise crops. While the implementation of best management practices (BMPs) has resulted in 80 to 90 per cent of the poultry manure being shipped off the aquifer, the subsequent shift to inorganic fertilisers has simply changed the source of the nitrate contamination, as young groundwater increasingly bears the isotopic signature of inorganic nitrogen fertiliser (ASASF, 2007). Recent research suggests that the application of inorganic fertilisers in the spring may lead to an ideal situation for rapid nitrate leaching (ASASF, 2007), a situation that is currently unaddressed by BMPs. After a decade of concentrated public awareness and the implementation of BMPs, the significant increase in nitrate concentration over the past five years is a surprising and disappointing result.

Governance Systems: Recent regulatory changes have focused on controlling the impacts of agriculture on the environment. The British Columbia government released an agricultural waste-control regulation and associated code of practice in 1996, containing minimum requirements for avoiding the flushing of manure, for the storage of manure in contained facilities, and for covering manure piles in the rainy season. The State of Washington passed a *Dairy Nutrient Management Act* in 1998 that required all dairy farmers to implement an approved Dairy Nutrient Management Plan by the end of 2003.

Many voluntary efforts have also been directed at reducing nitrate levels, including the formation of coordinating groups and industry self-monitoring. Coordinating efforts include:

- A Canadian federal-provincial groundwater coordinating committee, active since 1992.
- The Abbotsford-Sumas Aquifer Stakeholder Group (ASASG), active since 1995, composed of representatives from federal, provincial and local government agencies,

agricultural and industry groups, NGOs and Washington State participants. The ASASG has sponsored a public education campaign involving signage, environmental pledge booklets, and school presentations.
- The British Columbia Provincial-Industry Partnership Committee on Agriculture designed to reduce agricultural impacts on the environment.
- A bi-national multi-sectoral advisory body, the Abbotsford-Sumas Aquifer International Task Force, established in 1992, which strives to collect and coordinate scientific data, manage activities threatening the aquifer, and assist with legislation and policy advice; each jurisdiction maintains decision-making authority and responsibility to implement recommendations of the Task Force.
- A Canadian Water Network study on the use of BMPs.
- Industry self-monitoring programs consisting of BMPs promoted through the Industry Stewardship group and its subgroups, such as the Sustainable Poultry Farming Group, and environmental farm plans, which enable producers to identify potential environmental improvements on their farms.

Approaches to Improving the Sustainable Use of Groundwater

A wealth of scientific data has been collected over several decades and there has been extensive hydrogeological mapping in both the United States and Canada, with an effort to integrate this knowledge into a regional numerical groundwater model. This model was developed in Canada and has been used jointly by American and Canadian researchers, including simulation of climate-change impacts and nitrate transport.

The numerous governance and policy responses employed to date have not yet abated the contamination. Many involved with management of the aquifer acknowledge that voluntary programs alone will not minimise the problem. BMPs have been developed successfully for certain sectors, such as auto recyclers, but lower levels of success are witnessed with agricultural producers. Regulators note that there are few cases where the implementation of BMPs has improved groundwater quality at the scale of an aquifer; that enforcement of the provincial Code of Agricultural Practice is minimal; and that the voluntary environmental farm plans do not yet appear to be having an impact. Stricter controls on agricultural producers, industrial operations and individual households may be necessary, but there is currently little momentum for stricter regulation at the provincial level, and there are few resources for enforcement of existing controls.

A governance gap persists, particularly in the coordination of the numerous agencies charged with aquifer management. Environment Canada is responsible for the overall management of the transboundary effects of Canadian practices on the United States. The provincial and regional health and environment ministries, agencies, and boards also share responsibility. The British Columbia Ministry of Environment is responsible for pollution prevention and control. The Fraser Valley Health Authority is responsible for drinking water and community health. The City of Abbotsford is responsible for land-use allocation and planning and also for managing drinking-water provision in its role as water purveyor. The provincial Ministry of Environment, Fisheries and Oceans Canada, and Environment Canada together manage the environmental impacts of groundwater withdrawals and contamination (Hoover *et al.*, 2006).

Furthermore, there is no institutional framework for managing cumulative effects on the aquifer. Canadian groundwater managers are interested in piloting new governance mechanisms. Models that have been suggested include the geographically similar, agriculturally dependent Southern Willamette Valley Groundwater Management Area (Oregon), though the legal backdrop in that case is markedly different.

Lessons Learned

Improved management of the Abbotsford-Sumas aquifer depends on finding ways to translate the accumulated knowledge into changes on the ground. Research has identified several factors of success associated with a delegated water-governance model (Nowlan and Bakker, 2007). Three of these factors in particular are not present in the existing aquifer governance structures:

- Financial sustainability is a key factor of success. The existing coordinating bodies have minimal resources.
- A second success factor is policy feedback, i.e., a formal mechanism whereby decisions may result in changes to specific policies in clearly specified areas, under specific conditions. In the case of the aquifer, recommendations are often ignored. For example, recommendations emerging from a 2005 meeting of the British Columbia Washington Environmental Cooperation Council — which had noted that the intensity of agriculture was the key problem on the aquifer, that stronger regulation and increased compliance was needed, and that a change to the Agricultural Waste Control Regulation in British Columbia was needed — have not been implemented (ECC, 2005).
- Finally, committed participants will increase the chances of success of a water governance partnership. Also, equity among the different groups of participants will increase the level of commitment. However, agricultural producers in the Abbotsford-Sumas aquifer region note an inequity in how producers are treated. For example, growers in Delta, British Columbia, receive payment from the federal government for providing bird habitat, while Abbotsford raspberry farmers who protect soil quality and prevent contamination receive no compensation. The issue of equitable payment for protection of ecosystem services is a gap in the current management context.

6.6 THE GREAT LAKES BASIN: LESSONS IN LARGE SCALE TRANSBOUNDARY MANAGEMENT

The Great Lakes case study (Figure 6.11) was selected to demonstrate that, while local-scale groundwater management is important, large basin-scale issues require independent management and research, especially if there are transboundary issues between provinces or nations. Vertical integration of the management bodies, from the local level to the international level, is necessary.

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.11
The Great Lakes basin.

Background

It has been estimated that ‘indirect’ groundwater discharge to the Great Lakes basin accounts for approximately 22 per cent of the United States supply to Lake Erie, 42 per cent of its supply to Lakes Huron and Ontario, 35 per cent of its supply to Lake Michigan, and 33 per cent of its supply to Lake Superior. This supply is provided mainly by sustaining baseflow of rivers and streams discharging to the lakes (Grannemann *et al.*, 2000). On the Ontario side, it is estimated that about 20 per cent of the supply is from groundwater. Estimates of direct exchanges of water between groundwater and the lakes are completely inadequate (Grannemann *et al.*, 2000).

These indirect and direct discharges to the lakes affect water levels, chemical composition, and biotic systems, some of which are wholly dependent on groundwater (Grannemann *et al.*, 2000). Groundwater, like surface waters, may be contaminated by pollutants such as nutrients or pesticides from agricultural lands or urbanised areas, but in general is of good quality. In an era of warming waters due to climate change, groundwater inflow areas often provide essential habitat for cold water species of fish and other biota.

Sustainability Considerations

Groundwater Quantity: In general, it is thought that direct discharges from groundwater contribute to the total water supply, but there are a few locations in which drawdown of groundwater results in flows from the lakes into aquifers. In the western shore region of Lake Michigan, high-volume water withdrawals are made from the Cambrian-Ordovician aquifer system in the region from Chicago to Milwaukee. The high-volume pumping produced cones of depression in aquifers under both cities, with declines in groundwater levels as great as 274 and 114 metres respectively (Grannemann *et al.*, 2000). After 1980, pumping rates were reduced in the Chicago area and levels recovered as much as 76 metres in some locations, but continued to decline in areas of southwestern metropolitan Chicago. In these areas of high pumpage rates and declining groundwater levels, it is likely that flows reverse, resulting in a lowering of the lake levels, but so far by small amounts. Pumping of groundwater in this area also affected water quality through increased concentrations of radium and radon (Grannemann *et al.*, 2000). There is little knowledge of pumping rates and lowering of groundwater levels elsewhere in the basin. However, with the recent (2007) record low levels of Lake Superior and the very low levels in Michigan-Huron, any additional draw-downs, however small, are a cause for major concern.

Thus, in general, available evidence (Grannemann *et al.*, 2000) suggests that groundwater influences in the Great Lakes basin are important for the lakes and inflowing rivers and streams, yet quantification of quantity and quality effects is elusive because of major gaps in measurements and knowledge.

The International Joint Commission, in its 2000 report, summarised the major gaps in knowledge as follows (IJC, 2000):

- There is no unified, consistent mapping of boundary and transboundary hydrogeological units.
- There is no comprehensive description of the role of groundwater in supporting ecological systems.
- Although some quantitative information is available on consumptive use, in many cases the figures are based on broad estimates and do not reliably reflect the true level and extent of consumptive use.

- There are no simplified methods for identifying large groundwater withdrawals near boundaries of hydrological basins.
- Estimates are needed of the effects of land-use changes and population growth on groundwater availability and quality.
- There is inadequate information on groundwater discharge to surface water streams and inadequate information on direct discharge to the Great Lakes.
- There is no systematic estimation of natural recharge areas.

While these serious knowledge gaps apply to both the American and Canadian sides of the basin, the paucity of useful and reliable information is much more pronounced in Canada than in the United States. The United States Geological Survey has undertaken significant work on its side of the basin (Holtschag and Nicholas, 1998), but work by federal and provincial agencies and academia in Canada has been much more sporadic and less intensive.

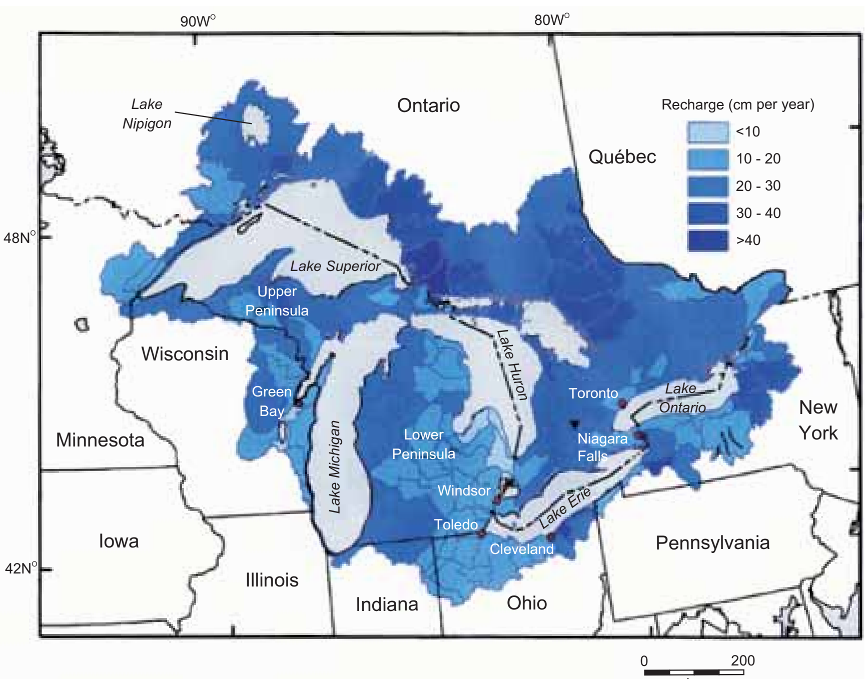
In 2004, the IJC reviewed progress on the recommendations made in its 2000 Report. It noted that the new Great Lakes Charter Annex, signed by the eight States and two Provinces (Ontario and Québec) concerned with the Great Lakes-St. Lawrence system, requires both countries to better understand and conserve groundwater as well as surface-water resources. However, the IJC also noted that while some additional hydrogeological work was evidently underway, it was not aware of any that had been completed (IJC, 2004).

The 2004 Review went on to say that "The Commission wishes to stress the critical importance of the recommendation that governments should commence a project to map and characterise all of the groundwater aquifers in the Great Lakes basin. Such a project would dramatically enhance the ability to manage these vital waters and advance scientific understanding of these unseen resources" (IJC, 2004).

In 2005, the United States Geological Survey began a five-year program to improve fundamental knowledge of the water balance of the Great Lakes basin, including the flow, storage, and withdrawal of water by humans. Interim findings suggest consistent and accurate estimates of recharge are needed to understand how recharge might affect groundwater availability and use. The USGS and Environment Canada (Neff *et al.*, 2005) collaborated to provide the first integrated study of long-term average groundwater recharge to the shallow aquifers in the United States and Canada within the Great Lakes region. Additional work has focused on the United States side of the basin. Sheets and Simonson delineated the basin groundwater divides to illustrate the area contributing groundwater to the lakes, and how groundwater divides can differ from surface-water divides (Sheets, 2006).

This difference makes the assessment of individual water-budget components challenging. Coon and Sheets provided an estimate of the groundwater in storage in the Great Lakes basin based on hydrogeological data from the Regional Aquifer System Analyses conducted by the United States Geological Survey from 1978 to 1995 (Coon and Sheets, 2006). Hodgkins *et al.* analysed historical changes in precipitation and streamflow in the United States Great Lakes basin from 1915 to 2004 and attributed increases in the annual seven-day runoff from 1955 to 2004 to human influences, including urbanisation (Hodgkins *et al.*, 2007). Currently, the USGS is developing a groundwater-flow model of the groundwater system within the Lake Michigan basin.

In 2004, the Groundwater Program of the Earth Sciences Sector of Natural Resources Canada started a project to develop a conceptual hydrogeological framework for southern Ontario, which includes the Great Lakes basin (Figure 6.12). This has led to the mapping and full assessment of one of the regional-scale aquifers within the basin — the Oak Ridges Moraine. However, limited resources have obliged the Earth Sciences Sector to conduct assessments only where considerable data already exist and where collaboration with the provinces is possible.



(Reproduced with permission from Neff *et al.*, 2005)

Figure 6.12

Shallow groundwater recharge rates in the Great Lakes basin.

Groundwater Quality: The revised Great Lakes Water Quality Agreement of 1987 recognised the potential of groundwater flows into the Great Lakes. Annex 16, Pollution from Contaminated Groundwater, focuses on the coordination of "programs to control contaminated groundwater affecting the boundary waters of the Great Lakes system" (IJC, 1978). Under the Great Lakes Water Quality Agreement, Annex 16 calls on the Parties to the Agreement to "identify existing and potential sources of contaminated groundwater affecting the Great Lakes" (IJC, 1978). Although focused in its scope, the Annex is unique in that it is one of the few international and bilateral agreements that expressly establish obligations with respect to groundwater. The Agreement requires the parties to map hydrogeological conditions in the vicinity of existing and potential sources of contaminated groundwater, and to develop standard approaches for sampling and analysis of contaminants in groundwater in order to assess the degree and extent of contamination and estimate the loadings of contaminants. Annex 16 also requires the parties to control the sources of contamination of groundwater and the contaminated groundwater itself, once the problem has been identified.

In 2006, a number of working groups reviewed the Great Lakes Water Quality Agreement and reported on the status and recommendations of the agreement and its annexes (US and Canada, 2006). With respect to Annex 16, a working group made a number of findings, including one indicating that the Annex does not reflect the environmental challenges facing the Great Lakes in relation to groundwater quality and groundwater quality-quantity interactions, and another indicating that there is insufficient mapping of groundwater resources in the Great Lakes basin. Among other things, the working group recommended that a revised Annex should reflect the reality of groundwater-surface-water interaction and the contamination of groundwater by non-point sources. It also recommended that the Annex include "programs for developing maps of groundwater resources that reflect their multiple layers and the different flow patterns across the basin." It further stated that management of Great Lakes water quality "is closely tied to the management of Great Lakes water quantity, including the management of groundwater quantity and flow" (US and Canada, 2006).

A further report by the Science Advisory Board to the IJC on water quality issues was available at the time of writing this panel report, but not the new full report on groundwater. Relevant issues in the basin that are addressed by the Science Advisory Board (IJC, 2008) include:

- Viruses from human fecal waste are common in groundwater due to malfunctioning septic and seepage systems and leaking sanitary sewers. Bacterial measurements do not correlate well with viral contamination.

- Ontario surveys in the 1990s showed that 14 per cent of wells consistently exceeded the guidelines for nitrogen compounds and 34 per cent exceeded bacterial guidelines.
- On-site human-waste treatment systems (OSSs) are proliferating even though it is estimated that 20 per cent of such systems fail to treat wastes adequately. In Ontario, 25,000 new or replacement OSSs are being installed annually.
- There may be a million or more underground storage tanks in the basin (10,000 in Ontario), of which an estimated five per cent to 35 per cent are leaking toxic substances such as oil, gasoline, diesel fuel, solvents and other waste fluids.
- Groundwater contaminant discharges from the industrial chemical complex into the Niagara River, and hence into Lake Ontario, do not appear to be decreasing.
- Ontario has an estimated 500,000 abandoned oil and gas wells, although a full inventory is not available and mandatory reporting has been 'problematic.'
- Ontario jurisdictions provide subsidies for decommissioning or improving water wells and for upgrading septic systems.

Nevertheless, additional work is being done. Phase Two of the Groundwater Program (2006–2009) includes plans to develop an understanding of the dynamics of groundwater in the basin, of general water budgets across southern Ontario, and of the scope of hydrogeological research gaps and priorities in order to assist in future planning and priority setting in the basin (Rivera, 2006). Some collaborative efforts between the United States Geological Survey and the Earth Sciences Sector are also underway (Rivera, 2007).

Lessons Learned

Despite calls for action from the Commissioner for Environment and Sustainable Development (CESD, 2001; CESD, 2008), from the International Joint Commission (IJC, 2004), and the recent initiatives from the Earth Sciences Sector of Natural Resources Canada, it is fair to say that only limited survey and analyses of groundwater in the Canadian portion of the Great Lakes basin had been carried out by the end of 2007, and that whatever current knowledge we do have is largely fragmented and incomplete. Thus, although much valuable work has been completed by the United States Geological Survey on the United States portion of the basin, a comprehensive assessment of the role of groundwater in the Great Lakes basin and its effects on lake-water quantity and quality remains elusive.

6.7 BASSES-LAURENTIDES, QUÉBEC: GROUNDWATER SCIENCE TO HELP MANAGE CONFLICTS AND PLAN GROUNDWATER USE

The Basses-Laurentides case study was selected to illustrate how a groundwater mapping project could be used to help managers and land planners resolve conflicts and plan groundwater use. Highlights include the merits of cooperative groundwater characterisation projects shared among municipalities and multiple layers of government, and the capacity requirements at the municipal level necessary to build on the characterisation and develop the systems for supporting land-use decisions.

Background

The Basses-Laurentides region covers an area of approximately 1,500 km^2 immediately north and west of Montréal. It is under the jurisdiction of four regional municipalities (Figure 6.13). The region has a population of approximately 250,000, one quarter of which use groundwater from regional aquifers as their sole source of supply.

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.13
Basses-Laurentides region, Québec.

The regional municipalities felt that they lacked sufficient information to properly manage land use, to make the best use of the region's groundwater, and to help resolve conflicts among water users. A three-year regional hydrogeology project was therefore undertaken in 1999, led by the Geological Survey of Canada (GSC) in close partnership with the four regional municipalities (Savard *et al.*, 2002). The regional municipalities were involved in elaborating the objectives of the project to ensure that results would help them better manage their water issues. Additional financial and technical support was provided by universities, other federal government departments, provincial agencies, and by the United States Geological Survey. The general objective of the project was to improve scientific knowledge of groundwater quantity and quality in order to assist in planning of groundwater use and to establish limits for sustainable groundwater extraction. The project budget of approximately $3.6 million was shared among the three orders of government.

The regional aquifers are sedimentary rocks that are overlain by unconsolidated quaternary deposits, primarily low-permeability clay that covers 75 per cent of the study area, limiting infiltration and recharge and inducing confined conditions in the bedrock aquifers. Glacial till of variable thickness and permeability covers the remaining area and hosts the main recharge areas. Recharge to the bedrock aquifers varies locally from zero to approximately 300 mm per year, with an average of 45 mm per year over the study area — or less than five per cent of the average annual precipitation of 1,040 mm (Hamel, 2002).

Compilation of groundwater usage data showed that the total annual groundwater extraction is 18 x 10^6 m^3, which represents approximately 18 per cent of the estimated aquifer recharge (Nastev *et al.*, 2006). Domestic usage from municipal and private wells represents approximately 31 per cent of the total extraction, and agricultural activities represent about 14 per cent. Groundwater extraction from quarries accounts for more than half of the total withdrawal rate, and extraction by water bottlers accounts for less than three per cent.

Sustainability Considerations

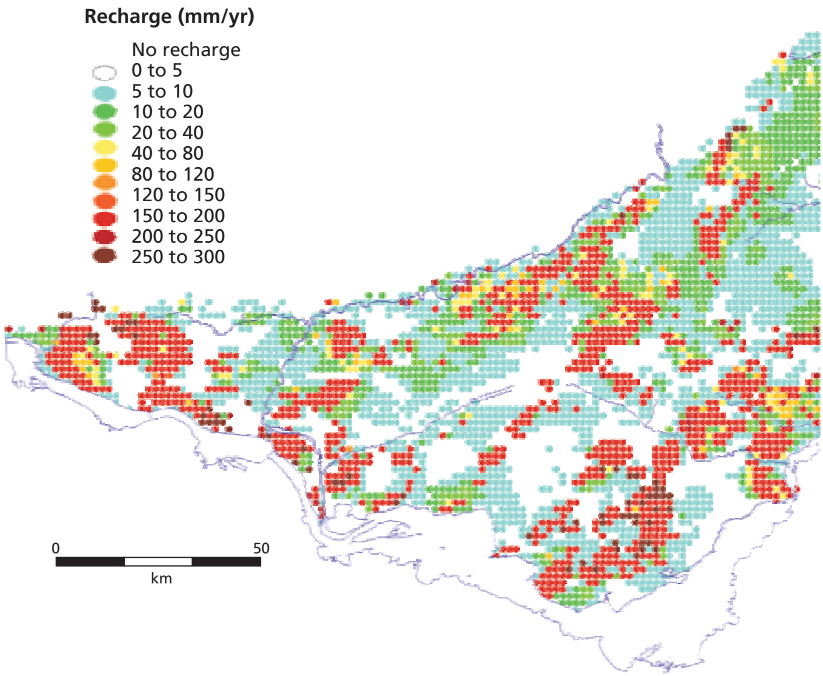
Groundwater Quantity: Near-surface groundwater levels and frequent flowing wells led to a perception in the area that groundwater was abundant. However, starting in the 1990s, a gradual decline of water levels was noted in some private wells, the number of flowing wells diminished, and some springs disappeared. Farmers claimed inherited rights to groundwater and were concerned about long-term groundwater availability. Tensions between groundwater users developed and water bottlers were targeted as bearing some responsibility for the groundwater problems. While these events coincided with periods of lower-than-average precipitation, they also coincided with the arrival of water-bottling firms and a general increase in groundwater extraction rates.

Groundwater Quality: Isolated cases of groundwater contamination, and the presence of several landfill sites, contributed to the population's concern about the sustainability of groundwater quality. Based on the analysis of samples, groundwater quality meets provincial drinking-water standards for almost all samples and there is very little evidence of human contamination (Cloutier *et al.*, 2006). Elevated salt concentrations were noted in some samples and are attributed to a mixture of ancient Champlain Sea water diluted with recharge water.

Approaches to Improving the Sustainable Use of Groundwater

The GSC developed a work plan to investigate and understand recharge to the bedrock aquifers and the spatial distribution of the quality and quantity aspects of groundwater. This work plan included water-level measurements, pumping tests, constant injection tests, specific capacity tests and analysis of the chemical composition of groundwater samples. Data were compiled into a database and distributed to the municipalities.

As a land-use planning tool, and to highlight the role of the recharge areas, groundwater vulnerability was assessed using the DRASTIC[47] method, which accounts for the nature of the geological units close to ground surface when computing a vulnerability index (Savard *et al.*, 2002). Good correlation was found between the highly vulnerable zones and the recharge zones shown in Figure 6.14. Maps produced during the project identified approximately 35 per cent of the study area where land-use planning should account for higher groundwater recharge and vulnerability (Savard *et al.*, 2002).



(Courtesy of Andréanne Hamel (Hamel, 2002))

Figure 6.14
Spatial distribution of recharge for the fractured rock aquifers of the Basses-Laurentides.

47 One of the most widely used groundwater vulnerability mapping methods is DRASTIC, named for the seven factors considered in the method: Depth to water, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone media, and hydraulic Conductivity of the aquifer (Aller *et al.*, 1985).

A numerical groundwater-flow model for the region was developed to assess the sustainability of future groundwater extraction in the region by computing average drawdown in the aquifer for different average withdrawal rates (Nastev *et al.*, 2006).

The current withdrawal rate of 18 x 10^6 m^3 per year produces a simulated annual drawdown of 0.6 metres in the aquifer, compared with a simulation without groundwater withdrawal. This drawdown is less than the seasonal water level fluctuation in the aquifer and thus is estimated to be sustainable. At an extraction rate of 24 x 10^6 m^3 per year, a drawdown of 2.2 metres is predicted in the aquifer, which is estimated to be sustainable, based again on annual water level fluctuations in the aquifer. Withdrawal rates between 24 x 10^6 m^3 per year and 51 x 10^6 m^3 per year could be used but would require tight control. Rates greater than 51 x 10^6 m^3 per year are assumed unsustainable, as the average regional drawdown becomes greater than eight metres. In light of the surficial geology, it was assumed that baseflow to streams and rivers is not affected by extraction of the groundwater, and the flow model did not consider surface water flow.

In support of land-use decisions, a spatially variable suitability index for groundwater extraction in the region was developed by combining simulated drawdown maps, groundwater quality zones, and aquifer vulnerability maps to indicate the areas most suitable for future groundwater extraction.

Upon completion of the project, the following recommendations were provided by the GSC to the local municipalities to support the implementation of the study findings (Savard and Somers, 2007):

- Groundwater vulnerability maps should be integrated into land-use planning.
- Maintaining groundwater quality should be a priority. Regular monitoring of groundwater quality in municipal wells is recommended.
- Establish wellhead protection areas for all municipal wells.
- The groundwater database should be maintained, updated, and used for local hydrogeological work.
- The local technical and scientific capabilities need to be increased.
- A groundwater management committee should be created for the region to integrate groundwater-management and land-use planning.

To date, one of the regional municipalities has integrated results from the regional hydrogeology project into land-use planning (MRC d'Argenteuil, 2005), and indicates that groundwater protection is a priority and that land-use planning will account for it. The project database is available to municipal staff and updates are planned. It is nevertheless reported that the municipalities do not have the expertise or resources to adopt and apply the knowledge base provided by the regional study.

Lessons Learned

The regional hydrogeology project required techniques and tools specifically designed for fractured rock aquifers, but these are not routinely available to hydrogeological consultants or professionals. The capacity and equipment of the GSC and partner agencies was thus an important factor in the success of the project.

The project helped paint a much clearer picture of the regional hydrogeology, including groundwater quality, vulnerability, aquifer recharge, and usage patterns. There is, however, still a lack of sufficiently detailed data at the local scale, for example, at the scale of a municipal pumping well.

The partnership among government agencies, universities and local authorities was effective as the partners received a greater return on their investment than would occur with a series of independent projects. Key findings included:

- Regional mapping is expensive, especially when field work is required. Most municipalities do not have the required budget, nor do they have the technical expertise.
- Characterisation of fractured rock aquifers requires different tools and methods, compared with non-fractured aquifers. The tools and methods exist but are still not widespread in practice.
- Contrary to popular belief, water bottlers extract only a very small fraction of all groundwater in the region, with impacts limited to local effects.

6.8 PRAIRIE GROUNDWATER

The Prairie groundwater case study demonstrates the importance and vulnerability of groundwater in Canada's largest agricultural region (Figure 6.15), and the possible severity of anticipated climate change impacts.

Background

Groundwater provides domestic water for over 1.4 million prairie residents, i.e., about 30 per cent of the population (Statistics Canada, 2003). In rural areas, its importance is even greater, with 90 per cent of domestic water supply being groundwater-sourced (Plaster and Grove, 2000). Reliance varies from 43 per cent in Saskatchewan, to 30 per cent in Manitoba and 23 per cent in Alberta, reflecting the influence of large urban centres that derive their water from surface water. On a local scale, the patchy occurrence of high-yield aquifers with acceptable water quality constrains development and stimulates piped surface-water systems through programs such as those offered by the Saskatchewan Water Corporation. Drought impacts, such as the failure of wells during the recent drought (1999–2003) in the rapidly growing belt of rural residences south of Saskatoon,

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.15
Prairie groundwater.

have prompted the building of pipelines to deliver treated river-water to rural residences where population density and groundwater uncertainty warrants. The most prominent of these is the City of Regina, which has moved from substantial groundwater use to water supplied by pipeline from Lake Diefenbaker in the South Saskatchewan River basin. Prairie hydrology is characterised by low precipitation, intermittent runoff generation and relatively large storage due to deep soils, many substantial aquifers and poorly drained post-glacial topography. Evaporation and runoff are limited by the cold semi-arid to sub-humid climate. Snowfall and subsequent snowmelt provide runoff and spring evaporation, but most summer rainfall infiltrates soils to later evaporate when taken up by roots and transpired by plants. This means that local-scale water resources can be limited and very sensitive to changes in climate, land-use and artificial drainage. The perception of plenty caused by seeing stored water in prairie lakes, ponds, and wetlands in wet years does not match the reality of low throughflow rates in the hydrological cycle.

The semi-arid to sub-humid conditions of the Prairies and the frequent occurrence of heavy soils restrict recharge of groundwater to local areas of coarse-textured soils or to seasonal ponds in topographic depressions (Fang and Pomeroy, 2008; Hayashi *et al.*, 2003; Lissey, 1971). Furthermore, many prairie-derived streams are underlain by heavy glacial till and have minimal groundwater connections and consequently little baseflow. Apart from a few natural springs, surface runoff occurs when the input of rainfall or snowmelt exceeds the infiltration capacity of the soil (Pomeroy *et al.*, 2007). It is typical of many first-order prairie streams to become completely dry shortly after the snowmelt period because of the lack of groundwater contributions.

However, where groundwater is discharged on hillslopes (Hood *et al.*, 2006) and in deep valley bottoms, it sustains important vegetation communities and provides wooded shelter in otherwise treeless, semi-arid plains. Groundwater can play an important role in maintaining summer and drought baseflow in streams emanating from Prairie uplands such as the Cypress Hills, Moose Mountain, Wood Mountain, Riding Mountain and the Manitoba escarpment. A reduction in groundwater discharge from these uplands due to extensive drought or climate change would negatively impact aquatic life, not only in the streams that rely on baseflow, but also in the riparian ecosystems.

Sustainability Considerations

Groundwater Quantity: Most Prairie water use is in the south, while most of the water supply is in the north or in rivers that cross the Prairies from wetter regions in the mountains, parklands and prairie uplands. Past drought in the south has shown that many local surface-water supplies are unreliable, and alternatives include pipelines from larger river systems and local groundwater. Heavy pumping from aquifers that rely mostly on recharge originating from wetlands may result in drying-up of these wetlands and could also lead to drying out of springs and associated wetlands (Van der Kamp and Hayashi, 1998).

Artificial drainage of wetlands in the central and eastern Prairies has been associated with higher streamflow and has resulted in a dramatic reduction in wetland and pond coverage. As many of these wetlands are the primary groundwater recharge zones for the Prairies, long-term effects on aquifers are expected, but current observational systems are inadequate to evaluate the extent of these effects.

Deep-buried valley aquifers have been considered an important source of water supply in times of agricultural droughts. However, as shown by Maathuis and Van der Kamp (1998), heavy pumping from such aquifers leads to significant drawdowns extending tens of kilometres from the pumping centre, and the recovery of the water levels to original static levels may take decades or even centuries. Such aquifers remain invaluable during droughts, but proper management is needed to assure recovery after droughts.

Groundwater Quality: The last few decades have seen dramatic increases in intensive livestock operations (feedlots) and in drilling for oil and gas. Contamination of unconfined and partly confined aquifers has been attributed to oil and gas well drilling and intensive livestock operations in parts of the Prairies (Bruce Henning,[48] personal communication).

Approaches to Improving the Sustainable Use of Groundwater

Technical Implications: All three Prairie Provinces have completed detailed groundwater maps for much of the settled agricultural zone, although this activity is not yet complete for all aquifers. With the exception of the Assiniboine Delta region, these maps have not been linked into a continuous geographic database or generally mapped to the major river basins for purposes of comprehensive water resource assessments. This creates difficulty both in assessing surface-water resources and in estimating sustainable use for certain aquifers. Since solutions to inadequate groundwater supply can require diversion of river-system waters, assessment of groundwater sustainability needs to be done at the large scales at which surface-water systems operate. The cross-border and cross-basin nature of some of the major aquifers makes improved understanding of surface and groundwater interactions important for sustainable management of water in the region, as water use increases with population and economic growth.

There are networks of monitoring wells run by all provinces, which are used to update the status of the major aquifers, but these are not compared across the region. Such comparisons would permit the detection of large-scale climate change or land-use impacts on recharge, or of a regional over-use that could affect interprovincial surface supplies from source areas. Integration of provincial databases for transboundary aquifers where water demand is likely to increase (e.g., Alberta-Saskatchewan border) is desirable.

Unconfined, shallow, surficial aquifers are affected most strongly by changing surface hydrology due to wet and dry cycles and so require more intense monitoring and frequent reporting to be managed sustainably. Greater information on the recharge rates of confined aquifers is required if these aquifers undergo further development as permitted by treatment systems.

Certain aquifers such as the Assiniboine Delta Aquifer in southern Manitoba are unconfined and have both high recharge and withdrawal rates. As such, they can be affected by drought and wet cycles. Climate fluctuations impact both precipitation and streamflow water inputs to the delta and withdrawals by evaporation and irrigation for intensive agricultural water use in the region. Climate change and upstream wetland drainage resulting in poor streamflow quality add further

48 Bruce Henning of Henning Drilling Ltd. is a southern-Alberta water, oil and gas well driller with over 40 years experience and over 2,000 wells to his credit. He has maintained extensive records of changes to groundwater conditions over this time.

uncertainty to the sustainability of these aquifers. Assessing the dynamics of surficial aquifers requires a comprehensive simulation of the atmospheric inputs, surface hydrology and groundwater hydrology. New models that couple atmosphere, hydrology, land surface, and groundwater are being developed in the Drought Research Initiative (DRI) by researchers at the University of Manitoba (Loukili *et al.*, 2006). These land-surface-hydrology-groundwater coupled models can be driven by the output of climate models. There is a strong need for coupled models to be deployed in order to better predict the sustainable use of water in aquifers such as the Assiniboine Delta aquifer.

Management Implications: Under current practices in the Prairie Provinces, most groundwater is allocated on the basis of single-point withdrawals. However, with the exception of a few aquifers, the provinces do not have sufficiently detailed aquifer-management information to be able to fully account for the availability of natural recharge and, therefore, the sustainable yield of the aquifer. While proponents have to demonstrate that their use is sustainable and must include existing users in their analysis, insufficient information and understanding may hamper consideration of the impacts of cumulative withdrawals on the aquifer and thus the sustainable allocation of water.

With anticipated increased consumption for urban, oilfield, livestock and irrigation use in southern Alberta and Saskatchewan, alternative sources of water will be explored, and these will inevitably include groundwater. With improved treatment technologies and lack of surface-water alternatives, groundwater supplies with high dissolved-solid concentrations (currently considered to be undesirable) may be seen as new viable water sources. This could result in substantial increases in groundwater withdrawals in southern Alberta and parts of Saskatchewan. Many of these aquifers have seen sustainable use only because withdrawals were very low, and may be unable to withstand the enhanced use that could develop. Recharge to these aquifers will have to be carefully monitored, and use will have to be managed to ensure sustainability, as high dissolved-solid concentrations are indicators of low recharge rates and long residence times underground.

Integrated surface and groundwater quality measurement programs are needed to better assess the current and developing threats to groundwater quality. In some cases legislation may need to be reassessed, or simply be enforced, so that the regulatory system can adequately control contamination of groundwater reserves. For instance, there have been cases where the development of solutions to groundwater contamination issues is left to local watershed associations or municipalities, with no rigorous provincial enforcement backed by scientific evidence (Smith Creek Watershed Association, personal communication).

Further development and implementation of best management practices and regulations for agriculture and the oil industry to minimise groundwater contamination can help to alleviate the development of these problems before remediation is required. For example, the development of continuous cropping patterns and minimum tillage systems for cultivated land in the Prairies has led to more efficient use of precipitation inputs for crop growth but less excess water available for groundwater recharge from wetlands or internally drained lakes. The reduction in summer-fallowed acreage in the last two decades, and conversion of cropland to grazing land, has reduced snowdrift formation and meltwater runoff to wetlands (Fang and Pomeroy, 2008; Van der Kamp *et al.*, 2003).

There is a long history of prominent groundwater research and monitoring conducted by the Prairie provincial research councils and universities. However, the agencies responsible for groundwater regulation and management (typically environment and agriculture ministries) are institutionally separate from this research and monitoring. This has been addressed in some cases by the development of comprehensive provincial water departments or authorities. For instance, the recent development of the Manitoba Water Stewardship department (integrating all water activities of the Manitoba government) and the development of the Saskatchewan Watershed Authority (with groundwater monitoring transferred from the Saskatchewan Research Council to the Authority) are examples of consolidation of monitoring and management. Alberta's Water for Life strategy attempts to bring a stronger science basis to water management. Further work is necessary to ensure clear lines of communication among groundwater researchers, policy-makers and regulators.

Local-scale water management is conducted on the basis of local watershed associations or authorities in most prairie jurisdictions. These local authorities have some decision-making powers with respect to irrigation, drainage and contamination issues, and have tremendous insight into local water-management issues. Some of their decisions have an impact on groundwater supply and management. In many instances, there is insufficient hydrogeological expertise available to these authorities to allow them to sustainably manage groundwater resources. Sustainable management of aquifers is further compromised where aquifers extend outside small drainage basins and cannot be managed effectively by local watershed authorities. This mismatch between watershed management and aquifer extent deters the comprehensive assessment of the groundwater-surface-water system and proper management of either surface or groundwater resources. One solution is to group or cross-link watershed authorities into sets of aquifer authorities, and provide these groups with suitable hydrogeological expertise to ensure sustainable management of groundwater.

Box 6.1: Role of the Prairie Provinces Water Board Agreement

In 1948, Alberta, Saskatchewan, Manitoba, and the Government of Canada signed the Prairie Provinces Water Board Agreement (PPWBA). The PPWBA established the Prairie Provinces Water Board (PPWB) with a mandate to recommend the best use of interprovincial waters and to recommend allocations among provinces (PPWB, 2005). Groundwater is currently not apportioned among the provinces because adequate supplies of surface water have, for the most part, historically been available in transboundary regions; with low groundwater withdrawals, apportionment of groundwater has not been a priority. In any case, there has often been insufficient knowledge of transboundary aquifers upon which to base apportionment decisions. The PPWB may consider groundwater projects and activities that have interprovincial implications and make recommendations to governments on these matters. However, the PPWB currently has not developed objectives or guidelines on groundwater apportionment.

The PPWB has a Committee on Groundwater that deals with questions related to the use and the quality of groundwater shared by the provinces. One of the goals of the PPWB is to ensure that interprovincial groundwater aquifers are protected and used in a sustainable manner. In order to meet this goal the PPWB is working to define and quantify aquifers along the boundaries on an as-needed case-by-case basis and to develop a method to apportion the water within transboundary aquifers. However, no agreement on an apportionment formula for shared aquifers has been made.

Nevertheless, as the importance of groundwater is growing, the PPWB wants to prevent possible transboundary issues by developing concepts for managing and apportioning interprovincial aquifers. Plaster and Grove (2000) note that any future Prairie Province groundwater apportionment agreement should have, as its overriding principles, the obligation not to cause appreciable harm, the equitable and reasonable use of shared waters, the obligation to give prior notice of water resource developments, and the duty to negotiate in good faith. Of these principles, the equitable and reasonable use of shared waters is considered the most essential. In addition to this basic principle, several factors need to be considered in any apportionment scheme. These include:

- priority of use;
- sustainable yield of the aquifer;
- joint apportionment of surface water and groundwater;
- specification of pumping locations and amounts;
- existing PPWB apportionment agreement; and
- provincial allocation methods.

The current challenges to the PPWB include:

- authorities over water are shared amongst jurisdictions;
- actions in one jurisdiction may affect other jurisdictions;
- the volume and timing of flows in streams that originate in the Prairies are highly variable throughout the year and from year to year;
- water use and consumption in southern Alberta and southwestern Saskatchewan is a large percentage of available supply;
- population and economic activity are increasing;
- climate change will affect timing and volume of available water;
- monitoring must be rationalised within existing budgets;
- threats to surface water and groundwater quality are increasing; and
- need for knowledge related to transboundary aquifers.

In order to address some of these challenges, the PPWB Committee on Groundwater has proposed that a conceptual aquifer plan project be undertaken (PPWB, 2006). The project would provide a better understanding of the kind of information that is needed to allocate, or apportion, surface and groundwater within a complete hydrological balance at transboundary locations. The committee is also currently discussing methods to quantify sustainable yield and quantify groundwater and surface water interactions.

Some interprovincial aquifers near Cold Lake, Alberta, may be affected by advancing oil sands development in Alberta (see Section 6.4). Development of oil sands has been proposed in Saskatchewan along the border region adjacent to current Alberta developments. Trans- and near-border oil sands developments are likely to pose new challenges that will require more information than is currently available if the PPWB is to ensure the equitable and reasonable use of shared groundwater systems.

Lessons Learned

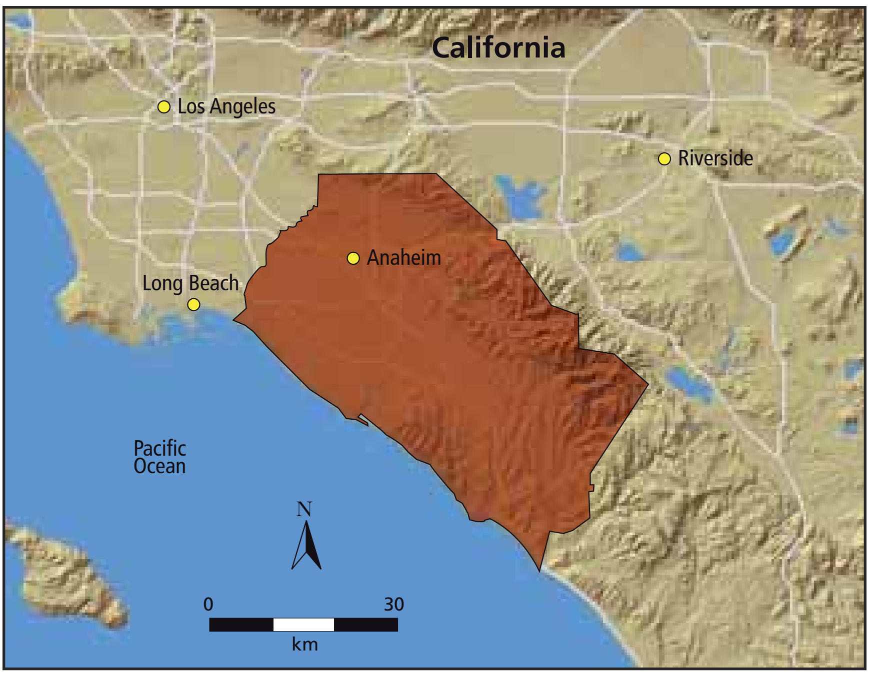
The Prairies are very dependent on groundwater for rural water supply; however, recharge of groundwater is restricted and, in some cases, very sensitive to changes in surface water and climate. The provinces do not have sufficiently detailed aquifer management information to be able to fully account for the availability of natural recharge and, therefore, the sustainable yield of some aquifers. There are particular vulnerabilities to drought, land-use change, and climate change that will require improved surface-groundwater predictive models. Sustainable, comprehensive management of Prairie water resources would be improved by better information on aquifer recharge, assessed in the context of major river basins and with consistent mapping and databases of aquifer characteristics across provincial boundaries.

Contamination from oil and gas exploration and exploitation and from intensive livestock operations may pose threats to groundwater quality in certain regions; it requires careful monitoring and more stringent regulation.

Further work is necessary to ensure clear lines of communication among surface and groundwater researchers, policy-makers, and regulators. Combinations of watershed authorities or cross-linking of authorities to form aquifer management authorities with enhanced hydrogeological expertise could substantially improve groundwater management.

6.9 ORANGE COUNTY WATER SUPPLY, CALIFORNIA: ENGINEERING SOLUTIONS FOR PROTECTING AND ENHANCING AQUIFERS

This case study considers a situation in which the goals of protecting supplies from depletion and contamination were violated, but in which scientific understanding, innovation, and engineering led to a sustainable system.



(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.16
Orange County, California.

Background

Orange County, California, is located in the southeastern part of the greater Los Angeles metropolitan area (Figure 6.16). The northern part of the county is underlain by the Orange County Groundwater Basin, which is managed by the Orange County Water District (OCWD). About 2.3 million people live in the basin, which receives an average of only 33 to 38 cm (13 to 15 inches) of rainfall annually. Despite the semi-arid climate and long history of groundwater extraction, the groundwater basin sustainably provides more than half of all the water used within the District.

Sustainability Considerations

Groundwater Quantity: Beginning in the late 1800s, settlers turned Orange County into a thriving agricultural centre, and groundwater was used to supplement flows from the Santa Ana River. There were hundreds of wells in the basin by the early 1890s, and by 1933 the increased groundwater demand had lowered the water table enough to prompt the California Legislature to create the Orange County Water District to protect and manage the basin. By the 1950s, years of heavy pumping had lowered the water table below sea level, and salt water from the Pacific Ocean had encroached as far as eight kilometres (five miles) inland. Subsurface mapping showed that the intrusion was primarily taking place across a seven-kilometre (four-mile) section of coastline called the Talbert Gap, through sediment laid down as an alluvial fan millions of years ago.

Groundwater Quality: As the region east of Orange County began to grow in population in the 1980s and 1990s, it became clear that the wastewater and stormwater discharges of these upriver communities would markedly increase the discharge of the Santa Ana River. In fact, the water in the river is usually composed primarily of tertiary-treated wastewater from these upstream dischargers. While recognizing that this water represented a significant new source for Orange County if it could be captured and stored, OCWD also understood that it would have elevated levels of nitrate, dissolved organic matter, heavy metals, petroleum hydrocarbons, and other pollutants.

Approaches to Improving the Sustainable Use of Groundwater

Groundwater Quantity: Extensive characterisation was done of the basin's properties through the digitization and interpretation of hundreds of borehole logs, water-level and discharge data from a large network of monitoring wells, and other inputs. This information was used to create and update a 'living' numerical model, which is used extensively for sustainable water management.

The threat to the water supply by salt-water intrusion led the OCWD and the Orange County Sanitation District (OCSD) to conceive a hydraulic barrier system to prevent further salt-water intrusion and protect the basin. Various sources for the water necessary to create this barrier were evaluated. These included deep-well water, water imported from other basins, reclaimed wastewater, and desalted seawater. The source of injection water finally adopted was a mixture of deep-well water and recycled secondary effluent. The first blended, reclaimed water from the plant now known as Water Factory 21 was injected into the coastal barrier in 1976, and the plant now produces about 85,600 m^3 per day (22.6 million gallons (Mgals) per day) of high-quality water for recharge.

The reclaimed water was chosen for many reasons. These included cost considerations; reduced dependency on water imported into the basin from the Colorado River and elsewhere in California; essentially constant availability during drought or emergencies; and reduced discharge of wastewater to the ocean.

Presently, 23 injection wells located about seven kilometres (four miles) inland recharge freshwater to the aquifers. This water flows both landward and seaward, simultaneously blocking further movement of seawater into the basin and replenishing the aquifer used for drinking water.

Groundwater Quality: Many years of research and negotiations with water management, public health, and wildlife management agencies led to the development of a network of constructed wetland ponds behind Prado Dam in Riverside County, east of Orange County. These wetlands reduce nitrate levels to below current drinking-water requirements and otherwise improve the water quality. This water, together with supplies imported from the Colorado River and from the State Water Project, is then captured along a 10-kilometre (six-mile) section of the Santa Ana River that belongs to OCWD. The system uses interlaced levees built of sand to slow the river's flow so that more of the water can percolate through the bottom of the river channel. It also uses diversion structures to channel water into nine recharge basins with depths ranging from 15 to 47 metres (50 to 150 feet), which were formed in years past by sand- and gravel-mining operations.

Lessons Learned

The extensive use of recycled wastewater for water supply in Orange County has raised a number of serious concerns as to its safety with respect to both pathogens and organic contaminants. To respond to this question, the Orange County Water District has, at times, assembled teams of experts in fields such hydrogeology, toxicology, epidemiology, and geochemistry, and given them wide latitude for directing the District's research in these areas. This has led to important work on identifying residence times of pathogens (a key to virus survival) and geochemical transformations of organic compounds in the subsurface. The large investment in science has also had the indirect benefit of building institutional confidence among water users.

The cost of the extra treatment, underground storage and recovery of wastewater for Orange County is in the range of US$0.30 to 0.50 per m^3 (US$400 to 600 per acre-foot), which is relatively high in absolute terms. Yet the cost of the cheapest alternative, imported water purchased from the Metropolitan Water District of Southern California, is about US$0.53 per m^3 (US$650 per acre-foot), and the cost of other alternatives, such as seawater desalting, is higher. In Orange County, the water is used for domestic, industrial, and commercial purposes, all of which are of relatively high value compared with most irrigation applications, especially fodder crops such as hay. Appraisals of water projects must address not only the costs of alternative sources of supply, but the value of the product water in its final uses (NRC, 2008).

6.10 DENVER BASIN, COLORADO

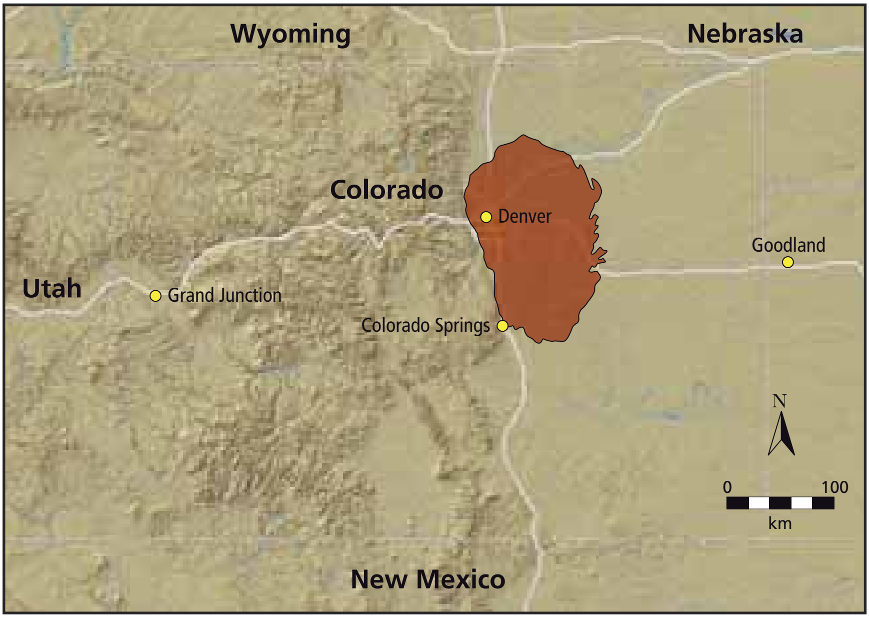
This case study demonstrates that governance may favour socio-economic objectives over maintenance of water level goals, especially in non-recharging aquifers with few ecosystem functions.

Background

The Denver Basin (Figure 6.17) is an important and essentially non-renewable source of groundwater for municipal, industrial, agricultural, and domestic uses in the eight-county Denver metropolitan area (home to 56 per cent of Colorado's population, or slightly more than 2.4 million people according to the 2000 census). The lack of available surface-water rights and accelerated urban growth has resulted in extensive development of the Denver Basin aquifers as both primary and supplemental sources of water supply (Topper *et al.*, 2003).

The Denver Basin aquifer system is a thick, layered sequence of sedimentary aquifers that underlies an area of about 18,000 km^2 (7,000 mi^2) on the eastern front of the Rocky Mountains in northeastern Colorado. The aquifer system, which is under confined conditions in most of the basin, is composed of four aquifers: Dawson, Denver, Arapahoe, and Laramie-Fox Hills. Typically the Dawson aquifer is unconfined. The remaining aquifers are under confined conditions in most locations and not in direct contact with surface water. Water can be produced from all of the sedimentary units, though the Arapahoe aquifer is the most productive and most frequently tapped by municipal supplies.

The Denver area has a semi-arid climate in which potential annual evaporation is about five times larger than annual precipitation. Most recharge to the Denver Basin aquifer system occurs in the high outcrop areas. The principal means of groundwater discharge are withdrawal from wells and inter-aquifer movement of water from the bedrock to overlying alluvial aquifers (Robson and Banta, 1995).



(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.17
Denver Basin, Colorado.

Surface water in the western United States is generally governed by the legal doctrine of 'prior appropriation,' where rights to the surface water are granted for any 'beneficial use.' These rights are granted in order of application, and thus are 'first in time, first in right.' Colorado groundwater law is complicated, but in general it defines any groundwater as 'tributary' to surface water (i.e., assumes it is well-connected to a stream), and thus it is regulated by prior appropriation unless it can be proven to be 'non-tributary,' or isolated from a stream. If groundwater is determined to be isolated from the surface water system, additional rules apply. Because Colorado surface water resources are fully appropriated, the fate of non-tributary groundwater has been hotly debated over the years.

Sustainability Considerations

Groundwater Quantity: Drilling in the Denver area produced flowing artesian wells as early as 1884. By 1890, artesian pressures were used for fountains at Union Station and for operating the organ bellows at Trinity Methodist Church. Pressures began to drop in the mid-1890s, but it was not until the 1950s that new technology, population growth, and drought would combine to force groundwater regulations (Topper and Raynolds, 2007).

Current estimates are that the basin contains 250 x 10^9 m^3 (200 million acre-feet) of recoverable water in storage. Although less than one per cent of this volume has been produced from the aquifer since predevelopment, water levels are declining at a rate of about nine metres per year (30 feet per year) in the most heavily pumped areas. Water levels in the Arapahoe aquifer south of Denver have declined nearly 90 metres (300 feet). Computer simulations of the aquifer system predict that the Arapahoe aquifer could become unconfined by the year 2020. Future prospects for this aquifer are of great concern to water managers (Topper and Raynolds, 2007).

Approaches to Improving the Sustainable Use of Groundwater

With surface water fully appropriated within the basin, there is a continued need for water to meet the demands of an increasing population. In 1985, state legislation created special rules that allocated deep Denver Basin groundwater. With this legislation, the state agreed that it was acceptable to mine the 'non-tributary' Denver Basin aquifers by taking out more water than was being recharged, even if negative consequences resulted.

The 1985 legislation defined non-tributary groundwater as "water which in 100 years will not deplete the flow of a natural stream at an annual rate greater than 1/10th of one per cent of the annual depletion of the well." The legislation also recognised that some of the deep Denver Basin aquifers were not completely isolated from overlying streams, and so were not non-tributary. These Denver Basin aquifers were termed 'not-nontributary,' generally within the outcrop areas. 'Not-nontributary' groundwater, by definition, is not directly connected to surface water, but may show connection over long time frames. Thus, two per cent of the not-nontributary groundwater used must be replaced by return flows (Topper and Raynolds, 2007).

State statutes presume that the productive life of the Denver Basin aquifer system will be at least 100 years, and well permits are issued based on pumping one per cent of the underlying aquifer volume per year. Of course, hydrogeological estimates were made to determine this volume. These estimates are based on measured water levels and the storage properties of the individual aquifers in the basin. Groundwater research in the basin continues in order to track the resource, improve the understanding of the system, and evaluate new information as it develops using a 'living model' approach.

Lessons Learned

Water level declines have been accepted as an inevitable consequence of the use of Denver Basin groundwater, and groundwater is being used in an unsustainable way. Ultimately, future groundwater availability in the Denver Basin may be based on economics rather than on legislation or the remaining volume in storage. As water levels decline due to over-pumping and well interference, flow rates decline, wells must be deepened, and lift costs rise. The cost of the water may rise to a point where it is no longer economically feasible to produce it. Colorado has compromised future groundwater availability with current use to enable development in areas that have no alternative water supply at this time. The hope is that additional options for water supply will develop in the future.

6.11 BIG RIVER BASIN, RHODE ISLAND

The Big River case study was selected to demonstrate that, with advances in groundwater modelling methods, the spatial and temporal patterns of groundwater abstraction can be optimised for the protection of riparian ecosystems.

Background

There would appear to be adequate water resources in the northeastern United States. Streams and lakes are plentiful. Precipitation is relatively abundant in the range of 100 to 125 cm per year (40 to 50 inches per year), and is typically distributed somewhat uniformly throughout the seasons. An example from Rhode Island (Figure 6.18) illustrates a common groundwater development issue that arises in the northeastern United States, despite relatively abundant water resources and productive aquifers.

(Reference map provided by Earth-To-Map GIS Inc.)

Figure 6.18
Big River basin, Rhode Island.

Water demand is increasing throughout Rhode Island, and the Rhode Island Water Resources Board (RIWRB), which is responsible for developing and protecting the State's major water resources, is concerned that increasing demand may exceed the capacity of current sources. RIWRB determined that development of approximately 60,000 m^3 per day (16 Mgal per day) of additional water supply in the area of the Big River basin southwest of Providence was necessary for future population growth and economic development in central Rhode Island. A proposed reservoir, on the books since the 1960s, has not been approved. Water managers were forced to turn to groundwater to meet the projected needs.

Sustainability Considerations

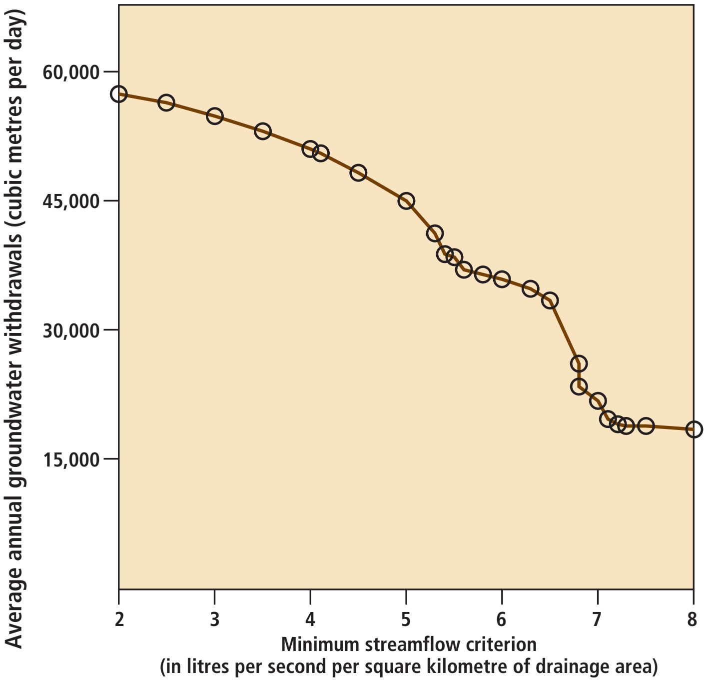
Ecosystem Protection: Shallow, high-yielding sand and gravel aquifers are an important source of water for many communities. Typically, wells that pump from these aquifers are located close to streams that are in direct hydraulic connection with the underlying groundwater system. Pumping from these wells reduces streamflow by capturing groundwater that would otherwise discharge to the streams and, in some cases, by drawing water out of the streams and into the adjoining aquifer.

Approaches to Improving the Sustainable Use of Groundwater

Previous investigations showed that groundwater could not be developed without reducing streamflow. What was not known, however, was what pumping rates could be sustained without unacceptable consequences on the streamflow. Where should the pumping wells be located to minimise the rate of streamflow depletion and the timing of that depletion?

The USGS, in collaboration with RIWRB, recently developed a simulation-optimisation model for the basin to determine the maximum amount of groundwater that could be pumped from 13 wells distributed across the basin while simultaneously maintaining minimum streamflow rates at four locations in the basin. The values of the minimum streamflow rates were varied in a series of model runs to test several management criteria that were being considered by the State (Granato and Barlow, 2005).

Groundwater pumping rates were calculated for several simulations. Each streamflow criterion is plotted in Figure 6.19 as the minimum amount of streamflow required at each of the four streamflow-constraint sites per square kilometre of drainage area to each site. For the criteria shown in the figure, model-calculated average annual pumping rates from the basin ranged from a minimum of about 19,000 m^3 per day (five Mgal per day) for the most restrictive criterion to a maximum of about 57,000 m^3 per day (15 Mgal per day) for the least restrictive. The graph indicates that relatively small changes in the streamflow criteria can result in large changes in model-calculated pumping rates. The nonlinear shape of the graph is



(Adapted and reproduced with permission from Barlow, 2005)

Figure 6.19

Relation between minimum streamflow criterion and total groundwater withdrawals calculated by the optimization model of the Big River basin, Rhode Island. (Each open circle on the figure represents a model run.)

a function of the unique hydrological and hydrogeological characteristics of the Big River Basin and the specific set of well sites and streamflow locations used in the simulation-optimisation model (Barlow, 2005).

Lessons Learned

Experience in the Big River basin illustrates that the relation between groundwater and surface water is complex. Adding specific streamflow criteria further complicates development strategies.

Incorporating and understanding the hydrological system via a computer model allows the groundwater scientist to evaluate groundwater availability in many ways, and to adjust those evaluations as societal decisions about water management change. An evaluation of multiple management strategies would not have been possible without groundwater modelling. Comparing these management strategies would have been difficult to determine by use of multiple simulations managed manually.

Simulation-optimisation models take groundwater modelling a step further by automating and quantifying an approach that allows repeated simulations designed to test different hydrological stresses, such as the effects of different well locations or pumping rates on streamflow. Simulation-optimisation modelling proved to be the most effective approach to evaluate the potential management options.

Detailed knowledge of the aquifer system, combined with recent improvements in simulation techniques, improved understanding of aquatic ecosystem needs, and new regulatory requirements allowed the establishment of minimum streamflow standards and permitted regulators to effectively define the maximum sustainable use of this system.

7 The Panel's Findings: A Framework for Sustainable Groundwater Management in Canada

7.1 THE GROWING IMPORTANCE OF SUSTAINABLE MANAGEMENT OF GROUNDWATER

Groundwater is the main source of water for almost ten million Canadians. It is critical to human health, to important aspects of the economy, and to the viability of many aquatic ecosystems. Groundwater is often the preferred source for communities, farms and individual households since it can be close to users, is relatively inexpensive and is often of better quality than heavily used surface waters. As surface waters become less reliable in a changing climate, there may well be more reliance on groundwater. The need for sustainable groundwater development, and the emergence of many issues that will place roadblocks on the path to sustainability, make it imperative that steps be taken to improve groundwater management in Canada.

Threats to groundwater include:

- rampant urbanisation;
- climate change;
- burgeoning energy production;
- intensification of agriculture; and
- contamination from diverse sources.

While not yet a national 'crisis,' the growing and emerging threats to groundwater require that Canada move with despatch towards a more sustainable management of this vital resource. Experience with over-exploitation and contamination of groundwater in other countries provides lessons to be heeded.

Aquatic ecosystems, which depend on groundwater contributions of flows to rivers and lakes, need more deliberate attention and protection in groundwater withdrawal allocations.

The developing energy-water nexus requires special attention. Oil sands developments, coalbed-methane extraction, irrigation for biofuel crops, and increasing use of geothermal energy all necessitate careful management of related groundwater resources and require measures to increase water-use efficiency.

The persistence of contamination of drinking water, as indicated by boil-water advisories and water-borne illnesses, is an ever-present threat to health. Heavy-rain events preceded two-thirds of water-borne disease outbreaks in North

America (including the Walkerton tragedy), and the frequency of severe storms is expected to increase with a warmer climate. Nitrates in groundwater in many agricultural areas are a persistent problem, potentially posing a threat to the health of infants and, because of transport through the hydrological cycle, creating the threat of adverse effects in receiving waters that contain fish and other aquatic species.

Recharge of groundwater aquifers is threatened in some areas by sprawling urban development and, more broadly, by climate change.

Existing problems in transboundary aquifers and the impact of groundwater on surface waters shared by Canada and the United States will grow as population and usage increase. Although the International Joint Commission (Canada-US) has, at times, interpreted the Boundary Waters Treaty to include groundwater, this is a somewhat imperfect treaty for the purpose. The United Nations General Assembly is considering a draft convention on Transboundary Aquifers that should be considered for adoption by Canada and the United States. Examples of transboundary issues involving groundwater include the Abbotsford-Sumas aquifer and the Great Lakes basin, as described in Chapter 6.

Public attitudes have also been evolving, with an increasing emphasis on environmental values. Never before has the quality and availability of water been of greater importance for Canadians.

7.2 SUMMARY OF THE PANEL'S RESPONSE TO THE CHARGE

The charge to the panel asked, "What is needed to achieve sustainable management of Canada's groundwater resources, from a science perspective?" The answers to that overarching question, and to the four sub-questions in the charge, form much of the content of this report. What follows is a summary, drawn from the main text, of the panel's response to the original charge.

> ***Primary Question:***
> What is needed to achieve sustainable management of Canada's groundwater resources, from a science perspective?

Sustainability Goals

What is meant by sustainable management of groundwater? In earlier times, the avoidance of over-pumping and consequent decline of the water table was the sole objective of users and management agencies. A broader view of the role of groundwater is reflected in the following sustainable-management goals developed by the panel to guide its assessment:

- **Protection of groundwater supplies from depletion:** Sustainability requires that withdrawals can be maintained indefinitely without creating significant long-term declines in regional water levels.
- **Protection of groundwater quality from contamination:** Sustainability requires that groundwater quality is not compromised by significant degradation of its chemical or biological character.
- **Protection of ecosystem health:** Sustainability requires that withdrawals do not significantly impinge on the amount and timing of groundwater contributions to surface waters that support ecosystems.
- **Achievement of economic and social well-being:** Sustainability requires that allocation of groundwater maximises its potential contribution to social well-being (interpreted to reflect both economic and non-economic values).
- **Application of good governance:** Sustainability requires that decisions about groundwater are made transparently, through fully informed public participation and with full account taken of ecosystem needs, intergenerational equity, and the precautionary principle.

Each of these five goals is necessary and none, in itself, is sufficient. The goals are also interrelated. The question of what constitutes 'significant' within the context of the first three goals involves judgment and is ultimately a societal decision that should be informed by scientific knowledge and sustainability principles, including the precautionary principle. The goals are also directions to guide data-gathering, groundwater modelling, groundwater management, and economic decision-making.

Evidence indicates — as outlined, for example, in the Canadian case studies in Chapter 6 — that a comprehensive sustainability framework has not yet been adopted in Canadian jurisdictions. Adoption by federal, provincial and local jurisdictions of such a framework, based on goals along the lines of those set out above, would be valuable in guiding efforts in groundwater management.

The measurement of sustainability with these, or similar goals, as benchmarks is a task requiring further development. More specifically, the assessment of sustainability will usually require the definition of several independent measures that are representative and easily retrievable from program databases. The measures should be designed to permit comparison with sustainability targets, reference values, ranges or thresholds, and therefore be able to serve as triggers for action when indicated.

The Requirement for Integration

Sustainability requires that groundwater and surface water be characterised and managed as an integrated system within the context of the hydrological cycle in a watershed or groundwatershed. In many jurisdictions, groundwater and surface water are studied and managed separately, as are water quality and quantity. Special efforts are needed to overcome this problem.

For the sustainable use of groundwater, the land-use planning and water-resource development process must consider the long-term availability and vulnerability of local groundwater resources and the potential for cumulative impacts. Hydrogeological studies can be effective in integrating groundwater concerns into land-use planning provided, of course, that the groundwater investigations precede the land-use development. The groundwater studies to provide this knowledge are best undertaken on a basin-scale and with a flow systems basis that requires detailed knowledge of recharge, sustainable yield and discharge conditions.

In many cases, groundwater management is a shared undertaking among several levels of government and includes a role for the public. The case studies of Oak Ridges, Basses-Laurentides, Waterloo, and Abbotsford-Sumas are good examples of coordinated and integrated cooperation among different levels of government and are worthy of wider emulation.

Sub-question 1:
What current knowledge gaps limit our ability to evaluate the quantity of the resource, its locations and the uncertainties associated with these evaluations?

A Framework for Analysis and Understanding

There are four investigative components that, when managed in an integrated manner, should lead to credible forecasts of groundwater behaviour in a sustainable-management context. These are: (i) a comprehensive water database (including geology and groundwater data as well as current stresses such as extraction, climate, and streamflow); (ii) an understanding of the geological framework through which the groundwater flows; (iii) a quantitative description of the hydrogeological regime, including the extent of major hydrogeological units and parameters such as hydraulic conductivity; and (iv) an appropriate groundwater-flow model.

Lack of Basic Data

See the response to sub-question 3.

Requirements to Understand Groundwater Flow

In Canada there are key gaps in our knowledge of the large-scale groundwater-flow dynamics (recharge, sustainable yield, discharge) that are essential for sustainable management. There is a need to develop a common framework for categorising aquifers at different scales (provincial, regional, or local). The development of such a framework would allow local studies to link to broader provincial and national assessments to facilitate a comprehensive understanding of groundwater-flow systems on a national scale.

The last comprehensive assessment of Canada's groundwater resources was published in 1967. The Groundwater Mapping Program managed by the Geological Survey of Canada (GSC) has undertaken to assess 30 key regional aquifers. At current rates, it is expected the mapping will not be complete for almost another two decades. In view of the importance of better hydrogeological knowledge as input both for models and for better groundwater management in general, a more rapid pace of aquifer mapping is necessary.

Understanding the Groundwater Needs of Ecosystems

Due to the infancy of the research into the baseline requirements of ecosystems — related, for example, to instream flow needs and temperature — it is difficult to identify cases in Canada where groundwater is being managed to sustain ecosystem health and thus to determine the quantity of water that can be extracted sustainably from an aquifer. In particular, there is no standard methodology for incorporating instream flow protection into laws and regulations, though a number of provinces are examining ways to address this gap.

Groundwater Implications of Energy Developments

Clear groundwater objectives (allocation, required quality) should be defined prior to the approval of any new energy-extraction projects. These objectives should be based on (i) adequate knowledge of current hydrogeological systems and their linkages to land and surface-water environments, and (ii) accurate and regularly updated predictions of future cumulative effects. Currently, adequate knowledge is lacking as to whether the aquifers in the Athabasca oil sands region can sustain the groundwater demands and losses in view of projected future development.

Impacts of Climate Change on Groundwater

Owing to climate change, the combination of reduced recharge in much of southern Canada and increased demand in a warming climate will affect groundwater levels in the coming decades. Much more research on this issue is urgently needed to ensure sustainability of supplies and to assess impacts on ecosystems. For example, models that couple atmosphere, land surface, hydrology and groundwater should be developed to permit better assessment of the impacts of changes in both climate and land use.

Sub-question 2:
What do we need to understand in order to protect the quality of groundwater supply — for health protection and safeguarding other uses?

Protecting the Quality of Drinking Water

The quality of groundwater-based municipal drinking water is generally excellent across Canada. However, the frequent occurrence of microbial contamination in small community wells, including wells in First Nations communities, is unacceptable and undermines the health of a significant number of Canadians. A stronger enforcement and regulatory environment for Canadian drinking water for communities may be necessary, supported by adequate resources and training of water providers.

Jurisdictions in Canada recognise the need for source-water protection as the first barrier to protect drinking-water quality. Nevertheless, available data are generally insufficient to properly delineate source-protection zones, especially in complex aquifer settings. Better geological understanding is needed to improve the accuracy of models used to delineate the source-protection zones.

Monitoring Groundwater Quality

There is considerable disparity in the requirement for, and the thoroughness of, groundwater quality monitoring across the country. Requirements vary from province to province with respect to water quality data for newly drilled domestic wells, but typically only bacteria or coliform testing is required.

There is no national assessment of trends in groundwater quality; however, the National Water Research Institute and the Geological Survey of Canada are now collaborating on collecting needed information. There may be a requirement for a (selective) groundwater-quality monitoring network, coordinated nationally, to detect any large-scale and long-term trends in groundwater quality due to changes in global or regional precipitation, chemistry, or other continental-scale factors.

Identifying Groundwater Contaminants

Proactive measures are necessary, at the local level, to identify substances that may render groundwater unsafe for consumption and inform residents of their presence. Common naturally-occurring examples are arsenic, radon gas and fluoride. Reconnaissance surveys and publication of information, coupled with mandatory testing of private wells in suspect areas, are needed to protect the health of rural residents. Human-caused contamination may result from agriculture, contaminated sites, or leaking storage tanks and sewer systems. These sources need to be identified, remediated where possible, and inventoried in provincial databases, and advisories need to be provided to groundwater users. Little is known about the transport and fate in the subsurface environment of new forms of contamination that may be present in treated sewage effluent, e.g., pharmaceuticals and personal-care products. This knowledge gap should be filled. Resources allocated to such threats to groundwater quality have not kept pace with needs.

Persistent Nitrate Contamination

Elevated nitrate concentrations, mainly from agricultural sources, continue to persist in many important Canadian aquifers. Despite widespread awareness of the problem, there has been little success in significantly reducing the incidence of nitrate contamination. Adoption of best management practices in agriculture has not been sufficient to adequately address this problem with potential impacts on the health of infants. Further efforts are therefore needed to address the technical, regulatory, and economic factors that are responsible.

Rural Groundwater Quality

Considering the currently poor quality of water in many rural wells, the inadequate monitoring programs and inconsistent educational programs that promote and assure rural well-water quality, the fact that most source-water protection initiatives are focused on municipal wells, and the prospect for further intensification of agriculture, it is apparent that rural groundwater quality requires increased attention, including community-based outreach programs addressing water wells and aquifers.

Sub-question 3:
For groundwater supply and quality monitoring purposes, what techniques and information are needed? What is the current state of the art and state of practice, and what needs to be developed in Canada?

The Need for Better Data

While all provinces and local agencies have ongoing water level monitoring programs, the number of observation points is generally insufficient and water quality data are not a priority of these programs. Systematic analyses of these data are not done in many cases, and no mechanism exists to identify emerging threats or evaluate the need for action, except in a reactive mode. With some exceptions, the resources dedicated to systematic water-related data collection have failed to keep pace with the demands of development over the past 20 years; for example, the number of stream gauges in Canada has declined from 3,600 to about 2,900.

Data on Groundwater Withdrawals

There is a critical lack of data on groundwater allocations, including allocations to municipal, industrial and agricultural users; on actual withdrawals of groundwater; and on volumes discharged or reused. Since groundwater cannot be managed effectively at any scale without these data, responsible agencies should assign a high priority to their collection. Environment Canada's Municipal Water and Wastewater Survey is currently the best source of national data on groundwater extraction for domestic and municipal purposes, but due to a poor response rate from many small municipalities to this voluntary survey, it is incomplete over large sections of the country. Measures to improve the response rate by assisting municipalities with the survey, and linking the collected data with provincial records of municipal water works, are necessary to better document groundwater use in Canada.

Climate Data

Existing networks of climate stations are inadequate for providing a year-round accounting of precipitation or temperature for many aquifers, thus increasing uncertainty which could lead to inappropriate groundwater management decisions. This is particularly critical in areas of high topographic relief and in remote regions, such as British Columbia and northern Canada.

Integration of Data

Agencies that undertake monitoring activities should implement hydrological monitoring systems that capture and integrate climate, surface water, groundwater and extraction or consumption data. Provincial water well records usually fail to capture better-quality geological data that could be obtained if other boreholes, such as those drilled primarily by consultants for hydrogeological or geotechnical investigations, were included.

Structure to Facilitate Management and Sharing of Data

Although many hydrogeological data are collected, there are few systematic efforts to assemble them into a collective database to improve understanding of groundwater. For example, there is considerable ongoing loss of valuable groundwater-related data principally collected in various reports and research studies carried out by consulting firms, universities and non-governmental agencies.

Given the poor record of groundwater data management across the country, it is critical that the collection, maintenance and management of groundwater-related data, and ready access to this data, be a priority for action across Canada. While Canada does not need a comprehensive national groundwater database, it is important to agree on a structure and set of best practices (perhaps based on a design and practices similar to those of the National Water Information System of the United States Geological Survey) to facilitate the sharing of data among the provinces and between the provinces and the federal government. The Groundwater Information Network (GIN, see Chapter 4) is developing standards for data management to facilitate sharing of information. Groundwater monitoring at all levels must be more strongly supported, and a platform for sharing data, such as the GIN, needs to be further developed through federal-provincial cooperation.

Sub-question 4:
What other scientific and socio-economic knowledge is needed to sustainably manage aquifers in Canada and aquifers shared with the United States?

Improved Understanding of the Value of Groundwater

An enhanced understanding of the value of groundwater's contribution to Canada's economy, environment, and society could promote more efficient decision-making regarding water allocations, water-related infrastructure, expenditures for source-water protection, and remediation of contaminated waters. Despite the availability of empirical estimation techniques and the efforts in other countries to value their water resources, relatively little research has been carried out in Canada regarding the value of water. There is effectively no current information on the valuation of groundwater by its users.

Market-Based Instruments to Support Sustainable Management

Current groundwater allocation methods in Canada rarely use market-based incentives, despite considerable evidence that greater use of economic instruments such as water prices, abstraction fees, and tradable permits has the potential to promote more sustainable groundwater use. The principal challenges facing their implementation include the lack of experience of governments in Canada with these instruments; a lack of data and understanding regarding the economic characteristics of users' groundwater demands and their impacts on others over time; and the need to coordinate the introduction of market-based instruments with existing regulatory frameworks.

In principle, use of economic instruments could address activities that result in changes in groundwater quality; however, the information requirements for setting a price on groundwater pollution are very challenging. The analysis of non-point source pollution (e.g., from agricultural activity), and the design of policies aimed at controlling it in a least-cost fashion, are likely to be case-specific.

The integration of economic models with hydrological models would provide managers with a powerful tool to promote sustainable groundwater use. To date, models reflecting links between economic activity and groundwater have tended to be devoted primarily to the use of groundwater in agriculture.

Encouraging the Efficient Use of Water

Municipal water prices can be designed to promote sustainable groundwater use. An important first step is that a local water agency's cost-accounting must fully record all of the costs of providing drinking water. Water agencies have typically recorded only operating costs and a portion of capital costs, thus providing water users with an implicit subsidy and an incentive to use water unsustainably.

Application of available technology and further research to improve the efficiency of water use in many industrial and domestic sectors — the oil sands developments being a prominent example — should be encouraged. Economic incentives, and in some cases regulations, may also need to be considered to encourage efficiency.

Valuing Ecosystem Benefits

Methods for assigning value to the ecosystem benefits derived from groundwater are poorly understood and incomplete. For the governance process to equitably balance ecosystem needs with socio-economic needs, comparable accounting procedures are necessary in both domains to quantify the value of water. The failure to fully account for the value of ecosystem functions means that the governance process will likely favour socio-economic interests over ecosystem interests.

7.3 LEGAL AND INSTITUTIONAL CONSIDERATIONS

An adequate base of scientific knowledge is necessary, but not sufficient, for the sustainable management of groundwater. As documented throughout this report, many of the most challenging hurdles lie in the domain of institutional and political factors, including fragmented and overlapping jurisdictions and responsibilities, competing priorities, and traditional approaches and ways of thinking.

Coordinated Governance and Management

The provinces, as resource owners and regulators, have the primary legal jurisdiction over groundwater. The federal government has legislative and proprietary powers to manage groundwater on federal lands and has many areas of policy and spending authority that can affect groundwater sustainability. There are several relevant areas, such as agriculture and environment, where responsibility is shared by the Government of Canada and the provinces. Local governments also have a significant influence on groundwater protection through their land-use powers.

The Canada Water Act, originally passed in 1970, enables the federal government to enter into agreements with the provinces and territories to undertake comprehensive river basin studies; to monitor, collect data, and establish inventories; and to designate water quality management agencies. It has seen little use recently, but could play a beneficial role in groundwater management in the future. *The Canadian Framework for Collaboration on Groundwater*, issued in 2003 by a committee of provincial and federal government representatives, has encouraged cooperation at the working level, but there is still a need for a more clear-cut, formally stated division of duties among the various levels of government.

Considering the interjurisdictional nature of groundwater management, and in light of the positive experiences in interjurisdictional cooperation outlined in several case studies in Chapter 6, the panel would advocate:

- that provincial agencies assist in the establishment and support of local agencies, based on provincial priorities that use flow-system-based, groundwatershed-scale hydrogeological analyses;
- that local agencies — at the scale of the basin, watershed or aquifer — design field programs, gather data, and develop models in order to use them in an adaptive-management style and make decisions, or support provincial decisions in respect of such matters as allocations, source protection, and land use planning; and
- that federal agencies support the basic and applied science needed to underpin sustainable groundwater management; work, as mutually agreed, with provincial and local authorities (including First Nations) to develop the specific hydrogeological and environmental knowledge that is required to implement sustainable-management strategies; and apply sustainability principles to the management of groundwater on federal lands and in boundary and transboundary waters.

Improved Laws and Regulations

There are several areas where the legal protection of groundwater quantity and quality could be improved, as noted throughout the report, specifically: protecting instream flow, addressing nitrate contamination and other agricultural impacts, preventing groundwater contamination, and assessing the cumulative impacts of activities that affect groundwater.

The Importance of Enforcement

Stronger enforcement of existing regulations would improve sustainable groundwater management. Most in need of improvement are: accurate and timely reporting of all licensed groundwater withdrawals, adherence to strengthened water-quality monitoring requirements, provision of complete documentation of geology and of well construction and well abandonment, and timely adherence to requirements for contaminated site clean-up and restoration.

Upgrading Capabilities to Support Sustainable Management

Local Capacity Building: Allocation of staff and funding to groundwater management has not kept pace with the increasing demands placed on the resource, leaving many Canadian basins with insufficient groundwater management expertise and capacity. Groundwater management at a local level, through a regional municipality or a watershed authority, will only be successful when accompanied by sufficient financial and human resources, together with a requirement to take action and report on progress. Several examples suggest that cooperative efforts involving the three orders of government have generated positive outcomes by combining available resources into a single, geographically focused, vertically integrated management approach.

State-of-the-Art Modelling: In most provinces, the use of models by regulatory agencies lags behind state-of-the-art application. Thus, as provincial authorities increasingly seek sustainable groundwater allocation strategies, there is a need to improve their capacity to employ basin-scale groundwater management models.

Need for Skilled People: There is currently a shortage of hydrogeologists in Canada and there will be an increasing demand for groundwater science and management skills as more rigour is applied to managing the resource. There is a need for hydrogeology training programs that integrate coverage of hydrological sciences and ecosystem-sustainability with other relevant fields such as watershed management, water resource economics, and water law.

7.4 A RESEARCH AGENDA

This report has identified a number of topics requiring further research. Action to initiate, accelerate, and fund these research activities requires priority attention in the relevant federal government agencies, including granting councils; in provinces and their research institutes; and in the academic community. Government-university collaboration can be productive in this field. The following do not constitute an exhaustive list but represent areas identified by the panel in the course of its work. In no specific order of priority, they are:

- Improved and more cost-effective methods for hydrogeological characterisation;
- Improved techniques for data analysis and reporting on groundwater quantity, quality, and usage;
- Development or improvement of guidelines and techniques to assess the quantity, quality (including temperature), and timing of groundwater flows to sustainably support aquatic ecosystems;
- Assessment of ongoing climate impacts on groundwater quantity and quality, including impacts of permafrost degradation on groundwater, and the design of appropriate adaptation strategies;
- Development of models that couple atmosphere, land surface, hydrology and groundwater, to help assess impacts both of land-use change and of climate change and variability;
- Improved techniques for delineating recharge and source-water protection zones for land-use planning;
- Research to understand the technical, regulatory, and economic factors that are responsible for persistent elevated nitrate concentrations in important aquifers;
- Assessment and reporting on the concentrations in groundwater of naturally occurring but potentially harmful contaminants (e.g., arsenic, radon), ubiquitous products such as pharmaceuticals, and bacterial and viral contamination;

- Continued research on the transport, fate, and remediation of contaminants;
- Research to improve the efficiency of water use in many industrial and domestic sectors, particularly in energy production; and
- Research on design and implementation of pricing and economic instruments to promote sustainable groundwater use.

7.5 REPORTING

The federal government, in cooperation with the provinces and territories, should report on the current state of groundwater in Canada, and on progress toward sustainable management. Such a report should be completed within the next two years and then updated at regular intervals, possibly every five years.

In this regard, there is a need for further development of appropriate and agreed-upon measurements or indicators of the key dimensions of groundwater sustainability, in order to guide management and to chart progress.

Bibliography

AAFC. 2009. *National Land and Water Information Service*. Available from http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1226330737632&lang=eng.

Adamowicz, W., D. Dupont, A. J. Krupnick, and J. Zhang. 2007. "Valuation of Cancer and Microbial Disease Risk Reductions in Municipal Drinking Water: An Analysis of Risk Context Using Multiple Valuation Methods". *RFF Discussion Paper* 7 (39):1-21.

Alberta Energy. 2008. *Oil Sands*. Available from http://www.energy.gov.ab.ca/oilsands/oilsands.asp.

Alberta Environment. 2005. "*Integrated Land Management Project Charter*", edited by Government of Alberta.

Alberta Environment. 2006. *South Saskatchewan River Basin Approved Water Management Plan*. Available from http://www3.gov.ab.ca/env/water/regions/ssrb/index.asp.

Alberta Environment. 2007. "*Cumulative effects management*", edited by Government of Alberta.

Alberta Research Council. 2007. "A Regional Water Cycle Approach To Managing Groundwater Resources in The Athabasca Oil Sands Area", edited by Alberta Research Council.

Aller, L., T. Bennett, J. H. Lehr, and R. J. Petty. 1985. "*DRASTIC - A standardized system for evaluating ground water pollution potential using hydrogeologic settings*", edited by U.S. Environmental Protection Agency: U.S. Environmental Protection Agency.

Alley, W. M., T. E. Reilly, and O. L. Franke. 1999. Sustainability of Ground-Water Resources. edited by US Department of the Interior. Denver: US Geological Survey Circular.

ASASF. 2007. Executive Summary. In Proceedings of the Abbotsford-Sumas Aquifer Science Forum, April 26, 2007, at Abbotsford, BC.

Bakker, K., and D. Cameron. 2002. "*Good Governance in Municipal Restructuring of Water and Wastewater Services in Canada*": Munk Centre for International Studies, University of Toronto.

Barlow, P. M. 2005. Use of Simulation-Optimization Modeling to Assess Regional Ground-Water Systems. *US Geological Survey Fact Sheet* (3095).

Barnett, P. J., D. R. Sharpe, H. A. J. Russell, T. A. Brennand, G. Gorrell, F. Kenny, and A. Pugin. 1998. "On the Origin of the Oak Ridges Moraine". *Canadian Journal of Earth Sciences* 35:1152-1167.

Barson, D., S. Bachu, and P. Esslinger. 2001. "Flow Systems in the Mannville Group in the East-Central Athabasca Area and Implications for Steam-Assisted Gravity Drainage (SAGD) Operations for *in Situ* Bitumen Production". *Bulletin of Canadian Petroleum Geology* 49 (3):376-392.

Bartlett, R. H. 1988. Aboriginal Water Rights in Canada: A Study of Aboriginal Title to Water and Indian Water Rights. Calgary: Canadian Institute of Resources Law.

Baxter, K. C. 2002. Management of the Basal McMurray Watersand During Bitumen and Heavy Oil Extraction. In Proceedings of the 75th Anniversary of Canadian Society of Petroleum Geologists' Convention.

Benson, V. S., J. A. Vanleeuwen, J. Sanchez, I. R. Dohoo, and G. H. Somers. 2006. "Spatial Analysis of Land Use Impact On Ground Water Nitrate Concentrations". *Journal of Environmental Quality* 35:421-432.

Birnie, P., and A. Boyle. 2002. *International Law and the Environment*. 2nd ed. Oxford: Oxford University Press.

Block, R. W., and J. Forrest. 2005. "A Gathering Storm: Water Conflict in Alberta". *Alberta Law Review* 43 (1):1-286.

Bradford, A. 2008. "Water Policy for Ecosystem Integrity: Oak Ridges Moraine Conservation Plan". *Water International* 33 (3):320-332.

Bredehoeft, J. D., S. S. Papadopulos, and H. H. Cooper Jr. 1982. Groundwater: The Water Budget Myth. In *Scientific Basis of Water Resource Management*, edited by G.S.C. Geophysics Research Forum. Washington, D.C.: National Academy Press.

Brentwood, M., and S. F. Robar, eds. 2004. *Managing Common Pool Groundwater Resources, An International Perspective*. Westport, CT: Greenwood Publishing Group.

British Columbia Ministry of Environment. 2007. *Observation Well Information*. Available from http://www.env.gov.bc.ca/wsd/data_searches/obswell/wellindex.html.

Brown, I. C. 1967. "Groundwater In Canada". *Economic Geology Report* 24:228.

Bukowski, J., G. Somers, and J. Bryanton. 2001. "Agricultural Contamination of Groundwater as a Possible Risk Factor for Growth Restriction or Prematurity". *Journal of Occupational and Environmental Medicine* 43 (4):377-383.

Burchi, S., and K. Mechlem. 2005. "Groundwater in International Law: Compilation of Treaties and Other Legal Instruments". In FAO Legislative Study 86. Rome: Food and Agricultural Organization of the United Nations.

Burn, D. H., J. M. Buttle, D. Caissie, G. MacCulloch, C. Spence, and K. Stahl. 2008. "The Processes, Patterns and Impacts of Low Flows Across Canada". *Canadian Water Resources Journal* 33:107-124.

Canada-Ontario Agreement. 2007. The Canada-Ontario Agreement Respecting the Great Lakes Basin Ecosystem. Canada.

Canada Council for Ministers of the Environment. 2002. *Linking Water Science to Policy*. Available from http://www.ccme.ca/assets/pdf/2002_grndwtrqlty_wkshp_e.pdf.

Carrara, C., C. J. Ptacek, W. D. Robertson, D. W. Blowes, M. C. Moncur, E. Sverco, and S. Backus. 2008. "Fate of Pharmaceuticals and Trace Organic Compounds in Three Septic System Plumes". *Environmental Science & Technology* 42 (8):2805-2811.

Cassidy, P., and C. Findlay. 2007. The Confluence of Environmental and Aboriginal Law. In *Canada Law Book, 2007; Environmental Law: The Year in Review.*

CBCL Limited. 2003. "Agricultural Water Supply Issues: Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador": Agriculture and Agri-Food Canada.

CEC, and Government of Canada. 2006. "*Children's Health and the Environment in North America: A First Report on Available Indicators and Measures*", edited by Commission for Environmental Cooperation. Montreal, QC. Canada: Commission for Environmental Cooperation.

CESD. 2001. Report of The Commissioner of The Environment and Sustainable Development. Ottawa: Office of the Auditor General of Canada.

CESD. 2005. Report of The Commissioner of The Environment and Sustainable Development. Ottawa: Office of the Auditor General of Canada.

CESD. 2008. Report of The Commissioner of the Environment and Sustainable Development. Ottawa: Office of the Auditor General of Canada.

City of Barrie. 2003. *TCE Update - Q & A*. Available from http://www.barrie.ca/docs/TCEQA.pdf.

Cloutier, V., R. Lefebvre, M. Savard, E. Bourque, and R. Therrien. 2006. "Hydrogeochemistry and Groundwater Origin of The Basses-Laurentides Sedimentary Rock Aquifer System, St. Lawrence Lowlands, Québec, Canada". *Hydrogeology Journal* 14 (4):573-590.

Cohen, S. J. 1997. "*Mackenzie Basin Impact Study*": Environment Canada.

Coon, W. F., and R. A. Sheets. 2006. "Estimate of Ground Water in Storage in The Great Lakes Basin, United States, 2006". In U.S. Geological Survey Scientific Investigations Report.

Corkal, D., W. C. Schutzman, and C. R. Hilliard. 2004. "Rural Water Safety From the Source to the On-Farm Tap". *Journal of Toxicology and Environmental Health* 67 (20-22):1619-1642.

Cumming, J., and R. Foroehlich. 2007. "NAFTA chapter XI and Canada's environmental sovereignty: investment flows, article 1110 and Alberta's Water Act". *University of Toronto Faculty of Law Review* 64.

CWIC. 2008. "*A Model Act for Preserving Canada's Waters*" edited by Canadian Water Issues Council. Toronto: Munk Centre for International Studies, University of Toronto.

CWRA. 1994. "*Sustainability Principles for Water Management in Canada: A Policy of the Canadian Water Resources Association*", edited by The Canadian Water Resources Association. Ottawa, Ontario: The Canadian Water Resources Association.

D'Aliesio, R. 2008. Water Rights Battle Hits Court. *Calgary Herald*.

de Gispert, C. 2004. "The Economic Analysis of Industrial Water Demand: A Review". *Environment and Planning C: Government and Policy* 22:15-30.

de Loë, R., J. Varghese, C. Ferreyra, and R. Kreutzwiser. 2007. "*Water Allocation and Water Security in Canada: Initiating a Policy Dialogue for The 21st Century*": University of Guelph, Water Management Group.

Demuth, M. N., and A. Pietroniro. 2003. "The Impact of Climate Change on the Glaciers of The Canadian Rocky Mountain Eastern Slopes and Implications for Water Resource Adaptation in the Canadian Prairies": CCAF-Prairie Adaptation Research Collaborative.

Devlin, J. F., and M. Sophocleous. 2005. "The Persistence of The Water Budget Myth and Its Relationship To Sustainability". *Hydrogeology Journal* 13 (4):549-554.

Dupont, D., and S. Renzetti. 1999. "An Assessment of The Impact of A Provincial Water Charge". *Canadian Public Policy* 25 (3):361-378.

Dupont, D., and S. Renzetti. 2001. "The Role of Water in Manufacturing". *Environmental and Resource Economics* 18 (4):411-432.

ECC. 2005. Record of Discussion for ECC Meeting: October 28, 2005. In *22nd Meeting of the BC/WA Environmental Cooperation Council*. Victoria, BC: BC/WA Environmental Cooperation Council.

Eckert, C. 2007. Alberta Water Act Regulation and Policy. Bow Riverkeeper.

ECO Canada. 2008. "When Supply Does Not Meet Demand: Labour Gaps and Issues in Canada's Contaminated Sites Sector".

Eggertson, L. 2008a. "Despite Federal Promises, First Nations' Water Problems Persist". *Canadian Medical Association Journal* 178 (8).

Eggertson, L. 2008b. "Investigative Report: 1766 Boil-Water Advisories Now in Place Across Canada". *Canadian Medical Association Journal* 178 (10).

Ehsanzadeh, E., and K. Adamowski. 2007. "Detection of Trends in Low Flows Across Canada". *Canadian Water Resources Journal* 32 (4):251-264.

Environment Canada. 1987. Federal Water Policy. Environment Canada.

Environment Canada. 2004a. Nitrate Levels in The Abbotsford Aquifer: An Indicator of Groundwater Contamination in The Lower Fraser Valley.

Environment Canada. 2004b. "Threats to Water Availability in Canada". In NWRI Scientific Assessment Report Series No. 3 and ACSD Science Assessment Series No. 1. Burlington, ON: National Water Research Institute.

Environment Canada. 2007. "Municipal Water Use: 2004 Statistics". In Municipal Water Use Report.

Environment Canada. 2008a. *Aquifers and wells*. Available from http://www.ec.gc.ca/water/images/nature/grdwtr/a5f3e.htm.

Environment Canada. 2008b. *Freshwater Website: Groundwater contamination from a waste disposal site*. Available from http://www.ec.gc.ca/Water/images/nature/grdwtr/a5f8e.htm.

Environment Canada. 2008c. *Freshwater Website: Typical Municipal Water Prices*. Available from http://www.ec.gc.ca/water/images/manage/use/a4f3e.htm.

Environment Canada. 2008d. *Groundwater - Nature's Hidden Treasure*. Available from http://www.ec.gc.ca/WATER/en/info/pubs/FS/e_FSA5.htm.

ERCB. 2006. Baseline Water Well Testing Requirement for Coalbed Methane Wells Completed Above the Base of Groundwater Protection. Available from http://www.ercb.ca/docs/documents/directives/directive035.pdf.

Espey, M., J. Espey, and W. D. Shaw. 1997. "Price Elasticity of Residential Demand for Water: A Meta-Analysis". *Water Resources Research* 33 (6):1369-1374.

EU. 2000. Directive 2000/60/Ec of The European Parliament and of The Council of 23 October 2000 Establishing A Framework for Community Action in The Field of Water Policy. edited by European Union Water Framework Directive.

Fairchild, G. L., D. A. J. Barry, M. J. Goss, H. A.S., P. Lafrance, P. H. Milburn, R. R. Simard, and B. J. Zebarth. 2000. "*Groundwater Quality*". In *The Health of Our Water: Toward Sustainable Agriculture in Canada*, edited by D.R. Coote and L.J. Gregorich. Ottawa: Agriculture and Agri-Food Canada.

Fang, X., and J. W. Pomeroy. 2008. "Drought Impacts on Canadian Prairie Wetland Snow Hydrology". *Hydrological Processes* 22 (15):2858-2873.

Farber, S. 2002. "Ecological Economics Regarding Freshwater Resources, Ch. 10". In May 2002 Workshop: Simon Fraser University.

Fernandes, R., V. Korolevych, and S. Wang. 2007. "Trends in Land Evapotranspiration Over Canada for the Period 1960-2000 Based on in Situ Climate Observations and a Land Surface Model". *Journal of Hydrometeorology* 8:1016-1030.

Fitzgerald, D. A., D. A. Kiely, R. D. Neilson, S. Shaw, R. J. Audette, M. Prior, E. Ashton, and E. Allison. 1997. "Alberta Farmstead Water Quality Survey: Technical report submitted to the Canada-Alberta Environmentally Sustainable Agriculture Agreement". Edmonton, Alberta: Alberta Agriculture, Food and Rural Development.

Freeze, R. A., and J. A. Cherry. 1979. *Groundwater*. Englewood Cliffs, NJ: Prentice-Hall.

Galloway, D., D. R. Jones, and S. E. Ingebritsen. 1999. "Land Subsidence in the United States". In US Geological Survey, Circular 1182.

Garduno, H., S. Foster, C. Dumars, K. Kemper, a. Tuinhof, and M. Nanni. 2003. "*Briefing Note 5 - Groundwater Abstraction Rights: From Theory to Practice*": World Bank Global Water Partnership Associate Program.

Garfinkel, J., J. Kohler, A. Lintner, and H. Wilkins. 2008. "Ontario's Water Hazard - The Cumulative Impact of Golf Courses on Our Water Resources": Earthroots.

Gartner Lee Ltd. 2002. Best Practices for Assessing Water Taking Proposals. Toronto: Ontario Ministry of the Environment.

Gerber, R., and S. Holysh. 2007. "*Application of the numerical groundwater flow model – considerations*", edited by C.A.M. Coalition and Regional Municipalities of York, Peel, Durham, and the City of Toronto (YPDT).

Gleick, P. 1996. Water Resources. In *Encyclopaedia of Climate and Weather*, edited by S.H. Schneider. New York: Oxford University Press.

Gleick, P. 2007. "Time to Rethink Large International Water Meetings". In The World's Water 2006-7: The Biennial Report on Freshwater Resources, edited by P. Gleick: Island Press.

Glennon, R. 2005. "Water Scarcity, Marketing and Privatization". *Texas Law Review* 83 (7):1873-1902.

Globalis Canada. 2005. *Canada: Urban Population*. Available from http://globalis.gvu.unu.edu/indicator_detail.cfm?IndicatorID=30&Country=CA.

Goss, M. J., D. A. J. Barry, and D. L. Rudolph. 1998. "Contamination in Ontario Farmstead Domestic Wells and its Association with Agriculture: Results from Drinking Water Wells". *Journal of Contaminant Hydrology* 32 (3-4):267-293.

Government of BC. 2007. "Progress on the Action Plan for Safe Drinking Water in British Columbia": Office of the Provincial Health Officer.

Government of BC. 2008. "*Living Water Smart*", edited by Water Stewardship Division. Vancouver, BC: Government of British Columbia.

Government of Canada. 1985a. *Auditor General Act*, A-17.

Government of Canada. 1985b. *Canada Water Act*. R.S., 1985, c. C-11.

Government of Canada. 1985c. *Fisheries Act*, R.S., 1985, c. F-14.

Government of Canada. 1992. *Canadian Environmental Assessment Act*, C-37.

Government of Canada. 1999. *Canadian Environmental Protection Act*, 1999 C-33.

Government of Canada. 2002. *Species at Risk Act*. C-5.

Government of Canada. 2004. Federal Water Framework.

Government of Canada. 2005. "Taking Action On Federal Contaminated Sites: An Environmental and Economic Priority", edited by Contaminated Sites Management Working Group.

Government of Canada. 2006a. "Report of the Expert Panel on Safe Drinking Water for First Nations - Volume 1", edited by Government of Canada.

Government of Canada. 2006b. "Report of the Expert Panel on Safe Drinking Water for First Nations, Volume 2 - Legal Analysis", edited by Government of Canada.

Government of Manitoba. 2007. "*Manitoba Water Stewardship Annual Report 2006-2007*". Winnipeg MB: Manitoba Water Stewardship Program.

Government of NB. 1989. *Clean Water Act*, C-6.1.

Government of NB. 1993. *Potable Water Regulation - Clean Water Act*, O.C. 93-979.

Government of Ontario. 1990. *Ontario Water Resources Act*, R.S.O. 1990, CHAPTER O.40.

Government of Ontario. 2002a. "Recommendation Report and Supporting Documents for the Former CWML Site Smithville Ontario". In Smithville Phase IV Bedrock Remediation Program. Smithville, Ontario.

Government of Ontario. 2002b. *Sustainable Water and Sewage Systems Act*, S.O. 2002 c-29.

Government of Ontario. 2004. *Water Taking and Transfer*, 387/04.

Government of Ontario. 2006. *Clean Water Act, 2006* c. 35.

Government of Ontario. 2007. *Safeguarding and Sustaining Ontario's Water Act*, S.O. 2007 C.12.

Government of PEI. 2003. State of the Environment. Department of Fisheries, Aquaculture, and Environment.

Government of PEI. 2004a. *Agricultural Crop Rotation Act*, A-8.01.

Government of PEI. 2004b. "Part V: Well Field Protection Requirements". *Royal Gazette of Prince Edward Island* CXXX (51):1.

Government of PEI. 2007a. *Groundwater Exploration and Extraction Permits*. Available from http://www.gov.pe.ca/envengfor/index.php3?number=1015765&lang=E.

Government of PEI. 2007b. Sustainable Resources Policy. Department of Agriculture and Forestry.

Government of PEI. 2008. "The Report of the Commission on Nitrates in Groundwater". Charlottetown, PEI.

Granato, G. E., and P. M. Barlow. 2005. "Effects of alternative instream-flow criteria and water-supply demands on ground-water development options in the Big River Area, Rhode Island". In U.S. Geological Survey Scientific Investigations Report 2004-5301.

Grannemann, N. G., R. J. Hunt, J. R. Nicholas, T. E. Reilly, and T. C. Winter. 2000. "The Importance of Ground Water In The Great Lakes Region". In *US Geological Survey Water Resources Investigations Report 00 - 4008*.

Griffin, R. 2006. Water Resource Economics: The Analysis of Scarcity, Policies, and Projects. Cambridge: MIT Press.

Griffiths, M., A. Taylor, and D. Woynillowicz. 2006. "*Troubled Waters, Troubling Trends*". Edmonton: The Pembina Institute.

GW MATE. 2006. "Sustainable Groundwater Management: Concepts and Tools". In GW-MATE Briefing Note Series, edited by GW-MATE. Washington D.C., USA: The World Bank.

Hall, M. 2004. "Transboundary Groundwater Management: Opportunities Under International Law for Groundwater Management in the United States-Mexico Border Region". *Arizona Journal of International & Comparative Law* 21 (3):873-911.

Hamel, A. 2002. Estimation of Recharge and Groundwater Flow Patterns in Regional Aquifers in South-western Québec, Université Laval.

Hayashi, M., G. Van Der Kamp, and R. Schmidt. 2003. "Focused Infiltration of Snowmelt Water in Partially Frozen Soil Under Small Depressions". *Journal of Hydrology* 270:214-229.

Health Canada. 1995. "*Summary of Guidelines for Canadian Drinking Water Quality*", edited by The Federal-Provincial Subcommittee On Drinking Water.

Health Canada. 2007. *Questions and Answers on Bottled Water*. Available from http://www.hc-sc.gc.ca/fn-an/securit/facts-faits/faqs_bottle_water-eau_embouteillee-eng.php.

Health Canada. 2008. "*Guidelines for Canadian Drinking Water Quality*". In *Environmental and Workplace Health*, edited by Federal-Provincial-Territorial Committee on Drinking Water of the Federal-Provincial-Territorial Committee on Health and the Environment: Health Canada.

Hii, B., M. Zubel, D. Scovill, G. Graham, S. Marsh, and O. Tyson. 2006. "Abbotsford-Sumas Aquifer, British Columbia, Canada, 2004 Groundwater Quality Survey - Nitrate and Bacteria".

Hilliard, C. 2007. "Study Shows Water Well Contamination Occurs Close to Home". *Prairie Water News* 17 (2):3-4.

Hoag, D. L., and J. S. Hughes-Popp. 1997. "Theory and Practice of Pollution Credit Trading, Water Quality Management". *Review of Agricultural Economics* 1 (2):252-262.

Hodge, R. A., S. Holtz, C. Smith, and K. Hawke-Baxter. 1995. "*Pathways To Sustainability: Assessing Our Progress*", edited by National Roundtable On The Environment and The Economy. Ottawa, ON.

Hodgkins, G. A., R. W. Dudley, and S. S. Aichele. 2007. "Historical Changes in Precipitation and Streamflow in The U.S. Great Lakes Basin, 1915-2004", edited by USGS.

Holtschag, D. J., and J. R. Nicholas. 1998. "Indirect Groundwater Discharge To The Great Lakes: Open-File Report", edited by USGS.

Holysh, S., S. Davies, L. Lemon, B. Jeffrey, A. Korniluk, A. Warren, S. Banz, B. Golas, C. Darling, L. Rivierre, B. Snodgrass, D. Goodyear, D. Ford, S. Meek, G. Soo Chan, R. Powell, M. Peacock, M. Majchrowski, R. Gerber, and H. Bretton. 2003. Groundwater Management Through Cooperation - An Example of Local Government Leadership From The Oak Ridges Moraine - Southern Ontario. In Proceedings of the International Association of Hydrogeologists Canadian National Chapter Meeting, at Winnipeg, Manitoba.

Homer-Dixon, T. 2001. The Ingenuity Gap: Can We Solve The Problems Of The Future. Toronto: Vintage Canada.

Hood, J., J. Roy, and M. Hayashi. 2006. "Importance of Groundwater in The Water Balance of An Alpine Headwater Lake". *Geophysical Research Letters* 33.

Hoover, G., A. Howatson, J. Churchill, and J. Roberts. 2006. "*Navigating The Shoals: Assessing Water Governance and Management in Canada*", edited by Conference Board of Canada. Ottawa.

Horbulyk, T., and L. Lo, eds. 1998. Welfare Gains From Potential Water Markets in Alberta, Canada. In K. Easter, M. Rosegrant and A. Dinar, *Markets for Water: Potential and Performance*. Boston: Kluwer Academic Press.

Howard, K. W. F., N. Eyles, P. J. Smart, J. I. Boyce, R. E. Gerber, S. L. Salvatori, and M. Doughty. 1995. "The Oak Ridges Moraine of Southern Ontario: A Ground-Water Resource at Risk". *Geoscience Canada* 22 (3):101-120.

Hrudey, S. E. 2008a. Canada must pay the true cost of safe drinking water. *The Globe and Mail*, April 25 2008.

Hrudey, S. E. 2008b. "Safe Water? Depends on where you live". *Canadian Medical Association Journal* 178 (8):975.

Hutson, S. S., N. L. Barber, J. F. Kenny, K. S. Linsey, D. S. Lumia, and M. A. Maupin. 2004. "*Estimated Use of Water in the United States in 2000*". In *USGS Circular*, edited by U.S.G. Survey. Denver, CO: USGS.

IAH. 2007. XXXV IAH Congress. In Proceedings of the XXXV Congress of the International Association of Hydrogeologists, at Lisbon, Portugal.

IJC. 1978. Great Lakes Water Quality Agreement. Edited by International Joint Commission: United States and Canada.

IJC. 2000. "Protection of The Waters of The Great Lakes - Final Report To The Governments of Canada and The United States", edited by International Joint Commission. Ottawa-Washington.

IJC. 2004. "Review of Recommendations in The Feb. 2000 Report On Protection of The Waters of The Great Lakes", edited by International Joint Commission. Ottawa-Washington.

IJC. 2008. "*Draft Report On The Status of Groundwater in The Great Lakes Basin*", edited by Science Advisory Board To The International Joint Commission.

IPCC. 2005. "IPCC Special Report on Carbon Dioxide Capture and Storage". In IPCC Special Reports: Intergovernmental Panel on Climate Change.

IPCC. 2007. "*Climate Change 2007, Synthesis Report*", edited by Intergovernmental Panel On Climate Change.

Jenkins, M. W., J. R. Lund, R. E. Howitt, A. J. Draper, S. M. Msangi, S. K. Tanaka, R. S. Ritzema, and G. F. Marques. 2004. "Optimization of California's Water System: Results and Insights". *Journal of Water Resources Planning and Management*: 130 (4):271-280.

Jiang, Y., G. Somers, and J. P. Mutch. 2004. Application of Numerical Modeling To Groundwater Assessment and Management in Prince Edward Island. In Proceedings of the 5th Joint Canadian Geotechnical Society and International Association of Hydrogeologists-Canadian National Chapter Groundwater Conference, at Québec.

Kassem, A., T. Mcrae, and M. Sydor. 2005. Using An Integrated Water Use and Supply Planning Model To Inform Decision-Makers On The Impacts of Climate Change and Variability On Irrigated Agriculture in Canada's South Saskatchewan River Basin. In *OECD Workshop On Agriculture and Water: Sustainability, Markets and Policies*. Adelaide, Australia.

Kassem, A. M., D. M. Tate, and P. A. Dossett. 1994. Water Use Analysis Model (Wuam) Demonstration.

Kassenaar, J. D. C., S. Holysh, and R. Gerber. 2003. Integrated 3d Hydrostratigraphic Interpretation in Complex Aquifer Systems. In Proceedings of the International Association of Hydrogeologists Canadian National Chapter Meeting, September, at Winnipeg, Manitoba.

Kassenaar, J. D. C., and E. J. Wexler. 2006. "Groundwater Modelling of The Oak Ridges Moraine Area". In CAMC-YPDT Technical Report #01-06.

Kelso, M., W. E. Martin, and L. Mack. 1973. *Water Supplies and Economic Growth in An Arid Environment: An Arizona Case Study*. Tucson, AZ: University of Arizona Press.

Kemper, K., S. Foster, H. Garduño, N. M., and A. Tuinhof. 2003. Briefing Note 7: Economic Instruments for Groundwater Management: Using Incentives To Improve Sustainability. Edited by World Bank.

Kennett, S. A. 2007. "Next Steps for Cumulative Effects Management in Alberta's Athabasca Oil Sands Region". In Resources, edited by Canadian Institute of Resource Law.

Keplinger, K. 2003. "The Economics of Total Maximum Daily Loads". *Natural Resources Journal* 43 (4).

Kolpin, D. W., E. T. Furlong, M. T. Meyer, E. M. Thurman, S. D. Zaugg, L. B. Barber, and H. T. Buxton. 2002. "Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance". *Environmental Science & Technology* 36:1202-1211.

Kolstad, C., and J. Freeman. 2007. Moving To Markets in Environmental Regulation: Lessons From Twenty Years of Experience. New York: Oxford University Press.

Kondouri, P. 2004. "Current Issues in the Economics of Groundwater Resource Management". *Journal of Economic Surveys* 18 (5):703-740.

Kulshreshtha, S. N., and C. Grant. 2007. "An Estimation of Canadian Agricultural Water Use". *Canadian Water Resources Journal* 32 (2):137-148.

Lawrence, J. 2007. Environment Canada's Groundwater Science: Potential for Federal Collaboration.

Lefebvre, A., W. Eilers, and B. Chunn. 2005. "Environmental Sustainability of Canadian Agriculture: Agri-Environmental Indicator Report Series - Report #2". Ottawa: Agriculture and Agri-Food Canada.

Lillebuen, S. 2005. Native Groups Sue Government over Oilsands. *Edmonton Journal*.

Lissey, A. 1971. "Depression-Focused Transient Groundwater Flow Patterns in Manitoba". *Geological Survey of Canada Special Paper* 9:333-349.

Locas, A., C. Barthe, B. Barbeau, A. Carriere, and P. Payment. 2007. "Virus occurrence in municipal groundwater sources in Québec, Canada". *Canadian Journal of Microbiology* 53 (6):688-694.

Locas, A., C. Barthe, A. B. Margolin, and P. Payment. 2008. "Groundwater microbiological quality in Canadian drinking water municipal wells". *Canadian Journal of Microbiology* 54 (6):472-478.

Loukili, Y., A. D. Woodbury, and K. R. Snelgrove. 2006. An Enhancement of The Canadian Land Surface Scheme for Climate Assessment Over The Prairies. In Proceedings of the American Geophysical Union, Fall Meeting 2006, December 11-15, 2006, at San Francisco.

Maathuis, H. 2005. "*Groundwater Observation Well Networks in Canada*". Saskatoon SK: Saskatchewan Research Council.

Maathuis, H., and G. Van der Kamp. 1998. "*Evaluation of Pumping and Recovery Data for The Estevan Valley and Tableland Aquifers*". Saskatoon SK: Saskatchewan Research Council.

Mahan, R., T. Horbulyk, and J. Rowse. 2002. "Market Mechanisms and The Efficient Allocation of Surface Water Resources in Southern Alberta". *Socio-Economic Planning Sciences* 36 (1): 25-49.

Meehl, G. A., T. F. Stocker, W. D. Collins, P. Friedlingstein, A. T. Gaye, J. M. Gregory, A. Kitoh, R. Knutti, J. M. Murphy, A. Noda, S. C. B. Raper, I. G. Watterson, A. J. Weaver, and Z. C. Zhao. 2007. Global Climate Projections. In *Climate Change 2007: The Physical Science Basis*, edited by S.D.Q. Solomon, Martin Manning, Melinda Marquis, Kristen Averyt, Melinda M. B. Tignor and Henry LeRoy Miller. New York: Cambridge University Press.

Meisner, J. D., J. S. Rosenfeld, and H. A. Regier. 1988. "The Role of Groundwater in The Impact of Climate Warming On Stream Salmonines". *Fisheries* 13 (3):2-8.

Meranger, J. C., K. S. Subramanian, and R. F. Mccurdy. 1984. "Arsenic in Nova Scotian Groundwater". *Science of The Total Environment* 39 (1-2):49-55.

Millennium EMS. 2007. "*Hydrogeological Baseline and Environmental Assessment Algar Project*", edited by M.E.S. Ltd. Edmonton, Alberta: Great Divide Oil Corporation.

Mitchell, B. 2004. Resource and environmental management in Canada: addressing conflict and uncertainty. 3rd ed. Don Mills, ON: Oxford University Press.

MRBB. 1997. Mackenzie River Basin Transboundary Waters Master Agreement.

MRC D'Argenteuil. 2005. Le Développement de la MRC D'Argenteuil dans une Stratégie D'aménagement : La Deuxième Proposition De Schéma D'aménagement et de Développement Révisé. Available from http://www.argenteuil.qc.ca.

Nastev, M., R. Lefebvre, A. Rivera, and R. Martel. 2006. "Quantitative Assessment of Regional Rock Aquifers, South-Western Québec, Canada". *Water Resources Management* 20:1-18.

Nature Conservancy. 2008. *The Nature Conservancy of Canada*. Available from http://www.natureconservancy.ca/site/PageServer?pagename=ncc_main.

NB DoE. 2005. "Protecting Sources of Municipal Drinking Water, An Overview of New Brunswick's Wellfield Protection Program". Edited by the New Brunswick Department of the Environment Sustainable Planning Branch. Fredericton, New Brunswick.

NB DoE. 2007. "*2006-07 Annual Report: Environment*", edited by Province of New Brunswick Department of the Environment.

NEB. 2006. "Canada's Oil Sands, Opportunities and Challenges To 2015: An Update", edited by National Energy Board. Calgary, Alberta.

NEB. 2008. *Canada's Oil Sands - Opportunities and Challenges To 2015: An Update Questions and Answers*. Edited by National Energy Board. Available from http://www.neb.gc.ca/clf-nsi/rnrgynfmtn/nrgyrprt/lsnd/pprtntsndchllngs20152006/qapprtntsndchllngs20152006-eng.html.

Neff, B. P., A. R. Piggott, and R. A. Sheets. 2005. *Estimation of Shallow Ground-Water Recharge in the Great Lakes Basin*. Available from http://pubs.usgs.gov/sir/2005/5284/pdf/SIR_2005_5284-Web.pdf.

NGSC. 2007. Intergovernmental Geoscience Accord. The National Geological Surveys Committee, The Geological Survey of Canada.

Nielsen, D. M. 2006. Practical Handbook of Environmental Site Characterization and Groundwater Monitoring. 2nd Edition. Edited by L. Taylor & Francis Group. Boca Raton, FL: CRC Press.

Nova Scotia Environment and Labour. 2002. "*A Drinking Water Strategy for Nova Scotia: A Comprehensive Approach to the Management of Drinking Water*", edited by Nova Scotia Department of Environment and Labour. Halifax, Nova Scotia: Province of Nova Scotia.

Novokowski, K., B. Beatty, M. J. Conboy, and J. Lebedin. 2006. "*Water Well Sustainability in Ontario: Expert Panel Report*". In *Sustainable Water Well Initiative*: Ontario Ministry of the Environment.

Nowlan, L. 2005. *Buried Treasure: Groundwater Permitting and Pricing in Canada*. Toronto: Walter and Duncan Gordon Foundation.

Nowlan, L., and K. Bakker. 2007. "*Delegating Water Governance: Issues and Challenges in The BC Context, Report for BC Water Governance Project*", edited by Fraser Basin Council, Ministry of Environment, Fraser Salmon and Watershed Program, Georgia Basin Living Rivers Program and Fisheries and Oceans Canada: Report for BC Water Governance Project prepared by the UBC Program on Water Governance.

NRC. 1994. "Alternatives for Ground Water Cleanup". In Report of The National Academy of Science Committee On Ground Water Cleanup Alternatives. Washington D.C: National Research Council (NRC).

NRC. 1997. "Valuing Ground Water: Economic Concepts and Approaches". In Report of The Committee On Valuing Groundwater. Washington, D.C.: National Research Council.

NRC. 2008. "Water Implications of Biofuels Production in The United States". In Committee on Water Implications of Biofuels Production in the United States. Washington, D.C.: National Research Council (NRC).

NRCan. 2003. *Canadian Framework for Collaboration on Groundwater*. Edited by Natural Resources Canada. Available from http://ess.nrcan.gc.ca/2002_2006/gwp/index_e.php.

NRCan. 2008. "*From Impacts To Adaptation: Canada in A Changing Climate 2007*", edited by D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush. Ottawa: Natural Resources Canada.

O'Connor, D. R. 2002a. Report of The Walkerton Inquiry. Part 1. The Events of May 2000 and Related Issues. Edited by Ontario Ministry of the Attorney General. Toronto, ON.

O'Connor, D. R. 2002b. Report of The Walkerton Inquiry. Part 2. A Strategy for Safe Water. Edited by Ontario Ministry of the Attorney General. Toronto, ON: Ontario Ministry of the Attorney General.

OECD. 1995. "*Canada: Environmental performance review*", edited by Organisation for Economic Cooperation and Development. Paris, France.

OECD. 1999. *The Price of water: Trends in OECD countries*. Paris, France: Organisation for Economic Cooperation and Development.

OECD. 2004. "*OECD Environmental Data: Compendium 2004*". Paris, France: Organisation for Economic Cooperation and Development.

Ogilvie and Usher. 2005. "*Watershed Planning: From Recommendations To Municipal Policies, A Guidance Document*", edited by The York, Peel, Durham, Toronto Groundwater Study, and Conservation Authorities Moraine Coalition: Ogilvie, Ogilvie & Company and Anthony Usher Planning Consultant.

OSDC. 2008a. Alberta's Vast Resource: The Biggest Known Oil Reserve in The World! Fact Sheet. Edited by Oil Sands Discovery Centre and Canadian Institute of Mining, Metallurgy and Petroleum. Fort McMurray, Alberta.

OSDC. 2008b. *The Oil Sands Story: The Resource*. Edited by the Oil Sands Discovery Centre. Available from http://www.oilsandsdiscovery.com/oil_sands_story/resource.html.

Parks, K. P. 2004. Regional Groundwater Management for Oil Sands Development, Alberta, Canada. In *Geological Society of America Denver Annual Meeting*. Colorado Convention Center: Exhibit Hall, Denver, CO: Geological Society of America Abstracts with Programs.

Parliament of Québec. 1999. *Water Resources Preservation Act*. 73.

Parliament of Québec. 2002. Groundwater Catchment Regulation: Environment Quality Act.

Peachey, B. 2005. "Strategic Needs for Energy Related Water Use Technologies Water and the EnergyINet".

Plaster, K., and G. Grove. 2000. "A Review of Transboundary Groundwater Apportionment". In Prairie Provinces Water Board. Regina, SK.

Pomeroy, J. W., D. De Boer, and L. Martz. 2007. Hydrology and Water Resources. In *Saskatchewan: Geographic Perspectives*, edited by B.D. Thraves. Regina: Canadian Plains Research Centre, University of Regina.

Powell, C. S. 1997. "Return of The Space Snowballs". *Scientific American* 277 (2):19-20.

PPWB. 2005. "*Prairie Provinces Water Board Annual Report, 2005*", edited by Prairie Provinces Water Board. Regina, SK: Government of Canada.

PPWB. 2006. "*Prairie Provinces Water Board Charter*", edited by Prairie Provinces Water Board. Regina, SK.

Program on Water Governance. 2008. *UBC Program on Water Governance*. Available from http://www.watergovernance.ca/index.htm.

Pullan, S. E., J. A. Hunter, H. A. J. Russell, and D. R. Sharpe. 2004. Delineating buried-valley aquifers using shallow seismic reflection profiling and downhole geophysical logs-an example from southern Ontario, Canada. In Proceedings of the International Conference on Environmental and Engineering Geophysics, at Wuhan, China.

Randall, A. D., R. M. Francis, M. H. Frimpter, and J. M. Emery. 1988. Region 19, North-eastern Appalachians. In *Hydrogeology: The Geology of North America v. O-2*, edited by W. Back, J.S. Rosenshein and P.R. Seaber. Boulder, CO: Geological Society of America.

Region of Waterloo. 2007a. "*Guiding Source Water Protection: Water Resources Protection Master Plan*", edited by Regional Municipality of Waterloo. Waterloo, Ontario: Regional Municipality of Waterloo.

Region of Waterloo. 2007b. "*Supplementary Tech Memo: Updated Cost Estimates*", edited by Regional Municipality of Waterloo. Waterloo, ON: Regional Municipality of Waterloo.

Region of Waterloo. 2008. *Region of Waterloo Website*. Available from http://www.region.waterloo.on.ca/web/region.nsf/fmFrontPage?OpenForm.

Reilly, T. E., K. F. Dennehy, W. M. Alley, and W. L. Cunningham. 2008. "*Ground-Water Availability in the United States*". Denver, CO: U.S. Geological Survey Circular 1323.

Renzetti, S. 1999. "Municipal Water Supply and Sewage Treatment: Costs, Prices and Distortions". *Canadian Journal of Economics* 32 (3):688-704.

Renzetti, S. 2002. *The Economics of Water Demands*. Norwell, Massachusetts: Kluwer Academic Publishers.

Renzetti, S., and D. Dupont. 2007. "The Economic Benefits of Water Use in Canada".

Renzetti, S., and J. Kushner. 2004. "Full Cost Accounting for Water Supply and Sewage Treatment: Concepts and Application". *Canadian Water Resources Journal* 29 (1):13-23.

Rivard, C., J. Marion, Y. Michaud, S. Benhammane, A. Morin, R. Lefebvre, and A. Rivera. 2003. "*Étude De L'impact Potentiel Des Changements Climatiques Sur Les Ressources En Eau Souterraine Dans L'est Du Canada*". Ottawa, ON: Geological Survey of Canada.

Rivera, A. 2005. "How Well Do We Understand Groundwater in Canada? A Science Case Study". In Earth Sciences Sector: Groundwater Program: Geological Society of Canada.

Rivera, A. 2006. "Reply To The Office of The Auditor General. Annual Monitoring Exercise - 2001 Report of The Commissioner of The Environment and Sustainable Development, Chapter 1". In 2001 Report of the Commissioner of the Environment and Sustainable Development, Chapter 1. Ottawa.

Rivera, A. 2007. "Update To the 2006 Reply To The Office of The Auditor General. Annual Monitoring Exercise - 2001 Report of The Commissioner of The Environment and Sustainable Development, Chapter 1". In 2001 Report of the Commissioner of The Environment and Sustainable Development, Chapter 1. Ottawa, ON.

Rivera, A., A. Crowe, A. Kohut, D. Rudolph, C. Baker, D. Pupek, N. Shaheen, M. Lewis, and K. Parks. 2003. Canadian Framework for Collaboration on Groundwater. Edited by Natural Resources Canada: Government of Canada.

Robson, S. G., and E. R. Banta. 1995. "*Ground Water Atlas of The United States: Arizona, Colorado, New Mexico, Utah*". Reston, VA: U.S. Geological Survey.

Rollins, K., J. Frehs, D. Tate, and O. Zachariah. 1997. "Resource Valuation and Public Policy: The Case of Water Pricing". *Canadian Water Resources Journal* 22:147-163.

Rudolph, D., and M. J. Goss. 1993. "*Ontario Farm Groundwater Quality Survey*": Agriculture and Agri-Food Canada.

Russell, H. A. J., T. A. Brennand, C. Logan, and D. R. Sharpe. 1998. Standardization and Assessment of Geological Descriptions From Water Well Records, Greater Toronto and Oak Ridges Moraine Areas, Southern Ontario. In *Current Research 1998-E*: Geological Survey of Canada (Author), Canada Natural Resources Canada.

Russell, H. A. J., D. R. Sharpe, C. Logan, and T. A. Brennand. 2001. Not Without Sedimentology: Guiding Groundwater Studies in The Oak Ridges Moraine, Southern Ontario. In Proceedings of the 35th Annual Meeting, North-Centre Section Geological Society of Canada: Geological Models for Groundwater Flow Modelling, April 22, 2001, at Illinois.

Sandborn, T. 2008. "Law Suit a Tar Sands Stopper?", *The Tyee*.

Saunders, O. J., and M. M. Wenig. 2006. Whose Water? Canadian Water Management and The Challenges of Jurisdictional Fragmentation. In *Eau Canada: The Future of Canada's Water*, edited by K. Bakker. Vancouver, BC: UBC Press.

Savard, M. M., M. Nastev, D. Paradis, R. Lefebvre, R. Martel, V. Cloutier, V. Murat, E. Bourque, M. Ross, K. Lauzière, M. Parent, A. Hamel, J.-M. Lemieux, R. Therrien, D. Kirkwood, and P. J. Gélinas. 2002. "*Regional Hydrogeologic Characterization of The Fractured Aquifer System in South-Western Québec: Part I - Regional Hydrogeology of The Aquifer System*". In *Bulletin*: Geological Survey of Canada.

Savard, M. M., and G. Somers, eds. 2007. Purposes and Approach of the Research Project on Climate Change Impacts on Nitrate Contamination of Prince Edward Island Groundwater. In M.M. Savard and G. Somers, *Consequences of Climatic Changes on Contamination of Drinking Water by Nitrate on Prince Edward Island*: Geological Survey of Canada, Agriculture and Agri-Food Canada, Prince Edward Island Department of the Environment, Energy and Forestry.

Sawyer, D., G. Perron, and M. Trudeau. 2005. "Analysis of Economic Instruments for Water Conservation".

Scanlon, B. R., R. C. Reedy, D. A. Stonestrom, D. E. Prudic, and K. F. Dennehy. 2005. "Impact of Land Use and Land Cover Change On Groundwater Recharge and Quality in The Southwestern US". *Global Change Biology* 11:1577-1593.

SCC. 2001. 114957 Canada Ltée (Spraytech, Société d'arrosage) v. Hudson (Town). In 2001 SCC 40, edited by Supreme Court of Canada.

SCC. 2004a. Haida Nation v. British Columbia (Minister of Forests). In *2004 SCC 73*, edited by The Supreme Court of Canada.

SCC. 2004b. Taku River Tlingit First Nation v. British Columbia (Project Assessment Director). In *2004 SCC 74*, edited by The Supreme Court of Canada.

SCC. 2005. Mikisew Cree First Nation v. Canada (Minister of Canadian Heritage). In *2005 SCC 69*, edited by The Supreme Court of Canada.

Schiffler, M. 1998. The economics of groundwater management in arid countries: theory, international experience and a case study of Jordan, GDI book series. London; Portland, OR: Frank Cass.

Schuster, C. J., A. G. Ellis, W. J. Robertson, D. F. Charron, J. J. Aramini, B. J. Marshall, and D. T. Medeiros. 2005. "Infectious Disease Outbreaks Related To Drinking Water in Canada, 1974-2001". *Canadian Journal of Public Health* 96 (4):254-258.

Sharpe, D. R., and H. A. J. Russell. 2006. Geological Frameworks in Support of Source Water Protection in Ontario. In *Annual Meeting, Geological Society of America*. Salt Lake City, UT. USA.

Sheets, R. A. 2006. *Compilation of regional ground-water divides for principal aquifers corresponding to the Great Lakes Basin, United States*, Scientific investigations report. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey.

Shiklomanov, I. 2000. "Appraisal and Assessment of World Water Resources". *Water International* 25 (1):11-32.

Shinnan, A. 2008. "*Industrial Water Use, 2005*". Ottawa, ON: Statistics Canada.

Sketchell, J., and N. Shaheen. 2000. Ground Water Quality in Rural Saskatchewan-Emerging Issues for Drinking Water. In Proceedings of the 9th National Conference on Drinking Water, at Regina, Saskatchewan.

Somers, G., B. Raymond, and W. Uhlman. 1999. "*1999 PEI Water Quality Interpretive Report*". Charlottetown: Prince Edward Island Department of Technology and Environment; and Environment Canada.

Somers, G., M. M. Savard, and O. Pantako. 2007. Impacts of Climate Change On The Water Supply Infrastructure in Prince Edward Island. In *Consequences of Climatic Changes On Contamination of Drinking Water By Nitrate On Prince Edward Island*, edited by M.M. Savard and G. Somers: Geological Survey of Canada, Agriculture and Agri-Food Canada, and Prince Edward Island Department of Environment, Energy and Forestry.

Sophocleous, M. 1997. "Managing Water Resources Systems: Why "Safe Yield" Is Not Sustainable". *Ground Water* 35 (4):561.

Sophocleous, M. A. 2007. "The Science and Practice of Environmental Flows and The Role of Hydrogeologists". *Ground Water* 45 (4):393-401.

Speck, S. 2005. "Do European Water Abstraction Taxes Affect Competitiveness?".

Statistics Canada. 2003. "*Human Activity and The Environment: Annual Statistics 2003*". Ottawa, ON: Statistics Canada.

Statistics Canada. 2005. *Population Projections for Canada, Provinces, and Territories: Highlights*. Available from http://www.statcan.gc.ca/pub/91-520-x/00105/4095095-eng.htm.

Statistics Canada. 2007. *Census Snapshot of Canada – Urbanization*, no. 11-008. Available from http://www.statcan.gc.ca/pub/11-008-x/2007004/pdf/10313-eng.pdf.

Stewart, S. 2002. "Springs from the Wiau Aquifer: A Necessary Calibration Point for Groundwater - Resource Assessments, Athabasca Oilsands Area". Edmonton, AB: Alberta Geological Survey, Alberta Energy and Utilities Board.

SWA. 2008. *Observation Well Network*. Available from http://www.swa.ca/WaterManagement/Groundwater.asp?type=ObservationWells.

Swain, H., S. Louttit, and S. E. Hrudey. 2006. "Report of The Expert Panel On Safe Drinking Water for First Nations". In Safe Drinking Water for First Nations. Ottawa, ON.

Tharme, R. E. 2003. "A Global Perspective On Environmental Flow Assessment: Emerging Trends in The Development and Application of Environmental Flow Methodologies for Rivers Source". *River Research and Applications* 19 (5-6):397-441.

Topper, R., and B. Raynolds. 2007. Citizen's Guide To Denver Basin Groundwater. Denver, CO: Colorado Foundation for Water Education.

Topper, R., K. L. Spray, W. H. Bellis, J. L. Hamilton, and P. E. Barkmann. 2003. "*Ground Water Atlas of Colorado*". In *Colorado Geological Survey, Special Publication 53*.

Township of Langley. 2007. "*Annual Report*", edited by Township of Langley. Langley, British Columbia.

Township of Langley. 2008. "*Water Management Plan*", edited by Township of Langley. Langley, BC.

Tuinhof, A. 2001. "*Groundwater Resources Component*". In *World Bank Mission Aide-memoire*, edited by Kenya Water Resources Management Strategy.

UNESCO, ed. 2006. Non-renewable groundwater resources: A guidebook on socially-sustainable management for water-policy makers. In S. Foster and D.P. Loucks. Paris, France: United Nations Educational, Scientific and Cultural Organization.

United Nations. 2008. Shared Natural Resources: The law of transboundary aquifers A/CN.4/L.724.

United Nations Environment Programme. 2002. *The World's Water Cycle*. Available from http://www.unep.org/dewa/assessments/ecosystems/water/vitalwater/05.htm.

UNEP. 2003. "Groundwater and its susceptibility to degradation: a global assessment of the problem and options for management". In Early warning and assessment report series. Nairobi, Kenya: UNEP.

US and Canada. 2006. "Review of The Canada-U.S. Great Lakes Water Quality Agreement, GLWQA Reviewers Assembly - Sharing Our Findings", edited by GLWQA Assembly. Toronto, Ontario.

US Government. 1972. Federal Water Pollution Control Amendments of 1972 33 U.S.C. § 1251.

USDA. 2007. Technical Guide to Managing Ground Water Resources. Edited by USDA.

USEPA. 1999. "*Groundwater Cleanup: Overview of Operating Experience at 28 Sites*", edited by US Environmental Protection Agency. Washington D.C.

USGS. 2008a. Oct 07 2008. *Advisory Committee on Water Information*. Available from http://acwi.gov/.

USGS. 2008b. Mar 22 2007. *The Cooperative Water Program*. Available from http://water.usgs.gov/coop/.

Van der Kamp, G., and G. Grove. 2001. Well Water Quality in Canada: An Overview. In Proceedings of the 54th Canadian Geotechnical Conference.

Van der Kamp, G., and M. Hayashi. 1998. "The Groundwater Recharge Function of Small Wetlands in The Semi-Arid Northern Prairies". *Great Plains Research* 8 (1):39-56.

Van der Kamp, G., M. Hayashi, and D. Gallen. 2003. "Comparing The Hydrology of Grassed and Cultivated Catchments in The Semi-Arid Canadian Prairies". *Hydrological Processes* 17:559-575.

Vigneault, H., D. Paradis, J. M. Ballard, and R. Lefebvre. 2007. Numerical Modelling of The Evolution of Groundwater Nitrate Concentrations Under Various Climate Change Scenarios and Agricultural Practices for Prince Edward Island. In *Consequences of climatic changes on contamination of drinking water by nitrate on Prince Edward Island*, edited by M. Savard and G. Somers: Geological Survey of Canada, Agriculture and Agri-Food Canada, and Prince Edward Island Department of Environment, Energy and Forestry.

WCEL. 2004. *British Columbia Guide to Watershed Law and Planning*. Available from http://www.wcel.org/issues/water/bcgwlp/.

WCWC. 2007. "*Walkerton Clean Water Centre 2006-07 Annual Report*", edited by Walkerton Clean Water Centre. Walkerton, Ontario: Walkerton Clean Water Centre.

WDGF. 2005. *The Walter and Duncan Gordon Foundation*. Available from http://www.gordonfn.org/.

Wexler, E. J., S. Holysh, D. Kassenaar, and R. Gerber. 2003. Regional and Sub-Regional Groundwater Flow Modelling, Oak Ridges Moraine Area of Southern Ontario. In Proceedings of the International Association of Hydrogeologists, Canadian National Chapter at Winnipeg, Manitoba.

WHO. 2004. "*Water Sanitation and Hygiene Links to Health: Facts and Figures*", edited by W.H. Organization. Geneva: World Health Organization.

WHO. 2007. "*Chemical Safety of Drinking Water: Assessing Priorities for Risk Management*", edited by T. Thompson, J. Fawell, S. Kunikane, D. Jackson, S. Appleyard, P. Callan, J. Bartram and P. Kingston. Geneva, Switzerland: World Health Organization.

WHO. 2008. *Water-related diseases: Fluorosis*. Available from http://www.who.int/water_sanitation_health/diseases/fluorosis/en/.

Winter, T. C., J. W. Harvey, O. L. Franke, and W. M. Alley. 1998. "*Ground Water and Surface Water A Single Resource*", edited by US Department of the Interior, US Geological Survey.

Woodward, J. 1994. *Native Law*. Toronto: Carswell.

WSC. 2006. "National Water Quantity Survey Program: Hydrometric Program": Environment Canada.

WSSD. 2002. "*Plan of Implementation*". Johannesburg, South Africa: The World Summit on Sustainable Development.

Young, R. A. 2005. Determining the Economic Value of Water: Concepts and Methods. Washington D.C.: RFF Press.

Appendix 1: The Basics of Groundwater Science

Hydrogeological Environments: Although groundwater is present almost everywhere below the land surface, one should not envision groundwater as a subterranean river or lake. Only in the rare situations associated with cave formation in limestone might one encounter such conditions. A more realistic image would be a firm sponge, with its solid framework representing the geological host material, and its connected network of pores filled with very slowly moving groundwater.

Soils, unconsolidated deposits, and porous and fractured rocks provide the hydrogeological environments for the occurrence of groundwater. In this capacity, they play two distinct roles: (i) they provide storage for the huge volumes of water that are held in the subsurface; and (ii) they provide the controls on the rates of groundwater flow that occur through the subsurface portion of the hydrological cycle. It is important that this duality of the groundwater resource be recognised at the outset. It is the huge stores of groundwater that attract the attention of large water users, but it is the renewable flow through the system that plays the greatest role in defining the sustainable yields that must be considered by water resource managers.

Porosity: Porosity reflects the storage capacity of a geologic deposit, defined as the percentage of a sample of the material that is occupied by pores. Porosities of sand and gravel deposits, like those found in fluvial valleys, or in glacial-outwash fans[49] on the Prairies, are usually about 30 to 40 per cent. Porosities of fractured crystalline rock, like that found on the Canadian Shield, are much lower, usually less than one per cent. Even at the lower end of this range, it is apparent that the huge volumes of subsurface geologic materials in a country as large as Canada give rise to a potentially very large volume of groundwater in storage.

Hydraulic Head: The hydraulic head is a measure of energy with both a gravity and a pressure component; it is readily measured in the field by the elevation of the water level. Groundwater flows through most types of geologic media from points of high hydraulic head to points of lower hydraulic head. In an area of equal fluid pressure, groundwater will flow under gravity from higher elevations to lower. Under conditions of horizontal flow, where the gravity component remains constant, groundwater will flow from positions of higher fluid pressure to lower. The change in hydraulic head over distance is called the hydraulic gradient (analogous to the atmospheric pressure gradients that drive winds). Gradients in

49 Sand and gravel transported away from a glacier by streams of melt water and either deposited as a floodplain along a pre-existing valley bottom or broadcast over a pre-existing plain in a form similar to an alluvial fan.

groundwater-flow systems may be directed downwards, upwards, or horizontally in different parts of the system.

Groundwater Flow: Groundwater flow is directly proportional to the hydraulic gradient that is driving the flow. Hydraulic gradients usually do not vary much from one place to another. The controlling factor on the rate of flow therefore resides in a proportionality factor, which is a property of the material through which the water is flowing. This material property is known as 'hydraulic conductivity' (or its closely allied cousin, 'permeability').

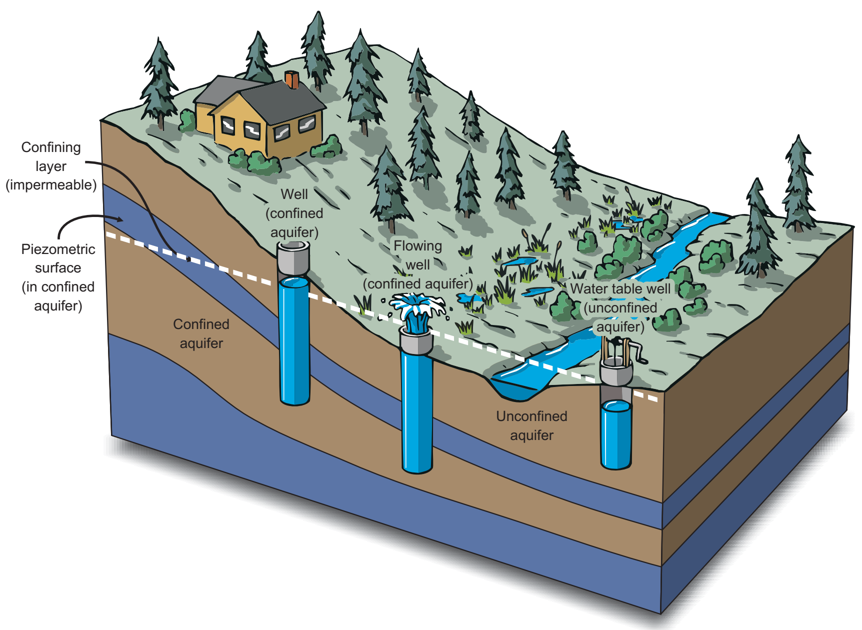
Hydraulic conductivity values can vary over many orders of magnitude, with values as high as 10 cm per second in the most permeable deposits, and as low as 10^{-10} cm per second in the least permeable ones. This range gives rise to huge differences in the rates of groundwater flow in different geological environments. Flow rates in high-permeability materials like unconsolidated sands and gravels, or highly fractured and porous basalts and limestones, could be of the order of hundreds of metres per year. Flow rates in low-permeability materials like unweathered marine clays, or sparsely fractured crystalline rocks, could be as low as a few centimetres per century.

Groundwater flow rates are typically much slower than those of surface water, and this gives rise to much longer residence times for groundwater relative to surface water. Residence times of a water particle in the surface-water portion of a watershed are of the order of a few weeks to a few months, while those for the groundwater-flow system can run to many thousands of years.

Aquifers and Aquitards: Geologic formations that exhibit values of porosity and hydraulic conductivity at the higher end of the range are known as aquifers. Two of the most common definitions describe an aquifer as: (i) a geologic unit that can yield significant quantities of water to wells, or (ii) a geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients. Less-permeable geologic units that tend to retard the flow of groundwater are known as aquitards. Most hydrogeological environments consist of some combination of aquifers and aquitards. For example, in a system of flat-lying interbedded sedimentary rocks, the more-permeable sandstone and limestone units would be the aquifers and the less-permeable shales, the aquitards.

The definitions of aquifer and aquitard are purposely imprecise with respect to bounding values of hydraulic conductivity. The use of the undefined term 'significant quantities of water' in the definition of an aquifer makes it clear that 'aquifer' is a relative term. A quantity of water that is significant in one hydro-geological environment (or to one particular user) may be insignificant in another circumstance. For example, in a bedded silt-sand sequence, the silt would be an aquitard, but in a silt-clay sequence, it might be an aquifer. Similarly, for a domestic well, a particular formation might yield suitable quantities of water and be considered a good aquifer, however the same unit might be entirely inadequate for supplying larger quantities needed for a municipal well and therefore would be considered a poor aquifer in that context.

Hydrogeologists differentiate unconfined aquifers from confined aquifers (Figure A1). In Canada, unconfined aquifers usually occur in surficial deposits where the water table is the upper boundary of the saturated thickness of the aquifer. In order for a well to tap the groundwater resource, it must be completed below the water table. The moisture that exists in the unsaturated zone above the water table is held by capillary and adsorptive forces, and will not flow into an open borehole. In most of Canada the water table lies just a few metres below ground surface. Confined aquifers occur at depth in geological formations that are bounded above and below by less-permeable aquitards. The differentiation is necessary because the mechanisms by which water is delivered to a pumping well, and the impacts such pumping has on the groundwater-flow system, are different in the two cases.

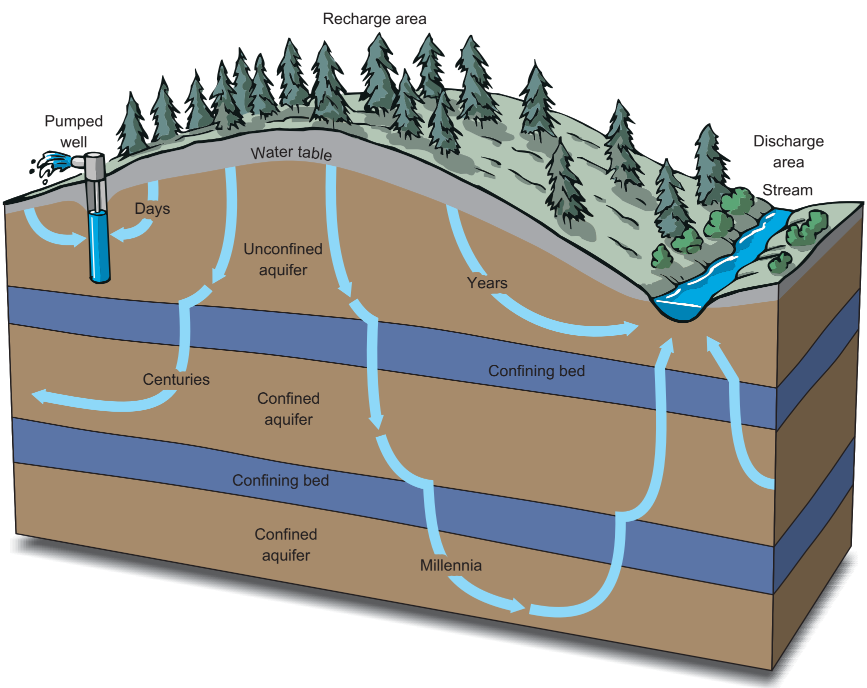


(Adapted and reproduced with permission from Environment Canada, 2008a)

Figure A1
Confined vs. unconfined aquifers.

Groundwater-flow Systems: Groundwater flow through the subsurface hydrogeological environment is an integral part of the hydrological cycle. Flow takes place through the sequence of aquifers and aquitards that make up a groundwater basin, delivering water from recharge areas to discharge areas. Recharge usually occurs in topographically higher areas of a groundwater basin. Water-table elevations tend to be a subdued reflection of surface topography, and the differences in water-table elevation provide the driving force that moves groundwater by gravitational flow from recharge areas toward discharge areas at lower elevations.

In recharge areas, the hydraulic gradient at the water table is directed downward, and recharging waters enter the groundwater-flow system to begin their slow journey through the groundwater basin. The exact routes of flow are controlled by the detailed topographic configuration, and by the lithology, stratigraphy and structure of the geologic formations, which define the three-dimensional distribution of aquifers and aquitards in the basin (Figure A2).



(Adapted and reproduced with permission from USGS, 2008a)

Figure A2

Simplified local, intermediate and regional flow system schematic.

Discharge areas are usually located in valleys and lowlands. There the hydraulic gradients are directed upward toward the land surface. Discharging groundwater re-enters the surface-water regime as inflow to lakes or baseflow to streams, or to become evapotranspiration from wetlands. The upward discharge of groundwater laden with salts dissolved from long flow paths through soluble rock formations often leads to the occurrence of saline soils in groundwater discharge areas, especially in the less humid prairies of Canada. Many Canadians are familiar with one very prominent discharge area, Banff Hot Springs. Hot springs are the discharge points for groundwater-flow paths that traverse rocks at depth that are still hot from long-ago volcanic or igneous activity.

Recharge and discharge areas and the connecting flow system between them can be found at a variety of scales from local to intermediate to regional. Although there is no hard and fast rule as to what constitutes a local groundwater-flow system, as opposed to a regional one, it can generally be considered that at a local scale the recharge and discharge area would be adjacent to each other, whereas at a regional scale the recharge area would be at the upper end of the groundwater basin and the associated regional discharge area would be far removed, near the lower end of the basin. Intermediate flow systems and their corresponding recharge and discharge areas would fall between them.

Groundwater basins often mirror surface-water basins in their size and extent, but it is not always so. In some hydrogeological environments, typically those that feature extensive horizontally bedded sedimentary units or those with large buried valley systems, major aquifers can deliver significant flows of groundwater beneath major surface-water divides.

Groundwater-Surface-Water Interactions: Groundwater and surface water are intricately connected. For example, groundwater that discharges into streams creates the baseflow that sustains stream flow in the periods between stormwater runoff events. While it is true that basin-wide water tables tend to fluctuate somewhat through the seasons, the effect on regional hydraulic gradients is small. The flow of groundwater into a given reach of a stream therefore remains relatively constant over time. The sharp changes in flow rate that are observed in many Canadian streamflow records are caused by surface runoff from storm events or seasonal snowmelt. The sustained low flows that are of such importance for water supply, fish habitat, and navigation are provided by groundwater inflows and, in the case of managed rivers, releases from storage structures such as dams. Nevertheless, it is acknowledged that in some regions, such as the Prairies, confined bedrock aquifers do not directly relate to surface watersheds and therefore the groundwater and the surface water systems may be considered decoupled over the time frames of interest.

Groundwater discharge is also responsible in large part for the maintenance of many wetlands. Without sustained groundwater inflows, these ecologically rich habitats would dry up. Canadian wetlands take many forms, from the pothole sloughs on the prairies to the myriad of small wetlands in the St. Lawrence lowlands of Ontario and Québec, and groundwater plays a sustaining role in most of them. Groundwater inflows also play a role in the hydrological balance of Canada's many lakes, both large and small, including the Great Lakes.

Pumpage of groundwater from aquifers for the purposes of water supply diverts some of the discharge that would have gone to surface water bodies and delivers it instead to pumping wells. Over-drafting, such as has occurred in groundwater basins in the southwestern United States can actually reduce baseflow to zero, leading to seasonally dry riverbeds and loss of wetland habitat.[50] Groundwater discharge to streams, wetlands and lakes often serves a critical function in maintaining sensitive aquatic species. The management of groundwater resource development must therefore consider impacts on both the groundwater and the surface-water regimes.

Well Yield, Aquifer Yield and Basin Yield: Water resource managers want to know how much water they can safely pump from the aquifers that lie within their jurisdiction. The concept of *yield* can be applied on three distinct scales. In the early years of groundwater science, the unit of study tended to be a single well; in later years, the aquifer; and now, the groundwater basin as a whole. Well yield can be defined as the maximum pumping rate that can be supplied by a single well without causing a lowering of the water level in the well to below the pump intake; aquifer yield can be defined as the maximum rate of withdrawal that can be supplied by all the wells in an aquifer without causing an unacceptable decline in hydraulic heads in the aquifer; and basin yield can be defined as the maximum rate of withdrawal that can be supplied by all the wells in all the aquifers in a groundwater basin without causing unacceptable declines in hydraulic head anywhere in the groundwater system, or causing unacceptable changes to any other component of the hydrological cycle. It should be clear that a basin-wide definition is the one that has the most relevance to the concept of sustainable groundwater yield.

Hydrogeologists track the changes in available groundwater storage by carrying out regularly scheduled measurements of water levels in monitoring wells. Falling water levels in monitoring wells, if they occur over long periods of time, may indicate unsustainably high pumpage of the groundwater resource.

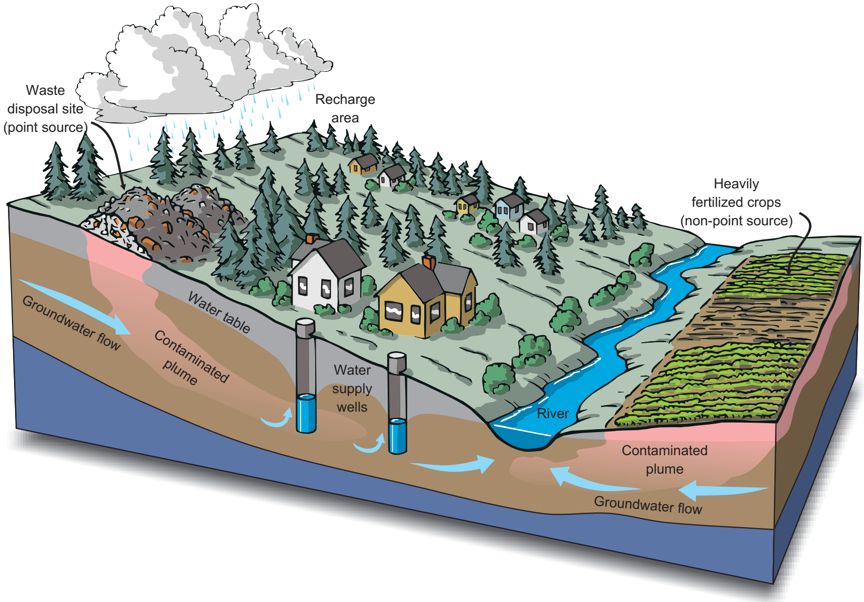
50 The Ogallala Aquifer covers an area of 647,000 km^2 and underlies much of New Mexico, Texas, Oklahoma, Kansas, Colorado, Nebraska, Wyoming and South Dakota and supports one-fifth of the irrigated agricultural land in the United States. In some places, extraction is 14 times recharge (Brentwood and Robar, 2004).

Groundwater Quality: Precipitation and snowmelt consist of relatively pure water, exhibiting only very low levels of dissolved chemical constituents. However, as infiltrating water passes through the unsaturated zone to become groundwater recharge, and then follows its flow path through the hydrogeologic environment to its discharge point, its chemistry is altered by a variety of geochemical processes, including mineral dissolution, ion exchange, and osmotic filtering, among others. The primary chemical process is dissolution of the soils or rocks through which the water flows. Overall, the total dissolved solids (TDS) content of the water increases with the length of flow path and residence time in the subsurface. Groundwater near recharge areas tends to be lower in TDS than that near discharge areas. Water in deeper aquifers tends to have higher TDS than that in shallow aquifers. In the extreme, groundwater may become too saline, or too high in some particular chemical constituent, to be suitable as a source of drinking water without treatment. Most of Canada's major aquifers deliver water of suitable quality, but there are also some places where use is limited by poor natural quality. Frequently, treatment processes can be implemented to reduce some nuisance parameters such as iron, manganese, and hardness.

Groundwater may also be rendered unusable due to a range of human activities. There are many documented cases in Canada of groundwater contamination from chemical plants, petroleum refineries, wood-processing plants, mines, waste-management facilities, gas stations, and other commercial and industrial facilities (Government of Canada, 2005). Among the most common contaminants are metals, petroleum products, chlorinated solvents such as dry-cleaning fluids and degreasing agents, and other organic chemicals.

The usual impact of these point pollution sources is the development of long, narrow plumes of contaminated water that advance through the subsurface at about the same rate as the groundwater flow itself (Figure A3). The contaminants may spread out and be diluted somewhat by the processes of molecular diffusion and hydrodynamic dispersion, and their rate of advance may be retarded somewhat by sorption of some of the chemical constituents onto the aquifer material. In addition, some organic contaminants such as petroleum products may be partially consumed, or biodegraded, by subsurface bacteria. Despite these mitigating factors, rates of plume advance can reach several hundred metres per year in permeable sand-and-gravel aquifers.

The presence of pumping wells in the vicinity of a contaminant plume will tend to draw the plume toward (and eventually, into) the wells. For any pumping well, it is possible to define a capture zone that encompasses all the 'flow tubes' that will eventually deliver water into the well. Modern preventive practice seeks to protect the recharge areas to these capture zones from pollution.



(Adapted and reproduced with permission from Environment Canada, 2008b)

Figure A3
Plumes of pollution from point and non-point sources of pollution.

Another class of groundwater contaminants arises from non-point pollution sources. These occur primarily in the agricultural sector from the use of fertilisers and pesticides. The most widely documented agriculturally based contamination in Canada is nitrate pollution from fertiliser application.

Microbial contamination may constitute the most common water-quality concern with respect to groundwater supplies in Canada. Such contamination is most common in rural areas where septic fields are widely used, and in agricultural areas where manures are commonly applied. Due to the short life spans of most bacterial species, coupled with small pore spaces that tend to inhibit significant movement of bacteria in the subsurface environment, bacterial contamination is generally restricted to shallow wells or aquifers. Nonetheless, poor well construction or other short-circuiting mechanisms such as fractures can allow bacteria to travel to deeper wells.

Groundwater-Related Hazards: Groundwater plays a role in several water-related hazards that come to public attention. Most obviously, over-pumpage of shallow groundwater tends to exacerbate the impacts of drought by reducing the most reliable component of stream flow during dry periods. The question of how such impacts might play out in the context of climate change will be an increasing preoccupation in future years.

Over-pumpage of groundwater is also directly responsible for cases of seawater intrusion and land subsidence. The intrusion of seawater into coastal aquifers is caused by a reversal of hydraulic gradients due to the installation of pumping wells near the coast. Land subsidence occurs when groundwater is pumped from stratified hydrogeological environments that feature interbedded sand and clay layers. The reduced fluid pressures created by the pumping from the sand layers cause the clay layers to compact, and this compaction leads to subsidence at the ground surface. Neither of these impacts has been widely reported in Canada, but there are many documented occurrences in the United States and other areas of the world where the soils are less consolidated and groundwater consumption is high.[51]

51 See for example data from the United Nations Economic and Social Commission for Asia and the Pacific available at: http://www.unescap.org/enrd/water_mineral/Land_cons.htm.

Appendix 2: Highlights from the Call for Evidence

The Expert Panel on Groundwater arranged for a Public Call for Evidence on what is needed to achieve sustainable management of Canada's groundwater. The 'Call' was posted on the Council's website from July 30 to November 2, 2007, and responses were invited from the general public. The following questions were asked:

- What are the opportunities, challenges or emerging crises for sustainable groundwater management in Canada?
- Do important gaps exist in knowledge or access to knowledge on groundwater issues? If so, what are they?
- Are there important gaps in the application of existing knowledge on groundwater? If so, what are they?
- Are there gaps in capacity (e.g., infrastructure, appropriate skills, information systems, regulatory frameworks) for sustainably managing groundwater in Canada?
- What should be the priorities for filling the gaps?
- Are there jurisdictions or particular situations in Canada which are exemplary (i.e., cases where groundwater is managed in particularly successful or innovative ways)?
- Do you have any additional concerns or insights on the management of groundwater in Canada which you believe would be helpful to the expert panel?

Specific notice of the Call for Evidence was sent by email to more than 70 contacts with an interest in groundwater across Canada, representing the provincial governments, NGOs, associations, think tanks, and individuals across Canada. In the end, 36 submissions were received. Not all authors agreed to make their submissions public. The 27 respondents listed below agreed to make their submissions public. To view the submissions, visit the Council's website at: www.scienceadvice.ca.

The following are the 27 submitters who agreed to have their submissions made public:

PROVINCIAL GOVERNMENTS

- Government of British Columbia: Ministry of Environment, Water Stewardship Division, Science and Information Branch
- Alberta Environment
- Government of Saskatchewan: Saskatchewan Watershed Authority
- Government of Nova Scotia: Nova Scotia Environment and Labour

NGOS

- Canadian Institute for Environmental Law and Policy (CIELAP)
- Conservation Ontario
- Pembina Institute
- Pollution Probe
- Scott Findlay, on behalf of H_2O Chelsea Community Water Research Program
- Sierra Club of Canada
- WWF-Canada
- Township of Langley (British Columbia)
- Technical Subcommittee of the Abbotsford-Sumas Aquifer Stakeholders Group (ASASG)

PROVINCIAL GROUNDWATER ASSOCIATIONS

- British Columbia Ground Water Association
- Saskatchewan Ground Water Association

OTHER ASSOCIATIONS

- Canadian Association of Petroleum Producers
- Canadian Bottled Water Association

INDIVIDUALS

- Bob Betcher, Hydrogeologist
- Brian Beatty, Hydrogeologist
- Bruce Peachey, President, New Paradigm Engineering
- Charles Lamontagne, Hydrogeologist
- Fred and Lynn Baechler, Hydrogeologists
- Grant Ferguson, Hydrogeologist
- Grant Nielsen, Hydrogeologist
- Mary Jane Conboy, Hydrogeologist
- Terry Hennigar, Hydrogeologist
- Yannick Champollion, Hydrogeologist

The following highlights represent what were concluded to be the most important themes that emerged throughout the 27 submissions. They are organised according to the following categories:

- General Context
- Key Knowledge Gaps

- Management or Policy
- Data and Information
- Skills or Training
- Energy
- Exemplary Cases

GENERAL CONTEXT

- The so-called 'myth of abundance' is a major impediment to proper stewardship.
- There is a perception that water is a gift from nature and that it should come free of cost.
- Canada (as a nation) can help to define what 'groundwater sustainability' means.
- The biggest opportunity or challenge in the dry to semi-dry western part of the country is the increasing need for groundwater to fill a larger role for water supply as surface water sources become increasingly utilised to capacity.
- The federal government should fund research and locally focused projects in each province using local people who have expert knowledge.
- While the panel is charged with carrying out an evaluation of sustainable groundwater management in Canada, in developing their report they should be in a position to compare how sustainable groundwater management is carried out in this country with approaches taken in other parts of the world, including the multi-jurisdictional sharing of responsibility.
- Increased data collection and improved compilation for public access is necessary and, in the absence of sufficient data, the precautionary principle should be used.
- Holistic adaptive management on a basin scale is seen as the correct approach to sustainability.
- An integrated approach to water resource management supports sustainable groundwater management by connecting groundwater and surface water, connecting quantity and quality, connecting allocation and water conservation, and connecting groundwater availability with planning for urban growth.
- The federal role should be to work one stage higher than the provinces; that is, not applying known and time-proven practices over and again, but carrying out research and studies which the provinces don't generally do.
- Looking forward, new challenges to sustainability may include tensions over whether development over a finite period is likely better than no development at all, the need to distinguish and allocate between consumptive and non-consumptive use and the need to promote groundwater knowledge in stakeholder's communities.

KEY KNOWLEDGE GAPS

- Impacts of new chemicals, currently pharmaceuticals and endocrine disruptors.
- Interaction with the biosphere, i.e., aquatic life in streams.

- Impact of land use, especially that of high-density subdivisions on individual wells, forestry and agriculture.
- The connections between groundwater, surface water and the increasing impacts of climate change.

MANAGEMENT AND POLICY

- The real management of the groundwater resource is done at the provincial level, with some jurisdictions even looking at management at the municipal or watershed level. As such we need to focus our attention, for now, on the provinces when discussing sustainable groundwater management. If there are available resources in this country that could be applied to all the mapping, studies and regulatory frameworks that are needed for sustainable groundwater management, then we should focus those resources in the provinces, not in federal agencies.
- Fragmentation of regulatory responsibility and oversight is a commonly noted obstacle to sustainable use; greater integrated action at all levels of government is warranted, perhaps including regulated frameworks for sustainable use. The technical expertise is largely available to develop a basin-scale understanding of our groundwater resources; what is missing is government commitment, as agencies are preferentially focused on regulatory enforcement rather than on developing a better understanding of the resource.
- Establish a national vision and strategy for groundwater and groundwater management, with the input of provinces and territories; develop national indicators for groundwater to measure progress.
- The Canadian research or applied research focus has been so much on contaminant hydrogeology that it seems we have been largely ignoring fundamental issues surrounding basic understanding of groundwater system interactions.
- Undertake Integrated Inventories: It is time to update our inventory techniques by looking at the entire hydrological cycle (groundwater — streams — lakes — near shore coastal environments and climate) so hydrogeologists can aid decision-makers in managing ‘ecosystems’.
- In British Columbia, a current major challenge is the lack of a legal framework for regulating the extraction of groundwater. Legal requirements (and corresponding capacity) for regulating, monitoring and reporting groundwater extraction need to be developed or updated.
- There is a need for a review of water allocation policies affecting different, competing sectors using water.
- There is a need for complete, comprehensive watershed-scale basin plans that provide an integrated understanding of the surface water and groundwater systems.
- Regulatory agencies often do not require a proponent to carry out sufficient ‘macro’ studies when large-scale developments are proposed (i.e., the volume beyond what may be influenced by a relatively short-term pumping test).

- It is critical that the jurisdictions in Canada give greater consideration to the use of water pricing as a tool of demand management. The costs can be accounted for in permitting programs.
- There is concern that in parts of the country the rate of increase in groundwater use will outpace the science and data available for proper management and that the precautionary principle requires further application.
- Physical science and data are not in themselves sufficient for sustainable use; there must be specific mechanisms to shift the values of users towards stewardship. Multi-disciplinary teams (hydrogeology, hydrology, ecologists, resource managers, etc.) need to be assembled. Sustainable development will require further understanding of water valuation and application of full-cost accounting.
- Industry groups express concern over different rules for different sectors, and the time and effort required to seek water-taking permits is not commensurate with the duration of the permit. Some groups seek greater availability and transparency of water data, others seek less.
- Sustainability of groundwater should be measured using metrics that can change to reflect current and forthcoming pressures.
- Reducing agricultural non-point sources continues to be a management challenge as nitrogen levels in groundwater are increasing in many parts of the country despite considerable abatement efforts.

DATA AND INFORMATION

- At present, there is a general shortage of data on actual use of groundwater in most jurisdictions in Canada. Where available, the data are not segregated into different use categories. Information on the real cost of water should also be made available to the public. There is a need for maintaining and regularly updating a user-friendly database on groundwater use, quality and quantity for the whole nation.
- Promote consistent groundwater management methods by developing national best practices for: groundwater management programs, groundwater monitoring networks, groundwater database structures, etc.
- Old, hard-copy groundwater data should be converted to electronic databases to facilitate data sharing and data analysis.
- Greater use should be made of the Internet to provide access to groundwater information.
- There is a need for a common public groundwater data set across Canada and development of a web-based knowledge-decision support-advice tool that relies on the common data set for local government, water suppliers, and the public to gain basic knowledge about groundwater generally and specifically in their local area.
- There is a need for sustained funding to collect and manage groundwater data (i.e., well construction reports) as well as for the legal authority to collect other groundwater data (e.g., pumping test data, water quality data).

- A consistent framework for monitoring and data collection and the application of appropriate standards for data, meta-data, mapping and web-based services are required.
- Many local communities do not have the tax base to acquire capacity to apply groundwater knowledge in local decisions; the groundwater resource in many local communities is still viewed as a mysterious and uncertain resource. Consideration should be given to developing a web-based knowledge-decision support-advice tool that relies on data, information in provincial (and federal) groundwater databases and expert knowledge to allow local governments to develop a basic understanding of the local groundwater resource.
- We need more emphasis on monitoring the impacts of large-scale withdrawals; a single monitoring well is generally not enough. The monitoring wells must be appropriately sited, the data reported and a regular review carried out by the regulator.
- There are still major gaps in data collection, data entry, and database management. The information system should be able to provide continuous access to a sophisticated Water Atlas where users could zoom in on any area in the province and have access to:
  - 3D aquifer maps with the capacity of generating cross-sections;
  - real-time groundwater levels;
  - location and use of any well and water intake;
  - river flows and water levels;
  - water chemistry; and
  - completed studies (local numerical models, capture zone analyses, pumping tests, etc.).
- It may be more important to address the needs of people consuming groundwater known to be contaminated before investing in the considerable resources to undertake complete mapping of all aquifers.
- National and provincial standards are needed for data collection, compatible archiving and retrieval frameworks, reasonable extraction limits, and legislated protection with enforcement for vulnerable and threatened aquifers.
- Develop aquifer inventories (quality and quantity) and groundwater use data.
- Enhance groundwater monitoring programs, including regular reporting of results.
- In many senses the gaps in knowledge are local gaps; an aquifer is being developed but we don’t know the full dimensions of the aquifer and the complex geology or hydrogeology within the aquifer and the surrounding aquitards or how the aquifer is connected to the unsaturated zone where recharge is occurring or how it discharges to surface water sources. These are typically local gaps that can be answered (partially) through site investigation.

- A national-scale, common-standard, geo-referenced database of groundwater quality and quantity information may encourage stakeholder interest and involvement by overcoming the fragmented and inconsistent data sets available through the provinces. Available data is fragmented within and across all levels of government and often veiled by issues of privacy or commercial competitive advantage.
- Efforts are needed to develop aquifer classification frameworks that support sustainable groundwater management, and methods are needed to use numerical groundwater modelling more effectively in groundwater management at a regional scale.
- Groundwater management is increasingly linked to surface water and ecosystem management. The scientific research and modelling-management tools necessary to effectively address multidisciplinary issues and ecosystem needs require further development.

SKILLS AND TRAINING

- There is a general lack of sufficiently qualified staff within most government agencies. Regulatory agencies in the provinces must recognise the need for qualified staff and ensure that people taking responsibility for groundwater monitoring are properly trained.
- More effort needs to be put into incorporating groundwater science in the training of professionals, technologists and trades people (e.g., water operators, plumbers, drillers, excavators).
- There is a lack of capacity in local government and with small and medium water suppliers. This is an important issue in British Columbia because of the lack of groundwater extraction regulations; the local extent of many aquifers in the province, and local decision-making, can impact the quantity and quality of the local resource.
- We need to ensure that groundwater is taught as a core program in engineering and geology programs and that groundwater is also taught in college programs where many of the environment officers and health inspectors come from.
- Additional support for, or pressure on, universities to expand their capabilities in hydrogeology would be valuable, particularly if there is a renewed emphasis on applied research and physical hydrogeology, something that seems to have been unfashionable over the past 10 or 20 years. An additional emphasis on applied or physical hydrogeology would generate graduates who could help the provinces in the sustainable management of groundwater withdrawals.
- Major universities across Canada (e.g., University of Waterloo, University of British Columbia, University of Calgary and Simon Fraser University) have developed academic groundwater programs in the last 20 years. These universities produce under-graduate and graduate students with excellent training in hydrogeology.

- A larger number of hydrogeologists graduating from university is required to meet the projected workforce demands.
- Expertise is necessary to better understand the links between ecosystem health and diversity and the discharge of groundwater to surface water.
- While Canada holds an impressive reputation for producing high-quality groundwater professionals, the global standard is shifting from 'finding water' to 'managing water,' and we must ensure our professionals are equipped to retain our reputation in this new area.
- Within parts of Canada, there may be room for improvement with respect to the skills and education required to be a professional hydrogeologist.
- Managing groundwater on a basin scale will entail multi-disciplinary teams. The necessary hydrogeological expertise will be broad, including quaternary geology, field methods, geophysics, hydrostratigraphy, isotope geochemistry, integrated groundwater-surface-water numerical modelling, cumulative impact assessments, contaminant remediation, data management, etc. Universities should seek to expose students to the full range of necessary skills and exemplify how these areas of expertise are integrated.
- A more integrated provincial and national research strategy may be valuable as the pace of groundwater research expands.

ENERGY

- In northern Alberta, improved monitoring and much research are needed to address the impacts of oil sands mining and *in situ* bitumen production on groundwater.
- A challenge in groundwater management is the current exclusion of oil, gas and coalbed-methane (CBM) exploration from groundwater legislation.
- What are the potential impacts of *in situ* leaching of uranium in southern Alberta?
- How might the wastewater from bitumen production be treated so as to avoid the creation of tailings ponds?
- The hydrogeological community should be prepared to address the groundwater implications of a growing commercial and domestic interest in geothermal energy.

EXEMPLARY CASES

- The private-well network operated by the Township of Langley, British Columbia, is an innovative example of how to collect and provide public access to groundwater quality data.
- The initiatives coming out of Alberta's data within its Water for Life strategy and policy are resulting in the development of comprehensive basin plans for key watersheds, such as the South Saskatchewan, where the stewardship approach of managing surface water and groundwater as one resource is being applied, and where regulation in groundwater development and use has been instituted.

- Groundwater evaluation in Manitoba incorporates physical hydrogeology, geochemistry and age dating, and 3-D modelling. All this work is being done by provincial staff with provincial financing and with some research support from the Geological Survey of Canada.
- Ontario's well-tagging program improves our knowledge of the position and identification of private wells.

Appendix 3: Major Recommendations of Canadian Reports on Groundwater Resources

This appendix lists excerpts of recommendations from major reports in Canada on the subject of groundwater. Many of the cited documents deal with water generally, and recommendations of less relevance to groundwater have been omitted.

By and large, these findings have not been fully implemented. It is also important to note that while many reports over the years have been geared towards provincial governments, we have limited this appendix to major policy-oriented reports directed primarily to the federal government, though many of the recommendations will be relevant to, and have implications for, provincial and local water management and policy.

FEDERAL WATER POLICY (1987)

Context: In the 1987 Federal Water Policy, the Government of Canada committed to a number of actions such as developing national guidelines for groundwater assessment and protection and measures to achieve appropriate groundwater quality in transboundary waters. The policy remains largely unimplemented.

Author: Officials from Environment Canada.

Recommendations

Water Pricing

The federal government is committed to the concept of 'a fair value for water.' To implement this concept in federal policies, programs and initiatives, the federal government will:

- endorse the concept of realistic pricing as a direct means of controlling demand and generating revenues to cover costs;
- develop new water-efficient technologies and industrial processes that minimise costs, and encourage water conservation and improved water quality;
- undertake, support and promote joint federal-provincial examination of the costs and pricing of water for both consumptive and non-consumptive water uses; and
- encourage the application of pricing and other strategies, such as the beneficiary/polluter pays concept, to encourage efficient water use.

Science Leadership:

In recognition of the national leadership role it must play in this endeavour, the federal government will:

- conduct and encourage the undertaking of physical, chemical, biological and socioeconomic investigations, which are directed to current and emerging issues;
- establish research advisory mechanisms with broad representation from scientific and applied research clientele, to advise on program needs and priorities;
- develop and maintain, with the provinces and territories, water data and information systems directed to improving the knowledge available for managing Canada's water resources;
- promote cooperative federal-provincial endeavours when the objectives are of joint interest;
- undertake and support research and technological development and transfer efforts;
- encourage opportunities for nongovernmental technological development, and the growth of a private sector water conservation industry; and
- foster international cooperation in scientific and technological research and development and in data and information collection systems.

Integrated Planning

In support of its commitment to this strategy of integrated, long-term planning for the development and management of water and related resources, the federal government will:

- adhere to integrated water resource planning in areas of federal jurisdiction, and in interjurisdictional waters subject to federal-provincial-territorial agreements, in order to ensure that all values are given full consideration;
- encourage, on the basis of a watershed, or other appropriate spatial unit, the integration of water management plans and objectives with those of other natural resource interests — fisheries, forestry, wildlife, mining, hydro power, and agriculture — to reflect the unity of natural processes and the interdependence of uses and users in that spatial unit;
- establish and apply evaluation criteria to all federally sponsored projects to ensure their compatibility with federal goals respecting water management, based on an appreciation of the values of water and related resources;
- ensure that all significant national and international water-related development projects, which are supported or initiated by the federal government or for which federal property is required, are subject to the Federal Environmental Assessment and Review Process, so that potential adverse environmental and socioeconomic effects can be identified and, to the extent possible, mitigated;
- ensure the participation or cooperation of all relevant coordinating and regulatory agencies; and
- encourage and support opportunities for public consultation and participation in the integrated planning.

Legislation

To these ends, the federal government will renew, consolidate or otherwise strengthen the application of existing federal legislation, so as to:

- produce legislative provisions to address interjurisdictional water issues relating to levels, flows and quality;
- control and manage toxic chemicals throughout their entire life cycle — from production to disposal;
- establish water quality standards and guidelines to better protect human health and the diversity of species and ecosystems;
- encourage existing mechanisms like the Prairie Provinces Water Board and develop others to address potential provincial-territorial and interprovincial water conflicts; and
- ensure the effectiveness of regulatory measures through the provision of appropriate enforcement and compliance measures.

Public Awareness

In order to promote public awareness and participation in programs and initiatives to improve and protect Canada's water resources, the federal government will:

- ensure that the public is consulted and that its views are considered in all major federal water management decisions;
- encourage public participation and initiate, develop and deliver a national water conservation awareness program;
- encourage the efforts of provinces and non-governmental organisations in public information and awareness; and
- ensure public access to information on the extent and health of water resources through appropriate means, including a State of the Environment reporting system.

Applying the Policy

At the federal level, the government will:

- ensure the effective coordination of federal water policies among federal departments and agencies;
- ensure a regular review of the water-related policies and programs of all federal departments to assess the degree to which these policies and programs are supportive of federal water policy;
- reconcile the water policy positions of all federal departments to promote a coordinated and thoughtful federal approach;
- ensure amendments or additions to federal water policy as appropriate; and
- apply the Environmental Assessment and Review Process to examine federally sponsored water-related developments and projects.

To achieve effective implementation of the policy, the federal government has designated the Interdepartmental Committee on Water (ICW) as the focal point for coordinating the policy among federal departments and agencies. As part of its responsibility, ICW will produce an annual report on the overall implementation of federal water policy, on the strengths and weaknesses of that policy's delivery and on areas for future examination; it will also serve as a focal point for explaining federal water policy and for providing integrated information on all aspects of that policy; and coordinate such interdepartmental studies as may be necessary to fulfil its terms of reference, and constitute subcommittees as may be appropriate to address particular problems or issues related to water policy.

At the federal-provincial-territorial level, the adoption and application of policy goals and strategies will be encouraged through:

- existing and improved federal-provincial coordinating mechanisms and bilateral arrangements, which include: consultation and information exchange so as to encourage compatible water policies and cooperative programs through forums such as the Water Advisory Committee of the Canadian Council of Resource and Environment Ministers (CCREM);
- support for formal and informal consultative or advisory committees to deal with either a single issue or a range of water problems;
- intergovernmental agreements for cooperative programs with all provinces/territories; and
- special agreements to respond to a particular water problem or issue in one or more of the provinces or territories.

Groundwater Contamination

The federal government is committed to the preservation and enhancement of the groundwater resource for the beneficial uses of present and future generations. To meet this commitment, the federal government will:

- develop, with provincial governments and other interested parties, appropriate strategies, national guidelines and activities for groundwater assessment and protection;
- conduct research and undertake technological development and demonstration projects in response to groundwater problems;
- develop exemplary groundwater management practices involving federal lands, responsibilities, facilities, and federally funded projects;
- develop measures to achieve appropriate groundwater quality in transboundary waters; and
- provide information and advice on groundwater issues of federal and national interest.

Drought

The federal government is prepared to support provincial initiatives directed to managing water supplies to realise their full value and to resolving real and potential problems associated with droughts. To this end, the federal government will:

- encourage and promote water demand management approaches and conservation technology with a view to extending the use of limited supplies;
- undertake, support and promote research into improving understanding of drought;
- encourage the development and dissemination of water conservation technologies and practices to promote the best use of current supplies; and
- encourage an integrated approach to planning and managing the augmentation and allocation of water supplies.

Water Data and Information Needs

The federal government is committed to maintaining cooperative data programs with the provinces and territories in the interest of understanding and managing the resource for the common good. To this end, the federal government will:

- work with the provinces and territories to produce reliable and timely data and information on the quantity, quality and variability of the nation's water resources;
- encourage the extension of data programs into the North and generally remote areas;
- maintain and promote the use of a range of national water databases, as well as a comprehensive directory of water-related data and sources of such data and information;
- encourage the integrated planning of information-gathering systems;
- augment certain data holdings on, for example, water use, water pricing, or groundwater, when they are needed to deal with new issues;
- undertake and promote new technology appropriate for general use across Canada; and
- implement cost-recovery policies for data and information, recognising that basic data constitute a common good.

GROUNDWATER ISSUES AND RESEARCH IN CANADA (1993)

Context: This report, commonly referred to as the 'Cherry Report,' comments on the federal government's activities with respect to groundwater in Canada. The report, prepared by an eight-member Task Force appointed by the Canadian Geoscience Council,[52] identifies problems and describes areas where improvements can be made on the part of the federal government with respect to groundwater knowledge and management activities. The 1993 report's overall conclusion states that "Canada needs to make major advances in areas such as groundwater inventory, protection and research in order to achieve responsible and effective management of this important freshwater resource." The Cherry task force also concluded that "it is reasonable to expect that within the next three years the federal government should show significant progress with the implementation of these recommendations."

Author: The report was prepared by an eight-member Task Force appointed by the Canadian Geoscience Council. The Task Force included:

John A. Cherry, Chair
Donald W. Pollock, Vice-Chair
H. Douglas Craig
R. Allan Freeze
John E. Gale
Pierre J. Gélinas
Robert E.J. Leech
Stephen R. Moran

Recommendations:

1. Establishment of Linkages, Partnerships and External Review

The federal government should establish an interdepartmental (federal) Groundwater Task Force to (i) clearly identify, coordinate and communicate groundwater issues and problems within the federal government and (ii) establish functioning partnerships and linkages between federal departments and between the federal government and other elements of Canadian society that deal with groundwater

52 The Canadian Geoscience Council was formed in 1972 at the request of the Science Council of Canada to promote the role of the earth sciences in the early strategies of the resource-based federal department of Energy Mines and Resources and the growing Canadian economy in general. In a time when Canadians had limited knowledge of our earth sciences, the Council recommended in 1971 "Provincial departments of education should promote the teaching of earth sciences in secondary schools". (Background Study for the Science Council of Canada, 1971 available at the Canadian Federation of Earth Sciences website.) More recently, the Council has led numerous task forces addressing federal earth science policy issues such as funding for geological surveys. In 2007, the Council became the Canadian Federation of Earth Sciences.

issues. This effort should involve directly the following federal ministries: Environment, Energy Mines and Resources, Agriculture, Health and Welfare, Fisheries and Oceans, National Defense [sic] and Industry Science and Technology.

There is a critical need for an overall federal strategy that encompasses all pertinent ministries, with their plans responding to the overall strategy.

This Federal Groundwater Task Force should appoint an Advisory Panel comprised primarily of leading groundwater specialists from outside the federal government, to provide guidance and insight so that bureaucratic impediments are minimised.

2. Establishment of Regional Centres for Groundwater Studies

The federal government should establish regional centres for groundwater studies with priority given to the immediate establishment of a centre in the Atlantic Region and second priority to a centre in the Prairie Region.

The Atlantic Centre: …should foster groundwater research by M.Sc. and Ph.D. students, primarily ones enrolled in universities in this region, thus providing continuing education opportunities for groundwater professionals employed in government and industry in the region.

Prairie Region Centre: What is needed now is the establishment of strong institution-to-institution partnerships and linkages (federal, provincial and universities) and some augmentation in research funding (federal and provincial) for initiation of research in important topic areas not currently being studied in the region, such as wetlands and mine-environment problems.

3. Education of Groundwater Professionals

The federal government should include mechanisms that foster advanced education of groundwater professionals in all of its groundwater research activities, whether the activity involves provision of research funds to universities, or the research is conducted primarily in-house.

4. Groundwater and the Canadian Mining Industry

Existing federally sponsored research efforts pertaining to (i) mine-environment problems and (ii) the use of groundwater in the exploration for new mineral deposits should provide improved research opportunities, and expanded partnerships between the various segments of the Canadian research community working on mine-environment and mineral-exploration problems.

These improvements should involve research groups in Energy Mines and Resources (Mineral and Energy Technology Sector and the Geological Survey of

Canada), Environment Canada, industry and academia. The progress of this research should be monitored closely by relatively independent panels or committees to ensure that the achievements are commensurate with the considerable expertise that now exists in Canada for this type of research.

5. Groundwater and Wetlands

The federal government should assess the state of knowledge of Canadian wetlands, including of the role of groundwater in wetlands hydrology, ecology and human impacts. It should then sponsor research aimed at filling the main gaps in knowledge of our wetlands ecosystems.

6. Establishment of a Groundwater Protection Office

The federal government should establish an Office For Disseminating Information About Groundwater Protection.

7. Contaminated Sites / Orphaned Sites Programs

The federal government should incorporate appropriate mechanisms and expertise for assessing groundwater and groundwater contaminant pathways into the Federal-Provincial Contaminated Sites Program and federal government programs pertaining to contaminated sites/environmental audits on federal lands. This would provide for sound decision-making with regard to prioritising sites and allocating funds for groundwater control or cleanup.

8. Identification and Hazard Assessment of New Contaminants in Groundwater

The federal government should assess the occurrence and degree of hazard associated with those types of groundwater contaminants that occur with significant frequency in Canadian groundwaters but which are not detected in the routine analyses of groundwater samples and which are not included in current federal or provincial water quality criteria or drinking water objectives.

The goal of this assessment should be the development of an information base that will provide for progressive updating of federal-provincial water quality guidelines and objectives in a manner appropriate for and relevant to groundwater resources.

9. National Standards for Groundwater Information Storage and Retrieval

The federal government should develop national standards and sponsor demonstration projects for computer storage, retrieval and display of groundwater information.

The federal initiative should develop minimum national standards for storage, retrieval and display of groundwater information by:

- providing a framework for appraising the new hardware and software systems that have recently entered the commercial marketplace for management and modelling of subsurface data;
- assessing the experience of Canadian provinces and other countries in managing groundwater information; and
- undertaking demonstration projects of appropriate technologies in cooperation with the provinces.

10. Aquifer Delineation and Groundwater Resource Characterisation

The federal government should establish a system of Groundwater Resource Inventory and Aquifer Characterisation Agreements with the provinces with the goal of achieving a specified minimum level of knowledge of the groundwater resources in each of the provinces and the Canadian North.

The Agreements could be modelled on the Mineral Development Agreements whereby the federal government provides incentive funding and the provinces conduct the investigations, in some cases in cooperation with federal agencies.

11. A Groundwater Information System for Land-Use Planning and Groundwater Protection

The federal government should develop, through research and field testing, a groundwater information system for land-use planning and groundwater management and protection.

For scientific information on groundwater to be used effectively in the context of land-use planning, water management and environmental protection, including groundwater protection, the information must be compiled and available in a form appropriate for such multidisciplinary use.

12. Inclusion of the Groundwater Environment in the State of the Environment Report

The federal government should include an assessment of the state of the groundwater environment in the next issue, and all future issues, of the 'State of the Environment Report'.

13. Priorities for Internal and External Federal Research

Groundwater research groups in the federal departments, primarily Environment Canada, Energy Mines and Resources and Agriculture Canada should develop research facilities that complement, in general, those that already exist in universities in Canada. Federal in-house research should emphasise those projects requiring long-term monitoring, or other forms of work not well suited for undertaking by non-federal research organisations. Priority should also be placed on research projects intended to provide answers to problems that are anticipated to arise in the future (anticipatory research).

14. Groundwater and Transportation

The federal government should assess the impacts of distribution of fuel for transportation on groundwater and initiate a federally coordinated effort to reduce these impacts by application of more cost effective remedial measures derived from research and development.

15. Groundwater and Agriculture

The federal government should initiate a systematic research program led by Environment Canada and Agriculture Canada to determine the impacts of Canadian agriculture on groundwater quality and to determine the degree to which adverse effects can be reduced through reasonable changes in practice.

16. Groundwater and the Great Lakes

The federal government in cooperation with the Province of Ontario should expand research efforts directed at determining the influence of groundwater and groundwater-borne contaminants on water quality and ecological systems in the Great Lakes.

17. Groundwater and Heavier-Than-Water Industrial Liquids

The federal government should ensure that within the framework of Canadian groundwater research there is research directed at heavier-than-water industrial organic liquids to a level commensurate with the degree to which these liquids are a problem at contaminated/orphaned sites in Canada.

Research is needed to better understand the long-term environmental impacts of these chemicals and to develop and assess better approaches for site investigations and cleanup.

18. Groundwater Contamination Benefit-Cost Analysis and Risk Assessment

The federal government should sponsor research aimed at improving methods for determining the risk to human health and the environment as a whole of various types of occurrences of groundwater contamination.

19. Socio-Economic Values of Groundwater

The federal government should sponsor research on the socio-economic aspects of groundwater resources in Canada.

Socio-economic studies are needed to provide a better framework for decision-making in contaminated sites programs, in development of groundwater protection programs, and in assessment of options for provision of new or expanded water supplies for communities that need more water for growth or to replace contaminated supplies.

20. Development and Commercialisation of Canadian Groundwater Technologies

The federal government should aggressively promote the development and commercialisation of Canadian technologies for groundwater monitoring, extraction and remediation so that the Canadian groundwater industry will have enhanced competitiveness in the world marketplace.

21. Report on the Canadian Groundwater Industry and Groundwater Research and Development

The federal government should produce in 1994 a comprehensive report on the capabilities and status of groundwater research and development in Canada and on the Canadian groundwater industry, comprising the manufacturing and service sectors including groundwater drilling, monitoring, treatment and remediation as well as the consulting sector. This report should be updated at three year intervals.

22. Enhancement of International Opportunities for the Canadian Groundwater Industry

The federal government should intensify its efforts and improve coordination of its activities directed at enhancing opportunities for the Canadian groundwater industry to engage in commercial activities outside Canada, particularly in rapidly developing market regions such as eastern Europe, the Pacific Rim, and Central and South America.

IJC: PROTECTION OF THE WATERS OF THE GREAT LAKES: FINAL REPORT (2000)

Context: "This is the Final Report of the IJC to the governments of the United States and Canada concerning protection of the waters of the Great Lakes. It was submitted in response to a February 10, 1999, Reference from the governments to undertake a study of such protection. This Final Report incorporates and, where appropriate, updates the Commission's Interim Report of August 10, 1999. It also extends and, in some cases, modifies the conclusions reached and recommendations made in the Interim Report" (IJC, 2000).

Author: International Joint Commission.

Recommendation VII. Groundwater

Governments should immediately take steps to enhance groundwater research in order to better understand the role of groundwater in the Great Lakes Basin. In particular, they should conduct research related to:

- unified, consistent mapping of boundary and transboundary hydrogeological units;
- a comprehensive description of the role of groundwater in supporting ecological systems;
- improved estimates that reliably reflect the true level and extent of consumptive use;
- simplified methods of identifying large groundwater withdrawals near boundaries of hydrological basins;
- effects of land-use changes and population growth on groundwater availability and quality;
- groundwater discharge to surface water streams and to the Great Lakes, and systematic estimation of natural recharge areas; and
- systematic monitoring and tracking of the use of water-taking permits, especially for bottled water operations.

In recognition of the frequent and pervasive interaction between groundwater and surface water and the virtual impossibility of distinguishing between them in some instances, governments should apply the precautionary principle with respect to removals and consumptive use of groundwater in the Basin.

REPORT OF THE COMMISSIONER OF THE ENVIRONMENT AND SUSTAINABLE DEVELOPMENT (2001)

Context: In 1995 the Office of the Auditor General of Canada was given a specific environment and sustainable development mandate. It was established through amendments to the *Auditor General Act* that created the position of Commissioner of the Environment and Sustainable Development. According to the website of the Office of the Auditor General, "the Commissioner of the Environment and Sustainable Development provides parliamentarians with objective, independent analysis and recommendations on the federal government's efforts to protect the environment and foster sustainable development. The Commissioner conducts performance audits, and is responsible for assessing whether federal government departments are meeting their sustainable development objectives, and overseeing the environmental petitions process."

Author: Commissioner of the Environment and Sustainable Development (at the time it was Johanne Gélinas, who served from August 2000 to January 2007).

Recommendations:
Our findings show that the federal government needs to decide its priorities for freshwater and clarify its commitments to achieving them.

Working with its partners, it needs to develop realistic, scheduled plans with clear accountability; stick to its plans; and provide open and transparent information on results (3.1.30).

3.1.31 Environment Canada should reassess its role and clearly articulate its responsibilities and commitments for freshwater management in the Great Lakes and St. Lawrence River basin, and clarify the commitments expected from other federal departments, especially, but not limited to the following:

- iv. promoting the concept of "a fair value for water" as stated in the Federal Water Policy.

3.1.33 The federal government should develop the information needed to manage freshwater, as follows:

- Natural Resources Canada, together with Environment Canada, should develop enough knowledge of groundwater in the basin to understand its contribution to the availability of surface water — in particular, knowledge of key aquifers, their geology, potential yields, and current withdrawals.

- Environment Canada should develop enough information on the key contaminants in the Great Lakes and St. Lawrence River basin, and on their sources to set priorities for action.

3.1.34 Health Canada should clearly articulate its responsibility for protecting human health in the basin from potential contaminants in drinking water. As part of this it should undertake, in conjunction with the Federal-Provincial-Territorial Subcommittee on Drinking Water if possible, a review of the status of drinking water quality, including its adherence to the guidelines for drinking water quality; the public's access to information on drinking water quality; and the need for nationally enforceable drinking water standards.

CANADIAN FRAMEWORK FOR COLLABORATION ON GROUNDWATER (2003)

Context: The Canadian Framework for Collaboration on Groundwater is an initiative of the Geological Survey of Canada. It was created following two national workshops in 2000 and 2001 involving representatives from all levels of government, academia, and the private sector. The Framework has not officially been endorsed by Natural Resources Canada.

Author: National *Ad hoc* Committee on Groundwater.

Recommendations

With respect to coordination and collaboration mechanisms, we recommend:

- establishing a Federal-Provincial Groundwater Committee (FPGC) to enhance cooperation among all levels of government;
- establishing a Canadian Groundwater Advisory Committee (CGAC), representing various stakeholders, to advise the FPGC; and
- annual reporting of the progress of CGAC and FPGC to stakeholders.

With respect to national cooperative programs, we recommend:

- enhanced funding for groundwater research and inventory;
- undertaking an assessment and inventory of Canada's groundwater resources;
- establishing a groundwater-monitoring 'network of networks';
- identifying critical needs for research on Canadian groundwater issues; and
- promoting linkages between government policy and the research community.

With respect to communication, we recommend:

- programs for raising the public's awareness on their role in protecting groundwater resources;
- providing a knowledge source of groundwater information for groundwater professionals and the public;
- developing and promoting an electronic national groundwater forum; and
- continuing to hold national groundwater workshops every two years.

With respect to performance standard and uniformity across Canada, we recommend:

- advanced training to enhance the knowledge and skills of groundwater professionals, well drillers, and technicians across Canada;
- accreditation for groundwater professionals, well drillers, and technicians across Canada;

- acceptance of provincial accreditation of groundwater professionals, well drillers, and technicians across Canada; and
- developing, promoting, and coordinating guidelines for best-management practices and technology transfer relating to groundwater.

FEDERAL WATER FRAMEWORK (2004)

Context: "The federal government declared water as a sustainable development priority in 2003. A senior-level interdepartmental committee, cochaired by Environment Canada and Health Canada, was given a mandate to develop a Federal Water Framework to address issues related to freshwater quality and quantity. The committee spent time, money, and effort to develop the Federal Water Framework, which was approved by its parent committee at the deputy minister level in February 2004. The Framework begins with a vision: 'Clean, safe, and secure water for people and ecosystems.' Associated with this vision are five ultimate outcomes encompassing the scope of federal activity on water. These outcomes relate to protecting human health through safe drinking water, ecosystem health, sustainable use and economy, hazards and environmental prediction, and the global dimension" (CESD, 2005).

The 2005 report of Commissioner of the Environment and Sustainable Development recommended that Environment Canada, with other federal departments and agencies, should establish clear next steps on what the Federal Water Framework will be used for, particularly in relation to its five ultimate outcomes (CESD, 2005). The CESD deemed the Department's response, excerpted below, to have failed to fully address the specifics of its recommendations.

Environment Canada's Response:

"In September 2004, the Minister of the Environment launched a process to develop a Competitiveness and Environmental Sustainability Framework for Canada (CESF). The purpose of the Framework is to attain the highest level of environmental quality as a means to enhance the health and safety of Canadians, preserve our natural environment, and advance our long-term competitiveness.

"The Federal Water Framework will help to reaffirm federal water policy priorities through the CESF. Some 19 federal departments completed the water framework task to describe their activities along five ultimate outcomes. The Water Framework serves as a tool to assist in identifying strengths and gaps in the departments' activities to address a full spectrum of water issues. Environment Canada will continue to promote the intent of the framework for priority setting and integrating water-related activities across the government.

"As key next steps, outcomes of the Federal Water Framework will be integrated into the broader CESF along the following lines:

Federal Water Framework outcomes	CESF outcomes
Human health	Health and safety of Canadians
Hazards and environmental prediction	
Ecosystem health	Natural environment
Sustainable use and economy	Long-term competitiveness

"The primary strategies for achieving the outcomes of the Federal Water Framework will be used in developing elements of the CESF related to water. A round-table discussion on water through the Deputy Ministers' Policy Committee on Environment and Sustainability will help to reaffirm federal water priorities and align water-related activities across mandates with the CESF. This round-table discussion and the above-noted alignments are planned for the fall of 2005" (CESD, 2005).

Author: A senior-level interdepartmental committee, cochaired by Environment Canada and Health Canada.

Recommendations:
The Framework begins with a vision: "Clean, safe, and secure water for people and ecosystems." Associated with this vision are five ultimate outcomes encompassing the scope of federal activity on water.

These outcomes relate to:

- protecting human health through safe drinking water;
- ecosystem health;
- sustainable use and economy;
- hazards and environmental prediction; and
- the global dimension.

WATER IN THE WEST: UNDER PRESSURE (2005)

Context: The Standing Senate Committee on Energy, the Environment and Natural Resources examined and reported on emerging issues related to its mandate.

Author: The Standing Senate Committee on Energy, the Environment and Natural Resources.

Recommendation 1

The Government of Canada should take the necessary steps to ensure that all of Canada's major aquifers are mapped by 2010. This data should be made available in the national groundwater database and supported by a summary document assessing the risks to groundwater quality and quantity.

Recommendation 2

The Government of Canada should work with industry and with other orders of government to develop a standard methodology for the collection and reporting of water-related data. The Government of Canada should take on the responsibility for the creation of a centralised depository for water statistics.

Recommendation 3

The Government of Canada must restore funding for longitudinal water studies. Such studies are essential to ensuring the sustainability of Canada's water resources.

Recommendation 4

The Government of Canada should bolster its support for the National Water Research Institute and the Prairie Farm Rehabilitation Administration so that these institutions can better address Western Canada's growing water challenges.

Recommendation 5

The Government of Canada should create a National Water Council. This Council, composed of representatives from industry, research institutes and all orders of government, would be tasked with identifying the key water issues that require attention from the federal government and proposing strategies for addressing them.

Council of Canadian Academies
Conseil des académies canadiennes

Council of Canadian Academies
180 Elgin Street, Suite 1401
Ottawa, ON K2P 2K3
Tel: 613-567-5000
www.scienceadvice.ca

Appendix X:

Erik W. Allen, "Process water treatment in Canada's oil sands industry: I. Target pollutants and treatment objectives," Journal of Environmental Engineering and Science, 7:123-138, 2008

Process water treatment in Canada's oil sands industry: I. Target pollutants and treatment objectives

Erik W. Allen

Abstract: Process water treatment has become a critical issue for Canada's oil sands industry. Continuous recycling of tailings pond water (TPW) has contributed to a decline in water quality that has consequences for bitumen recovery, water consumption, and reclamation efforts. Potential roles for water treatment were assessed through a review of process water quality and toxicity data from two long-term oil sands operations. Target pollutants were identified according to exceedances of environmental and industrial water quality guidelines. From 1980 to 2001, the salinity of TPW increased at a rate of 75 mg/L per year. Recent increases in hardness, sulphate, chloride, and ammonia have raised concerns over scaling and corrosion. Naphthenic acids released during bitumen extraction are the primary source of toxicity in TPW. Biodegradation of naphthenic acids has been demonstrated in pond experiments; however, recalcitrant compounds may contribute to chronic toxicity in reclaimed environments. Water treatment objectives established in this review provide benchmarks for the selection of candidate water treatment technologies.

Key words: oil sands, tailings ponds, naphthenic acids, toxicity, reclamation.

Résumé : Le traitement des eaux de procédé est devenu une question très importante pour l'industrie canadienne des sables bitumineux. Le recyclage continu de l'eau des parcs à résidus (TPW) contribue à diminuer la qualité de l'eau, ce qui impacte la récupération du bitume, la consommation d'eau et les efforts de remise en état. Les rôles potentiels du traitement de l'eau ont été évalués par un examen de la qualité de l'eau de procédé et des données de toxicité pour deux exploitations à long terme de sables bitumineux. Les polluants ciblés ont été identifiés selon les excédents aux lignes directrices environnementales et industrielles sur la qualité de l'eau. Entre 1980 et 2001, la salinité de la TPW a augmenté à un rythme de 75 mg/L par an. Les récentes augmentations en dureté, en sulfates, en chlorures et en ammoniac ont soulevé des inquiétudes quant à l'incrustation et la corrosion. Les acides naphténiques libérés durant l'extraction du bitume sont la principale source de toxicité dans la TPW. La biodégradation des acides naphténiques a été démontrée dans des expériences dans les parcs à résidus; toutefois, les composés récalcitrants peuvent contribuer à une toxicité chronique dans les environnements remis en état. Les objectifs du traitement de l'eau établis dans cette revue fournissent des points de référence pour la sélection des technologies de traitement des eaux.

Mots-clés : sables bitumineux, parcs à résidus, acides naphténiques, toxicité, remise en état.

[Traduit par la Rédaction]

Introduction

The oil sands in northern Alberta, Canada, represent one of the largest oil deposits in the world, with proven reserves of 174 billion barrels of bitumen (Alberta Energy and Utilities Board 2005). As an unconventional fossil fuel, bitumen is more costly to recover and process than conventional oil and gas; however, increased global demand for oil coupled with technological advances in bitumen production have triggered rapid growth in the industry. Oil production from the oil sands has reached 1 million barrels per day, and is projected to triple over the next decade (National Energy Board 2006).

Received 6 December 2006. Revision accepted 28 August 2007. Published on the NRC Research Press Web site at jees.nrc.ca on 27 February 2008.

E.W. Allen. Advanced Separation Technologies, CANMET Energy Technology Centre-Devon, Natural Resources Canada, 1 Oil Patch Drive, Devon, AB T9G 1A8, Canada (e-mail: erallen@nrcan.gc.ca).

Written discussion of this article is welcomed and will be received by the Editor until 31 July 2008.

Rapid expansion of Alberta's oil sands industry presents several challenges with respect to the protection of local freshwater resources such as the Athabasca River basin (Griffiths et al. 2006). Oil sands mines consume large volumes of water, importing an average of 3 barrels of river water for every barrel of oil produced (Syncrude Canada Limited 2005; Shell Canada 2005*b*; Suncor Energy Incorporated 2005*b*). While only a small fraction (<2%) of the river's annual flow is currently allocated to the oil sands, it remains unclear whether or not low winter flows can support the expected increase in water consumption over the next decade (Peachey 2005).

Most of the freshwater imported by oil sands mines is used in hot water extraction, a flotation process that separates bitumen from sand and clay. The resulting process water is alkaline, slightly brackish, and acutely toxic to aquatic biota due to high concentrations of organic acids leached from the bitumen during extraction (MacKinnon and Sethi 1993). Under a zero discharge policy, oil sands producers are required to store all process waters and tailings on-site, a condition that has led to the construction of over 70 km^2 of tailings ponds (Dominski 2007) and a significant inventory of waste. The volume of impounded process water at Syncrude's Lease 17/22 was approaching 1 billion m^3 in 2004, (MacKinnon 2004); the current total volume of impounded tailings sludge (among all operators) has exceeded 700 million m^3 (Dominski 2007). At mine closure, process water and tailings will be reintegrated in the landscape through various reclamation scenarios, with the intent of restoring sustainable aquatic and terrestrial ecosystems.

While oil sands producers have made improvements in water use efficiency and have invested in reclamation research, the industry still faces several hurdles related to water use. Recycling of tailings pond water (TPW) has slowed the increase in freshwater withdrawals (Syncrude Canada Limited 2005), but has contributed to a long-term decline in process water quality that threatens to affect bitumen recovery through disruption of extraction chemistry (Kasperski 2003) and scaling and corrosion of extraction facilities (Rogers 2004). Tailings treatments such as consolidated tailings (CT), whereby calcium sulphate is added to mature fine tailings and sand, further enhance the salinity and hardness of process water (Marr et al. 1996). As producers become increasingly dependent on process water recycling, the decline in water quality may reduce bitumen recovery rates, leading to increased demand for water.

Many of the operational and environmental challenges related to the management of oil sands process water could be addressed through the selection of appropriate water treatment technology. Process water treatment could allow operators to regulate water quality to suit the bitumen extraction process, reduce the need for freshwater withdrawals by recycling TPW for utilities and other operational uses, offset withdrawals through discharges of treated water, promote bioremediation through the removal of pollutants that contribute to acute and chronic toxicity in aquatic biota, and ensure that downstream sites meet water quality guidelines for the protection of aquatic ecosystems (e.g., CCME 2005).

Water treatment technologies are rapidly evolving to meet the water management needs of the oil industry, yet the viability of these emerging technologies for oil sands operations remains unclear. As a prerequisite to the evaluation of process water treatment options, process water quality and toxicity data from two long-term oil sands mining projects were reviewed to identify target pollutants and establish water treatment priorities. Target pollutants were identified based on their exceedance of environmental and industrial water quality criteria. Process water quality data were compiled from published papers, reports, and conference presentations.

Oil sands overview

There are three major oil sand deposits in the province of Alberta covering over 140 000 km^2 in the northern half of the province (Alberta Department of Energy 2005) (Fig. 1). Oil sands deposits are situated at varying depths beneath an overburden of muskeg, glacial tills, sandstone, and shale. Shallow oil sand deposits (i.e., up to 75 m) are accessed via surface mines, and account for only 18% of the total recoverable bitumen, most of which is in the Athabasca deposit (Alberta Department of Energy 2005). For deeper deposits, bitumen is extracted via in situ processes in which steam is injected into a well to heat and loosen the bitumen so that it can be pumped to the surface through a production well. Surface mining currently accounts for 65% of total production from the oil sands, and is forecast to remain at this level through 2010 (Alberta Department of Energy 2005). At present, there are three major producers in mineable oil sands: Suncor Energy Corp. (Suncor), Syncrude Canada Ltd. (Syncrude), and Albian Sands Inc. (Albian).

Surface mined oil sands are transported as a slurry from the mine to the extraction plant. Bitumen extraction follows modified versions of the Clark Hot Water Process, in which bitumen is separated from sand and clay particles by a combination of mechanical energy, heat, and the presence of surfactants leached from the bitumen (Kasperski 2003). Historically, caustic soda (NaOH) was added to promote the release of surfactants and improve bitumen separation. Downstream effects of alkalinity on water chemistry and tailings formation (e.g., MacKinnon 2001) has led some operators to reconsider this method.

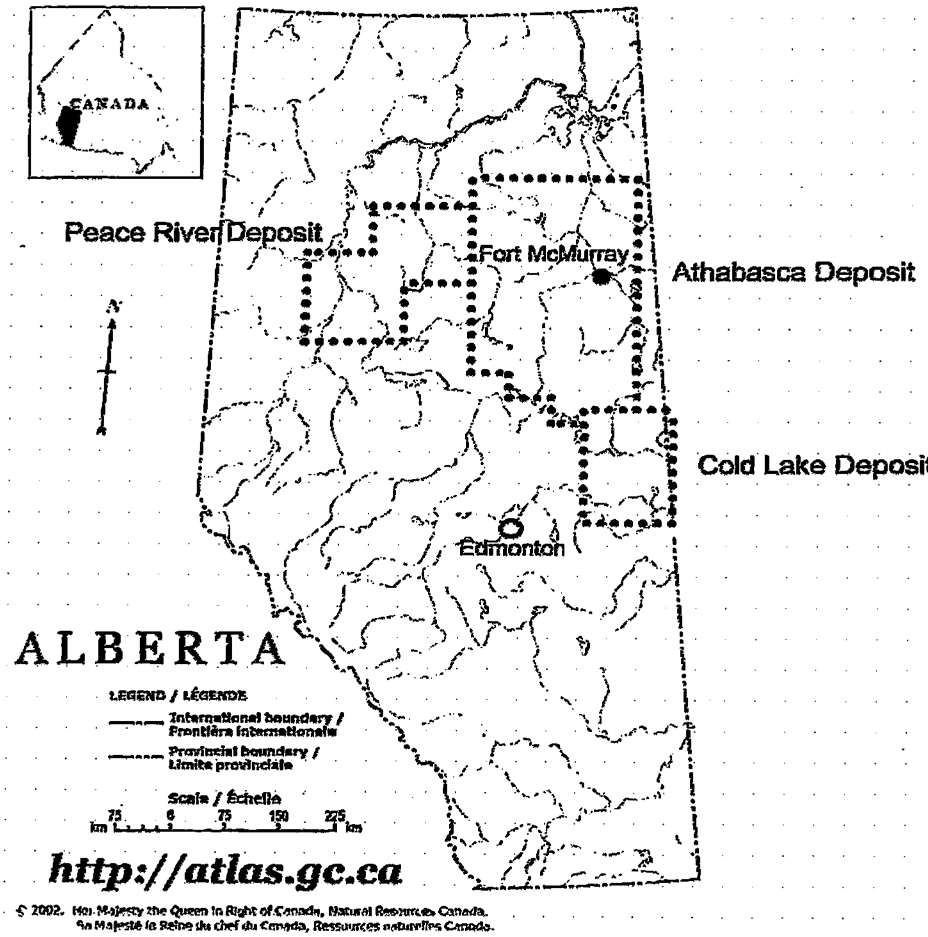
The aerated slurry is then piped into the primary separation vessel, where bitumen separated via flotation (froth) is skimmed from the surface and pumped to a froth treatment plant after which it is sent to be upgraded to synthetic sweet crude oil. Residual bitumen is recovered from the middlings of the primary separation vessel. Depending on ore quality, approximately 1 m^3 of oil sand is required to produce 1 barrel of oil (Scott et al. 1985). A simplified flow diagram and materials balance for an oil sands mining operation is presented in Fig. 2.

Tailings

Tailings composed of water, dissolved salts, organics, minerals, and bitumen are pumped from separation vessels and froth treatment facilities to a series of settling basins and tailings ponds. The composition of oil sands tailings varies with ore quality, source, extraction processes, and age, but generally contain ~70 to 80 wt% water, ~20 to 30 wt% solids (i.e., sand, silt, and clays) and ~1–3 wt% bitumen (Kasperski 1992). Upon delivery to settling basins, tailings divide into three fractions: (*i*) rapidly-settling sand particles; (*ii*) an aqueous suspension of fine particles (silt and clay); and (*iii*) a clarified surface water layer (total suspended solids = ~15–70 mg/L) with residual bitumen (MacKinnon and Sethi 1993). The fine tailings settle to 20 wt% solids within a few weeks, but require several years to reach 30–35 wt% solids, at which point consolidation slows considerably and the sludge is designated as mature fine tailings (MFT) (Scott et al. 1985). Evidence from Syncrude tailings ponds suggests that MFT is settling 30% faster than predicted, but still requires 10 years to consolidate to 44% solids (MacKinnon 2001).

Enhancement of settling rates has been demonstrated with centrifugation, pH adjustment, lime, inorganic coagulants, organic flocculants and other methods (Kasperski 1992; MacKinnon 2001), although only a few of these approaches have been applied at a commercial scale (e.g., CT, paste technology). The CT process increases the settling rate of the solids, but releases a particle-free pore water with ele-

Fig. 1. Major oil sands areas in Alberta, Canada.



vated concentrations of TDS and hardness (Marr et al. 1996). The use of calcium sulphate as a settling aid requires careful control of calcium levels to prevent scaling of heat exchangers and losses in bitumen extraction efficiency (Kasperski and Mikula 2003). Paste technology is another recently implemented process, in which flocculants are added to thicken and reduce the volume of tailings (Shell Canada 2007).

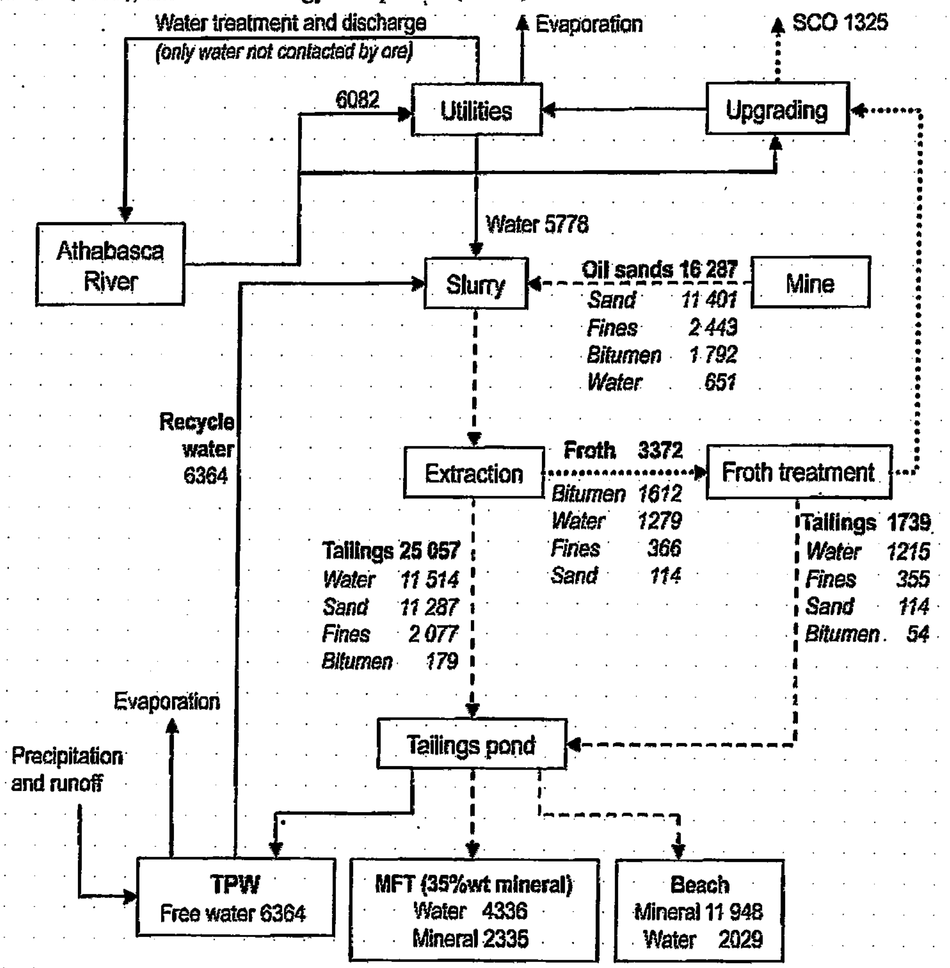
Water usage

The Athabasca River is the primary source of water for oil sands producers in the Athabasca deposit. Other important sources of water include groundwater, site runoff, overburden drainage, and water contained in oil sands (connate water). In 2004, annual freshwater imports by the three major oil sands mining companies totaled 114 million m^3, which corresponds to an average of 3.1 barrels of water per barrel of oil produced (Syncrude Canada Limited 2005; Shell Canada 2005*b*; Suncor Energy Incorporated 2005*a*). The actual volume of water used in extraction is considerably higher, given that the process relies largely on recycled water from tailings ponds. In 2004, Syncrude recycled the equivalent of 16.4 barrels of water per barrel of oil produced (228 million m^3; Syncrude Canada Limited 2005). Recycled water accounts for approximately 80%–85% of the water used in extraction processes (Syncrude Canada Limited 2005; Suncor Energy Incorporated 2005*a*).

Given the large fraction of process water retained in tailings after extraction, achieving the levels of freshwater use intensity and process water recycling reported by oil sands producers likely requires a large inventory of process water and (or) the implementation of CT and other technologies to recover process water. This can be demonstrated by calculating the flow rates for a hypothetical oil sands operation where the amount of recycled water available is limited to the free water that forms above tailings, which results in a higher water use intensity and a lower percentage of process water recycled (Fig. 2). Note that flow rates will vary among operations depending on ore quality, extraction and upgrading techniques, and tailings treatment.

As of 2005, the total allocation of Athabasca River flow for oil sands producers was 360 million m^3 per year (11.4 m^3/s), roughly 1.7% of the river's annual flow (Peachey 2005). While the annual flow far exceeds allocation, there are concerns that low winter flows (e.g., 75 m^3/s, Dec. 2001) (Alberta Environment 2004) may not support the water demand of a rapidly expanding industry. Where impacts to aquatic ecosystems are expected, Alberta Environment may limit withdrawals to 10% of natural flow (Alberta Environment 2006). Allocated withdrawals for ex-

Fig. 2. Simplified flow diagram (t/h) for an oil sands mining operation (solid lines = aqueous streams; dashed lines = oil sands and tailings; dotted lines = bitumen/oil; SCO, synthetic crude oil; TPW, tailings pond water; MFT, mature fine tailings). The calculated values for water, tailings, and bitumen are based on the following assumptions: oil production of 200 000 bpd; ore composition: bitumen (11 wt%), sand (70 wt%), fines (15%), water (4 wt%); fraction of imported freshwater used in extraction = 95%; water content in slurry = 45 wt%; bitumen extraction efficiency = 87%, upgrading efficiency = 85%. It was also assumed that the only sources of water were the Athabasca River, water contained in the ore, and the free water recovered from tailings. Consolidated tailings or other tailings treatments were not considered in the calculations. Flow rates and paths were based on data compiled from Kasperski (1992), Kasperski (2003), Shell Canada (2005*a*), Syncrude Canada Limited (2005), and Suncor Energy Incorporated (2005*b*).



isting and planned operations on the Athabasca River correspond to an instantaneous pumping rate of 22.3 m³/s, which may account for up 30% of the river volume during low flow periods (Sawatsky 2004).

Tailings pond water quality

Inorganic chemistry

Tailings pond water is moderately hard (15–25 mg/L Ca^{2+}, 5–10 mg/L Mg^{2+}) with a pH of 8.0–8.4 and an alkalinity of ~800–1000 mg/L HCO_3^- (Table 1). Total dissolved solids (TDS) concentrations (2000 to 2500 mg/L) are in the slightly brackish range, having increased in both Syncrude and Suncor's tailings ponds at a rate of 75 mg/L per year between 1980 and 2000 (MacKinnon and Retallack 1981; Nix 1983; MacKinnon and Sethi 1993; Kasperski 2001; MacKinnon 2004) (Fig. 3). Dissolved solids are dominated by sodium (~500 to 700 mg/L), bicarbonate, chloride (~75 to 550 mg/L), and sulphate (~200 to 300 mg/L). At Syncrude, chloride and hardness concentrations in the Mildred Lake Settling Basin (MLSB) increased sharply throughout the 1990s, whereas Suncor experienced a rapid increase in sulphate concentration in the same period. Increases in bicarbonate concentrations appear to have leveled off during the early- to mid-nineties, and both operators have reported declining concentrations in recent years. Syncrude have also reported a slight decline in TDS concentrations beginning in 2000 (MacKinnon 2001). Similar to the dominant ions, ammonia concentrations in MLSB have increased by 3.5-fold, from an initial concentration of 4 mg/L in 1980 to 14 mg/L in 2001 (MacKinnon 2001). Dissolved solids are considerably more concentrated in TPW than in local surface waters: sodium, chloride, sul-

Table 1. Inorganic water chemistry of oil sands process waters, the Athabasca River, and regional lakes.

Variable (mg/L unless otherwise noted)	Syncrude MLSB (2003)[a]	Syncrude demonstration ponds (1997)[b]	Suncor TPW (2000)[c]	Suncor CT release water (1996–97)[d]	Suncor CT Pond seepage (1996–97)[d]	Athabasca River (2001)[e]	Regional lakes (2001)[e]
TDS	2221	400–1792	1887	1551	1164	170	80–190
COND ($\mu S \cdot cm^{-1}$)	2400[f]	486–2283	1113–1160[f]	1700	1130	280	70–226
pH	8.2[g]	8.25–8.8	8.4	8.1	7.7	8.2	7–8.6
Sodium	659	99–608	520	363	254	16	<1–10
Calcium	17	15–41	25	72	36	30	2–25
Magnesium	8	9–22	12	15	15	8.5	1–8
Chloride	540	40–258	80	52	18	6	<1–2
Bicarbonate	775	219–667	950	470	780	115	9–133
Sulphate	218	70–513	290	564	50	22	1–6
Ammonia	14[g]	0.03–0.16	14[f]	0.35	3.4	0.06	<0.05–0.57

Note: MLSB, Mildred Lake Settling Basin; TPW, tailings pond water; CT, consolidated tailings; TDS, total dissolved solids; COND, conductivity; data represent mean values from samples collected during the year indicated; ranges indicate mean values for multiple sites.

[a](MacKinnon 2004).
[b](Siwik et al. 2000).
[c](Kasperski 2001).
[d](Farrell et al. 2004).
[e](Golder Associates Limited 2002).
[f](MacKinnon and Sethi 1993).
[g](MacKinnon 2001).

phate, bicarbonate, and ammonia concentrations exceed Athabasca River values by up to 40-, 90-, 30-, 8-, and 200-fold, respectively (Golder Associates Limited 2002).

Organic chemistry

Organic compounds detected in tailings pond water include bitumen, naphthenic acids (NAs), asphaltenes, benzene, creosols, humic and fulvic acids, phenols, phthalates, polycyclic aromatic hydrocarbons (PAHs), and toluene (Strosher and Peake 1978; MacKinnon and Retallack 1981; Gulley 1992; MacKinnon and Sethi 1993; Madill et al. 2001; Rogers et al. 2002*b*). A wide range of bitumen concentrations (measured as oil and grease) have been detected in tailings ponds. Nix (1983) reported concentrations of 9, 31, and 12 mg/L in Suncor ponds 1A, 1, and 2 respectively; Gulley (1992) later reported 92 mg/L in Pond 1A. MacKinnon and Boerger (1986) reported an oil and grease concentration of 25 mg/L in MLSB. Dissolved organic matter (DOM) ranges in concentration from 50 to 100 mg/L, and is mostly comprised of organic acids, 80% of which are NAs (Nelson et al. 1993).

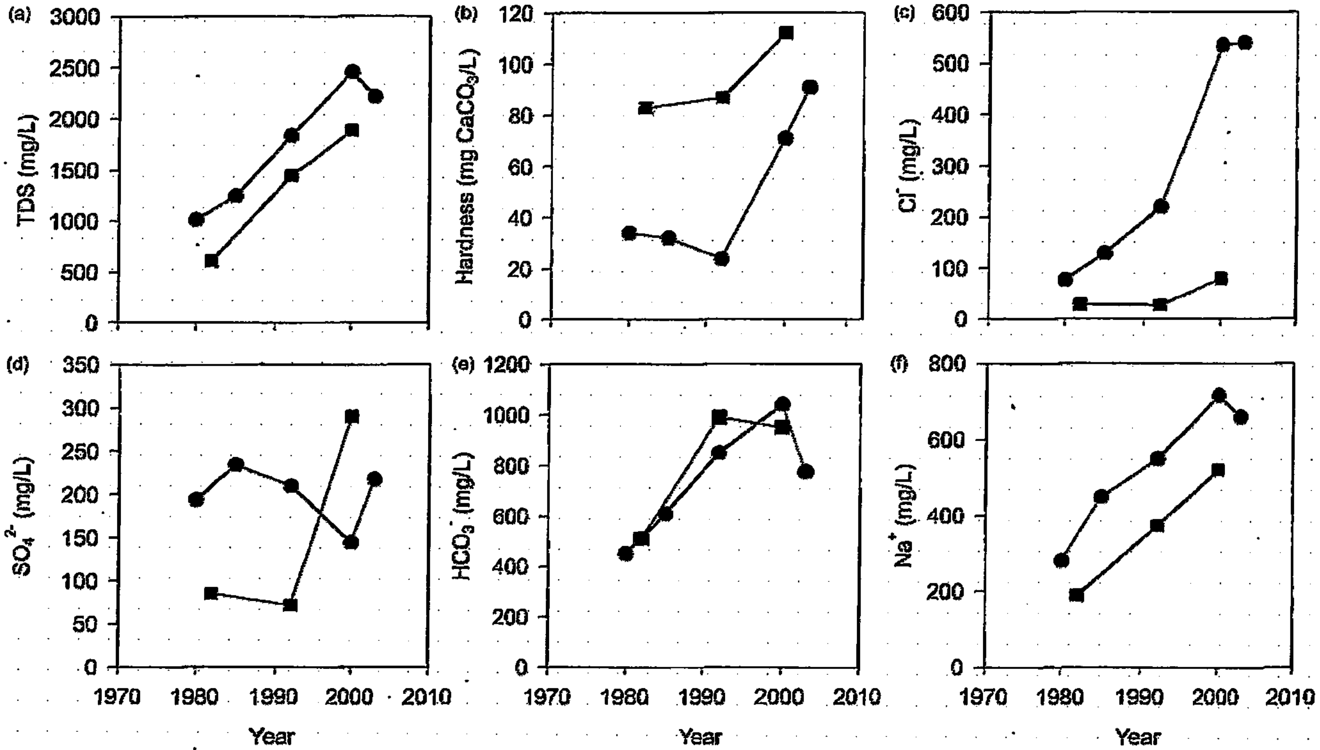
Naphthenic acids are alkyl-substituted cyclic and aliphatic carboxylic acids that are removed from bitumen during the extraction process. Concentrations of NAs range from 40 to 70 mg/L in tailings ponds, but can be has high as 130 mg/L in fresh tailings water (Holowenko et al. 2002; MacKinnon 2004). Naphthenic acids are the main source of acute toxicity in TPW (Verbeek et al. 1993) and depending on their composition and age, can have toxic effects at relatively low concentrations. For example, Holowenko et al. (2002) reported a Microtox® IC_{50} value of 32 vol% for MLSB water; the corresponding NA concentration was 16 mg/L (based on 49 mg/L NA in the original sample). Natural degradation processes have caused NA concentrations in MFT pore water (10–15 m depth) to decline over time, from 73 mg/L in 1995 to 33 mg/L in 2003, although concentrations in dike seepage have remained relatively high (~75 mg/L) (MacKinnon 2004). Background concentrations of NAs in surface water are typically less than 1 mg/L (Headley and McMartin 2004).

Among the aromatic compounds detected in process water are several toxicants of concern including benzene, toluene, phenol, and PAHs (Table 2). Historical concentrations of benzene and toluene in Suncor process water (e.g., >0.6–6.3 and 1–3 mg/L, respectively; Gulley 1992) have in some cases far exceeded CCME guidelines for the protection of aquatic life (0.37 and 0.002 mg/L, respectively) (CCME 2005). More recent data from Syncrude indicate much lower concentrations of these and other compounds; for example, surface water concentrations of BTEX (benzene, toluene, ethylbenzene, and xylene) in MLSB were below detection levels (i.e., <0.010 mg/L) in 1998 (Rogers et al. 2002*b*). Total phenol concentrations in MLSB appear to have declined over time, ranging from 0.3 mg/L in 1981, to 0.15 mg/L in 1985, 0.02–0.04 mg/L in 1992, and 0.008 mg/L in 1998 (MacKinnon and Retallack 1981; MacKinnon and Benson 1985; Nelson et al. 1993; Rogers et al. 2002*b*).

Toxicity

The toxic effects of oil sands process water on aquatic biota have been documented since the early stages of oil sands development. In 1975, it was reported that drainage water from the Great Canadian Oil Sands (GCOS, the precursor to Suncor) lease was acutely toxic to rainbow trout (*Oncorhynchus mykiss*), with an LC_{50} of less than 20% (Hrudey 1975). MacKinnon and Retallack (1981) described the environmental hazards associated with the Syncrude tailings ponds after 3 years of operation, including toxicity to aquatic biota (e.g., 96 h LC_{50} = 10% for rainbow trout), poor water quality, floating bitumen mats, and the risk of infiltration of TPW

Fig. 3. Temporal changes in the concentrations of inorganic ions in tailings pond water at Syncrude Canada Ltd. (circles) and Suncor Energy Corp. (squares); note that Suncor began to implement consolidated tailings (CT) treatment ca. 1997 (data sources: MacKinnon and Retallack 1981; Nix 1983; MacKinnon and Boerger 1986; MacKinnon and Sethi 1993; Kasperski 2001; MacKinnon 2001; MacKinnon 2004).



into groundwater. Between 1981 and 1992, Microtox® LC_{50} values in MLSB ranged from 25% to 43% (Nelson et al. 1993).

Early speculation that organic acids were the primary source of toxicity (MacKinnon and Retallack 1981) was confirmed by Verbeek et al. (1993) with the Environmental Protection Agency (EPA) Toxicity Identification and Evaluation (TIE) protocol. Acute toxicity in MLSB water was removed by adjustment of pH to 2.5 followed by centrifugation, or by reverse phase solid phase extraction with C_{18}, indicating that the toxicants were organic acids with a non-polar component (NAs). Toxicity in Suncor Pond 1A was completely removed by extraction of organic compounds with a non-polar component; however, sparging with nitrogen removed 20%–35% of acute toxicity, indicating the contribution of volatile organic compounds (light hydrocarbon mixtures released into the tailings as diluent) to acute toxicity (Verbeek et al. 1993).

While earlier studies focused mainly on the acute toxicity of TPW, more recent studies have addressed the chronic effects of process waters on aquatic and terrestrial biota in constructed wetlands and ponds (e.g., van den Heuvel et al. 1999*b*, 2000; Siwik et al. 2000; Bendell-Young et al. 2000; Pollet and Bendell-Young 2000; Leung et al. 2001; Colavecchia et al. 2004) (for a summary see Table 3). This research will be discussed in greater detail after a brief review of the land reclamation options currently under consideration.

Wet landscape reclamation

As part of their licensing agreement with the government of Alberta, oil sands operators must reclaim tailings ponds, mining sites, and other disturbed land to self-sustaining ecosystems with a land use equivalent to the original landscape (Alberta Department of Energy 1995). Reclamation plans include dry and wet landscape options. For the dry landscape option, fine tailings will be dewatered, mixed with sand, buried, and capped with soil. The wet landscape option will feature end-pit lakes (EPLs) in mined-out areas, in which fluid fine tails will be capped with a layer of process water and river water (FTFC 1995). Natural sedimentation in the EPLs is expected to provide a buffer layer at the water:tailings interface to reduce the transfer of contaminants from the tailings to the water column. Lake morphometry will be designed to resist water column mixing during wind events.

The reclamation plans are supported by ongoing research on the viability of EPLs and treatment wetlands to form sustainable ecosystems and provide effective remediation of NAs and other pollutants. Both Suncor and Syncrude began to conduct research on wet reclamation in the 1980s, building a series of prototype ponds in which mature fine tailings were capped with water (e.g., Nix 1983). Most studies have demonstrated that small, isolated ponds begin to detoxify naturally over a period of several months to 2 years, and are eventually colonized by aquatic plants (e.g., Nix 1983; Boerger et al. 1992; Nix and Martin 1992; Gulley and

Table 2. Organic chemistry of oil sands process water, the Athabasca River, and regional lakes.

Variable (mg/L)	Syncrude MLSB (1985–1998)	Syncrude demonstration ponds (1996–97)[a]	Suncor tailings ponds (1982–1998)	Athabasca River (2001)[b]	Regional lakes (2001)[b]
DOC	58[c]	26–58	62–67[c]	7	14–27
BOD	25[d]	-	<10–70[e]	<2	-
COD	350[d]	-	86–525[f] 260–973[e]	40[d]	-
OG	25[d]	-	9–31[f] 92[e]	<0.5	-
NA	49[g]	3–59	68[g]	<1	1–2
Phenols	0.008[h]	0.001–0.003	0.03–1.8[f] 0.03–1.4[e]	<0.001	0.002–0.004
Cyanide	0.5[d]	-	0.01–0.04[e]	0.004[d]	-
PAHs	0.01[h]	-	-	-	-
Toluene	-	-	1–3[c]	-	-
Benzene	-	-	<0.6–6[c]	-	-
BTEX	<0.01[h]	-	-	-	-

Note: DOC, dissolved organic carbon; BOD, biochemical oxygen demand; COD, chemical oxygen demand; OG, oil and grease; NA, naphthenic acids; PAH, polycyclic aromatic hydrocarbon; BTEX, benzene, toluene, ethylbenzene, xylene; MLSB, Mildred Lake Settling Basin; data represent mean values from samples collected during the year indicated; ranges indicate mean values for multiple sites.

[a](Siwik et al. 2000).
[b](Golder Associates Limited 2002).
[c](MacKinnon and Sethi 1993); MLSB and Suncor Ponds 1–3.
[d](MacKinnon and Boerger 1986).
[e](Gulley 1992); Suncor Ponds 1A, 4.
[f](Nix 1983); Suncor Ponds 1A, 1, and 2.
[g](Holowenko et al. 2002): MLSB and Suncor Pond 5.
[h](Rogers et al. 2002*b*).

MacKinnon 1993; Alberta Department of Energy 1995; MacKinnon et al. 2001). The degradation of NAs in isolated TPW has been shown to occur at a rate of 16% per year over the first 5 years (130 to 24 mg/L) (MacKinnon 2004). The same study showed that further degradation of NAs beyond 5 years was negligible, but that the toxicity of the sample (Microtox® IC_{20}) continued to decline, reaching 100 vol% at 10 years. Aeration and nutrient additions have been shown to increase detoxification rates by stimulating natural microbial populations that degrade NAs (Nix 1983).

There is conflicting evidence as to whether or not wet landscape environments formed from reclaimed tailings and process water can sustain fish populations and other aquatic biota. Although natural detoxification of process water has been demonstrated in small ponds, there is some evidence that larger systems may not detoxify as rapidly. For example, after being dormant for 5 years, Suncor's Pond 1A remained highly toxic to brook trout (*Salvelinus fontinalis*) (96 h LC_{50} = 24%), although some detoxification had occurred (<10% LC_{50} values are typical for active tailings ponds) (Nix 1983). In a study by Boerger et al. (1992), it was demonstrated that fine tailings retain their toxicity beyond 2 years (e.g., Microtox® EC_{50} of 59%), but do not transfer toxicity to the freshwater surface layer.

Another concern is the persistence of chronic toxicity after natural degradation has removed the acutely toxic fraction of naphthenic acids. For example, yellow perch (*Perca flavescens*) stocked in experimental reclamation ponds (MFT capped with surface runoff) for 3 to 10 months suffered increased mortality rates, gill lesions, tumors, and fin erosion (van den Heuvel et al. 2000). In a related study however, yellow perch exhibited positive effects after being stocked for 5 to 11 months in the same demonstration pond, including increased fecundity and body condition, though this may have been linked to reduced competition in the reclamation ponds relative to reference sites (van den Heuvel et al. 1999*b*). Normal growth rates were reported for larval fathead minnows (*Pimephales promales*) raised in experimental reclamation ponds for 59 days, although elevated mortality rates were detected at certain sites (Siwik et al. 2000).

Tailings amendment processes such as CT treatment may also contribute to the chronic toxicity of process water. Fathead minnows exposed to CT release water and dike seepage from a Suncor CT pond all died within 28 days (Farrell et al. 2004). Bendell-Young et al. (2000) reported low species diversity among benthic fauna in wetlands receiving dike seepage water, CT release water, or phosphate-amended CT water. The authors also found that fish in the wetlands receiving process waters exhibited signs of stress (based on changes in blood chemistry), and in the case of a wetland receiving dilute dike seepage waters, died within 14 days of capture.

Concerns over the viability of proposed wet reclamation options focus on the lengthy residence time required to degrade naphthenic acids and the incomplete degradation of recalcitrant compounds (Quagraine et al. 2005*b*). Researchers have made considerable progress in their attempts to characterize the hundreds of individual NAs in oil sands process water, and to isolate the fraction responsible for toxicity (Holowenko et al. 2001, 2002; Rogers et al. 2002*b*; Lo et al. 2003; Hao et al. 2005). A critical finding was that NA compounds vary in terms of toxicity and biodegradability.

Table 3. Summary of recent studies on experimental reclamation ponds and treatment wetlands in the oil sands.

Study objective	Findings	Reference
Toxicity of tailings pond sediments to early life stages of fathead minnows (*Pimephales promelas*)	Fathead minnows hatched over sediments from oil sands deposits and tailings ponds (treatments ranged from 0.05 to 25 g sediment/L) exhibited increased mortality, malformations, and reduced size; toxic effects may be related to PAHs where sediment total PAH concentrations > 500 µg/L	(Colavecchia et al. 2004)
Toxicity of dike seepage to wetland plants	Plants exposed to oil sands effluent had higher photosynthetic rates than plants in reference wetlands; accumulation of stress related proteins in cattail roots may reflect osmotic stress from high salinity; concluded that cattail and clover can adapt to oil sands effluent (in the form of dike seepage)	(Crowe et al. 2001)
Effects of oil sands wetland outflow on terrestrial plant growth	Effluents from a naturally-formed dike seepage wetland and a CT pond inhibited the germination of terrestrial plant species such as rye, wheat, pea, canary grass, and clover	(Crowe et al. 2002)
Effects of CT water on survival of fathead minnows	Fathead minnows exposed to CT release water and dike seepage water did not survive beyond 28 days, and experienced gill hyperplasia and decreased lymphocytes; concluded that wastewater will require amelioration to support fish populations	(Farrell et al. 2004)
Effects of process water on phytoplankton biomass and community composition	Phytoplankton communities were sampled in 10 water bodies across the oil sands region; biomass was not correlated with either NAs or major ions; NA and major ion concentrations explained 40% of the variability in the phytoplankton community	(Leung et al. 2003)
Effects of process water on phytoplankton community	Microcosm experiments showed effects of process waters (<5 years old, [NA] > 20 mg/L) on phytoplankton community composition; the greatest changes occurred in the microcosms with the highest NA concentrations and salinity	(Leung et al. 2001)
Mutagenicity of polyaromatic compounds in tailings porewater	Pore water extracts were not mutagenic based on Ames *Salmonella* assay	(Madill et al. 2001)
Effects of seepage ponds and wetlands on growth, development, and survival of frogs	Tadpoles (*Bufo boreas* and *Rana sylvatica*) in wetlands receiving effluent exhibited reduced growth, prolonged developmental time, and decreased survival compared to reference sites	(Pollet and Bendell-Young 2000)
Acute and subchronic toxicity of NAs to rodents	Exposure of rats to a wide range of NA dosages (0.6–300 mg/kg) indicated hepatotoxicity, but worst-case scenario exposure in tailings pond water should not cause acute toxicity; subchronic exposure may cause health problems	(Rogers et al. 2002*a*)
Growth effects on larval fathead minnows	Fathead minnow larvae exposed to water from Syncrude demonstration ponds (5- to 9-year old capping experiments) showed no evidence of impeded growth at 7 d or 56 d, although increased mortality was detected at several sites	(Siwik et al. 2000)
Physiological endpoints in swallows inhabiting process water wetlands	Found no differences in reproductive success, growth rate, or immune response between swallows inhabiting oil sands wetlands and reference sites; elevated hepatic ethoxyresorufin-*O*-deethylase (EROD) activity in nestlings living on reclaimed sites indicated the presence of xenobiotics in their diet, which were likely derived from contaminants associated with oil sands processing	(Smits et al. 2000)
Effects of aromatic compounds on fish hormone levels	At river sites within the Athabasca oil sands deposit and adjacent to oil sands development, fish had lower steroid production and higher activity of a hepatic enzyme relative to reference sites, suggesting exposure to aromatic compounds; PAHs could potentially cause endocrine disruption in aquatic biota	(Tetreault et al. 2003)
Chemical indicators of exposure to process waters in fish	Yellow perch in experimental reclamation ponds (i.e., water capped tailings) had elevated mixed-function oxygenase (MFO) activity and PAH concentrations relative to reference sites; however, these chemical endpoints did not appear to be linked to physiological responses in the fish	(van den Heuvel et al. 1999*a*)
Effects of reclamation pond water on fish physiology	Yellow perch living in experimental reclamation ponds had increased gonad size, fecundity, and condition factors (at 5 and 11 months) relative to a reference lake; this may have reflected greater resource availability or reduced inter- and intraspecific competition in the experimental ponds	(van den Heuvel et al. 1999*b*)

Table 3 (*concluded*).

Study objective	Findings	Reference
Effects of long-term (3–10 months) exposure of yellow perch (*Perca flavescens*) to reclamation ponds	Increased occurrence of disease and gill lesions in yellow perch from experimental reclamation ponds may be related to immune system suppression; incidence of disease was positively correlated with concentrations of oil sands-related compounds, did not identify a specific substance as the stressor	(van den Heuvel et al. 2000)

Naphthenates in fresh TPW are dominated by a group of compounds with carbon numbers 13–16; however, if the water is isolated and aged for several years, the composition of the mixture shifts towards larger molecules (i.e., C_{22+}) (Holowenko et al. 2002). Toxicity has been shown to decrease with increasing relative abundance of C_{22+} compounds, suggesting that the smaller compounds (C_{13-16}) not only degrade faster, but are more toxic than the larger molecules (Holowenko et al. 2002). Subsequent research has shown that NAs with a high number of multi-ring structures are less toxic and more resistant to microbial degradation than less complex structures (Lo et al. 2006).

Due to the variable toxicity among NA compounds, decreases in acute toxicity may not necessarily correlate with changes in total NA concentration. For example, CT treatment has been shown to significantly reduce toxicity (i.e., from IC_{50} of 20%–30% in pond water to 70%–100% in CT release water) despite only a slight reduction (25%) in NA concentration (Marr et al. 1996). Similarly, a 38% reduction in NA concentration in 1-year old process water (from 129 to 81 mg/L) eliminated LC_{50} toxicity for trout, zooplankton, and Microtox® (LC_{50}) (MacKinnon et al. 2001), even though much lower NA concentrations in "fresh" tailings water have proven to be acutely toxic to aquatic biota.

Polycyclic aromatic hydrocarbons may also contribute to chronic toxicity in process water. Although water column concentrations of PAHs are predicted to be low in reclaimed environments (Gulley 1992), the potential for chronic effects on aquatic biota (e.g., endocrine disruption, behavioural and growth effects) remains a concern. Tetreault et al. (2003) sampled fish populations in two rivers that drain into the Athabasca River near major oil sands developments, and found evidence of reduced steroid production and increased exposure to natural oil sands compounds (based on hepatic enzyme activity) at sites within the oil sands deposit and adjacent to an oil sands development, compared to reference sites. The authors suggested that PAHs detected in river sediments and water may contribute to endocrine disruption, which is supported by numerous studies on the physiological effects of PAH exposure on fish in other regions (e.g., Lintelmann et al. 2003). Other studies have reported evidence of PAH exposure among fish populations in demonstration ponds (van den Heuvel et al. 1999*a*), and cited PAHs as potential stressors causing increased mortality and malformations in fish (Colavecchia et al. 2004).

Salinity concentrations in process water are currently insufficient to be acutely toxic, but may influence biological productivity, community composition, or act as a stressor that increases the toxicity of other compounds to biota in reclaimed environments. Crowe et al.'s (2001) study on plant growth in process water reported the production of dehydrin-related proteins in cattail roots that may have been indicative of osmotic stress caused by the high salinity. Significant shifts in phytoplankton species composition have been linked to elevated concentrations of salinity and NAs in oil sands process waters (Leung et al. 2001). A subsequent study found no correlation between phytoplankton biomass and NA or major ion concentrations, and concluded that major ions had at least as much of an ecological effect as NAs (Leung et al. 2003).

Water treatment objectives

Process water recycling

With the exception of chemical additives to promote the settling of fine clay particles, TPW is not treated prior to reuse in the extraction process. The consequent decline in process water quality has raised concerns over the effects of water chemistry on bitumen recovery, scaling, corrosion, and fouling of extraction plant infrastructure. Given that the proposed expansion of mining projects may lead to restrictions on freshwater imports, operators may eventually need to consider treatment of TPW and other process waters to meet the operational requirements currently served by the Athabasca River (e.g., extraction, boiler feedwater, upgrading, drinking water, and other domestic uses). In the following sections, potential treatment objectives for the industrial reuse of tailings pond water are established based on water quality criteria for bitumen extraction and boiler feedwater treatment.

Bitumen extraction chemistry

Process water chemistry strongly influences bitumen extraction and froth quality. Bitumen recovery is optimized at alkaline pH due to increased activity of surfactants, negative charges on clay and sand surfaces, and reduced interfacial tension between bitumen droplets and solids (Kasperski 2003). Where needed (e.g., low or moderate grade ores), process water pH is controlled through the addition of alkaline reagents such as sodium hydroxide (Schramm et al. 1985). Changes in process water pH or alkalinity as a result of water treatment would thus affect the sodium hydroxide dosage, and should be taken into consideration when selecting treatment technologies.

Divalent cations interfere with bitumen recovery by increasing the adhesion of bitumen to sand and clay particles, reducing the adhesion of bitumen to air bubbles, neutralizing surfactants, and increasing the coagulation of clay particles (Kasperski 2003). While bitumen recovery rate has been negatively correlated with calcium + magnesium concentration (over a range of ~0.1 to 10 mmol/L), the effect is not consistent across ore types (Cuddy et al. 2000). Much of the variability in bitumen recovery at different calcium concentrations may be attributable to differences in fines content and ore chemistry (Kasperski 2003).

Table 4. Hypothetical treatment objectives for industrial reuse of oil sands tailings pond water.

Variable (mg/L unless otherwise noted)	Oil sands tailings pond water	Industrial water quality guidelines (mg/L)			Treatment objective (% removal)
		Conventional boiler (900–1500 psi)[a]	Once-through steam generator[b]	Bitumen extraction[c]	
Alkalinity	635–779[d]	100	-	-	>85
Calcium	17–25[d]	0.005	0.05	~50–140	>99
COND (µS cm^{-1})	1506–2400[e]	150–1000	-	-	33–94
Copper	0.7[f]	0.015	-	-	98
DO	-	0.007	0.04	-	-
Hardness	91–112[d]	n.d.-0.05	0.5	-	>99
Iron	0.08[e]-2.4[f]	0.02	0.05	-	37–92
Oil	25[g]-92[h]	1	1	-	96–99
pH	8.2–8.4[i]	8.5–9.5	9–9.5	7–9	-
Silica	1.75[g]	2–8	50	-	-
TDS	1900–2221[d]	100–650	8000	-	52–95
TSS (%)	0.7[e]	-	0	0.5–2	100

Note: TPW, tailings pond water; COND, conductivity; DO, dissolved oxygen; TDS, total dissolved solids; TSS, total suspended solids; MLSB, Mildred Lake Settling Basin; ASME, American Society of Mechanical Engineers; OTSG, once through steam generator.

[a](ASME 1994).
[b](Zaidi and Constable 1994).
[c](Hall and Tollefson 1979; Kasperski 2003).
[d](Kasperski 2001; MacKinnon 2004).
[e](MacKinnon and Sethi 1993).
[f](Nix 1983).
[g](MacKinnon and Boerger 1986).
[h](Gulley 1992).
[i](MacKinnon 2001).

Where hardness concentrations are prohibitive to bitumen extraction, treatment of process water to precipitate calcium carbonate has proven to be effective at preventing the decline in bitumen recovery. Magnetic treatment of process water with a total hardness of 235 ppm improved bitumen recovery from 45% to 65%, and appeared to reduce the binding of cations to clay particles, possibly as a result of increased precipitation of calcium carbonate (Amiri 2006).

High concentrations of sodium chloride (1000–2000 mg/L and 3000–6000 mg/L) have also been shown to reduce bitumen recovery, albeit in low grade ores only (see Kasperski 2003). A positive effect on bitumen recovery was reported for sodium chloride additions up to 1149 mg/L, which is within the range of reported values from tailings ponds. Additional water quality requirements for bitumen extraction include low clay content (suspended solids of 0.5% to 2% are sufficient for extraction process), removal of substances that could flocculate clays, and removal of particulate or dissolved substances that might deposit on heat exchange surfaces (Hall and Tollefson 1979).

Based on the process water quality data reviewed herein, there are no significant exceedances of bitumen extraction criteria in process water. Current hardness concentrations are insufficient to reduce bitumen extraction, although long-term trends in TPW quality, coupled with expansion plans and the potential for increased reliance on tailings release water and other streams with high water hardness (e.g., site runoff, basal aquifer water) point towards an eventual need for water treatment.

Scaling, fouling, and corrosion

Prevention of scaling, fouling, and corrosion are major concerns for oil sands operators, particularly at in situ operations where produced water is recycled for steam generation (e.g., Zalewski and Bulkowski 1998; Hart 2002), although problems related to scale formation and fouling have also been reported at the extraction facilities of mining operations (pers. comm., K. Kasperski 2006). Recent increases in hardness and pH in TPW have translated into significant increases in the Langelier Saturation Index (a scaling index for calcium carbonate), necessitating the use of anti-scalants (Rose and Rideout 2001). Common components of scales formed from produced water include carbonate, silica, sulphate, phosphate, and iron oxides (CH2M Hill Canada 1981; Zalewski and Bulkowski 1998).

Chemicals of concern with respect to process water corrosivity include TDS, sulphate, chloride, bicarbonate, ammonium, NAs, copper, and dissolved oxygen (CONRAD 1998; Rogers 2004). As previously noted, concentrations of these chemicals, as well as water hardness, have increased considerably in the tailings ponds. Applying the strict guidelines of conventional boiler feedwater treatment to prevent scaling, corrosion, and fouling in TPW would require up to 100% removal of suspended solids, >95% removal of bitumen, 99% removal of hardness, 85% removal of alkalinity, 98% removal of copper, 33%–94% reduction in conductivity, and 37%–92% removal of iron (Table 4), although less aggressive treatments would be sufficient to prevent scaling and fouling of hot water extraction facilities.

Table 5. Hypothetical treatment objectives for environmental discharge of oil sands process water.

Pollutant (mg/L)	Oil sands tailings pond water[a]	Environmental guideline (mg/L) CEQG[b]	EPEA[c]	USEPA[d]	Other	Treatment objective (% removal)
Inorganic						
Ammonia	14	1.4	5	0.8–1.3[e]	-	64–93
Bicarbonate	775–950	-	-	-	500[f]	50
Chloride	80–540	-	250–500		150[g]	70
Sulphate	218–290	-	-		50[g]	80
TDS	1900–2221	-	-	-	1340[h]	50–60
Organic						
Benzene	<0.01–6.3	0.37	-	-	-	<99
BOD	<10–70	-	25	-	-	<65
COD	86–973	-	200	-	-	<80
Cyanide	0.01–0.5	0.005	-	0.005	-	50–99
Naphthenic acids	50–70	-	-	-	30[i]	20–74
					5[j]	90
					1[k]	99
Oil and grease	9–92	no odour or visible sheen	5–10	1% of 96-h LC_{50} for selected biota	35[l]	<90
Phenols	0.02–1.5	0.004	1	0.001	-	33–99.7
Toluene	<0.01–3	0.002	-	1.3[m]	-	<99
PAHs	0.01	0.00001–0.00006[n]	-	-	-	>99
Trace metals						
Aluminum	0.07–0.5	0.1	-	0.75	-	<80
Arsenic	0.006–0.015	0.005	-	0.15	-	<67
Chromium	0.003–2	-	-	0.074[o]	-	<63
Copper	0.002–0.9	0.002	-	0.009[o]	-	>95–99
Iron	0.8–3	0.3	3.5	1	-	<50
Lead	0.04–0.19	-	-	0.0025[o]	-	94–99
Nickel	0.006–2.8	-	-	0.052[o]	-	93–99
Zinc	0.01–3.2	-	-	0.12[o]	-	96

Note: TDS, total dissolved solids; BOD, biochemical oxygen demand; COD, chemical oxygen demand; PAH, polycyclic aromatic hydrocarbons.
[a](MacKinnon and Boerger 1986; Gulley 1992; Siwik et al. 2000; Leung et al. 2001; Kasperski 2001; MacKinnon 2004).
[b]CEQG, Canadian Environmental Quality Guidelines; surface water quality guidelines for the protection of aquatic life (CCME 2005).
[c]EPEA, Environmental Protection and Enhancement Act; example maximum discharge limits for various Alberta industries (Alberta Environment 1999); monthly average guideline for BOD (Alberta Environment 1997).
[d]USEPA, United States Environmental Protection Agency; water quality criteria for the protection of aquatic life; (USEPA 1999).
[e]USEPA 30-day average concentration at pH 8.0–8.3.
[f]$NaHCO_3$ toxicity (zooplankton) of 10 mequiv. HCO_3/L (Mount et al. 1997).
[g]Ambient water quality guidelines (Government of British Columbia 2000).
[h]General guideline cited by SETAC (2004); effects vary with ionic composition.
[i]Microtox® LC_{50} value for a commercial mixture of naphthenic acids (Herman et al. 1994).
[j]Toxicity to fish from a commercial mixture of naphthenic acids (Patrick et al. 1968).
[k]Background concentration in surface waters (Headley and McMartin 2004).
[l]USEPA Effluent Limitation Guideline, Agriculture and Wildlife Category, National Pollutant Discharge Elimination System (NPDES).
[m]USEPA drinking water guideline.
[n]Criteria for individual compounds.
[o]Continuous concentration at hardness = 100 mg/L $CaCO_3$.

Environmental discharge and reclamation

For the purposes of environmental discharge and (or) reclamation, the goal of water treatment would be to remove toxicity and ensure that biota in reclaimed and downstream aquatic systems are not affected by acute or chronic effects of chemicals associated with oil sands processing. Poor water quality in EPLs could hinder recolonization of reclaimed environments and bioremediation of pollutants (Quagraine et al. 2005*b*). Although oil sands operators are currently bound to a zero discharge policy, treatment and discharge of process waters could represent an option to offset water consumption. To identify target pollutants and determine hypothetical treatment objectives, TPW quality data were compared to environmental water quality benchmarks such as the CCME's surface water quality guidelines for the protection of aquatic life (CCME 2005), industrial discharge limits under Alberta's Environmental Protection and Enhancement Act (EPEA) (Alberta Environment 1999), and background concentrations in local surface waters (Golder Associates Limited 2002). Treatment objectives based on exceedances of these criteria were then determined for target chemicals (Table 5).

Naphthenic acids

As the principal source of toxicity in the tailings ponds, NAs represent the main pollutant of concern with respect to reclamation or environmental discharge. Although the acutely toxic fraction of NAs have been shown to degrade naturally over time in experimental pits and wetlands, the lengthy water residence time required for degradation may not be practical where the direct discharge of water is required. Also, high molecular weight NA compounds appear to be resistant to biodegradation and could persist in reclaimed environments. Further research is needed to determine if recalcitrant NAs in reclaimed environments pose a chronic toxicity risk. Since concentration-based limits have not been established in Canada, background concentrations in local surface- and groundwater (i.e., ~1–5 mg/L) are suggested as a target for NA removal. Given typical NA concentrations of 50–70 mg/L in TPW, the corresponding water treatment objective would be 90%–99% removal.

Bitumen

Residual bitumen in the tailings ponds poses a hazard to aquatic biota, and its biodegradation could be a source of NAs in EPLs (Quagraine et al. 2005*a*). Bitumen slicks would not only interfere with the establishment of aquatic communities in reclamation ponds, but would also contribute to the fouling of advanced treatment technologies. Previously reported bitumen concentrations in tailings ponds water have been at least 2.5- to 9-fold higher than the EPEA maximum discharge limit of 10 mg/L (Table 5), thus up to 90% removal may be required.

Volatile organic compounds

Based on historical data, concentrations of benzene, cyanide, PAHs, phenols, and toluene in TPW have previously exceeded CCME guidelines for the protection of aquatic ecosystems by at least an order of magnitude (Table 5). While there is little evidence that aromatic compounds contribute significantly to acute toxicity in process waters, certain compounds have been detected in fish (van den Heuvel et al. 1999*a*) and there are concerns over endocrine disruption and other chronic effects (Tetreault et al. 2003). To reduce aromatic hydrocarbon concentrations in process water below CCME guidelines, removal rates of up to 99% may be required. Volatilization, dilution, and natural degradation may sufficiently reduce the concentrations of certain compounds in proposed wet landscape systems; for example, total phenol concentrations in demonstration ponds (0.001–0.003 mg/L; Siwik et al. 2000) are well below the EPEA discharge limit (1 mg/L) and slightly below the CCME surface water quality guideline (0.004 mg/L).

Total dissolved solids

High concentrations of TDS in process water may affect zooplankton community structure and contribute to acute or chronic toxicity in aquatic biota. Total dissolved solids concentrations in excess of 1340 mg/L are generally considered sufficient to cause toxicity in aquatic biota due to ion imbalance (SETAC 2004). Ion imbalance refers to a condition in which common ions occur in different ratios or at concentrations above or below tolerance levels for aquatic biota, which can induce chronic stress that impairs normal metabolic functions. As such, the toxic effects of TDS are strongly dependent on the ionic composition of the water (e.g., Mount et al. 1997).

The dominant ions in tailings pond water exceed several water quality criteria. Current concentrations of chloride and sulphate in TPW exceed water quality guidelines for the protection of aquatic life by 3- to 4-fold (USEPA 1999; Government of British Columbia 2000), and sodium chloride concentrations may be sufficient to induce chronic effects in zooplankton (Harmon et al. 2003). In other systems, sodium bicarbonate concentrations comparable to those of TPW have been shown to cause acute toxicity in zooplankton (Mount et al. 1997). To date, evidence of toxic effects from salinity levels in TPW has been limited to osmotic stress in plants (Crowe et al. 2001) and shifts in phytoplankton community structure (Leung et al. 2003). Salinity could contribute to the acute toxicity of TPW because osmotic stress is an important component of the toxic effect of NAs on aquatic biota (see Quagraine et al. 2005*b*). Based on current concentration, removal rates of up to 50%–60% for TDS, 70% for chloride, and 80% for sulphate would be required to meet the criteria cited above.

Ammonia

Ammonia is highly toxic to fish and other aquatic biota. Total ammonia nitrogen concentrations of 14 mg/L in TPW (MacKinnon 2004) exceed both the USEPA's criterion continuous concentration (0.8–1.3 mg/L for pH range of 8.0–8.3), which is a guideline for long-term exposure (i.e., 30-day average) (USEPA 1999), and the EPEA maximum daily discharge limit for refineries in Alberta (5 mg/L) (Table 5). For TPW, ammonia removal rates of 64%–93% would be required to meet surface water guidelines.

Trace metals

Trace metals detected in TPW include aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), molybdenum (Mo), titanium (Ti), vanadium (V), and zinc (Zn) (Hall and Tollefson 1979; MacKinnon and Retallack 1981; MacKinnon 1981; Nix 1983; Gulley 1992; FTFC 1995; Siwik et al. 2000). Among these elements are toxic metals that have been labeled as priority pollutants under the USEPA's Clean Water Act (e.g., As, Cd, Cr, Cu, Ni, Pb, and Zn) (USEPA 2006). Historical data from tailings ponds indicate some exceedances of CCME water quality guidelines for trace metals (Table 5), however the scarcity of recent data makes it difficult to determine if current concentrations are problematic. Trace metal concentrations in experimental reclamation ponds do not exceed surface water quality guidelines (e.g., Siwik et al. 2000; Farrell et al. 2004). Trace metals that have previously exceeded CCME guidelines in oil sands process water include Al, As, Cr, Cu, Fe, Pb, Ni, and Zn (exceedances ranging from 50% to 100%) (MacKinnon and Retallack 1981; Nix 1983; Gulley 1992).

Conclusions

Target pollutants for the operational reuse of oil sands process water include suspended solids, bitumen, hardness, sulphate, chloride, ammonium, and iron. Increasing concentrations of water hardness in recycled water may eventually exceed bitumen extraction criteria and saturation points for scaling, necessitating some form of water treatment to sustain bitumen recovery without increasing the consumption of freshwater.

Chemicals of environmental concern in oil sands process water include NAs, bitumen, ammonia, sulphate, chloride, aromatic hydrocarbons, and trace metals. While NAs are the main contributors of acute toxicity to aquatic biota, various compounds have exceeded CCME water quality guidelines at some point during oil sands operations and could contribute to chronic toxicity in reclaimed aquatic environments. Proposed reclamation procedures rely on natural processes to ameliorate the process water quality in proposed artificial aquatic ecosystems comprised of mature fine tailings capped with process water. Small-scale versions of the proposed systems have demonstrated natural detoxification over a period of months; however, it remains unclear whether or not full-scale systems will be as effective, or how residual pollutants will affect aquatic and terrestrial food webs in the reclaimed landscape. Alternative forms of water treatment may offer more effective and rapid removal of environmental contaminants. The target pollutants and treatment objectives proposed herein provide a framework for the assessment of emerging water treatment technologies and their potential to minimize environmental impacts while optimizing bitumen production from oil sands deposits.

Acknowledgements

The author thanks Dr. Kim Kasperski for reviewing the manuscript and Nancy Aikman for technical assistance with research materials.

References

Alberta Department of Energy. 1995. Fine tails and process water reclamation. *In* Advances in Oil Sands Tailings Research. Alberta Department of Energy, Oil Sands and Research Division, Edmonton, Alta. pp. 3–17.

Alberta Department of Energy. 2005. Alberta's oil sands 2004. [online]. Available from http://www.energy.gov.ab.ca/docs/oilsands/pdfs/PUB_osgenbrf.pdf [cited 1 March 2006].

Alberta Energy and Utilities Board. 2005. Alberta's reserves 2004 and supply/demand outlook 2005–2014. Report no. ST98–2005. Alberta Energy and Utilities Board, Calgary, Alta.

Alberta Environment. 1997. Domestic wastewater management guidelines for industrial operations. Industrial Waste and Wastewater Branch, Air and Water Approvals Division, Alberta Environment, Edmonton, Alta.

Alberta Environment. 1999. Summary of Alberta industrial wastewater limits and monitoring requirements. Report No. 0-7785-0911-7. Environmental Sciences Division, Environmental Service, Alberta Environment, Edmonton, Alta.

Alberta Environment. 2004. Water in the oil sands industry. *In* Proceedings of the Canadian Oil Network for Research and Development (CONRAD) Water Usage Workshop, Feb.24–25, 2004, Fort McMurray, Alta.

Alberta Environment. 2006. Draft interim framework: Instream flow needs and water management system for specific reaches of the Lower Athabasca River. Alberta Environment, Edmonton, Alta.

ASME. 1994. Consensus operating practices for the control of feedwater and boiler water chemistry in modern industrial boilers. American Society of Mechanical Engineers, ASME Books, New York, NY.

Amiri, M.C. 2006. Efficient separation of bitumen in oil sand extraction by using magnetic treated process water. Sep. Purif. Technol. 47: 126–134. doi:10.1016/j.seppur.2005.06.016.

Bendell-Young, L.I., Bennett, K.E., Crowe, A., Kennedy, C.J., Kermode, A.R., Moore, M.M., Plant, A.L., and Wood, A. 2000. Ecological characteristics of wetlands receiving an industrial effluent. Ecol. Appl. 10: 310–322. doi:10.2307/2641005.

Boerger, H., MacKinnon, M., Van Meer, T., and Verbeek, A. 1992. Wet landscape option for reclamation of oil sands fine tails. *In* Proceedings of the Second International Conference on Environmental Issues and Management of Waste in Energy and Mineral Production. A.A. Balkema, Rotterdam. pp. 1249–1261.

CCME. 2005. Canadian Environmental Quality Guidelines. Canadian Council of Ministers of the Environment, Winnipeg, Man.

CH2M Hill Canada. 1981. Review of treatment and recycling of produced water from heavy oil fields. Report prepared for the Alberta Oil Sands Technology and Research Authority (AOSTRA), Edmonton, Alta.

Colavecchia, M.V., Backus, S.M., Hodson, P.V., and Parrott, J.L. 2004. Toxicity of oil sands to early life stages of fathead minnows (Pimephales promelas). Environ. Toxicol. Chem. 23: 1709–1718. doi:10.1897/03-412. PMID:15230323.

CONRAD. 1998. Naphthenic acids background information: Discussion report. Canadian Oil Sands Network for Research and Development (CONRAD) Environmental Aquatics Technical Advisory Group (CEATAG), Edmonton, Alta.

Crowe, A.U., Han, B., Kermode, A.R., Bendell-Young, L.I., and Plant, A.L. 2001. Effects of oil sands effluent on cattail and clover: photosynthesis and the level of stress proteins. Environ. Pollut. 113: 311–322. doi:10.1016/S0269-7491(00)00187-1. PMID:11428139.

Crowe, A.U., Plant, A.L., and Kermode, A.R. 2002. Effects of an industrial effluent on plant colonization and on the germination and post-germinative growth of seeds of terrestrial and aquatic plant species. Environ. Pollut. 117: 179–189. doi:10.1016/S0269-7491(01)00131-2. PMID:11843534.

Cuddy, G., Farwell, K., and Wright, B. 2000. Empirical studies on the relationship between process water chemistry and oil sands processability. Problem Ores, 1st Extraction Fundamentals Seminar, Canadian Oil Sands Network for Research and Development (CONRAD), Fort McMurray, AB [online]. Available from http://www.conrad.ab.ca/seminars/problem_ores/Agenda.htm [cited 1 Feb 2006].

Dominski, M. 2007. Surface mined oil sand: tailings practices, performance, and projections. Alberta Energy and Utilities Board. *In* Proceedings of the 3rd International Heavy Oil Conference, March 5–7, 2007, Calgary, Alta. Alberta Energy and Utilities Board.

Farrell, A.P., Kennedy, C.J., and Kolok, A. 2004. Effects of wastewater from an oil-sand-refining operation on survival, hematology, gill histology, and swimming of fathead minnows. Can. J. Zool. 82: 1519–1527. doi:10.1139/z04-128.

FTFC. 1995. Advances in Oil Sands Tailings Research, Vol. II: Fine tailings and process water reclamation. Fine Tailings Fundamental Consortium, Alberta Department of Energy, Oil Sands and Research Division, Edmonton, Alta. pp. 2.1–2.52.

Golder Associates Limited. 2002. Oil sands regional aquatics monitoring program (RAMP) 2001. Vol. 1: Chemical and biological monitoring. Report prepared for the RAMP Steering Committee, Fort McMurray, Alta.

Government of British Columbia. 2000. Ambient water quality guidelines. Water, Air and Climate Branch, Environmental Protection Division, Ministry of the Environment, Victoria, BC.

Griffiths, M., Taylor, A., and Woynillowicz, D. 2006. Troubled waters, troubling trends: Technology and policy options to reduce water use in oil and oil sands development in Alberta. The Pembina Institute, Drayton Valley, Alta.

Gulley, J.R. 1992. Study of oil sands sludge reclamation under the tailings sludge abandonment research program. Final Report. Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada, Edmonton, Alta.

Gulley, J.R., and MacKinnon, M. 1993. Fine tails reclamation utilizing a wet landscape approach. *In* Proceedings of Oil Sands-Our Petroleum Future Conference, Fine Tailings, Fundamentals Consortium, Edmonton, Alta. pp. 1–24.

Hall, E.S., and Tollefson, E.L. 1979. Hydrocarbon removal from and upgrading of aqueous waste water from oil sands recovery operations. Report prepared for Alberta Environmental Research Trust, Alberta Environment, Edmonton, Alta.

Hao, C., Headley, J.V., Peru, K.M., Frank, R., Yang, P., and Solomon, K.R. 2005. Characterization and pattern recognition of oil-sand naphthenic acids using comprehensive two-dimensional gas chromatography/time-of-flight mass spectrometry. J. Chromatogr. A, **1067**: 277–284. doi:10.1016/j.chroma.2005.01.041. PMID:15844533.

Harmon, S.M., Chandler, G.T., and Specht, W.L. 2003. A comparison of the Daphnids, *Ceriodaphnia dubia* and *Daphnia ambigua*, for their utilization in routine toxicity testing in the southeastern United States. Arch. Environ. Contam. Toxicol. **45**: 79–85. doi:10.1007/s00244-002-0116-8. PMID:12948176.

Hart, P.R. 2002. Chemical removal of organic foulants from produced water recycled as steam. Soc. Petrol. Eng. J. SPE, **78966**: 1–7. doi:10.2118/78966-MS.

Headley, J.V., and McMartin, D.W. 2004. A review of the occurrence and fate of naphthenic acids in aquatic environments. J. Environ. Sci. Health A Tox. Hazard. Subst. Environ. Eng. **39**: 1989–2010. PMID:15332664.

Herman, D.C., Fedorak, P.M., MacKinnon, M.D., and Costerton, J.W. 1994. Biodegradation of naphthenic acids by microbial populations indigenous to oil sands tailings. Can. J. Microbiol. **40**: 467–477. PMID:8050066.

Holowenko, F.M., MacKinnon, M.D., and Fedorak, P.M. 2001. Naphthenic acids and surrogate naphthenic acids in methanogenic microcosms. Water Res. **35**: 2595–2606. doi:10.1016/S0043-1354(00)00558-3. PMID:11456157.

Holowenko, F.M., MacKinnon, M.D., and Fedorak, P.M. 2002. Characterization of naphthenic acids in oil sands wastewaters by gas chromatography-mass spectrometry. Water Res. **36**: 2843–2855. doi:10.1016/S0043-1354(01)00492-4. PMID:12146873.

Hrudey, S.E. 1975. Characterization of wastewaters from the Great Canadian Oil Sands bitumen extraction and upgading plant. Surveillance Report. Environment Canada, Environmental Protection Service, Ottawa, Ont.

Kasperski, K.L. 1992. A review of properties and treatment of oil sands tailings. AOSTRA J. Res. **8**: 11–53.

Kasperski, K.L. 2001. Extraction and water chemistry. Canadian Oil Sands Network for Research and Development (CONRAD) Oil Sands Extraction Fundamentals and Process Water Workshop, May 7–8, 2004 [online]. Available from http://www.conrad.ab.ca/seminars/process_water/Agenda.htm [cited 1 February 2006].

Kasperski, K.L. 2003. Review of research on aqueous extraction of bitumen from mined oil sands. Unpublished report. CANMET Energy Technology Centre, Natural Resources Canada, Devon, Alta.

Kasperski, K.L., and Mikula, R.J. 2003. Water treatment in oil sands: a novel approach to calcium control. *In* Proceedings of Corrosion 2003 Conference, San Diego, Calif. p. 7.

Leung, S.S., MacKinnon, M.D., and Smith, R.E.H. 2001. Aquatic reclamation in the Athabasca, Canada, oil sands: naphthenate and salt effects on phytoplankton communities. Environ. Toxicol. Chem. **20**: 1532–1543. doi:10.1897/1551-5028(2001)020<1532:ARITAC>2.0.CO;2. PMID:11434295.

Leung, S.S., MacKinnon, M.D., and Smith, R.E.H. 2003. The ecological effects of naphthenic acids and salts on phytoplankton from the Athabasca oil sands region. Aquat. Toxicol. **62**: 11–26. doi:10.1016/S0166-445X(02)00057-7. PMID:12413790.

Lintelmann, J., Katayama, A., Kurihara, N., Shore, L., and Wenzel, A. 2003. Endocrine disruptors in the environment. Pure Appl. Chem. **75**: 631–681. doi:10.1351/pac200375050631.

Lo, C.C., Brownlee, B.G., and Bunce, N.J. 2003. Electrospray-mass spectrometric analysis of reference carboxylic acids and Athabasca oil sands naphthenic acids. Anal. Chem. **75**: 6394–6400. doi:10.1021/ac030093d. PMID:16465694.

Lo, C.C., Brownlee, B.G., and Bunce, N.J. 2006. Mass spectrometric and toxicological assays of Athabasca oil sands naphthenic acids. Water Res. **40**: 655–664. doi:10.1016/j.watres.2005.12.008. PMID:16434073.

MacKinnon, M.D. 1981. A study of the chemical and physical properties of Syncrude's tailings pond, Mildred Lake, 1980. Environmental Research Report 1981–1. Syncrude Canada Ltd., Edmonton, Alta.

MacKinnon, M.D. 2001. Process-affected waters: impact of operating factors on recycle water quality [online]. Canadian Oil Sands Network for Research and Development (CONRAD) Oil Sands Extraction Fundamentals and Process Water Workshop, May 7–8, 2004. Available from http://www.conrad.ab.ca/seminars/process_water/Agenda.htm [cited 1 February 2005].

MacKinnon, M.D. 2004. Oil sands water quality issues: properties, treatment, and discharge options [online]. Canadian Oil Sands Network for Research and Development (CONRAD) Oil Sands Water Usage Workshop, February 24–25, 2005. Available from http://www.conrad.ab.ca/seminars/water_usage/2004/Agenda.htm [cited 1 February 2006].

MacKinnon, M.D., and Benson, W. 1985. Chemical treatment of tailings pond water: clarification and detoxification. Unpublished report. Syncrude Canada Research, Edmonton, Alta.

MacKinnon, M.D., and Boerger, H. 1986. Description of two treatment methods for detoxifying oil sands tailings pond water. Water Pollut. Res. J. Can. **21**: 496–512.

MacKinnon, M.D., and Retallack, J.T. 1981. Preliminary characterization and detoxification of tailings pond water at the Syncrude Canada Ltd Oil Sands Plant. *In* Land and Water Issues Related to Energy Development. Ann Arbor Science, Denver, Colo. pp. 185–210.

MacKinnon, M.D., and Sethi, A. 1993. A comparison of the physical and chemical properties of the tailings ponds at the Syncrude and Suncor oil sands plants. *In* Proceedings of Our Petroleum Future Conference, Alberta Oil Sands Technology and Research Authority (AOSTRA), Edmonton, Alta.

MacKinnon, M.D., Gulley, J.R., and Van Meer, T. 2001. Role of wetlands in attenuation of process-related components [online]. Environmental Research Group (EnRG) Research Symposium, May 3, 2001, Edmonton, Alta. Available from http://www.conrad.ab.ca/seminars/research_sym/Agenda.htm [cited 1 February 2006].

Madill, R.E., Orzechowski, M.T., Chen, G., Brownlee, B.G., and Bunce, N.J. 2001. Preliminary risk assessment of the wet landscape option for reclamation of oil sands mine tailings: bioassays with mature fine tailings pore water. Environ. Toxicol. **16**: 197–208. doi:10.1002/tox.1025. PMID:11409191.

Marr, J.B., Mohammed, M., MacKinnon, M., and Rogers, M. 1996.

Removal of naphthenic acid from water via pH adjustment, coagulation and sand filtration. *In* Proceedings of the International Water Conference, Engineer's Society of Western Pennsylvania, Pittsburgh, Pa. pp. 738–754.

Mount, D.R., Gulley, D.D., Hockett, J.R., Garrison, T.D., and Evans, J.M. 1997. Statistical models to predict the toxicity of major ions to *Ceriodaphnida dubia*, *Daphnia magna*, and *Pimephales promelas* (fathead minnows). Environ. Toxicol. Chem. **16**: 2009–2019. doi:10.1897/1551-5028(1997)016<2009:SMTPTT>2.3.CO;2.

National Energy Board. 2006. Canada's oil sands. Opportunities and challenges to 2015: An update. National Energy Board, Calgary, Alta.

Nelson, L.R., MacKinnon, M., and Gulley, J.R. 1993. Application of toxicity testing in the evaluation of reclamation options for oil sands fine tails. *In* Proceedings of Oil Sands- Our Petroleum Future Conference, Fine Tailings Fundamentals Consortium, Edmonton, Alta. pp. 1–11.

Nix, P.G. 1983. Detoxification of tailings pond top water. Report prepared for Suncor Energy Inc., Fort McMurray, Alta.

Nix, P.G., and Martin, R.W. 1992. Detoxification and reclamation of Suncor's oil sand tailings ponds. Environ. Toxicol. Water, **7**: 171–188. doi:10.1002/tox.2530070208.

Patrick, R., Cairns, J., and Scheier, A. 1968. The relative sensitivity of diatoms, snails, and fish to twenty common constituents of industrial wastes. Prog. Fish-Cult. **30**: 137–140.

Peachey, B. 2005. Strategic needs for energy related water use technologies. Water and the EnergyINet. Report prepared for the Alberta Energy Research Institute, Calgary, Alta.

Pollet, I., and Bendell-Young, L. 2000. Amphibians as indicators of wetland quality in wetlands formed from oil sands effluent. Environ. Toxicol. Chem. **19**: 2589–2597. doi:10.1897/1551-5028(2000)019<2589:AAIOWQ>2.3.CO;2.

Quagraine, E.K., Headley, J.V., and Peterson, H.G. 2005*a*. Is biodegradation of bitumen a source of recalcitrant naphthenic acid mixtures in oil sands tailing pond waters? J. Environ. Sci. Health A Tox. Hazard. Subst. Environ. Eng. **40**: 671–684. doi:10.1081/ESE-200046637.

Quagraine, E.K., Peterson, H.G., and Headley, J.V. 2005*b*. In situ bioremediation of naphthenic acids contaminated tailing pond wates in the Athabasca Oil Sands Region- demonstrated field studies and plausible options: a review. J. Environ. Sci. Health A Tox. Hazard. Subst. Environ. Eng. **40**: 685–722. doi:10.1081/ESE-200046649.

Rogers, M.E. 2004. Issues with using process-affected water (scaling, corrosion and fouling) [online]. Canadian Oil Sands Network for Research and Development (CONRAD) Water Usage Workshop, Feb. 24–25, Fort McMurray, Alta. Available from http://www.conrad.ab.ca/seminars/water_usage/2004 [cited 1 February 06].

Rogers, V.V., Wickstrom, M., Liber, K., and MacKinnon, M.D. 2002*a*. Acute and subchronic mammalian toxicity of naphthenic acids from oil sands tailings. Toxicol. Sci. **66**: 347–355. doi:10.1093/toxsci/66.2.347. PMID:11896302.

Rogers, V.V., Liber, K., and MacKinnon, M.D. 2002*b*. Isolation and characterization of naphthenic acids from Athabasca oil sands tailings pond water. Chemosphere, **48**: 519–527. doi:10.1016/S0045-6535(02)00133-9. PMID:12146630.

Rose, D., and Rideout, B. 2001. Antiscalant use at Suncor Energy Inc. [online]. CONRAD Oil Sands Process Water Workshop, May 7–8, Fort McMurray, AB. Available from http://www.conrad.ab.ca/seminars/process_water/Agenda.htm [cited 1 February 2006].

Sawatsky, L. 2004. Water Supply Security for the oil sands mines by upstream offsite storage [online]. Canadian Oil Sands Network for Research and Development (CONRAD) Oil Sands Water Usage Workshop, Feb. 24–25, Fort McMurray, Alta. Available from http://www.conrad.ab.ca/seminars/water_usage/2004/Water_supply_security_for_oil_sands_mines_Sawatsky.pdf [cited 1 February 2006].

Schramm, L.L., Smith, R.G., and Stone, J.A. 1985. On the processibility of mixtures of oil sands. AOSTRA J. Res. **1**: 147–161.

Scott, J.D., Dusseault, M.B., and Carrier, W.D., III. 1985. Behaviour of the clay/bitumen/water sludge system from oil sands extraction plants. J. Appl. Clay Sci. **1**: 207–218. doi:10.1016/0169-1317(85)90574-5.

Shell Canada. 2005*a*. Application for the approval of the Muskeg River mine expansion project. Shell Canada Ltd., Calgary, Alta.

Shell Canada. 2005*b*. The Athabasca Oil Sands Project. 2004 Sustainability Report [online]. Available from http://www.shell.com/static//ca-en/downloads/about_shell/what_we_do/aosp_sd_report.pdf [cited 1 February 2006].

Shell Canada. 2007. 2006 Sustainable Development Report [online]. Available from http://www.shell.com/static//ca-en/downloads/society_environment/sd06.pdf [cited 1 July 2007].

Siwik, P.L., Van Meer, T., MacKinnon, M.D., and Paszkowski, C.A. 2000. Growth of fathead minnows in oilsand-processed wastewater in laboratory and field. Environ. Toxicol. Chem. **19**: 1837–1845. doi:10.1897/1551-5028(2000)019<1837:GOFMIO>2.3.CO;2.

Smits, J.E., Wayland, M.E., Miller, M.J., Liber, K., and Trudeau, S. 2000. Reproductive, immune, and physiological end points in tree swallows on reclaimed oil sands mine sites. Environ. Toxicol. Chem. **19**: 2951–2960. doi:10.1897/1551-5028(2000)019<2951:RIAPEP>2.0.CO;2.

SETAC. 2004. Whole effluent toxicity testing: Ion imbalance. [online]. Society of Environmental Toxicology and Chemistry, Pensacola, Fla. Available from http://www.setac.org/htdocs/files/TIP-Ion.pdf [cited 1 February 2006].

Strosher, M.T., and Peake, E. 1978. Characterization of organic constituents in waters and wastewaters of the Athabasca Oil Sands mining area. Report No. 20. Alberta Oil Sands Environmental Research Program (AOSERP), Alberta Environment, Edmonton, Alta.

Suncor Energy Incorporated. 2005*a*. Performance indicators [online]. Available from http://www.suncor.com/data/1/rec_docs/618_Indicators.pdf [cited 1 February 2006].

Suncor Energy Incorporated. 2005*b*. Suncor Energy 2005 Report on sustainability [online]. Available from http://www.suncor.com/data/1/rec_docs/616_Suncor%20SD%20Report_2005%20.pdf [cited 1 February 2006].

Syncrude Canada Limited. 2005. Syncrude Canada Limited 2004 sustainability report [online]. Available from http://sustainability.syncrude.ca/sustainability2004/download/SyncrudeSD2004.pdf [cited 1 February 2006].

Tetreault, G.R., McMaster, M.E., Dixon, D.G., and Parrott, J.L. 2003. Using reproductive endpoints in small forage fish species to evaluate the effects of Athabasca Oil Sands activities. Environ. Toxicol. Chem. **22**: 2775–2782. doi:10.1897/03-7. PMID:14587921.

USEPA. 1999. National recommended water quality criteria- Correction. Report EPA 822-Z-99-001. Office of Water 4304, United States Environmental Protection Agency, Wash.

USEPA. 2006. Water quality standards database [online]. Available from http://oaspub.epa.gov/wqsdatabase/wqsi_epa_criteria.rep_parameter [cited 1 October 2006].

van den Heuvel, M.R., Power, M., MacKinnon, M.D., and Dixon, D.G. 1999*a*. Effects of oil sands related aquatic reclamation on yellow perch (*Perca flavescens*). II. Chemical and biochemical indicators of exposure to oil sands related waters. Can. J. Fish. Aquat. Sci. **56**: 1226–1233. doi:10.1139/cjfas-56-7-1226.

van den Heuvel, M.R., Power, M., MacKinnon, M.D., Van Meer, T., Dobson, E.P., and Dixon, D.G. 1999*b*. Effects of oil sands related aquatic reclamation on yellow perch (*Perca flavescens*). I. Water quality characteristics and yellow perch physiological and population responses. Can. J. Fish. Aquat. Sci. **56**: 1213–1225. doi:10.1139/cjfas-56-7-1213.

van den Heuvel, M.R., Power, M., Richards, J., MacKinnon, M., and Dixon, D.G. 2000. Disease and Gill lesions in yellow perch (*Perca flavescens*) exposed to oil sands mining-associated waters. Ecotoxicol. Environ. Saf. **46**: 334–341. PMID:10903831.

Verbeek, A., McKay, W., and MacKinnon, M. 1993. Isolation and characterization of the acutely toxic compounds in oil sands process water from Syncrude and Suncor. *In* Proceddings of Oil Sands- Our Petroleum Future Conference, Fine Tails Fundamentals Consortium, Edmonton, Alta. pp. F10–1-F10–11.

Zaidi, A., and Constable, T. 1994. Produced water treatment design manual. Wastewater Technology Centre, Burlington, Ont.

Zalewski, W., and Bulkowski, P. 1998. Lithium silicate scale in oilfield steam generation. J. Can. Petrol. Technol. **37**: 51–55.

Appendix XI:

“Naphthenic Acids in Athabasca Oil Sands Tailings Waters Are Less Biodegradable than Commercial Naphthenic Acids,” Angela C. Scott et al, Environ. Sci Technol. 2005, 39, 83888-8394.

Naphthenic Acids in Athabasca Oil Sands Tailings Waters Are Less Biodegradable than Commercial Naphthenic Acids

ANGELA C. SCOTT,[†]
MICHAEL D. MACKINNON,[‡] AND
PHILLIP M. FEDORAK*,[†]

Department of Biological Sciences, University of Alberta, Edmonton, Alberta, T6G 2E9 Canada, and Syncrude Canada Ltd., Edmonton Research Centre, 9421-17 Avenue, Edmonton, Alberta, T6N 1H4 Canada

Naphthenic acids (NAs) are natural constituents in many petroleum sources, including bitumen in the oil sands of Northern Alberta, Canada. Bitumen extraction processes produce tailings waters that cannot be discharged to the environment because NAs are acutely toxic to aquatic species. However, aerobic biodegradation reduces the toxic character of NAs. In this study, four commercial NAs and the NAs in two oil sands tailings waters were characterized by gas chromatography–mass spectrometry. These NAs were also incubated with microorganisms in the tailings waters under aerobic, laboratory conditions. The NAs in the commercial preparations had lower molecular masses than the NAs in the tailings waters. The commercial NAs were biodegraded within 14 days, but only about 25% of the NAs native to the tailings waters were removed after 40–49 days. These results show that low molecular mass NAs ($C \leq 17$) are more readily biodegraded than high molecular mass NAs ($C \geq 18$). Moreover, the results indicate that biodegradation studies using commercial NAs alone will not accurately reflect the potential biodegradability of NAs in the oil sands tailings waters.

Introduction

Naphthenic acids (NAs) are complex mixtures of predominately alkyl-substituted cycloaliphatic carboxylic acids (containing cyclopentane and cyclohexane rings) and small amounts of acyclic acids (*1*). They are described by the general chemical formula $C_nH_{2n+Z}O_2$, where n indicates the carbon number and Z is zero or a negative, even integer that specifies the hydrogen deficiency resulting from ring formation. Although simple saturated fatty acids found in biological membranes fit this formula for $Z = 0$, these acids are very susceptible to biodegradation, so they would not persist as NAs. Some possible NAs structures are given elsewhere (*2*).

NAs occur naturally in a variety of petroleums (*1, 3–10*) and are thought to have originated from aerobic microbial degradation of petroleum hydrocarbons (*11–13*). NAs are also found in Athabasca oil sands ores (*14, 15*). Commercial NA preparations, obtained via extraction of petroleum distillates (*1, 16*), are used as textile and wood preservatives, emulsifiers, surfactants, paint driers, and adhesion promoters in the manufacture of tires (*1*).

The complexity of NA mixtures provides a major challenge in the development of suitable analytical methods for them. Separation and identification of individual compounds have not been achieved, and most studies refer to NAs as a group. Accepted quantification methods include Fourier transform infrared (FTIR) spectroscopy (*17–19*) and high-performance liquid chromatography (HPLC) (*19, 20*). Characterization of NAs by mass spectrometry (MS) (*5–7, 21–24*) and gas chromatography–electron impact mass spectrometry (GC-MS) (*18, 25, 26*) can provide qualitative data useful for comparing NAs from different sources. The total ion chromatogram (TIC) of a NA preparation is an unresolved "hump" (*25, 27*). Holowenko et al. (*26*) presented GC-MS data by plotting relative ion intensities as a function of n and Z values. In this case, only ions having mass-to-charge ratios consistent with plausible NA structures were included. The resulting three-dimensional bar graphs illustrate the distribution of compounds in a particular NA mixture.

Syncrude Canada Ltd. and Suncor Energy Inc. (Fort McMurray, Alberta, Canada) employ a caustic hot water extraction method for the separation of bitumen from oil sands ore (*16*). During this process, the release of NAs from the bitumen into the aqueous phase is enhanced (*16, 28*). The resulting process water is transported to on-site ponds where tailings water (TW) is retained and a portion of the released waters is recycled back to the plant (*16, 29*). Storage of process-affected waters is part of the "zero discharge" policy specified in the licenses of operating companies. Currently, there is more than 600×10^6 m^3 of process-affected waters stored at Syncrude's Mildred Lake site.

NAs are acutely toxic to a range of organisms (*30, 31*). MacKinnon and Boerger (*28*) demonstrated that with chemical and microbiological treatment approaches, the toxicity of TW could be reduced, presumably by removal or biodegradation of NAs, although this was not shown directly. Herman et al. (*32*) followed biodegradation of NAs extracted from Mildred Lake Settling Basin (Syncrude) in laboratory cultures and also observed detoxification, as determined by the Microtox method. Clemente et al. (*2*) used enrichments of NA-degrading microorganisms to biodegrade commercially available NAs (Kodak Salts and Merichem). Microtox analyses of culture supernatants revealed a reduction in toxicity after less than 4 weeks of incubation (*2*).

On the basis of the findings of previous studies, it was hypothesized that NAs in the oil sands TW would be readily biodegraded. However, repeated attempts to extensively biodegrade NAs from Syncrude, Suncor, and Albian Sands Energy Inc. were unsuccessful using laboratory cultures of TW bacteria (Clemente, Scott, Fedorak, unpublished results).

Comparison of three-dimensional plots from GC-MS analyses of some commercial NAs (*2, 27*) with those of NAs in oil sands TW (*26*) clearly shows differences in the relative distributions of high and low molecular mass acids; commercial NAs tend to have n from about 7 to 17, whereas NAs in TW have a broader range of n from about 7 to 28. There are also differences in the distribution of Z families within a group of acids sharing the same n. These dissimilarities may account for the differing biodegradation rates, and have prompted the current study in which four commercial NAs preparations were individually added to TW from two tailings ponds in order to follow the biodegradation patterns resulting from the activities of microbial communities indigenous to these TWs. Biodegradation was monitored by measuring the

* Corresponding author phone: (780) 492-3670; fax: (780) 492-9234; e-mail: phil.fedorak@ualberta.ca.
[†] University of Alberta.
[‡] Syncrude Canada Ltd.

10.1021/es051003k CCC: $30.25

Published on Web 09/30/2005

decrease in NA concentrations by HPLC and by following changes in the NA profile of each mixture using GC-MS.

Experimental Section

Naphthenic Acids. Kodak naphthenic acids ("Kodak acids") (lot 115755A) and Kodak naphthenic acids sodium salt ("Kodak salts") (lot B14C) were purchased from The Eastman Kodak Company (Rochester, NY). The sodium content of the salt preparation was 9 wt % (*20*). Merichem refined naphthenic acids ("Merichem acids") were provided by Merichem Chemicals and Refinery Services LLC (Houston, TX). Fluka naphthenic acids ("Fluka acids") were obtained from Fluka Chemie (Buchs, Switzerland). Total acid number (TAN) for each commercial preparation was determined at the National Centre for Upgrading Technology (Devon, Alberta, Canada) according to American Standard Test Method D664 (*33*). The Kodak salts were converted to their acid form prior to submission for TAN analysis.

Tailings Waters. Samples of TW from active settling basins were provided by Syncrude Canada Ltd. and Suncor Energy Inc. in June 2004. Syncrude TW was collected from the clarified water zone of its West In Pit, whereas the Suncor TW was sampled from its Consolidated Tailings Pond.

Incubation Methods. Biodegradation experiments were conducted to monitor the loss of NAs from viable incubations and changes in the NAs composition during incubation for a total of 40 days (Syncrude TW experiment) or 49 days (Suncor TW experiment). Microbial communities indigenous to TW were the sources of microorganisms used in these experiments.

Individual stock solutions of the four commercial NA mixtures were prepared at approximately 1 g L^{-1} in dilute NaOH. Solution pH was adjusted to between 10 and 11, to dissolve the NAs as sodium naphthenates.

All incubations had a final liquid volume of 200 mL in 500-mL Erlenmeyer flasks. Incubations of each combination of the TW samples and the four commercial NAs were prepared in triplicate with 180 mL of well-mixed Syncrude or Suncor TW plus 10 mL stock NA solution. Each incubation was also supplemented with 10 mL modified Bushnell−Haas medium (*34*) to ensure nitrogen and phosphorus were not limiting nutrients. The initial concentrations of N and P were 1 and 0.7 mM, respectively, and the total NAs concentration ranged from 30 to 100 mg L^{-1}.

Four sets of positive control flasks (one for each commercial preparation) containing only commercial NAs were prepared in triplicate by adding 20 mL stock NA solution to 170 mL sterile MilliQ water. An inoculum for each of these flasks was prepared by centrifuging 200 mL TW at 12 000*g* for 15 min, discarding the supernatant, and resuspending the resulting pellet in 10 mL modified Bushnell−Haas medium. The entire 10-mL suspension was then transferred to a positive control flask, providing nitrogen and phosphorus as well as viable microorganisms in approximately the same proportion as incubations set up directly in TW. Negative controls contained 20 mL filter-sterilized (using Millex-GS, 0.22 μm, Millipore, Bedford, MA) stock NAs solution and 180 mL sterile MilliQ water. Filter-sterilized TWs could not be used for this purpose because they contain NAs.

Viable and sterile controls, with either Syncrude or Suncor TW as the only source of NAs, were also prepared in triplicate. In this case, 190 mL TW and 10 mL medium were added to 500-mL Erlenmeyer flasks. TW used for the sterile controls was heat-killed by autoclaving at 121°C, 15 psi, twice for 20 min, with 24 h between treatments.

Incubations were carried out under aerobic conditions at room temperature (approximately 20°C) on a shaker at 200 rpm. Samples were taken from the incubations and stored at −20 or 4 °C prior to analysis by HPLC or GC-MS.

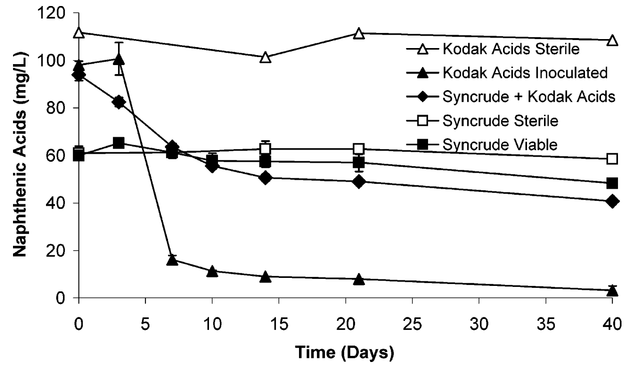


FIGURE 1. Aerobic biodegradation of Kodak acids and Syncrude NAs in laboratory incubations of TW bacteria. NA concentrations in Syncrude incubations and controls were determined from a Kodak acids calibration curve. Error bars (often smaller than the symbols) represent one standard deviation from the average of triplicate incubations. Minimum detection limit of the HPLC method is ~5 mg L^{-1} (*19*).

Analysis of Incubation Supernatants. NAs quantification was carried out using the derivatization protocol and HPLC method described earlier (*19*). Individual calibration curves were prepared with each commercial NAs preparation, and the specific slopes and intercepts from each calibration curve were used to calculate the NAs concentration in samples containing the corresponding commercial NAs.

Prior to analysis by GC-MS, NAs were extracted from incubation supernatants and derivatized using previously published methods (*2*). A GC-MS protocol (*26*) was used to generate TICs and average mass spectra of the unresolved "humps" of NAs.

Results

Incubations with Kodak Acids and Syncrude TW. Figure 1 summarizes the NAs concentrations in various incubations with Kodak acids and Syncrude TW. These concentrations were determined by HPLC using Kodak acids to prepare the calibration curves. The Kodak acids were readily biodegraded by bacteria in the Syncrude TW. For example, when the Kodak acids were the only source of NAs in the incubations, the concentration was rapidly depleted between days 4 and 7 (Figure 1). Sterile controls containing only the Kodak acids showed no change in NAs concentration after 40 days (Figure 1).

In contrast, the NAs that occurred naturally in the Syncrude TW proved to be more recalcitrant than the commercial NAs. The concentrations of these native NAs in the viable incubations remained almost equivalent to those in the sterile control (Figure 1). At the end of the 40-day incubation time, NAs concentrations in the viable incubations with Syncrude TW were about 20% less than in the sterile control with Syncrude TW. In another set of incubations, Kodak acids were added to the Syncrude TW to give a total initial NAs concentration of 94 mg L^{-1}. Within 7 days of incubation, the NAs concentration was depleted to 64 mg L^{-1}: the concentration contributed by the Syncrude TW (Figure 1). By the end of the 40-day incubation period, the NAs concentration in these incubations was about 48 mg L^{-1} or 17% lower than in the sterile control with Syncrude TW. The results in Figure 1 suggest that the NAs in the Syncrude TW were more resistant to biodegradation than commercial NAs.

From the data in Figure 1, it appeared that, in the incubations with Kodak acids added to Syncrude TW, most of the commercial NAs were degraded leaving mainly those that originated in the TW. To test this hypothesis, extracts of the Kodak acids, Syncrude TW, and an incubation

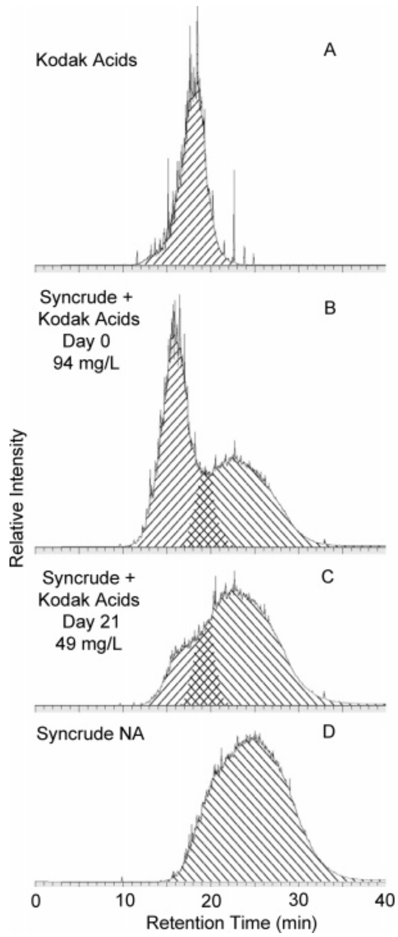


FIGURE 2. TICs for (A) Kodak acids, (B) Kodak acids plus Syncrude NAs on day 0, (C) this mixture on day 21, and (D) Syncrude NAs. Crosshatching illustrates possible overlapping areas of the two NA "humps". Average NA concentration in incubation supernatants is given for both time-points.

containing Syncrude TW amended with Kodak acids were derivatized and analyzed by GC-MS. The "humps" that were observed in TICs of these samples were quite revealing and are shown in Figure 2. The TICs for Kodak acids (Figure 2A) and Syncrude NAs (Figure 2D) were clearly different. The shape of their respective "humps" and the retention times over which they occurred were visibly distinct. The Kodak acids sample eluted from the GC column with a shorter retention time than the NAs extracted from Syncrude TW. Using this same GC-MS method, Clemente and Fedorak (*27*) demonstrated that, in general, lower molecular mass NAs eluted earlier than higher molecular mass NAs. Thus, the Kodak acids mixture has a high proportion of low molecular mass NAs. The Kodak acids hump was also narrower, suggesting that the composition of NAs in this mixture is less diverse than the NAs from the Syncrude TW, which gave a wider hump.

The two middle panels of Figure 2 show the TICs of extracts from incubations that contained Syncrude TW supplemented with Kodak acids. Figure 2B is the analysis of the extract taken just after the incubation was started. It showed the presence of two overlapping "humps", corresponding to Kodak acids and NAs from the Syncrude TW. By day 21, the Kodak acids hump had almost completely disappeared (Figure 2C). This was attributed to biodegradation because a decrease in the NAs concentrations also occurred between these two times (Figure 1). The hump that remained at day 21 (Figure 2C) more closely resembled the hump from NAs in the Syncrude TW (Figure 2D) than the hump from the Kodak acids (Figure 2A). These results, like those from the HPLC analyses (Figure 1), are consistent with the preferential biodegradation of the commercial NAs.

Data used to generate three-dimensional plots, as in (*26*), (not shown) indicated a shift in the NAs composition during incubation. For example, at time zero in incubation with a mixture of Syncrude NAs and Kodak acids, 65% of the ions corresponded to NAs with $n \leq 17$. On day 7, the proportion of ions in this n range was 51%, and on day 21 the proportion had decreased to 44%. These results corroborate the TICs in Figure 2B and 2C showing the preferential removal of lower molecular mass NAs.

Incubations with Kodak Acids and Suncor TW. Microorganisms from the Suncor TW were able to degrade the Kodak samples. Changes in the NAs concentrations (determined by HPLC with Kodak acids used for the calibration curves) followed a pattern similar to that in Figure 1. With only the Kodak acids present, the NAs concentration decreased quickly from 81 to 11 mg L^{-1} during the first 10 days, and then remained essentially constant over the rest of the 49-day incubation.

Biodegradation of NAs in the incubations of Suncor TW supplemented with Kodak acids was evident by the decrease in NA concentrations, similar to the trend observed in the experiment with Syncrude TW supplemented with Kodak acids (Figure 1). With the supplemented Suncor TW, the initial NAs concentration (68 mg L^{-1}) decreased rapidly during the first 14 days of incubation when it reached the concentrations (37 mg L^{-1}) measured in the sterile control and viable incubation that contained only the Suncor TW. By day 49, the concentration of residual NAs in the Kodak acid-supplemented Suncor TW incubations had dropped to about 26 mg L^{-1}, which was 30% less than that in the sterile control that contained only Suncor NAs.

Initially, there was little change in the concentration of NAs in the incubations that contained only the Suncor NAs. However, after 49 days, the concentration in these incubations had decreased to approximately 25% less than that in the sterile control, which was similar to the extent of biodegradation in the incubations with Suncor TW amended with Kodak acids. Overall, the results from the HPLC analyses suggested that the NAs in the Suncor TW were less susceptible to biodegradation than the Kodak acids.

Figure 3 compares the TICs from GC-MS analyses of incubation supernatants. The "humps" shown in Figure 3A and 3D are from the Kodak acids and the NAs in the Suncor TW, respectively. The day-zero sample from the incubation containing Suncor TW amended with Kodak acids (Figure 3B) shows a combined hump composed of the NAs shown in Figure 3A and 3D. After 49 days of incubation, the NAs concentration had decreased to about one-third of the original concentration, and the composition had changed, as evident by the TIC (Figure 3C). The hump with the shorter retention time (corresponding to the Kodak acids) disappeared, and the residual hump had a different shape than the original Suncor NAs hump (Figure 3D), particularly in the material that eluted with retention times between 10 and 25 min. These losses of the early eluting NAs are consistent with the preferential biodegradation of the lower molecular mass NAs.

Analyses of the data from three-dimensional plots (Figure 4) illustrate the preferential removal of the lower molecular mass NAs over the 49-day incubation time. For example, at time zero, 68% of the ions corresponded to NAs with $n \leq 17$. On day 14, 53% of the ions corresponded to NAs with $n \leq 17$, and on day 49, 47% of the ions corresponded to NAs with $n \leq 17$.

Results from Incubations with Other Commercial NAs. During the early stages of these experiments, the Kodak acids were used to prepare the calibration curves for all of the

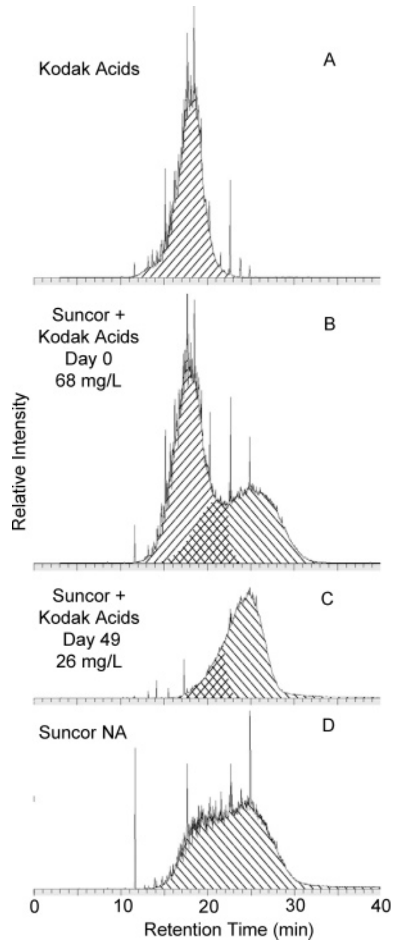


FIGURE 3. TICs for (A) Kodak acids, (B) Kodak acids plus Suncor NAs on day 0, (C) this mixture on day 21, and (D) and Suncor NAs. Crosshatching illustrates possible overlapping areas of the two NA humps. Average NA concentration in incubation supernatants is given for both time-points.

incubations, regardless of which commercial NAs preparation was added to the TW. However, this gave unreliable results. For example, when an incubation of Syncrude TW was amended with 50 mg Fluka acids L^{-1}, the results from the calibration curve prepared with Kodak acids showed only 8 mg NAs L^{-1} above that in the TW. This discrepancy was rectified by preparing individual calibrations curves with each of the four commercial NAs preparations and using the appropriate calibration curve for analyses of incubations amended with the corresponding commercial NAs. Table 1 summarizes typical parameters from four calibration curves.

The Kodak acids gave a calibration curve with the highest slope, which was nearly double the slope of the Fluka preparation (Table 1). It was presumed that the slopes would vary with the TAN of the NAs preparations because the derivatizing reagent reacts with the carboxylic acid moiety. However, there is no correlation between TAN values and the slopes of the calibration curves (Table 1). The reason for the different slopes remains unknown. The consequence of using the four different calibration curves was that concentrations of NAs measured in the TW varied depending upon which commercial NAs preparation was used (Table 1). For example, the concentrations of NAs in the Syncrude TW ranged from 60 to 97 mg L^{-1}.

Despite the difficulties determining the true concentrations of NAs in these incubations, the HPLC method was useful for following changes in NAs concentrations over time to determine whether the commercial preparations were more susceptible to biodegradation than NAs in the oil sands

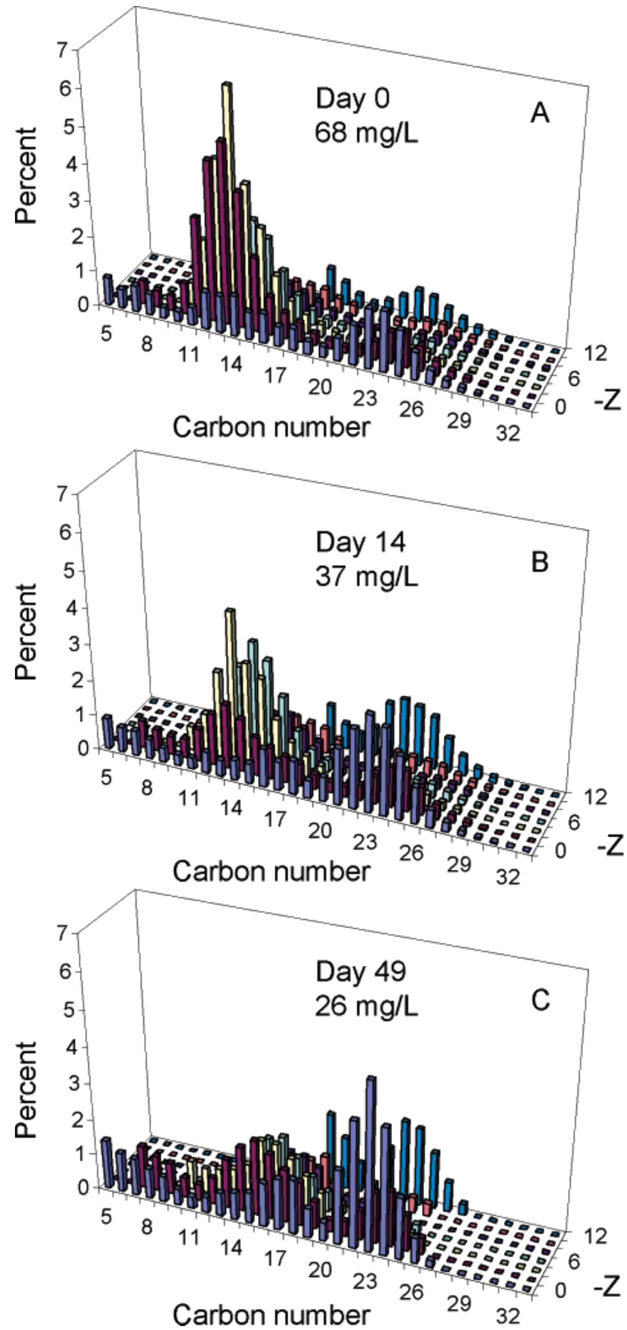


FIGURE 4. Changes in the distribution of residual acids recovered from incubations grown on Suncor NAs plus Kodak acids. Results are from GC-MS analyses of samples taken after (A) 0, (B) 14, and (C) 49 days of incubation. The sum of all the bars in each panel is 100%. Average NA is concentration is given for each time.

TW. Incubations containing each of the commercial NAs alone and in combination with the NAs in the two TW samples were established and monitored for NAs concentrations. Results from these eight incubations are summarized in Table 2. Plotting the NAs concentrations over time resulted in graphs that had the same general shape as Figure 1. For example, Figure 1 shows that after 10 days of incubation there was 88% removal of the Kodak acids when they were the only NAs in the incubations. This figure also shows that the concentration of NAs in incubations with Syncrude TW amended with Kodak acids reached the concentration in the Syncrude TW sterile control after 7 days incubation. The values “88%” and “7 days” are the entries in the first line of Table 2.

TABLE 1. Total Acid Number (TAN) Values, Parameters from Typical Calibration Curves of Four Different NA Standards, and NA Concentrations in Tailings Water Determined with the Different NA Standards

NA standard	TAN (mg KOH g^{-1})	slope[a] (mAU mg^{-1} L^{-1})	*Y*-intercept[c] (mAU)	R^2	NA concentrations[b] (mg L^{-1}) Syncrude TW	Suncor TW
Kodak acids	264	12.7	212	0.9997	60 ± 1	35 ± 2
Merichem acids	268	10.4	243	0.9982	73 ± 2	42 ± 2
Kodak salts	195	9.1	234	0.9993	69 ± 1	41 ± 2
Fluka acids	235	6.7	225	0.9959	97 ± 4	61 ± 3

[a] mAU = milliabsorbance units; mg L^{-1} refers to the concentration of naphthenic acids. [b] Average of triplicates, ± one standard deviation. [c] *Y*-intercepts were similar because the composition of reagent blanks was identical for each set of calibration standards.

TABLE 2. Summary of the Biodegradation Studies with Two TW Samples and Four Commercial NA Preparations

TW	commercial NAs	commercial NAs alone: percent removal after 10 days	commercial NAs added to TW: time to reach concentration equivalent to TW sterile control (days)
Syncrude	Kodak acids	88	7
	Merichem acids	90	7
	Fluka acids	81	14
	Kodak salts	69	21
Suncor	Kodak acids	87	14
	Merichem acids	93	7
	Fluka acids	87	10
	Kodak salts	77	21

Each of the commercial NAs preparations was biodegraded by microorganisms from the two TW samples. After 10 days of incubation, over 80% of the Kodak acids, Merichem acids, and Fluka acids was degraded when they were the only source of NAs in the incubations (Table 2). The Kodak salts were degraded more slowly than the other three commercial preparations, with less than 80% being degraded after 10 days of incubation. Similarly, the Kodak-salts-amended incubations required 21 days of incubation before the NAs concentrations decreased to those in the sterile controls with TW water. Incubation times of ≤14 days were required for the same decrease in incubations that were amended with the other commercial NAs (Table 2). On the basis of the results from HPLC analyses, all four commercial NAs preparations were more readily biodegraded than the NAs in the two TW samples.

Samples from each of the incubations amended with commercial NAs were extracted and analyzed by GC-MS. The time zero samples all yielded TICs that were similar to those of Figures 2B and 3B. That is, two "humps" were apparent: one that eluted early, composed of the commercial NAs, and one that eluted late, corresponding to the NAs in the TW. Extended incubations resulted in the loss of the early hump, as illustrated by Figures 2C and 3C. All of these results indicated that the NAs in the TW samples were more persistent than those in the commercial preparations.

Discussion

The various concentrations of NAs in a given TW sample determined using different commercial NAs for calibration curves (Table 1) demonstrate the difficulties associated with the analysis of NAs. During the development of the HPLC method, Clemente et al. (*20*) did not observe differences in slopes of calibration curves prepared with Kodak acids and Merichem acids as standards. Yen et al. (*19*) improved this HPLC method, but they did not determine the slopes of calibration curves with various commercial NAs preparations. The results in Table 1 are the first evaluation showing how the measured concentrations of NAs in TW samples determined using the HPLC method can be affected by the commercial NAs preparation chosen for the calibration curve. The reason for this difference is yet to be determined, but the slopes of the calibration curves are not related to the TAN values (Table 1) of the NAs preparations. The oil sands industry standard method for measuring NAs concentration in water samples uses a FTIR spectroscopy method (*17*) with Kodak acids as the calibration standard. Using the same calibration standard, Yen et al. (*19*) showed that the HPLC method was in good agreement with the FTIR method.

GC analyses of complex mixtures often produce "humps" in the chromatograms, commonly known as unresolved complex mixtures (*35*−*38*). Little detailed information can be obtained from these "humps", but they can be quite different with respect to their shape and retention times. For example, Frysinger et al. (*38*) presented two GC chromatograms of organic materials extracted from different marine sediments. The "humps" in both chromatograms were distinctly different from each other. Likewise, the TICs of NAs presented in Figures 2 and 3 show distinctly different shapes and retention times. These TICs were used to glean information about the NAs extracted from our various laboratory incubations.

On the basis of GC-MS analyses of Syncrude TW samples that had aged for various lengths of time in pits that receive no fresh input of TW, Holowenko et al. (*26*) hypothesized that NAs with $n \leq 21$ are more susceptible to biodegradation than those with $n \geq 22$. Figures 2 and 3 illustrate that the NAs with the shorter retention times and lower molecular masses are biodegraded more rapidly than those with the longer retention times.

Using three-dimensional plots to summarize the data from the GC-MS can be a convenient method to observe differences between NAs preparations (*26*). For example, the NAs in oil sands TW are typically composed of a wide range of molecular mass, with n of 5−28 (*26*) or even 40 (*23*). In contrast, commercial preparations are often composed of mainly low molecular mass NAs, with n of about 10−14 (*2, 14*). This narrow range of molecular mass in the commercial NAs depends on the boiling range of the petroleum fractions from which the NAs are recovered. Kodak salts are somewhat different than the other commercial NAs because the majority (∼80%) of NAs in these salts fall in the n 14−21 range. On the basis of the molecular mass distributions from GC-MS analyses, the Kodak salts more closely resemble the NAs in Syncrude TW (*14*) and Suncor NAs (data collected during this study) than do any of the other three commercial preparations.

The data in Table 2 show that, among the commercial preparations, Kodak salts were most resistant to biodegradation by microorganisms in the TW from Syncrude and Suncor. This is consistent with the fact that the Kodak salts contain higher molecular mass NAs than the other three commercial preparations. In addition, the Kodak salts contain a high proportion of multi-ring acids, similar to the NAs in the TWs. The proportion of ions that correspond to 3-, 4-, and 5-ring acids ($Z = -6$, -8, and -10, respectively) comprises 23% of the ions detected in the GC-MS analysis of these salts, and the proportions of 3- to 5-ring acids in the Syncrude and Suncor NAs are 37% and 35%, respectively. By comparison, the proportions of ions that correspond to 3- to 5-ring acids in the Kodak, Merichem, and Fluka acids are only 9%, 8%, and 16% of the total ions, respectively. These comparisons suggest that the structures of the NAs in the Kodak salts are more complex than those in the other three commercial preparations.

In contrast to the data presented in Table 2 for the Kodak salts, Clemente et al. (*2*) showed that the Kodak salts were nearly completely removed from laboratory incubations within only 10 days. However, Clemente et al. (*2*) used an enrichment culture that had been maintained for several months by repeated transfer to fresh medium with Kodak salts, increasing the biodegradative capability of the culture. No enrichment procedure was used in the current study. Instead, the commercial preparations were inoculated on day 0 with a suspension of microorganisms taken directly from the TW samples.

In one study, carboxylic acid fractions were separated from 33 crude oils, including some crudes that were biodegraded and some that were not biodegraded (*12*). In general, the greater the degree of biodegradation, the higher the concentration of carboxylic acids in the crude oils. Bitumen in the Athabasca oil sands deposit is known to be the residue of conventional crude that has undergone extensive biodegradation (*39*). Thus, the presence of NAs in the oil sands is expected. Recently, Clemente (*15*) reported that the average NAs concentration in seven oil sands ore samples from Syncrude was 200 mg kg^{-1} of ore. Presumably, as NAs in the oil sands "incubated" over geological time, those acids that were most susceptible to biodegradation would have been degraded, leaving mainly the recalcitrant NAs in the ore. These would be released during the alkaline, hot water extraction process used to recover the bitumen (*16*), and the recalcitrant NAs would remain in the TW.

In laboratory studies, Watson et al. (*13*) subjected a weathered, light Arabian crude oil to microbial degradation under aerobic conditions for up to 80 days. They observed that, after extensive biodegradation of the crude oil, there was an increase in the concentrations of branched and cyclic carboxylic acids with $n > 20$. These eluted from the GC as a hump, and they were considered to be NAs. These acids resisted further biodegradation for the duration of the experiment. The observed persistence of the high molecular mass NAs in our incubations is consistent with the findings of Watson et al. (*13*).

Several biodegradation studies (*2, 32, 40*) have used commercial NAs preparations (mainly Kodak acids, Kodak salts, and Merichem acids) as surrogates for NAs in TW. At the time that Herman et al. (*32*) did their biodegradation studies, the GC-MS method used in the current study was not available for monitoring changes caused by microbial metabolism. Microbial activity was monitored by measuring microbial respiration and the release of CO_2 from the NAs (or other organic compounds) in their cultures (*32*). In retrospect, the results reported by Herman et al. (*32*) showed the same trends as those of the current study. For example, microbial cultures oxidized 48% of the carbon from the Kodak salts to CO_2, whereas they oxidized only 20% of the carbon in a NAs extract from TW to CO_2 (*32*). These results demonstrated that the commercial NAs are more susceptible to biodegradation than the NAs in TW, as shown in Figure 1. Because it is now known that commercial NAs generally have lower molecular masses than NAs in TW, it is not surprising that the latter are more resistant to biodegradation.

Our investigation has shown that commercial NAs, with predominantly low molecular mass acids, are not appropriate surrogates for predicting the biodegradability of NAs in the TW because the commercial NAs are much more readily biodegraded than the NAs in the TW. Thus, subsequent studies should use NAs from oil sands sources to accurately assess their biodegradability. Because of the demonstrated recalcitrance of the high molecular mass NAs in TW, oil sands companies are exploring new methods to remove the toxicity of these compounds.

Acknowledgments

Funding was provided by Syncrude Canada Ltd. and the Canadian Water Network. We thank H. Dettman, L. Harrower, P. Kong, and R. Whittal for their assistance. A.C.S. gratefully acknowledges the support of an NSERC Scholarship.

Literature Cited

(1) Brient, J. A.; Wessner, P. J.; Doyle, M. N. Naphthenic acids. In *Encyclopedia of Chemical Technology*, 4th ed.; Kroschwitz, J. I., Ed.; John Wiley & Sons: New York, 1995; Vol. 16, pp 1017−1029.

(2) Clemente, J. S.; MacKinnon, M. D.; Fedorak, P. M. Aerobic biodegradation of two commercial naphthenic acids preparations. *Environ. Sci. Technol.* **2004**, *38*, 1009−1016.

(3) Seifert, W. K.; Teeter, R. M. Preparative thin-layer chromatography and high-resolution mass spectrometry of crude oil carboxylic acids. *Anal. Chem.* **1969**, *41*, 786−795.

(4) Seifert, W. K.; Teeter, R. M.; Howells, W. G.; Cantow, M. J. R. Analysis of crude oil carboxylic acids after conversion to their corresponding hydrocarbons. *Anal. Chem.* **1969**. *41*, 1638−1647.

(5) Dzidic, I.; Somerville, A. C.; Raia, J. C.; Hart, H. V. Determination of naphthenic acids in California crudes and refinery wastewaters by fluoride ion chemical ionization mass spectrometry. *Anal. Chem.* **1988**, *60*, 1318−1323.

(6) Fan, T.-P. Characterization of naphthenic acids in petroleum by fast atom bombardment mass spectrometry. *Energy Fuels* **1991**, *5*, 371−375.

(7) Wong, D. C. L.; van Compernolle, R.; Nowlin, J. G.; O'Neal, D. L.; Johnson, G. M. Use of supercritical fluid extraction and fast ion bombardment mass spectrometry to identify toxic chemicals from a refinery effluent adsorbed onto granular activated carbon. *Chemosphere* **1996**, *32*, 1669−1679.

(8) Jones, D. M.; Watson, J. S.; Meredith, W.; Chen, M.; Bennett, B. Determination of naphthenic acids in crude oils using nonaqueous ion exchange solid-phase extraction. *Anal. Chem.* **2001**, *73*, 703−707.

(9) Tomczyk, N. A.; Winans, R. E.; Shinn, J. H.; Robinson, R. C. On the nature and origin of acidic species in petroleum. 1. Detailed acid type distribution in a California crude oil. *Energy Fuels* **2001,** *15*, 1498−1504.

(10) Qi, B.; Fei, X.; Wang, S.; Chen, L. Study on distribution and composition of carboxylic acids of Bohai crude oil in China. *Pet. Sci. Technol.* **2004**, *22*, 463−473.

(11) Tissot, B. P.; Welte, D. H. *Petroleum Formation and Occurrence*; Springer: New York, 1978.

(12) Meredith, W.; Kelland, S.-J., Jones, D. M. Influence of biodegradation on crude oil acidity and carboxylic acid composition. *Org. Geochem.* **2000,** 1059−1073.

(13) Watson, J. S.; Jones, D. M.; Swannell, R. P. J.; van Duin, A. C. T. Formation of carboxylic acids during aerobic biodegradation of crude oil and evidence of microbial oxidation of hopanes. *Org. Geochem.* **2002**, *33*, 1153−1169.

(14) Clemente, J. S.; Prasad, N. G. N.; Fedorak, P. M. A statistical comparison of naphthenic acids characterized by gas chromatography−mass spectrometry. *Chemosphere*. **2003**, *50*, 1265−1274.

(15) Clemente, J. S. The Characterization, Analyses and Biodegradation of Naphthenic acids. M.Sc. Thesis, University of Alberta, Edmonton, Alberta, Canada, 2004, 212 pp.

(16) Schramm, L. L.; Stasiuk, E. N.; MacKinnon, M. Surfactants in Athabasca Oil Sands slurry conditioning, flotation recovery, and tailings processes. In *Surfactants, Fundamentals and Applications in the Petroleum Industry*; Schramm, L. L., Ed.; Cambridge University Press: Cambridge, 2000; pp 365−430.

(17) Jivraj, M. N.; MacKinnon, M.; Fung, B. Naphthenic acid extraction and quantitative analysis with FT-IR spectroscopy. In *Syncrude Analytical Manuals*, 4th ed.; Syncrude Canada Ltd. Research Department: Edmonton, AB, 1995.

(18) Holowenko, F. M.; MacKinnon, M. D.; Fedorak, P. M. Naphthenic acids and surrogate naphthenic acids in methanogenic microcosms. *Water Res.* **2001**, *35*, 2595−2606.

(19) Yen, T.-W.; Marsh, W. P.; MacKinnon, M. D.; Fedorak, P. M. Measuring naphthenic acids concentrations in aqueous environmental samples by liquid chromatography. *J. Chromatogr., A* **2004**, *1033*, 83−90.

(20) Clemente, J. S.; Yen, T.-W.; Fedorak, P. M. Development of a high performance liquid chromatography method to monitor the biodegradation of naphthenic acids. *J. Environ. Eng. Sci.* **2003**, *2*, 177−186.

(21) Hsu, C. S.; Dechert, G. J.; Robbins, W. K.; Fukada, E. K. Naphthenic acids in crude oils characterized by gas chromatography−mass spectrometry. *Energy Fuels* **2000**, *14*, 217−223.
(22) Rudzinski, W. E.; Oehlers, L.; Zhang, Y. Tandem mass spectrometric characterization of commercial naphthenic acids and a Maya crude oil. *Energy Fuels* **2002**, *16*, 1178−1185.
(23) Lo, C. C.; Brownlee, B. G.; Bunce, N. J. Electrospray-mass spectrometric analysis of reference carboxylic acids and Athabasca oil sands naphthenic acids. *Anal. Chem.* **2003**, *75*, 6394−6400.
(24) Barrow, M. P.; Headley, J. V.; Peru, K. M.; Derrick, P. J. Fourier transform ion cyclotron resonance mass spectrometry of principal components in oilsands naphthenic acids. *J. Chromatogr., A* **2004**, *1058,* 51−59.
(25) St. John, W. P.; Rughani, J.; Green, S. A.; McGinnis, G. D. Analysis and characterization of naphthenic acids by gas chromatography-electron impact mass spectrometry of *tert*-butyldimethylsilyl derivatives. *J. Chromatogr., A* **1998**, *807*, 241−251.
(26) Holowenko, F. M.; MacKinnon, M. D.; Fedorak, P. M. Characterization of naphthenic acids in oil sands wastewaters by gas chromatography−mass spectrometry. *Water Res.* **2002**, *36*, 2845−2857.
(27) Clemente, J. S.; Fedorak, P. M. Evaluation of the analyses of *tert*-butyldimethylsilyl derivatives of naphthenic acids by gas chromatography-electron impact mass spectrometry. *J. Chromatogr., A* **2004**, *1047*, 117−128.
(28) MacKinnon, M.; Boerger, H. Description of two treatment methods for detoxifying oil sands tailings pond water. *Water Pollut. Res. J. Can.* **1986**, *21*, 496−512.
(29) MacKinnon, M. Development of the tailings pond at Syncrude's oil sands plant; 1978−1987. *AOSTRA J. Res.* **1989**, *5*, 109−133.
(30) Clemente, J. S.; Fedorak, P. M. A review of the occurrence, analyses, toxicity, and biodegradation of naphthenic acids. *Chemosphere* **2005**, *60*, 585−600.
(31) Headley, J. V.; McMartin, D. W. A review of the occurrence and fate of naphthenic acids in aquatic environments. *J. Environ. Sci. Health, Part A: Environ. Sci. Eng.* **2004**, A39, 1989−2010.
(32) Herman, D. C.; Fedorak, P. M.; MacKinnon, M.; Costerton, J. W. Biodegradation of naphthenic acids by microbial populations indigenous to oil sands tailings. *Can. J. Microbiol.* **1994**, *40*, 467−477.
(33) American Standard Test Method. *Annual Book of ASTM Standards, Section 5 Petroleum Products, Lubricants, and Fossil Fuels*; ASTM: West Conshohocken, PA, 2001; Volume 05.06., D664.
(34) Wyndham, R. C.; Costerton, J. W. Heterotrophic potentials and hydrocarbon biodegradation potentials of sediment microorganisms within the Athabasca oil sands deposit. *Appl. Microbiol.* **1981**, *41*, 783−790.
(35) Blumer, M.; Souza, G.; Sass, J. Hydrocarbon pollution of edible shellfish by an oil spill. *Mar. Biol.* **1970**, *3*,195−202.
(36) Ahmed, M. T.; Mostafa, G. A.; Al Rashi, S. A.; Askar, A. A. Capillary gas chromatography determination of aliphatic hydrocarbons in fish and water from Oman. *Chemosphere* **1998**, *36*, 1391−1403.
(37) Reddy, C. M.; Eglinton, T. I.; Nounshell, A.; White, H. K.; Xu, L.; Gaines, R. B.; Frysinger, G. S. The West Falmouth oil spill after thirty years: the persistence of petroleum hydrocarbons in march sediments. *Environ. Sci. Technol.* **2002**, *36*, 4754−4760.
(38) Frysinger, G. S.; Gaines, R. B.; Xu, L.; Reddy, C. M. Resolving the unresolved complex mixture in petroleum-contaminated sediments. *Environ. Sci. Technol.* **2003**, *37*, 1653−1662.
(39) Hunt, J. M. *Petroleum Geochemistry*; W. H. Freeman and Company: San Fancisco, CA, 1979; pp 388−391.
(40) Lai, J. W. S.; Pinto, L. J.; Kiehlmann, E.; Bendell-Young, L. I.; Moore, M. M. Factors that affect the degradation of naphthenic acids in oil sands wastewater by indigenous microbial communities. *Environ. Toxicol. Chem.* **1996**, *15*, 1482−1491.

Received for review May 27, 2005. Revised manuscript received August 10, 2005. Accepted August 23, 2005.

ES051003K

Appendix XII:

E. N. Kelly at al, “Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries” (December 2009)
Proceedings of the National Academy of Sciences

Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries

Erin N. Kelly[a], Jeffrey W. Short[b], David W. Schindler[a,1], Peter V. Hodson[c], Mingsheng Ma[a], Alvin K. Kwan[a], and Barbra L. Fortin[a]

[a]Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada T6G 2E9; [b]Oceana, 175 South Franklin Street, Suite 422, Juneau, Alaska 99801; and [c]Department of Biology and School of Environmental Studies, Queen's University, Kingston, ON, Canada K7L 3N6

Contributed by David W. Schindler, October 23, 2009 (sent for review September 21, 2009)

For over a decade, the contribution of oil sands mining and processing to the pollution of the Athabasca River has been controversial. We show that the oil sands development is a greater source of contamination than previously realized. In 2008, within 50 km of oil sands upgrading facilities, the loading to the snowpack of airborne particulates was 11,400 T over 4 months and included 391 kg of polycyclic aromatic compounds (PAC), equivalent to 600 T of bitumen, while 168 kg of dissolved PAC was also deposited. Dissolved PAC concentrations in tributaries to the Athabasca increased from 0.009 μg/L upstream of oil sands development to 0.023 μg/L in winter and to 0.202 μg/L in summer downstream. In the Athabasca, dissolved PAC concentrations were mostly <0.025 μg/L in winter and 0.030 μg/L in summer, except near oil sands upgrading facilities and tailings ponds in winter (0.031–0.083 μg/L) and downstream of new development in summer (0.063–0.135 μg/L). In the Athabasca and its tributaries, development within the past 2 years was related to elevated dissolved PAC concentrations that were likely toxic to fish embryos. In melted snow, dissolved PAC concentrations were up to 4.8 μg/L, thus, spring snowmelt and washout during rain events are important unknowns. These results indicate that major changes are needed to the way that environmental impacts of oil sands development are monitored and managed.

airborne deposition | oil sands processing | water contamination | hydrocarbons | oil sands mining

The Alberta oil sands consist of water, sand, and bitumen, a heavy and viscous hydrocarbon, that is recovered by surface mining or by in situ steam injection. To produce crude oil, bitumen must be extracted with hot water and upgraded by using heat, pressure, and catalysts (1). Production of bitumen increased from 482,000 to 1.3 million barrels per day from 1995 to 2008 (2, 3). The area disturbed by mine operations was 530 km^2 in 2007, and the area of tailings ponds surpassed 130 km^2 in 2008 (1, 4). Oil sands production by both mining and in situ methods will increase rapidly, with projected output ranging from 2.0 to 2.9 million barrels per day by 2020 (5).

Some residents of downstream Fort Chipewyan are convinced that the oil sands industry is responsible for higher than expected cancer rates (6). However, government, industry and related agencies, relying in part on the joint Regional Aquatic Monitoring Program (RAMP), report that effects are minimal, that natural sources cause elevated contaminant concentrations in the Athabasca and its tributaries (7), and that human health and the environment are not at risk from oil sands development (8–10), see *Controversy Background Information* in *SI Text*.

Since 1997, the RAMP, funded by industry and directed by a multistakeholder committee, has monitored aquatic ecosystems near the oil sands development (11). However, it lacks scientific oversight, and a peer review severely criticized its ability to detect effects (12). RAMP data are not publicly available, and the methods used to analyze, interpret, and report the data are not entirely transparent.

We conducted an independent, detailed, and accessible assessment of the loadings of polycyclic aromatic compounds (PAC) to the north-flowing Athabasca River, its tributaries, the Athabasca Delta, and Lake Athabasca (Fig. 1). In February to March and June to August 2008, we sampled water using polyethylene membrane devices (PMDs). In March, the accumulated snowpack was sampled at most sites. Athabasca River sites were selected upstream and downstream of oil sands mining and processing activity. Upstream and downstream sites near oil sands development are directly exposed to erosion of the McMurray geologic formation (McMF), where most oil sands occur (13).

Three sites along each of four impacted tributaries were selected using 2006 Landsat imagery. The first was located upstream of oil sands development and the McMF, the second midstream within the McMF but upstream of mining activity, and the third near stream mouths at the confluence with the Athabasca, downstream of development and downstream or within the McMF. Comparable sites were chosen on two reference tributaries unaffected by industry. In the summer, additional stream mouth sites, with and without upstream development, were included to increase statistical power.

After sampling, 2008 Landsat imagery revealed marked changes in the extent of oil sands development since 2006. Some tributary sites could be compared as planned, but some midstream and stream mouth sites unaffected in 2006 were affected by new development in 2008. To assess the impacts of this new development, the change in development between 2006 and 2008 was categorized visually from Landsat imagery as nil–small (N-S) and medium–large (M-L). This gave four classes of new development: midstream/N-S, midstream /M-L, stream mouth /N-S, and stream mouth /M-L. To compare the relative importance of natural erosion and mining on PAC mobilization, PAC concentrations in water were regressed against the proportion of the catchment within the McMF, overall land disturbance, and land disturbed by oil sands mining in 2008. These comparisons were made for all tributaries combined and separately for the Athabasca.

Samples were analyzed for PAC (sum of parent and alkylated homologues of two-, three- and four- ring polycyclic aromatic hydrocarbons+ dibenzothiophene). Melted snow was analyzed for the mass of particulate and associated PAC retained on 0.45-μm glass fiber filters and for dissolved PAC in filtrate. Because PMDs accumulate only dissolved PAC from water (14), equivalent water concentrations were calculated from PAC concentrations in PMDs,

ENVIRONMENTAL SCIENCES

Author contributions: E.N.K., J.W.S., D.W.S., and P.V.H. designed research; E.N.K., M.M., A.K.K., and B.L.F. performed research; E.N.K. and J.W.S. analyzed data; and E.N.K., J.W.S., D.W.S., and P.V.H. wrote the paper.

The authors declare no conflict of interest.

[1]To whom correspondence should be addressed. E-mail: d.schindler@ualberta.ca.

This article contains supporting information online at www.pnas.org/cgi/content/full/0912050106/DCSupplemental.

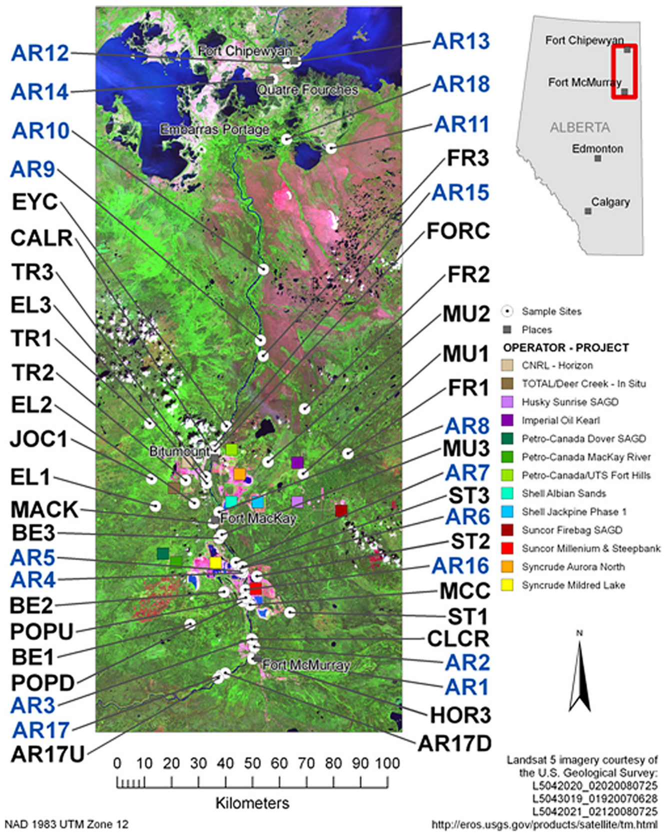


Fig. 1. Study Area Map. Sites: blue, Athabasca River; black, tributaries (AR17U, unnamed creek; AR17D, unnamed creek; HOR, Horse River; CLCR, Clarke Creek; POP, Poplar Creek, BE, Beaver River; ST, Steepbank River; MCC, McLean Creek; MACK, MacKay River; EL, Ells River; JOC, Jocelyn Creek; MU, Muskeg River; FR, Firebag River; FOR, Fort Creek; TR, Tar River; CALR, Calumet River; EYC, Eymundson Creek; 1, upstream; 2, midstream; 3, stream mouth). Landsat 5 image is a false color composite, where blue is water, green is vegetation, and pink is nonvegetated and/or developed areas. Squares represent existing and approved oil sands projects.

assuming equilibrium between PMDs and ambient water concentrations after ≈30-day deployment. Further details are provided in *Methods* and *Analytical and Statistical Method Details* in *SI Text*.

Results

Particulates and PAC in Snow. Substantial deposition of airborne particulates was discovered within 50 km of the Suncor and Syncrude upgrading facilities, near AR6 (Fig. 2 and Fig. S1). Particulate deposition exponentially declined from 19 g/m^2 at AR6, near the upgrading facilities, to <0.35 g/m^2 at sites >50 km distant (particulates = $10.6 \times e^{-0.0714*x}$ g/m^2, x = km from AR6, $r^2 = 0.71$, $P < 0.0001$, $n = 23$; Fig. S2*A*). Integrating over a 50-km radius indicates deposition of 11,400 metric T of particulates during ≈4 months of snowfall.

Most particulates collected at AR6 consisted of oil sands bitumen. An oil slick formed on the surface of melted snow (Fig. S3), and the PAC distribution was similar to the four oil sands samples, i.e., dominated by dibenzothiophenes, phenanthrenes/anthracenes, fluoranthenes/pyrenes, and benzanthracenes/chrysenes (Fig. S4 *A* and *B*). Compared with the oil sands, PAC in the snow particulates were slightly enriched in naphthalenes and unsubstituted four- to five-ring PAC, suggesting admixture with volatile and combustion-derived PAC [i.e., dominated by less-substituted four or more-ring PAC (15)]. Using a measured mean ratio of 0.000649 ± 0.000168 (see *Analytical and Statistical Method Details* in *SI Text*) for total PAC to bitumen in oil sands, the 0.414 mg of PAC per gram of particulate in AR6 snow was equivalent to 64% bitumen.

The proportion of PAC in snow particulates declined rapidly with distance from AR6, indicating that bitumen was deposited closer to the source than particulates (Fig. 3). Measured PAC deposition declined exponentially (PAC = $1.06 \times e^{-0.130*x}$ mg/m^2, $r^2 = 0.76$, $P < 0.0001$, $n = 23$; Fig. S2*B*) from 7.87 mg/m^2 at AR6, near the upgrading facilities, to 0.011 mg/m^2 or less at sites over 50-km distant. This is equivalent to deposition of 391 kg of PAC within a 50-km radius of AR6 over 4 months, or 600 T of bitumen. Deposition of PAC declined significantly more rapidly with distance from AR6 than particulates (t test, $P < 0.01$), suggesting association of bitumen PAC with heavier or denser particles.

Dissolved PAC in the filtrate from melted snow also declined with distance from AR6 (Fig. 3), and were dominated by fluorenes, dibenzothiophenes, and phenanthrenes/anthracenes, consistent with partitioning into air or water of more volatile and soluble PAC in bitumen (Fig. S4*C*). Dissolved PAC deposition declined exponentially with distance from AR6 (dissolved PAC = $0.148 \times e^{-0.0691*x}$ mg/m^2, $r^2 = 0.59$, $P < 0.0001$, $n = 23$; Fig. S2*C*), with a similar decay constant (−0.0691) as particulates (−0.0714; $P > 0.8$). Integrating over a 50-km radius gives 168 kg of dissolved PAC accumulated during 4 months. Dissolved PAC concentrations in

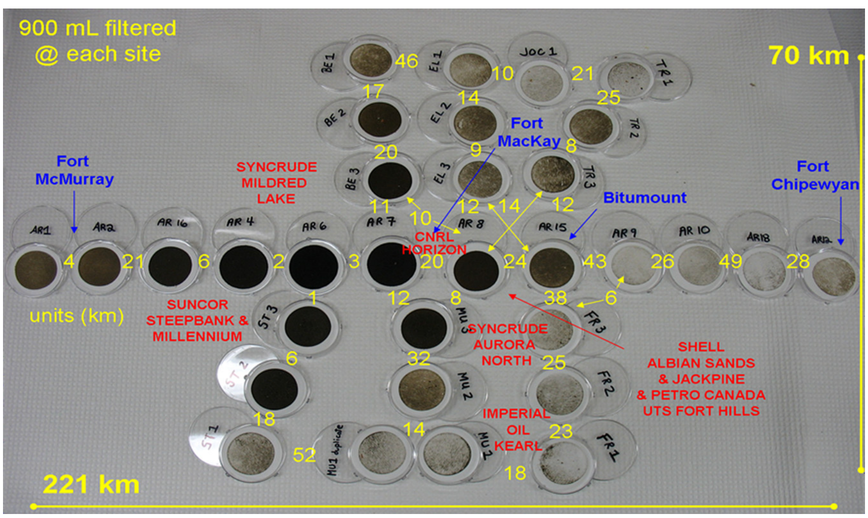


Fig. 2. White 0.45-μm Whatman GF/F filters after 900 mL of melted snow from each site was filtered. Yellow, distance between sites; blue, communities; red, existing and approved surface mining projects.

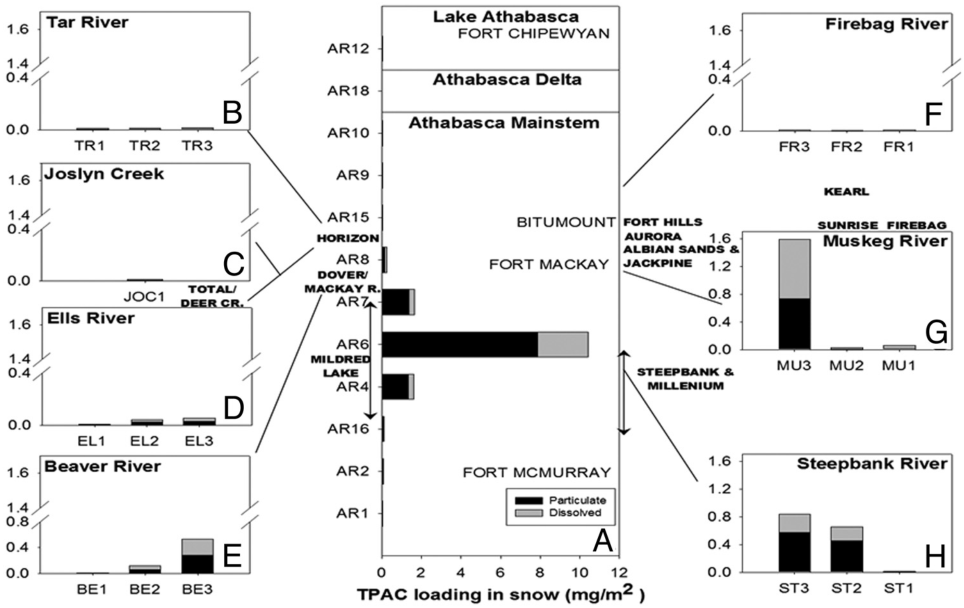


Fig. 3. Particulate and dissolved PAC loading (mg/m^2) in accumulated snowpack, March 2008. (*A*) Athabasca River, Athabasca Delta, and Lake Athabasca. (*B*) Tar River. (*C*) Joslyn Creek. (*D*) Ells River. (*E*) Beaver River. (*F*) Firebag River. (*G*) Muskeg River. (*H*) Steepbank River. Bolded font indicates existing and approved projects (Syncrude: Mildred Lake and Aurora, Suncor: Millennium, Steepbank and Firebag In-situ, Petro Canada Dover-MacKay River In-situ, Husky Oil Sunrise In-situ, TOTAL/Deer Creek In-situ, Shell: Albian Sands/Muskeg River and Jackpine, CNRL: Horizon, Imperial Oil: Kearl, Petro Canada/UTS: Fort Hills). Mildred Lake spans AR16 to AR7, whereas Steepbank and Millennium span AR16 to AR6, as indicated by arrows. Upgrading facilities are near AR6.

melted snow declined from 4.8 μg/L at AR6 to <0.27 μg/L at sites >50 km away, and exceeded 0.7 μg/L at 9 of 10 sites within 22 km of AR6.

PAC in Tributaries. Dissolved PAC concentrations in the six tributaries sampled during winter and summer mostly increased from upstream to downstream and were greater in summer than winter (Fig. 4*A*). Mean concentrations increased from 0.009 μg/L at upstream sites in both winter and summer to 0.023 ± 0.0059 μg/L and 0.202 ± 0.160 μg/L at stream mouth sites, respectively, similar to melted snow. Differences among sites along tributaries were highly significant (two-way ANOVA, ln

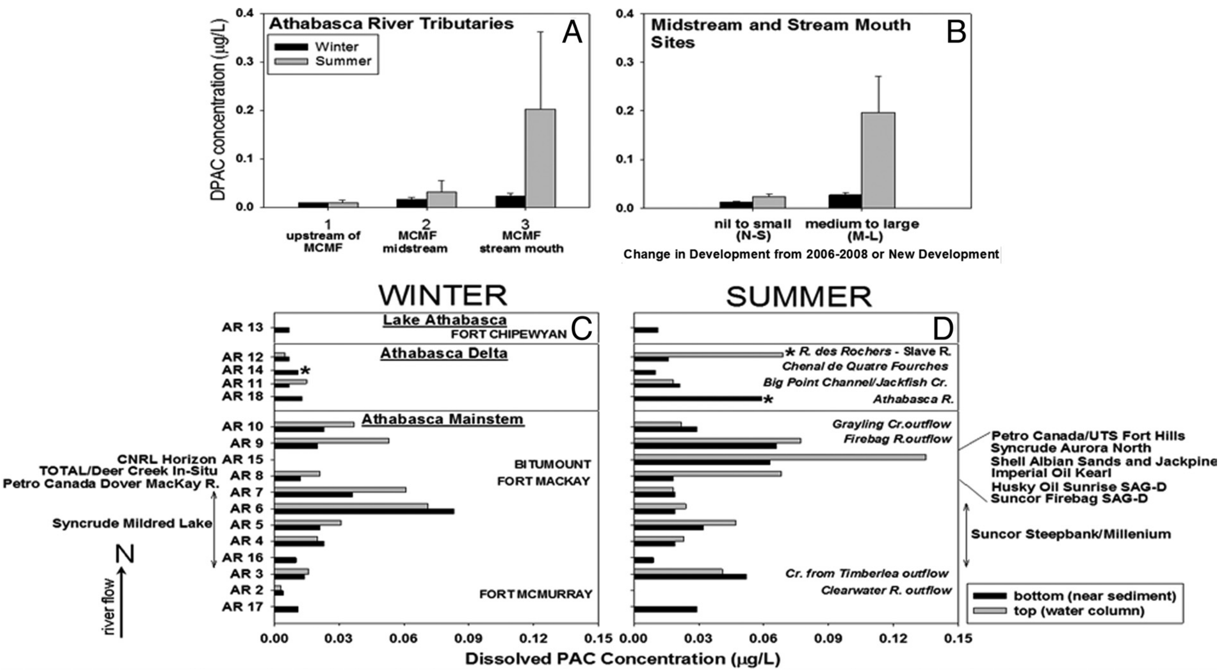


Fig. 4. Estimated winter and summer dissolved PAC concentrations (μg/L). (*A*) Tributaries. (*B*) Midstream and stream mouth tributary sites in relation to "new" development (change in development from 2006 to 2008), $n = 5–8$. Athabasca River, Athabasca Delta, and Lake Athabasca (*C*) Winter. (*D*) Summer. * indicates samples contaminated by diesel fuel (see *Analytical and Statistical Method Details* in *SI Text*), not included in calculations; MCMF, McMurray Formation; N, north. Error bars are standard error of the mean.

transformed, $P = 0.004$), but not between seasons ($P = 0.91$). The power to detect seasonal differences was low ($\beta = 0.05$), so a seasonal effect could not be discounted. The greater trend of increasing PAC downstream in summer compared with winter (Fig. 4*A*) was nearly significant (interaction $P = 0.095$) at only moderate power ($\beta = 0.30$).

This analysis included all upstream, midstream, and downstream tributary sites, regardless of development. Almost all development was near the stream mouth on some tributaries, with insignificant development near midstream or upstream sites. Analyzing only these tributaries, no significant increase in PAC concentrations between upstream and midstream sites was found (Fig. S5*A*). Thus, when development was insignificant, flow of water through the McMF did not significantly affect PAC concentrations, indicating that natural sources are not solely responsible for increased concentrations of PAC midstream or at stream mouths.

Increasing PAC concentrations from upstream to downstream in the tributaries (Fig. 4*A* and Fig. S5*A*) could reflect increasing contributions from natural erosion of the McMF, greater disturbance from development, or both. Little of the variability in summer PAC concentrations of tributaries was explained by the proportion of McMF, total surface land disturbance, or oil sands mining disturbance in watersheds ($r^2_{\mathrm{McMF}} = 0.009$, $r^2_{\mathrm{disturbance}} = 0.003$, $r^2_{\mathrm{oil\ sands}} = 0.000$; $P > 0.69$, $df = 19$).

In contrast, when midstream and stream mouth sites were grouped, PAC concentrations were strongly associated with new land disturbance or mining activity expansion from 2006 to 2008. Mean PAC concentrations increased 2-fold from 0.012 ± 0.0012 at N-S sites to 0.027 ± 0.0052 μg/L at M-L sites in winter, and 8-fold from 0.024 ± 0.0055 to 0.197 ± 0.0738 μg/L in summer (Fig. 4*B*). Season and disturbance effects were highly significant (two-way ANOVA, ln transformed, $P < 0.004$), and the season and disturbance interaction was nearly significant ($P = 0.065$, $\beta = 0.36$). The power to detect the seasonal effect was $\beta > 0.85$, much greater than for the previous test ($\beta = 0.05$). Comparing only midstream or stream-mouth sites leads to essentially the same conclusions (Fig. S5 *B* and *C*). Thus, seasonal differences in PAC concentrations are likely real, and increased PAC concentrations in both winter and summer result from land disturbance by oil sands development between 2006 and 2008.

Approximately 75% of PAC homologues accumulated by PMDs deployed at the M-L sites consisted of three-ring PAC, dominated by alkyl-substituted dibenzothiophenes, phenanthrenes/anthracenes and fluorenes, with the remainder mostly four-ring PAC including alkyl-substituted fluoranthenes/pyrenes and benzanthracenes/chrysenes and negligible naphthalenes (Fig. S4*D*). Enrichment of three-ring PAC in PMDs compared with oil sands (Fig. S4*A*) is consistent with greater solubility of three- vs. four-ring PAC. The near absence of naphthalenes in PMDs is also consistent with low concentrations of these PAC in bitumen (Fig. S4*A*).

Athabasca River, Athabasca Delta, and Lake Athabasca. Dissolved PAC concentrations were usually low at most sites on the Athabasca River, Athabasca Delta, and Lake Athabasca, but often greater during summer (Fig. 4 *C* and *D*). In winter, concentrations were mostly <0.025 μg/L, except at sites near oil sands upgrading facilities and tailings ponds which ranged from 0.031 to 0.083 μg/L (Fig. 4*C*). In summer, PAC concentrations in the Athabasca were usually <0.030 μg/L. Upstream and within oil sands development, concentrations were unrelated to the proportion of McMF, total surface land disturbance, and oil sands mining disturbance ($r^2_{\mathrm{McMF}} = 0.137$, $r^2_{\mathrm{disturbance}} = 0.006$, $r^2_{\mathrm{oil\ sands}} = 0.085$; $P > 0.33$, $df = 8$). However, immediately downstream of new development, concentrations ranged from 0.063 to 0.135 μg/L (Fig. S6).

Discussion

The increased deposition of particulates and PAC in snow close to the Suncor and Syncrude upgrading facilities clearly implicates them as sources and corresponds to a similarity between patterns of PAC congeners in particulates and oil sands (Fig. S4 *A* and *B*). The enrichment of snow particulates by the more volatile PAC and by five-ring PAC (e.g., benzo[a]pyrene) is typical of PAC volatilized by heat or particulates produced by combustion. The dominance of oily material in snow from AR6 also suggests a separate organic bitumen phase in stack emissions that is present as droplets larger and less buoyant than average particulates, and precipitates near the source. Alternatively, the heavier particles might be bitumen-contaminated dust eroded by wind from mine sites (Fig. S7), but this was inconsistent with the high organic content of particulates near AR6. Although mining can mobilize dust, deposition would likely be localized and site-specific, and further study is needed to establish detailed loadings.

The similar deposition patterns of particulates and dissolved PAC in melted snow (Fig. S2 *A* and *C*) suggests that dissolved PAC did not leach from particulates, but was scavenged from the atmosphere. Snow samples were filtered within an hour of thawing, leaving little time for PAC dissolution. More likely, PAC dissolved in the snowmelt were readily desorbed from non-bitumen particulates or scavenged from vapor-phase PAC by ice nuclei in plumes of condensing steam from stack emissions, as occurs with metals (16).

The oil sands industry is a known source of air pollutants. Snow surveys in 1978 and 1981 identified elevated metal deposition via flyash particulates 25 km north and south, and 10 km east and west of Suncor and Syncrude upgrading facilities (16, 17). In 1978, 96% of particulates were deposited within 25 km of the stacks (17), but PAC deposition was not measured. From 2005 to 2007, the mean annual release of particulates measured by Suncor and estimated by Syncrude (stack and fugitive emissions) was 6037 ± 927 T (18). In contrast, during the 4 months before sampling in 2008, emissions were almost twice as large at 11,400 T and contaminated an area nearly 2-fold larger, with only ≈60% of particulates falling within a 25-km radius. Assuming similar deposition rates during the year implies a total annual particulate deposition of ≈34,000 T. This is nearly five times current reported emissions, and similar to annual deposition rates of 32,594 T in 1978 (19), before precipitators were installed. The discrepancy may be due to dust from mining (Fig. S7) or somewhat elevated loading estimates that were based on a circle around AR6, despite somewhat greater particulate deposition north/south of upgrading facilities than east/west (16). The close association of deposition with proximity to the upgrading facilities suggests that they are the primary source.

Airborne PAC from oil sands development conveys a considerable burden to the surrounding watershed. Historical stack discharges of particulates rich in aluminum (Al) (16, 17), and a strong correlation between Al and PAC concentrations in snow ($r = 0.94$, $P < 0.001$), suggest that large amounts of particulate PAC have been discharged since the onset of oil sands production in the 1960s. If deposition rates are constant throughout the year, the estimated annual release of PAC is now ≈1,200 kg associated with ≈1,800 T of bitumen particulates, and another 500 kg of dissolved PAC. This amount of bitumen released in a pulse would be equivalent to a major oil spill, repeated annually.

Given that particulate deposition rates in the 1970s before installation of stack precipitators (19) were as great as today, this situation has likely persisted for 30–40 years. As a result, current background PAC concentrations in surface soils, vegetation, snow, and runoff over a broad area of boreal forest may be greater than true background concentrations contributed naturally by oil sands in the region. Although RAMP collects snow for hydrologic monitoring (11), pollutant concentrations are not reported. In the early 1980s, snow sampling was recommended in northeastern Alberta and adjacent areas of Saskatchewan and the Northwest Territories to assess the effects of air emissions from expanding oil sands development (16, 17). The absence of such a program has made it progressively more difficult to separate pollution inputs from rising background contamination. With more oil sands development projects approved and proposed, including new and expanded upgrading facilities, the increased deposition of airborne PAC will further raise regional "background" concentrations.

Tributaries impacted by oil sands development indicate a second major flux of PAC to receiving waters. Recent disturbances (new roads, deforestation, encampments, exploration, mining) expose and distribute fresh bitumen to wind and soil erosion and enhance bitumen transport to surface waters, which leach out the most available PAC. The lack of correlation between PAC concentrations in water and the extent of older development suggests that disturbed areas eventually stabilize. However, the lack of correlation may also reflect increasing background PAC concentrations. At sites distant from upgrading facilities and unaffected by land disturbance, the regional background of total dissolved PAC in surface waters is ≈ 0.015 μg/L, closely comparable with concentrations in remote Canadian Arctic rivers (20). In contrast, at the most impacted stream mouths, PAC concentrations were 10- to nearly 50-fold greater (e.g., EL3, PAC = 0.682 μg/L), similar to concentrations toxic to fish embryos [as low as 0.4 μg/L (21)]. The PAC in oil sands, snow, and water were dominated by homologues of three-ringed alkyl phenanthrenes, alkyl dibenzothiophenes, and alkyl fluorenes, PAC most closely associated with embryotoxicity of crude oil (22, 23). Embryos of fathead minnows (*Pimephales promelas*) and white sucker (*Catostomus commersoni*), species native to the Athabasca watershed, showed higher rates of mortality, reduced rates of growth, and signs of pathology typical of PAC toxicity when exposed to as little as 0.01–0.1 μg/L of alkyl phenanthrene in oil sands leachates (calculated from refs. 24 and 25). PAC can also limit fish production through endocrine disruption. Compared with reference fish, gonads of slimy sculpin (*Cottus cognatus*) and pearl dace (*Margariscus margarita*) collected near active oil sands processing were less capable of synthesizing sex steroids (26). PAC may contribute to a greater prevalence of abnormal juvenile and adult fish captured in the Athabasca near and downstream of oil sands mining (11, 27).

During spring, the snowmelt pulse could increase PAC concentrations in tributaries to those toxic to both aquatic and terrestrial organisms (28, 29). Dissolved PAC would be immediately available to biota but particulate PAC may be taken up by filter feeders or partition into water for uptake by fish across gills. Residual particles may also accumulate on the forest floor with organic material or in underlying soils, causing PAC to leach more gradually into surface waters, adding to the overall PAC burden.

Of the 24 fish species resident in the Athabasca and its tributaries (30), 19 spawn in the spring or early summer (31). Embryos of these species are likely present when PAC concentrations are greatest. If located in shallow tributaries receiving PAC-enriched snowmelt, embryos may also experience photo-enhanced toxicity (32). Newly hatched whitefish embryos exposed to sublethal concentrations of retene (alkyl phenanthrene) died when coexposed to visible and UV light (33). Toxicity may also increase if PAC and metals associated with oil sands act synergistically, as observed for *Daphnia magna* (34).

Dissolved PAC did not persist as far as the Athabasca River Delta and Ft. Chipewyan, at least during the seasons sampled. However, PAC-contaminated sediments in the Athabasca Delta and Lake Athabasca (35, 36) are consistent with long-range atmospheric and fluvial transport of particulate PAC. Our sampling did not include the intervening spring snowmelt, which would release a pulse of PAC up to 50 km from oil sands upgrading facilities into nearby tributaries and the Athabasca. Although this should increase PAC concentrations in tributaries, it might not be detected in the main stem because of high-volume dilution by uncontaminated snowmelt from areas upstream of oil sands mining. PAC may also be removed from the water column by microbial degradation and adsorption to organic matter that settles out of the water column (37). These dilution and removal processes likely account for declining concentrations of dissolved PAC as the Athabasca flows to Lake Athabasca and Fort Chipewyan.

Conclusions

Due to substantial loadings of airborne PAC, the oil sands industry is a far greater source of regional PAC contamination than previously realized. Despite previous recommendations (17), there is no apparent detailed monitoring of PAC fluxes via wet and dry deposition in the winter or summer, when similar or greater contributions are likely. Monitoring of air, the snowpack, spring snowmelt, and summer rain and vegetation is essential to identify and control sources of PAC and their potential environmental and human health impacts. A second important source of PAC is landscape disturbance. Surprisingly, impacts are related primarily to recent disturbance (<2 y), which suggests that revegetation or erosion controls mitigate long-term loadings.

Controls on waterborne PAC are critical because concentrations at tributary mouths and at one site on the Athabasca are already within the range toxic to fish embryos. However, the impacts on the Athabasca ecosystem of mining wastewater, snowmelt, or contaminated groundwater remain enigmatic due to high seasonal variability of flow and dilution capacity.

Our study confirms the serious defects of the RAMP (12). More than 10 years of inconsistent sampling design, inadequate statistical power, and monitoring-insensitive responses have missed major sources of PAC to the Athabasca watershed. Most importantly, RAMP claims that PAC concentrations are within baseline conditions and of natural origin have fostered the perception that high-intensity mining and processing have no serious environmental impacts. The existing RAMP must be redesigned with more scientific and technical oversight to better detect and track PAC discharges and effects. Oversight by an independent board of experts would make better use of monitoring resources and ensure that data are available for independent scrutiny and analyses. The scale and intensity of oil sands development and the complexity of PAC transport and fate in the Athabasca watershed demand the highest quality of scientific effort.

Methods

Study Design. Seventeen sites were chosen on the main stem Athabasca, the Delta, and Lake Athabasca, from south of Fort McMurray (upstream of development) to Fort Chipewyan (downstream of development) (Fig. 1). The Athabasca River is exposed to the McMF 50 km upstream of Fort McMurray and is present within its banks to Eymundson Creek (38).

Tributaries draining from the east (Steepbank, Muskeg, and Firebag Rivers) and west (Beaver, Ells, and Tar Rivers), including reference rivers (Firebag and Ells Rivers) and those impacted by oil sands development (Steepbank, Muskeg, Beaver, and Tar Rivers), and the Horse River stream mouth, were sampled in winter and summer (Fig. 1). Nine other stream mouth sites (AR17down, AR17up, Clarke, Poplar, McLean, Fort, and Eymundson Creeks and MacKay and Calumet Rivers) were sampled only in summer.

GIS analyses were performed by using ArcGIS 9 ArcMap version 9.2 (39), to delineate catchments, extract disturbance and geologic data, and calculate distances between AR6 and other snow sampling sites (see *Analytical and Statistical Method Details* in *SI Text* for details).

Field Sampling. In March, snow was collected from 12 sites on the Athabasca River, Athabasca Delta, and Lake Athabasca and from 19 tributary sites. Samples were collected close to the middle of the river, and replicated at MU1. At each site, the depth and weight of five snow cores were recorded to calculate snow density, snow water equivalents, and PAC areal deposition rates. For PAC, an integrated sample of the snowpack was melted and vigorously stirred, and a subsample (775–4,000 mL) was filtered through a 0.45-μm muffled Whatman GF/F filter. The filter was frozen, and the filtrate was decanted, spiked with a suite of perdeuterated hydrocarbon surrogate standards in 0.5 mL of acetone, shaken, extracted twice with 100 mLl of DCM, and stored at −20 °C.

PMDs were deployed in the Athabasca and its tributaries for ≈30 days to passively monitor dissolved PAH in summer and winter and provide a time-integrated measure of dissolved PAH (14). PMDs were cleaned by sonication successively with dichloromethane (DCM), put in DCM-cleaned metal holders, wrapped in DCM-rinsed aluminum foil and stored in heat-sealed Ziploc bags at −20 °C. At 12 locations on the Athabasca River and the Horse River mouth, two PMDs were deployed per site, near the river bottom and in surface water. One PMD was deployed near the river bottom at the five other Athabasca sites, and all tributary sites. PMDs were retrieved by using global positioning system coordinates and a metal detector (winter). Replicate PMDs were deployed within 500 m at sites where PAC were assumed to be high (MU3) or low (EL1). One trip blank and five field blanks, handled like deployed PMDs, were included with winter and summer samples.

Oil sands samples were collected in summer from the Syncrude lease area, the east and west bank of the Athabasca River north of Bitumount, and underwater at the mouth of the Steepbank River. All samples were frozen.

Laboratory. PAC were measured at the University of Alberta Biogeochemical Analytical Laboratory by using an Agilent 6890N gas chromatograph coupled to a 5975 inert XL mass selective detector and 7683B injector (modified refs. 14 and 40). Detailed methods and instrument and method detection limits are presented in *Analytical and Statistical Method Details* in *SI Text* and Table S1, respectively.

Analytical and Statistical Methods. Details of QA/QC, contamination by diesel fuel, PAC source identification, estimation of aqueous PAC concentrations and PAC deposition calculations are provided in *Analytical and Statistical Method Details* in *SI Text*.

ACKNOWLEDGMENTS. Dr. K. Timoney, R. Grandjambe, R. Radmanovich, R. Ladouceur, S. Laurent, T. Boag, P. Jordan, K. Vladicka-Davies, M. Davies, and H. La provided assistance with planning and field and/or laboratory work. Parks Canada and the Government of Alberta granted research permits. The Athabasca Chipewyan, Mikisew Cree, and Fort MacKay First Nations and Métis provided traditional ecological knowledge and access to traditional territories. Matt Hanneman and Peter Lee (Global Forest Watch) supplied GIS data and defined catchments. Charlene Nielsen completed GIS analyses and created the study area map. Reviewer comments improved the manuscript. This work was funded by the the Tides Foundation and the Walter and Duncan Gordon Foundation.

1. Government of Alberta (2008) *Environmental Management of Alberta's Oil Sands*. (Oil Sands Management Division, Government of Alberta, AB, Canada).
2. ERCB (Energy Resources Conservation Board) (2005) *Alberta's Reserves 2004 and Supply/Demand Outlook 2005–2014*. ST98-2005, Power Point file of graphs and data from 2005 report. Available from www.ercb.ca/portal/server.pt/gateway/PTARGS_0_0_308_265_0_43/http%3B/ercbContent/publishedcontent/publish/ercb_home/publications_catalogue/publications_available/serial_publications/st98.aspx.
3. ERCB (Energy Resources Conservation Board) (2009) *Alberta's Energy Reserves 2008 and Supply/Demand Outlook 2009–2018*. ST98-2009, Power Point file of graphs and data from 2009 report. Available from: www.ercb.ca/portal/server.pt/gateway/PTARGS_0_0_308_265_0_43/http%3B/ercbContent/publishedcontent/publish/ercb_home/publications_catalogue/publications_available/serial_publications/st98.aspx.
4. Price M (2008) *11 Million Litres a Day the Tar Sands' Leaking Legacy*. (Environmental Defense, Toronto, ON, Canada).
5. CAPP (Canadian Association of Petroleum Producers) (2009) *Crude Oil Forecast, Markets and Pipeline Expansions* (Canadian Association of Petroleum Producers).
6. Chen Y (2009) *Cancer Incidence in Fort Chipewyan, Alberta 1995–2006* (Alberta Cancer Board, Division of Population Health and Information Surveillance, Alberta Health Services).
7. RAMP (Regional Aquatics Monitoring Program), WBEA (Wood Buffalo Environmental Association), CEMA (Cumulative Environmental Management Association) (2008) *Joint Community Update 2008 Reporting Our Environmental Activities to the Community* (RAMP, WBEA and CEMA, Fort McMurray, AB, Canada).
8. HEAP (The Alberta Oil Sands Community Exposure and Health Effects Assessment Program) (2000) *Summary Report. Health Surveillance* (Alberta Health and Wellness, Government of Alberta, Edmonton, AB, Canada), www.health.alberta.ca/newsroom/pub-environmental-health.html.
9. HEMP (Wood Buffalo Environmental Association Human Exposure Monitoring Program) (2007) *Methods Report and 2005 Monitoring Year Results* (Wood Buffalo Environmental Monitoring Association, Fort McMurray, AB, Canada), www.health.alberta.ca/newsroom/pub-environmental-health.html.
10. HEMP (Wood Buffalo Environmental Association Human Exposure Monitoring Program) (2007) *2006 Monitoring Year Results* (Wood Buffalo Environmental Monitoring Association, Fort McMurray, AB, Canada), www.health.alberta.ca/newsroom/pub-environmental-health.html.
11. RAMP (Regional Aquatics Monitoring Program) (2009A) *2008 Final Technical Report* (Hatfield Consultants, Kilgour and Associates Ltd., Klohn Crippe Berger Ltd., and Western Resource Solutions).
12. Ayles GB, Dubé M, Rosenberg D (2004) *Oil Sands Regional Aquatic Monitoring Program (RAMP) Scientific Peer Review of the Five Year Report (1997–2001)* (Fisheries and Oceans Canada, Winnipeg, Manitoba, Canada).
13. Strausz OP, Lown EM (2003) *The Chemistry of Alberta Oil Sands, Bitumens and Heavy Oils* (Alberta Energy Research Institute, Calgary, AB, Canada).
14. Carls MG, Holland LG, Short JW, Heintz RA, Rice SD (2004) Monitoring polynuclear aromatic hydrocarbons in aqueous environmental with passive low-density polyethylene membrane devices. *Environ Toxicol Chem* 23:1416–1424.
15. Wakeham SC, Schaffner C, Giger W (1980) Polycyclic aromatic hydrocarbons in recent lake sediments I. Compounds having anthropogenic origins. *Geochim Cosmochim Acta* 44:415–429.
16. Barrie LA, Kovalick J (1980) *A Wintertime Investigation of the Deposition of Pollutants Around an Isolated Power Plant in Northern Alberta*. Prepared for the Alberta Oil Sands Environ Res Program by Atmos Environ Service. AOSERP Report 90 (Alberta Oil Sands Environmental Research Program).
17. Murray WA (1981) The 1981 snowpack survey in the AOSERP study area. Prepared for the Alberta Oil Sands Environ Res Program by Promet Enviromental Group. AOSERP Report 125 (Alberta Oil Sands Environmental Research Program).
18. National Pollutant Release Inventory (NPRI) (2009) www.ec.gc.ca/inrp-npri/.
19. Allan R, Jackson TA (1978) Heavy metals in bottom sediments of the mainstem Athabasca River system in the AOSERP study area. Prepared for the Alberta Oil Sands Environ Res Program by Inland Waters Directorate, Fisheries and Environment Canada. AOSERP Report 34 (Alberta Oil Sands Environmental Research Program).
20. Yunker MB, Backus SM, Pannatier EG, Jeffries DS, Macdonald RW (2002) Sources and significance of alkane and PAH hydrocarbons in Canadian arctic rivers. *Estuar Coast Shelf Sci* 55:1–31.
21. Carls MG, Rice SD, Hose JE (1999) Sensitivity of fish embryos to weathered crude oil: Part I. low-level exposure during incubation causes malformations, genetic damage, and mortality in larval pacific herring (*Clupea pallasi*). *Environ Toxicol Chem* 18:481–493.
22. Hodson PV, et al. (2007) Alkyl PAH in crude oil cause chronic toxicity to early life stages of fish. *Proceedings of the 28th Arctic and Marice Oilspill Program (AMOP)* (Technical Seminar, Environmental Science and Technology Division, Environment Canada, Ottawa, ON, Canada), pp 291–300.
23. Incardona JP, Collier TK, Scholz NL (2004) Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. *Toxicol Appl Pharmacol* 196:191–205.
24. Colavecchia MV, Backus SM, Hodson PV, Parrott JL (2004) Toxicity of oil sands to early life stages of fathead minnows (*Pimephales promelas*) *Environ Toxicol Chem* 23:1709–1718.
25. Colavecchia MV, Hodson PV, Parrott JL (2006) CYP1A induction and blue sac disease in early life stages of white sucker (*Catostomus commersoni*) exposed to oil sands. *J Toxicol Environ Health A* 69:967–994.
26. Tetreault GR, McMaster ME, Dixon DG, Parrott JL (2003) Using reproductive endpoints in small forage fish species to evaluate the effects of Athabasca oil sands activities. *Environ Toxicol Chem* 22:2775–2782.
27. Timoney K (2007) *A Study of the Water and Sediment Quality as Related to Public Health Issues, Fort Chipewyan, Alberta*. (Treeline Ecological Research, Edmonton, AB, Canada).
28. Sharma M, McBean EA (2001) PAH deposition to snow surface. *Environ Sci Pollut Res* 8:11–18.
29. Meyer T, Wania F (2008) Organic contaminant amplification during snowmelt. *Water Res* 42:1847–1865.
30. RAMP (Regional Aquatics Monitoring Program) (2009B) Appendices. *2008 Technical Report* (Hatfield Consultants, Kilgour and Associates Ltd., Klohn Crippe Berger Ltd., and Western Resource Solutions).
31. Scott WB, Crossman EJ (1998) *Freshwater Fishes of Canada* (Galt House Oakville, ON, Canada).
32. Newsted JL, Giesy JP (1987) Predictive models for photoinduced acute toxicity of polycyclic aromatic hydrocarbons to *Daphnia magna*, Strauss (Cladocera, Crustacea). *Environ Toxicol Chem* 6:445–461.
33. Vehniainen ER, Hakkinen J, Oikari A (2003) Photoinduced lethal and sublethal toxicity of retene, a polycyclic aromatic hydrocarbon derived from resin acid, to coregonid larvae. *Environ Toxicol Chem* 22:2995–3000.
34. Xie F, et al. (2006) Assessment of the toxicity of mixtures of copper, 9,10-phenanthrenequinone, and phenanthrene to Daphnia magna: Evidence for a reactive oxygen mechanism. *Environ Toxicol Chem* 25:165–174.
35. Evans M (2003) Assessment of natural and anthropogenic impacts of oil sands contaminants within the northern river basins, Long-range Transport of Hydrocarbons to the Northern Deltas and Lakes: Pathways and Fate. *Assessment of Natural and Anthropogenic Impacts of Oil Sands Contaminants Within the Northern River Basins - Final Summary Report - Task 5: Hydrocarbons/oil sands and heavy oil research and development*, Brua RB, Cash KL Culp JM. Submitted to the Panel on Energy Research and Development (Environment Canada, Saskatoon, Saskatchewan, Canada).
36. Akre CJ, Headley JV, Conly FM, Peru KM, Dickson LC (2004) Spatial patterns of natural polycyclic aromatic hydrocarbons in sediment in the lower Athabasca River. *J Environ Sci Health A* 39:1163–1176.
37. French-McCay DF (2004) Oil spill impact modeling: Development and validation. *Environ Toxicol Chem* 23:2441–2456.
38. Conly FM, Crosley RW, Headley JV (2002) Characterizing sediment sources and natural hydrocarbon inputs in the lower Athabasca River, Canada. *Environ Eng Sci* 1:187–199.
39. ESRI (Environmental Systems Research Institute (2006) *ArcGIS: Release 9.2* (Environmental Systems Research Institute, 1999–2006, Redlands, CA), www.esri.com.
40. Short JW, Jackson TJ, Larsen ML, Wade TL (1996) Analytical methods used for the analysis of hydrocarbons in crude oil, tissues, sediments, and seawater collected for the natural resources damage assessment for the Exxon Valdez oil spill. *Am Fish Soc Symp* 18:140–148.

Appendix XIII:

Erin Kelly et al., “Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries” in (September 14, 2010) 107 Proceedings of the National Academy of Sciences 37, 16178-16183

Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries

Erin N. Kelly[a], David W. Schindler[a,1], Peter V. Hodson[b], Jeffrey W. Short[c], Roseanna Radmanovich[a], and Charlene C. Nielsen[a]

[a]Department of Biological Sciences, University of Alberta, Edmonton, AB, Canada T6G 2E9; [b]Department of Biology and School of Environmental Studies, Queen's University, Kingston, ON, Canada K7L 3N6; and [c]Oceana, Juneau, AK 99801

Contributed by David W. Schindler, July 2, 2010 (sent for review March 2, 2010)

We show that the oil sands industry releases the 13 elements considered priority pollutants (PPE) under the US Environmental Protection Agency's Clean Water Act, via air and water, to the Athabasca River and its watershed. In the 2008 snowpack, all PPE except selenium were greater near oil sands developments than at more remote sites. Bitumen upgraders and local oil sands development were sources of airborne emissions. Concentrations of mercury, nickel, and thallium in winter and all 13 PPE in summer were greater in tributaries with watersheds more disturbed by development than in less disturbed watersheds. In the Athabasca River during summer, concentrations of all PPE were greater near developed areas than upstream of development. At sites downstream of development and within the Athabasca Delta, concentrations of all PPE except beryllium and selenium remained greater than upstream of development. Concentrations of some PPE at one location in Lake Athabasca near Fort Chipewyan were also greater than concentration in the Athabasca River upstream of development. Canada's or Alberta's guidelines for the protection of aquatic life were exceeded for seven PPE—cadmium, copper, lead, mercury, nickel, silver, and zinc—in melted snow and/or water collected near or downstream of development.

oil sands mining | oil sands processing | trace metals | airborne deposition | water contamination

Bitumen production in the Alberta oil sands increased from 482,000 to 1.3 million barrels/d between 1995 and 2008 (1, 2) and is projected to double by 2020 (3). By 2008, mining had disturbed 530 km^2 of boreal landscape, with tailings ponds covering more than 130 km^2 (4, 5). Development of the oil sands, including mining, processing, and tailings pond leakage, has raised concerns about pollution of the Athabasca River (AR) (5, 6). Downstream residents fear that increased cancer rates (7) may be related to pollution from the oil sands industry. Based in part on results from the Regional Aquatic Monitoring Program (RAMP), industry, government and related agencies claim that human health and the environment are not at risk from oil sands development (8, 9) and that sources of elements and polycyclic aromatic compounds (PAC) in the AR and its tributaries are natural (10). However, the reliability of RAMP findings has been questioned repeatedly (11–13). Hence, accurate, independent assessments of the effects of the oil sands industry on concentrations of toxic elements in the AR and its tributaries are unavailable.

The north-flowing AR, its tributaries, the Athabasca Delta (AD), and Lake Athabasca (LA) (figure 1 in reference 13) were investigated to test the hypothesis that increased concentrations of elements in these waterbodies are entirely from natural sources. In February and June 2008, surface water was collected from 37 and 47 sites, respectively. In March, the accumulated winter snowpack was sampled at 31 sites. Sites on the AR were chosen upstream or downstream of oil sands mining and processing activity. Upstream sites and all sites near oil sands development are exposed directly to the McMurray Geologic Formation (McMF), where most oil sands occur (13). Using 2006 Landsat imagery, three sites along each of four tributaries affected by oil sands development were chosen. The first was located upstream of oil sands development and the McMF, the second was midstream within the McMF but upstream of mining, and the third was near stream mouths above the confluence with the AR, downstream of development and downstream of or within the McMF. Comparable sites were selected on two undeveloped reference tributaries. To increase statistical power, additional stream mouth sites, with and without upstream development, were sampled in June. Here we present results for the 13 elements on the US Environmental Protection Agency (EPA) list of priority pollutants (PPE): Sb, As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag, Tl, and Zn.

Based on 2008 Landsat imagery, it was determined that some midstream and stream mouth sites that were undeveloped in 2006 had been developed by the oil sands industry by 2008. To assess the effects of development on the AR and its tributaries, digital disturbance data [change analysis of forest ecozones within Alberta (1991–2001) and Canada access (roads, mines, forest fragments, and reservoirs buffered by 500 m), and the extent of oil sands development in 2008 (14)] were merged using geographic information system (GIS) software to create an index of relative overall land disturbance. Based on the percentage of disturbed area, each watershed was classified as either less disturbed (<25%) or more disturbed (>25%).

In addition to watershed disturbance, the process of upgrading bitumen to synthetic crude oil involves coking, coke combustion, and production of wastes and fly ash that contain PPE (15–17). Environment Canada's National Pollutant Release Inventory shows that upgrading is a substantial and increasing source of PPE to air.

Some PPE are of particular concern in the lower AR. There is a fish consumption advisory for Hg in walleye (*Sander vitreus)* (18), and the toxicity of PAC discharged by oil sands development (13) can be increased by coexposure to As (19, 20). Concern also exists over Sb, As, Cd, Cr, Cu, Pb, Ni, and Se concentrations in water and/or sediment from the AR (12).

Results

Deposition of PPE in Snow. Four deposition patterns were identified for particulate (Dataset S1) and dissolved (Dataset S2) PPE in snow. PPE with deposition masses that decreased exponentially with distance from upgrading facilities near site AR6, similar to

Author contributions: E.N.K., D.W.S., P.V.H., and J.W.S. designed research; E.N.K. and R.R. performed research; E.N.K. and C.C.N. analyzed data; and E.N.K., D.W.S., P.V.H., and J.W.S. wrote the paper.

The authors declare no conflict of interest.

Freely available online through the PNAS open access option.

[1]To whom correspondence should be addressed. E-mail: d.schindler@ualberta.ca.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1008754107/-/DCSupplemental.

particulates and PAC (13), were classified as type 1 (Fig. 1*A*). These PPE include Pb, Hg, Ni, and Be associated with particulates. PPE with deposition patterns in which masses deposited decreased exponentially with distance from upgrading facilities (like type 1) but also increased locally near oil sands development because of land clearing, mining, road dust, or other emissions were classed as type 2 (Fig. 1*A*). PPE in this class include particulate Sb, As, Cd, Cr, Cu, Ag, Tl, and Zn and dissolved Sb, Cr, Cu, Ni, Tl, and Zn. Deposition of some PPE was from local sources only and was classified as type 3 (Fig. 1*A*). Type 3 PPE included dissolved Cd, Pb, and Hg. PPE that were not detected either in particulate (Se) or in dissolved form (As, Be, Se, Ag) were classified as type 4.

Sites were designated as background (BG) or near development (ND), depending on their location and deposition, for each PPE. For PPE with type 1 deposition, all sites within 50 km of the upgraders at AR6 were considered ND, and all sites more than 50 km away were considered BG (Datasets S1 and S2). However, Be exhibited type 1 deposition only within 2 km of AR6, and the designations of ND or BG were adjusted accordingly. For PPE with type 2 or 3 deposition patterns, the magnitude of deposition near oil sands development varied among sites and PPE. These differences reflect the wide variety of possible sources and the chemical-physical properties of each element. Hence, each particulate and dissolved PPE was graphed in order of descending deposition, and for each PPE the difference between ND and BG was defined as the point between a marked decrease in deposition from sites ND and consistent deposition at BG sites (*SI Text*). Occasionally, concentrations of PPE greater than BG were observed at sites distant from oil sands development, such as the northernmost AR, AD, or LA sites. Based on distance, these greater concentrations probably were from local sources unrelated to oil sands mining and processing. Thus, these sites were designated BG.

Particulate-bound PPE deposition in snow. Upgrading facilities were identified as a source of particulate PPE. The mean deposition of type 1 and 2 PPE at sites ND was up to 30-fold greater than BG (two-sample t test; $P < 0.05$; Fig. 1*B* and Fig. S1*A*), and maximum deposition was as much as 120-fold greater than BG. Some PPE, such as As, Be, Cu, and Tl, were detected only at sites ND (Fig. 1*B* and Dataset S1), with maximum concentrations at site AR6. Although mean Cr deposition was 14-fold greater than BG at sites ND, these concentrations were not quite significantly different from BG (two-sample t test; $P = 0.06$) (Fig. 1*B*, Fig. S1*A*, and Dataset S1).

Type 1 particulate PPE deposition in snow was correlated with deposition of particulate PAC (13) ($r^2 > 0.8$, except for Hg, $r^2 = 0.5$; all $P < 0.002$). Estimated total depositions of Pb, Hg, and Ni over 4 mo at sites within a 50-km radius of site AR6 were 162, 1.1, and 583 kg, respectively (*SI Text* and Dataset S1).

Local inputs of PPE with type 2 deposition caused by oil sands development were discernible as far as 85 km from site AR6 (Fig. 1*A*, Fig. S1*A*, and Dataset S1), with mean and maximum loadings as much as 28- and 169-fold greater than at BG sites, respectively (Fig. 1*B*).

Dissolved PPE deposition in snow. Deposition of dissolved PPE in snow generally was less than that of particulate PPE (Fig. 1 and Datasets S1 and S2). Dissolved PPE with a type 2 deposition pattern, including Ni, Sb, Cr, Cu, Tl, and Zn, were as much as 5-fold greater than BG at ND sites (Fig. 1*B*, Fig. S1*B*, and Dataset S2), with maxima at sites other than AR6. Deposition of dissolved Cd, Pb and Hg, with a type 3 pattern, were as much as

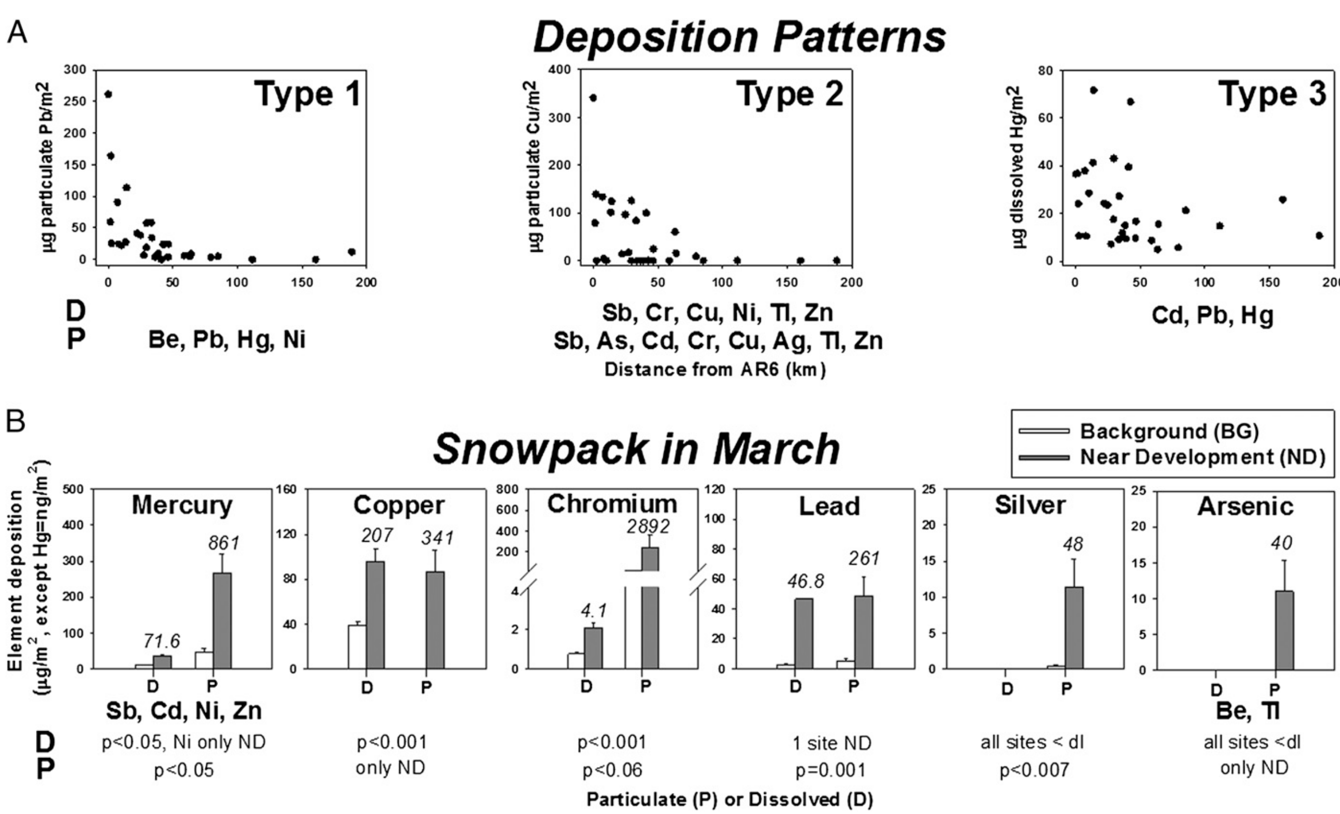


Fig. 1. Snow deposition patterns (*A*) and deposition of PPE in snowpack collected in March (*B*). D, dissolved. P, particulate. (*A*) Type 1, exponential decline from upgrading facilities; Type 2, exponential decline from AR6 and local sources; Type 3, local sources only. (*B*) Dissolved and particulate deposition expressed in µg/m^2 (except Hg, which is expressed in ng/m^2). Data are presented as mean ± SE BG sites (white bars) and ND sites (gray bars). The numbers above the gray bars represent the maximum value near development. The distribution of elements listed below each panel is similar to that in the panel above, and statistics refer to all elements with similar distributions. dl, detection limit.

18-fold greater than BG at ND sites (Fig. 1*B*, Fig. S1*B*, and Dataset S2). Sites with the greatest concentrations of Sb, Cd, Cr, Cu, Pb, Tl, and Zn were not always the same as sites with the greatest deposition (Dataset S2), because snow depth and density were greater at some ND sites.

Deposition of dissolved type 2 and 3 PPE (Fig. 1*A*, Fig. S1*B*, and Dataset S2) was greater than established BG concentrations as far as 85 km from AR6. This finding is consistent with the presence of localized sources of PPE in addition to upgraders (Fig. 1 *A* and *B*, Fig. S1*B*, and Dataset S2).

PPE in Tributaries. In all six tributaries sampled, concentrations of PPE in water did not increase significantly from upstream sites outside the McMF to midstream and stream mouth sites within the McMF in either summer or winter (Dataset S3). Thus, PPE concentrations were unaffected by contact of river water with the McMF and were unrelated to the proportion of McMF within each watershed in summer or winter ($r^2_{McMF} < 0.2$; $P > 0.2$; df = 26). Differences among sites were not statistically significant, even in three tributaries with almost all development near stream mouths (two-way ANOVA; Dataset S3), and PPE concentrations sometimes were greater at sites upstream of the McMF than at midstream sites within the McMF. Within the McMF, concentrations of seven PPE increased up to 5-fold from midstream to stream mouth sites in summer, but not in winter, although differences were not significant (paired *t* test; Dataset S3). PPE concentrations during low flow under ice often were greater than in summer (Dataset S3).

In contrast, concentrations of some PPE in tributary water increased significantly near oil sands development and were significantly correlated with overall land disturbance (e.g., Cd, Zn: $r^2_{disturbance} = 0.2$ and 0.3; $P = 0.05$ and $P < 0.01$, respectively; df = 18) and with the proportion of oil sands development within a watershed (e.g., Cd, Ni: $r^2_{oil\ sands} = 0.4$ and 0.3; $P \leq 0.01$ and 0.02, respectively; df = 18). Concentrations of some PPE in winter, such as Hg, Ni, and Tl, were as much as 2-fold greater in watersheds with more development (two-way ANOVA and two-sample *t* test; $P < 0.02$; Fig. 2*A*, Fig. S1*C*, and Dataset S4) than in less developed watersheds. In summer, concentrations of PPE in watersheds exposed to >25% overall development were as much as 8-fold greater than in less developed watersheds (two-way ANOVA and two-sample *t* test; $P < 0.02$; Fig. 2, Fig. S1*C*, and Dataset S4).

At all midstream and stream mouth sites, Sb, Cd, Cr, Pb, Ni, Ag, and Zn concentrations were greater in winter (two-way ANOVA; $P < 0.03$), whereas Hg concentrations were greater in summer ($P < 0.002$). At more disturbed sites, concentrations of As, Be, Hg, and Se were greater in summer than in winter, but at less disturbed sites only Hg was more concentrated in summer. Similar patterns were observed when only stream mouth sites were considered (Dataset S4).

PPE in the Athabasca River, Athabasca Delta, and Lake Athabasca. Neither summer nor winter concentrations of PPE in the AR at sites upstream from or near development were related significantly to the proportion of McMF within a watershed. Cd was an exception, with concentrations inversely related to McMF in winter ($r^2_{McMF} = 0.4$; $P = 0.05$; df = 8). In contrast, Zn concentrations in the AR during winter were related to the proportion of overall land disturbance within a watershed ($r^2_{disturbance} = 0.7$; $P < 0.002$; df = 8).

In winter, concentrations of Cr, Hg, Ni, and Ag in the AR under ice were up to 8-fold greater just downstream of tailings ponds, impoundments, or other oil sands development infrastructure than upstream. Hg remained slightly increased (1.5-fold) downstream and in the AD. However, none of the concentrations downstream was significantly greater than upstream (two-way and one-way ANOVA; $P > 0.05$; Fig. 3, Fig. S1 *D*, *E*, and *F*, and Dataset S5), probably because of low statistical power ($\beta < 0.171$). In summer, concentrations of Sb, As, Cr, Cu, Pb, Hg, and Ni, were up to 4-fold greater in the AR near oil sands development than upstream (one-way ANOVA, $P < 0.01$; multiple comparison, $P < 0.05$; Fig. 3, Fig. S1*D*, and Dataset S6). Concentrations of Be, Se, Ag, Tl and Zn were detectable near oil sands development but not upstream (Fig. 3, Fig. S1*D*, and Dataset S6).

Downstream of the oil sands development, and extending as far as the AD, concentrations of many PPE remained significantly greater than upstream (Sb, As, Cr, Cu, Pb, Hg, Ni; one-way ANOVA, $P < 0.02$; multiple comparison, $P < 0.05$; Fig. 3, Fig. S1*E*, and Dataset S6). Ag, Tl, and Zn were detectable only near oil sands development and in the AD (Fig. 3, Fig. S1*D*, and Dataset S6). At LA, near the AR discharge, concentrations of eight PPE were as much as 2-fold greater than upstream of oil sands development (Sb, As, Cd, Cr, Cu, Pb, Hg, Ni; Fig. 3, Fig. S1*F*, and Dataset S6). Within the AR and AD, concentrations of Cr, Cu, Pb, Hg, Ni, and Tl were greater in summer than winter (two-way ANOVA; $P < 0.02$; Dataset S5), but concentrations of Zn were greater in winter (two-way ANOVA; $P < 0.004$; Dataset S5).

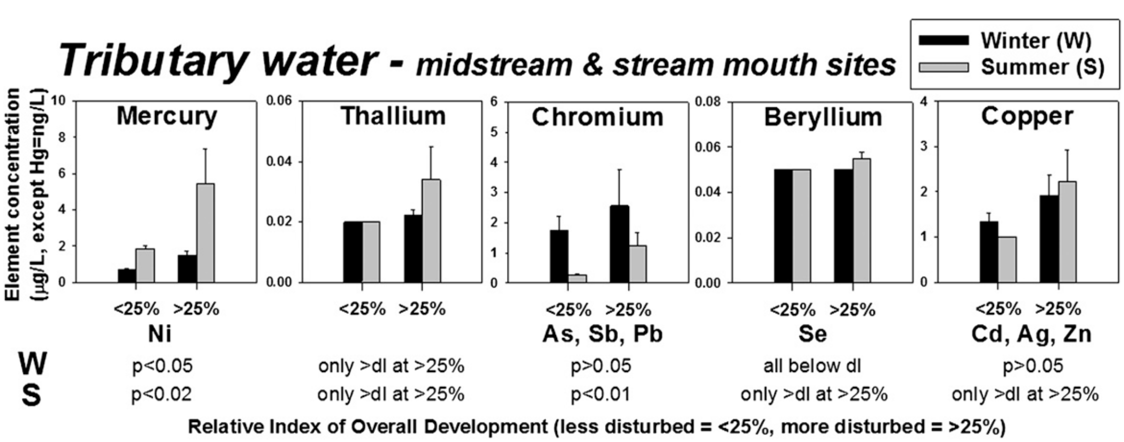


Fig. 2. Element concentrations (mean ± SE, expressed in μg/L, except for Hg, which is expressed in ng/L) in water from midstream and tributary mouth sites by relative index of overall disturbance by development: <25%, less disturbed; >25%, more disturbed. Black bars, winter (W); gray bars, summer (S). dl, detection limit; only >dl at >25%, above dl only at more disturbed sites. The distribution of elements listed below panels is similar to that in the panel above, and statistics refer to all elements with similar distributions.

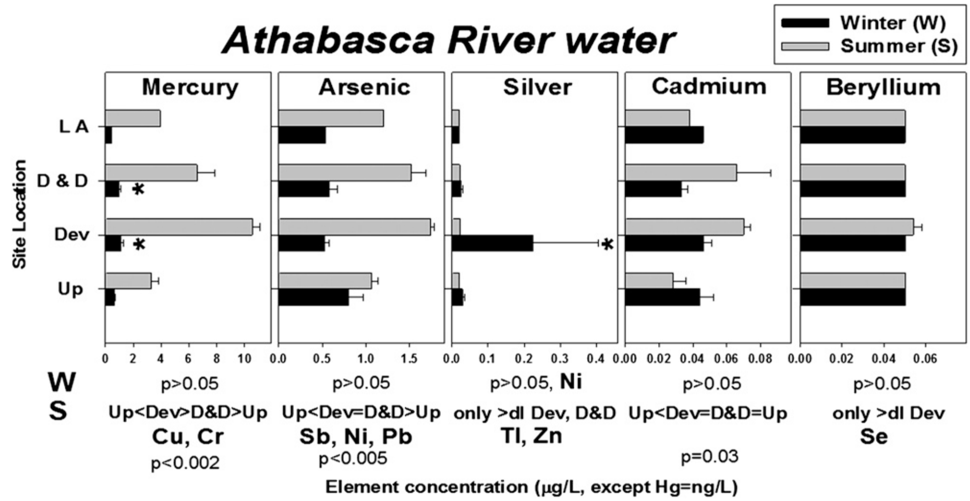


Fig. 3. Element concentrations (mean ± SE, expressed in μg/L, except for Hg, which is expressed in ng/L) in water from the AR collected in winter (W, black bars) and summer (S, gray bars). Up, AR upstream ($n = 3$); Dev, AR downstream/near development ($n = 7$); D&D, AR downstream and Athabasca Delta ($n = 6$); LA, Lake Athabasca ($n = 1$); dl, detection limit and only >dl Dev, greater than dl only at sites near development. *Increases near development and downstream that were not statistically significant (power $\beta < 0.171$). The distribution of elements listed below panels is similar to that in the panel above, and statistics refer to all elements with similar distributions.

Discussion

Oil sands development releases significant masses of PPE to the AR and its watershed via air and water, confirming major transport pathways previously identified for PAC (13). Deposition patterns of PAC (13) and type 1 and 2 PPE were similar and were consistent with oil sands upgraders being an atmospheric source. In contrast to PAC, type 2 and 3 deposition patterns for PPE were consistent with local sources of airborne PPE. Local sources of PPE were identified as far as 85 km from AR6, indicating that PPE contamination is more widespread than PAC. In the AR and its tributaries, PPE were related to overall land disturbance, whereas PAC contamination was caused primarily by new development (13). Concentrations of PPE downstream of development on the AR, within the AD, and as far as one location on LA remained greater than upstream concentrations. Thus, during summer, PPE contamination was measurable further from the source than PAC.

Airborne Contaminants. Within 50 km of upgrading facilities (AR6), 11,400 metric tons of airborne particulates were deposited in 2008 during ~4 mo of snowfall (figure 2 of ref. 13). The majority of the particulates consisted of oil sands bitumen, as indicated by the large proportion of oil per unit particulate mass and similar distributions of PAC and PPE in oil sands and particulates (figure S2 a and b in ref. 13). Differential fractionation of PPE during upgrading and low solubility of some elements in water may be responsible for any differences in the distribution of PPE in oil sands and in particulates (Fig. S2 *A* and *B*). Coke and fly ash from upgraders contain significant amounts of Ni and elements other than PPE, and relative concentrations of elements in ashed coke and fly ash (16, 17) are similar to those in snow particulates. Particulate elements decline more rapidly with distance from AR6 than do dissolved elements. Thus, partitioning between phases likely occurred before emission rather than after melting of snow (Datasets S1 and S2).

Type 2 and 3 deposition patterns implicate local sources, such as land clearing, mining, road dust, and other emissions related to oil sands development, as substantial additional sources of PPE contamination (Datasets S1 and S2). Oil sands industries have emitted airborne PPE for at least 30 y. Increased deposition attributed to fly ash was found 25 km north and south and 10 km east and west of upgrading facilities during snow surveys in 1978 and 1981 (21, 22). Deposition declined from 1978 to 1981 after installation of precipitators (22). By 2008, the area contaminated by particulates was nearly 2-fold larger than in 1978–1981. Deposition of particulates was about 34,000 metric tons in 2008, five times greater than emission inventories and close to annual deposition rates before precipitators (13).

Although no PPE were measured in earlier studies, deposition of other elements (e.g., total K, Na, and Ca and dissolved Al) was significantly greater in 2008 than in 1978, before installation of precipitators (paired t test; $P < 0.006$) and was greater than in 1981, after installation ($P < 0.04$). In contrast, deposition of particulate Al, V, and Ti and dissolved V was significantly lower in 2008 than in 1978/1981 ($P < 0.03$; *SI Text*). Hence, the success of technologies in controlling different elements appears uneven, although differences among studies also may relate to site, sampling, and analytical differences.

Nonetheless, excessive deposition of elements has occurred for more than 30 y, and emissions of As, Pb, and Hg to the air by Suncor and Syncrude increased ~3-fold between 2001 and 2008 (23). Our estimates of the annual particulate deposition of Pb, Hg, and Ni, integrated within a 50-km radius of AR6, were 36%, 96%, and 59% lower, respectively, than reported annual emissions. This difference probably indicates that some emissions are deposited outside the 50-km radius. Hg concentrations in fishes respond rapidly to changes in atmospheric deposition of Hg (24); these changes are of concern because Hg concentrations in fishes from the AR and AD are already high (18).

Riverborne Contaminants. Similarities between the relative concentrations of PPE in snow and river water link emissions of airborne elements to the AR and its tributaries (Fig. S2 *C* and *D*). PPE in the snow pack probably were released as a pulse during spring melt. In summer, PPE are deposited directly to waterbodies and the watershed. During snowmelt and rain events, elements are discharged to surface waters, but a proportion is retained in soil and vegetation. Particulate and dissolved Ni best represent the type 1 deposition pattern. In summer, when direct deposition of airborne contaminants to the river occurs, Ni concentrations are strongly correlated with concentrations of all other PPE in the AR and its tributaries ($r^2 > 0.8$, except Ag = 0.5; $P < 0.001$). In winter, when airborne elements are deposited to snow on river ice, particulate deposition of all PPE except Se declines exponentially

ENVIRONMENTAL SCIENCES

from AR6, although some also are affected by local sources. In river water under ice, concentrations of Ni were not correlated with other PPE, suggesting that concentrations under ice reflect inputs from erosion or effluent discharge, not atmospheric sources. Concentrations of three PPE and four other elements known to be increased in oil sands process water are much greater in the AR only near tailings ponds or oil sands development in winter. This finding suggests tailings pond leakage or discharge as sources of elements to the AR.

The pattern of increased PPE concentrations in snow and the river system does not support the claim that contamination of the AR and its tributaries is only from natural erosion of oil sands. Concentrations of PPE did not increase significantly as water flowed through the McMF from midstream to stream mouth sites, in winter or summer (Dataset S3), and element concentrations in bottom and suspended sediments of tributaries did not reflect greater exposure to natural oil sands (25). Previous records of upstream-to-downstream trends in waterborne Ni and Zn concentrations during high flow (26) probably reflect runoff of snowmelt and rain from disturbed areas or areas contaminated by atmospheric deposition.

Instead, our results indicate that the source of PPE was from oil sands development. In tributaries, overall land disturbance caused a major flux of PPE to water (Fig. 2 and Dataset S4). In summer, increased concentrations of many PPE were significantly related to development at midstream and tributary mouth sites (Fig. S1 and Dataset S4). At less disturbed tributary sites, concentrations of most PPE were greatest under winter ice (Dataset S4). However, at more disturbed tributary sites, concentrations of several PPE were greater in summer than winter (Dataset S4), indicating the impact of land disturbance. If the source were natural erosion of oil sands, concentrations at all sites would have been greater in summer than winter.

In the AR, PPE concentrations were greater downstream of oil sands development, particularly in summer, and many remained increased over upstream concentrations at downstream and AD sites (Fig. 3 and Dataset S6). This increase may be the result of natural increases in BG concentrations downstream, based on the river continuum concept (27). However, among all PPE, the pattern of increases over upstream concentrations in the AD and LA was similar to increases ND (Fig. S1), indicative of a persistent anthropogenic signal with oil sands development as the most likely source. Long-term trends (1989–2006) at an AR site downstream of oil sands development show that metal concentrations generally decreased, but with no significant trends after flow adjustment except for a decline in Pb (28). In contrast, from 1960–2007, stream flow and concentrations of three elements decreased, but turbidity, nutrients, As, and Al increased at Old Fort, just within the AD, probably because of anthropogenic disturbance (29). In sediments, metal concentrations increased downstream to the AD and LA (30), indicating deposition of suspended particulates in the meandering channels of the AD.

Increased airborne deposition of elements for ~40 y probably has increased PPE and PAC (13) concentrations in surface soils, vegetation, snow, and runoff over a broad area of boreal forest. Although RAMP has sampled snow for hydrologic monitoring (31), pollutant concentrations were not reported, despite past recommendations for regional monitoring of contaminants in snow (21, 22). Given the lack of detailed long-term monitoring, it is difficult to tell how much upstream concentrations have increased over true BG as the result of long-term airborne deposition (13). Previously, concentrations of several elements in tributaries to the AR have exceeded guidelines for the protection of aquatic life during spring (26). These concentrations were thought to be natural and useful as baseline data to assess future emissions (26). However, reaches of these tributaries are within 50 km of AR6, where we show that deposition of many elements to snow is increased. Emissions from new and expanded upgrading facilities will further increase regional BG concentrations.

Concentrations of Cd, Cu, Pb, Hg, Ni, Ag, and Zn in melted snow and in tributary and AR water exceeded guidelines for the protection of aquatic life (*SI Text*) to the greatest extent at sites near development (Fig. S3). For example, seven PPE exceeded guidelines in snow at ND sites, whereas only Cd exceeded guidelines at some BG sites (Fig. S3). Cd in snow was 200- and 30-fold greater than the hardness-dependent and interim guidelines, respectively, of the Canadian Council of Ministers of the Environment (CCME) Water Quality Guidelines for the Protection of Aquatic Life, and Ag was 13-fold greater than CCME guidelines at one AR site in February (Fig. S3) (32). Other highly toxic metals (Cd, Cu, Pb, Hg, Ni, and Zn) exceeded guidelines by up to 5-fold (Fig. S3). Guidelines were exceeded more often in summer than in winter at AR sites.

Similarly, guidelines were exceeded during the spring freshet (26), when metals should be most toxic because water hardness decreases from >100 mg/L to <5 mg/L. For example, under these conditions, the CCME guideline of 2–4 μg Cu/L would be acutely lethal to minnow embryos (33), creating an annual risk of recruitment failure for 19 fish species that spawn in the AR and its tributaries in spring or early summer (34). Metal mixtures also can act synergistically (35), and some PPE potentiate PAC toxicity to aquatic organisms (19).

PPE concentrations in melted snow and in tributary and AR water did not exceed drinking water quality guidelines (Fig. S3). Nevertheless, increased deposition of elements considered priority pollutants under the US EPA Clean Water Act are of concern to human health. As indicated, a fish consumption advisory exists for Hg in walleye from the AR (18), and the AD wetlands provide an increased potential for Hg methylation (36). Links have been proposed between diseases prevalent in Fort Chipewyan and the carcinogenicity of PAC (6, 12). Effects of PAC can be potentiated by coexposure to As (20), which is above BG concentrations downstream of development as far as the AD. Also, high loadings of Cd to snow may present health risks because moose bioaccumulate Cd in liver and kidneys, reflecting regional distributions of Cd in vegetation (37). Monitoring PPE in vegetation and country foods where oil sands emissions fall on aboriginal treaty lands is essential.

Conclusions. Contrary to claims made by industry and government in the popular press, the oil sands industry substantially increases loadings of toxic PPE to the AR and its tributaries via air and water pathways. This increase confirms the serious defects of RAMP (11–13), which has not detected such patterns in the AR watershed. Detailed long-term monitoring is essential to distinguish the sources of these contaminants and control their potential impacts on environmental and human health (13). A robust monitoring program to measure exposure and health of fish, wildlife, and humans should be implemented in the region affected by oil sands development (38, 39).

Methods

Study Design. Sites were selected to distinguish contributions of oil sands development or natural sources to element loading. A detailed description of the study design, GIS analyses, and a study area map can be found in (13).

Field Sampling. Snow was collected from 12 sites on the AR, AD, and LA and from 19 tributary sites in March 2008. To calculate areal deposition rates of elements, snow cores were collected as described in (13). An integrated sample of the snowpack was collected for Hg and other elements with a plastic shovel, acid-washed Teflon scraper, and an acid-washed Teflon scoop. Samples were placed into acid-washed 2-L Teflon jars (Hg) or acid-washed wide-mouthed high-density polyethylene bottles (other elements) and stored frozen until analysis.

In February and June unfiltered water samples were collected at all sites for analysis of Hg and 30 other elements using an ultraclean sampling protocol (40). Hg samples were acidified 500:1 with concentrated trace metal grade HCl. For other elements, 250-mL samples were acidified with 0.5 mL of optima grade nitric acid. Duplicates, a trip blank, and six field blanks were included in both winter and summer sampling campaigns. Oil sands sampling is described in (13).

Laboratory. Snow was melted and filtered through 0.45-μm glass fiber filters. Filters were dried, and the mass of particulate was determined. Unfiltered (total) snow and river water and filtered (dissolved) snow samples were analyzed for Hg at the University of Alberta Low-Level Mercury Analytical Laboratory by cold vapor atomic fluorescence spectrometry (CVAFS). Samples were analyzed for other elements at the Queen's University Analytical Services Unit using inductively coupled plasma atomic emission spectroscopy with an ultrasonic nebulizer (ICP-AES) and at the Royal Military College Analytical Sciences Group using ICP-MS. Both laboratories are accredited by the Canadian Association for Laboratory Accreditation to International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) standard 17025. Concentrations of elements in particulates were calculated as: particulate = total − dissolved.

Samples of oil sands were analyzed for elements at the Université du Québec á Rimouski Laboratoire de Chimie Marine et Spectrométrie de Masse, Institut des Sciences de la Mer de Rimouski, by ICP-MS.

Analytical and Statistical Methods. To compare the relative importance of natural erosion and mining on element mobilization, element concentrations in water were regressed against the proportion of the watershed within the McMF, overall land disturbance, and land disturbed by oil sands mining in 2008. These comparisons were made for all tributaries combined and separately for the AR.

Details of analyses for Hg and other elements, quality assurance/quality control, treatment of samples below the detection limit (<dl), source identification of elements in snow, calculations of area-wide element deposition, designation of BG versus impacted for snow, percent above dl calculations, comparison with historical element-loading in snow, comparison with guidelines, and statistical methods are provided in *SI Methods*.

ACKNOWLEDGMENTS. K. Timoney, R. Grandjambe, B. Fortin, R. Ladouceur, S. Laurent, T. Boag, P. Jordan, K. Vladicka-Davies, M. Davies, H. La, A. Rutter, D. Kelly, and R. Saint-Louis provided assistance with planning, field work, and/or laboratory analyses. Parks Canada and the Government of Alberta Sustainable Resource Development granted research permits. The Athabasca Chipewyan, Mikisew Cree, and Fort MacKay First Nations and Métis provided ecological knowledge and access to traditional territories. M. Hanneman and P. Lee supplied GIS data and defined watersheds. The Tides and the Walter and Duncan Gordon Foundations funded this work.

1. Energy Resources Conservation Board (ERCB) (2005) Alberta's reserves 2004 and supply/demand outlook 2005-2014. ST98-2005, Power Point file of graphs and data from 2005 report.http://www.ercb.ca/portal/server.pt/gateway/PTARGS_0_0_308_265_0_43/http%3B/ercbContent/publishedcontent/publish/ercb_home/publications_catalogue/publications_available/serial_publications/st98.aspx. Accessed September 15, 2009.
2. Energy Resources Conservation Board (ERCB) (2009) Alberta's energy reserves 2008 and supply/demand outlook 2009-2018. ST98-2009, Power Point file of graphs and data from 2009 report.http://www.ercb.ca/portal/server.pt/gateway/PTARGS_0_0_308_265_0_43/http%3B/ercbContent/publishedcontent/publish/ercb_home/publications_catalogue/publications_available/serial_publications/st98.aspx. Accessed September 15, 2009.
3. Canadian Association of Petroleum Producers (CAPP) (2009) *Crude Oil Forecast, Markets and Pipeline Expansions* (Canadian Association of Petroleum Producers, Calgary, AB, Canada).
4. Government of Alberta (2008) *Environmental Management of Alberta's Oil Sands* (Oil Sands Management Division, Edmonton, AB, Canada).
5. Price M (2008) *11 Million Litres a Day: The Tar Sands' Leaking Legacy* (Environmental Defense, Toronto).
6. Timoney KP, Lee P (2009) Does the Alberta tar sands industry pollute? The scientific evidence. *Open Conservation Biology Journal* 3:65–81.
7. Chen Y (2009) *Cancer Incidence in Fort Chipewyan, Alberta 1995-2006* (Alberta Cancer Board, Division of Population Health and Information Surveillance, Alberta Health Services, Edmonton, AB, Canada).
8. Alberta Oil Sands Community Exposure and Health Effects Assessment Program (HEAP) (2000) Summary report. Health Surveillance, Alberta Health and Wellness, Government of Alberta, Edmonton, AB, Canada.http://www.health.alberta.ca/newsroom/pub-environmental-health.html. Accessed October 28, 2009.
9. Wood Buffalo Environmental Association Human Exposure Monitoring Program (HEMP) (2007) Methods report and 2005 monitoring year results. Wood Buffalo Environmental Monitoring Association, Fort McMurray, AB, Canada.http://www.health.alberta.ca/newsroom/pub-environmental-health.html. Accessed October 28, 2009.
10. Regional Aquatics Monitoring Program (RAMP) Wood Buffalo Environmental Association (WBEA), (Cumulative Environmental Management Association) (CEMA) (2008). *Joint Community Update 2008 Reporting our Environmental Activities to the Community* (RAMP, WBEA, and CEMA, Fort McMurray, AB, Canada).
11. Ayles GB, Dubé M, Rosenberg D (2004) *Oil Sands Regional Aquatic Monitoring Program (RAMP) Scientific Peer Review of the Five Year Report (1997-2001)* (Fisheries and Oceans Canada, Winnipeg, MB).
12. Timoney K (*2007*) *A Study of Water and Sediment Quality as Related to Public Health Issues, Fort Chipewyan, Alberta* (Nunee Health Board Society, Fort Chipewyan, AB).
13. Kelly EN, et al. (2009) Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. *Proc Natl Acad Sci USA* 106:22346–22351.
14. Global Forest Watch Canada (2009) *Recent anthropogenic changes in Alberta's forest ecozones, Canada_Access_Combined, and Athabasca bituminous sands industrial footprint, 2008: Mapped from Landsat TM Multi-spectral scanner – path 42/Row 20, 19/03/2008 [digital data]*, Available upon request from info@globalforestwatch.ca.
15. Allen EW (2008) Process water treatment in Canada's oil sands industry: I. Target pollutants and treatment objectives. *Journal of Environmental Engineering and Science* 7:123–138.
16. Jack TR, Sullivan EA, Zajic JE (1979) Leaching of vanadium and other metals from Athabasca Oil Sands coke and coke ash. *Fuel* 58:589–594.
17. Jang H, Etsell TH (2006) Mineralogy and phase transition of oil sands coke ash. *Fuel* 85:1526–1534.
18. Government of Alberta (2009) 2009 Alberta Guide to Sportfishing Regulations.http://www.albertaregulations.ca/fishingregs/other-information.html#mercurycontamination. Accessed December 5, 2009.
19. Fleeger JW, Gust KA, Marlborough SJ, Tita G (2007) Mixtures of metals and polynuclear aromatic hydrocarbons elicit complex, nonadditive toxicological interactions in meiobenthic copepods. *Environ Toxicol Chem* 26:1677–1685.
20. Fischer JM, et al. (2005) Co-mutagenic activity of arsenic and benzo[a]pyrene in mouse skin. *Mutat Res* 588:35–46.
21. Barrie LA, Kovalick J (1980) *A Wintertime Investigation of the Deposition of Pollutants Around an Isolated Power Plant in Northern Alberta.* Prepared for the Alberta Oil Sands Environmental Research Program by Atmospheric Environment Service. AOSERP Report 90. 115 p.
22. Murray WA (1981) *The 1981 Snowpack Survey in the AOSERP Study Area.* Prepared for the Alberta Oil Sands Environmental Research Program by Promet Environmental Group. AOSERP Report 125. 115 p.
23. National Pollutant Release Inventory (NPRI) (2010) www.ec.gc.ca/inrp-npri/. Accessed May 13, 2010.
24. Harris RC, et al. (2007) Whole-ecosystem study shows rapid fish-mercury response to changes in mercury deposition. *Proc Natl Acad Sci USA* 104:16586–16591.
25. Conly FM, Crosley RW, Headley JV, Quagraine EK (2007) Assessment of metals in bed and suspended sediments in tributaries of the Lower Athabasca River. *Journal of environmental science and health. Part A, Toxic/hazardous substances and environmental engineering* 42:1021–1028.
26. Headley JV, Crosley B, Conly FM, Quagraine EK (2005) The characterization and distribution of inorganic chemicals in tributary waters of the lower Athabasca River, oil sands region, Canada. *Journal of environmental science and health. Part A, Toxic/hazardous substances and environmental engineering* 40:1–27.
27. Vannote RL, Minshall GW, Cummings KW, Sedell JR, Cushing CE (1980) The River Continuum Concept. *Canadian Journal of Fisheries and Aquatic Sciences* 37:130–137.
28. Glozier NE, Donald DB, Crosley RW, Halliwell D (2009) *Wood Buffalo National Park Water Quality: Status and Trends from 1989-2006 in Three Major Rivers; Athabasca, Peace and Slave* (Prairie and Northern Office, Water Quality Monitoring and Surveillance Division, Water Science and Technology Directorate, Environment Canada, Saskatoon, SK).
29. Hebben T (*2009*) *Analysis of Water Quality Conditions and Trends for the Long-Term River Network: Athabasca River, 1960-2007* (Alberta Environment, Water Policy Branch, Environmental Assurance, Edmonton, AB).
30. Allan R, Jackson TA (1978) *Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area.* Prepared for the Alberta Oil Sands Environ Res Program by Inland Waters Directorate, Fisheries and Environment Canada. AOSERP Report 34 (Alberta Oil Sands Environmental Research Program).
31. Regional Aquatics Monitoring Program (RAMP) (2009) *2008 Final Technical Report* (Hatfield Consultants, Kilgour and Associates Ltd., Klohn Crippe Berger Ltd. and Western Resource Solutions).
32. Canadian Council of Ministers of the Environment (2007) Canadian water quality guidelines for the protection of aquatic life.Summary Table. Update 7.1. December 2007 http://www.ccme.ca/publications/ceqg_rcqe.html?category_id=124. Accessed November 4, 2009.
33. Welsh PG, et al. (1996) Estimating acute copper toxicity to larval fathead minnows in soft water from measurements of dissolved organic carbon, calcium and pH. *Canadian Journal of Fisheries and Aquatic Sciences* 53:1263–1271.
34. Scott WB, Crossman EJ (1998) *Freshwater Fishes of Canada* (Galt House, Oakville, ON), 996 pp.
35. Wah Chu K, Chow KL (2002) Synergistic toxicity of multiple heavy metals is revealed by a biological assay using a nematode and its transgenic derivative. *Aquat Toxicol* 61:53–64.
36. St. Louis VL, et al. (1994) Importance of wetlands as sources of methyl mercury to boreal forest ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences* 51:1065–1076.
37. Glooschenko V, et al. (1988) Cadmium levels in Ontario moose and deer in relation to soil sensitivity to acid precipitation. *Sci Total Environ* 71:173–186.
38. NRBS (Northern River Basins Study) *(1996) Northern River Basins Study Report to the Ministers* (Government of Canada, Alberta, and Northwest Territories).
39. Alberta Health *(1999) Northern River Basins Human Health Monitoring Program Report* (Health Surveillance, Government of Alberta, Edmonton, AB).
40. St. Louis VL, et al. (1996) Production and loss of methylmercury and loss of total mercury from boreal forest catchments containing different types of wetlands. *Environ Sci Technol* 30:2719–2729.

Appendix XIV:

Canada-Alberta Administrative Agreement for the Control of Deposits of Deleterious Substances under the Fisheries Act

Source: http://www.ec.gc.ca/ee-ue/default.asp?lang=En&n=26F90F87-1

Canada-Alberta Administrative Agreement for the Control of Deposits of Deleterious Substances under the Fisheries Act

---

This agreement between

THE GOVERNMENT OF CANADA as represented by the Minister of Fisheries and Oceans and the Minister of Environment (herein referred to as "Canada")

OF THE FIRST PART

AND

THE GOVERNMENT OF ALBERTA as represented by the Minister of Environmental Protection (herein referred to as "Alberta")

OF THE SECOND PART

WHEREAS, both Canada and Alberta recognize that sustainable development and social well-being depend upon the preservation of a high standard of environmental quality;

AND WHEREAS, the Canadian Council of Ministers of the Environment have endorsed the Statement of Interjurisdictional Cooperation on Environmental Matters to provide an overall framework for effective intergovernmental cooperations on environmental matters;

AND WHEREAS, the Canadian Council of Ministers of the Environment have endorsed the National Commitment to Pollution Prevention as a key component of environmental protection and sustainable development;

AND WHEREAS, both Canada and Alberta are committed to minimizing duplication and overlap, and maximizing cooperation and coordination for environmental matters;

AND WHEREAS, Section 5 of the Department of Fisheries and Oceans Act enables the federal Minister of Fisheries and Oceans, with the approval of the Governor in Council, to enter into agreements with a provincial government respecting the carrying out of programs for which the Minister of Fisheries and Oceans is responsible;

AND WHEREAS, Section 7 of the Department of Environment Act enables the federal Minister of Environment, with the approval of the Governor in Council, to enter into agreements with a provincial government respecting the carrying out of programs for which the Minister of Environment is responsible;

AND WHEREAS, Section 20 of the Environmental Protection and Enhancement Act (EPEA) enables the Minister of Environmental Protection to enter into agreements with the Government of Canada relating to any matter pertaining to the environment;

AND WHEREAS, the Governor in Council, by Order in Council P.C. 1994-879, dated May 26, 1994, has authorized the federal Minister of Fisheries and Oceans and the federal Minister of the Environment to enter into this Agreement with Alberta;

NOW THEREFORE, Canada and Alberta agree as follows:

1.0 DEFINITIONS FOR THIS AGREEMENT AND THE ANNEXES HERETO:

"Access to Information Act" means the Access to Information Act R.S. 1985 c. A-1 as amended;

"Agreement" means the Canada - Alberta Administrative Agreement for the Control of Deposits of Deleterious Substances under the Fisheries Act;

"annual report" means the state of the environment report prepared annually pursuant to section 15 of EPEA;

"approval" means an "approval" as defined in section l(f) of EPEA;

"authorization" means an authorization issued under the Pulp and Paper Effluent Regulations (PPER);

"Authorization Officer" means the official named in Column II of Schedule V of the PPER;

"CEPA" means the Canadian Environmental Protection Act; R.S. 1985 c.16 (4th supp.) as amended;

"deleterious substance" means "deleterious substance" as defined in subsection 34(1) of the Fisheries Act;

"deposit" means "deposit" as defined in subsection 34(1) of the Fisheries Act;

"DFO" means the Federal Department of Fisheries and Oceans;

"EC" means the Federal Department of the Environment (Environment Canada);

"EPEA" means the Environmental Protection and Enhancement Act, S.A. 1992 c. E-13.3;

"EP" means the provincial Department of Environmental Protection;

"federal lands" means "federal lands" as defined in section 52 of the CEPA;

"federal works and undertakings" means "federal works and undertakings" as defined in section 52 of the CEPA;

"Fisheries Act" means the Fisheries Act R.S. 1985, c.F-14, as amended;

"fish habitat" means "fish habitat" as defined in subsection 34(1) of the Fisheries Act;

"inspector" means an "inspector" as defined under clause l(gg) of EPEA and subsection 38(1) of the Fisheries Act;

"investigator" means an "investigator" as defined under clause l(hh) of EPEA;

"PERT" means the Alberta Environmental Protection Pollution Emergency Response Team;

"Privacy Act" means the Privacy Act; R.S. 1985 c. P-21 as amended;

"PPER" means the Pulp and Paper Effluent Regulations made pursuant to the Fisheries Act, SOR/92-269 as amended;

"release(s)" means a release that is required to be reported under section 99 of EPEA and under section 3 of the Release Reporting Regulation AR 117/93 as amended by AR 247/93 and deposits of deleterious substances which are required to be reported pursuant to subsection 38(4) of the Fisheries Act and the PPER;

"Technical Advisory Panel" means the panel established pursuant to Annex 1 to EPS 1/RM/18 describing aquatic environmental effects monitoring requirements at pulp and paper mills and off- site treatment facilities regulated under the PPER;

"water frequented by fish" means "water frequented by fish" as defined in subsection 34(1) of the Fisheries Act.

2.0 PURPOSE

2.1 The purpose of this Agreement is to establish the terms and conditions for the cooperative administration of subsection 36(3) and the related provisions of the Fisheries Act, the regulations under the Fisheries Act designated in the annexes, and the EPEA.

3.0 OBJECTIVE

3.1 The objective of this Agreement is to streamline and coordinate the regulatory activities of Canada and Alberta in relation to the protection of fisheries and to reduce duplication of regulatory requirements for the regulated sector.

4.0 PRINCIPLES OF COOPERATION

4.1 The principles of this Agreement are:

COMMITMENT TO ACTION	the Parties to this Agreement recognize that they are committed to act on environmental matters within their respective areas of jurisdiction while respecting the jurisdiction of other governments.
COLLABORATION	to maximize efficiency and effectiveness, the Parties are committed to recognizing each other's strengths and capabilities and to cooperate in the harmonization of environmental legislation, regulations, policies, programs and projects.
CONSULTATION	where one Party's legislation, regulations, policies, programs and projects affect the other Party's jurisdiction, the Parties undertake to provide one another with timely notification and appropriate consultation.
TRANSBOUNDARY ENVIRONMENTAL EFFECTS	recognizing the transboundary nature of the environment, the Parties undertake to cooperate in the management of environmental issues that traverse jurisdictional boundaries within Canada.
SERVICE TO STAKEHOLDERS	the Parties undertake to provide improved service to all stakeholders by minimizing duplication and overlap of operational activities and providing single window delivery to the fullest extent possible.
INFORMATION SHARING	each Party agrees to share information with the other Party relating to the administration of their respective legislation subject to each Party's legislated requirements and to protect confidential business and personal information.
EMERGENCY RESPONSE	the Parties undertake to continue to cooperate in ensuring an immediate and coordinated response to environmental emergencies.
COST SHARING	each Party will bear its own costs in relation to this Agreement. Each Party's financial obligation under this Agreement is subject to sufficient funds being appropriated and allocated to the respective Party for the purposes of this Agreement. Where one Party carries out work, by prior agreement between the Parties, that is identified as solely of interest to the other Party, the Party not carrying out the work will reimburse the Party carrying out the work for its incremental costs in carrying out that work. Environment Canada's financial obligation under this Agreement is subject to the approval of the Treasury Board, Government of Canada and to sufficient funds being appropriated and allocated.

5.0 ACTIVITIES

5.1 The Parties agree to establish detailed collaborative arrangements for a variety of activities related to the administration of their respective legislation. Such collaborative arrangements shall be detailed separately as annexes which form part of this Agreement.

5.2 Without limiting this Agreement, the following activities shall be considered as appropriate subjects for detailed collaborative arrangements:

MONITORING	the Parties may agree to develop complementary and cooperative monitoring programs with provisions for information sharing. Such programs can be used to evaluate and detect trends in environmental quality and to determine the effectiveness of pollution control programs.
RESEARCH	the Parties may agree to develop complementary and cooperative research programs with provisions for information sharing.
PUBLICATIONS	the Parties may agree to cooperate in the publication of reports arising from their respective activities in the administration of EPEA and the Fisheries Act.
CONFERENCES	the Parties may agree to cooperate in the organization and sponsorship of conferences, meetings and symposia dealing with fisheries, environmental quality and toxic substance issues of both national and regional interest.
INFORMATION SHARING	the Parties may agree to procedures for sharing information related to the administration of their respective legislation. The Parties may also agree to share confidential business and personal information to the extent permitted by their respective legislation and on the understanding that the legislated confidentiality requirements of each Party will be fully respected.
RELEASES	the Parties may agree to immediately inform each other of releases that are required to be reported pursuant to their respective legislation and releases that violate the requirements of their respective legislation. The Parties may also agree to coordinate their response to such releases.
INSPECTION	the Parties may agree to coordinate their inspection activities in order to make better use of limited resources and to reduce the administrative burden for those subject to both federal and provincial requirements.
INVESTIGATION AND ENFORCEMENT	the Parties may agree to cooperate in the investigation of offences and in taking enforcement actions in response to violations of their respective legislation. Such cooperation may involve, but is not limited to the sharing of technical and compliance data and the

	attendance in court of inspectors, analysts and expert witnesses.
REPORTING	the Parties agree to share such information as will enable each to meet its statutory reporting obligations to the Legislature or Parliament, as the case may be.
ADMINISTRATION OF REGULATIONS	the Parties may agree to specific arrangements and roles in the administration of regulations made pursuant to the Fisheries Act and regulations made pursuant to EPEA.

6.0 MANAGEMENT COMMITTEE

6.1 A Management Committee shall be established to direct the implementation of this Agreement. The membership of the Committee shall include an equal number of federal and provincial officials appointed respectively by the Parties. The Management Committee shall be co-chaired by one federal and one provincial member.

6.2 The membership of the Management Committee shall be prescribed in annex 1.

6.3 The responsibilities of the Management Committee shall include:

1. implementing this Agreement;
2. establishing terms of reference to guide its activities;
3. developing collaborative arrangements for activities such as those listed in section 5.2 and detailing those arrangements in annexes to this Agreement;
4. establishing a mechanism whereby disagreements between the Parties can be addressed in accordance with the legislative obligations of each Party;
5. making cost sharing arrangements for the implementation of this Agreement in accordance with the Principles of this Agreement;
6. establishing a cooperative approach to public communications and media inquiries arising from the activities undertaken pursuant to this Agreement;
7. evaluating the administration of this Agreement on a regular basis and preparing recommendations for its revision and amendment as appropriate;
8. reviewing and preparing a report on the administration of this Agreement on an annual basis to satisfy the statutory reporting requirements of the Parties.

6.4 Decisions of the Management Committee shall be taken on the basis of unanimous consent amongst the Committee members.

7.0 TERM OF THE AGREEMENT

7.1 This Agreement, including annexes 1, 2, 3, 4, and 5, shall enter into force on the 1st day of September, 1994 and shall remain in force until terminated by one or both Parties.

8.0 AMENDMENT OF THE AGREEMENT

8.1 This Agreement or any annexes may be amended from time to time subject to the approval of the Governor in Council.

9.0 TERMINATION OF THE AGREEMENT

9.1 This Agreement and Annexes may be terminated by either Party giving to the other Party at least six (6) months written notice of its intention to terminate the Agreement.

IN WITNESS WHEREOF, this Agreement has been executed on the day of , 1994 on behalf of Canada by the Minister of Fisheries and Oceans and the Minister of the Environment and on behalf of Alberta by the Minister of Environmental Protection.

IN THE PRESENCE OF:

GOVERNMENT OF ALBERTA

Witness	Minister of Environmental Protection
	Approved pursuant to the Alberta Department of Federal and Intergovernmental Affairs Act
Witness	Minister of Federal and Intergovernmental Affairs

GOVERNMENT OF CANADA

Witness	Minister of Fisheries and Oceans
Witness	Minister of the Environment and Deputy Prime Minister

---

Annex 1
Management Committee

1.0 Purpose and Responsibilities:

1.1 The Management Committee is responsible for ensuring this Agreement is implemented and for the development of collaborative arrangements for the various activities identified in this Agreement.

1.2 Collaborative arrangements developed by the Management Committee will be recommended to the Federal and Provincial Ministers for inclusion as annexes to this Agreement.

1.3 The Management Committee may establish joint federal- provincial working groups for purposes of developing collaborative draft arrangements.

1.4 The Management Committee may discuss and develop proposals, for consideration by the Ministers of EP, EC and DFO, for cost sharing in respect of any of the annexes in accordance with the Principles of this Agreement.

2.0 Resolution of Disagreements

2.1 Any disagreements between the Parties pursuant to the administration and implementation of this Agreement should be resolved as soon as practicable.

2.2 Disagreements may be resolved through oral or written communication between the co-chairpersons or at a regular or specially called meeting of the Management Committee.

2.3 Failure to resolve an issue at this level will result in the issue being forwarded to the Regional Director General, Central and Arctic Region, for the Department of Fisheries and Oceans, the Regional Director General, Prairie and Northern Region, for the Department of the Environment, and one or more of the Assistant Deputy Ministers of the Department of Environment Protection.

2.4 Where a consensus cannot be reached, each Party shall be free to take whatever action it considers necessary and appropriate under its own legislation, after providing reasonable notice to the other Party of the nature and timing of such action.

3.0 Public Communications

3.1 Where possible, public communications and media inquiries, arising from the activities undertaken pursuant to this Agreement, will be coordinated by the co-chairpersons.

3.2 Special arrangements for public communications or media inquiries may be developed for specific annexes.

3.3 Where one co-chairperson responds to public communications and media inquiries without prior consultation with the other Party, that co- chairperson will inform the other co-chairperson and other committee members, as soon as possible.

4.0 Meetings

4.1 The Management Committee will meet a minimum of once (1 time) per year to evaluate the administration and implementation of this Agreement and the annexes and if necessary provide recommendations for its revision and updating as appropriate.

4.2 The annual meeting will be held in April of each year or as mutually agreed to by the co-chairpersons and will include the review of the administration of this Agreement and the preparation of a report to satisfy the statutory reporting requirements set out in the respective federal and provincial legislation.

5.0 Membership

5.1 The Committee shall be comprised of three (3) federal and three (3) provincial members as follows:

Federal
Manager, Alberta Office,
Environmental Protection Directorate,
Prairie and Northern Region, Environment Canada -
Co-chairperson

Director, Habitat Management
Central and Arctic Region
Fisheries and Oceans Canada

Chief, Ecosystem Quality Branch
Environmental Conservation
Prairie and Northern Region
Environment Canada

and;

Provincial
Director, Standards and Approvals
Alberta Environmental Protection - Co-chairperson

Director, Pollution Control Division
Alberta Environmental Protection

Director, Fisheries Management Division
Alberta Environmental Protection

5.2 Management Committee members may designate alternates to attend Management Committee meetings in their respective places when unable to personally attend.

5.3 The Management Committee may invite individuals to meetings as observers or for the purpose of making presentations.

Annex 2
Releases

1.0 Purpose

The purpose of this annex is to clarify roles and responsibilities of the Parties in sharing information respecting releases and in responding to releases in identified areas of shared jurisdiction.

2.0 Objectives

2.1 The Parties share the objective of encouraging and monitoring the reporting of releases by widely publicizing the single toll-free telephone number to be used to satisfy the reporting requirements under EPEA and the Fisheries Act.

2.2 The Parties share the objective of minimizing the number of releases in Alberta through preventative means such as contingency planning and pollution prevention and control regulation.

2.3 The Parties share the objective of mitigating the adverse effects of releases through fast and effective response.

2.4 The Parties share the objective of informing the public in a timely and thorough manner concerning releases.

3.0 Reporting

3.1 PERT will maintain and operate a 24 hour, seven (7) day a week environmental spill response toll-free telephone number, to receive reports of all releases in Alberta.

3.2 EP will advise EC immediately upon receipt of a report of the following types of release:

1. a release involving a deposit of a deleterious substance into water frequented by fish or a release which is likely to result in harmful alteration, disruption or destruction of fish habitat;
2. a release on federal lands, works or undertakings; or
3. a release involving or which may affect lands or waters outside of the territorial boundaries of Alberta.

3.3 EC will advise EP immediately of any release in Alberta that is reported directly to EC.

4.0 Response

4.1 For the purpose of this annex the lead response agency will be the agency with the primary responsibility for responding to releases and may include, but not be limited to

1. accident investigation;
2. providing clean - up advice;
3. ensuring remedial action;
4. co-ordinating remedial response by multiple agencies;
5. providing information for the purpose of public notification; and
6. following up on remedial activities.

4.2 For the purpose of this annex the support agency will be the agency that provides technical advice, monitoring equipment and coordination with other agencies as requested by the lead response agency.

4.3 EP will be the lead response agency for releases in Alberta with the exception of releases under paragraph 3.2 (b).

4.4 EP will be the lead response agency for releases under paragraph 3.2(a) and (c) unless agreed otherwise by the Parties on a case by case basis.

4.5 EC will act as a support agency for releases under paragraph 3.2 (a) and (c) and as requested for specific releases.

4.6 EC will be the lead response agency for releases under paragraph 3.2 (b).

4.7 EP will act as a support agency for releases under paragraph 3.2 (b).

4.8 Both Parties will consult with and advise one another regarding actions taken in dealing with specific releases of joint interest, and will document actions taken and present the other Party with evidence gathered as necessary to support possible legal or other action.

4.9 EP and EC will provide reports of releases as requested by the other Party.

4.10 At the request of either Party, a joint review of release response procedures, either for specific releases or for releases in general, will be held.

4.11 The lead response agency will be responsible for coordinating news media relations in the event of a release, without limiting the other Party from acting within its jurisdictional mandate.

4.12 Where feasible, the Parties will mutually share and provide mutual access to training programs, expert advice, research and development information, and specialized analytical laboratory services.

5.0 Disagreements

Any disagreements between the Parties may be referred to the Management Committee at any time by either Party for resolution.

Annex 3
Inspection, Investigation and Enforcement

1.0 Purpose

The purpose of this annex is to coordinate inspection activities of the Parties in order to make better use of resources and to coordinate investigation and enforcement roles and responsibilities in response to alleged contraventions of the provincial or federal legislation.

2.0 Inspections

2.1 The Parties are responsible for inspections under their respective legislation.

2.2 The Parties will meet annually to co-ordinate inspection strategies for the regulated sectors of common interest.

2.3 At the annual meeting the Parties will consider the following areas:

1. development of an inspection plan to co-ordinate tbe inspections conducted by EP and EC;
2. timely sharing of information obtained during inspections by one Party with the other Party;
3. development of a single point of contact for the purpose of compliance reporting by the regulated sector; and
4. conducting joint inspections where necessary.

2.4 The Parties agree to share information acquired through the conduct of inspections respecting possible contraventions of provincial or federal legislation.

2.5 The Minister of DFO may, with the consent of the Minister of EP, designate employees of EP who in the opinion of the Minister of DFO are qualified to be so designated, as Fisheries Act inspectors with the power to conduct inspections with respect to the Fisheries Act regulatory requirements and the power to take or direct remedial action pursuant to Section 38 of the Fisheries Act.

3.0 Investigation and Enforcement

3.1 EC and EP will conduct investigations into alleged contraventions of their respective legislation.

3.2 The parties will conduct a joint investigation for alleged contraventions of both federal and provincial legislation.

3.2.1 EP shall be the lead party in joint investigations unless otherwise agreed upon by the parties.

3.2.2 The Parties will confer upon undertaking an investigation and agree on the roles of the lead party and the support party in the investigation.

3.2.3 The Parties agree to exchange all relevant information obtained during an investigation.

3.2.4 The Parties will discuss the appropriate enforcement response at the conclusion of the investigation.

3.2.5 Each party will attempt to coordinate enforcement responses but each party reserves the right to proceed unilaterally with its own enforcement action.

3.2.6 Each party has the right to set and follow its own enforcement policy.

3.2.7 The Parties agree to share evidence, staff, expertise, witnesses and analysts for the purpose of preparing for and conducting trials.

3.2.8 The parties recognize that both federal and provincial Attorneys General retain their discretion to prosecute violations of their respective legislation.

4.0 Training of Inspectors and Investigators

4.1 Training may be provided to inspectors or investigators of Alberta and Canada for the implementation of the Agreement and this annex.

4.2 EC will provide EP staff with access to the requisite training courses for Fisheries Act inspector designation.

5.0 Meetings

The Parties agree to meet once per month or as mutually agreed upon to provide updates on ongoing investigations of mutual interest and to review decisions respecting joint investigations.

6.0 Disagreements

Any disagreements between the Parties may be referred to the Management Committee at any time by either Party for resolution.

Annex 4
Information Sharing

1.0 Purpose

The purpose of this annex is to facilitate the full and open sharing of information between the Parties for the purpose of the administration of this Agreement.

2.0 Types of Information

Information that may be shared between the Parties pursuant to this Annex will include, but not be limited to, information in the possession of the Parties relating to:

1. fish and fish habitat;
2. environmental effects of deleterious substances and in particular their effect on fish;
3. human health effects of deleterious substances;
4. industrial processes;
5. pollution prevention and abatement technology;
6. compliance monitoring;
7. investigation and enforcement activity; and,
8. economic impacts of regulatory controls and technologies.

3.0 Disclosure of Information

3.1 Each Party will share information received pursuant to this Agreement or the annexes with the other Party in a timely fashion or as provided in the other annexes to this Agreement.

3.2 Each Party is subject to the limitations for public disclosure contained in section 33 of EPEA, the federal Privacy Act and the federal Access to Information Act.

3.3 Information provided by one Party to the other Party, pursuant to this Agreement or any of the annexes, shall not be released to the public if it could reasonably be expected to harm the enforcement of any law of Canada or a province or to the conduct of lawful investigations.

4.0 Manner of Disclosure between the Parties

4.1 EC and EP shall each identify one employee of their respective Departments to act as a contact for requests for information under the Ageement and annexes.

4.2 Within a reasonable time after receipt of a request for information under section 2, the Party receiving the request shall provide the information to the other Party.

5.0 Disagreements

Any disagreements between the Parties may be referred to the Management Committee at any time by either Party for resolution.

Annex 5
Administration of Pulp and Paper-effluent Regulations

1.0 Purpose

The purpose of this annex is to facilitate federal-provincial cooperation in the regulation of pulp and paper mill effluent in order to maximize the effectiveness of regulatory efforts and reduce the administrative burden on the pulp and paper industry.

2.0 Roles and Responsibilities of the Authorization Officer

2.1 The Authorization Officer shall receive all of the information described in Section 4.1 of this Annex, which mill operators are required to submit to an Authorization Officer pursuant to the PPER.

2.2 The Authorization Officer shall conduct the issuance, amendment and withdrawal of any authorizations pursuant to Sections 16, 17, and 18 of the PPER.

2.3 The Authorization Officer shall form the Technical Advisory Panel described in Annex 1 to "Aquatic Environmental Effects Monitoring Requirements" EPS 1/RM/18.

3.0 Reports of Deposits Out of the Normal Course of Events

3.1 Where pulp and paper mill operators are required to report deposits out of the normal course of events pursuant to Section 38 of the Fisheries Act, they may meet this requirement by reporting to PERT.

3.2 Upon receipt of a report pursuant to Section 38 of the Fisheries Act, PERT will immediately notify the Alberta Office Manager, Environmental Protection Branch, Prairie and Northern Region of EC.

3.3 The arrangements outlined in paragraphs 3.1 and 3.2 above, constitute an arrangement for the purposes of paragraph 36(1)(b) of the PPER.

4.0 Information Sharing - Monthly Monitoring Reports; Ownership Information; Emergency Response Plans; Reference Production Rates; Effluent Outfalls

4.1 Where the Authorization Officer is a provincial employee, he/she will provide the Alberta Office Manager, Environmental Protection Branch , Prairie and Northern Region of EC with a copy (in hard copy or electronic format) of the following information submitted by operators pursuant to the PPER:

1. monthly reports on the results of monitoring referred to in paragraphs 7(1)(b) and 7(3)(b) of the PPER;

2. information on the ownership of mills and off-site treatment facilities referred to in paragraphs 7(1)(c) and 7(3)(c) of the PPER;
3. emergency response plans referred to in paragraphs 7(1)(e) and 7(3)(d) of the PPER; and,
4. the notification of reference production rates referred to in subsection 12(3) of the PPER.

4.2 Where the Authorization Officer is a provincial employee, copies of information referred to in section 4.1 of this annex will be provided to the Alberta Office Manager, Environmental Protection Branch, Prairie and Northern Region of EC within ten (10) working days of receipt of the information.

4.3 The Regional Director of Fisheries and Habitat Management in DFO shall provide the Authorization Officer with copies of information respecting effluent outfalls provided to the Minister of DFO pursuant to section 27 of the PPER within ten (10) working days of receipt of the information.

5.0 Environmental Effects Monitoring

5.1 The Authorization Officer will convene a meeting of the Technical Advisory Panel at least once per year to review the implementation of environmental effects monitoring requirements contained in the PPER and in approvals.

5.2 Whenever feasible, the Authorization Officer shall harmonize federal and provincial environmental effects monitoring requirements.

6.0 Disagreements

Any disagreements between the Parties may be referred to the Management Committee at any time by either Party for resolution.

Appendix XV:

“Follow-up on Committee Hearings,” (20 March 2009) (responses of Alberta Environment and Environment Canada to questions posed by the Chair of the House of Commons Standing Committee on the Environment and Sustainable Development)

FOLLOW-UP ON COMMITTEE HEARINGS

Name of Committee: **Standing Committee on the Environment and Sustainable Development**

Follow-up required/Next steps:

The Chair of the Standing Committee on Environment and Sustainable Development has asked Environment Canada to provide the following information:

1. To explain EC's input in environmental assessments dealing with water quantity and to provide the scientific reports produced by EC related to inflow needs studies.

RESPONSE:

Environment Canada Water Advice for Oil Sands Environmental Assessments

In EC's submissions to the four previous Joint panels, water advice has been provided in the following areas:

- Water quality:
  - Cumulative effects on water and sediment quality as a result of oil sands development, the need for monitoring into the far future and an action plan to address adverse effects detected
  - Improve on-site monitoring programs to include water and sediment quality monitoring in pit lakes and wetlands that receive tailings or seepage flows from pits
  - Water quality objectives should be developed for specific sites or regions within the Athabasca Oil Sands Area, with particular emphasis on developing objectives for oil sands related toxic substances
  - Any tailings release or tailings seepage to any waters frequented by fish, or a place under conditions that may enter waters frequented by fish, may constitute violations of the *Fisheries Act*

- Water quantity:
  - Flow alteration resulting from mining and remediation should mimic as closely as possible, normal seasonal patterns
  - Reduction in flows and levels of water could impact the productivity of the Peace-Athabasca Delta and surrounding lakes.

- Modeling:
  - Adequate baseline data should be collected prior to project initiation to ensure that hydrologic characteristics and water and sediment chemistry are completely characterized in all water bodies. This baseline is needed to establish adequate data for comparison to future monitoring; to evaluate the effectiveness of mitigation and the accuracy of predictions that were used for the project; and to allow for adaptive management
  - Modeling impact predictions should be updated as new data become available, and include public reporting as well as external scientific peer-review.

In the context of oil sands impacts, water quantity and flow are discussed by DFO in regards to water intake and dewatering and the resulting impacts on fish and fish habitat. EC's discussion of water quantity and flow focus on the potential impacts to surface water quality.

EC conducts science on water flows in the Athabasca River and the potential for downstream effects. That science is made available through EC's participation in collaborative and multi-stakeholder fora, as well as through publication.

The recommendations provided by EC are guided by the following desired outcomes:

- Regional and site-specific monitoring efforts are consistent with and linked to mitigation and action plans for any adverse effects related to water quality.
- Site- or region-specific water quality objectives are developed to address cumulative effects of deleterious substances on local and regional aquatic ecosystems, including the Delta and western Lake Athabasca.
- Research is initiated or continued to develop a better understanding of the fate and effects of toxic substances on aquatic life.

2. To produce a copy of the Strategic EA advice provided by EC to the Ministry of Finance to promote investment in the oil sands in 1996-2002.

RESPONSE: Environment Canada did not contribute to a strategic environmental assessment on that subject

3. Detailed explanation on the design of tailings ponds.

RESPONSE:

Tailings Ponds at Oil Sands Mines
General Information
Provided by Alberta Environment
Contact: Kem Singh, Regional Approvals Manager, Northern Region
Kem.Singh@gov.ab.ca 780-427-7012

1) Production of Fluid Tailings

Oil sand tailings are waste streams that contain dispersions of bitumen, sand, clay, water and some contaminants of concern. Naphthenic acids are the primary source of toxicity. Tailings are contained in settling ponds which serve four basic functions:

- a place to store water for recycling,
- a settling pond (which through time allows water to separate from waste materials),
- a disposal area for coarse and fine tailings, and
- a place to contain contaminants such as naphthenic acids, residual bitumen, polycyclic aromatic hydrocarbons (PAHs), heavy metals and other anions and cations which result from leaching processes of water through oil sands and continual recycling. Many of these contaminants will be reduced over time by natural bioremediation processes.

Tailings ponds are part of the internal water system for mines – Alberta Environment does not allow the release of bitumen extraction process affected waters at this time. Tailings ponds provide up to 90% of a company's water needs for bitumen extraction from oil sand through the re-use of water in the ponds, reducing the amount of freshwater used.

2) Footprint and Distribution of Fluid Tailings

At this time there are 7 major tailings ponds and 7 sub-ponds in the region and there are more ponds proposed for approved facilities. However, some existing ponds will be reclaimed before these are constructed. The existing ponds cover 14,200 hectares or about 25% of current mine disturbance and are expected to more than double in footprint by 2020.

3) Management of Fluid Tailings

Any proposal to construct a tailings pond is examined by technical experts from a number of regulatory bodies including Alberta Environment, Alberta Sustainable Resource Development and the Energy Resources Conservation Board.

The proposed design and location of a pond is reviewed to ensure it is suitable from environmental, resource conservation and economic points of view. Ponds are constructed with groundwater seepage-capture facilities, and are closely monitored.

The Energy Resources Conservation Board regulates tailings ponds from the perspective of material management. Alberta Environment regulates tailings ponds from the perspective of water quality and reclamation and also geotechnical stability through its Dam Safety Branch.

The Energy Resources Conservation Board has recently issued a tailings Directive. The Directive requires increased monitoring and reporting associated with tailings ponds and requires operators to meet enhanced performance criteria for managing their tailings. The Directive lays out specific enforcement actions should targets not be met.

This Directive is the first step of a larger initiative by the Government of Alberta to deliver performance criteria for the reduction of fluid tailings.

4) Tailings Seepage

No impacts of seepage have been detected in the Athabasca River despite intensive investigations to do so and no ecological impacts have been found. All tailings ponds seep and there are no current feasible options to seal these structures completely (due to size, lack of clay, cost). The solution to the seepage is that tailings ponds must have seepage recapture systems. The effectiveness of these systems is ensured through a corresponding network of monitoring wells. All seepage recapture systems are working well. There are no detectable impacts of seepages entering the Athabasca River or other surface water bodies. For example, modeled seepages from Tar Island Dyke (the oldest tailings pond which is currently being reclaimed) would be diluted 40 million times if they enter the Athabasca River. Extensive monitoring confirms seepages, if they occur, are undetectable.

5) Fluid Tailings and Wildlife

While tailings ponds represent a potential threat to wildlife (e.g., waterfowl) due to toxicity issues posed by residual hydrocarbons and naphthenic acids in tailings waters, the government has effective and enforceable regulations to minimize these threats through the *Environmental Protection and Enhancement Act* (EPEA). All approval holders are required to submit a Waterfowl Protection Plan to the Director.

The Waterfowl Protection Plan must include information on (a) techniques/procedures used to minimize avian mortality at all tailings, composite tailings and waste ponds; and (b) a comprehensive program for monitoring and documenting avian mortality, timing of incidents, and species affected. The plans are reviewed by Alberta Sustainable Resource Development's Fish and Wildlife Branch and are coordinated through AENV.

More than 500 waterfowl died in the Syncrude Aurora tailings pond in April, 2008. This tragedy occurred because deterrents (propane-fired cannons) were not installed in time due to a late season snow storm. These deterrents have proven effective for over a decade with total avian mortality averaging less than 50/year from all sources of on-site mortality for all companies combined (note these numbers have increased recently due to an increase in overall tailings ponds). Significant improvements in bird deterrent systems are now available and have been implemented at some mines.

are likely to become strong and trafficable at much faster rates than traditional tailings methods. Gypsum is readily available as a waste product of flu-gas desulphurization. This technology can be used to address some but not all of the accumulated mature fine tails that have not settled in existing tailings ponds. Suncor, Syncrude, Albian, Shell, CNRL, Petro-Canada all use or will use this technology.

Paste Technology – The addition of specific chemical coagulants to tailings water in thickener vessels prior to transport to tailings ponds has been demonstrated to enhance consolidation rates and dewatering of fine tails.

10) Alternative Tailings Technologies

Commercial bitumen recovery from surface mines has relied on variants of the "Clark Hot Water Extraction Process", an extraction process which performs for a wide range of oil sands ores and operating conditions. A consequence of this extraction process is the production of very large fine tails containment basins (tailings ponds). There are many proposed approaches for bitumen extraction which rely on alternative technologies and tailings management; some of these have reached the pilot and demonstration phases. Full scale commercial application of these technologies has not been demonstrated to date. The most recent summary of these technologies can be found in "Fine Tailings Fundamentals Consortium (1995)". An update to this publication is required.

The "counter-current drum separator" for extraction, a process demonstrated at the Fort Hills Demonstration Site, was the proposed extraction technology to be used by the Northern Lights Project (Synenco). Filtered tailings technology coupled with centrifugation was proposed for the Joslyn North Mine (Total E&P Canada Ltd.). Both technologies have been demonstrated to use less water and produce greater amounts of dry stackable tailings early in mine development thereby reducing the need for a large mine footprint occupied by soft tailings deposits such as those found in the existing mines. Synenco has withdrawn their mine application and Total E&P has indicated changes to their proposed technology are forthcoming.

4. Details on the methods of compliance verification for oil sands operators with respect to section 36 (3) of the *Fisheries Act* and the "qualifications" of Alberta Environment inspectors with respect to the *Fisheries Act*.

RESPONSE:

With respect to the latter, we have confirmed that Alberta Environment inspectors are not designated as Fishery Inspectors under the *Fisheries Act*.

With respect to the former, Environment Canada and the Province of Alberta work under an administrative agreement in enforcing the *Fisheries Act*. Under that agreement, the Province, in carrying out their duties under relevant provincial legislation, commits to forwarding any information that they may become aware of that may indicate a *Fisheries Act* infraction to the EC Enforcement Branch, Alberta office. This applies to the oil sands sector as well.

Specifically concerning tailings ponds and potential leaching of waste, companies are required by their operating permits to maintain test wells to ensure that waste water is not leaching from the ponds. The sampling is done by private environmental consulting firms on behalf of the companies and reports are then sent to the Environment Alberta as proof of on-going compliance. To date, EC Enforcement has not received a referral from Environment Alberta indicating that they suspect any possible *Fisheries Act* violations.

Environment Canada Enforcement Branch is finalizing plans for on-site inspections at the four (4) facilities operating in the Fort McMurray area. These inspections will likely take place in May 2009, once the snow has melted. The Province will be advised of these plans and be invited to participate in a joint inspection.

Coordinated by: Pierre Boucher, Environment Canada, 819-953-5504
Date March 20, 2009

Appendix XVI:

Oil Sands Regional Aquatic Monitoring Program (RAMP) Scientific Peer Review of the Five Year Report (1997-2001) (February 13, 2004)

Oil Sands
Regional Aquatic Monitoring Program
(RAMP)
Scientific Peer Review of the
Five Year Report (1997-2001)

Submitted to:
RAMP Steering Committee
February 13, 2004

Prepared by:
G. Burton Ayles, Winnipeg, Manitoba
Monique Dubé, Saskatoon, Saskatchewan
David Rosenberg, Winnipeg, Manitoba

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Oil Sands Regional Aquatics Monitoring Program (RAMP) is a multi-stakeholder, multi-objective long-term program, designed to incorporate both traditional and scientific knowledge to address monitoring needs in the Region. The RAMP organizational structure is a Steering Committee with representatives from the oil and gas industry, other industries in the Region, First Nations, and provincial and federal governments. In 2003, the Steering Committee initiated an independent scientific peer review of the monitoring program to ensure that the program continued to meet monitoring objectives and to ensure that knowledge and understanding being applied was appropriate to the task.

The specific purposes of the review were:

1. to assess the program for adequacy against the relevant objectives of RAMP;
2. to evaluate the program design, methods, and results of RAMP with respect to the objectives of detecting change, determining regional variability and cumulative effects, and verifying EIA predictions; and
3. to provide recommendations for changes to the program, including an assessment of the potential impact of those changes to the integrity of the program in the future.

The review was based primarily on a Five Year Report that presented the results of the monitoring program between 1997 and 2001. Discipline specialists carried out reviews of the various components of RAMP viz., climate and hydrology, water quality, sediment quality, benthic invertebrates, fish populations, aquatic vegetation and acid sensitive lakes. The review has been structured around the three fundamental goals of RAMP as identified in the Five Year Report, i.e. characterizing existing variability, detecting regional trends and cumulative effects, and monitoring to verify EIA predictions.

Narrative summaries of the assessments, including major gaps and recommendations for each component, are presented in this report. As well, there is a general assessment of common themes or issues and recommendations for future improvement of the overall program. Details of the assessments of the various components or programs of RAMP are found in Appendix IV of this report.

The reviewers found many signs of positive progress with RAMP. The very existence of a major regional aquatic monitoring program is a very positive sign for Alberta. Beginning joint monitoring by companies in 1997 was a progressive initiative leading to benefits now and in the future. The companies involved are to be commended for their vision and their significant financial contribution over the years. A long-term initiative such as this is rare. As well, the RAMP initiative to draw individual components into a comprehensive regional aquatic monitoring program is seen as a positive step towards relevance and effectiveness. This program offers a significant opportunity to ensure environmental protection, support environmental rehabilitation in the future and enhance our level of knowledge and understanding of boreal aquatic ecosystems in a disturbed and undisturbed setting.

The general consensus of the reviewers was that the Five Year Report was well organized and written in a manner that is accessible to most stakeholders, with a few exceptions. It fairly describes the evolution of RAMP over the years and, with the unfortunate exception of the aquatic vegetation and the acid sensitive lakes programs, which were not addressed, it is a good description of what was done. The problems with the report are found in lack of details of methods, failure to describe rationales for program changes, examples of inappropriate statistical analysis, and unsupported conclusions.

That being said, the reviewers raised significant concerns about the Program itself. They felt there was a serious problem related to scientific leadership, that individual components of the plan seemed to be designed, operated and analyzed independent of other components, that there was no overall regional plan, that clear questions were not been addressed in the monitoring and that there were significant shortfalls with respect to statistical design of the individual components.

Based on the results of the individual reviews the Design and Integration Team presents the following recommendations for future improvement of monitoring of the aquatic environment of the Oil Sands Region of Alberta:

I. Organizational Recommendation on Scientific Leadership

We recommend that RAMP establish a new independent position of project scientific leader reporting to the RAMP Steering Committee and responsible for the overall scientific design of the program and ensuring program quality and relevance through independent peer review. RAMP should also establish an ongoing system of independent scientific input to the program through (1) informal or formal commentary on early ideas and initial plans; (2) workshops and planning sessions that involve independent researchers, and RAMP contractor staff and RAMP technical committee members in interchange and debate; (3) formal written review of monitoring plans; and (4) formal review of progress on a periodic basis.

II. Primary Technical Recommendations

1. Adoption of an Ecosystem Approach and Decision-Making Strategy. We recommend that RAMP adopt a strategic, integrated, regional monitoring design and decision-making strategy for measurement of development-related change at an ecosystem level while incorporating site-specific needs. Monitoring must fit within the context of an adaptive management framework and focus beyond project-specific needs. This approach should:

- Consider how decisions on change will be made and the information that is required to make those decisions. For example, what indicators will be measured to assess a particular development activity? What will the indicator be compared against to determine when a change has occurred? Will changes of a certain magnitude and direction trigger a specific line of decisions or an approach to greater monitoring intensity? What will the process be if water

quality indicators show a change but no change was measured in fish indicators?
- Consider the development projections to 2020 in the oil sands area and select strategic monitoring locations accordingly. Depending upon the watershed, development level, and physical, chemical, and biological characteristics the monitoring approach can be customized. Sampling intensity and frequency can also be customized;
- Integrate RAMP components (i.e. hydrology, water and sediment quality, benthic invertebrate community structure, fish population health, aquatic vegetation and acid sensitive lakes) at integrated monitoring stations;
- Use adaptive feedback loops within and among components for constant examination of experimental designs and results; changes should be made to the program based on solid results rather than on speculation;
- Show clear links to objectives and have clearly stated hypotheses or testable study objectives; and
- Ensure that all terms, especially statistical ones, are defined and used precisely in reports, and a glossary for all component subject areas be produced as an aid to authors and readers of reports. Precise use of terms aids understanding.

2. Adoption of Effects-Based Monitoring within the Strategy. We recommend that RAMP orient its efforts towards effects-based monitoring. The objective should be to document environmental change occurring as a result of development, not to carry out descriptive studies. Included in the effects-based approach should be the following:
- Selection of key response indicators for each RAMP component, based upon potential changes resulting from oil sands development;
- On-going synthesis of information related to development pressures including type of development activity, location of activity, stressors released, effects predicted, assumptions used in predictive tools, location of modeling nodes, etc. A monitoring program designed to monitor development-related change cannot do so in the absence of information on the development. This was recognized as a significant shortfall of the RAMP program. Reviewers recognized that much of this information is likely included in the EIA reports. However, effects-based monitoring mandates an on-going comparison between development activities and environmental condition. One without the other will not measure development-related change;
- Establishing a core level of consistency for sample station selection, indicator selection, sampling frequency and timing that does not change from year to year;
- Selection of reference and "low-impact" stations within or outside the Region for each component subject area. Those subject areas that can go into an established biomonitoring program will get this benefit automatically;
- Use of biostatistical analyses that report statistical confidence levels and power analyses for indicators of change. These statistical results are critical to assist with interpretation of the environmental changes to establish confidence in the decision-making strategy;

- Consideration of the knowledge and understanding gained from other successful effects-based monitoring programs that measure development-related change relative to natural variability; for pertinent subject areas such as water quality, benthos, fish and possibly aquatic vegetation, a bona fide, regional biomonitoring program (Environmental Effects Monitoring [EEM] or the Reference Condition Approach [RCA]) should be initiated; and
- Incorporation of other existing regional information such as NRBS, NREI, PERD, EEM, the Muskeg River design initiative (CEMA) and information collected independently by industry. Future periodic summary reports, such as the next Five Year Report, should incorporate monitoring results and studies from programs other than RAMP, if the information contributes to the objectives.

3. Testing Environmental Impact Assessments (EIA) Prediction. We recommend that RAMP complete an exercise to test predictions from already completed EIAs using actual data generated on a site or sites. As a first step in this evaluation, RAMP should prepare a synthesis or summary, on a project-specific basis, of what the impact predictions were for different project activities, including location and timing of impact and Valued Ecosystem Components (VECs) affected.

4. Development of an Information Management System. We recommend that RAMP establish a comprehensive information management and assessment system, including an electronic database management system that would enable electronic reporting of raw data in a standard and consistent format, interchange of data among component subject areas, and on-going assessment of data using consistent analyses.

5. Increased Emphasis on the Athabasca River as a Priority Watershed. We recommend that RAMP use the Athabasca River as a central focus for monitoring across component subject areas because it is the largest and most important aquatic ecosystem in the region and the natural recipient of the effects of oil sands development.

II. Secondary Technical Recommendations

1. Contributions to New Knowledge. We recommend that RAMP recognize the importance of creating new knowledge and incorporating this knowledge into the monitoring program through an adaptive management framework.

2. Traditional Ecological Knowledge (TEK). We recommend that RAMP actively promote the use of TEK by incorporating it into the design of scientific programs. Key indicators for future monitoring and the interpretation of results need to be identified, and specific, ongoing programs should be devoted to observing changes in these key indicators.

3. Publications. We recommend that RAMP initiate a policy of encouraging individuals and the contractor to publish monitoring data and new knowledge in established technical and primary publications as well as in-house reports. RAMP should also establish a RAMP Technical Report Series for wider distribution of monitoring results within the region, provincially and nationally.

INTRODUCTION

Environmental Impact Assessments (EIAs) in the Oil Sands Region of northeastern Alberta document baseline environmental conditions and predict effects of proposed developments. Understanding long-term natural variability in the region is essential in determining if changes to the aquatic environment are due to the effects of development, natural extremes or both. The Oil Sands Regional Aquatics Monitoring Program (RAMP) is a multi-stakeholder, multi-objective long-term program, designed to incorporate both traditional and scientific knowledge to address the monitoring needs in the Region. The RAMP organizational structure is a Steering Committee with representatives from the oil and gas industry, other industries in the Region, First Nations, and provincial and federal governments. There are four subcommittees: Technical, Communications, Finance and Investigators. The RAMP technical program was initiated in 1997 and annual reports have been produced since 1997 (RAMP, 1997-2001). In May 2003, under the direction of the RAMP Steering Committee, the contractor, Golder and Associates, (Golder)[1] completed a Five Year Report covering the period 1997 to 2001 (RAMP, 2003).

In 2003, the Steering Committee initiated an independent scientific peer review of the monitoring program to ensure that the program continued to meet monitoring objectives and to ensure that knowledge and understanding being applied was appropriate to the task. The Steering Committee established a Review Team[2], who contracted with us, Dr. Burton Ayles, Dr. David Rosenberg and Dr. Monique Dubé (the Design and Integration Team), to design, lead and coordinate the review.

The specific purposes of the review were:

1. to assess the program for adequacy against the relevant objectives of RAMP;
2. to evaluate the program design, methods and results of RAMP with respect to the objectives of detecting change, determining regional variability and cumulative effects, and verifying EIA predictions; and
3. too provide recommendations for changes to the program including an assessment of the potential impact of those changes to the integrity of the program in the future.

This report presents the results of our review. Our description of the structure of the review includes a brief discussion of the need for an independent scientific peer review in environmental and resource management programs, the contribution such reviews can make to improved planning and decision making and considerations of what should be included in a review. We then describe the specific process for this review. The subsequent sections are summaries of the independent scientific peer reviews of the various components of RAMP viz., climate and hydrology, water quality, sediment quality, benthic invertebrates, fish populations, aquatic vegetation and acid sensitive lakes. These assessments include specific recommendations for each component. The

[1] Beginning in 2003, RAMP contracted with Hatfield Consulting (Hatfield) to carry out the monitoring aspects of RAMP.
[2] Bryan Kemper, Christine Brown, Preston McEachern, and Mark Spafford.

final section provides our overall assessment and recommendations. A separate Appendix (Appendix IV) contains detailed reviews of each of the components following a prescribed template.

METHODOLOGY FOR THE REVIEW OF RAMP

General Approach

Peer review has traditionally been used to assure the quality of research carried out in government and academic laboratories. The process for large-scale planning and evaluation of complex environmental and resource management programs is neither well established nor universally accepted (Fleishman, 2001), but it is our belief that independent scientific peer review can contribute significantly to the design, operation and modification of monitoring of the aquatic environment of the Oil Sands Region. Independent scientific review can help to ensure that decisions reflect the best current scientific knowledge. It can help to focus RAMP on objective scientific variables apart from historical, economic or social variables. It will help to raise the trust of all stakeholders in the RAMP. And, perhaps most importantly, without an independent scientific peer review, any claims of objective and scientific validity may be suspect (adapted from Meffe et al., 1998). It was our intention that this review address only science issues in the belief that this approach should help RAMP to clarify areas of potential overlap between science and non-science. Non-science issues fall under the purview of RAMP, the companies and the stakeholders, not our review.

Our independent scientific review should be a tool for improvement of RAMP. Most environmental regulatory agencies accept the “precautionary principle” as a general guideline for doing business, and many environmental regulators use terms like “current best practices” or “best available science” (Dorcey and Hall, 1981; CSTA, 1999; Bisbal, 2002; WSOCD, 2002) and the Alberta Energy Utilities Board uses the phrase “best available technologies”. Our expectations are that RAMP programs should follow the precautionary principle and they should be using the best science. As well as an expectation of good science, there are other characteristics that guided us in the development of the plan for this review. We felt it was important that bias and special interest were minimized so we selected reviewers who are not involved directly in aquatic monitoring or research in the Region. This choice made the task somewhat harder because individual reviewers did not have much background knowledge and had to take time to familiarize themselves with the overall area. The reviewers possibly being unaware of some pertinent information or program introduced the possibility of errors in our assessments and recommendations. However, we feel that the risks of error were justified by the benefits of impartiality. We tried to minimize such mistakes, and ensure that all relevant information was considered, by reviewing additional information beyond the Five Year Review Report (see template reports for details), holding an interim meeting with the RAMP Technical Committee and periodic exchanges with the Review Team. We have attempted to ensure that our conclusions and recommendations are consistent with available scientific information and that our assumptions are explicit. We did not enter into the planning for this review with a standardized or set format in mind. Circumstances for independent scientific review of large-scale environmental projects vary greatly by issue, and we felt that our process had to be tailored specifically to the monitoring program at hand. We developed our process based on our personal knowledge of research management and control, reviews of current literature on independent scientific reviews of natural resource management projects (e.g. Meffe et. al.

1998; CSTA 1999; Roosenberg, 2000; Fleishman 2001). Our initial plans were modified after discussion with the Review Team and individual reviewers, and we modified the process as we proceeded and problems were identified. We did not always agree with suggestions from the individual reviewers or the RAMP Review Team and, ultimately, the responsibility for the review process is ours. We know that there are risks associated with alternative monitoring plans and we hope to give RAMP the knowledge to make the necessary decisions.

Scope of this Review

Our review is based on the published annual and summary reports of RAMP. Specific programs in RAMP were established each year by committees and subcommittees after consultation with industrial, aboriginal, environmental and regulatory stakeholders and expert independent consultants. As the Oil Sands Region experienced rapid growth from 1997 to 2001, changes to RAMP were made annually. These changes not only affected RAMP's objectives, and organizational structure, but the study area and study design as well. Potential sampling methods, sentinel species and reference lakes and streams were also evaluated during this period. Some methods were adopted and then abandoned during following years. Through the years, RAMP included the following environmental monitoring in the Oil Sands Region:

- hydrology and climate (monitoring began in 1995, but became a component of RAMP in 2000);
- water quality in rivers (1997 to 2001);
- sediment quality in rivers (1997 to 2001) and wetlands (1998 to 2001);
- benthic invertebrates in rivers (1997, 1998, 2000 and 2001) and two lakes (1997 to 2001);
- fish populations in rivers (1997 to 2001);
- aquatic vegetation (1999 to 2001); and
- acid sensitive lakes (1999 to 2001).

Each year the detailed monitoring activities and results for that particular year were summarized in an annual report prepared by Golder. The Five Year Report, completed in May 2003, includes the analysis of data over the five year period from 1997 to 2001, where Golder considered sufficient data were available viz.: climate and hydrology, water quality, sediment quality, benthic invertebrates, and fish populations. Components of the RAMP program that did not have sufficient data, such as the aquatic vegetation and acid sensitive lakes, were not included in the Five Year Report.

Although there are eight stated goals for RAMP (see RAMP Terms of Reference for details) the Five Year Report addresses only the three program objectives considered most relevant to aquatic monitoring (Appendix I). They are:

1. Characterizing Existing Variability - To collect scientifically defensible baseline and historical data to characterize variability in the oil sands area (the capacity to detect change was of particular importance for reviewers to consider).
2. Detecting Trends and Cumulative Effects - To monitor aquatic environments in the Oil Sands Region to detect and assess cumulative effects and regional trends

(the capacity to detect cumulative effects and trends for new disturbances was of particular importance for reviewers to consider).

3. Monitoring to Verify EIA Predictions - To collect data against which predictions contained in EIAs can be verified;

This peer review focused primarily on the Five Year Report but incorporated acid sensitive lakes and aquatic vegetation to the extent that they appear in the annual reports. Our analyses of the individual components of the RAMP summarized in the following chapters and detailed in Appendix IV has been structured around the three fundamental goals of RAMP as identified in the Five Year Report. Other RAMP goals were addressed as they were deemed relevant by the reviewers.

Process for the Review

Reviewers - The Review Team established a number of task areas and tentatively identified a number of possible reviewers for specific areas. We contacted the independent scientists and biologists who would carry out the individual reviews. Of our 16 primary reviewers (Table 1 and Appendix II) four were from universities, seven from government agencies and five were consultants. The Review Team approved all of the reviewers.

Table 1. RAMP independent scientific peer review. Names, institutions and components reviewed by individual reviewers.

Reviewer and Institution or Agency	**Component Reviewed**
Neil Arnason, Ph.D., University of Manitoba,	Biostatistics
Burton Ayles, Ph.D., Consultant	Coordinator
Jan Barica, Ph.D., Consultant (UNEP)	Water quality and acid sensitive lakes
Brian Brownlee, Ph.D., Environment Canada	Sediment quality
Uwe Borgman, Ph.D., Environment Canada	Sediment quality
Martin Carver, Ph.D., Consultant	Climate and hydrology
Monique Dubé, Ph.D., Environment Canada	Benthic invertebrates, water quality, fish populations, Coordinator
Nancy Glozier, M.Sc., Environment Canada	Water quality
Kelly Munkittrick, Ph.D., University of New Brunswick	Fish populations
John Post, Ph.D., University of Calgary	Fish populations
David Rosenberg, Ph.D., Consultant	Benthic invertebrates, Coordinator
Carl Schwarz, Ph.D., Simon Fraser University	Biostatistics
Brian Souter, M.Sc., Department of Fisheries and Oceans	Fish abnormalities

Stephanie Sylvestre, M.Sc., Environment Canada	Benthic invertebrates
Alan Thomson, M.Sc., Consultant	Climate and hydrology
Michael Turner, Ph.D., Department of Fisheries and Oceans	Acid sensitive lakes
Marley Waiser, Ph.D. Environment Canada	Aquatic vegetation

Components - RAMP programs were reviewed by teams of two to three specialists in a particular subject or component viz., climate and hydrology, water quality, sediment quality, benthic invertebrates, fish populations, aquatic vegetation and acid sensitive lakes. The format used for the assessment of each program was generally similar but each team had the latitude to address issues more specific to its area. Biostatistics were addressed within each component and a separate biostatistics report was prepared as well (Appendix III). A biostatistics specialist was available for consultation/questions from individual teams and review final template reports and narrative summaries for appropriateness of statistical recommendations.

Template for Review – Because of the complexity of the program and of a review involving so many individuals, we felt it necessary to give the reviewers significantly more guidance than they would have received if asked to review a scientific paper for a journal publication. Reviewers were asked to report on inadequacies in the report(s) that could be corrected through reanalysis/reinterpretation of data or results and reported in future annual or periodic reports. They were also asked to report on inadequacies that required changes to the program itself. A template was provided for the individual program reviews. This template contained the elements that the Design and Integration Team considered desirable in a well-designed regional aquatic monitoring program. The specialist teams were asked to prepare separate template reports for each of the three primary RAMP objectives that the Five Year Report had been structured around. The template was relatively comprehensive and but all of the points would necessarily relate to each of the objectives. Common elements considered in the review of each objective for each subject area were: assessments of relevance to objectives; appropriateness of experimental design; interpretation of results and conclusions; nature of outputs; linkages to other components and programs; an assessment of gaps, omissions and recommendations; and an assessment of the proposed program for 2003 to 2009. Specific questions or directions to be considered were provided for each of the elements (see Appendix IV). A draft template was circulated to reviewers and members of the Review Team for comments before beginning the review but we remain responsible for any weaknesses, or strengths, of the approach. However, some elements that we thought should be included in a review (e.g. cost effectiveness), could not be addressed because the necessary information was not available.

Narrative Reports - Based on the detailed template reports the specialist teams were asked to prepare summaries for their components following a common format. They were asked to describe the scope of their review and any special perspectives that they might have. The assessment section focused on the adequacy of the monitoring and whether it met the objectives. Reviewers were asked to emphasize the most important/relevant aspects and leave secondary aspects to the template reports (Appendix IV). They were asked to make recommendations that addressed gaps identified in their review, and to provide enough details on implementation to provide guidance for further program design. The narrative summaries formed the basis of the assessments and recommendations in this report. With the exception of formatting, we did not edit these summaries. They are the creation of the specialist teams.

Integration – The various elements of an aquatic monitoring program need to be carefully integrated if the program is to be effective, and the same approach applies to any review of that program. We addressed this need for integration with ongoing interchange between the specialist teams and the Design and Integration Team, cross appointments of some of the specialists to more than one component and review of each of the component reports by the Design and Integration Team. The Design and Integration Team was also responsible for identifying common issues, discussing them with the Review Team and the RAMP Technical sub-committee during an interim meeting, and preparing the overall assessment and recommendations.

Recommendations – Recommendations from the specialist review teams will be found in the narrative sections that follow. More detailed comments are in the template assessments, particularly in the final section under each objective. The overall recommendations for this review were prepared by the Design and Integration Team. We reviewed all of the component reports looking for common themes in the assessments and recommendations. Our overall recommendations cross RAMP component areas and RAMP objectives. They are in general order of priority and they are closely inter-related.

ASSESSMENT OF CLIMATE AND HYDROLOGY COMPONENT PREPARED BY ALAN THOMSON AND MARTIN CARVER

1.0 Introduction

The climate and hydrology section of the RAMP Five Year Report is reviewed in this section. The review was conducted by two professional hydrologists with wide experience in the assessment of regional hydrological monitoring programs (see Appendix II). The review follows the format of the RAMP Five Year Report and is divided into three sections, each addressing one of the first three principle RAMP objectives:

1. Charaterizing existing variability;
2. Detecting and assessing cumulative effects; and
3. Monitoring to evaluate environmental impact assessment (EIA) predictions.

This review comments on the design, methods, results and conclusions of the RAMP climate and hydrology section. The review also makes an overall assessment of the section, comments on the gaps in the section and makes recommendations for changes to the overall climate and hydrology monitoring program, data analysis and data reporting. Lastly, comments are made as to the future direction of the climate and hydrology program within RAMP.

This review is a condensed version of the review found in Appendix IV, and includes only the more important issues. The reader should refer to the review in the appendices for additional discussion, analysis and recommendations concerning the climate and hydrology section.

2.0 Charaterizing Existing Variability

Under the title of the first primary objective, Charaterizing existing variability, the report discusses the location of long-term climate and hydrometric stations installed by Environment Canada to monitor both climate and hydrologic parameters in watersheds in the oil sands development region. Data retrieved from the climate and hydrometric stations are analyzed for variability in temperature, precipitation, water yield, flood discharge, and low-flow discharge. Watershed response to precipitation input is discussed and comparisons are made between watersheds. Recommendations are made in the Five Year Report that will increase both the quantity and quality of data collected. This primary objective is further described as “collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area” (p. 2-1 of the Five Year Report). The technical subcommittee established more detailed objectives, which are:

- to characterize the natural variation in climatic and hydrologic parameters, including precipitation, air temperature, water yield, flood peak discharges and low flows in the Oil Sands Region and identify linkages between climatic and hydrologic parameters; and
- to define baseline ranges for climatic and hydrologic parameters for the area monitored by RAMP.

The reviewers assessed this objective for the adequacy of the monitoring design, the methods used, the statistical analysis and the results and conclusions reached. Recommendations are also made under each of these subjects.

2.1 Monitoring Design

The reviewers had three major concerns about the monitoring design as outlined in the report:

- monitoring program design;
- monitoring groundwater; and
- monitoring of low flows.

2.1.1 Monitoring Program Design

To assess whether the monitoring program design is adequate to characterize natural variation in climate and hydrologic parameters, it is necessary to understand the rationale for the design of the monitoring program. The few details provided for the long-term hydrometric stations are mostly location oriented. There is little discussion of each station's attributes, the quality of data, data limitations, and most importantly, what role the station plays in the overall monitoring program. As an example, the station location rationale that exists for Station S4A (a short-term hydrometric station) as presented in Table 2.2 represents the absolute minimum in detail that the reviewers consider adequate. The apparent lack of monitoring station rationale documentation points to the need for a monitoring design and analytical plan that would outline RAMP's climate and hydrology monitoring objectives, strategies, and background information. This information would help in developing a scientifically defensible implementation, data collection, and reporting plan. See additional discussion under Objectives 2 and 3.

It is unclear from reviewing the Five Year Report whether the monitoring program is able to describe "the natural variation in climate and hydrologic parameters…in the Oil Sands Area". The focus study area, as defined by Figure 1.2 in the Five Year Report, is much larger than the area covered by the many long- and short-term hydrometric and climate monitoring stations. In addition, it is not clear from the Five Year Report the scope of the monitoring required and the level of detail and certainty required. Should all ecoregions be monitored? Should all geomorphologically distinct zones be represented? Should a complete range of watershed areas be monitored? (For example, there is no watershed represented in the 2,000-5,000 km^2 category.)

Due to the issues raised above, it is difficult to assess whether the current monitoring network is sufficient to characterize natural variation in climate and hydrologic parameters in the Oil Sands Region. It is recommended that a detailed discussion be presented in subsequent monitoring reports that outlines the monitoring design principles, objectives, and how the current long-term monitoring network addresses those objectives.

2.1.2 Monitoring Groundwater

Local groundwater resources are predicted to be significantly affected by oil sands developments as presented in recent EIAs for CNRL's Horizon and Shell's Jackpine Phase 1 projects. As such, oil sands developers are required to monitor local groundwater resources. Local and regional groundwater resources, however, are not monitored by RAMP. Groundwater contribution to baseflows predominate over all other water sources during low-flow winter months. Since the overwintering survival of many aquatic species is dependent upon the quality and quantity of baseflows, the reviewers consider it important to monitor local and regional groundwater resources. It is recommended that the RAMP hydrology monitoring program consider:

- monitoring local and regional groundwater by data acquisition from oil sands developers; and
- groundwater monitoring station placement in areas considered environmentally sensitive that are outside of oil sands developers' existing and proposed groundwater monitoring zones.

2.1.3 Monitoring of Low Flows

The collection of low-flow data seems to be a weak link in the hydrometric data collection system. For six of the seven long-term monitoring stations, sampled data do not exist post-1987 for the November-to-February period when low flows predominate. It is imperative that low flows be monitored at all hydrometric stations as low-flow discharge often dictates survival of aquatic biota, including fish, during winter months. The reviewers acknowledge that the Five Year Report recommends increased winter monitoring at some stations. However, the report notes that some small streams and tributaries may freeze to the bottom and thus provide no baseflow, and therefore do not warrant monitoring. Until this assumption can be proven over time and through various wet and dry cycles, 12-month monitoring should be conducted at all hydrometric stations. It is recommended that discharges be monitored from November through February for all hydrometric stations, regardless of known or assumed historical or current discharge characteristics.

2.2 Methods

The methods used to analyze the data appear appropriate. However, there are some issues of concern that should be addressed in future reports. These issues are detailed in the review found in Appendix IV.

2.3 Statistical Analysis

A standard statistical analysis was performed on both the long-term climate and hydrometric data. Mean annual discharge, frequency analysis, range of data, coefficient of variation, standard deviation and skewness were calculated for water yield, flood discharge and low-flow discharge. The report also computed the correlation between precipitation and water yield for each of the seven long-term hydrometric stations, and commented on the variability of hydrologic parameters between monitored watersheds. Concerns about the statistical methods used focus on two areas:

- time period for frequency analysis of hydrometric data; and
- frequency analysis using interpolated data.

2.3.1 Time Period for Frequency Analysis of Hydrometric Data

Frequency analysis of hydrometric data requires a significantly long period of record for the results to have a reasonable degree of statistical confidence. The report notes this and adds that "…48 years of record would be required to provide a 100-year flood estimate accurate to within 25% of the expected population value at a 95% confidence limit…" (p. 3-11). The data used to conduct a frequency analysis, with the exception of the Athabasca River station number 07DA001, fall short of recommended record periods to produce statistically meaningful results. Of the seven hydrometric stations in the region chosen for long-term variability analysis, one has 44 years of continuous data, and the remaining six have, on average, 28 years of continuous and interpolated data. It is possible to conduct frequency analysis on such data, but it is recommended that the statistical confidence level be reported and illustrated using confidence bands on all figures that indicate extreme events. There is concern that the length of data record for six of the seven hydrometric stations is insufficient to accurately predict future flood events with acceptable statistical confidence at this time.

2.3.2 Frequency Analysis Using Interpolated Data
Since 1987, six of the seven long-term hydrometric stations have not sampled discharges for the period November to February, representing 33% of the year. In order to conduct a complete analysis, reasonable methods are employed to fill the annual November to February data gap. For some calculations, such as water yield, the error associated with this data interpolation is likely minimal. However, with other calculations, such as low-flow frequency analysis, the statistical error may be large and unacceptable. The confidence level associated with the low-flow analysis is not reported. There is also concern that the interpolated values may be biased data for this analysis since data trends from pre-1987 are used to fabricate the post-1987 data. Although the reviewers recognize that the data gaps must be filled, it is recommended that a detailed discussion of the data-biasing implications and statistical error associated with low-flow data interpolation and analysis be presented.

2.4 Results
The results of the analysis are adequately presented, although the accuracy of some of the results is of concern, given the above comments. There is also a good general description of each watershed's geomorphology and the hydrologic response to precipitation that generally can be expected. The variability on an annual basis of both climate and hydrometric data is also reported satisfactorily. However, what is absent in the report is a detailed variability analysis on other periods; for example, among all of the June records or all of the July records. There is need to report figures and statistics such as variability between months, during periods important to fish and other aquatic biota, between peak flood dates, between low-flow events, during "wet" and "dry" cycles, etc. There are many variability statistics useful in charaterizing watersheds pertinent to biological processes that are not included in this report. It is recommended that time periods and parameters of interest for variability analysis be identified and a thorough analysis be completed and reported. The lack of depth in the variability analysis is the weakest aspect of the reporting for Objective 1.

3.0 Detecting And Assessing Cumulative Effects

The program assessed in this section is addressed to the second primary objective, detecting and assessing cumulative effects, for the climate and hydrology section. The report examines long-term climate and discharge data from Environment Canada for watersheds in the oil sands development region near Fort McMurray. Trends in precipitation, air temperature, water yield, flood discharge, and low flows are analyzed to identify temporal and spatial patterns in the existing data. Findings are presented and some suggestions put forth to explain the observed trends. The program's ability to detect change is also discussed.

The second primary objective, detecting and assessing cumulative effects, involves monitoring aquatic environments in the Oil Sands Area to detect and assess cumulative effects and regional trends. The technical subcommittee established more detailed objectives:

- to investigate trends over time in precipitation, temperature, water yield, flood peak discharges and low flows, based on available long-term climatic and hydrologic data; and
- to evaluate whether cumulative effects can be evaluated at this time and whether the data collected by RAMP will be appropriate to do so in the future.

The specific reframed objectives sharpen the primary objective by providing clearer statements of what will be addressed under the topic of "assessment and detection of cumulative effects and regional trends". However, the reframed objectives limit the scope of this overall section:

- only precipitation, air temperature, water yield, flood peak discharges and low flows are considered; and
- the assessment of cumulative effects is limited to an assessment of whether they can be evaluated now and in the future.

These changes reduce the scope of Objective 2. Although the following review comments acknowledge and make use of the information provided in these more specific objectives, the review assumes that the broader objective is also to be met, i.e. assessing and detecting cumulative effects and regional trends. The reviewers assessed this Objective for the adequacy of the monitoring design, the methods used, the statistical analysis and the results and conclusions reached. Comments and recommendations that fall under each of these subjects are found below.

3.1 Monitoring Design

Concerns about the monitoring design for the second objective focus on four subjects:

- Analytical plan;
- Strategies used to detect cumulative effects;
- Parameters chosen for analysis; and
- Extent of appropriate data.

3.1.1 Analytical Plan

It is difficult to identify the fundamentals of the analytical plan on which the cumulative effects analysis is built. Cumulative effects studies remain an emerging area of EIA. Given that there has been a lack of consensus on what a cumulative effects analysis should include (e.g. Reid 1993), studies with cumulative effects objectives need to be clear on what is under consideration. For example, under RAMP what is a cumulative effect? What are the key impacts and potential interactions? How does the monitoring design allow effect to be connected to cause given the measurables and data sets involved both now and in the future? The Five Year Report (p. 2-2) implies a definition of cumulative effects to be “the sum of all the effects on the aquatic environment” and that cumulative effects “are the result of both natural and man-made changes”. This definition is confusing because one would think that a study like this would seek to detect whether human-caused impacts are occurring and, if so, what is their total effect? The distinction between human-caused and naturally caused variability should be central to a cumulative effects analysis. The Five Year Report also says (p. 2-2) that the concepts of cumulative effects and regional trends have been “combined” and that “a regional trend, particularly a trend at a downstream location, incorporates the cumulative effect”. Again, the idea of combining trends and cumulative effects is confusing and its rationale unclear. Given the centrality of this discussion to the entire objective, it is recommended that the analytical plan for the cumulative effects analysis be worked out and clearly presented. In support of this discussion, it is recommended that the report include a glossary providing a clear expression of the meaning of these and other terms; this would also support greater comprehension by other, less technical readers.

3.1.2 Strategies Used to Detect Cumulative Effects

Beyond the fundamentals, what are RAMP’s analytical strategies to detect human-caused impacts and distinguish them from natural variability? Given the physical size of the study area and the scope for development-related impacts superimposed and/or interacting with natural variability, it is to be expected that detection of impact will be a major challenge. Meeting this challenge may require a variety of monitoring approaches and use of alternative data sources, particularly given the large range in applicable spatial and temporal scales and the degree of variability from natural disturbances. RAMP emphasizes the application of before-and-after monitoring both in terms of shorter-term environmental impact assessments and the longer-term cumulative effects assessment. The cumulative impact monitoring relies heavily on eight long-term Environment Canada data sets to establish background trends, yet these may be insufficient for the task (see 3.1.4 below).

What other approaches can be explored? At a minimum, it is recommended that control watersheds be established to act as benchmark comparisons as the oil sands developments are further implemented. It seems that none of the study basins is being held as a control given that all of the study basins shown in Figure 3-3 are within areas that have been or will be developed during the course of RAMP. Depending on the analytical framework, it may be necessary to include a suite of approaches to address data limitations—paired watersheds, analysis of lake bed cores, interpretation of historic airphotos, etc. Opportunistic use of basin “nesting” in the network layout may be helpful in achieving more insights with limited resources. It is recommended that the report provide the rationale and theoretical basis for the monitoring design chosen to address cumulative effects detection, including its strengths and weaknesses and explanation for the chosen sampling intensities. It may be efficient to establish a stronger connection with the EIAs done in the area.

The Five Year Report refers to the use of a regional hydrologic water-balance model to estimate changes to stream discharge from developments within a watershed (p. 3-68 and 3-122). On p. 3-115, a recommendation is given for calibrating a regional hydrologic model that has been used in environmental impact assessment in the area. While this could be a useful component within the range of approaches, the reviewers caution about using calibration data that are not free of impact. This highlights the usefulness of control basins. It is recommended that the report provide greater detail about this model—how it was built and how it will be applied. This may be a critical component to the cumulative effects analysis if the larger, more complex scales are to be adequately addressed.

3.1.3 Parameters Chosen for Analysis

The detailed Objective 2a limits the investigation of trends and cumulative effects to two climate and three hydrometric parameters. While this may be necessary in light of limitations in the long-term data, it is probably not satisfactory from the perspective of potential impacts. For example, the omission of groundwater from the monitored variables has been discussed under Objective 1 and is a major concern with respect to the cumulative effects analysis. The modest attention given the Athabasca River system is another source of concern, particularly in light of the lack of long-term data sets for the reaches downstream of oil sands developments. Without a detailed discussion in the report providing what is known about the mechanisms for impacts from oil sands development on aquatic systems and ideally identifying specific hypotheses about cumulative effects given the site specifics of the Fort McMurray area, it is difficult to provide more specific comments. It is recommended that the Five Year Report include a section in Chapter 2 describing how oil sands activities can affect aquatic systems and, in particular, regional hydrology, specifically identifying the mechanisms for impact. This discussion would provide a stronger theoretical basis for the subsequent choice of monitored parameters and hence would assist in monitoring the complete range of relevant hydrologic parameters. It is particularly important with respect to Objective 2 due to the complexity of detecting cumulative effects but would also be helpful in addressing Objective 3. It may also be of assistance to less technical readers.

Given the extent of oil sands development in this region and their intensive use of water resources that all, ultimately, derive from the Athabasca River system, it may be necessary to monitor the Athabasca River in more detail. The cumulative impact on low flows from the aggregate of regional development could have significant impacts on fish habitat. Also, are the stations on the Athabasca River and their data sets sufficient to characterize the changes that may occur given the size of this system and the potential for cumulative effects? It is recommended that the potential for cumulative impacts on the Athabasca River system be discussed along with the strategy in place to identify the effects and link them to cause.

3.1.4 Extent of Appropriate Data

There is concern that the monitoring design seems to have grown in an ad hoc manner, driven by regulatory requirements, and without the benefit of an overarching monitoring design and analytical plan. The majority of recently installed monitoring stations is located in a small part of the study area. For example, the majority of the recently installed hydrometric and all of the climate stations are located in the Tar/Calumet River and Muskeg River watersheds. It is not clear without a monitoring design and analytical plan whether the monitoring station network is sufficient and able to detect an effect.

There is also concern that the hydrometric data record may be inadequate for detecting an effect. According to Table 3-10 (p. 3-28), the long-term data set consists of one climate record of 58-years' duration, one streamflow record of 44-years' duration, and six streamflow records of between 26- and 29-years' duration. All but one of the data sets have less than 16 years of continuous annual data because between 1987 and 2001 all stations but one do not have data from November through February (representing 33% of each year). In addition, there is only one long-term station on the Athabasca River and it is located upstream of most of the developments, just north of Fort McMurray. Given the variability of hydrologic data in general, and these data in particular, these data records may be inadequate for detecting effects, especially cumulative effects, over the range of space and time scales that must be considered by this objective.

There is a specific concern with respect to the record of air temperature. Data from the Fort McMurray station indicate a shift as of 1971 and yet this is prior to the start of six of the seven long-term stations. It is recommended that the 1971 temperature shift be fully assessed so that trends can be adequately understood. There may be a simple reason for the shift that is held in Environment Canada or other published data. Regardless, how does this shift affect the trends and the analyses themselves?

3.2 Methods

The methods used to sample and record climate and hydrometric data appear appropriate. Although there are some data gaps, this is typical and understandable given the harsh northern Alberta environment. The statistical methods used to analyze the data are discussed in the following section. Methodological issues concerning the monitoring design were discussed in the previous section.

3.3 Statistics

Statistical analysis for trends and cumulative effects consists of the repeated application of the Spearman Test for Trend to eight long-term data sets from Environment Canada. The reviewers have a number of concerns with the approach and how it was carried out and reported.

3.3.1 Statistical Considerations in Conducting Trend Analysis

The Spearman Test for Trend is applied repeatedly to the long-term data sets to identify the presence of trends in the climate and hydrologic data over the past decades. In some cases the data are discovered to possess serial dependence which may violate the trend result. Serial dependence reduces the independence of the data and this in turn reduces the alpha and/or beta levels for the test, reducing the significance of the result. The serial dependence is not addressed in any of the trend analyses, nor are corrections or alternatives to the Spearman Test discussed. One suggestion provided here to correct for the serial dependence is to partition the annual data record into sub-periods that are treated as distinct populations. These subsets can be tested for differences (e.g. between three populations: early, middle, late). It is recommended that serial dependence be addressed in the trend analysis. It is also recommended that alternatives to the Spearman Test for Trend be discussed and, if appropriate, applied.

Exogenous influences are ones in which an additional variable has an important influence on the trend under study and obscures the trend through time under analysis. Exogenous variables are suggested and identified yet analysis is not carried out to address them: for example, the influence of precipitation and temperature on discharge. For the Beaver River, a temperature trend is observed in the data and used to infer an explanation for the water yield trend at one of the long-term hydrometric stations; however, an analysis is not provided to investigate this hypothesis. Removal of confounding effects may remove statistical noise sufficiently to identify real trend signals present in the data, should they exist. It is recommended that analyses be carried out to address the existence of exogenous variables so that the presence/absence of time trends can be adequately assessed.

3.3.2 Reporting of Power (beta) and Statistical Significance (alpha)

The statistical power of the trend detection is not discussed. The report identifies an absence of trends when it is unclear whether the statistical tests applied to the data can detect the trend if it does exist. Not finding a trend does not mean that a trend is absent. This is what the power of the test indicates yet this information is not provided. Power is a function of alpha level, effect size, sample size, and variance (Peterman, 1990). Given the variability inherent in these hydrologic data, the power may be low and hence warrants a discussion and likely a re-analysis. It is recommended that statistical power of each trend test be determined and presented in the report.

The report acknowledges that there are insufficient data to complete a rigorous statistical analysis of the short-term climate and hydrometric data. It is not stated, however, how much data will be required before a statistical analysis with sufficient power or confidence can be generated. It is suspected that several decades of data will be required at each station before there is reasonable confidence in the data and the statistical power is adequate to reach conclusions concerning trends and effects. It is likely that many of the oil sands development reserves, as currently defined, will be exhausted and the landscape reclaimed before the monitoring data will be of much use in verifying EIA predictions. It is questionable then that these data should be collected at all if they will be unable to detect change. It is recommended that a power analysis of the monitoring design be conducted to determine whether the monitoring network that currently exists will be able to detect an effect (and to what degree) if it is present.

The alpha level (statistical significance) of the results is generally presented as significant (90%) or highly significant (95%). It is recommended that the actual alpha level be provided so that the reader can make a more informed interpretation of the outcome of the statistical tests.

3.3.3 Parametric Analyses

The concerns for the trend analyses above (robustness to serial correlation, use of explanatory covariates to reduce variability, power computations) can all be better addressed using parametric (regression and autoregressive) methods. Although parametric linear regression models only capture the linear component of any trend, they nevertheless would permit more flexible, robust and insightful data analyses than non-parametric analyses for purposes of planning monitoring designs. It is recommended that suitable parametric linear model analyses for trend be applied to the hydrological data. These analyses should be directed at determining the sample sizes needed and effect sizes detectable in an achievable monitoring design.

3.4 Results

The section entitled "Conclusions and recommendations" (3.3.4) is essentially a summary of Section 3.3. It focuses almost entirely on the detailed Objective 2a, namely identifying trends in the five hydrologic and climate parameters. The trends and serial dependence are repeated without a conclusion or interpretation provided about the validity of the results. Also, the summaries would be easier to read if they were tabulated. The major objective of determining cumulative effects is not addressed at all in Section 3.3.4, nor in the other concluding sections associated with this objective (e.g. 8.1.2). Overall, given the concerns raised above, the conclusions presented (p. 3-119 to 3-120) do not logically follow from the analyses presented. It is recommended that the Five Year Report include comment on the implications of the findings for achieving the major and detailed objectives.

4.0 Monitoring To Verify EIA Predictions

The program assessed in this section addresses the third primary objective, Monitoring to verify EIA predictions, for the climate and hydrology section. The report discusses the location of RAMP monitoring stations installed since 1997 to monitor both climate and hydrologic parameters in watersheds in the vicinity of or contained wholly within oil sands development areas. Data retrieved from the climate and hydrometric stations are analyzed for temperature, precipitation, water yield, flood discharge, and low-flow discharge. Recommendations are made in the Five Year Report that will increase both the quantity and quality of data collected.

This primary objective is further defined as "collecting data against which predictions contained in environmental impact assessments (EIA's) can be verified". The more detailed objectives, as established by the technical subcommittee are defined as follows:

- to characterize the behaviour of the smaller local areas (streamflow and precipitation) monitored by RAMP and assess their likely behaviour in the longer term; and
- to evaluate whether EIA predictions can be evaluated at this time and whether the data collected by RAMP will be appropriate to do so in the future.

The specific reframed objectives sharpen the primary objective by providing clearer statements of what will be addressed under the topic of "Monitoring to Verify EIA Predictions". However, the reframed objectives limit the scope of this overall section since monitoring to evaluate EIA predictions is limited to an assessment of whether they can be evaluated now and in the future. Although the following review comments acknowledge and make use of the information provided in these more specific objectives, the review assumes that the broader objective is also to be met, i.e. monitoring to evaluate EIA predictions.

The reviewers assessed this objective for the adequacy of the monitoring design, the methods used, the statistical analysis and the results and conclusions reached. Comments that fall under each of these subjects are found below. For the statistical issues, the reader should refer to Appendix III.

4.1 Monitoring Design

The monitoring design program is meant to satisfy the detailed objectives described above. The reviewers are concerned about several aspects of the monitoring design of RAMP for the short-term stations. These concerns involve:

- linkage between EIA predictions and the monitoring network;
- rationale for the design of the monitoring network; and
- monitoring of low flows.

4.1.1 Linkage Between EIA Predictions and the Monitoring Network

The areas monitored by RAMP appear to represent smaller local areas reasonably well. In addition, the network of RAMP climate and hydrometric stations that is not associated with any particular oil sands development appears appropriately located in order to characterize pre-disturbance hydrology of smaller local areas. Whether stations associated with particular oil sands developments are established in the correct locations to verify EIA predictions, however, is unclear. The reviewers found it very difficult to assess whether each station is located in the correct place when the EIA predictions that require verification are not included in the report and the monitoring design is not clearly presented. For example, as outlined in the Shell Jackpine Phase 1 EIA, oil sands mining will likely excavate into the Pleistocene Channel Aquifer. Will the RAMP hydrometric Station S2 located on Jackpine Creek be able to monitor and detect the changes to surficial hydrology due to this activity? More generally, what water-related issues outlined in EIAs require verification, how will a station location and sampling rate detect changes to surficial waters as predicted in the EIAs, and how much data over what period are required in order to detect an effect at each station? (See discussion in review of Objective 2 on statistical power analysis.) These questions indicate the level of analysis and discussion that is required in order to satisfy the second detailed objective. Thus, it is recommended that a detailed discussion that identifies the variables that are likely to be impacted and the magnitude of the impact that it is necessary to detect be provided. Based on this discussion, the variability, controls, sample sizes, etc. that enable detection can be determined. It is also recommended that, where applicable, the linkage between monitoring station location and operation and relevant EIA predictions be detailed, discussed and analyzed where possible. Only after these discussions take place will it be possible to determine whether EIA predictions can be verified. The lack of discussion over what specific EIA predictions the monitoring network is attempting to verify and how the current and proposed monitoring network will be able to evaluate EIA predictions is one of the weakest but most important aspects of this section.

4.1.2 Rationale for the Design of the Monitoring Network

In order to assess whether the monitoring program design is adequate to evaluate EIA predictions, it is necessary to understand the monitoring design rationale. Although the monitoring design rationale is presented in Table 2.2 of the RAMP Program Design and Rationale (RAMP, 2002b) and in p. 3-70 to 3-75, detail and discussion are lacking. For a monitoring program the size and importance of RAMP, a lengthy discussion, even a separate report, outlining the monitoring program design rationale is required. Such a report would include details concerning station location rationale, history, location limitations, geomorphological features present in the watershed, watershed response to precipitation, how the station location suits the data requirements of RAMP's components (benthics, sediment, water quality, etc.), how the station complements the regional monitoring objectives and requirements, etc. Without this kind of background information, it is impossible to determine whether the RAMP monitoring stations are located correctly, are sampling at a sufficient rate and what additional stations are required at what locations in order to effectively and efficiently monitor effects and to evaluate EIA predictions. See Objectives 1 and 2 for additional discussion.

4.1.3 Monitoring low flows

Several of the short-term or recently installed hydrometric stations do not sample low flows during the winter season, on the assumption that some of the smaller monitored streams freeze to the bottom. Monitoring low flows, however, is important as the quantity and quality of low-flow discharge often dictates survival of aquatic biota, including fish over-wintering periods. Since oil sands development is likely to affect low flows, it is important to monitor these changes. The environmental impact of having winter flows reduced to zero could be extremely significant for a stream that typically experiences low to very low flows. It is recommended that all reasonable efforts be made to provide continuous sampling and recording of winter flows at all RAMP hydrometric stations, regardless of known or assumed winter discharge characteristics.

4.2 Methods

The methods used to analyze the data appear appropriate. However, there are some issues of concern that should be addressed in future reports. These issues are detailed in the template report found in Appendix IV.

4.3 Results

The results of the analysis are adequately presented, although the accuracy of some of the results is of concern, given the comments above and presented in Appendix IV. There is also a good general description of each watershed’s geomorphology and the hydrologic response that can be expected. The variability on an annual basis of both climate and hydrometric data is also reported satisfactorily. What is absent from the report, however, is a detailed variability analysis on a monthly basis; for example, between all of the June records or all of the July records. There is also need to report figures and statistics such as variability between months, during periods important to fish and other aquatic biota, between peak flood dates, between low-flow events, etc. There are many variability statistics useful in charaterizing watersheds pertinent to biological processes that are not included in this report. Although the reviewers acknowledge that there are few data with which to work, this additional analysis would help to characterize the behaviour of smaller local areas. It is recommended that the parameters that require variability analysis and comparison (i.e. monthly data, month-to-month data, low-flow periods, etc.) be identified and a thorough variability analysis and comparison be completed and reported.

5.0 Recommendations and Suggested Implementation

5.1 Overall Assessment

The report is written in a manner that is accessible to most stakeholders, with a few minor exceptions. For the most part, the report section is well organized and clearly written. The reviewers acknowledge that it is difficult to write a report to be readable and acceptable to all stakeholders and reviewers of differing backgrounds and understanding of environmental monitoring practices. In order to reach a broader audience, many terms, particularly statistical terms, should be defined and their usefulness in charaterizing natural variability, including strengths, weaknesses and limitations of tests outlined. This information could be included in a glossary in an appendix. Researchers and decision-makers would have a difficult time using this report because it does not provide enough technical detail, depth of analysis and discussion around pivotal issues. It is recommended that the report audience be defined in the introduction, and additional information be included in an appendix for readers outside of the defined audience. It is also recommended that brevity be enhanced through a greater use of tables to avoid repetitive text where possible.

With respect to the three objectives, the reviewers have a number of concerns with the hydrology and climate section. For the first objective, most of these concerns deal with the lack of information on the analytical plan and monitoring design in addition to statistical analysis, statistical error associated with data interpolation, and the limited scope of the variability analysis. The background information provided for each watershed is informative and the explanation of how and why different watersheds react to precipitation inputs differently is helpful.

In assessing the second objective, the reviewers recognize that trend and cumulative effects analyses are demanding in long-term data requirements and that new programs are limited, to some extent, by what has been done before. RAMP has looked at the data sets available and begun an analysis relevant to this objective. A number of shortcomings were encountered in reviewing the second objective. A coherent analytical basis for the cumulative effects analysis was not provided in the Five Year Report. In addition, it is very difficult to evaluate the monitoring network distribution until the monitoring design is clearly presented. Some definitions are ambiguous or not provided, leaving the reader unclear about what is being monitored. Some statistical tests are incomplete. As a result, some of the conclusions reached are inappropriate at this time. Additional key background information relevant to the objective, greater attention to detail, and a presentation of the strengths and weaknesses of the data sets (in relation to the objective) would strengthen the section.

Overall, the section on the third objective was written well but there are several key issues that are either omitted or need additional discussion and review. Specific EIA predictions are not presented, evaluation of the monitoring program is incomplete, and data variability analysis is inadequate. The report makes many recommendations to increase temporal and areal data collection abilities. The reviewers concur with many of the recommendations concerning monitoring station upgrading that are mentioned in this section, especially to measure low flows during winter.

5.2 Gaps

In light of the concerns outlined above, the reviewers have identified several major gaps in the climate and hydrology section:

- lack of a detailed monitoring design and analytical plan;
- significant data gaps over the low-flow period, the time most critical for many aquatic biota;
- lack of a detailed monitoring design and analytical plan;
- significant data gaps over the low-flow period, the time most critical for many aquatic biota;
- limited data variability and comparison analysis;
- absence of statistical power reporting in trend analysis;
- absence of a strong analytical framework for monitoring and detecting cumulative effects;
- lack of long-term data sets including absence of certain parameters;
- lack of linkage between monitoring station location and relevant EIA predictions that are meant to be verified by monitoring stations;
- need for monitoring of low flows at all hydrometric monitoring stations, regardless of known or assumed discharge characteristics; and
- incomplete consideration for the cumulative impacts to the Athabasca River system.

The reviewers recognize that the basic objectives are ambitious and difficult to meet and, as a result, gaps and program weaknesses are to be expected. RAMP has begun the job of assembling information sources for addressing hydrologic impact. Some of the above gaps may be dealt with in subsequent annual reports by including new material to expand on what has already been presented. In other cases, the gaps point to new areas that the RAMP will need to move into if the basic objectives are to be met. Many specific recommendations are provided below.

5.3 Recommendations

Recommendations have been provided throughout this review pertaining to the three primary objectives. Additional recommendations and discussion of the recommendations below are found in Appendix IV. The following is a summary of the most significant recommendations for each objective. For each recommendation given, the section number is provided where the detailed rationale can be found (in this report).

Objective 1

Five primary recommendations are outlined below in order of priority.

1. Provide a detailed discussion in subsequent monitoring reports outlining the monitoring design principles, objectives, and how the current and proposed monitoring network addresses those objectives (2.1.1).
2. Identify time periods and parameters of interest for variability analysis and complete a thorough variability analysis and report (2.4).
3. Monitor flows from November through February for all hydrometric stations, regardless of known or assumed historical or current discharge characteristics (2.1.3).
4. Report the statistical confidence level and illustrate using confidence bands on all figures indicating extreme events (2.3.1).
5. Include local and regional groundwater monitoring by data acquisition from oil sands developers; place groundwater monitoring stations in areas considered environmentally sensitive and outside of oil sands developers' existing and proposed monitoring areas (2.1.2).

Objective 2
Seven primary recommendations are outlined below in order of priority.

1. Develop the analytical plan for the cumulative effects analysis and clearly present it (3.1.1).
2. Provide in the report the rationale and theoretical basis for the monitoring design chosen to address cumulative effects detection, including its strengths and weaknesses and explanation for the chosen sampling intensities (3.1.2).
3. Conduct a power analysis of the monitoring design to determine whether the monitoring network that currently exists will be able to detect an effect (and to what degree) if it is present (3.3.2).
4. Apply a suitable parametric linear model analysis for trend to the hydrological data.
5. Discuss the potential for cumulative impacts on the Athabasca River system along with the strategy in place to identify the effects and link them to cause (3.1.3).
6. Include a section in Chapter 2 of the Five Year Report describing how oil sands activities can affect aquatic systems and, in particular, regional hydrology and specifically identifying the mechanisms for impact (3.1.3).
7. Establish control watersheds to act as benchmark comparisons as oil sands developments are further implemented (3.1.2).
8. Determine and present in the report statistical power of key tests (3.3.2).

Objective 3
Four primary recommendations are outlined below in order of priority.

1. Provide an in-depth discussion that identifies the variables that are likely to be impacted and the magnitude of the impact that it is necessary to detect. Based on this discussion, determine the variability, controls, sample sizes, etc. that enable detection (4.1.1).
2. Analyze and describe the linkage between monitoring station location and relevant EIA predictions, as applicable (4.1.1).

3. Identify parameters that require variability analysis (i.e. monthly data, month-to-month data, low-flow periods, etc.) and conduct a thorough variability analysis and report (4.3).
4. Provide continuous sampling and recording of winter flows at all RAMP hydrometric stations, regardless of known or assumed flow characteristics (4.1.3).

General Recommendations

In addition to these specific recommendations, the following are also provided:

1. Include in the report a glossary providing a clear expression of the meaning of technical terms (3.1.1).
2. Provide greater detail about the regional hydrologic water-balance computer model used for EIA predictions—how it was built and how it will be applied (3.1.2)?
3. Define the report audience in the introduction and include additional information in an appendix for readers outside of the defined audience. Enhance brevity through the greater use of tables to avoid repetitive text where possible (5.1).

5.4 RAMP 2002-2009 Plan

The reviewers have included many recommendations throughout the review of the climate and hydrology sections. These recommendations should be considered in the development of future RAMP monitoring activities. However, as stated throughout this review, the need for a monitoring design and analytical plan is apparent. No additions or modifications to the RAMP climate and hydrology monitoring program should be made without first developing a monitoring design and analytical plan.

5.5 Concluding Remarks

The review summarized in this report highlights the major gaps in RAMP preventing the objectives from being met. By carrying out the recommendations provided, the key gaps can be addressed. Where it is not possible to address certain recommendations, it may be preferable to adjust the RAMP objectives to reflect what is possible given the data sets involved.

ASSESSMENT OF WATER QUALITY COMPONENT
PREPARED BY NANCY GLOZIER, JAN BARICA AND MONIQUE DUBÉ

1.0 Introduction

The Regional Aquatic Monitoring Program (RAMP) "…was designed as a long-term monitoring program that incorporated both traditional and scientific knowledge" (p. 1-2, RAMP, 2003). RAMP is a multistakeholder program composed of funding (oil sands industries) and non-funding (regulators, First Nations, NGOs, and local communities) participants with membership having evolved through the five-year period since 1997. Its mandate is substantial; specifically, "to monitor, evaluate, compare, review and communicate the state of the aquatic environment in the Athabasca Oil Sands Region" (p. 1-4; RAMP, 2003). In addition to documenting changes in aquatic ecosystems over time, an objective within RAMP was to determine if observed changes were caused by natural variability, cumulative effects of development, or both. With the Oil Sands Region experiencing rapid growth from 1997 to 2001, annual modifications were made to the monitoring program. These changes affected RAMP's organizational structure, objectives, study area, and study design. This chapter deals with the water quality monitoring program. A major issue that arose in the review of the water quality section was that the frequent changes associated with the program over time and space made it very difficult to get a sense of what was measured, where, and when.

The three reviewers of the water quality component have extensive experience in study design, and analysis of water quality data. The review concentrated on Chapter 4 of the Five Year Report, with additional reference to Chapter 8 (Conclusion and Recommendations), the annual RAMP reports (1997-2001), the Oil Sands RAMP Program Design and Rationale, and the Biostatistics Review of RAMP (Appendix III). These documents were reviewed in the context of the RAMP main and sub-objectives of the water quality program. The main objectives included: characterizing existing variability, detecting and assessing cumulative effects and monitoring to verify EIA predictions. The sub-objectives included: influence of river discharge on water quality, fall vs. winter sampling, spatial trends in the Athabasca River, correlation between parameters, and duration of sampling for establishing baseline conditions. Finally, the 2002-2009 Program Design Document was reviewed to determine if the proposed design identified gaps and issues, subsequently improving the RAMP program to ensure that the main objectives were being addressed. This chapter is a summary of the water quality template, which appears Appendix IV, and to which the reader is directed for greater detail.

2.0 Characterizing Existing Variability

The water quality (WQ) component attempts to "characterize existing variability" through three sub-objectives: (1) parameter correlations, (2) examination of data relative to changes in discharge and (3) comparisons of parameter concentrations observed in fall vs. winter sampling. There appears to be confusion throughout the report and across the major sections (water, fish, benthos) on why and how to meet the objective of characterizing variability. The intention should be to develop an understanding of the range and magnitude of key indicators of water quality, specifically in relation to potential effects from oil sands development. Documenting the existing natural variability allows for future comparisons of the effects of developments (i.e. we would have the "baseline" to evaluate the importance of any shift in indicator values resulting from landuse changes). Unfortunately, the RAMP WQ program has varied so significantly over time it is difficult to determine if data currently exist to characterize variability for any of the aquatic systems potentially impacted by oil sands development.

Specifically, the parameter correlations performed in the report show little relevance to characterization of variability that could be used in the future as baseline information. The data are available, but are not presented in a manner consistent with documenting baselines. Although examining general correlations among parameters from the RAMP parameter list is a general/universal approach for any water quality monitoring program, rationale on parameter importance to the RAMP program is lacking. For example, principal components analysis (PCA) was done on conventional parameters (nutrients, major ions, and 19 metals (16 of them as dissolved), in no order of significance of their potential impacts. The parameter correlations should have ultimately identified key indicator water quality parameters that can be used to monitor change due to oil sands activity. A desktop exercise was required as a first step to list which parameters are currently being monitored, which are regulated and for what purpose, which are used in the environmental impact assessment (EIA) predictive models, which parameters are expected to change with development, and which parameters currently have site specific objectives or Canada Council of Ministers of the Environment (CCME) criteria for the protection of freshwater aquatic life. From this desktop inventory, a more focused analysis could have been conducted. Nowhere in this section is there a recommendation on which parameters should be measured in the future because these parameters are the most suitable indicators to characterize ecosystem variability. Additional information that would contribute to characterizing variability would include spatial and seasonal patterns within and between appropriate groups of reference sites.

Two further exercises performed under the objective of characterizing variability were (1) determining the relationships between river discharge and (2) parameter values/variability in fall and winter. Although these relationships are interesting, they present nothing unexpected and have no direct relevance to oil sands environmental concerns. Correlations of parameters to the river flow rates (Figures 4.8-4.9, Table 4.14) are expected; as in any river, major ion concentrations in the Athabasca River increase during the periods of low flow (winter). These relationships do provide useful hydro-geochemical information, and should be published separately in a science journal. However, the main objective of these two exercises is unclear. It is assumed that the authors want to determine when the period of maximum impact might be (or the period of greatest sensitivity) and monitor accordingly. Consideration of the appropriate time to sample depends upon the activities of the development, logistics, and when the other aquatic components are being measured. What if significant differences in water quality are observed downstream of development in the winter? The next question will be: Are those changes affecting biota? This highlights a key factor missing from the RAMP program, i.e. the linkages between components and the identification of which components are considered "effect" components and which are considered "supporting" components. Following the national Environmental Effects Monitoring Program (Environment Canada 2001), water quality assessments are considered supporting information for examining effects on biota. This approach should be seriously examined for the RAMP program and, presumably, would lead to a clearer understanding of the role of chemical water quality within the program.

Thus, this objective has not been adequately addressed over the first five years of RAMP.

3.0 Detecting Regional Trends and Cumulative Effects

The second objective, detecting regional trends and cumulative effects, was addressed in the RAMP WQ section using three approaches: (1) temporal trend analysis, (2) examining spatial patterns/trends between sites, and (3) with power analyses to determine the ability to detect changes in water quality.

Temporal trends were examined for water quality data collected on the main stem of the Athabasca and Muskeg Rivers. Alberta Environment's database on the Athabasca River allowed for long term (1976-2001) temporal trend analyses at two sites: (1) upstream of Fort McMurray and (2) far downstream at Old Fort. Shorter term (1997-2001) temporal trends were examined for two Muskeg River sites (upstream and downstream). Seasonal Kendall tests and Sen's slope were used for trend analysis (WQ StatPlus). Although some trends were detected, discussion regarding the importance of the variables that changed with time or their relevance to expected changes with oil sands development is lacking. Additionally, direct or indirect comparisons of the magnitude of changes through time and between sites are not discussed. Finally, there is no basis given for selection of the two aquatic systems assessed or discussion of how they factor into the existing and proposed development on these systems over time and space.

Spatial trends were examined for the same sites, upstream and downstream on the Athabasca River and Muskeg Rivers, as well as additional sites on tributaries and in wetlands. Overall spatial patterns between these sites were determined using PCA. The differences between the main stem of the Athabasca River, its tributaries, the Muskeg River, and wetland habitats are interesting but not particularly surprising. The point of spatial analyses within RAMP should be to determine if differences relative to locations of oil sands development exist, not to compare different aquatic ecosystems to each other. Some relevant points missed in these analyses include the establishment of baseline conditions and which aquatic ecosystems have similar chemical/physical characteristics. These similarities could then be linked to similarities/dissimilarities in the biotic community assessments.

A major conclusion in this section, stemming from comparisons of the two Alberta Environment sites on the Athabasca River (separated by >150 km), that "cumulative development in the oil sands area had not resulted in the degradation of water quality within this stretch of the river" (p. 4-52, Section 4.3.1.3) is not warranted. The single downstream site on the Athabasca River is ~90 km downstream of current oil sands activity and there are many confounding factors, apart from any changes due to the natural river continuum, to warrant this conclusion.

The work on the Muskeg River is the first indication that there was a sampling design suitable to measure changes due to oil sands development. However, the direction this section takes is confusing; observed differences in sulphate are attributed to discharges from the Alsands Drain but then it is stated that cause-effect is unknown. The authors do not assimilate this information or establish it as a baseline for future assessments. The next questions could have been: What is the magnitude of the change (i.e. how far downstream does it go) and what are the biotic community response patterns in this aquatic system?

An assessment of the ability to detect a certain magnitude of change in water quality parameter values was discussed. In regard to the nonparametric trend analysis, the recommendation of four sampling years was based on the software recommendations for these analyses. This is certainly a consideration; however, a recent publication on the design of water quality monitoring programs to detect trends (Vecchia, 2003) should be consulted for confirmation. The number and seasonal placement of samples depends on the pattern and variability of water quality characteristics within the watershed.

For ANOVA-type analyses a series of power analyses were conducted to determine the magnitude of change in a parameter the current program would be capable of detecting (i.e. the effect size). For some parameters (e.g. total boron) a large change (228%) would be undetectable, whereas for others (total dissolved solids, TDS) a small change (6%) between sites would be statistically detectable. This is important information and should influence redesign of the monitoring program. However, the first step is to establish the core parameters of concern influenced by oil sands development and an acceptable level of change linked to effects on biota. Once this desktop exercise is complete, then power analyses can be most useful in redesigning the RAMP WQ program.

Unfortunately the current monitoring design for this objective is not adequate to measure cumulative change related to oil sands development. However, with the background information now available, an excellent opportunity exists to improve RAMP with clear objectives established.

4.0 Monitoring to Verify EIA Predictions

It was assumed that this section would summarize the current EIA predictions, review the available information from RAMP, and compare these predictions and results to determine the accuracy of the EIA predictions. However, the fundamentals of the EIA were not summarized or even cited anywhere within the Five Year WQ Report. Instead, this section attempted to answer the following questions:

1. Are the sampling locations appropriate to evaluate the EIA predictions when development actually happens?
2. Are the water quality parameters appropriate to evaluate the EIA predictions?
3. Is the appropriate type of information being collected to detect human influences?

Therefore it is difficult to assess whether this section meets its objectives of verifying the EIA predictions. The following comments pertain directly to how the RAMP WQ report addressed the three questions posed.

Discussion regarding appropriate sampling locations revolved around presenting arguments as to why the sampling locations are valid for EIA. An alternative approach would have included a discussion on the limitations in the current sampling locations and suggestions of priority areas that need further examination for EIA evaluations. For example, the EIA nodes on the Athabasca River are located downstream of the tributaries. However, the RAMP WQ program monitored the Athabasca River upstream of the tributaries. The authors conclude that the latter approach was sufficient because, even though they were trying to examine the cumulative impact of a tributary on the Athabasca, monitoring upstream of the tributary confluence "can still be used to monitor potential effects from upstream". However, this would likely not be valid, particularly if there are a multitude of other influences in between. The standard approach would be to monitor both upstream and downstream of the tributary confluence with the Athabasca River.

Additionally, the validity of the statement that "inclusion of the upstream station of the Embarras River site near Old Fort permits potential verification of cumulative development within the basin (p. 4-72)" depends entirely upon your definition of cumulative. The goal of an EIA is to monitor the cumulative impacts of oil sands development. That means examining the effects of developments in isolation and in combination to determine if changes are localized or if they begin to accumulate in additive, synergistic, etc. fashion. This requires a systematic, spatially and temporally iterative approach to monitoring. Monitoring one site 165 km away may, over the long term, show changes but there will be no mechanism to determine if those changes were due to development, climate change, or just the normal changes a river goes through over time and as part of the natural river continuum. We completely disagree with the author's assessment of the program's ability to measure change.

Parameter lists are apparently complete; however, more discussion regarding consistency across all sampling programs would improve the analyses. Regarding nutrient analyses, no particular forms were measured nor were totals. These would add additional comparisons outside of RAMP. The parameter list needs a complete focus to a consistent core, consistent with Alberta Environment and focused on what is essential to understand the fundamentals of WQ and what indicators you would expect to change with oil sands development. Finally, a comment must be made regarding Table 4.1. Much of our time and effort was absorbed in attempting to clearly understand the water quality monitoring program. Although it is recognized that there are complexities, numerous changes, and numerous agencies involved, Table 4.1 did not elucidate the strengths/weaknesses of the program. The vast array of symbols (15) used to indicate which parameters or combination of parameters were sampled, at which site/time, disallows use of the table in an easy and transparent manner and precludes the review of the table for one particular parameter type. For example if one was looking for all the sites and times for which

PAHs were sampled, there are 6 independent symbols for which PAHs were included as part of a unique combination.

The RAMP program provides a significant opportunity to illustrate how baseline and follow-up monitoring can be done in a consistent way over time. The ultimate objective of determining if the EIA predictions were accurate, adaptively managing the system if they were not, and developing a process and database to improve predictive models and monitoring in the future are all real possibilities of this program that have yet to be realized.

5.0 Recommendations and Suggested Implementation

The RAMP Five Year WQ Report is an exhaustive document that contains a large amount of valuable information. The RAMP writing team did a reasonable job attempting to compile such an enormous amount of information. However, some severe editing, eliminating frequent repetitions, and condensing the report size would greatly improve its quality and accessibility to the key messages.

RAMP and its stakeholders should be commended for their willingness to participate in an external review of the program as well as for their willingness to work together over a regional scale. Clarification of the mandate and objectives of the RAMP WQ program, however, is required before further interpretation is completed. The lack of a clear purpose/roll for the WQ monitoring program within RAMP likely contributed substantially to the majority of the issues raised in this review. It should be recognized that the three primary objectives of the RAMP WQ program (and RAMP overall) are interdependent. The overall goal is to synthesize on an on-going basis what the original EIA impact predictions were and, through a well-designed monitoring program, determine if those impact predictions were accurate. Getting to this stage requires characterization of variability as well as on-going measurement of spatial and temporal trends and cumulative effects.

Overall, RAMP has enormous potential to serve as a national and international example of integrated, multi-stakeholder monitoring. Unfortunately the WQ component of the program falls severely short of the three main RAMP Objectives, based upon the annual reports and the Five Year Report. It is clear that large volumes of data exist and certainly analyses of these data could be repeated with clearer questions and greater focus. That being said, after five years and considering the development pushing ahead in the oil sands, it is alarming that the main monitoring program for the area significantly lacks strategic direction and scientific process. In the current state and based on the annual reports and the Five Year Report, the RAMP WQ program is not in a position to measure and assess development-related change locally or in a cumulative way.

The major gaps of this component are as follows:

1. There is not a strategic process for establishing sampling locations or for addressing the three primary objectives in an organized, focused and science-directed way.

2. There is no integration between WQ and other RAMP components and a lack of understanding of the role of WQ in RAMP. Is the WQ program a supportive component to the biotic component or an effect endpoint in and of itself? The former would be consistent with other Canadian monitoring programs.
3. There is a lack of core consistency for parameters measured, analyses conducted, statistics conducted, and reporting of results.
4. There is a lack (or insufficient knowledge) of specific markers or WQ indicators of oil sands development.
5. The study design does not build upon well-established, state-of-the science knowledge in Canada and elsewhere.
6. The current method of result dissemination and reporting is not sustainable. An information management and assessment system is required that builds off similar initiatives in the region.
7. Although there has been cooperation with provincial monitoring programs and other scientific programs such as PERD and perhaps NREI, these reports are not reviewed or provided in the Five Year Report.

Major recommendations for improving the WQ program within RAMP are divided into two components: (1) study design and (2) integration/management.

1. **Study Design.** A strategic overhaul of the RAMP WQ monitoring program is required in conjunction with a review of the other RAMP components. Revisions should include development of a strategic sampling plan, selection of a core parameter list including detection limits and analysis methods and core reporting requirements. The sampling plan and selection of core parameters should be directly related to the location and nature of existing and proposed developments. The parameters selected for the current RAMP are not oil-sands-development specific, but of a generic type, used by most WQ monitoring programs. Selection of key parameters should be done in view of the RAMP results to date and “markers” of oil sands impacts highlighted and expanded. Consideration of winter sampling for specific reasons (e.g. in areas of development) could be considered, but should not be at the loss of the core autumn sampling. The program should also build upon existing success stories that are established and proven outside of RAMP (e.g, EEM, effects-based monitoring). Finally, it is imperative that the WQ program not be conducted in isolation to the other RAMP components (benthos, fish) but rather as an integral part of an integrated site assessment. The current program stretches too far and wide at the expense of replication and consistency. The panel design proposed by B. Schwarz (Appendix III) should be considered as well as the recent US Geological Survey (USGS) document regarding sampling design for WQ monitoring programs (Vecchia, 2003). A clear opportunity exists for RAMP to utilize the large volumes of data available to create a world-class, science-based cumulative effects monitoring program.

2. **Integration/Management**. The component-based approach to RAMP (water group, benthic invertebrate group, fish group) has led to fragmentation and a lack

of integration. Consideration should be given to dissolving this management structure, or at the very least, developing an integration team that also serves as a scientific advisory panel. RAMP has been severely limited by the many of changes in the program.

An information management and assessment system should be considered because the existing assessment and reporting process is not sustainable. This system should consider and build from other initiatives in the area and consider inclusion of provincial, federal, industry (e.g. oil and grease measurements), and RAMP data. This information system would provide key plots and analyses on a consistent basis over time for all components. Location of sample stations on a GIS-based map and relative to existing and future development is also required. It is too difficult to track where water, benthic invertebrate, sediment and fish samples were taken because the program has changed so frequently.

Finally, we gave an overall ranking of unsatisfactory for the WQ program. We wish to make it clear that this ranking does not pertain to the actual Five Year Report itself but to the overall RAMP WQ program, how it addresses the three primary objectives, and its current implementation relative to other scientific practice in WQ monitoring in Canada.

ASSESSMENT OF SEDIMENT QUALITY COMPONENT
PREPARED BY BRIAN BROWNLEE AND UWE BORGMANN

1.0 Introduction

RAMP (Oil Sands Regional Aquatic Monitoring Program) began in 1997 as an aquatic monitoring program within the area of oil sands development in northeastern Alberta. We have reviewed the sediment quality sections of the Five Year Report covering the period 1997-2001, and portions of the sediment quality sections of the annual reports from 1997 to 2002. More detailed review comments are Appendix, IV.

Three RAMP objectives were evaluated:

1. Characterizing existing variability
2. Detecting and assessing cumulative effects and regional trends; and
3. Monitoring to verify (test) environmental impact assessment (EIA) predictions.

We reviewed both the Five Year Report and the program. In the case of sediment quality, for some objectives, the Five Year Report did not do justice to the program. Accordingly, we referred to the annual reports to gain a better understanding of what the program was doing and accomplishing. For the first objective, we found it helpful to distinguish between the program and Five Year Report in the template reviews. Relatively minor changes are recommended for the program, but major improvements are needed in the areas of data analysis and reporting for future summaries.

2.0 Characterizing Existing Variability

Recommendations for the program are limited to quality control, within-site variability and expansion of sediment toxicity testing to include bioaccumulation of metals. Until variability is better characterized, there is no reason to increase sampling intensity. Spatial coverage is already extensive, with 36 sites being sampled in 2002.

For some sites and substances, year-to-year variability has been high; for example, total recoverable hydrocarbons upstream from Donald Creek, east bank. Within site (same sampling occasion) and year-to-year variability for a site need to be separately defined and characterized. The closest example we are aware of that may be applicable was done during the Northern River Basins Study. Crosley (1996) collected 10 replicate samples at a number of sites on the Athabasca River. These 10 replicates were separated into coarse and fine fractions and then analyzed for resin acids. Crosley's results may have limited applicability because the nearest site was well upstream of Fort McMurray and samples were separated into fine and coarse fractions.

Toxicity testing was done on nearly half of the sediment samples collected from 1997-2001. We recommend that future work include bioaccumulation measurements for metals, because body concentrations are a better indicator of bioavailability and the cause of toxicity (Borgmann et al., 2001; Borgmann 2003a, b). In the template, we suggested "metals with concentrations close to ISQGs" as a category for data analysis. However, this may be a bit simplistic since ISQGs (Interim Sediment Quality Guidelines) are based on correlations and not on cause-effect relationships. Since the focus should be on metals in both water and sediment that are most likely to cause toxicity, comparison of metal concentrations in water with water quality guidelines is better than comparison of metal concentrations in sediment with ISQGS. In this area, the water quality and sediment quality components should coordinate.

The data analysis in the Five Year Report tested for substances that co-occur, examined the effect of sediment composition on PAH levels, and looked for indicator “parameters” that would enable reduction in the number of PAHs analyzed. Existing variability was not characterized. Other notable omissions were the lack of use of river hydraulics and sediment transport in discussing the results, and sources such as natural erosion of oil sands were not considered.

3.0 Detecting and Assessing Regional Trends

We question whether Principal Components Analysis is the best way to look at temporal and spatial trends in the region, and the ability to detect change. The Five Year Report was devoted exclusively to Principal Components. We question the value and validity of PCA for monitoring temporal trends. Further discussion can be found in Appendix VI.

Very little mention was made in the Five Year Report about cumulative effects. Sediment toxicity results were not presented or discussed in the Report.

4.0 Monitoring to Verify EIA Predictions

The Five Year Report considered three questions: are the samplings sites in appropriate locations, does the analytical list include all relevant substances and parameters discussed in EIAs, and is RAMP collecting or obtaining the necessary information to distinguish between natural variability and changes associated with human (industrial) activity?

We suggest that a more effective and meaningful way to evaluate RAMP against this objective would be to take recent EIA as a case study. For example:

1. What RAMP data were used in preparing the EIA?
2. How many years of baseline data were available?
3. How will the monitoring programs of RAMP and the project(s) be coordinated?
4. What predictions were made in the EIA?
5. How will the current RAMP go about testing these predictions?
6. Will RAMP be able to detect project-specific impacts?
7. Can cumulative effects in the region be identified?
8. Can RAMP distinguish between natural variability and industrial inputs?
9. Can RAMP identify the effect of sources other than industrial: natural erosion of oil sands, municipal sources, upstream sources, forest fires, etc.?

This may give a good indication of the likely future performance of RAMP in attaining this objective.

5.0 Recommendations and Suggested Implementation

Objective 1 – Program

- Quality Control. Analogous to water sampling, use clean sand or a low-level sediment reference material for field and trip blanks.
- Quality Control. When high concentrations appear at some sites, as in 2000 for total recoverable hydrocarbons (TRH) and many of the PAHs, there should be a procedure in place to double check and confirm that this did not occur because of field or laboratory contamination.
- Within-Site Variability. For statistical purposes, it is desirable to define within-site variability. One possibility is to take a sufficiently large number of samples at one site to define variability.
- Incorporate bioaccumulation measurements for metals in the sediment toxicity testing.

Objective 1 – Five Year Report and Data Analysis

- Redo the data analysis to demonstrate the range of variability for different substances.

Objective 2

- For reasons of temporal trend analysis, the baseline sampling period for new projects should be extended from three to five or more years, as recommended in the Five Year Report. This will require earlier notification of intent by proponents.
- Using the same approach as in the Five Year Report, temporal and spatial trends and the ability to detect change should be analyzed using examples of individual substances or logical groups of substances. The use of Principal Components in the report did not reveal much about the character of the underlying results.

Objective 3

- The most effective way of determining how well RAMP results will support testing of EIA predictions may be to use a recent EIA as a test case.

ASSESSMENT OF BENTHIC INVERTEBRATES COMPONENT PREPARED BY DAVID ROSENBERG, MONIQUE DUBÉ, AND STEPHANIE SYLVESTRE

1.0 Introduction

The Oils Sands Regional Aquatic Monitoring Program (RAMP) "…was designed as a long-term monitoring program that incorporated both traditional and scientific knowledge" (p. 1-2/3). Its intent was to document change in aquatic communities over time and determine if change was caused by natural variability, cumulative effects of development, or both (p. 1-1/4). RAMP is a multistakeholder initiative composed of funding (oil sands industries) and nonfunding (regulators, First Nations, NGOs, and local communities) members (p. 1-3/2). The Oil Sands Region experienced rapid growth from 1997-2001, the period of review for RAMP, so changes were made to the program annually (p. 1-3/3). These changes affected RAMP's organizational structure, objectives, the study area, and the study design, as will be evident below. RAMP included several subject areas. This chapter deals with benthic invertebrates, the animals that live on the bottoms of lakes and rivers. These organisms are routinely used in biomonitoring the water quality of lakes and rivers (e.g. Rosenberg and Resh, 1993).

The reviewers of the benthic invertebrate component all have extensive experience in biomonitoring using benthic invertebrates. The review concentrated on Chapter 6 of the five-year review document, with additional reference to the annual benthic invertebrate reports produced during the 1997-2001 review period. The review mainly focussed on the three objectives enunciated in the Five Year Report (p. 6-6 to 6-7): (1) "collecting scientifically defensible baseline and historical data to characterize variability in the oil sands area"; (2) "monitoring aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends"; and (3) "collecting data against which predictions contained in environmental impact assessments (EIAs) can be verified". This chapter is a summary of the more detailed benthic invertebrate template, which appears in Appendix IV at the end of this report. **The chapter and the template are meant to be read together** because there are several cross-cutting issues not specifically identified in sections 2-4 below, which appear in Section 5 (recommendations).

2.0 Characterizing Existing Variability

This objective was broken into two subobjectives: (1) spatial variation in benthic community structure, and (2) baseline ranges for key benthic community variables. The first subobjective was an exploratory analysis of patterns in benthic data from historical and 1997-2001 sampling, and an attempt to identify environmental variables driving those patterns. The results were largely inconclusive, and no specific recommendations were made. The second subobjective was an attempt to characterize variability by establishing baselines for a number of invertebrate metrics. This part was only marginally successful because of the disparate data involved and the short sampling period. The development of critical effect sizes to be used in future evaluations of monitoring data was recommended.

Not much directly pertinent to the detection of development-related change was delivered in the examination of this objective. The fault lies with the naïve nature of the objective. Biomonitoring approaches are currently being used that incorporate variability as part of the way they are done; there is no need for separate studies of variability. Moreover, given the disparate database, it is not surprising that the analysis was largely futile.

The objective should be reoriented around detecting development-related change. Use of already existing biomonitoring programs such as Environmental Effects Monitoring (EEM; Environment Canada, 1997, 1998, 2001; Glozier et al. 2002; Walker et al. 2002; Dubé, 2003) or the Reference Condition Approach (RCA; Reynoldson et al., 1995; Rosenberg et al. 1999; Wright et al. 2000; Bailey et al. 2004); would do this. Use of EEM or RCA would also solve other major problems: (1) standardized data collection (i.e. sampling the same sites over time, using consistent sampling gear and mesh size), (2) use of critical effect sizes and core effect endpoints (these items have to be designed and included at the outset of the program), and (3) provide reference site/area data (sadly missing from the present work).

Examination of the objective could have been improved had the extant EEM program upstream on the Athabasca River been accessed.

Our difficulty in trying to work with the raw data in assessing this objective indicates the need for an electronic data management system. Such a system would allow reporting of data in a standard format and ongoing assessment using consistent analyses.

Last, lessons learned from examining this objective do not seem to be carried forward to future sampling.

3.0 Detecting and Assessing Regional Trends

The author has equated “cumulative” with “regional”, and so the former has been dropped from the title of this objective. In fact, the two terms are not synonymous, and neither has been suitably addressed in this section (see Appendix IV for details).

Objective 2 is broken into three subobjectives: (1) long-term trends, (2) 2000 vs. 2001 comparisons, and (3) upstream-downstream comparisons and trends.

Subobjective 1 – It is hard to imagine why the author tried to identify long-term trends using spotty data from a five-year program. How can identification of long-term trends help a biomonitoring program? How can five years be considered long term, especially when data within the five years are bedevilled by changes in methods and locations and are not consistent?

Guesses as to what is controlling trends seen are pie in the sky; it appears that methods changes are mostly responsible.

Planning for the future is equally chancy; no pilot study or calibration activities are planned beyond letting the sampling run for another five years to see what happens.

The repeated observation that rivers in the study have unique benthic assemblages (p. 6-50/4) is highly dubious (see Objective 1, p. 6-35/4). This statement is hard to believe because of the coarse level of taxonomic identification used in the work, and because rivers in the same region are not likely to have markedly different species of benthic invertebrates in them. However, the author rightly identifies the need for reference rivers, although there is no indication how data from such rivers are to be used (p. 6-50/4).

The author makes no specific recommendation for this subobjective. It is probably a blind alley, and should be dropped as a further goal.

Subobjective 2 – Only the second half of this subobjective comes close to being part of a bona fide biomonitoring program. The power analyses and recommendations that flowed from them (i.e. number of samples, sites sampled, size of samples, etc.) are very useful, and seem to edge toward the EEM program.

The author considers the benthic program is still in its "initial phase" (disappointing because the program has run for five years), so adjusting the sampling design would not entail the loss of an unacceptably large amount of information (p. 6-61/4). The adjustment would also result in better compatibility with historical data. However, why not simply change to an already established biomonitoring program? After all, the author states (p. 6-62/2): "The recommended approach is based on study designs used in pulp mill EEM..." (see also p. 6-60/2). The recommendations from the power analyses seem not to have been used in the RAMP Program Design and Rationale document for future sampling.

The RAMP benthic program could have been further along had information from other programs in the region been used (e.g. EEM, NRBS, NREI). For example, EEM is not sector dependent and the monitoring approach is universal.

Subobjective 3 – It is hard to understand how this consideration adds anything to the program. There is some question about the experimental design used. Upstream/downstream comparisons to measure change are difficult to make if the sites selected are also upstream and downstream of a major tributary. It will never be possible to discriminate between development-related change and tributary effects (in this case, the Christina River is a tributary of the Clearwater River). Thus, the finding that "…existing differences may reflect the influence of the Christina River" (p. 6-63/3) is not surprising.

Results for the Mackay, Muskeg, and Steepbank rivers are also difficult to interpret, especially because the data were collected over three different years. Future experimental design should try to incorporate three types of sites, to evaluate cumulative effects: (1) outside or upstream of all development ("pure" reference sites), (2) downstream of proposed development but upstream of existing development (reference now), and (3) downstream of existing development (affected sites). Spatial comparisons can then be used to evaluate presence, direction, and magnitude of change to sites either in isolation or as combinations.

Recommendations for alterations of the study design are the same as for Subobjective 2, and derive from power analysis results.

4.0 Monitoring to Verify EIA Predictions

We thought this section would try to use existing data to test the veracity of predictions made by previous EIAs (i.e. are the data collected by RAMP suitable to verify EIA predictions?). Instead, the section is a compilation of EIAs that have been done, with an overlay of benthic monitoring locations. The section considers worthwhile sites, and recommends that less-worthwhile sites be changed. All in all, the section is a paper exercise, rather than being a substantive testing of EIA predictions using RAMP data. Even a compilation of EIA predictions that could be tested using RAMP data in the future would be useful. After five years of monitoring, evaluating the objective by determining whether the data are right to do it – instead of actually doing it – is unsatisfactory.

It is clear that a suitable, overall effects-based monitoring design must be adopted, or development-related change will not be assessed.

5.0 Recommendations and Suggested Implementation

1. Adopt an overall effects-based monitoring program or development-related change will not be assessed. Models are provided by EEM and RCA. In fact, EEM has been operating upstream on the Athabasca River for as long as the RAMP has been around. Adoption of either the EEM or the RCA model would provide the following benefits:
    - the protocols for these programs are well developed, so the details of site selection, sampling, sample processing, and data analysis can be imported directly into RAMP
    - personnel experienced in EEM and RCA are available to offer advice
    - EEM and RCA allow for the addition of sites as oil sands development proceeds
    - reference sites or areas would be included in an EEM or RCA program
    - RAMP could then focus on detecting change rather than on descriptive approaches, and would be able to interpret regional trends and cumulative effects.

    On balance, adoption of the EEM program would be the best choice because it is already operating in the area and because it would cause less disruption than the RCA to RAMP. However, considerable effort will likely be needed to see what elements of RAMP can be salvaged and applied directly to the EEM program.

2. The Athabasca River must be included in any monitoring program for oil sands development. It is the largest, most important ecosystem in the region and will be the receiver of the cumulative effects of development. In the face of EEM,

NRBS, NREI, and PERD programs on the Athabasca River, it is a mystery why RAMP chose to abandon the Athabasca after only one year of study (1997). It should be the core of the RAMP program for all subject areas. RAMP claimed that direct sampling of benthos in the Athabasca River downstream of Fort McMurray was not possible because of shifting substrates. We could not assess this claim because the Five Year Report lacked information and a review of past sampling attempts. RAMP should review industry, research, and provincial benthic biomonitoring programs before attempting other approaches to collect benthos (e.g. artificial substrates) on the Athabasca River.

3. An electronic database management system should be started as soon as possible to enable electronic reporting of raw data in a standard and consistent format and on-going assessment of data using consistent analyses. This recommendation is essential, given the long-term nature of oils sands development. Existing initiatives in Environment Canada's Prairie and Northern Region have integrated provincial and federal water quality data, water quantity data (HYDAT), EEM data for the Athabasca, and point-source quality (i.e. pulp mill and municipal sewage effluents) and quantity data. For example, EcoAtlas-CE has been developed under the NREI program, is currently being expanded to include EIA data, and is available for RAMP to use and develop.

4. The separate components of RAMP need to be better integrated to answer questions and needs between components (e.g. connections between water quality, benthic invertebrates, and fisheries). The overall approach should be an ecosystem-level study, rather than several disparate pieces. The lack of integration amongst aquatic components seriously compromises the ability of RAMP to assess effects-based biological changes.

5. RAMP needs to lean more heavily on regional programs that have been done (e.g. AOSERP, NRBS) or that are underway (e.g. EEM, NREI, PERD) for historical and contemporary information generated and lessons learned. It is also advisable that RAMP activities be more tightly coupled to the CEMA-sponsored Muskeg River study.

6. RAMP has an opportunity to contribute to new functional knowledge, and is encouraged to do so through primary publications. The standard is high for such publications, which means the standard of RAMP activities must also be high.

7. Benthic macroinvertebrates can be used in a variety of ways in biomonitoring activities. RAMP's predominant use has been attributes of community structure (e.g. abundance, density, taxa richness). More use should be made of the biomonitoring potential of benthic macroinvertebrates (e.g. the recent proposal to use mussels as sentinel organisms for contaminants).

ASSESSMENT OF THE FISH POPULATIONS COMPONENT PREPARED BY JOHN POST, KELLY MUNKITTRICK, MONIQUE DUBÉ AND BRIAN SOUTER

1.0 Introduction

We reviewed mainly the five-year review document, with additional reference to the annual reports produced during the 1997-2001 review period (Post, Munkittrick, Dubé). Souter reviewed the Fish Abnormalities Report as part of the ramp 2000 Annual Report.. Three general objectives are listed in Chapter 7 on Fish Populations: (1) collecting scientifically defensible baseline and historical data to characterize variability, (2) monitoring aquatic environments to detect and assess cumulative effects and regional trends, and (3) collecting data against which predictions contained in environmental impact assessments (EIAs) can be verified.

Three main issues were raised: (1) ensure important fish populations are not aversely affected by development, (2) maintain “ecological integrity”, defined as no adverse effects on growth, reproduction and survival, and (3) use early warning indicators. Three additional considerations were raised: i) use statistics to indicate “significant” patterns, ii) use all available data, and iii) link to other RAMP programs.

The review of the Fisheries component had six specific objectives:

1. characterize variability in individual and population-level metrics
2. evaluate program’s ability to do (1);
3. identify cumulative effects;
4. evaluate program’s ability to do (2);
5. use information collected to verify EIA predictions; and
6. can the program be improved?

This chapter is a summary of the fisheries template reports, which appear in Appendix IV, and to which the reader is directed for greater detail.

2.0 General Comments

The program lacks a clear focus and clear hypotheses regarding what it is trying to do. As it currently stands, the project has suffered from inconsistencies in study design, study area, sampling methods, and quality control practices. The synthesis does not focus on telling us what we should know by now, e.g. what species are resident (in what seasons) and what species migrate here (and when and for how long)? This baseline information is critical to understanding when and how sampling should be conducted.

As it stands the RAMP Fisheries program does not provide a very useful assessment for discerning current impacts or as a benchmark for assessment of future impacts. The collection methods (boat electrofishing) have not been characterized to see what the variability is, and whether they are adequate for the questions (once the questions are developed). The sampling times vary between years, and the synthesis compares fish collected in spring and autumn, resident and non-resident. Much of the statistical analysis is weak or wrong, and does not focus on providing a synthesis that we can use to move forward. Little attention has been paid to the problems of pseudoreplication inherent in many analyses.

3.0 Characterizing Existing Variability

This section tells us about the species inventories, and only 19 of 30 reported species were seen during the inventory. The species inventory varies because of changes in sites, seasons and sampling methods. The report documents that, for many of the larger species, there are seasonal differences in size of individual fish, suggesting migration into the study area of larger individuals from outside the system. It is crucial to understand fish migration patterns so any effects on fish relative to oil sands developments can b e assessed. Local evaluations have to use fish whose life-history characteristics and performance attributes reflect local conditions. Migrating fish make linkages to development difficult. It is also critical that the surveys use similar sites, methods and seasons, and design the study based on knowledge of the system. The sentinel species should be abundant enough that sufficient samples can be collected, be resident during critical portions of their life cycle, and have measurable characteristics (e.g. if aging is difficult for a particular species than that species may not be a good indicator). Power analysis should be used to ensure that sufficient samples are collected.

The fish tissue analyses are not useful for assessment purposes – PAHs will not accumulate to significant levels in fish muscle until environmental levels are very high. They will be detectable at lower concentrations in bile. The design of the contaminants collections, and study design in general, should be based on hypotheses related to anticipated potential impacts, or specific questions raised by the impact assessments. Furthermore tissue collections were from fish species (whitefish and walleye) that differed from the species collected in the sentinel surveys. In 1998, samples were collected from a reference area. In 2001, samples were collected from only the oil sands area with an n=1. This approach of measuring organics and metals in tissues of different species, from different sites, and in different years, with no replication has no validity.

The sentinel species work is a good first step towards an effects-based program. However, the study design for the sentinel species component needs to be closely evaluated as to its purpose and what questions are being examined. For example, the sculpin component evaluated reproductive development when growth-somatic indices (GSIs) were <2%. Prespawning female slimy sculpin will have a GSI of >35%, so evaluating before their gonadal investment has started does not tell us much about development related changes. In areas where fish cannot be collected between late November and early May, this species may not be a good, potential sentinel for reproductive evaluations. However, if other options for species are limited, there are other potential approaches, including examining the proportion of the population composed of young-of-the-year fish during the early fall as an indicator of reproductive success and recruitment.

There appears to be a lack of understanding of which indicators should be measured in the sentinel surveys and why. In the 2001 Report for example, GSI was measured in slimy sculpin at sites downstream of development on the Steepbank River. The conclusion reached (see comments on the 2001 Report in Appendix IV) illustrate that the authors do not understand how changes in indicators fit into an overalll effects-based assessment.

Radiotagging studies for the purpose of effects-based assesment should not collect post-spawning fish. Post-spawning aggregations of local and no-local fish, in many cases, represent aggregations from multiple groups of fish that reside in different parts of the river system. If the purpose is to evaluate local impacts, then fish should be collected during the period of suspected maximum residency (for suckers that would be early autumn), and then the fish can be followed. This is especially important in areas like this one, where we know that the seasonal distributions of fish size change, reflecting an influx of large fish at spawning time. The purpose of the study is not to see where fish come from to spawn; it should be to evaluate whether there are local fish, and if changes in olocal fish can be measured relative to development activities.

Difficulties with the counting fence need to be resolved. It can provide very good data.

The fish abnormalities study also falls short as an effort to characterize variability. The report was "cobbled together" from various sources, methods to identify abnormalities were not consistently applied from year to year, and reporting was inconsistent. There is also no photographic record provided to support result interpretation. There were no links made between water quality and the growths and lesions observed.

4.0 Detecting and Assessing Regional Trends

Much of the field sampling involved inconsistencies in methods and spatial and temporal coverage, rendering the pattern analysis biologically uninformative. A more focused, hypothesis driven, mechanism-based program would be more efficient and likely much more informative in the long run. It is necessary to standardize sampling sites and methods to allow the proper assessment of trends.

There appears to be confusion on the linkages between species selected to characterize variability and species selected to measure development-based change. Monitoring suckers during spawning runs and in the absence of a suitable reference site confound any interpretation of change. Measuring tracers in a different set of species confounds the issue further. If the goal is to measure changes in fish due to oil sands activities then select a resident sentinel, select a reference site(s) (see Appendix IV) and select a tracer for that sentinel. The work by J. Parrott, NWRI, Burlington, Ontario on the Steepbank River is a good example of how this can be done.

Several statements are made in the Five Year Report and Annual Reports indicating that changes measured in sentinels might be due to natural factors. Parrott does an excellent job illustrating a study design that separates a reference site from a site exposed to natural oil sands seepage and from a site downstream of development. In this instance, changes in EROD and sex steroid activities in a sentinel showed clear spatial changes. The importance of reference or "lo-impact" sites to separate natural changes from man-made disturbances cannot be emphasized enough.

5.0 Monitoring to Verify EIA Predictions

EIA predictions were divided into fish habitat, species composition, abundance, health and tissue tainting. It was recognized in the report that habitat was limited in the first two years and discontinued. It was also recognized that the inventory and abundance data was restricted, sites varied, and the selected method was size-selective. The fish health component is a recent addition to the program and, as mentioned above, there may need to be some consideration of the study design for this component. Tissue tainting studies have been conducted, but it is important to separate the questions of tainting, contamination, and violation of EIA predictions (i.e. PAH accumulation).

There are no EIA predictions included in the report. Several generic fish health characteristics are listed but they are not associated with impact predictions. Therefor, it is not possible to assess how RAMP could be used to test EIA predictions.

6.0 Conclusions

If the study is going to use monitoring to tell us something, it has to accept that such monitoring needs to use state-of-the-art technology, needs to be science-based, needs to focused on adaptive management, and has to be committed to telling us about the variability and confidence we can place in conclusions. The main objective should be to initially document, for specific reaches of river, representative reaches and regional reference areas, what species use the area, when they use it, why they use it, and how variable it is. Once these data are available, the baseline monitoring program needs to be developed, using specific questions focused on what the expected changes would be, and what the specific monitoring objectives are. If the study wants to do this, it should commit the money to do it properly, to regularly evaluate progress, have an external science advisory committee, and commit to science-based development of the information needed.

The objective to recognize and incorporate Traditional Ecological Knowledge (TEK) into the monitoring and assessment activities might be considered relevant to the fish abnormalities component. Fish abnormalities are a concern to First Nations in the area and we had expected that a report on fish abnormalities would have some reference top TEK.

ASSESSMENT OF AQUATIC VEGETATION COMPONENT
REPARED BY MARLEY WAISER

1.0 Introduction

The OIL Sands Regional Aquatics Monitoring Program (RAMP) was initiated in response to the large increase in oil sands mining and related developments north of Fort McMurray and the need to coordinate environmental monitoring activities so that potential cumulative effects could be identified and addressed. RAMP was initiated by Suncor Energy Ltd., Oil Sands, Syncrude Canada Ltd., and Shell Canada Ltd.

Surveys of wetland vegetation were conducted in 1997, 1998, and 2001 as part of the RAMP program. Three wetlands sites, Shipyard (adjacent to Suncor's Steepbank Mine), and Kearl and Isadore's lakes (adjacent to Shell's proposed Muskeg Mine Project), were sampled in each of these years. During this time, an effort was made to find a suitable reference wetland site. In 1997, the reference site was Lease 25 wetlands but this site was dropped in 1998 either due to poor access or because it was too close to future oil sands development. In 1998, Spruce Pond was investigated as a possible reference site but it too was dropped due to its hypertrophic status, which made comparison to the other less-enriched sites impossible. In 2002, McClelland Lake was chosen for sampling, although it is unclear from the material provided why this site was chosen.

Vegetation was documented by: mapping wetland classes according to the Alberta Wetland Inventory and using aerial photographs; photographing vegetation from fixed points; conducting a vegetation survey along fixed transects (evaluate species present and relative percent cover); recording vegetation vigor and health; and collecting water quality parameters (water depth, pH, conductivity, dissolved oxygen, percent dissolved oxygen, total dissolved solids and temperature). In 2001, the program was expanded to include calculation of species richness, species diversity (Shannon-Wiener), an index of similarity (Jaccard's), an index of dissimilarity (Bray-Curtis) and some limited statistical analyses (Kruskal-Wallis nonparametric tests).

2.0 Characterizing Existing Variability

The 1997 yearly report states that the objective of the wetland vegetation program, was to provide a description of wetland types, plant species composition and vegetation health as a baseline for future monitoring. In 1998, the scope of the study was to further describe the vegetation communities in Isadore's, Kearl and Shipyard lakes (second year of data to describe natural variability) and to identify and evaluate reference wetlands. In 2001, the stated objective was to continue the task of characterizing the natural variability in the wetland types representative of the three study lakes. The 2001 report also states that the key to RAMP success is to select and verify monitoring methods that will differentiate effects of oil sands development from natural variability and existing anthropogenic effects. The existing reports for 1997, 1998 and 2001 have done a good job, but only of describing the wetland types, plant species composition and vegetation health. The reviewer, however, could not find a clear statement in any document provided of which monitoring methods RAMP investigators selected and verified to differentiate natural from anthropogenic variability.

Wetlands are highly variable ecosystems and teasing out anthropogenic variation from that which is natural is not an easy task. The reviewer is concerned that the sampling frequency (once but at the most twice per year) is too low. Consequently, researchers may not be able to distinguish natural variability from that which may be anthropogenic or arise from the effects of oil sands development. In the 2002 document, under sampling frequency, no mention is made regarding the number of times per year wetland vegetation will be sampled. If sampling can only be done once per year, then it should be done when the plant community is at its peak and at a time of year when the greatest impact from oil sands development is expected (i.e. the time of year when problems are most likely to occur – usually called the index period). According to the US Environmental Protection Agency (EPA) (EPA, 2002 - #4 Study Design for Monitoring Wetlands http://www.epa.gov/waterscience/criteria/wetlands/), "once wetland condition has been characterized, one-time annual sampling during the appropriate index period may be enough for multiple-year monitoring of indicators of biotic integrity. However, metrics and ecological indicator development [which as far as the reviewer can tell have not yet been established by RAMP], may require more frequent sampling to define conditions that relate to the stressor or the impact of interest". Sampling frequency must be addressed by the investigators and this must be done before the next wetland vegetation monitoring takes place.

One of the clear objectives of RAMP is to characterize variation. Because of the high natural variation associated with wetlands and the fact that RAMP is supposed to be investigating the effects of oil sands development on aquatic ecosystems, it is imperative that reference site(s) be found. The current lack of a reference site precludes the ability to detect what is natural variation and what is anthropogenic. According to Richardson and Vymazal (2001) "Reference or undisturbed areas must be included in all biomonitoring analyses if changes in communities are to be assessed accurately". Finding and sampling a large number of reference sites to define regional variability may not be necessary if physically similar sites (size, hydrology, elevation, etc.) can be found close to the disturbance site but out of range of possible disturbances. Reference sites such as these should be selected based on physical or chemical attributes not affected by human intervention (elevation for example) (Rader and Shiozawa, 2001). If a few local reference sites cannot be found, there are other options. For example, sampling a number of minimally affected sites could work (Wright et al., 1995). As well, there is the possibility of establishing reference conditions within each wetland using paleolimnological techniques, providing that sediments have been relatively undisturbed through time. Finding reference sites is a "must do" for the RAMP program. Although the 2002 report does identify the need for reference sites, it should be at the very top of the list of what must be done in order for RAMP to become an effective scientific program that fulfils its objectives.

3.0 Detection of Effects and Monitoring Cumulative Effects

In the Executive Summary of 1997, a statement is made that RAMP is largely an effects-oriented project whose priority is early detection of potential effects. The stated objective of the wetland vegetation subprogram is to "provide a description of wetland types, plant species and composition and vegetation health as a baseline for future monitoring". This objective is not in line with the stated objectives of the overall program; the emphasis for this subprogram should be on effects monitoring with regard to wetland vegetation, not monitoring of vegetation. If the objective is on effects, then the rationale has to be more clearly defined.

The existing rationale is stated as follows: "wetland vegetation has been documented as an important biomonitoring parameter for examining potential effects to wetland systems". But that is where it ends. The reviewer agrees with this statement, but unfortunately, the investigators do not seem to have thought about how they are going to use the data that they have collected to demonstrate effects of oil sands development. There is no clear, well thought-out, scientifically based plan in place detailing why all of these data are being collected and how these data will be used to detect effects. Nowhere in the documentation could the reviewer find a clear statement of what constitutes unacceptable change in wetland vegetation. Consequently, RAMP has failed miserably with respect to meeting the objective of detecting effects and monitoring cumulative effects.

As a first step, the investigators need to figure out which aspects (attributes = measurable components of a biological system) of wetland vegetation are the most likely to respond to disturbance resulting from oil sands development. Karr and Chu (1999) point out that "a bewildering variety of biological attributes can be measured but only a few provide useful signals about the impact of human activities". Consequently the careful choice of attributes, which will show a consistent response to oil sands development, is imperative. The goal would be to identify those vegetation attributes that respond reliably to human activities, are minimally affected by natural variability, and are cost-effective to measure (EPA, 2002; #6). The data have probably already been collected, so it would be a matter of sorting out which of the vegetation parameters measured are most likely to respond to the stressors provided by oil sands development.

Attributes that respond to human disturbance are called "metrics". Metrics can be divided into three groups: community based, metrics based on plant functional groups and species-specific metrics (EPA, 2002). Metrics are used to detect ecological impairment and diagnose causes of impairment. This approach has been widely used in wetland research. In a study of 26 Minnesota wetlands, for example, an index of biological integrity was developed using 10 vegetation metrics (Helgen and Gernes, 2001), in an effort to compare the biological integrity of reference wetlands to wetlands in agricultural areas or those receiving stormwater inputs. Vegetation metrics included the number of vascular genera, number of nonvascular taxa, sum of all sedge species cover classes, sensitive species, tolerant taxa, grass-like taxa, monocarpic species, number of aquatic guild species, distribution of cover in a sample and sum of persistent litter taxa-cover classes. Scoring criteria were developed by sorting metric values from high to low and then dividing the data into three groups. The maximum score for the index was 50, whereas the minimum was 10. A reference wetland in a state park received a score of 50, whereas one agriculturally affected site received a score of 10 (Helgen and Gernes, 2001). Such an approach would have great applicability to the

RAMP study (refer to the EPA website http://www.epa.gov/waterscience/criteria/wetlands/ and the module “Using vegetation to assess environmental conditions in wetlands” for an in-depth discussion of the use of metrics for wetland evaluations).

4.0 Monitoring to Verify EIA Predictions

The reviewer could not find reference to “monitoring to verify EIA predictions” in the documents provided concerning wetland vegetation. If this is one of the objectives of RAMP, then this oversight needs to be addressed.

5.0 Recommendations and Suggested Implementation

1. Change objectives and rationale so that they are clearly stated and scientifically based. The investigators need to look at the monitoring program and decide, based on an intensive search of the scientific literature, which attributes of wetland vegetation they should be monitoring, i.e. which attributes will give the most information regarding variability (natural and anthropogenic) and effects of oil sands development.
2. Work done must reflect the objectives and rationale. The investigators need to keep their focus on what the objectives of the research are and make sure that the research they propose will meet the stated objectives. To date this has not been done.
3. The time of year of sampling and sampling frequency for wetland vegetation needs to be re-examined. If sampling can only be done once per year, then it should be done when the plant community is at its peak and at a time of year when the greatest impact from oil sands development is expected (i.e. the time of year when problems are most likely to occur, usually called the index period). According to the EPA (2002 - #4 Study Design for Monitoring Wetlands http://www.epa.gov/waterscience/criteria/wetlands/), “once wetland condition has been characterized, one-time annual sampling during the appropriate index period may be enough for multiple-year monitoring of indicators of biotic integrity. However, metric and ecological indicator development [which as far as the reviewer can tell have not yet been established by RAMP] may require more frequent sampling to define conditions that relate to the stressor or the impact of interest”. Due to the high variation within wetland systems, if one is going to compare systems then it is important that sampling be done at the same time of the year on a year-to-year basis. According to EPA (2002), “the establishment of a standard sampling window ensures that representative results are obtained at each site and that valid comparisons can be made between different wetlands”. Wetland vegetation sampling was not done in the same month from year to year in the RAMP study. This should be addressed for future sampling efforts.
4. Establish attributes of wetland vegetation that are metrics, i.e. attributes that are appropriate for monitoring the effects of oils sands development on wetland vegetation (see comments in Appendix IV). Then base the wetland vegetation

monitoring program on measuring those metrics. Combine the metrics into a multimetric index which will allow the investigators to score and compare affected sites to reference sites. In this way, effects can be measured. Karr and Chu (1999) point out that "a bewildering variety of biological attributes can be measured but only a few provide useful signals about the impact of human activities". Consequently the careful choice of attributes that will show a consistent response to oil sands development is imperative. The goal would be to identify those vegetation attributes that respond reliably to human activities, are minimally affected by natural variability, and are cost-effective to measure (EPA, 2002; #6). The data have probably already been collected, so it would be a matter of sorting out which of the vegetation parameters measured are most likely to respond to the stressors provided by oil sands development.

5. Because of the high natural variation associated with wetlands, and to meet the stated objective of determining effects, it is imperative that a reference site or sites be found. This must be done if researchers are to meet the objective of determining the effects of oil sands development on wetland vegetation. Without a reference site, collection of more vegetation data would be a waste of time and effort. The current lack of a reference site precludes the ability to detect what is natural variation and what is anthropogenic (due to oil sands development). According to Richardson and Vymazal (2001) "Reference or undisturbed areas must be included in all biomonitoring analyses if changes in communities are to be assessed accurately". Reference sites serve as the standard against which other sites will be judged. Finding and sampling a large number of reference sites to define regional variability may not be necessary if physically similar sites (size, hydrology, elevation, etc.) can be found close to the disturbance site but out of range of possible disturbances. Such reference sites should be selected based on physical or chemical attributes not affected by human intervention (Rader and Shiozawa, 2001). If a few local reference sites cannot be found, there are other options. For example, sampling a number of minimally affected sites could work (Wright et al.,1995).
6. Consult with a statistician to improve not only the way that data are analyzed but also how to better integrate the vegetation data with the water chemistry and quality data.
7. Improve referencing to scientific literature – don't base your study solely on technical and government reports.
8. Don't wait five years for a review. Have an outside objective scientific panel with the appropriate experience and expertise review work done on a yearly basis.
9. Less representation by industry and more representation by non-partisan groups (Environment Canada, universities, etc.) is advised. The make-up of the RAMP committees is too heavily weighted towards industry. The lack of scientific expertise on these committees is reflected in lack of scientific rigor in the RAMP wetland vegetation reports.
10. Proposed research should be vetted first by outside experts. Before going out into the field to collect data, submit proposed monitoring and effects research to appropriate qualified scientific personnel for review and comment.

ASSESSMENT OF ACID SENSITIVE LAKES COMPONENT
PREPARED BY MICHAEL TURNER AND JAN BARICA

1.0 Introduction

The Acid Sensitive Lakes (ASL) program was designed to provide an early warning of the effects of acid deposition emanating from the Oil Sands Region. In particular, a properly designed ASL program will support the Cumulative Environmental Management Association (CEMA) objective of activating "the management response in the case of a yellow or red condition is intended … to ensure there are no exceedances of management objectives beyond the level of protection area". The ASL component of the Oil Sands Regional Aquatics Monitoring Program (RAMP) was initiated in 1999 in partnership with Alberta Environment. This review was carried out by two individuals with two complementary backgrounds. The senior reviewer has considerable expertise on the effects of acidification on lakes, while the second reviewer has broad experience in water quality monitoring systems in lakes and rivers in many areas of the world (see Appendix II).

Although there are no trends yet seen that support the idea that acidification is occurring, the ASL program reports that there are "already some concerns regarding acidification in the Oil Sands Region in the foreseeable future".

The potential for acidification is of concern because acidification represents one of the most seriously damaging impacts that humans can wreak upon ecosystems. Impacts can range from the physicochemical to biological changes that alter the structure and function of these ecosystems. Biological changes include irreversible impacts upon habitat productivity, foodweb integrity, ecosystem health and biodiversity.

An objective of the CEMA framework was to "avoid change in water chemistry that will result in change to ecological receptors either in the short term or through a long-term trend". This objective stemmed from the recognition that "it is possible that some change in water chemistry will occur from anthropogenic emissions. Any such change will be limited so that it is consistent with the management framework goal".

Selection of Lakes

Up to 50 moderately to highly acid sensitive lakes in northeastern Alberta (i.e. the region expected to be impacted by Oil Sands development) have been selected for regular monitoring, although this number has varied from year to year. In 2002, 39 lakes in the Oil Sands Region were included to represent a gradient in acid deposition; also we used 5 lakes in the nearby Caribou Mountains plus 5 lakes in the Canadian Shield that are distant from sources of acidifying emissions (reference lakes). These lakes were deemed to represent systems that were moderately to highly sensitive to acidification (<20 mg/L $CaCO_3$), close and away from the Oil Sands area, and accessible by at least float plane.

Table 10.1 (2002 Report) presents modeled acid deposition rates with critical loads calculated for individual RAMP lakes (developed by CASA-established guidelines in 1996-1999). The critical load is defined as the highest load that will not cause chemical changes leading to long-term harmful effects on the most sensitive ecological systems (study done outside RAMP), set at 0.25 keq $ha^{-1}yr^{-1}$ for sensitive soils in Alberta, taking into account the expected buffering capacity of the lakes and input of base cations for the watershed. It represents the amount of acid deposition below which acid neutralizing capacity (ANC) or pH remain above a specific threshold value (ANC set at <5 $ueq \cdot L^{-1}$ or pH 6 for the Oil Sands Region by the NO_x – SO_x Management Working Group (outside RAMP).

Sampling Program
The lakes have been monitored annually. Vertically integrated collections from the euphotic zone from up to five sites in each lake were combined to form a single composite sample for chemical analysis. Full vertical profiles of Secchi depth, dissolved oxygen (DO), temperature (T), conductivity and pH are done at the deepest location in each lake. Parameters monitored include standard (routine, generic, core) indicators used in water quality monitoring, both of acid lakes and other water bodies (i.e. pH, total suspended solids [TSS], total dissolved solids [TDS], alkalinity, bicarbonate and other major ions, nutrients, DO, etc.). Table 8.2 of the same report presents a detailed rationale for core ASL monitoring program, with general guiding principles, site selection, and specific methods and procedures.

Scope of Material
The materials considered for this review included: RAMP 1999: 2.1.4, 3.1, 8.1, 9.1.4, 9.2 RAMP 2000: 2.1.4, 4.4, 8, 10.1.4; RAMP 2001: 2.1.4, 3.5, 4.2.4, 10, 11.1.3, 12.1.4 RAMP 2002: 1.2.6, 2.1.5, 3.6, 4.2.6, 10; RAMP Five Year 1997-2001 Report (ASL sections 1.4.5.2, 1.5.5.3 and 1.6.5.3); RAMP Program Design and Rationale (2002) section 8 and Table 8.1; Horizon Oil Sands Project Application (technological aspects); and notes on the RAMP 2003 Oct. 22 meeting. As well, the reviewers examined supplementary material provided by B. Kemper including: CEMA: Acid deposition management framework recommendations for the oil sands region of north-eastern Alberta; CEMA Research priorities and monitoring enhancements related to acidification and the management of critical loads in north eastern Alberta; and Preliminary review of the effects of acid deposition on northern Saskatchewan lakes (D. Ballagh, 1999).

It is important to recognize that the lack of an integrated overview document (as was available for other RAMP projects) diminished the effectiveness of the review and significantly increased the effort required. Frequent changes to the objectives and scope of the review further diminished the effectiveness of the review planning, and have arguably caused the review to be incomplete. It is imperative that a consolidated report for the ASL program be prepared that includes documentation of the linkages with other programs (e.g. in diagrammatic form). Only then can an effective review of the program be conducted.

2.0 Assessment of Acid Sensitive Lakes Program

The program as it has been described in the annual reports is unlikely to achieve its stated objectives, although implementation of the several studies recommended by the CEMA NO_x - SO_x working group would markedly improve the program and its effectiveness. If the CEMA recommendations are not acted upon, it is unclear that the program can achieve its stated objectives of:

1. Collecting scientifically defensible baseline and historical data to characterize variability in the acid sensitive lakes;
2. Monitoring aquatic environments to detect and assess cumulative effects and regional trends; and
3. Collecting data against which predictions contained in environmental impact assessments (EIAs) can be verified.

Assessment related to ASL Program Objectives

The ASL program's first objective is to collect scientifically defensible baseline and historical data to characterize variability in the oil sands area. Despite the limited frequency of sampling (once a year) and short length of the monitoring program (1999-2002), the Program has delivered some useful information and new knowledge. However, it could not collect scientifically justifiable baseline and historical data to enable characterization of the variability in the Oil Sands Region. Nor was a procedure proposed that would enable valid statistical detection of trends in the future; currently, data are insufficient for a trend analysis.

The second program objective was to monitor aquatic environments in the Oil Sands Region to detect and assess cumulative effects and regional trends. The data collected since 1999 have been insufficient to detect any regional trends or cumulative effects of acid depositions. (Nor would we expect to detect a trend in four years.) However, sulphate concentrations in several lakes of the Birch Mountains in the Oil Sands Region are already high, and are similar to or exceed values seen in experimentally acidified lakes of the Experimental Lakes Area (ELA) at their most acid. This suggests that some acidification may already have occurred. This observation applies only to the chemical parameters monitored because so far there is no biological monitoring being conducted in the ASL program.

The third objective was to collect data against which predictions contained in environmental impact assessments (EIA) can be verified. The power of the monitoring program described in the RAMP ASL program annual reports is insufficient to verify EIA predictions. Principle concerns include:

- sampling frequency is inadequate to monitor parameters that are known to be seasonally variable;
- the timing of sampling avoids possible spring acid pulses that occur elsewhere in acid impacted regions;
- many important early warning lake responses are biotic and these are not being monitored;
- some of the lakes being monitored are not particularly acid sensitive; and
- deposition (including dry deposition) is not being monitored forcing decisions to rely solely on modeled scenarios.

See below for additional concerns.

Assessment Related to Linkages and Integration
Within the Program: The water chemistry of the acid sensitive lakes appears to exist largely in isolation of other components of RAMP; certainly other components were excluded from the ASL reports. Although some phytoplankton and zooplankton samples have been collected, no plans have yet been identified to have them analyzed or interpreted.

RAMP to Region: Although the selection of sampling stations seems acceptable, it is unclear how representative the selected lakes are from a regional perspective. Certainly it is good that more than one cluster of lakes is being studied. However, there are good reasons for adding at least one or two more clusters, including the acid sensitive lakes in northwestern Saskatchewan.

RAMP to Other Programs: It is also unclear from the annual RAMP ASL reports what is going on in other (possibly related) ASL studies in northern Alberta because the annual reports have been presented largely in isolation of such activities. There is no evidence of any linkage of this component to other environmental monitoring programs in the annual reports except for Table 8.2 of the 2002 RAMP Program Design and Rationale. Recently received information from Bryan Kemper indicates that there are several important additional efforts proposed by CEMA that are outside the activities identified in the RAMP annual reports. These proposed studies and their interactions with RAMP monitoring need to be linked in a summary report.

Concerns and Gaps
The ASL Program provided useful and scientifically valid information that will contribute to regional, national and international understanding of relationships of various components of northeastern Alberta acid sensitive ecosystems. There have been some adaptive changes made to the program, although sometimes the changes have not always been well implemented (e.g. although gran alkalinity began to be measured in the second year, the older measurements remain the reported values). However, there are so many serious issues that remain to be adapted to that we believe the experimental design described in the ASL Program RAMP reports is unsuitable for testing the program objectives.

We are concerned that the gaps in the present ASL monitoring program will prevent development of a statistically sound base to assess the variability of the selected parameters and to develop even an indication of acidification trends. These gaps include:

1. Inadequate sampling frequency and inappropriate timing of sample collection: once-a-year sampling is insufficient. A single annual sample of water chemistry collected from each lake cannot provide an adequate assessment of the average values of any chemical substance that is nonconservative (i.e. most of those that are of interest such as pH). Given the shallow nature of many of these lakes, and probable rapid water renewal, it is likely that water chemistry conditions in the lakes are highly variable. For example, there are cases where interannual differences in pH exceed one unit even after only three years of sampling, but

probably not as a result of changes in acidic deposition. As a result, the power to detect interannual differences or trends in response to changes in loading of acidic substances will probably be exceedingly low.

The spring acid pulse has been neglected, yet it may indicate the impact of accumulated deposition over the winter. Program changes in lake selection will likely make it more difficult to detect temporal trends.

2. Biological indicators are missing that could better and more sensitively identify the effects of acidification on aquatic ecosystems. In addition to the chemical characteristics of ASL, we need to look at their biota, and functional and structural indicators, such as those that are related to productivity and biodiversity. Other biotic indicators include changes in phytoplankton species composition coupled with shifts to acidophilic genera, changes in zooplankton assemblages, and altered phytobenthic, zoobenthic and fish productivity. Such indicators have been useful elsewhere in the study of acid sensitive lakes world-wide, and would yield a more convincing demonstration of the effects of acidification on aquatic biota, which should be our primary concern.

3. Often metals in addition to acidity per se can be biologically damaging. The sub-program ignores measurement of any metals (e.g. mercury and aluminum) even though metals are sampled and analyzed in other subprograms.

4. It is unclear how changes are to be detected in the monitored lakes. The lack of a scientifically challengeable hypothesis prevents objective evaluation of the monitoring data in order to detect temporal trends. It is also unclear what quantitative criteria will be used for detecting change. There is discussion of several acid sensitive parameters (e.g. alkalinity [gran or fixed-point titration] or ratio of bicarbonate:divalent cations). There are also analyses of year-to-year trends using several crude means (eyeballing clustered histograms or box and whisker plots of pH and alkalinity). Yet there is no statement of what parameter, rate and degree of change or technique of analysis will be used to assess whether acidification is occurring. Also is acidification to be evaluated on a lake-by-lake basis, or as a result of a regional cluster analysis?

   Detection of trends in the monitored lakes will be challenging because of fluctuations in the sampling program. Although the program has been adaptive in some respects, i.e. adjusting methods and lakes, such adjustments can increase the difficulty of detecting long-term trends. For example lake selection varied over 1999-2002 in a relatively nonsystematic way; 38 lakes were sampled (Table 3.27 of 2001 report), although only 27 were sampled in all 3 years. What precautions will be taken to factor out the influence of sampling irregularity on the ability to detect temporal trends? Moreover, the criteria for lake removal and addition are sometimes unclear. For example, in the Oil Sands Region, the pH was higher in the replacement lakes (A300, L29) than in the lakes dropped (A47, L1, L30) (compare pH in Figure 10.1 of RAMP 2001 Vol. 1). It would seem that selecting higher pH and higher alkalinity lakes runs counter to the principle of selecting acid sensitive lakes.

5. It is noteworthy that the acid deposition rates in the Oil Sands Region were modeled, rather than measured, in a number of recent EIAs for oil sands development (six companies listed). It appears that there is no verification step to ensure that the lakes are actually receiving the modelled acidic inputs. The primary focus was on modeling the Potential Acidic Input (PAI) in keq $ha^{-1} \cdot yr^{-1}$, including wet and dry deposition by sulphur and nitrogen compounds from sources within the area and from background sources, accounting for the mitigating effect of base cations (Table 10.1, 2001 Report). PAI values are expected to represent potential "near-future" deposition rates, as some yet undeveloped (i.e. planned and/or approved) projects were considered in modeling. But no depositional data are provided in this section to substantiate that these PAI are likely to be correct. As a result, the lack of verifiable depositional information diminishes the validity of future projections, increases the uncertainty of interpreting the monitoring observations, and limits the ability to evaluate the responsiveness of the monitored lakes.

   Furthermore, the CEMA document identifies the Henriksen model as "difficult to apply and validate in low-relief wetland-rich terrain". We concur that there is need for a dynamic model that is adapted to the northeastern Alberta region, and that has been verified. The CEMA report identifies efforts that could result in model development and verification.

6. The lack of hydrology and chemical data for the watersheds of the study systems limits the understanding of the relationship between the aquatic chemistry data being collected and the acidic deposition that is occurring.

   Because the lakes selected in the Oil Sands Region are predominantly shallow, they are likely to have relatively rapid water renewal times. (Although these data are not presented, a hydrologist could provide theoretical water renewal rates based on average catchment hydrological yields, average precipitation, and photometric assessment of catchment areas.) As a result, many of the monitored lakes will likely reflect terrestrial catchment influences more strongly than in-lake processes, which would predominate with longer water renewal times. Therefore, it is less clear how the ASL program will serve as an early warning of excess acid deposition.

   The lakes selected may be relatively insensitive to changes in acid loading for yet another reason. Lake trophic status could confound the ability to detect acidification because only one lake is oligotrophic, and the rest range from mesotrophic to hypereutrophic status. Typically oligotrophic lakes are more acid sensitive than are eutrophic lakes, which can have greater acid buffering capacity (e.g. ELA's L302N experiment evaluating nutrient additions on alkalinity generation, and P. Dillon's similar experiments in the Dorset region of southeastern Ontario).

7. Conventional measurements may be insufficient to characterize the chemistry of the monitored lakes, which often have high concentrations of dissolved organic materials. Additional information is required about the buffering capacity in such aquatic ecosystems of the organic complexes that are common in the lakes of the Oil Sands Region.

8. The monitoring program does not distinguish between acidic emissions from the oil sands operations from other regional or long-distance sources. Perhaps there is some marker of the oil sands operations that will enable oil sands emissions to be distinguished in the depositional areas from background deposition or from other sources. Routine parameters such as pH, alkalinity, N- and S-compounds, and base cation ratios are so far the only parameters used in monitoring of acid sensitive ecosystems world-wide. Although this is a weakness of all ASL monitoring programs, in the event of increased deposition, it will be difficult to identify the source of acid emissions.

9. The idea of including "reference sites" or lake clusters in the ASL program is excellent. However, it is unclear what criteria were used for selecting these reference sites. How have these reference sites been matched with the Oil Sands Region lakes? It is also unclear how the reference data will be used to assess temporal trends in oil sands emissions-affected lakes.

3.0 Recommendations and Suggested Implementation

Independently of our review, the CEMA report "Research Priorities and Monitoring Enhancements …" made several recommendations that are germane to the objectives of the RAMP ASL program. In many cases, the recommendations pertain to issues of concern that we have identified in our review and, as a result, overlap to some degree with our recommendations. As such, these projects merit mention, and we encourage that they be considered for incorporation into, or refinement of, the ASL program. The germane projects that the CEMA report has recommended include:

- early detection of acidification of small watersheds and dynamic model development;
- hydrologic regime of potentially acid sensitive lakes – determining annual through-put flux;
- determining the mechanism of organic acid buffering and its response to anthropogenic deposition of sulphur and nitrogen;
- seasonal changes in lake chemistry;
- determining historical changes in lake chemistry and relationship to productivity using paleolimnology; and
- coupling the ASL program with other relevant model verification and terrestrial monitoring studies.

The primary recommendations that we suggest for improving the ASL program are in order of priority:

1. Integration of programs and research plans
    a. Integrate the RAMP-related ASL program with other programs, e.g. the CEMA NO_x-SO_x Working Group-related efforts. A matrix of activities, organizations and their linkages needs to be presented that defines well the context of RAMP's ASL program; Table 8-1 of the 2002 RAMP Program Design and Rationale is an incomplete start. Although integration of RAMP's ASL program with other efforts may already be underway, without a summary report it is unclear that this is so. If the ASL program is actually a separate endeavour from these other activities, then substantial efforts are needed to unify these ASL-related activities to avoid "reinventing the wheel", and wasting resources.
    b. A related recommendation is that there should be a coherent and integrated monitoring and research plan put forward. Exclusion of the ASL program from the final report was incorrect. In the absence of a final report for the ASL program, there is little evidence of a plan for 2004-2009 except for continuation of monitoring efforts. If we have to project forward what we have seen through 2002, then the plan cannot be considered satisfactory. Note that some of what could be a plan for 2004-2009 appears to be embodied in CEMA documents.
    c. Coupled with these coordination efforts is the need to ensure that the ASL program is well linked to regional monitoring of the deposition of acidic substances. This monitoring must also include monitoring of dry deposition, which recent information from Environment Canada (Bob Vet) indicates could be a large component of total deposition (ca. 30-50%). Reliance on unverified modeled deposition is unsatisfactory.

2. Proposed changes to the current monitoring program
    a. Clearly state the working hypothesis or question that is to be tested in detecting long-term changes in acid status of the monitored lakes. State the criteria that will be used to test that hypothesis.
    b. Increase the sampling frequency within each year using an analysis of the power to detect change, and adjusting the sampling effort accordingly. (CEMA notes that sampling for the US Environmental Protection Agency [EPA] monitoring program occurs four or five times a year.)
    c. Introduce spring-time sampling as a priority. Exclusion of spring-time samples precludes the ability to detect acid pulses in the monitored lakes.

3. Additional parameters to be introduced into or integrated with the RAMP monitoring program
    a. Add an in-lake biological component to this study. This would both help with the evaluation of the biotic sensitivity of the systems, and enhance the power to detect change. Relatively inexpensive possibilities include phytoplankton

and zooplankton; currently planktonic samples are collected but there is neither a plan nor resources for their analysis and interpretation. More energy intensive alternatives include study of fish populations, zoobenthos and benthic algal assemblages. A further expansion would be to consider waterfowl usage of these systems such as is done by Environment Canada's Canadian Wildlife Service.

b. Add a metal component to the program (perhaps linking to the water quality component), particularly aluminum and mercury. For example it has often been reported that mercury bioaccumulation can be increased in acidifying systems. Mercury contamination can be serious for the health of wildlife, for domestic fisheries and for recreational fisheries. It is likely that the oil sands emissions will also include increased deposition of mercury in the downwind regions. Hence, mercury could be increasing in aquatic biota both because of increased deposition and because of pH-related changes.
c. Several of the monitored systems need to be better characterized in terms of their watershed characteristics, including their lake bathymetry and rates of water renewal, for example; CEMA has made a similar recommendation.

4. Proposed research needs to complement the RAMP monitoring program
   a. Establish intensive study watersheds that are known to be acid sensitive and are receiving acidic inputs. These sites should be hydrologically calibrated, and information should be gathered that defines well the biological and chemical properties of the lakes in the context of their watersheds and depositional regimes. (Note that CEMA shows this as a proposed study.) Extra effort directed to these systems would be designed to help interpret the broader regional results.
   b. Spend effort to understand the role of organics in the acidification and buffering of these lakes. (This has also been recommended by CEMA.)

5. Suggested modifications to the lake selection
   a. Once depositional information is available, it should be verified that the lake cluster deemed to be a suite of reference lakes is actually suitable for this purpose.
   b. Add downwind lakes in Saskatchewan that are known to be acid sensitive, known to be receiving acid deposition, and projected to acidify.

OVERALL ASSESSMENT OF THE RAMP AND RECOMMENDATIONS FOR THE FUTURE

Introduction

The Oil Sands Regional Aquatics Monitoring Program (RAMP) in the Oil Sands Region of northeastern Alberta was designed to measure baseline environmental conditions, and predict and assess effects from proposed developments. RAMP was designed as a long-term monitoring program that incorporates both traditional and scientific knowledge. This review has focused on three major objectives of RAMP, specifically: (1) characterizing existing variability, (2) detecting regional trends and cumulative effects, and (3) monitoring to verify environmental impact assessment (EIA) predictions. Following the organization of the program and the annual reports and the Five Year Report, the review was divided into seven components viz., climate and hydrology, water quality, sediment quality, benthic invertebrates, fish populations, aquatic vegetation and acid sensitive lakes. Our overall assessment is based on the narrative reports found in the previous sections, the template-based reviews (Appendix IV) and separate discussions with some of the component reviewers. In this section, we present a number of issues and concerns that were common to several different components and program objectives. Based on the assessments, we make recommendations for future action. Our recommendations are separated into three types: (1) organizational, (2) primary technical, and (3) secondary technical.

We saw many signs of positive progress with RAMP. The very existence of a major regional aquatic monitoring program is a positive sign for Alberta. Initiating joint monitoring by the oil industry in 1997 was a progressive initiative leading to benefits now and in the future. The companies involved are to be commended for their vision and their significant financial contribution over the years. A long-term initiative such as RAMP is rare.

The RAMP initiative to draw individual components into a comprehensive regional aquatic monitoring program is a positive step towards relevance and effectiveness. This is a major region of Alberta and is an area of significant environmental disturbance. RAMP offers an important opportunity to ensure environmental protection, support environmental rehabilitation in the future and enhance our level of knowledge and understanding of boreal aquatic ecosystems in disturbed and undisturbed settings.

The general consensus of the reviewers was that the Five Year Report was well organized and written in a manner that is accessible to most stakeholders, with a few exceptions. It fairly describes the evolution of RAMP over the years and, with the unfortunate exception of the aquatic vegetation and the acid sensitive lakes programs, which were not addressed, it is a good description of what was done. The problems with the report are found in lack of details of methods, failure to describe rationales for program changes, examples of inappropriate statistical analysis, and unsupported conclusions.

Although the Five Year Report was compiled in a satisfactory way, the *content* of the report raised significant concerns with the reviewers about the integrity of the RAMP

Program itself. In the current state, RAMP is not in a position to measure and assess development-related change locally or in a cumulative way. Reviewers reported serious problems related to scientific leadership and a lack of integration and consistency across components with respect to approach, design, implementation, and analysis. Reviewers also reported a lack of an overall regional plan, that clear questions were not been addressed in the monitoring and that there were sometimes significant shortfalls with respect to statistical design of the individual components. Although RAMP appears to recognize that characterization of variability, assessment of regional trends and cumulative effects, and verification of EIA predictions are essential objectives for the program, there is no clear direction on how to achieve and integrate these objectives, despite good existing examples in other national and regional monitoring programs.

There are several levels of recommendations that were provided in this review. Individual component templates and summary reports contain recommendations on details specific to that component. However, after the Design and Integration Team compiled these component-based recommendations, deficiencies, concerns and "theme" areas emerged that were common threads across components. These theme recommendations are provided below and are the most important considerations for RAMP.

Recommendations

The following recommendations are meant to provide a more reliable and systematic approach to aquatic monitoring:

I. Organizational Recommendation on Scientific Leadership

We recommend that RAMP establish a new independent position of project scientific leader reporting to the RAMP Steering Committee and responsible for the overall scientific design of the program and ensuring program quality and relevance through independent peer review. RAMP should also establish an ongoing system of independent scientific input to the program through (1) informal or formal commentary on early ideas and initial plans; (2) workshops and planning sessions that involve independent researchers, RAMP contractor staff and RAMP technical committee members in interchange and debate; (3) formal written review of monitoring plans; and (4) formal review of progress on a periodic basis.

Several findings support the need for a new organizational structure: the need for a clearly delineated overall regional monitoring plan with clear questions to be addressed; the need for establishing a core level of consistency across program components; the need for ongoing independent scientific input into planning programs; the need for ongoing independent scientific peer review of progress (e.g. see the vegetation component); a lack of integration between individual components of the program; and the initiation of program elements that lie outside the capacity/responsibility of the contractor. The RAMP program has been designed by committee consensus and the program has been reactionary and ever-changing. This has resulted in a program where few stations have been sampled consistently over time, consistently across components and using consistent methods. Under these circumstances it will not be possible for the

RAMP to meet its 3 primary objectives. We feel these problems are the result of a lack of a scientific leader.

An independent scientific leader reporting to the Steering Committee would be responsible for the overall scientific design of the program and would work with the main contractor, other minor contractors and outside specialists to lead strategic planning and evaluation. This individual's position would be full-time and responsibilities would be more than a simple liaison officer between the RAMP Steering Committee and the contractor. This individual would have an aquatic, scientific background, hold a strategic vision, and be familiar with EIA approaches and programs such as EEM, RCA, and federal and provincial monitoring. This individual would be the strategic planner of the program and would require adequate resources to do the task. Independent scientific leadership is needed and it should not rest with the lead coordinator for the contractor. The contractor is responsible for delivering the program and reporting on it. The contractor should not be responsible for the overall design or the evaluation of progress, which would create a conflict of interest.

Some of the reviewers suggested an alternative model to the single contractor model, e.g. more along the lines of the NRBS, with a secretariat that provided scientific leadership and coordination and many individual private contractors, and university and government researchers carrying out the projects. We disagree because that model is more suited to individual projects, rather than a long-term, integrated monitoring program.

Several component groups recommended the establishment of an external science advisory panel (e.g. climate and hydrology, fisheries, vegetation), but we recommend against such an option. Given the uncertainty that exists in the management decisions that will be necessary, we feel emphasis should be placed on more flexible, adaptive approaches in which the expertise and knowledge of the wider scientific community can be called upon. Problems with an ongoing advisory board include: (1) board advice is restricted to the expertise of the board members. Expanding the size of the board increases the expertise but smaller boards function better in terms of member participation and overall output; (2) individuals involved in the initial plans cannot be expected to be as objective as those outside the process during reviews of progress; (3) the ongoing time commitments for board members can become too great, with the result that members become unable to commit time and effort at the desired level; and (4) board member ennui after repeated input on the same issues. Issue-specific scientific input may be more difficult to organize than an ongoing advisory board but the results are likely to be more effective when the participation is tailored to the issue. Scientists thrive on novelty and are more ready to participate in specific planning and review exercises on a periodic, rather than ongoing, basis. As well, they are more willing to take part when their time commitments can be clearly defined, their specific expertise is obviously useful, and acceptance of their advice is more probable.

II. Primary Technical Recommendations

1. Adoption of an Ecosystem Approach and Decision-Making Strategy

We recommend that RAMP adopt a strategic, integrated, regional monitoring design and decision-making strategy for measurement of development-related change at an ecosystem level while incorporating site-specific needs. Monitoring must fit within the context of an adaptive management framework and focus beyond project-specific needs. This approach should:

- Consider how decisions on change will be made and the information that is required to make those decisions. For example, what indicators will be measured to assess a particular development activity? What will the indicator be compared against to determine when a change has occurred? Will changes of a certain magnitude and direction trigger a specific line of decisions or an approach to greater monitoring intensity? What will the process be if water quality indicators show a change but no change was measured in fish indicators?
- Consider the development projections to 2020 in the oil sands area and select strategic monitoring locations accordingly. Depending upon the watershed, development level, and physical, chemical, and biological characteristics the monitoring approach can be customized. Sampling intensity and frequency can also be customized;
- Integrate RAMP components (i.e. hydrology, water and sediment quality, benthic invertebrate community structure, fish population health, aquatic vegetation and acid sensitive lakes) at integrated monitoring stations;
- Use adaptive feedback loops within and among components for constant examination of experimental designs and results; changes should be made to the program based on solid results rather than on speculation;
- Show clear links to objectives and have clearly stated hypotheses or testable study objectives; and
- Ensure that all terms, especially statistical ones, are defined and used precisely in reports, and a glossary for all component subject areas be produced as an aid to authors and readers of reports. Precise use of terms aids understanding.

RAMP has changed from year to year. This lack of consistency and strategy has severely limited the ability of RAMP to monitor the environment relative to existing and future development pressures. This comment was common across components including acid sensitive lakes, benthic invertebrates, fisheries, water quality and aquatic vegetation. Development projections to 2020 have been available since the inception of RAMP and extensive information on development has been submitted by independent proponents under the EIA process. The goal of RAMP should be to describe key environmental components, overlay development-related stressors on those environmental components and determine if the change in one can be explained by the other. The monitoring program must be designed to collect environmental information capable of detecting change due to a specific development including selection of appropriate parameters and indicators, and collection at appropriate times and frequencies. For example, investigators stated that “wetland vegetation has been documented as an important biomonitoring parameter for examining potential effects to wetland systems”. Yet they failed to spell out exactly how the vegetation monitoring will enable the investigators to detect effects of oil sands development. Investigators must state what constitutes unacceptable change in an environmental component in response to oil sands development.

A strategic vision cannot not be implemented unless there is scientific leadership of RAMP as discussed in Recommendation 1. After five years, and considering the development pushing ahead in the oil sands, it is alarming that the main monitoring program for the area significantly lacks strategic direction and scientific process.

2. Adoption of Effects-Based Monitoring within the Strategy
We recommend that RAMP orient its efforts towards effects-based monitoring. The objective should be to document environmental change occurring as a result of development, not to carry out descriptive studies. Included in the effects-based approach should be the following:

- Selection of key response indicators for each RAMP component, based upon potential changes resulting from oil sands development;
- On-going synthesis of information related to development pressures including type of development activity, location of activity, stressors released, effects predicted, assumptions used in predictive tools, location of modeling nodes, etc. A monitoring program designed to monitor development-related change cannot do so in the absence of information on the development. This was recognized as a significant shortfall of the RAMP. Reviewers recognized that much of this information is likely included in the EIA reports. However, effects-based monitoring mandates an on-going comparison between development activities and environmental condition. One without the other will not measure development-related change;
- Establishing a core level of consistency for sample station selection, indicator selection, sampling frequency and timing that does not change from year to year;
- Selection of reference and "low-impact" stations within or outside the Region for each component subject area. Those subject areas that can go into an established biomonitoring program (see below) will get this benefit automatically;
- Use of biostatistical analyses that report statistical confidence levels and power analyses for indicators of change. These statistical results are critical to assist with interpretation of the environmental changes to establish confidence in the decision-making strategy;
- Consideration of the knowledge and understanding gained from other successful effects-based monitoring programs that measure development-related change relative to natural variability; for pertinent subject areas such as water quality, benthos, fish and possibly aquatic vegetation, a bona fide, regional biomonitoring program (Environmental Effects Monitoring [EEM] or the Reference Condition Approach [RCA]) should be initiated; and
- Incorporation of other existing regional information such as NRBS, NREI, PERD, EEM, the Muskeg River design initiative (CEMA) and information collected independently by industry. Future periodic summary reports, such as the next Five Year Report, should incorporate monitoring results and studies from programs other than RAMP, if the information contributes to the objectives.

3. Testing Environmental Impact Assessment (EIA) Predictions

We recommend that RAMP complete an exercise to test predictions from already completed EIAs using actual data generated on a site or sites. As a first step in this evaluation, RAMP should prepare a synthesis or summary, on a project-specific basis, of what the impact predictions were for different project activities, including location and timing of impact and Valued Ecosystem Components (VECs) affected.

Conducting a follow-up by verifying impact predictions using real data would be a valuable exercise to illustrate exactly what the deficiencies and gaps are in the existing monitoring program and what needs to be done so that predictions can be verified. The Five Year Report did not attempt to verify EIA predictions.

4. Development of an Information Management System

We recommend that RAMP establish a comprehensive information management and assessment system, including an electronic database management system that would enable electronic reporting of raw data in a standard and consistent format, interchange of data among component subject areas, and on-going assessment of data using consistent analyses.

The current method of reporting and data integration is not sustainable, and access to information by RAMP users cannot be facilitated using this approach. Reviewers found table after table of data too difficult to synthesize, and the value of the data was lessened by this reporting structure. This recommendation, however, does not pertain to simply a database with query capabilities. RAMP requires a spatially explicit (GIS-based) system where development layers can be overlain with environmental information for all components and stations. There is a requirement for the data to be graphed using standard formats over time and space, and for the data to be exportable for statistical analyses. There are several on-going initiatives within the region that RAMP could benefit from including the federal EcoAtlas-CE system and the provincial information management initiatives. RAMP information should not be placed into a system that operates independently of these other systems. RAMP depends heavily upon federal and provincial monitoring data (e.g. water quality program) and should make efforts to integrate any system they develop. RAMP should also incorporate other industry data that are being collected independently of the current RAMP program. Participation in an existing information management system will ensure cost-effectiveness and continuity in data management and access among contractors.

5. Increased Emphasis on the Athabasca River as a Priority Watershed

We recommend that RAMP use the Athabasca River as a central focus for monitoring across component subject areas because it is the largest and most important aquatic ecosystem in the region and the natural recipient of the effects of oil sands development.

There is currently no ability within RAMP to assess oil sands development impacts on the Athabasca River in an integrated way. Hydrology data on the Athabasca River were described by reviewers as being significantly limited. Water quality monitoring was conducted at sites too far separated and with inadequate statistical replication to measure changes due to oil sands development independent of the river continuum (natural changes). Benthic invertebrate monitoring was conducted in the early 1990s but was discontinued due to sampling challenges. Fish work was conducted but there is no integration of this component with the other RAMP components. Given that other monitoring programs have operated successfully on the Athabasca, and the river is a critical integrator of potential impacts, this is an unexplained gap. Development of the strategic plan and effects-based monitoring design should be a first priority for the Athabasca River.

III. Secondary Technical Recommendations

1. Contributions to New Knowledge

We recommend that RAMP recognize the importance of creating new knowledge and incorporating this knowledge into the monitoring program through an adaptive management framework.

The primary purpose of RAMP is to produce knowledge of how the ecosystem is changing over space or time and/or in response to impacts. A side benefit to monitoring can be the production of new functional knowledge or understanding, which will only result when the data produced by monitoring are used to test an explicit hypothesis. If monitoring is to contribute to the long-term assessment of aquatic resources then it must take place as part of a specific experimental design. Reviewers felt that there is an unrealized opportunity that is not being met for creation of new scientific understanding from RAMP monitoring. Comments about RAMP contributions to new knowledge can be found in the climate and hydrology and benthic invertebrate reports. RAMP could be producing results that contribute to regional, national or international understandings of spatial and temporal trends and cumulative effects and about the nature of impacts on ecosystem function. In so doing it could contribute to better models and better prediction of environmental impacts in the future but, as currently operated, it will not do so, until a better-designed, overall strategic monitoring framework is in place.

2. Traditional Ecological Knowledge (TEK)

We recommend that RAMP actively promote the use of TEK by incorporating it into the design of scientific programs. Key indicators for future monitoring and the interpretation of results need to be identified, and specific, ongoing programs should be devoted to observing changes in these key indicators.

We considered that, even though five of the eight RAMP objectives (Appendix I) were not the focus of the Five Year Report, there should be some evidence in the content of the programs that would tell us whether those objectives were being addressed at all. We asked the reviewers for comments on those objectives as they related to the discipline they were reviewing. Comments were most often received on TEK. Several of the reviewers felt that TEK could be contributing to the program. However, there is no evidence anywhere that it has been considered other than in some of the statements on objectives early in program development. It is assumed that some of the parameters measured in the water-quality, vegetation or fisheries components were identified by stakeholders as VECs in the environmental assessment process. However, the report does not include any information on which parameters were included. Thus, it is not clear if TEK was used as a basis for parameter selection. A separate review of a fish abnormalities study was completed and, although the original concerns came from local residents, there was no evidence that their knowledge had been used in any way. For fisheries programs in particular, local knowledge can provide information on what species have been historically important, and during what seasons they are present, and it can contribute to the overall understanding of the functioning of the system (e.g. are these species migratory with harvests from outside the immediate system, and are they locally important as well?).

A recent government report on science advice for government effectiveness (CSTA, 1999) states that decision-makers should be taking due weight of the traditional knowledge of local peoples. It goes on to say that traditional knowledge, like scientific knowledge, needs to be subjected to due diligence, including rigorous internal and external review and assessment. It is clear to us that RAMP has not taken account of traditional knowledge to the extent one might expect for a study of this nature, especially since it is one of the stated program objectives. Incorporation of TEK with western science needs to be addressed in the ecosystem approach and decision-making strategy.

3. Publications

We recommend that RAMP initiate a policy of encouraging individuals and the contractor to publish monitoring data and new knowledge in established technical and primary publications as well as in-house reports. RAMP should also establish a RAMP Technical Report Series for wider distribution of monitoring results within the region, provincially and nationally.

Comments about the potential usefulness of RAMP primary and technical publications were made in the water-quality, benthic invertebrates, vegetation and acid sensitive lakes reports. We strongly believe that the results of the RAMP program should be widely disseminated in a more formal manner. High publication standards require high monitoring standards. Publication of results imposes more scientific rigor on the monitoring program, it adds to credibility of the program, it increases exposure of project managers to current scientific information in other areas, and it contributes new information to the program itself. It also adds to the personal capacity and credibility of the individuals involved in the monitoring, resulting in employees who are more satisfied in their jobs.

The proposed technical report series should be structured like some of the government data or technical report series (e.g. Canadian Manuscript Report of Fisheries and Aquatic Sciences). It would be a series of reports generated from the information management system on an on-going basis. This effort would not be onerous if designed properly.

There is a formal procedure for establishing a new series of reports. An ISSN should be included in each report. Numbers can be applied for online at http://www.nlc-bnc.ca/issn/index-e.html. An electronic copy should be sent to observe the legal requirement for filing a depository copy with the National Library of Canada (see http://www.nlc-bnc.ca/6/25/index-e.html.) and copies should be sent to regional, provincial and federal libraries to ensure cataloguing in environmental databases.

Conclusion

The above are general recommendations that we feel need to be implemented for RAMP. Other general and specific component subject recommendations are presented in the individual narratives above and in the template reports in Appendix IV. There are a number of individual recommendations that could be implemented immediately. We recognize that RAMP is entering initial planning for 2005, so there will be a temptation for RAMP Steering Committee members, RAMP Technical Committee members and the contractors to seize upon “favored” recommendations for immediate action.

We would urge caution in this respect. We have tried to emphasize that there are some overall structural changes that need to take place within the program. The primary need is for scientific leadership and input to a strategic planning process that treats the program as a single entity not as a series of individual components. To begin immediate implementation of minor specific changes risks continuation of a pattern that has created some of the problems with RAMP in the first place, i.e. lack of continuity and change of programs without sound justification.

We have not identified specific research recommendations because of our belief that the core monitoring program needs to be changed in a major way (see above), and should be the focus of intense effort over the short term. Thus, specific research recommendations should follow reorganization of the monitoring program.

ACKNOWLEDGEMENTS

Most importantly we would like to thank and acknowledge the work of the individual component reviewers: Neil Arnason, Jan Barica, Brian Brownlee, Uwe Borgmann, Martin Carver, Nancy Glozier, Kelly Munkittrick, Carl Schwarz, Brian Souter, Stephanie Sylvestre, Alan Thomson, Michael Turner, John Post, and Marley Waiser. The reviewers were all experienced with reviewing scientific reports for journal publication and familiar with reviewing research proposals for agencies such as NSERC but large-scale independent scientific peer review of aquatic environmental monitoring programs is not a common occurrence. This task was larger and more complex than any of us had imagined and we appreciate their hard work, perseverance and understanding as we strove to produce a understandable and useful assessment of this important program.

We would also like to thank the RAMP Review Team -- Bryan Kemper, Christine Brown, Preston McEachern, and Mark Spafford -- for their initial direction and support during the process and the RAMP Technical Sub-committee for their input and suggestions following the October 23, 2003 progress report.

We want to acknowledge the work of the contractor, Golder Associates Ltd., of Calgary who were responsible for carrying out the RAMP until 2002 and responsible for preparing the annual reports and the Five Year Report. The Golder staff are to be commended for their efforts in operating this very important program, responding to the problems and issues in the environment of the Oil Sands Region and the complex demands of the regulators, the oil companies and the other stakeholders that make up the RAMP Steering Committee.

We would like to thank and acknowledge the work of Donna Laroque of Winnipeg. She was responsible for formatting the template reports, and inputting, and formatting much of the overall report.

We would like to acknowledge the following individuals who provided advice and/or assistance to components of the review: Dr. Michael Church, University of British Columbia; Mr. Tim Davis, Water Survey of Canada; Dr. Wayne C. Huber, Oregon State University, Dr. Robert Newbury, Newbury Hydraulics, D. W. Schindler, University of Alberta; Bill Hume, Environment Canada; and Lawrence Cheng and Preston McEachern, Alberta Environment, Dave Ballagh, Saskatchewan Environment, Dr. Art Tautrz, BC Fisheries Branch.

BIBLIOGRAPHY

Reports Reviewed

RAMP (Oil Sands Regional Aquatics Monitoring Program). 1997-2001. Annual Reports 1997-2001. Submitted to RAMP Steering Committee by Golder Associates Ltd., Calgary, AB.[3]

RAMP (Oil Sands Regional Aquatics Monitoring Program). 2000b. Fish abnormalities. Submitted to RAMP Steering Committee by Golder Associates Ltd., Calgary, AB. 39 p.

RAMP (Oil Sands Regional Aquatics Monitoring Program). 2002a. Annual Report 2002. Submitted to RAMP Steering Committee by Golder Associates Ltd., Calgary, AB.[4]

RAMP (Oil Sands Regional Aquatics Monitoring Program). 2002b. Program design and rationale: version 2. Submitted to RAMP Steering Committee by Golder Associates Ltd., Calgary,AB. 298 p.

RAMP (Oil Sands Regional Aquatics Monitoring Program). 2003. Five Year Report. Submitted to RAMP Steering Committee by Golder Associates Ltd. Calgary,AB. 602 p.

Reports Cited in Text

Bailey, R.C., R.H. Norris, and T.B. Reynoldson. 2004. Bioassessment of freshwater ecosystems using the Reference Condition Approach. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Bisbal, G.A. 2002. The best available science for the management of anadromous salmonids in the Columbia River basin. Canadian Journal of Fisheries and Aquatic Sciences 59:1952-1959.

Borgmann, U., W.P Norwood, T.B. Reynoldson and F. Rosa. 2001. Identifying cause in sediment assessments: bioavailability and the sediment quality triad. Canadian Journal of Fisheries and Aquatic Sciences 58:950-960.

Borgmann, U. 2003a. Derivation of cause-effect based sediment quality guidelines. Canadian Journal of Fisheries and Aquatic Sciences 60:352-360.

Borgmann, U. 2003b. Assessing metal impacts in sediments: key questions and how to answer them. In M. Munawar (editor) Sediment quality assessment and management: insight and progress. Ecovision World Monograph Series, Aquatic Ecosystem Health and Management Society, pp. 23-28.

[3] Reports are available on CD from Golder Associates Ltd., 1000-940 6th Avenue S.W., Calgary, Alberta, Canada, T2P 3T1, Att. Kym Fawcett e-mail kfawcett@golder.com
[4] RAMP (Oil Sands Regional Aquatics Monitoring Program). 2002. Annual Report 2002. Submitted to RAMP Steering Committee by Golder Associates Ltd., Calgary, was examined by the acid sensitive lakes reviewers.

Crosley, R.W. 1996. Environmental contaminants in bottom sediments, Peace and Athabasca River Basins, October, 1994 and May, 1995. Project Report No. 106. Northern River Basins Study, Edmonton, AB.

CSTA (Council of Science and Technology Advisors). 1999. Science Advice for Government Effectiveness (SAGE). Available from Science and Technology Directorate, Industry Canada, Ottawa, ON. 11 p.

Dorcey, A.H.J. and K.J. Hall. 1981. Setting ecological research priorities for management: The art of the impossible in the Fraser estuary. West Water Research Centre, the University of British Columbia, Vancouver, BC. 78 p.

Dubé, M.G. 2003. Cumulative effects assessment in Canada: a regional framework for aquatic ecosystems. Environmental Impact Assessment Review (in press).

Environment Canada. 1997. Benthic invertebrate community expert working group final report: recommendations from cycle 1 review. EEM/1997/7. National EEM Office, Science Policy and Environmental Quality Branch, Environment Canada, Ottawa, ON.

Environment Canada. 1998. Pulp and paper technical guidance for aquatic environmental effects monitoring. EEM/1998/1. National EEM Office, Science Policy and Environmental Quality Branch, Environment Canada, Ottawa, ON.

Environment Canada. 2001. Metal mining guidance document for aquatic environmental effects monitoring. National EEM Office, Science Policy and Environmental Quality Branch, Environment Canada, Ottawa, ON. (Available from: www.ec.gc.ca/eem)

Fleishman, E. 2001. Moving scientific review beyond academia. Conservation Biology 15:547-549.

Glozier, N.E., J.M. Culp, T.B. Reynoldson, R.C. Bailey, R.B. Lowell, and L. Trudel. 2002. Assessing metal mine effects using benthic invertebrates for Canada's environmental effects program. Water Quality Research Journal of Canada 37:251-278.

Helgen, J.C. and M.C. Gernes. 2001. Monitoring the condition of wetlands: Indexes of biological integrity using invertebrates and vegetation. In R.B. Rader, D.P. Batzer and S.A. Wissinger (editors). Bioassessment and management of North American freshwater wetlands. John Wiley and Sons, New York. pp.167-186.

Karr, J.R. and E.W. Chu. 1999. Biological monitoring and assessment: Using multimetric indexes effectively. Island Press, Cobelo, CA.

Meffe, G.K., P. Dee Boersma, D.D. Murphy, B.R. Noon, H.R. Pulliam, M.E. Soulé, D. Waller. 1998. Independent scientific review in natural resource management. Conservation Biology 12:268-270.

Peterman, R.M. 1990. Statistical power analysis can improve fisheries research and management. Canadian Journal of Fisheries and Aquatic Sciences 47:2-15.

Reid, L.M. 1993. Research and cumulative watershed effects. General Technical Report PSW-GTR-141. USDA Forest Service Pacific Southwest Research Station. 118 p.

Rader, R.B. and D.K. Shiozawa. 2001. General principles of establishing a bioassessment program. In R.B. Rader, D.P. Batzer and S.A. Wissinger (editors). Bioassessment and management of North American freshwater wetlands. John Wiley and Sons, New York, pp.13-44.

Reynoldson, T.B., R.C. Bailey, K.E. Day, and R.H. Norris. 1995. Biological guidelines for freshwater sediment based on Benthic Assessment of SedimenT (the BEAST) using a multivariate approach for predicting biological state. Australian Journal of Ecology 20:198-219.

Richardson, C.J. and J. Vymazal. 2001. Sampling macrophytes in wetlands. In R.B. Rader, D.P. Batzer and S.A. Wissinger (editors). Bioassessment and management of North American freshwater wetlands. John Wiley and Sons, New York, pp.297-338.

Rosenberg, D.M. and V.H. Resh. 1993. Introduction to freshwater biomonitoring and benthic macroinvertebrates. In D.M. Rosenberg and V.H. Resh (editors). Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York, pp.1-9.

Rosenberg, D.M., T.B. Reynoldson, and V.H. Resh. 1999. Establishing reference conditions for benthic macroinvertebrate monitoring in the Fraser River catchment, British Columbia, Canada. DOE-FRAP 1998-32. Fraser River Action Plan, Environment Canada, Vancouver, BC.

US Environmental Protection Agency (USEPA). 2002. Methods for evaluating wetland condition: #10 – Using vegetation to assess environmental conditions in wetlands. #6 Developing metrics and indexes of biological integrity. #4 Study Design for Monitoring Wetlands. (On EPA website: http://www.epa.gov/waterscience/criteria/wetlands/)

Vecchia, A.V. 2003. Water-quality trend analysis and sampling design for streams in North Dakota, 1971-2000. Water-Resources Investigations Report 03-4094. U.S. Department of the Interior, U.S. Geological Survey. 73 pp. (Available from www.usgs.gov)

Walker, S.L., K. Hedley, and E. Porter. 2002. Pulp and paper environmental effects monitoring in Canada: an overview. Water Quality Research Journal of Canada 37:7-19.

Wright, J.F. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology 20:181-197.

Wright, J.F., D.W. Sutcliffe, and M.T. Furse (editors). 2000. Assessing the biological quality of fresh waters. Freshwater Biological Association, Ambleside, Cumbria, UK.

WSOCD (Washington State Office of Community Development). 2002. Citations of recommended sources of best available science for designating and protecting critical areas. 89 p. Olympia, Washington. (Available from: Washington State Office of Community Development, P.O. Box 48350, Olympia, WA 98504-8350.)

APPENDIX I: OBJECTIVES OF THE OIL SANDS REGIONAL AQUATIC MONITORING PROGRAM (RAMP)

These objectives are taken from the Terms of Reference of RAMP and from the Five Year Report. The focus of the Five Year Report and this review is on the first three objectives. The specialist reviewers were also asked to note whether, based on their reading, the program also addressed the last five objectives.

1. **Characterizing Existing Variability** - To collect scientifically defensible baseline and historical data to characterize variability in the oil sands area. (Note from Design and Integration Team - The capacity to detect change was of particular importance for reviewers to consider.)
2. **Detecting Regional Trends and Cumulative Effects** - To monitor aquatic environments in the oil sands area to detect and assess cumulative effects and regional trends. (Note from Design and Integration Team - The capacity to detect cumulative effects and trends in consideration of new disturbances was of particular importance for reviewers to consider.)
3. **Monitoring to Verify EIA Predictions** - To collect data against which predictions contained in environmental impact assessments (EIAs) can be verified.
4. **Monitoring to Meet Regulations** - To collect data that may be used to satisfy the monitoring required by regulatory approvals of developments in the oil sands area.
5. **Traditional Ecological Knowledge** - To recognize and incorporate traditional knowledge (including Traditional Ecological Knowledge and Traditional Land Use Studies) into the monitoring and assessment activities.
6. **Communication** - To communicate monitoring and assessment activities, results and recommendations to communities in the Regional Municipality of Wood Buffalo, regulatory agencies, environmental committees/organizations and other interested parties.
7. **Flexibility and Adaptability** - To design and conduct various RAMP activities such that they have the flexibility to be adjusted, on review, to reflect monitoring results, technological advance and community concerns.
8. **Cooperation** - To seek cooperation with other relevant research and monitoring programs where practical, and generate interpretable results which can build on their findings and on those of historical programs.

APPENDIX II: BIOGRAPHIES OF INDIVIDUAL REVIEWERS OF THE RAMP PROGRAM

Neil Arnason, Ph.D
Department of Computer Sciences
University of Manitoba
Winnipeg, MB
phone: 204-474-6918
e-mail: arnason@cs.umanitoba.ca

Dr. Neil Arnason received his B.Sc. and M.Sc. in statistics at the University of Waterloo and a Ph.D. in biometrics from Edinburgh (1971). Since then, he has taught courses in statistics, quantitative ecology, and computer science at the University of Manitoba where he is now a Full Professor in the Department of Computer Science. His research is in population estimation methods, and he has published papers (in Biometrics, Journal of Wildlife Management, Canadian Journal of Fisheries and Aquatic Sciences, among other journals) and software (from his website www.cs.umanitoba.ca/~popan) related to the estimation of animal abundance and migration rates. He consults with biologists from all over the world on population survey design and data analysis. He is a member of the Statistical Society of Canada and was president of the Biostatistics Section (1998-1999) and currently is active on the Professional Accreditation committee. He is also a member of the Biometrics Society, the American Statistical Society and a Fellow of the Royal Statistical Society.

Burton Ayles, Ph.D.
B. Ayles and Associates
255 Egerton Road
Winnipeg, MB R2M 2X3
phone: 204-257-4453
fax: 204-257-4453
e-mail: aylesb@escape.ca

Dr. Burton Ayles received his B.Sc. and M.Sc. in zoology and genetics from the University of British Columbia and his Ph.D. in fisheries genetics from the University of Toronto (1972). He worked for 25 years for the federal Department of Fisheries and Oceans as a research scientist and manager at all levels in the organization, including, Regional Planner, Regional Director of Operations, Regional Director of Research, and Regional Director General for the Central and Arctic Region (Prairies, Ontario and the Arctic). As a senior DFO manager he was intimately involved in design and evaluation of regional and national science and technology programs on an ongoing basis. In 1998 Dr. Ayles took an early retirement from the federal government and established B. Ayles and Associates Fisheries and Environmental Consulting, providing advice and evaluation on policy, research and management. Dr. Ayles is a Canada Member of the Canada/Inuvialuit Fisheries Joint Management Committee which, with the Department of Fisheries and Oceans and the Inuvialuit Game Council, is responsible for management of fisheries and marine mammals in the western Canadian Arctic. He has been active planning and organizing workshops, planning sessions and reviews for a range of fisheries and aquatic environmental activities including: Arctic fisheries and oceans research, water quality in the prairies, and sustainability of the Muskeg River, amongst others.

Jan Barica, Ph.D, D.Sc.
2153 Lincoln Court
Burlington, ON
L7P 3S4
phone: 905-335 1633
e-mail: jbarica@cogeco.ca

Dr. Jan Barica's career with the government of Canada's Department of Fisheries and Oceans and Department of Environment, over 30 years as a research scientist and research manager, focused on management and restoration/rehabilitation of lakes, reservoirs and river basins. In Canada he worked on hypereutrophic lakes in western Canada and their utilization for fish culture; algae control, manipulation of algal blooms by nutrient-ratio adjustment, aeration and dredging; and on basin-wide eutrophication controls in the Great Lakes and their tributaries, lake-wide management programmes for Lake Ontario and Erie, remediation action plans in the Areas of Concern (Hamilton Harbour, Severn Sound); water quality surveillance programmes; and long-term data interpretation. Throughout his career he was actively involved in many international activities ranging from Iraq to the Philippines, Thailand, South America and many countries in eastern Europe. Since his retirement in 1999 he has been active in UNEP-UNDP-GEF-IDRC programs in Ukraine, Belarus and Russia on water quality, biodiversity and strategic planning.

Brian Brownlee, Ph.D.
Environment Canada
Room 200, 4999-98 Ave
Edmonton, AB T6B 2X3
phone: 780-951-8745
e-mail: brian.brownlee@ec.gc.ca

Dr. Brian Brownlee received his B.Sc. and M.Sc. in chemistry from the University of Alberta and his Ph.D. in synthetic organic chemistry from the University of New Brunswick (1971). He is a research scientist with Environment Canada's National Water Research Institute and has over 30 years experience in research on water quality related issues in Canada. Specific areas studied include oil sands contaminants, taste and odour in drinking water supplies, urban runoff, benzothiazoles, nurient dynamics, and pulp mill contaminants. His research has covered an extensive geographic range including the Great Lakes, small prairie lakes, the Alberta oil sands, northern Alberta rivers and southern Ontario lakes and streams, amongst others.

Uwe Borgmann
National Water Research Institute
Environment Canada
867 Lakeshore Road, P.O. Box 5050
Burlington, Ontario, Canada, L7R 4A6
phone: 905-336-6280

fax: 905-336-6430
email: uwe.borgmann@ec.gc.ca

Dr. Borgmann received his M.Sc. in zoology and oceanography from the University of British Columbia and his Ph.D. in biology from the University of Ottawa (1975). He was a research scientist with the Department of Fisheries and Oceans for 20 years and since 1996 he has been a research scientist with Environment Canada's, National Water Research Institute. His current research interests include invertebrate toxicology with emphasis on metals; relationship between metal bioaccumulation and toxicity; and application of bioaccumulation and other bioavailability measures to environmental risk assessments of metals. He is also an adjunct professor at the University of Waterloo and has supervised several M.Sc. and Ph.D. students. He is active on several scholarly and professional societies including currently acting as Associate Editor, Canadian Journal of Fisheries and Aquatic Sciences, and as a member of the editorial board of the journal, Aquatic Ecosystem Health and Management.

Martin Carver, Ph.D., P.Eng., P.Ag.
Carver Consulting
#1 - 4925 Marello Road
Nelson, BC. V1L 6X4
phone: 250 352-1187
fax: 250 352-1197
e-mail: carver@netidea.com

Dr. Martin Carver received his M.A.Sc. from the University of Waterloo, and his Ph.D. in 1997. He is an international consultant with 13 years' experience in water resources and land management emphasizing watershed condition, water quality, forestry and agriculture. His expertise includes: hydrologic/fluvial geomorphological research and modeling; development of forest hydrology and watershed management assessment procedures; geomorphological and hydrological field measurements and monitoring; riparian and hydrologic assessments of streams; water quality assessment and diagnosis and watershed restoration. Recent activities include preparation and delivery of a three-day course in Equador on the management of tropical mountain watersheds; review of technical studies for Connor Creek watershed to recommend priority hydrologic mitigation/restoration activities; preparation of an integrated riparian management plan for Arrow Creek – a large high-value watershed in Creston, BC; conducted and reviewed watershed assessments for watersheds in the Nelson Forest Region and in Ecuador.

Dubé, Monique, Ph.D
National Water Research Institute, Environment Canada
11 Innovation Blvd.
Saskatoon, SK S7N 3H5
phone: 306-975-6012
fax: 306-975-5143
e-mail: monique.dube@ec.gc.ca

Dr. Monique Dubé is a Research Scientist in the Cumulative Impacts on Aquatic Ecosystems Group at the National Water Research Institute of Environment Canada in Saskatoon, SK. She is also an Adjunct Professor at the Toxicology Centre at the

University of Saskatchewan and a member of the Canadian Rivers Institute. Her expertise includes effects assessment of industrial and municipal effluents on riverine food webs and development of mesocosm and stable isotope approaches for environmental effects monitoring. Recent activities include: development of a regional cumulative effects assessment framework for aquatic ecosystems and an associated software system for framework implementation; membership in the National Environmental Effects Monitoring Science Committee on pulp and paper and metal mining industries across Canada; and participation as an invited outside expert in a workshop on the sustainability of the Muskeg River ecosystem.

Ms. Nancy E. Glozier, M.Sc.
Aquatic Ecosystems Scientist
Environment Canada, PNR Wildlife Research Centre
115 Perimeter Road, Saskatoon, SASK S7N 0X4
phone: 306- 975-6057
e-mail: nancy.glozier@ec.gc.ca

Nancy Glozier received both her B.Sc., in zoology, and her M.Sc. (1989), in aquatic ecology, from the University of Calgary. She joined Environment Canada as a research support technician and since 2002 she has been aquatic ecosystems research scientist. Her recent research interests include environmental fate and effects of pulp and paper mill effluents, use of mesocosms for assessment of cumulative effects in algal, benthic and fisheries communities, and applications of the use of artificial streams for Environmental Effects Monitoring (EEM) amongst others. She is currently a member of Environment Canada's National Science committee and a member of the EEM benthic expert subgroup for metal mining.

Kelly Munkittrick, Ph.D.
Department of Biology, University of New Brunswick
P.O. Box 5050, Tucker Park Road
Saint John, NB E2L 4L5
phone: 506-648-5825
fax: 506-648-5811
e-mail: krm@unb.ca

Dr. Kelly Munkittrick received his Ph.D. in Toxicology from the University of Waterloo, and spent time in private industry and consulting environments before joining the Federal Government in 1990. He currently holds a Tier 1 Canada Research Chair in Ecosystem Health Assessment at the Department of Biology, University of New Brunswick, Saint John. Prior to his appointment, he worked for 10 years for the federal government as a Project Chief with the Ecosystem Health Assessment Project at Environment Canada's National Water Research Institute, and as a Research Scientist with Fisheries and Oceans' Great Lake Laboratory for Fisheries and Aquatic Sciences. His research interests are on environmental health assessment, cumulative effects assessment and the impacts of industrial discharges on wild fish populations. He has co-chaired interdisciplinary working groups related to Environmental Effects Monitoring, and is a past co-chair of both the Environment Canada and the Canadian (5NR) Interdepartmental Endocrine Disruptor Working Group.

Dr. John Post, Ph.D.
Department of Biological Sciences, University of Calgary
2500 University Drive
Calgary T2N 1N4
phone:403 220-6937
e-mail: jrpost@ucalgary.ca.

Dr. John Post is an Associate Professor in the Biology Department of the University of Calgary. He received his Ph.D. from York University in Toronto. His research interests include energy dynamics and bioenergetics models, recruitment variability in fishes and population dynamics, dynamics of foraging, growth, spatial behaviour and survival in structured fish populations, the interface between fish biology and fisheries management, and aquatic food web dynamics. His teaching responsibilities have included ecology and evolution, aquatic communities and ecosystems, quantitative biology and ecology of fish. Recent specific activities include: energy allocation strategy in age-0 fish; density dependent inter-cohort interactions and recruitment dynamics; models and a bull trout time series; and recruitment dynamics and size structure in experimental fish populations.

David Rosenberg, Ph.D.
Freshwater Institute
501 University Crescent
Winnipeg, MB R3T 2N6
phone: 204-983-5253
e-mail: rosenbergd@dfo-mpo.gc.ca

Dr. David. Rosenberg received his B.Sc. and Ph.D. from the University of Alberta (1973). He has spent all of his professional life at the Freshwater Institute in Winnipeg, most of it using benthos to monitor environmental disturbance. He has participated in ecological studies of proposed Mackenzie Valley pipelines, diversion of the Churchill River into the Nelson River in northern Manitoba, and experimental reservoir creation at the Experimental Lakes Area in Ontario. More recently, he helped establish a biomonitoring program for the Fraser River in BC, and was part of a group that tried to convince the Federal Government that Canada needs a national biomonitoring program. He retired from the Department of Fisheries and Oceans in September 2001. Recent activities include: Managing Editor of the Journal of the North American Benthological Society; participation as an invited outside expert in a workshop on the sustainability of the Muskeg River ecosystem; and contributing to a planned book on North American river ecosystems

Dr. Carl James Schwarz, Ph.D.
Department of Statistics and Actuarial Science
Simon Fraser University
8888 University Drive
Burnaby, BC V5A 1S6
phone: 604-291-3376
fax: 604-291-4368
e-mail: cschwarz@stat.sfu.ca

Dr. Carl Schwarz is a Professor in the Department of Statistics and Actuarial Science at Simon Fraser University. His research interests are in the use of statistics in ecology - particularly in estimating animal abundances and related parameters using capture-recapture methods and in the design and analysis of environmental monitoring studies.

Brian W. Souter, M.Sc.
Department of Fisheries and Oceans
Central and Arctic Region
Winnipeg MB, R3T 2N6
phone: 204-983-5125
fax: 204-984-2404
e-mail: souterb@dfo-mpo.gc.ca

Brian Souter received his B.Sc. and M.Sc. in microbiology and fisheries from the University of Guelph (1974) and he is a fish health specialist with the Department of Fisheries and Oceans. He has directed the federal fish health certification program in the region since 1977 and he has been the DFO technical representative on the Great Lakes fish health committee of the Great Lakes Fishery Commission since 1980. He works with the National Registry of Aquatic Animal Health to revise the Fish Health Protection Regulations and the Manual of Compliance, and to develop components of the National Aquatic Animal Health Program. He is also the DFO representative on a task force with the mandate to counteract the threat of whirling disease to Alberta's wild and cultured salmon stocks. He has also authored or co-authored several publications on fish health in central Canada.

Stephanie Sylvestre, M.Sc.
Environmental Studies Scientist
Aquatic and Atmospheric Sciences Division
Environment Canada, Environmental Conservation Branch
#201 - 401 Burrard Street,
Vancouver BC, V6C 3S5
phone: 604-664-4099
fax: 604-664-9126
e-mail: stephanie.sylvestre@ec.gc.ca

Stephanie Sylvestre received her B.Sc. from University of Windsor and her M.Sc. from the University of Western Ontario. She joined Environment Canada as an Environmental Studies Officer in 1994 and is now an Environmental Studies Scientist with the Aquatic and Atmospheric Sciences Division in Vancouver. Recent activities include: stream assessments in the Georgia Basin using the reference condition approach for benthic invertebrate monitoring; water quality assessment of agricultural and residential runoff; expanding the use of the benthic invertebrate monitoring approach developed for the Fraser River basin to assess streams in the Georgia Strait basin; PAHs and other contaminants in suspended sediment and water in the Fraser River basin.

Alan R. Thomson,MRM P.Eng
Mountain Station Consultants, Inc.
906 Ninth Street

Nelson, BC V1L 3C3
phone fax 250-352-0016
e-mail: alant@alumni.sfu.ca

Alan R. Thomson, is a principal of Mountain Station Consultants of Nelson, BC, and specializes in resolving natural resource management issues that involve the interaction of aquatic and biological resources. In his 11-year consulting practice, Alan has completed numerous contracts that involve watershed and stream assessments, river hydrology and engineering, design of new and restoration of existing aquatic biota habitats, river channel and bank stabilization, bioengineering, fish migration assessment and passage creation, policy and investigative research, and strategic planning and water quality enhancement and recovery. Recent contracts include: being an expert witness and advisor to the Department of Fisheries and Oceans at environmental impact assessment joint panel hearings concerning oils sands development in northern Alberta, and restoring fish habitats in several streams in British Columbia.

Michael A. Turner, Ph.D.
Fisheries and Oceans Canada
501 University Crescent,
Winnipeg, Manitoba R3T 2N6
phone: 204-983-5215
fax: 204-984-2404
e-mail: turnermi@dfo-mpo.gc.ca

Dr. Michael Turner received his M.Sc. and Ph.D. from the University of Manitoba. He is a Research Scientist of the Department of Fisheries and Oceans in Winnipeg. His primary research is at the Experimental Lakes Area in northwestern Ontario. He has a long history of work on the impact of acidification on lakes. His current limnological research focuses on the littoral ecology of boreal lakes impacted by habitat disruption and by climate variability and change. He also leads a research team studying the recovery of boreal lakes from acidification.

Marley Waiser, Ph.D.
Aquatic Ecosystem Impacts Research Branch
National Water Research Institute
Environment Canada
11 Innovation Boulevard
Saskatoon, SK S7N 3H5
phone: 306-975-5762
fax: 306-975-5143
e-mail: Marley.waiser@ec.gc.ca

Dr. Marley Waiser received her Ph.D. from Napier University in Edinburgh, Scotland. She is a Research Scientist with the Aquatic Ecosystem Protection Research Branch of Environment Canada’s National Water Research Institute in Saskatoon. She is also an adjunct professor with the Department of Applied Microbiology, University of Saskatchewan in Saskatoon. Dr. Waiser’s research has focused mainly on the microbial ecology and biogeochemistry of prairie aquatic ecosystems including saline lakes and wetlands. Her research has been published in Limnology and Oceanography, Canadian

Journal of Fisheries and Aquatic Research, Archiv für Hydrobiologie, Biogeochemistry and Aquatic Microbial Ecology. Currently, she is investigating the effects of sulfonylurea herbicides on the microbial ecology of prairie wetlands as part of a larger collaborative effort looking at the fate and effects of this new generation of herbicides. Dr. Waiser is also part of a team of scientists who are investigating the relationships between terrestrial and aquatic dissolved organic carbon, with special reference to prairie ecosystems.

Appendix III
Oil Sands Regional Aquatic Monitoring Program (RAMP)
Scientific Peer Review of the Five Year Report (1997-2001): Reviews of Biostatistics

Submitted to:
RAMP Steering Committee

Report Prepared by:
Carl Schwarz
Department of Statistics and Actuarial Science
Simon Fraser University
8888 University Drive
Burnaby, BC, V5A 1S6

cschwarz@stat.sfu.ca
http://www.stat.sfu.ca/~cschwarz

1. INTRODUCTION

The Oil Sands Regional Aquatics Monitoring Program (RAMP) in the Oil Sands Region of north-eastern Alberta was designed to measure baseline environmental conditions and predict effects from proposed developments. RAMP was designed as a long-term monitoring program that incorporates both traditional and scientific knowledge. Specific programs in RAMP were established each year by committees and subcommittees after consultation with industrial, aboriginal, environmental and regulatory stakeholders and expert independent consultants. As the Oil Sands Region experienced rapid growth from 1997 to 2001, changes to RAMP were made annually. These changes not only affected RAMP's objectives, and organizational structure, but the study area and study design as well. Potential sampling methods, sentinel species and reference lakes and streams were also evaluated during this period. Some methods were adopted and then abandoned during the program.

This is a review primarily of the biostatistical analysis conducted as part of this first five years of the program.

The entire Five Year Report was reviewed to examine if the analyses conducted in the report are suitable, if the conclusions can be supported by the analyses chosen, and to make recommendations for changes to future years of RAMP. A less detailed review of the interim reports was also conducted (Appendix IV).

2. GENERAL COMMENTS

2.1 Replication and pseudo-replication.

A major concern in Environmental Impact studies is proper replication and the avoidance of pseudo-replication (Hurlburt, 1984). Replication provides information about the variability of the collected data under identical treatment conditions so that differences among treatments can be compared to variation within treatments. This is the fundamental principle of ANOVA.

For example, consider a survey to investigate sediment quality at various locations on a river. A simple design may take a single sample at each of 4 locations:

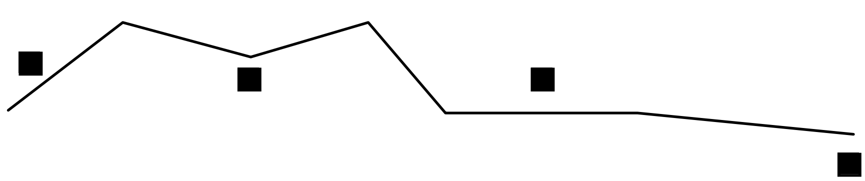


Figure 2.1(a) A simple survey that provides little useful information.

These four values are insufficient for any comparison of the variable across the four locations because the natural variation present in readings at a particular location is not known.

In many ecological field studies, the concepts of experimental units and randomization of treatments to experimental units are not directly applicable making "replication" somewhat problematic. Replication is consequently defined as the taking of multiple INDEPENDENT samples from a particular location. The replicated samples should be located sufficiently far from the first location so that local influences that are site specific do not operate in common on the two samples. The exact distance between samples depends upon the biological process. For example if the locations are tens of kilometers apart, then spacing the samples hundreds of meters apart will likely do for most situations. This gives rise to the following design:

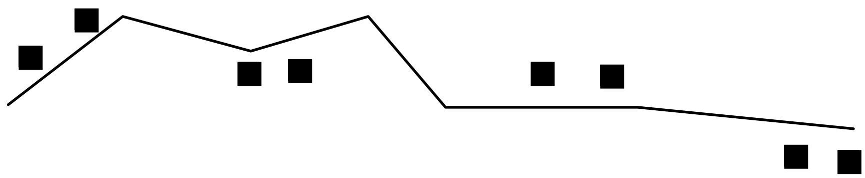


Figure 2.1(b). A replicated survey (if the points are independent within a pair).

Now a statistical comparison can be performed to investigate if the mean response is equal at four locations. This particular design would give rise to the following statistical model

Y = location sample(location)-R

where *location* represents the effect of different locations, and *sample(location)-R* represents the random, independent replicates at each location. The ANOVA table would construct a test for location effects using the F-ratio of

$$F = \frac{ms(location)}{ms(sample(location))}$$

with the idea that variation in means among locations would be compared to variation in readings within a location.

The key point is that the samples should be independent but still representative of that particular location. Hence, taking two samples from the exact same location, or splitting the sample in two and doing two analyses on the split sample will not provide true replication. These would be pseudo-replicates. Hurlburt (1984) defines pseudo-replication as

> "Pseudo-replication is defined as the use of inferential statistics to test for treatment effects with data from experiments where either treatments are not replicated (though samples may be) or replicates are not statistically independent."

Consequently, a design where duplicate samples or split-samples are taken from the exact same location (Figure 2.1(c)) would be an example of pseudo-replication.

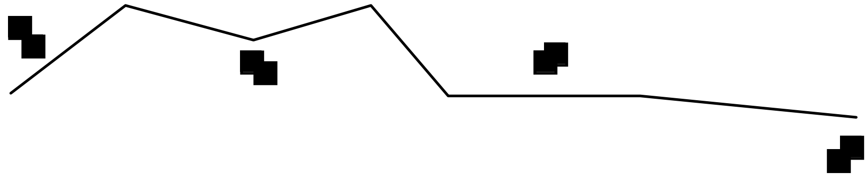


Figure 2.1(c). A pseudo-replicated survey.

Note that the data from Figure 2.1(b) and Figure 2.1(c) looks “identical”, i.e. pairs of “replicated” observations from four locations. Consequently, it would be very tempting to analyze both experiments using exactly the same statistical model and ANOVA table. However, there is a major difference in interpretation of the results.

The design in Figure 2.1(b) with real replicates enables statements to be made about differences in the mean response among those four general locations. However, the design in Figure 2.1(c) with pseudo-replication only allows statements to be made about differences among those four particular sampling sites which may not truly reflect differences among the broader locations.

Obviously the line between real and pseudo-replication is somewhat ill-defined. Exactly how far apart do sampling sites have to be before they can be considered to be independent. There is no hard and fast rule and biological consideration and knowledge of the processes involved in the environmental impact must be used to make a judgment call.

The same considerations apply when sampling across time. Samples need to be taken far enough apart in time so that they are independent. For example, if data from continuous logging is used (say every minute over a year), then it would be unfair to treat all 500,000+ observations are being independent when a regression line is fit.

What is the relevance to the RAMP report? In some part of the report, this has been recognized. For example, Section 6.1.1 (page 6-25) states:

> “Individual samples collected from the same site do not represent replicates in the statistical sense because they are not independent. Widely-spaced samples from a reach (each sample representing a site) were used as replicates to compare reaches.”

But, consider Section 4 of the report and Figures 4.12 and 4.13. The authors again recognize some obvious pseudo-replication (e.g. only one measurement is selected from multiple measurements in a location in a day), but Figures 4.12 and 4.13 show clustering of data points at a larger time scale. Hence treating all the points in these figures as independent likely overstates the observed relationship, i.e. the reported p-value is too small. Other cases of potential pseudo-replication are cited in the Technical Comments below.

Another consequence of pseudo-replication is that estimates of variation used in power analyses are too small which lead to underestimates of the required sample size to detect a specified difference.

All of the analyses in the report should be reviewed with the dangers in pseudo-replication in mind. The report should also provide a clearer description of the sampling design – the text at the bottom of page 6-5 could serve as a prototype for similar statements in the other chapters of the report.

2.2 Matching Analysis with Design

Another common concern with environmental field studies is ensuring that the analysis matches the design by which the data were collected. All two-factor designs are not analyzed in the same way!

For example, consider (as in Chapter 5) a study to compare a variable in sediments among four locations and two sides of the river[5].

Two possible design are shown in Figures 2.2(a) and 2.2(b)

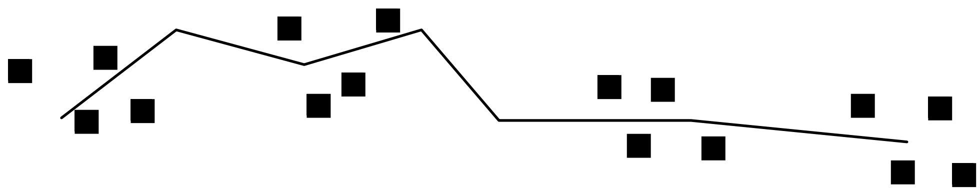


Figure 2.2(a) A design to study the effects of side and location with independent replicates at each location/side combination.

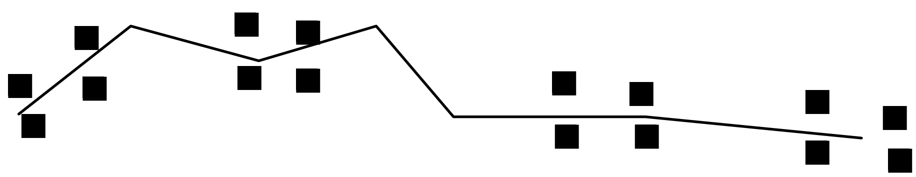


Figure 2.2(b) A design to study the effects of side and location with paired replicated at each location/size combination.

Both designs have exactly the same number of data points and without looking carefully at how the data were collected, the raw data does not provide information about the actual design. However, the analysis of these designs is quite different.

The analysis of the design in Figure 2.2(a) would use the statistical model

Y = location side location*side sample(location*side)-R

where *location*, *side*, and *location*side* represent the effects of location, side, and their potential interaction (i.e. is the effect of side consistent among all locations?). The term *sample(location*side)-R* represents the (random) variation of the response variable among replicate samples at the same location/side. Because there are independent replicates at each side/location, an model-independent estimate of this variation is available directly from the data. Note that this model makes an implicit assumption is that

[5] It is not necessary to take replicate samples at ALL side-location combinations, nor is it necessary to have equal number of replication samples at ALL side-location combinations. However, balanced designs (with equal number of replicates) have the advantage that tests for each effect are now orthogonal to each other and that simple software can be used to analyze these designs.

the replicate samples on each side of the river are independent among themselves on the side and among the two sides of the river. Hence the sample points are take NOT directly across from each other on both sides of the river. The statistical comparisons would be computed as:

$$F_{location} = \frac{ms(location)}{ms(sample(l*s))}, F_{side} = \frac{ms(side)}{ms(sample(l*s))}, F_{\text{interaction}} = \frac{ms(\text{interaction})}{ms(sample(l*s))}$$

However, the analysis of the design in Figure 2.2(b) must now allow for the existence of potential small scale effects within each location that affect both sides of the river simultaneously? This would render the two replicate samples on each side no-longer independent. There are two "sizes" of effects. First location effects operate on a large scale (on sets of 4 samples) while micro-location effects operate on paired points on each side of the stream. The statistical model is now:

Y = location site(location)-R side location*side residual-R

where *location, side,* and *location*side* terms again represent the effects of location, side, and their potential interaction. The *site(location)-R* term represent the micro-location effects that affects both sides of the river simultaneously. Because there are replicate pairs of points at each location, the within location variation can be computed independently of the model. The *residual*-R term represents the variation among individual sample points and is found by subtraction.[6] This model is a variant of a split-plot design with locations being main plots, and the sides of the river within each pair at each location being the subplots. The

$$F_{location} = \frac{ms(location)}{ms(site(location))}, F_{side} = \frac{ms(side)}{ms(residual)}, F_{\text{interaction}} = \frac{ms(\text{interaction})}{ms(residual)}$$

Notice that the test for location is NO LONGER computed using the residual variation – it must be constructed using the site-to-site variation within each location. The reason for this is that there are now two scales of effects – location effects affect groups of 4 points, while the site effects within location affect a pair of points (both sides of the river).

The situation becomes more complex once sampling is replicated across years. Again, consider the first design where the sampling is repeated in two years:

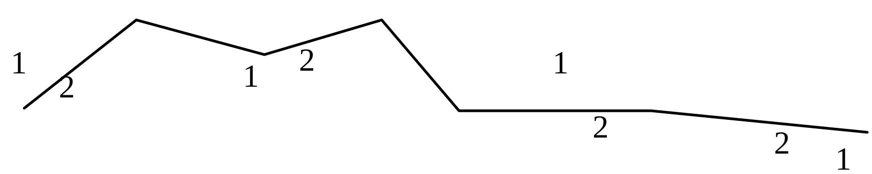


Figure 2.2(c) An (inadequate) sampling design with independent measurements across time. The values 1/2 represent years 1/2 measurements

Here, the sample points in year 2 are situated at random within each location ignoring bank effects but far enough from the original sample location to be independent of micro-location effects. [This design suffers from the same defect as outlined earlier,

[6] This design could have replicate points at each side within each pair at each location which would then allow a model-independent estimate of this variation to also be computed.

i.e. no real replication, but is used only to illustrate a comparison with a paired design below.] Contrast this to the design in Figure 2.2(d) where sampling is deliberately located at the SAME sampling sites in both years:

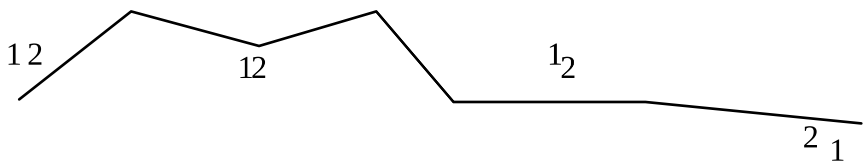


Figure 2.2(d) An (inadequate) sampling design with paired measurements across time. The values 1/2 represent years 1/2 measurements

Now a proper model that incorporates time effect must account for both the large scale location effects but also potential micro-location effects. [Again, there is no replication at any of the location –year points and so is a poor design.]

This is relevant to the RAMP report because many of the chapters involve two (or more) factor models but the reports always treat the data as if it came from completely randomized designs (as in Figure 2.2(a)) rather than looking closely at how the data were collected. In many cases, time is a factor, and it is not clear if sample points are paired across time or are independent across time. The analysis is different in these two cases. The report should pay more attention to how the data were collected

Additional examples are provided in Morrison et al (2001) on the need for proper matching of design and analysis.

2.3 Lack of suitable replication - consequences

In many cases, it appears that no suitable replication was collected during the sampling design. Rather than simply throwing up ones hands and abandoning the analysis, what are the consequences of no real replicates?

Consider again (as in Chapter 5) a two factor design to investigate the effects of location and bank upon sediment quality. A simple design might take samples from each side of the bank at each of the 4 locations:

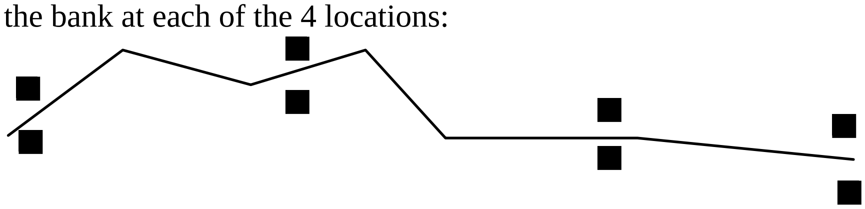


Figure 2.3(a) A design to compare effects of bank and location without replicates.

At first glance, this appears to be similar to the previous designs (Figure 2.1(b) or Figure 2.1(c)) with the same number of total replicates except they are now taken on both sides of the river. However, unless a very strong, untestable assumption is made, no valid statistical test can be made for the effect of side or the effect of location! This design has NO real replicates.

The assumption that must be made is that the effects of side is EQUAL at all locations and that the effect of location is EQUAL on both sides, i.e. that there is NO interaction between the effects of location or site. The is insufficient information in the experiment to test this assumption.[7] The statistical model for this experiment under this very strong assumption would be

Y = location side residual-R

where *location* and *side* represent the effects of side and location respectively. The *residual-R* term represents the residual, random variation, after adjusting for location and side. Note that unlike the previous model, the *residual-R* term can only be computed after adjusting for side and location – there is no data-driven estimate of this variation.

This model appears to be the same as the model as for a randomized block design. [A key assumption of a randomized block design is that blocks and factors also do not interact]. However, there is subtle difference between factors and blocks that will not be discussed in this report that implies that they are not identical. The F-statistics for testing effects of location or side would be computed as:

$$F_{location} = \frac{ms(location)}{ms(residual)}, F_{side} = \frac{ms(side)}{ms(residual)}$$

where *ms(residual)* represents the remainder after adjusting for the effects of *side* and *location.*

So on first glance, it does appear that a valid statistical test has been performed – but it will only be valid if the assumption of no interaction is true.

The situation becomes more complex once sampling is replicated across years! Again, consider the first design where the sampling is repeated in two years:

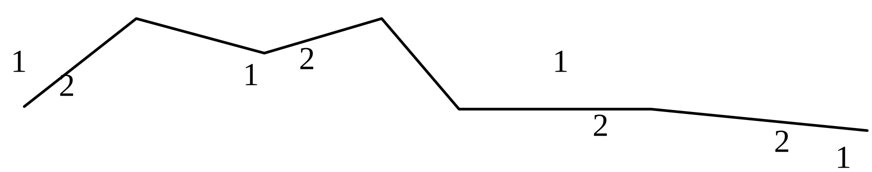


Figure 2.3(b). A design to compare the effects of location and time without replication and independent randomizations in each year.

Here, the sample points in year 2 are situated at random within each location ignoring bank effects but far enough from the original sample location to be independent of micro-location effects. This design suffers from the same defect as outlined earlier, i.e. no real replication and so analyses are only possible if a very strong, untestable assumption is made – namely, no year*location interaction, i.e. the year effects are equal for all locations, and the location effects are equal for all years. The model that must be fit is

[7] A crude profile plot of the value of the response variable at each location for each side could be used to informally check if the profiles are parallel which would indicate that no apparent interaction exists, but this is only an informal check.

Y = location year residual-R

where *location* and *year* represent the location and year effects and *residual-R* represents the random variation that must be found after fitting the model. The design can again be improved by replicating the measurements at location-year combinations.

Contrast this to the design where sampling is deliberately located at the SAME sampling sites in both years:

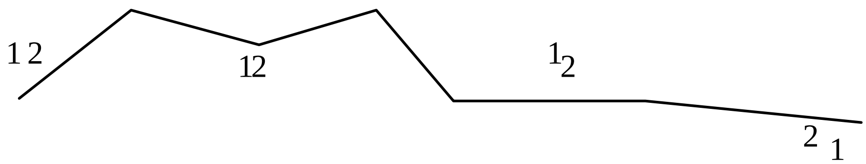


Figure 2.3(c) A design to compare the effects of location and time with paired observations across years.

Now a proper model must account for both the large scale location effects but also potential micro-location effects. However, because there is no replication at any of the location –year points, a model can only be fit if strong untestable assumptions are made – in particular that there is no year-location interaction and that there is NO micro-location effect. The model for this design is:

Y = location year residual-R

This is the same model as for the previous case, but this is an artifact of the poor experimental design chosen – without proper replication, only very simple models that make strong assumptions can be fit. There is a fundamental difference between these two designs – the former is akin to a completely randomized design while the latter is a variant of a split-plot design. With proper replication the model would look quite different.

The RAMP report has many comparisons of the above type. In general, these comparisons may be misleading because of the lack of proper replication. At the very least, these implicit assumptions should be stated directly in the report.

2.4 Reporting results; p-values and power analyses

The report has numerous tables reporting the results of testing for the effects of various factors. In many cases, p-values are the statistic of choice and in some cases, only an indication of statistical significance (i.e. $p<.05$) are provided.

Many authors have reviewed the problems with p-values (e.g. Steidl et al 1997; Cherry, 1998; Johnson, 1999). Basically, the p-value does not provide sufficient information to assess the magnitude of the difference detected and can be misleading to readers. Other problems include:

- The choice of null hypothesis is often arbitrary.
- Conclusions are stated a rejecting or not-rejecting the hypothesis when in fact the data may not be that clear cut.
- The choice of α-level (i.e. 0.05 significance level) is arbitrary. Should

different decisions be made if the p-value is 0.0499 or 0.0501? The value of α used in a study should reflect the costs of Type I errors, i.e. the costs of false positive results and the costs of Type II errors, i.e. the costs of false negative results.

- Users of statistics have often emphasized certain standard levels of significance such as 10%, 5%, or 1% indicated (typically) by asterisks. These reflect a time when it was quite impossible to compute the exact p-values, and only tables were available. In this modern era, there is no excuse for failing to report the exact p-value.
- In many cases, hypothesis testing is used when the evidence is obvious. This leads to statements similar to “p<.00001”.
- P-values are prone to mis-interpretation as they measure the plausibility of the data assuming the null hypothsis is true, rather than measuring the “truthfulness” of the hypothesis.
- P-values are highly affected by sample size. With sufficiently large sample sizes every effect is statistically significant but may be of no biological interest.
- The tradeoffs between Type I and II errors, power, and sample size are rarely discussed in this context.
- Just because the null hypothesis is rejected does not imply that the effect is very large. For example, if you were to test if a coin were fair and were able to toss it 1,000,000 times, you would reject the null hypothesis of fairness if the observed proportion of heads was 50.001%. But for all intents and purposes, the coin is fair enough for real use. Statistical significance is not the same as practical significance. Other examples of this trap, are the numerous studies that show cancerous effects of certain foods. Unfortunately, the estimated increase in risk from these studies is often less than 1/100 of 1%!
- Just because an experiment fails to reject the null hypothesis, does not mean that there is no effect! A Type II error - a false negative error - may have been committed. These usually occur when experiments are too small (i.e. inadequate sample size) to detect effects of interest.
- In some experiments, hundreds of statistical tests are performed. However, remember that the p-value represents the chance that this data could have occurred given that the hypothesis is true. So a p-value of 0.01 implies, that this event could have occurred in about 1% of cases EVEN IF THE NULL IS TRUE. So finding one or two significant results out of hundreds of tests is not surprising!

Some of the problems with p-values were recognized in the report. For example, page 7-95 states:

> “In many studies, a statistically significant difference in biological measures is used as evidence that a change has occurred. Indeed, several industry-wide monitoring programs have adopted this approach (Environment Canada 1998, 2002). Unfortunately, extrapolation from statistical significance to ecological

> significance is difficult because statistical significance depends upon sample size, and may not relate to the size of the impact."

The report recommends that ecological significance be stated in terms of the variability of the natural populations:

> "The approach proposed by Kilgour et al. (1998) was used to determine the ecological significance of the observed differences. They define ecologicallyrelevant differences as observations from impact locations that fall outside the normal range of variation based on reference-location data. They also define the normal range as the region enclosing 95% of reference-location observations. The 95% region can then be expressed generically as standard deviations in univariate responses. For example, in single responses that are normally distributed, the region defined by $\mu \pm 1\ \sigma$ incorporates about 67% of the population, and $\mu \pm 1.96\ \sigma$ incorporates about 95% of the population. These calculations were performed with the RAMP data, and all mean values of exposure population parameters fell within the normal range based on the three reference populations; …"

While this an improvement over the lack of determination of an ecologically significant result, the report should review these proposed ecologically significant effects carefully because changes in the mean that are much smaller than a standard deviation of individual observations can have large ecological impacts.

Rather than relying upon p-values a summary measure, the earlier cited papers have suggested that more emphasis be place on confidence intervals for effect sizes. For example, the report contains many tables such as Table 4.17, where a comparison between two levels of a factor is shown. The mean values for each level are shown, and the F-statistic is shown with asterisks (* or ** or ***) representing if the effect was "significant". These types of tables could be greatly improved if the estimated difference was shown along with the estimated confidence interval for the difference. In this way, the reader can assess the magnitude of the differences and if these are biologically important.

Along with reporting confidence intervals for effect sizes, power analyses provide information on the likelihood of success in detecting real changes. The report has numerous power computations, but these could be improved/corrected in the following ways:

- better terminology, e.g. "effect size" should read "minimum detectable difference"
- using the proper estimate of variation. As noted below, pseudo-replication will lead to estimates of variation that are too small and estimates of minimum detectable differences that are too small, i.e. the actual power is much less than "advertised".
- discussion of power of trend tests confuse the minimum sample size that is technically needed to compute a statistic with the sample size needed to detect a

specified decline. For example, the Mann-Kendall test looks for monotonicity of the trend and this is dependent upon the actual slope and the natural variation in addition to the sample size. The first two components were not discussed at all in the report.

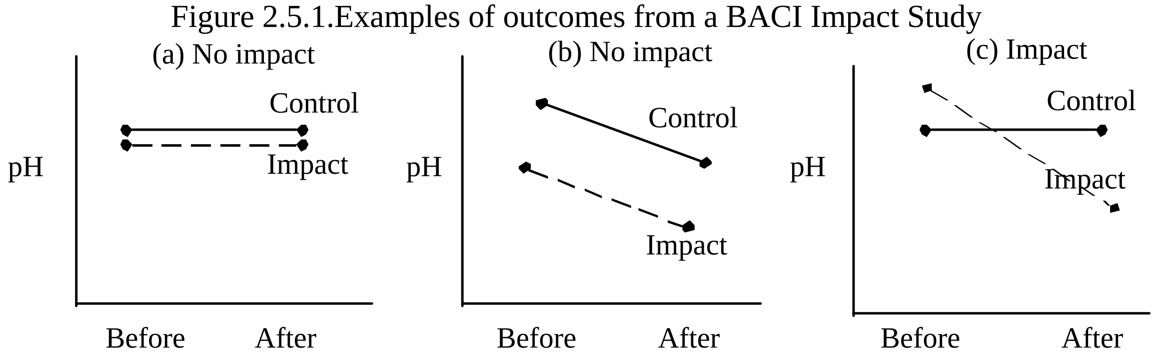
2.5 Types of Monitoring Designs

The simplest monitoring design is a before/after measurement at a single site. For example, soil pH is measured before and after emissions begin. This design is widely used in response to obvious accidental incidences of potential impact (e.g. oil spills, forest fires), where, fortuitously, some prior information is available. In these types of studies, the manager obtains a single measurement of pH before and after the event. If the second survey reveals a change, this is attributed to the event.

Unfortunately, there may be no relationship between the observed event and the changes in the pH - the change may be entirely coincidental. Even worse, there is no information collected on the natural variability of the pH over time and the observed changes may simply be due to natural fluctuations over time. Decisions based on this design are extremely hard to justify.

The most basic monitoring design that can distinguish natural changes from changes that follow an impact are the Before/After/Control/Impact (BACI) design where pH is measured at the site before and after the impact, and at a control site (not affected by the impact) before and after the impact. Figure 2.5.1 illustrates three possible outcomes.

Figure 2.5.1.Examples of outcomes from a BACI Impact Study



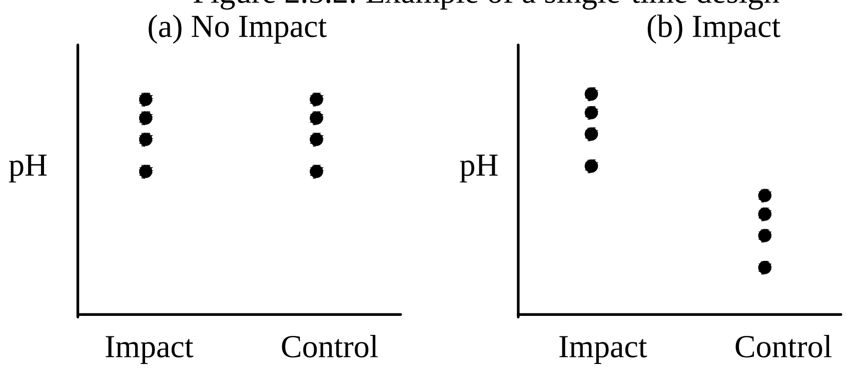
In Figure 2.5.1(a), the pH measurements did not change from before to after the impact at either the control or impacted site and there is no evidence of an impact. In Figure 2.5.1(b), both sites have changes in pH over time, but the change is equal for both sites. Because both sites changed in a parallel fashion, there is no evidence of a differential effect of the impact. In Figure 2.5.1(c), the change is no longer parallel between both sites, and there is evidence of an impact.

But what can be done if baseline (before impact) measurements are available.

Weins and Parker (1995) considered the problem of assessing environmental impacts when before measurements are not possible (e.g. in the case of accidental impacts such as oil spills). They divide potential designs into various classes – the two most relevant to this study are the single-time designs (the current document) and the multiple-time designs (for the future).

In the absence of before measurements, the single-time designs take samples from several sites within the impacted area and from several sites outside the impacted areas. For example, Figure 2.5.2 illustrates this design with four sites chosen from the impacted area and four sites chosen from the control area.

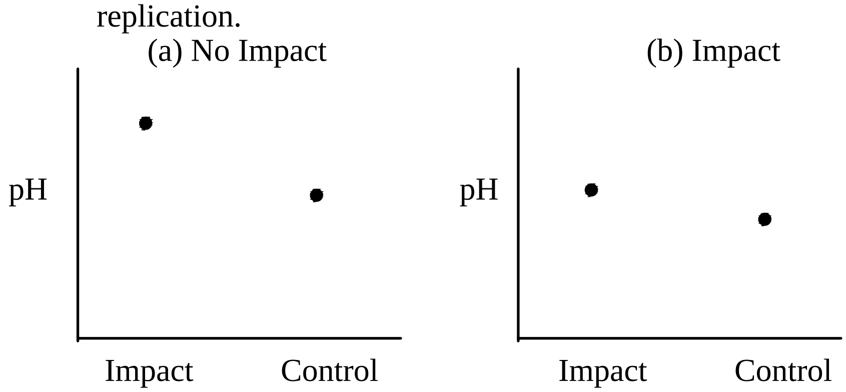
Figure 2.5.2: Example of a single-time design



In Figure 2.5.2(a), the average pH level is about the same in both areas while in Figure 2.5.2(b), there is clear evidence that the mean has declined. The greatest danger with this design is that the observed difference between impacted and control sites may just be due to random variation and not related to the impact but carefully choosing control areas to be a similar as possible to the impacted areas should reduce this possibility.

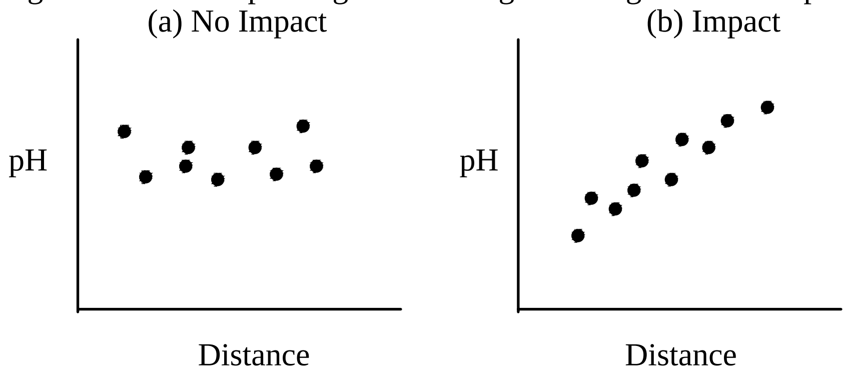
Note that replication within the impact and control areas is also vital as mentioned earlier. As an illustration of the danger that no replication poses, consider Figure 2.5.3 - the same values are used as in Figure 2.5.2, except that only one site was measured from each area. Just by chance, these happened to correspond to the highest and lowest pH in each group.

Figure 2.5.3: Example of misleading results that could be obtained without replication.



In some cases, such in this study, the impact can be quantified and a gradient of exposure can be established. For example, distance from the source of emissions may be used as a surrogate for exposure. Figure 2.5.4 illustrates two potential relationships:

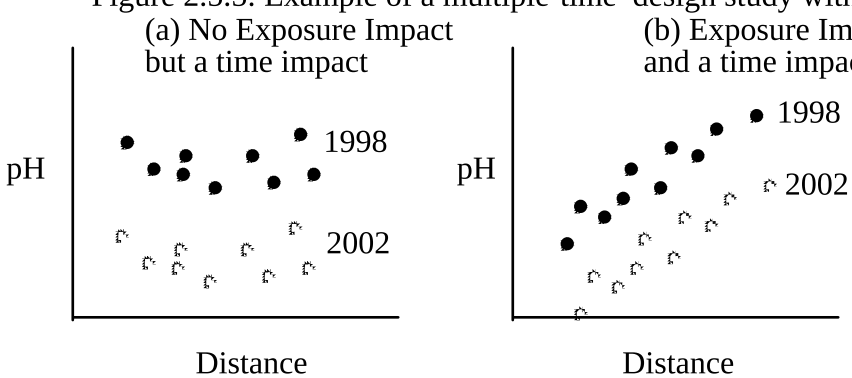
Figure 2.5.4: Example single-time design with a gradient of exposure



Note that a wide range of exposures needs to be monitored and that the design assumes that all other factors that might affect the response are equal except for exposure. For example, it may turn out that all sites are located in a northerly direction from the emission source and latitude effects are what causing the response variable to change.

This study is intended to continue over time, and so both temporal and exposure effects can be examined as outlined in Weins and Parker (1995). Figure 2.5.5 illustrates two responses that could occur (others are possible):

Figure 2.5.5: Example of a multiple-time design study with gradient of exposure



In Figure 2.5.5(a), there does not appear to be any relationship of the response to exposure but something appears to be happening over time. In Figure 2.5.5(b), there appears to be a relationship with exposure and again some effects of time.

The lack of baseline information for some aspects of the study have been recognized by the authors. For example in section 4.3.3, the report states:

"In response to the question "Is RAMP collecting or otherwise obtaining the type of information required to differentiate natural variability from changes associated with human activity?", the answer is mixed. In the case of sulphate levels in the Muskeg River, adequate baseline data had been collected before and after the initiation of development at both upstream and downstream locations to clearly identify a significant change attributable to human activity in the basin. However, as discussed in Section 4.3.3, sufficient baseline information may not be available in less well-studied systems to determine if, for example, significant temporal variations can be detected prior to development.

The Weins and Parker (1995) paper should be reviewed to see if their suggested designs may provide further monitoring options for this study. This is alluded to in the report:

"Since there will be a potential for the appearance of long-term trends unrelated to oil sands developments (e.g., due to climate change or long-term hydrological cycles), monitoring to detect long-term trends should incorporate at least one reference river. Although the analysis described in Section 6.2.1.2 suggests that each river is unique in terms of its benthic community, it is possible that long term trends unrelated to development would be similar in all regional rivers. This would allow the consideration of time-trends observed in reference rivers in the interpretation of data from potentially affected rivers. Based on the extent of planned oil sands development in the region and its hydrological features, finding reference rivers is problematic. Therefore, if significant long-term trends are found by future assessments without corresponding reference river data, the possibility of factors other than oil sands developments causing the observed trends will need to be considered, possibly by evaluating the consistency of trends among rivers monitored throughout the region."

A more systematic exploration of potential monitoring designs for this case should be included in the report.

Finally, the report comments many times that the same monitoring station was not measured over time or that stations are added or dropped over time. There are obvious tradeoffs between fixed monitoring stations and random monitoring stations which are discussed in many books. However, the RAMP steering committee should consider using **panel-designs** which are a combination of fixed and random monitoring stations. A classical panel design would, for example, start with 12 monitoring stations, and allow up to 1/3 of the stations to rotate each year. Some stations, if feasible, could not be rotated. A simple example is shown below:

	Stations monitored												
yr	1	2	3	4	5	6	7	8	9	10	11	12	13
1	x	x	x	x	x	x	x						
2	x	x	x	x	x	x	x	x	x	x			
3	x	x	x	x	x	x	x	x	x	x	x	x	x
4	x	x	x	x	x	x	x	x	x	x	x	x	x

5	x	x	x	x				x	x	x	x	x	x
6	x	x	x	x							x	x	x

These designs combined the best features of fixed and random monitoring. A few stations have long term measurements, while the rotated stations allow for sample refreshment (because, for example, of natural disaster at a station or change in conditions at the station).

2.6 Data storage, meta data

This topic is missing from the report, but the RAMP review should look at how the data for this study is being stored. In particular, the use of simple Excel-type spreadsheets may be inadequate as linking between sheets of different information from the same location may be missing.

An important component of data storage is consideration of maintenance of meta-data, i.e. information about the actual data such a location, sampling method, who collected, who analyzed the data etc. How is this information being stored?

2.7 Choice of analysis methods.

The report uses three basic methods.

2.7.1 Estimation of extreme values (precipitation, stream flow, and temperature)
The report uses two programs – the Consolidated Frequency Analysis (CFA) from Environment Canada and the FRQ from Kite to estimate return events. Based upon a reading of the report, these appear to be appropriate methodologies.

However, the described methods of analysis in Section 3.2.1.1 (Precipitation events) is rather unclear. Unlike annual min/maximum records, there is only value per year for precipitation. Consequently, how is the data separated into wet and dry years prior to fitting the appropriate extreme value distribution? Different separations would lead to different estimates of wet/dry return periods.

Note that the precision of the estimated events is lively very poor. Chow (1977) wrote that in order to accurately predict a 10-year recurrence frequency event, 100 years of records are needed, but, in order to accurately predict a 100-year recurrence event, about1,000 years of records will be needed.

The report did not do a power analysis to examine the size of changes that can be detected given the available data. I suspect that the power is very poor given the extreme variation in the data, so that it may not be cost effective to even monitor these variables.

Consequently, I would suggest that (a) the estimated parameters of the fitted distribution should be displayed in tables such as Table 3.10, so that future users do not need to refit the data and (b) a proper power analysis be done.

2.7.2 ANOVA

The report uses ANOVA extensively to investigate if changes in the mean response have occurred among locations, year, bank, upstream/downstream etc.

ANOVA is a very general methodology but it is extremely important that designs have proper replication (see earlier comments) and that the analysis matches the experimental design. As seen in my comments below, there are several instances where pseudo-replication is apparently taking place, where no real replication occurs, or where the wrong model has been fit.

Some of the analyses need to be redone using the appropriate replicates and/or models.

The report commonly reports p-values but does not report estimates of effect sizes. As noted earlier, it is better practice to report effect sizes rather than simple p-values which have a number of "defects".

Power analyses may need to be redone to incorporate the proper estimate of variation, i.e. pseudo-replication typically leads to estimates of variation that are too small and power estimates that are too large; in split-plot designs the different error terms are used for power analyses of the different factors.

2.7.3 Regression

The report uses regression analysis to check for temporal trends. Often a non-parametric regression method (Mann-Kendall method) is used.

The primary concern that I have with the regression analyses have to do with the failure of the observations to be independent, e.g. pseudo-replicates are used as real-replicates.

The report attempts to do a power analysis for the non-parametric testing method but confuses the technical minimum sample sizes with a the real power to detect a specified trend. These should be redone to properly report the power to detect, e.g. a 10% decline over 10 years.

2.7.4 Principal Component Analysis

Principal Component Analysis (PCA) is commonly used to reduce a large set of inter-correlated variables to a smaller set of underlying "variables". For example, in Chapter 4, PCA was used to reduce a large number of water chemistry variables to a smaller set – for example, many metals seem to vary together among the samples.

The idea of PCA is to extract a component that has the highest possible variance; then extract a second component that has the next highest variance but is orthogonal to the first etc. PCA is common done on the correlation matrix of the observations as the correlation matrix does not change if the measuring scale of individual variables changes.

For example, changing the measuring units from cm to m would reduce the variance of a variable by a factor of 100, but has not effect on its correlation with other variables. I was somewhat puzzled then by the analysis in Chapter 6 where the PCA was done on the covariance matrix which is not measuring-scale independent.

The interpretation of a principal component (PC) is obtained by examining the correlation of each individual variable with the extracted PC. Sets of variables that are highly correlated provide an interpretation of the component. For example in Table 4.9, a reasonable interpretation of the first component is “concentration of heavy metals”, while that for the second components appears to be related to “salts”. The report appears to have interpreted the extracted PC correctly.

The extracted PC are often then regressed against other variables, e.g. stream flow. Again, the report appears to have done these appropriately.

The usefulness of PCA for environmental impact studies is mixed. A PCA could be used to identify a common factor that may be easier to measure than a set of disparate variables. However, in some cases, there is little to be gained – for example, chemical analyses of water use methods that produce the individual constituent components a very little marginal cost. When additional data are collected and included in a PCA analysis, the new data can change the computation of the PC slightly so results cannot be directly compared across years. It would be advantageous to use the PCA results to define a new variable (e.g. sum of total metal concentrations) whose definition does not change from year to year.

3 DETAILED TECHNICAL COMMENTS

3.1 Chapter 1 comments

Section 1.7.4 Changes in monitor plans over time – consider a panel design with sites being rotated in and out a suitable design?

3.2 Chapter 3 comments

a) Section 3.2.1.1 - Precipitation methods

Need to carefully define the calendar year. For example, snowfall is recorded from October to May which crosses a year boundary. To which year is this assigned? For example in Table 3.6, calendar year 1945 has both snowfall and rainfall records? The report needs an exact definition of the recording year., e.g. 1945 year corresponds to Sept 1 1944-31 August 1945.

How can two different distributions be fit for dry and wet years to determine return periods for 10/100 year events? It seems to me that a single curve needs to be fit to the entire data and the appropriate percentiles determined (e.g. the .01, .1 or .9 and .99 points.

b) Section 3.2.2.1 - Temperature methods

Same comments as above. Dec-Feb data belong to which year? For example in Table 3.8, is Dec-Feb for 1945 associated with Dec 1944-Feb 1945 or Dec 1945-Feb 1946.

Second last paragraph with "correlation between two data sets" and "… cold winter unlikely to CAUSE a cold summer…". Correlation does not imply causation.

c) Section 3.2.3.1 - Runoff depth analysis

The consolidated frequency analysis program of Environment Canada and the FRQ program by Kite were used to runoff depth – were these used for previous two sections on Precipitation and Temperature?

Figure 3.12 legend differs from rest of graphs in series. Try and make all legends/axes/lines consistent. Try and use consistent colors through out the document, e.g. for the 100/10 return periods values.

Why is goodness of fit used to select appropriate distribution? More modern theory would use AIC for model selection and model averaging (Burnham and Anderson, 2002). Using the distribution that fits best, may lead to a better fit than can be justified..

Report the fitted parameters of distributions so others can use these to estimate other return periods etc without having to reaccess the raw data.

d) Section 3.3 Testing for temporal trends.

Estimate the actual trend line and report a 95% confidence interval – this can be done even with non-parametric methods as done in later chapters of the report. Absence of a detection of a trend does not imply that there is no trend – rather that it may be small relative to the effect size. Show a plot with the fitted trend curve.

If you find serial dependence in the data set, does it make sense to do Spearman test for trend which assumes independent data points? I suspect that this non-independence makes the Spearman test incorrect – an example of pseudo-replication.

Report the actual p-value of the test statistics rather than simple if significant at the 1% or 5% levels. Report confidence intervals when ever possible. See the papers cited in the introduction on problems with the way the results are presented.

e) Section 3.3.1.1 – Precipitation – Results and Discussion

"Difference at the 95% confidence interval" makes no sense. Reword here and elsewhere in document.

f) Section 3.3.1.2 - Testing for trend in temperature

The split-sample test – was the year 1971 specified a-priori or was data snooping used?

g) Section 3.4 Monitoring To Verify EIA Predictions

What is missing is a estimate of the size of change than can be detected given the monitoring data, i.e. a power analysis of the recorded data. I suspect that this is extremely low given the high variability in the data.

Consequently, it may not be sensible to collect this data if it has essentially no chance of detecting any reasonable size of impact!

Figure 3.50 looks strange as lines are not parallel to X-axis.

3.3 Chapter 4 comments

h) Section 4.1.1 – Program Overview

Because not all sites sampled in all years, think of a panel design.

There is a big discrepancy in sample sizes among tables. Did Athasabasca really have 300-800 samples or do some of these include split/duplicate samples? Look like the potential for lots of pseudo-replication.

i) 4.2.1.1 - Methods

"Split and duplicate samples were reduced to single samples to guarantee data independence. This process was completed through either random selection or, in cases of unequal analysis, by choosing the sample that had been submitted for the more complete analysis."

While the goal of achieving independence among the samples is laudable, the approach is crude and may "waste" information. Duplicate/split samples are easily handled in modern statistical software through nesting terms. At the very least, the average of the split/duplicate samples should have been used rather than using a single random selection.

"… values recorded as zero were eliminated". Is this really true? A zero value is NOT the same a not recorded and contains valuable information. I suspect this was to avoid problems with log(0) in the analyses, but why is real data eliminated? It is not clear in the remainder of this section if 0 values were excluded for all analyses.

I can see eliminating entire class of variables if the majority of readings are non-detectable, but this also has dangers. For example, suppose that upstream of a oilsand project a certain component is non-detectible, but downstream from an oilsand project, most a non-detectable but, around 20% show extreme levels of a chemical?

The method of dealing with non-detectible (assigning 1/2 of the nd limit) is crude, but will work reasonable well as long as the number of nd is relative small (say 20% of the dataset or less).

j) Section 4.2.1.1.- Explicit TSS relationship

Do the plots first to see any outliers or weird points that may reduce the sample correlation coefficient to zero regardless if a linear relationship exists or not.

Note the problem with p-values. A correlation in Table 410 of .33 was significant for the Athabasca River but not for the Wetlands solely because of sample sizes of around 300 and 30 in the two locations.

k) Section 4.2.2.1 - Methods

Use ANCOVA to see if relationship is the same between the different sources. Is this possible as the flow variable is different in different streams?

l) Section 4.2.2.2 – Results and Discussion

Analysis pools over all years/seasons. A more complex model should be used to account for year/season effects.

m) Section 4.2.3.2 – Results and Discussion.

Analysis is incorrect. Replicate measurements within a season are pseudo-replicates (Hurlbert, 1984) and cannot be treated as independent sample points. A model such as

Y = year season year*season sample(year*season)

should be fit so that the test for season is against the year*season interaction, or an "average" must be computed for each season to give ONE measurement per year/season combination. The consequences of the incorrect analysis in the report is typically too many significant results.

As pointed out, many of the variables of interest are highly related to stream flow which is also related to season. Hence, the test of season is essentially a test of stream-flow.

Earlier, analyses were done on log(concentrations), but this section's writing makes it sound like the analyses were done on the raw concentrations. For example in Table 4.15 – Table 4.16 report what appear to be simple MEANS rather than geometric means if the analysis is done on the log-scale?

n) Section 4.3.1.2 – Analysis of Temporal trends in water quality

It appears that analysis is incorrect. There are multiple measurements taken in any particular year that are likely highly correlated, but these are treated as independent observations. For example, there are only about 25 years of data in the long-term study, but over 150 data points are presented. This can be seen in Figures 4.12 and 4.13 where there is evident clustering of points within years. Again, the likely effect is too many significant results.

Similar comments about the analysis in Tables 4.20 and 4.21 – the sample sizes are not real, independent measurements but are pseudo-replicates. In the Section on the Muskeg River, the report suggests the continuous measurements increase the sample sizes. Again this is pseudo-replication – two measurements taken very close together in time and space are not the same as two independent measurements.

4.3.1.3 – Conclusions and Recommendation.

Absence of a statistically significant results does not imply the non-existence of an effect. Power and sample size may have been inadequate to detect a change of biological importance.

4.3.2.1. –Trends in Athabasca River

See earlier comments in Section 4.3.1.2 – I suspect the analyses are incorrect because of non-independence of the data. Indeed Table 4.22 shows sample sizes that are too large for the model fit – i.e. include pseudo-replication within the year/season/location terms of the model. If year and season are blocking variables, then the year*season interaction term should be included to make this a paired design for testing location. Not a BACI design, so even if differences are detected, these cannot be attributed to oil sand development, but rather may have always existed.

4.3.2.1 – Trends in Muskeg River

This is a BACI design as pre-development data is available. Same problems as before with pseudo-replication within each year/location/season combination. Model is incorrect – if season and year are blocks, then season*year must be included. The authors state that year and season are random effects – this is not necessary is they are serving as blocking. In any case, if these were really random effects, then it is likely that MSE is NOT the appropriate denominator for the F-tests. Contrary to the author's assertion it is NOT a split-plot design – rather it is a variant of an incomplete block design.

In BACI designs, the interaction term is the prime term of interest – it indicated if the difference between upstream and downstream changed from before to after the impact occurred. The authors used a multiple comparison procedure if interaction was detected – but again, there is only one contrast of interest and this is of interest regardless if interaction was detected.

4.3.2.2 Results and Discussion

Unclear if the PCs were constructed using pooled data if they are plotting different definitions of PCs?

Table 4.22 – were the analyses done on the log(concentration) or the raw concentrations? Again, sample size indicates that pseudo-replication occurred.

Table 4.24 should estimate the change in the difference between upstream and downstream (with a standard error) for ALL comparisons as this is the real story.

o) Section 4.3.3 – Ability to detect change

Power analyses likely wrong because of pseudo-replication. I didn't see a power table.

Comments about power analysis in the case of interaction are not correct – there is only contrast of interest in the Muskeg River comparison so a power analysis easily done. The authors have misinterpret the intent of Steidhl (1997) – they have problems with retrospective power analyses if you use these to explain why your particular test didn't work – there is no problem in using the results of an existing experiment to predict future power. As well, the author should take Steidhl (1997) to heart and produce far more point estimates and confidence intervals.

4.3.3.2 Spatial Trends

The report computes the minimum detectable difference for a specified power than an "effect size". However, the report treats observations within a season/year combination as the indepedendent replicates when, as noted earlier, these are pseudo-replicates. The "n" in the power analysis refers to the number of blocks, i.e. the number of year/season combination as this is the "experimental" unit in question. All results are incorrect in this section.

Table 4.25 legend talks about "abundance" data which are not discussed in this chapter.

The author are surprised that for one variable the observed difference was less than the minimum detectable difference but was no declared statistically significant. However, even with an 80% power, there is still a 20% chance that a difference of that magnitude will not be detected – perhaps the study was just "unlucky".

p) Section 4.3.3.3 Conclusions and Recommendations

The report recommends that baseline data be expanded from 3 to 5 years of data but this report does not provide evidence to back up this assertion.

q) Section 4.4.3 Idenfying changes related to human activity

As the report indicates a BACI design is the minimum requirement to detect changes in environmental impact studies.

r) Section 4.5 Conclusions

It is unclear how the PCs will be used in the future as these will change depending upon the data collected – i.e. more samples are used and the component weights will change as more data are added. Consequently, estimates of means and standard deviations of current PC are not very informative.

s) Section 4.5.2.3 Ability to Detect Change

While I agree that a longer baseline is useful, this report provides insufficient justification for moving from 3 to 5 years. Unfortunately, in my experience, I suspect that 5 years will be insufficient to detect important biologically important difference! This aspect of the report needs to be reworked and strengthened.

3.4 Chapter 5 comments

The report is unclear on exactly how much sampling is done for sediment. For example, Table 5.1 appears to show that for the Athabasca river, that a single sample was taken in 2001 on the west bank upstream of Donald Creek. Unfortunately, taking a single sample at each location/bank combination provides no information about the variation at each site within a year, and unless strong assumptions are made about interactions (e.g. no year by location interaction), statistical tests cannot be performed. This needs to be clarified and duplicate sample should be taken at some (preferably all) bank/location/year combinations. These samples should be far enough apart so that they provide useful information on the variation within a year/location/bank combination, otherwise it is implicitly assumed that there is NO variation within a year/location/bank combination.

t) Section 5.1.1

With so few sites sampled over time, detecting changes over time will be difficult. Some consideration should be given to implementing a panel design.

u) Section 5.2.1 Methods

See earlier comments about eliminating 0 values. Authors have misinterpreted Zar (1984) about using the arcsin transformation. This is to be used ONLY for count data that has been expressed as a percentage – not for compositional data such as derived from this analysis of silt samples.

v) Section 5.3.1.1 Methods

Why were the modifications for Sen's method used here and not previously?

w) Section 5.3.2.1 Methods

Again, the lack of proper experimental design/data makes modeling difficult. As noted earlier, some replicate samples at the same location/year/bank need to be taken to obtain an estimate of local variation without making strong assumptions. For example, without replicate samples, it is necessary to assume that there is NO variation within a particular location/bank/year combination among replicate samples.

It is not necessary to drop terms from the ANOVA model if they are not statistically significant and the original model can be used to extract all the relevant information. This follows the principle that a non-statistically significant result does not necessarily mean the non-existence of an effect.

Rather than doing multiple comparisons looking for all possible differences among the pairs of yea/locations/bank combinations, focus in on interesting comparisons – typically among locations only.

x) Section 5.3.2.2 Results

Figures 5.13 and 5.16 look strange. The two PCs are supposed to be orthogonal to each other by the method of construction, yet the plots appear t show a distinct relationship between the two components?

5.3.3.1 Temporal trends

The requirement to expand sampling to 6 years only looks at the minimum technical requirement – it doesn't consider the actual size of the trend. While the Mann-Kendall test is "non-parametric" and only uses the relative magnitudes of the data points, its performance does indeed depend upon the actual slope of the line and the residual variation. For example, a very strong slope with small variation would imply that a monotone pattern in the points would occur often, while the same slope with a large residual variation would be less likely to have a monotone trend. An example of this is seen in Figure 5.20 of the report. Consequently, a proper power analysis would examine various combinations of effects, for example what is the chance of detecting an average 10% decline over 5 years under the variation seen in the data collected so far. The recommendation in the report that six years of data need to be collected is too simplistic.

The recommendation of accelerated sampling is pseudo-replication and is not recommended. As the report indicates, taking all samples within a single year makes no sense.

y) 5.3.3.2 Spatial Trends

Treating the east/west bank as replicates is likely fine for examining location differences within a particular year, but cannot serve as replicates for differences among years. Refer to initial discussion about experimental design for some of the perils of this recommendation.

z) 5.3.3.2 Spatial Trends – Results and Discussion

The discussion of the relative sources of variation is confusing because the ANOVA model that the report used lumps all variation into one term. There are several sources of variation – not all of which are important for detecting each type of difference. The comments about increasing sample size leading to decreased in error term in the ANOVA are wrong – increasing effort does not lead to a reduction in the various components of variance – it does lead to improved precision.

The recommendation about increasing sampling effort in to detect difference at Donald Creek need careful review to ensure that the proposed sampling design match the principles of good experimental design as outlined in the introduction.

Section 5.5.3.3.
Recommendations on increasing sampling effort in baseline are simplistic and based only on minimum technical requirements to do the computations – a proper power analysis needs to be done.

3.5 Chapter 6 Comments:

Much of the conclusions in this section are limited by the small number of years of data collected (usually 2 or fewer). The report also makes a very valid point that without reference streams that are not subject to impact, it is impossible to separate temporal effects from impact effects.

Section 6.1.1 (page 6-25)
"Individual samples collected from the same site do not represent replicates in the statistical sense because they are not independent. Widely-spaced samples from a reach (each sample representing a site) were used as replicates to compare reaches." Exactly the point made in the introduction to this report. The proposed design as listed on the bottom of page 6-5 is exactly the type of description of sampling plans needed in the other chapters of the report.

Section 6.1.3.3.
"Sampling designs have changed over time; for example, historical data and 1998 RAMP data were collected at individual sites with closely spaced replicate samples, whereas subsequent RAMP surveys concentrated on several km long reaches, with single replicates at each site." This again illustrates the need for very well documented data files so that later researchers can see exactly how survey were conducted.

(1) Section 6.2.1.1

The Principal Component analysis was done on the covariance matrix rather than the correlation matrix. Unfortunately, using the covariance matrix implies that the principal components are highly influenced by very abundant species as these are often the most variable as well. In most cases when the covariance matrix is used, the first principal component will simply be related to total abundance and is not very informative, i.e. in sites where there are lots of invertebrates, all taxa have higher abundances compared to places where abundances are lower. As well, basing results on the covariance matrix implies the results are not unit-independent, i.e. expressing densities on a different scale could change the results. A PCA on the correlation matrix is recommended.

aa) Section 6.2.1.2

As expected because the covariance matrix was used in the PCA analysis, the first component is essentially total abundance. The second component measures contrasts among three taxa.

bb) Section 6.3.1.3 – Appropriateness of study design

Report is quite correct that some reference rivers are needed in order to separate temporal trend from environmental impact trends.

cc) Section 6.3.1.4 – Conclusions and recommendations

The assertion by the authors that detecting temporal trends requires sampling a fixed locations is not correct. It is true that fixed monitoring stations often have a greater power to detect temporal changes, but sampling designs with new stations at each time point can also detect changes.

dd) Section 6.3.2.4 – Appropriateness of study design

“Representativeness” is induced by random sampling. Just because the distibution of a species is patchy, does not imply that a single sample is not “representative”. I suspect that the authors meant that small sample sizes imply that results are extremely imprecise, i.e. have a large confidence interval.

The recommendation to reduce sampling costs by reducing the number of sites measured but increasing the sub-samples per site needs further investigation. In particular, some sub-sampling should be done to see the relative sizes of the within-site and among-site variations so that an “optimal” allocation of effort across sites and within sites can be determined. The current data does not provide sufficient information to make this assessment.

ee) Section 6.3.2.5 – Conclusions and Recommendations

In general I concur with the suggestions, but some additional data needs to be collected before committing to a long term change in the number of sites measured. What is needed is some sub-sampling at the sites to establish the within-site and among-site ratio of variation.

3.6 Chapter 7 comments

Nothing much can be done with this part of the study because of the many one-off studies conducted over the years. There is a need to standardize what will be done over the next few years.

ff) Section 7.2.1.1.- Methods

The authors compared length-frequency distribution using a repeated measures design and a non-parametric method (Page 7-13) based on classifying the data into length classes. A more direct and more appropriate analysis would use the raw data and to compare the cumulative frequency distributions using a Kolmogorov-Smirnov test or to use the binned data and use a log-linear model or chi-square test.

Figure 7.8 and similar figures. Plot the log(weight) on the Y axis; show all the data with the fitted lines for each year/season as needed. See for example, Figure 7.44 which is close, but it would nice to see the data points as well.

No mention was made of the formal analysis of fish health – but this is straight forward and is easily done using logistic regression (for percent of abnormalities) or ANOVA for the external pathology index

4. SUMMARY RECOMMENDATIONS

1. **Ensure adequate replication**. All future monitoring plans should be reviewed to ensure that real replicates will be available so that the proper statistical comparisons can be made with a minimum of untestable assumptions.

2. **Review existing analyses for pseudo-replication.** Existing analyses should be reviewed to ensure that pseudo-replicates have not been used in place of the real replicates. This will impact the reported power analyses as well.

3. **Match analysis with design.** Existing analyses should be reviewed to ensure that the model used is appropriate for the statistical design. When future studies are proposed, a "mock" analysis plan should be provided to ensure that correct model will be used in the analysis.

4. **Improve reporting of results.** Decrease the use of hypothesis testing and increase the use of confidence intervals in reporting results. As part of the report, the results should be placed in context of biologically important effects. For example, graphs similar to Figure 6 found in Steidhl et al (1977) would be very useful in interpreting the results of the report:

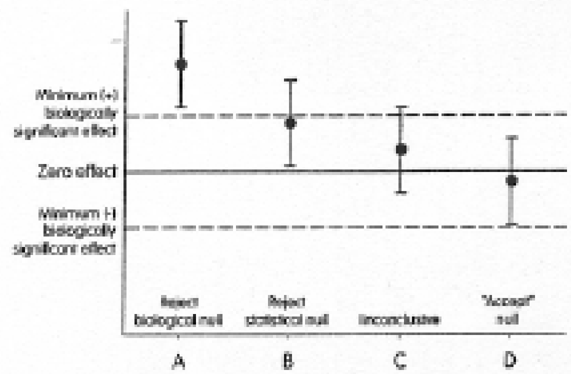


Fig. 6. Hypothetical observed effects (circles) and their associated 100(1 − α)% confidence intervals. The solid line represents zero effect and dashed lines represent minimum biologically significant effects. In case A, the confidence interval for the estimated effect excludes zero effect and includes only biologically significant effects, so the study is both statistically and biologically significant. In case B, the confidence interval excludes zero effect, so the study is statistically significant; however, the confidence interval also includes values below those thought to be biologically significant, so the study is inconclusive biologically. In case C, the confidence interval includes zero effect and biologically significant effects, so the study is both statistically and biologically inconclusive. In case D, the confidence interval includes zero effect but excludes all effects considered biologically significant, so the "practical" null hypothesis of no biologically significant effect can be accepted with 100(1 − α)% confidence.

5. **Data handing issues**. In any long term study, data storage and availability is a crucial issue. This is particularly true if contractors change during a project. Data should be available in electronic format to all interested participants. RAMP should consider setting up a separate long-term data storage/management facility whose duties would be to serve as data manager, archiver, and provider. Ideally, data could be served to interested parties using a WWW server. For example, a university could serve as a contractor. This was partially discussed in the RAMP Program Design document in the supplementary material.

6. **Consider panel designs for ongoing monitoring.** These design combine the best features of fixed and random monitoring stations.

5. REFERENCES:

Burnham, K. P. and Anderson, D. R. (2002). Model selection and inference: a practical information-theoretic approach. New York: Springer Verlag.

Cherry, S. (1998) Statistical tests in publication of the Wildlife Society Wildlife Society Bulletin, 26, 947-954.

Hurlbert, S. H. (1984). Pseudo-replication and the design of ecological field experiments. Ecological Monographs 54, 187-211.

Johnson, D. H. (1999) The Insignificance of Statistical Significance Testing. Journal of Wildlife Management, 63, 763-772.

Morrison, M. L., Block, W. M., Strickland, M .D. and Kendall, W. L. (2001). Wildlife study designs. Springer: New York.

Steidl, R. J., Hayes, J. P., and Shauber, E. (1997). Statistical power analysis in wildlife research. Journal of Wildlife Management 61, 270-279.

Weins, J. A., and Parker, K. R. (1995). Analyzing the effects of accidental environmental impacts: approaches and assumptions. Ecological Applications, 5, 1069-1083.

APPENDIX A TO BIOSTATISTICS REPORT
COMMENTS ABOUT THE INTERIM REPORTS

A less detailed review of the interim reports was conducted as many of the reports are simple data summaries with the multi-year analysis deferred to the Five-Year report reviewed above. The 1999 report has many good features in its use of statistics. It could serve as a model for all the other reports.

A.1 1997 Report

Some real replication occurred:
There appears to be some replicate sampling for some the data collected. For example, in Water Quality testing, multiple samples were taken on either bank etc. From the data in Table 3.1, the variation among samples within the same site seems to nearly as large as the variation among sites. This highlights the importance of real replication during the sampling protocols. The information from this Table may be useful in determining how many replicate samples will be needed for future studies.

Incorrect distinction between standard error and standard deviation:
Section 3.47 Standard Error and Standard Deviation

> "Standard error (SE) and standard dev**i**ation (SD) both express the var**i**ab**il**ity of resu**l**ts around the mean. However, standard error takes the sample size into consideration when calculated. By including sample size, SE gives an indication of how well we've measured the entire population. This is particularly true if you have very different sample sizes for the groups you are comparing; the larger the sample size, the more confidence you have that the data represents the popu**l**at**i**on. Standard error is calculated as: S**E=**SD + 5/11;where n**=**sample s**i**ze. M**i**crosoft Exce**l** will calcu**l**ate SD automatically. In order to calculate SE the formula in Excel would be " =StDev(cells with data)/(sample size)^0.5 ". The "A.05" denotes square root (by asking excel to calculate to the power of 0.5). Standard error **i**s now considered to be the appropriate measure to use in any technical presentation of data and should be used in any figures or tables of fish population statistics."

This is mostly incorrect. Standard deviations measure the variation of individual measurements around the mean. Standard errors measure the precision of an estimate. [Technically, the standard error of an estimate measures the variation of the estimate if repeated samples of the same size were taken from the population.]

The formula quoted above is ONLY valid for the standard error of a mean collected under a simple random sample. It is NOT valid for other estimates nor for other designs. However, it is possible to compute a standard error for other estimates and for other designs.

Standard deviation should be used when variation of individuals values is to be highlighted. Standard error is to be used when the estimate of the underlying population parameter (e.g. the population mean) is to be highlighted.

A.2 1998 Report

gg) Section 3.1.1.2 Field Methods for water and sediment quality – some real replication?

Figure 3-1 indicates that for the most part there was no real replicate sampling, but at the very top site (on the map), there may be real replication.

hh) Section 3.2.2 Benthic Invertebrates field methods – some real replication?

Some replication done here?

Section 4.2, Table 4-8 – illustration of dangers of p-values.
This is an illustration of one of the “dangers” of p-values. The p-values reported here are for a test that the slope of the size at age curve is zero. Yet, this is a silly hypothesis because it known to be false and not biologically interesting. It would be much more informative to report confidence intervals for the slopes and intercepts.

Similarly, in the discussion of the comparison of results between 1997 and 1998 (page 4-11), it was stated that the intercepts were “significantly different”, yet no value was given for the estimated difference along with a standard error. If the estimated difference was .001 with a se of .0001, who cares? Table 4-9 is much more informative and should be the standard way of presenting such results.

In graphs similar to Figure 4-5, the Y axis should be in relative frequency (e.g. %) rather than absolute frequency.

Figure 4-12, please show the raw data as well so that it can be seen if the observed change in the regression line is “caused” by a few anomalous fish.

A.3 1999 Report

ii) Section 3.1.2.2 – Good practice for multiple comparisons

“To control experiment-wise error, a significance level of p=0.017 (i.e., £\/no. of comparisons, 0.05/3) rather than p=0.05 was used (i.e., Bonferroni’s adjustment).”

This is a good practise that should be extended to the other reports. This report also has a good discussion of power analysis and biologically meaningful difference.

This report presented statistical issues well and did power analysis well. It should serve as a model for future reports.

A.4 2000 Report

jj) Table 4.7 – some information on real replicates variation?

Table 4.7. Here is some information on local variation of sediment values among replicate stations. I disagree with the conclusion that the variation is small – it looks rather alarmingly large often varying ±50% of the mean value! This information should be used to establish the number of replicates needed at individual sites for future sampling plans.

A.5 2001 Report v. 1

kk) Misunderstanding about the use of the arcsine transformation

Page 3-52. Misunderstanding about the use of the arsine transformation – not necessary for compositional data such as LSI or GSI. The arcsine transformation is only appropriate for proportions that are derived from counts of discrete objects, e.g. what proportion of fish have lesions, where the binomial distribution is the underlying description of the data. Compositional data does not follow a binomial distribution and so the use of this transformation is inappropriate.

Misunderstanding of the Kruskal-Wallis test.
Page 3-65.

> "The Kruskal-Wallis test is used instead of Analysis of Variance when samples do not come from normal populations, are heterogeneous or do not have equal numbers of data in each group (Zar 1999). The Kruskal-Wallis test was the appropriate test to use for RAMP since different lakes were sampled using varying numbers of transects and plots. The test was applied to identify significant differences between the lakes for vegetation groups, species, and water chemistry."

This is not correct. Non-parametric tests, despite their name, also have assumptions. For example, they assume equal variances in all groups. It is not necessary to use the KW test if sample sizes are unequal in groups, and it is not appropriate if the variances are heterogeneous. They also require the same attention to matching design and analysis, i.e. the KW test assumes a single factor completely randomized design. Designs with transects and plot within transects are NOT completely randomized designs, and consequently should not be analyzed using a KW test, nor with a single-factor CRD ANOVA.

A.6 Ramp Program Design and Rationale1

Section 4.2 Sediment sampling – compositing vs real replicates.

Page 4-5 .

> "At each sample site, except upstream of Fort McMurray and upstream of the Embarras River, one composite sample will be prepared every fall by combining 4 to 6 grab samples collected from depositional areas located between the east river bank and 25% of the river width (Table 4-1). The process will then be repeated between the west river bank and 25% of the river width."

The compositing is fine as the replicates samples within a small physical area in the sample size are pseudo-replicates, but there is no real replication at the sample locations. I would also take some real replicates (see my earlier report) at some sites, i.e. move 200 m upstream or downstream, to identify the actual within site variability.

Need for real replication:
Table 4-3 needs to be expanded to indicate how many real replicates will be gathered – at the moment, only a single replicate is gathered at each sampling location.

ll) Reallocation of resources from split/duplicate samples?

In the QA/QC the program is willing to spend some money on split-samples. Perhaps divert some of this money to real replication.

How was it known that three samples composited will be enough?

mm) Section 5.1.2 Benthic sampling – real replication used, but better rationale needed

Here the necessity for real replication is explained. Why were 15 samples taken – what is the rationale for this?

nn) Section 6.1.1.2 Fish Inventory – Dangers of CPUE as adundance measure

> "Species distribution, composition and relative abundance (i.e., catch per uniteffort) will be recorded."

CPUE to measure abundance is notorious poor because of changing gear, changes in catch efficiency over time, difficulty in standardizing etc. I suspect a better measure of impact would be fish health indices, composition (young vs old), and length-frequency shifts.

oo) Section 6.1.2.2 Mackay River Fish Inventory – more rationale needed about tagging

Fish are to be tagged, but sampling will be done very three years? Who will return tags that hare added? Will the tags last three years?

pp)Section 6.3.1.1.Muskeg River radiotelemetry – unclear purpose?

What information will be gained by this monitoring?

Section 6.3.4 Database development for RAMP Fisheries – need for implementation

This is a major issue for all components of the RAMP program – how will data be stored, accessed, and protected during the life of the monitoring program? This is covered in Appendix 1 with a power point presentation on the FWIS – is this available to RAMP?

Section 7 – Vegetation surveys –cluster/two stage sampling

Many of the vegetation surveys have implemented real replication, but subsequent analyzes need to take into account the cluster/two-stage sampling design:

"In 2001, 11 plots were located on 6-transects with approximately two plots per transect." (Shipyard Lake study).

Section 7.1.1.5 Reference wetlands – panel design should be considered?

Good that at least two reference wetlands are being measured. The report mentions the possibility of bringing in new lakes if problem sarise with the control lake – try and get as much advance notice as possible of this. Perhaps plan for a panel design from the start.

Section 8 – Gradient exposure designs.

Sampling plan is appropriate with a gradient in exposure and spatial controls that will not be exposed. If the oil sands expands, will the gradient in exposure change over time? This was an issue for the TEEM monitoring project where the expansion of the oilsands has exposed many of the "control" sites to deposition.

Appendix IV. Oil Sands Regional Aquatic Monitoring Program (RAMP): Scientific Peer Review of the Five Year Report (1997-2001): Reviews of Individual RAMP Components.

TABLE OF CONTENTS OF APPENDIX IV

For the convenience of readers Appendix IV has been separated into seven electronic files: one for each component. The files are named "2004 RAMP review- hydrology template.doc, 2004 RAMP review-sediment quality template.doc... etc.". Each electronic file includes the Introduction and template description sections followed by the component report following the prescribed template.

Appendix XVII:

Alberta Energy and Utilities Board and Canadian Environmental Assessment Agency, “Report of the Joint Review Panel ... Decision 2004–005: Canadian Natural Resources Limited, Application for an Oil Sands Mine, Bitumen Extraction Plant, and Bitumen Upgrading Plant in the Fort McMurray Area” (EUB/CEAA, 2004)

Joint Panel Report
EUB Decision 2004-005

Canadian Natural Resources Limited

Application for an Oil Sands Mine, Bitumen Extraction Plant, and Bitumen Upgrading Plant in the Fort McMurray Area

January 27, 2004

Joint Review Panel Established by the Alberta Energy and Utilities Board and the Government of Canada

REPORT OF THE JOINT REVIEW PANEL ESTABLISHED BY THE ALBERTA ENERGY AND UTILITIES BOARD AND THE GOVERNMENT OF CANADA
EUB Decision 2004-005: Canadian Natural Resources Limited, Application for an Oil Sands Mine, Bitumen Extraction Plant, and Bitumen Upgrading Plant in the Fort McMurray Area
January 27, 2004

Published by

Alberta Energy and Utilities Board
640 – 5 Avenue SW
Calgary, Alberta
T2P 3G4
Telephone: (403) 297-8311
Fax: (403) 297-7040
Web site: www.eub.gov.ab.ca

and

Canadian Environmental Assessment Agency
200 Sacré-Coeur Blvd.
Gatineau, Quebec K1A 0H3
Tel.: 819-997-1000
Fax: 819-994-1469
Web site: www.ceaa-acee.gc.ca

CONTENTS

EXECUTIVE SUMMARY

Canadian Natural Resources Limited (CNRL) filed Application No. 1273113 with the Alberta Energy and Utilities Board (EUB), pursuant to Sections 10 and 11 of the Oil Sands Conservation Act, for approval for an oil sands mine, a bitumen extraction plant, and a bitumen upgrader and associated facilities. The project, designed to produce approximately 37 000 cubic metres per day of upgraded bitumen product, would be located approximately 70 kilometres north of Fort McMurray. Project construction would commence in 2004, with initial production in 2007 and full production by 2011.

The project required an environmental assessment under the Canadian Environmental Assessment Act (CEAA). On June 26, 2003, the federal Minister of Fisheries and Oceans referred the environmental assessment of the project to a review panel. On August 18, 2003, Canada and the EUB entered into an agreement to establish a joint environmental assessment panel (the Panel) for the project. Under the agreement, the Panel was charged with fulfilling the review requirements of both CEAA and the Energy Resources Conservation Act (ERCA).

The Panel considered Application No. 1273113 at a public hearing held in Fort McMurray, Alberta, during September 15-19, 22-26, and 29, 2003. Participants who provided evidence at the hearing included CNRL and other oil sands developers, First Nations and local aboriginal groups, local residents, nongovernment environmental groups, a local medical staff association, and representatives from both provincial and federal regulatory agencies. While participants raised a number of issues for the Panel to consider, most issues centred on the environmental impacts of the project and the socioeconomic impacts of rapid industrial development.

Having regard for its responsibilities under ERCA and CEAA, the Panel carefully considered all of the evidence pertaining to Application No. 1273113. The Panel finds that CNRL's project is in the public interest and the Panel is prepared, subject to the approval of the Lieutenant Governor in Council, to approve Application No. 1273113. Furthermore, the Panel concludes that the project is unlikely to result in significant adverse environmental effects, provided that the mitigation measures proposed by CNRL and the recommendations of the Panel are implemented.

In approving Application No. 1273113, the Panel set out conditions relating to mining operations, resource conservation, and tailings management. In addition, the Panel also made recommendations to the federal and provincial governments that would aid in the mitigation of the environmental effects of the project and in the need for follow-up measures.

This executive summary is provided for the benefit of the reader and does not form part of the report. All persons making use of the executive summary are reminded that the report should be consulted for all purposes relating to the interpretation and application of the Panel's views.

HORIZON OIL SANDS PROJECT JOINT REVIEW PANEL
Calgary Alberta

CANADIAN NATURAL RESOURCES LIMITED
APPLICATION FOR AN OIL SANDS MINE,
BITUMEN EXTRACTION PLANT, AND
BITUMEN UPGRADING PLANT **Decision 2004-005**
IN THE FORT MCMURRAY AREA **Application No. 1273113**

1 DECISION AND RECOMMENDATIONS TO CANADA AND ALBERTA

Having regard for its responsibilities under the Energy Resources Conservation Act (ERCA) and the Canadian Environmental Assessment Act (CEAA), the joint Canada and Alberta Energy and Utilities Board (EUB/Board) review panel (the Panel) has carefully considered all of the evidence pertaining to the application and finds that Canadian Natural Resources Limited's (CNRL's) project is in the public interest for the reasons set out in this report. Therefore, under its mandate through the EUB, the Panel is prepared, subject to the approval of the Lieutenant Governor in Council, to approve Application No. 1273113. The Panel's approval is subject to the conditions listed in Appendix 1. The Panel expects that CNRL will adhere to all commitments it made during the consultation process, in the application, and at the hearing to the extent that those commitments do not conflict with the terms of any approval or licence affecting the project or any law, regulation, or similar requirement CNRL is bound to observe.

With regard to its responsibilities as set out under CEAA and to the Panel's terms of reference, the Panel concludes that the project is unlikely to result in significant adverse environmental effects, provided that the mitigation measures proposed by CNRL and the recommendations of the Panel are implemented.

The Panel recommends to Canada that

- the Department of Fisheries and Oceans (DFO) require CNRL to gather additional hydrologic data and to verify the predictions of its hydrologic model (Section 13.10);
- DFO assess the need to integrate the findings of the Instream Flow Needs (IFN) subgroup of the Cumulative Environmental Management Association (CEMA) into its authorizations (Section 13.10);
- DFO, in cooperation with Alberta Environment (AENV), establish an IFN for the Athabasca River in the event that CEMA is unable to do so by the end of 2005 (Section 13.10);
- DFO require CNRL to develop and implement a comprehensive surface water quality and sediment quality monitoring program (Section 14.6);
- DFO require CNRL to share monitoring results of its compensation lake with other stakeholders in the region (Section 15.6);
- DFO require CNRL, in consultation with Environment Canada (EC), to develop and implement a comprehensive fish-monitoring program (Section 15.6);

- DFO require CNRL to conduct follow-up studies on potential impacts of fish tainting compounds from the project on relevant fish species (Section 15.6);
- Health Canada (HC), in cooperation with Alberta Health and Wellness (AHW), consider undertaking a regional health study primarily dealing with First Nations, Metis, and other aboriginal people (Section 18.6); and
- EC and DFO review and optimize their financial and human resourcing of CEMA with a view to produce results in an earlier time frame (Section 20.6).

The Panel recommends to Alberta that

- AENV invite all interested stakeholders to participate in the process of assessing the need for a regional groundwater resource characterization initiative (Section 12.7);
- AENV's Dam Safety Branch require CNRL to include updated seepage modelling results, Quaternary deposits mapping, groundwater monitoring plans, and mitigation measures as part of the external tailings area (ETA) detailed design report (Section 12.7);
- AENV consider the involvement of stakeholders, in particular EC, in the design and implementation of CNRL's groundwater monitoring program (Section 12.7);
- AENV require CNRL to gather additional hydrologic data and to verify predictions of its hydrologic model (Section 13.10);
- AENV, in cooperation with DFO, establish an IFN for the Athabasca River in the event that CEMA is unable to do so by the end of 2005 (Section 13.10);
- AENV assess the need to integrate the findings of the IFN subgroup of CEMA into its authorizations (Section 13.10);
- AENV require CNRL to monitor for the effects of acid deposition in regional water bodies (Section 14.6);
- AENV require CNRL to develop and implement a comprehensive surface water quality and sediment quality monitoring program (Section 14.6);
- AENV and Alberta Sustainable Resource Development (ASRD) require CNRL to conduct follow-up studies on potential impacts of fish tainting compounds on relevant fish species (Section 15.6);
- AENV and ASRD require CNRL, in consultation with EC, to develop and implement a comprehensive fish-monitoring program (Section 15.6);
- ASRD and AENV identify wetlands research as a priority for CEMA to address and consider requiring CNRL to develop and initiate a program to facilitate wetlands restoration (Section 16.1.6);
- AENV and ASRD include EC in their discussions with CNRL to determine acceptable monitoring and mitigation requirements for wildlife (Section 16.2.5);
- AENV and ASRD consider setting or developing performance measures for progressive reclamation (Section 16.4.5);
- AENV monitor EPL development and testing (Section 16.5.5);

- AENV limit long-term (quarter-year or annual average) sulphur dioxide (SO_2) emissions to levels that correspond with 99.2 per cent sulphur recovery at full calendar-day production rates (Section 17.5);
- AHW, in cooperation with HC, consider undertaking a regional health study primarily dealing with First Nations, Metis, and other aboriginal people (Section 18.6);
- AENV and ASRD provide stakeholders with an update on their expectations of RSDS, its deliverables, and the timing of those deliverables (Section 20.6);
- AENV and ASRD review and optimize their financial and human resourcing of CEMA to produce results in an earlier time frame (Section 20.6); and
- in addition to establishing an IFN for the Athabasca River in cooperation with DFO (Section 13.10), AENV develop and implement environmental management plans and objectives in the event that CEMA is unable to meet its timelines (Section 20.6).

2 INTRODUCTION

2.1 Application

CNRL filed Application No. 1273113 with the EUB, pursuant to Sections 10 and 11 of the Oil Sands Conservation Act (OSCA), for an oil sands mine, a bitumen extraction plant, and a bitumen upgrader and associated facilities in the Fort McMurray area. The project would also receive third-party oil sands material (mined ore or intermediate process streams, such as bitumen) for processing at its site and produce and ship oil sands material (mined ore or intermediate process streams, such as bitumen) from its site for processing at third-party facilities. In support of its proposal and as part of its application to the EUB, CNRL also submitted an environmental impact assessment (EIA) report to the Director of the Regulatory Assurance Division, Alberta Environment, pursuant to the Environmental Protection Enhancement Act (EPEA).

The proposed project is to be located approximately 70 kilometres (km) north of Fort McMurray in Townships 96 and 97, Ranges 11 to 13, West of the 4th Meridian. The project would be located on CNRL’s leases, with sufficient resources to support mining activities for 42 years. Figure 1 shows the project location.

The project would be developed in three phases, as shown in Table 1.

Table 1. Development schedule and estimated capital costs

		Production rate (m^3/cd)		Capital expenditure
	Year	Upgraded oil	Bitumen	(billion $)
Phase I	2007	18 000	21 500	4.9
Phase II	2009	24 600	28 600	1.7
Phase III	2011	37 000	42 900	1.4
Total				8.0

The project includes the planning, construction, and operation of the following major oil sands facilities:

- shovel-truck mine to provide ore to support a bitumen production capacity of 42 900 cubic metres per calendar day (m^3/cd);
- relocatable ore preparation plants, using crushers and slurry hydrotransport;
- bitumen recovery plant, using primary separation cells and secondary and tertiary flotation;
- bitumen cleaning plant and associated environmental units;
- tailings pumping plant with coarse sand cyclones and fine tailings thickeners;
- tailings pond system for coarse sand tailings and thickened fine tailings impoundment, water inventory, and recycling;
- bitumen upgrader, using delayed coking and hydrotreating to produce an upgraded oil product and sulphur and coke by-products;
- on-site energy services infrastructure to generate electricity and steam, treat and recycle water, and provide potable water and sanitary sewage;
- road access and facilities to transport electric power, natural gas, and upgraded oil products;
- water requirements, including water intake facilities on the Athabasca River;
- storage facilities for diluted bitumen and intermediate and upgraded oil; and
- on-site infrastructure, including an air strip, offices, warehouses, security and loss prevention, health and safety, labs, fire hall, land fill, and hazardous waste storage.

The project also includes

- plans to manage, control, and mitigate environmental impacts during construction and operation of all facilities;
- a comprehensive mine drainage plan to intercept water that would flow onto the mine area from undisturbed areas (run-on water) and to collect run-off water in disturbed areas;
- management plans for all tailings produced by bitumen recovery and cleaning plants;
- management plans for all waste products produced by the project;
- a life-cycle water management plan;
- a closure plan and a ten-year conservation and reclamation (C&R) plan;
- initial and ongoing consultations with stakeholders on the social, economic, and environmental impacts of the project; and
- a number of bilateral agreements with stakeholders.

2.2 Canada/Alberta Joint Panel Review Process

CNRL also applied to DFO for approval under Section 35(2) of the Fisheries Act for the alteration, disruption, or destruction of fish habitat. Prior to DFO issuing an authorization, an environmental assessment of the project under CEAA was required.

On June 26, 2003, the Honourable Robert Thibeault, Minister of Fisheries and Oceans, referred the environmental assessment of the project to a review panel, pursuant to Section 21(b) of CEAA.

On July 30, 2003, the Canadian Environmental Assessment Agency announced that it was proposing to establish a joint environmental assessment panel for the project. Following a 21-day public comment period, The Honourable David Anderson, Minister of the Environment, and Neil McCrank, Q.C., Chairman of the EUB, signed an agreement to establish the Panel. The agreement is included as Appendix 2.

Under the agreement, the Panel is charged with fulfilling the review requirements under both CEAA and ERCA. Under ERCA, the Panel must determine whether the project is in the public interest. In making this determination, the Panel is required to consider a range of factors, including resource conservation, safety, economic and social impacts of the project, and effects on the environment.

Under its CEAA mandate, the Panel must assess the environmental effects of the project, including the environmental effects of malfunctions or accidents that could occur in connection with the project and any cumulative environmental effects that would likely result from the project in combination with other projects or activities that have been or would be carried out.

Under its CEAA mandate, the Panel must also determine the significance of the environmental effects of the project. In examining whether any potential adverse effects associated with the project were significant, the Panel considered their

- magnitude,
- geographic extent,
- duration and frequency,
- degree to which they are reversible or irreversible, and
- ecological context.

Under its CEAA mandate, the Panel must also consider whether there were technically and economically feasible measures that would mitigate any significant adverse environmental effects of the project.

This report sets out the Panel's decision and its reasons, rationale, conclusions, and recommendations with respect to its review of the project under ERCA and CEAA, and it includes a discussion of recommended mitigation measures and follow-up programs. The report also provides a summary of comments received from the public.

2.3 Hearing

The Panel consisted of J. D. Dilay, P.Eng. (Presiding Member), R. Houlihan, P.Eng., Ph.D., and G. Kupfer, Ph.D. The Panel considered the application at a public hearing held in Fort McMurray, Alberta, during September 15-19, 22-26, and 29, 2003. Accordingly, the Panel considers that the record was completed on October 16, 2003.

Those who appeared at the hearing and the abbreviations used in this report are set out in Appendix 3.

2.4 Submission of MEC

The Marlboro Environmental Committee (MEC) made a presentation at the hearing respecting the operations of certain facilities of Rio Alto Exploration Ltd. near Edson, Alberta, that were subsequently taken over by CNRL. MEC stated that it had no comments relating to the EIA or the project.

The Panel believes that MEC's issues are not related to the project and, therefore, the Panel does not deal with those issues further in this report. It has referred MEC's issues to AENV and the EUB's Field Surveillance staff to be dealt with as an operational matter.

3 ISSUES

The Panel considers the issues respecting the applications to be

- purpose, need, and alternatives to the project,
- adequacy of environmental impact assessment and need for follow-up,
- resource recovery,
- tailings management,
- environmental effects (water, terrestrial, and air),
- health effects,
- measures to enhance beneficial environmental effects,
- regional initiatives,
- social and economic effects,
- public consultation,
- capacity of renewable resources, and
- traditional use and cultural resources.

The following sections of the report summarize the evidence of CNRL and the interveners and provide the Panel's assessment of the issues. If CNRL or an intervener expressed no views on a particular issue, there is no corresponding section for that party provided in the report.

4 PURPOSE, NEED, AND ALTERNATIVES TO THE PROJECT

4.1 Views of CNRL

CNRL indicated that the purpose of the project was to produce oil at a competitive cost in an environmentally friendly manner and to provide wealth and an enhanced standard of living for the communities in which CNRL would be operating.

CNRL concluded that the orderly and economic development of its Athabasca oil sands resources through the project was a significant component of the company's growth strategy. It stated that the vastness of the resource, demonstrated extraction technology, and proven economics provided an attractive, long-term opportunity for sustained production. In addition to access to significant oil sands resources, CNRL indicated that it had the financial and human resources to undertake a project of this magnitude. CNRL stated that investment in the Athabasca oil sands was in the public interest. It believed that the project would offset declines in conventional oil production and help secure North America's energy resources for many years to come.

CNRL concluded that its schedule and implementation plan balanced many factors that would contribute to the success of the project. These factors included financing, market development, risk management, technology assembly, construction manpower, material availability, and operation staffing. To facilitate successful implementation, CNRL stated that it developed a phased approach that would lead to full production capacity over a period of nine years.

CNRL stated that it chose the project mine area for the following reasons:

- The area had a large, continuous ore body capable of supporting mine production at a level high enough to provide economies of scale.
- Its mining leases to the north and south could be developed as satellite mines without the need to replicate plant infrastructure.
- The area had adjoining in situ reserves for future development potential.

CNRL also used the following criteria to determine whether a particular oil sands mining, bitumen extraction, or bitumen upgrading technology would be considered:

- minimal environmental impact,
- contribution to an acceptable investment rate of return,
- confidence that technology would be commercially proven by 2003,
- compatible with the oil sands deposit, and
- reliable all-season performance.

CNRL determined that both dredging and hydraulic mining alternatives were highly inefficient in winter operations. CNRL was also concerned about bitumen recovery due to ore dilution from reduced mining selectivity. Therefore, CNRL did not evaluate these technologies further. It also eliminated underground and bucketwheel technologies from its consideration. It maintained that underground methods could not be proven by 2003 and considered bucketwheel systems to be too complex.

CNRL deemed dragline technologies unsuitable because the depth and thickness of ore zones at the project mine precluded adequate in-pit overburden casting. It was also concerned about slope stability.

CNRL considered shovel-truck technologies and rated them as comparable to other technologies but different in their merits. Conventional shovel-truck mining offered the best mine plan flexibility, least technical risk, and highest tailings adaptability, but rated lower on labour, energy intensity, and economics. CNRL indicated that technologies other than shovel-truck offered moderate technical risk with better energy use and lower labour intensity and that the potential for an autonomous shovel-truck system to reduce labour intensity was appealing. CNRL also indicated that continuous mining system combinations that were flexible and mobile and that preconditioned oil sands also had appeal.

CNRL selected shovel-truck with relocatable ore preparation plants as the mining method for the project.

With respect to Canadian oil reserves, including conventional, offshore, and heavy oil, CNRL stated that there were no direct alternative means of producing the project's oil except through oil sands mining and production. CNRL indicated that the bitumen ore would be most effectively and efficiently recovered through mining techniques. It stated that alternative bitumen recovery techniques, such as in situ methods, were far less efficient in recovery.

4.2 Views of the Panel

The Panel notes that no interveners argued against CNRL's stated need and purpose for carrying out the project. The Panel accepts CNRL's stated need and purpose and the criteria that CNRL used to evaluate the alternatives it identified. The Panel notes that the purpose and need for the project provide the context for the Panel's consideration of the alternatives to the project.

The project, as scoped by the signatories to the Panel agreement, is to construct and operate an oil sands surface mining, extraction, and upgrading facility. The Panel, having considered the alternatives to the project, concludes that sufficient information about the alternatives and CNRL's analysis of those alternatives has been provided and that the information supports CNRL's selection of the project.

5 ADEQUACY OF ENVIRONMENTAL IMPACT ASSESSMENT AND NEED FOR FOLLOW-UP

This section deals with intervener assertions that the assessment of the environmental impacts of the project was incomplete. Notwithstanding that other sections in this report deal with the specific concerns of interveners, this section summarizes the overall views.

5.1 Views of CNRL

CNRL stated that the EIA was prepared in accordance with the requirements prescribed under EPEA, OSCA, and any federal legislation that applied to the project. It completed the EIA in accordance with the terms of reference issued by AENV following requests for input from federal and provincial regulators, stakeholder groups, regional communities, and CNRL. Under the terms of reference, the EIA would

- identify the environmental resources potentially affected by the project;
- predict positive and negative impacts and the extent to which negative impacts could be mitigated;
- quantify and assess impact significance where possible;
- identify information sources;
- explain the selection of key components to be examined in the EIA and the influence of the consultative process in the selection; and

- describe the following for each environmental parameter:
  - existing baseline conditions,
  - the nature and significance of effects and impacts of the proposed project,
  - how biodiversity is addressed,
  - plans to eliminate, minimize, or mitigate negative effects and impacts,
  - residual impacts and their significance,
  - a plan to monitor effects and impacts and to demonstrate acceptable environmental performance, and
  - a plan to address those adverse impacts that require cooperative resolution by government, industry, and the community.

The EIA was also required to address the cumulative effects that were likely to result from the project in combination with other existing, approved, and planned projects or foreseeable activities in the region.

CNRL used two major study areas to assess the potential impacts of the project, the regional study area (RSA) and the local study area (LSA). CNRL indicated that the RSA was used to evaluate the impacts of the project in terms of the larger geographic and ecological contexts. CNRL used the LSA to evaluate areas directly impacted by the project. CNRL indicated that the spatial extent of the study areas varied for different EIA components.

CNRL stated that it based the temporal considerations for the EIA on the project description and included unique conditions that affected environmental components differently. For most project components, CNRL's impact analyses considered construction and operations together. Some of CNRL's EIA components, particularly the terrestrial components, examined the project under three temporal conditions: predevelopment, full development, and closure. For the terrestrial assessments, it defined closure as 80 years following reclamation.

CNRL noted that, although not explicitly included in the criteria, there would always be some uncertainty associated with the information, methods, and conclusions used in an EIA because of its predictive nature.

CNRL noted that AENV had confirmed in writing that its EIA was complete pursuant to Section 53 of EPEA.

5.2 Views of MCFN

With respect to the sections of the EIA that it had reviewed, the Mikisew Cree First Nation (MCFN) identified a number of gaps and uncertainties dealing with aquatic and terrestrial resources. In the area of water resources, these gaps related to baseline data quality, monitoring programs, modelling analysis, cumulative effects analysis, climate change, hydrogeology monitoring, and water quality analysis. In the area of terrestrial resources, these gaps related to cumulative footprints, monitoring, traditional knowledge, and vegetation sampling. MCFN requested that CNRL's approval be delayed or denied until the gaps in the EIA had been filled and the predictions, proposed mitigation, monitoring, and reclamation plans from a revised EIA had been reviewed and approved by the stakeholders, particularly MCFN and the EUB. Notwithstanding these gaps, MCFN outlined a number of recommendations dealing with social and environmental issues that it wanted implemented in the event that the project was approved. These recommendations are outlined in other sections of this report.

5.3 Views of Alberta

AENV stated that the EIA was complete, pursuant to Section 53 of EPEA. AENV stated that it did not expect an EIA to remove all uncertainties about a project. It noted that the provincial team's review of the EIA pointed to the need for additional data collection in some areas, environmental monitoring to assess the validity of predictions and identify potential impacts, and potential management programs. AENV stated that should the Panel recommend for approval CNRL's application and in the event that the project was approved under EPEA and the Water Act, there would be opportunity to require the collection of additional data before the project was constructed.

AENV stated that the inclusion of certain terms and conditions in its EPEA approval relating to data collection, monitoring, emission management programs, and additional validation of existing modelling of impacts could address the uncertainties and many of the concerns raised throughout the hearing process.

In its closing remarks, AENV stated that having regard for all of the information collected through its involvement in this project and its attendance at the hearing, it had no objection in principle to the proposed project provided that the Panel found the project to be in the public interest having regard to the social, economic, and environmental impacts; that the matters raised by Alberta were properly addressed; and that CNRL complied with all regulatory requirements of the Alberta departments.

5.4 Views of the Panel

Under CEAA, the Panel has a responsibility to conduct an assessment of the environmental effects of the project. In conducting this assessment, the Panel must ensure that all information required for its assessment is obtained and made available to the public. The Panel considered the spatial and temporal boundaries that CNRL used in its EIA and concludes that the boundaries are reasonable and reflect the ecological context of the project. The Panel has reviewed the EIA and the information brought forward during the hearing and concludes that it has the necessary information to conduct its assessment of the environmental effects of the project.

The Panel has also considered the need for and requirements of follow-up in the environmental assessment of the project. This need is discussed throughout this report in the appropriate sections. The specific areas of follow-up identified by the Panel include

- basal aquifer depressurization,
- tailings management,
- effects on fish and fish habitat,
- effects on water quality and quantity,
- effects on wildlife, and
- reclamation.

The Panel is of the view that the specific recommendations in this report should allow CNRL to further develop the follow-up programs early in the planning stages of the project, discuss them with the appropriate regulatory authorities and other stakeholders, and ensure their implementation. The Panel recommends that CNRL consult and work with appropriate stakeholders with specific expertise in the development of the follow-up programs.

Specific recommendations in this report related to follow-up programs provide a mechanism to ensure that the programs are sufficiently detailed and scientifically rigorous.

CNRL's follow-up programs should

- contain sufficient baseline information,
- be quantitative in nature and have statistical power,
- include a description of the mitigation to be implemented,
- include detailed descriptions of the monitoring methods, timing, and duration of the study,
- contain reporting and success measurement criteria,
- be developed in consultation with stakeholders having specific expertise or interests,
- ensure that consultation with the regulatory authorities has been carried out, and
- ensure that results are communicated to stakeholders.

6 ALTERNATIVE MEANS OF CARRYING OUT THE PROJECT

6.1 Views of CNRL

During the planning stages of the project, CNRL considered several alternative means of recovering the bitumen resource. In selecting the technology for the project, CNRL evaluated the cost, reliability, operability, maintainability, economic and energy conservation performance, and commercial readiness of components for each segment of the project.

With respect to surface mining alternatives, CNRL evaluated mine plans using several criteria, including environmental impacts, transportation logistics, and mine economics. In considering facility location alternatives, CNRL investigated several alternative locations for the plant site and external tailings pond. The location for the plant site was based on economics, resource conservation, environmental impacts, geotechnical conditions, and future expansion potential.

CNRL undertook a comprehensive selection process to identify appropriate bitumen extraction technologies. It stated that the process had to deliver equal or higher bitumen recovery for equivalent feed than existing oil sands facilities did and had to meet EUB guidelines.

CNRL examined many criteria to select the bitumen upgrading technology and concluded that the best option was to produce a fully upgraded product that was low in sulphur and would compete favourably with sweet conventional crude oils in its chosen market. From 83 initial alternatives for primary upgrading, including delayed coking, fluid coking, flexicoking, ebullated bed and slurry hydrocracking, and solvent deasphalting, CNRL chose delayed coking. It selected conventional hydrotreating for secondary upgrading and the Shell Claus Off-gas Treating

(SCOT) technology for sulphur recovery, based on minimization of emissions, overall reliability and cost, and compliance with the *Interim Directive (ID) 2001-3: Sulphur Recovery Guidelines for the Province of Alberta* of 98.8 per cent sulphur recovery.

CNRL investigated possible sources of raw water, including the Athabasca, Tar, and Calumet Rivers, groundwater, peatland drainage, and overburden dewatering.

The main criteria for selecting the water supply included reliable availability of water, sufficient water volume, acceptable water quality, minimal environmental impacts, and mitigation possibilities. CNRL stated that the Athabasca River was the only reliable source of sufficient quantities of raw water, and its proximity to the plant site made the river the most economical and reliable source for the project with the least impact on the environment. For these reasons, CNRL selected the Athabasca River as the primary source for the raw water supply.

For the water intake site, CNRL conducted an assessment of five alternative locations along the west bank of the Athabasca River. The main criteria CNRL used to select the intake site were availability of adequate water supply, channel section configuration and stability, long-term health and safety factors, proximity to the proposed plant site, regulatory requirements, and environmental impacts.

Following initial screening using historical air photos, CNRL conducted bathymetric and fish habitat surveys on three sites. It concluded that the mouth of the Tar River and Sutherland Island was the preferred site.

CNRL also evaluated seven conceptual river intake designs for this location on the river, with the main criteria for selecting the intake design being regulatory criteria and acceptability, engineering and technical performance, capital, operational, and maintenance costs, and environmental impacts. CNRL concluded that the bank intake noted above was the preferred river intake system.

CNRL considered eight alternative diversion plans for the Tar and Calumet Rivers. It assessed each alternative based on environmental, technical, and economic criteria, including minimizing losses of aquatic and terrestrial habitats, minimizing conflict with project processes, maximizing ease of operations, avoiding bitumen resource sterilization, and minimizing capital, operational, compensation, and closure expenditures. CNRL ranked impoundment of the Tar River the highest overall. CNRL stated that this alternative would provide fish habitat compensation at a lake, provide process water to the project, and divert upstream flows from the mining area so as to minimize ore sterilization.

6.2 Views of the Panel

The Panel concludes that CNRL has provided adequate information on alternative technologies and construction methods that are technically and economically feasible for the Panel to consider these alternative means and their environmental effects. The Panel accepts the shovel-truck mining, water-based bitumen extraction, and bitumen upgrading by delayed coking as the preferred alternative means of carrying out the project. The Panel accepts the need to divert portions of Tar and Calumet Rivers to access the reserves. The Panel believes that the CNRL mine plan and the location of the plant and waste disposal are necessary for resource recovery and consistent with good engineering and environmental management practices. The Panel also accepts that water is needed for the project and that the most suitable source is the Athabasca River.

7 MINE PLANNING AND RESOURCE RECOVERY

7.1 Lease Boundary Mining

7.1.1 Views of CNRL

CNRL indicated that the southeastern portion of the project's ore body extended onto the adjacent Deer Creek Energy Limited (DCEL) lease. CNRL stated that it had had discussions with DCEL over the past two years to develop plans for recovering resources along the southeast common lease boundary, but no formal agreement had been reached. CNRL further stated that it believed an agreement could be reached if project development were to proceed, and it committed to continuing discussions with DCEL.

CNRL stated that it had proposed to leave a pillar of oil sands of some 9.9 million cubic metres (10^6 m^3) of recoverable bitumen along the southeastern portion of the common lease boundary. This design would provide an additional 177 10^6 m^3 of in-pit tailings storage space and allow in-pit tailings operations to begin up to one year earlier, when compared to the base case of constructing a dike on CNRL's side of the lease boundary.

CNRL stated that it would complete additional work in the lease boundary area to finalize a mine development plan prior to overburden removal. CNRL did not see the need for the Panel to place time constraints upon the completion of this work.

7.1.2 Views of DCEL

DCEL stated that it intended to complete additional drilling, geological modelling, and an economic mine development analysis within the potentially mineable oil sands area adjacent to the southeast portion of the CNRL lease boundary in early 2004. The results of this information would form the basis of a preliminary mining feasibility study. DCEL stated that it would share this information with CNRL to help the parties arrive at a mutually agreeable development plan that maximized recovery of resources along the southeast portion of the CNRL lease boundary.

7.1.3 Views of the Panel

The Panel notes that CNRL is committed to continuing discussions with DCEL to develop plans for recovering resources along the southeast portion of the CNRL lease boundary. It also notes that plans must be in place well in advance of mining at the lease boundary to allow for tree clearing, placement of ditches and dewatering of muskeg, location or relocation of infrastructure, and incorporation of material volumes into workable mine and tailings management plans. The Panel finds that requiring CNRL to submit mining details and alternatives at least five years prior to commencement of mining at the lease boundary is a prudent course of action. This would allow time to gather additional information if any is required and to evaluate the mining alternatives identified. The five-year submission requirement is further justified in the event that leaseholders cannot reach agreement and EUB intervention is required.

CNRL has indicated that there are two areas where the mineable resources are shown to cross the common lease boundary, a southwest area and a larger southeast area. Given that mine start-up is scheduled during 2005 and southwest mining is scheduled for 2011, the Panel believes that it would be impractical to require CNRL to submit information on mining details and alternatives five years prior to mine development reaching the southwest area.

The Panel therefore directs that on or before December 31, 2007, CNRL shall submit for EUB approval a southwest area lease boundary report containing a comprehensive evaluation of the lease boundary geology and reserves, geotechnical conditions, alternative mining scenarios and impacts, and associated costs, in accordance with Section 3.1 of EUB *ID 2001-7: Operating Criteria—Resource Recovery Requirements for Oil Sands Mine and Processing Plant Sites*.

The Panel also directs that at least five years prior to mining at the southeast lease boundary, but no later than December 31, 2010, CNRL shall submit for EUB approval a southeast area lease boundary report containing a comprehensive evaluation of the lease boundary geology and reserves, geotechnical conditions, alternative mining scenarios and impacts, and associated costs, in accordance with Section 3.1 of *ID 2001-7*.

7.2 Plant Site Location

7.2.1 Views of CNRL

CNRL indicated that it had conducted an evaluation of potential plant sites and that it had originally selected a plant site adjacent to the south boundary of the lease. CNRL stated that this plant site was underlain by some 42.5 10^6 m^3 of recoverable bitumen.

CNRL also indicated that the originally proposed plant site location was underlain by thick sequences of geotechnically weak Clearwater clay. CNRL stated that it performed additional geotechnical analyses to determine the feasibility of constructing a major bitumen upgrading facility at this location. The results indicated that the construction of such a facility upon this type of foundation was without precedent. CNRL also stated that it considered pile foundation costs to be prohibitive due to the volume of concrete required. CNRL further stated that pile foundation movements would pose a serious risk to the operation of heavy upgrading components, such as the cokers.

As a result of the concerns regarding foundation conditions, CNRL relocated its proposed plant site northward to the location shown on Figure 1. CNRL believed that the new plant site location would address the geotechnical concerns associated with the originally proposed site, since Clearwater clays were absent in portions of the new location. It recognized that construction of the plant in the new location would result in the sterilization of approximately 53.9 10^6 m^3 of recoverable bitumen, 11.4 10^6 m^3 more than the original site. However, CNRL indicated that its analysis showed that the additional costs associated with the original plant site exceeded the value of the additional foregone bitumen resources associated with the new plant site.

CNRL also stated that there were the following significant cost and environmental benefits associated with the new mine plan that resulted from the new plant site location:

- a reduction in the seepage through the Pond 1 tailings dike, resulting from the change from tailings sand to overburden material,

- a reduction in the Pond 1 dike cost and mobile fleet emissions, resulting from the shorter haul distances associated with the Pond 1 dike location, and
- a reduced mine footprint and accelerated in-pit tailings disposal schedule.

CNRL stated that the area required for the new plant site would include all of the facilities associated with the three phases of the project. It also stated that an additional area surrounding the new plant site had been set aside to protect various upgrading components from the effects of foundation movement caused by mining.

7.2.2 Views of the Panel

The Panel considers the volume of recoverable bitumen present beneath each plant site location to be significant. However, it believes that no alternative plant site location is available that would meet CNRL's criteria for locating its plant while avoiding resource sterilization altogether. The Panel therefore accepts that some resource sterilization is necessary for the construction of the project plant site. The Panel also accepts that the costs and risks associated with the original plant site location are important considerations in the evaluation of the plant site.

The Panel therefore finds that CNRL has justified the additional resource sterilization beneath the new plant site. Notwithstanding the overall acceptance of the proposed plant site, the Panel believes that since the layout of the plant site facilities remains to be finalized, some reduction in size may be realized through optimization of facilities. It therefore directs that six months prior to the construction of the plant site, CNRL shall submit a report to satisfy the EUB that all reasonable efforts have been made to optimize the plant site area with respect to the minimization of resource sterilization. The Panel notes that any additional oil sand sterilization resulting from an increase to the plant site area would require prior EUB approval.

7.3 Discard Site Design and Overburden Disposal Areas

7.3.1 Views of CNRL

CNRL stated that a number of overburden discard sites would be required for the permanent storage of mine waste materials over the life of the project. These include several out-of-pit discard site locations in addition to those located in the mined-out pit.

7.3.2 Views of the Panel

The Panel finds that the discard site locations are reasonable, based on the currently available drilling information. The Panel also understands that further drilling will be completed within these discard site locations prior to the geotechnical designs being finalized. The Panel directs CNRL to submit for EUB approval detailed geotechnical designs for all external overburden disposal areas at least six months prior to field preparation in these areas.

7.4 Operating Criteria

7.4.1 Views of CNRL

CNRL stated that it would comply with the operating criteria set out in *ID 2001-7* but that it expected that situations might arise during operations requiring a relaxation of the criteria. CNRL stated that it would apply to the EUB at the appropriate time for approval of such a relaxation, complete with justification to support its application. CNRL also stated that a relaxation of operating criteria might be required during start-up operations.

7.4.2 Views of the Panel

The Panel accepts CNRL's commitment to meet the overall bitumen recovery requirements in *ID 2001-7*. The Panel believes these criteria to be a minimum acceptable level of performance and expects operators to design their plant facilities and mining operations to meet them.

The Panel notes that the operating criteria performance measuring process is an after-the-fact process in that the quantity of bitumen that should have been recovered during a given year is estimated after the year is completed. Enforcement action, if required, would take place after mining has been completed. As outlined in *ID 2001-7*, a report issued at the end of the year outlining deviations from the EUB directive would not preclude the EUB from taking enforcement action.

Notwithstanding the above, the Panel also understands that operating a new oil sands project can be challenging, especially during the initial four-to-six-month period. Therefore, if after completing detailed engineering designs, CNRL believes that it will be unable to meet the requirements specified in *ID 2001-7* during commissioning, the Panel expects that CNRL will submit a detailed plan specifying the expected increased bitumen losses and provide a technical and economic justification to the EUB for approval. The plan must be submitted at least three months prior to the processing of oil sands in the extraction plant.

7.5 Pit Wall Stability Adjacent to the Athabasca River

7.5.1 Views of CNRL

CNRL stated that it had completed preliminary geotechnical and geological work to establish pit limits for the east side of the south pit adjacent to the Athabasca River. CNRL also stated that it planned to complete additional geotechnical, geological, and mine evaluation work prior to undertaking any major disturbance in this area and that it could submit this information with the annual mine plan.

7.5.2 Views of the Panel

The Panel notes that the EUB is responsible for ensuring the stability of overburden dumps and mine pit walls. The Panel also notes that because CNRL has not specifically identified the ore quality and quantity adjacent to the Athabasca River, the value of this resource is uncertain at this time. The Panel recognizes CNRL's plans to conduct further evaluations and mine design work in this area. It directs CNRL to submit a report to the EUB for approval at least five years prior to mining at the final pit wall, but no later than December 31, 2016. This report must contain an evaluation of the mineable oil sands ore quality and nonrecoverable quantity in the east final pit wall area adjacent to the Athabasca River and a detailed geotechnical stability evaluation of the final east pit wall location.

7.6 Shovel-Mobile Ore Preparation Plant

7.6.1 Views of CNRL

CNRL proposed to commence use of the Shovel-Mobile Ore Preparation Plant (MOPP) technology during Phase 2 of the project. The MOPP system incorporates a conventional mining shovel supplying oil sands to a mobile crusher and a slurry preparation plant. CNRL stated that a major component of the MOPP technology was being operated successfully in Australia and South Africa. CNRL reported that it planned to test this technology during the winter of 2003/2004 and to have a commercial unit fully operational by 2009.

7.6.2 Views of the Panel

The Panel is encouraged to see testing of the type of equipment proposed for use by CNRL, and it recognizes the benefits that could be realized if the technology is successful. The Panel approves the use of this new technology, provided that it meets operating criteria. The Panel directs CNRL to submit the details of the MOPP testing to the EUB as part of each annual mine plan submission, beginning with the September 2004 submission and ending one year after MOPP has achieved one month of its nominal production capacity.

7.7 Basal Aquifer Depressurization

7.7.1 Views of CNRL

CNRL stated that its basal aquifer depressurization activities could result in depressurization of laterally continuous basal aquifers on DCEL's lease. CNRL stated that, as a result, there was a potential that pressure changes in the basal water sands could transfer vertically through the overlying bitumen and affect the pressure in any overlying steam-assisted gravity drainage (SAGD) steam chamber. CNRL noted that at this time only a relatively small portion of DCEL's Joslyn Creek project appeared to be over basal water. CNRL stated that the current drilling information indicated that there could be a localized hydraulic connection in the basal aquifer at its lease boundary with DCEL. However, CNRL did not believe that the data supported a hydraulic connection to DCEL's Joslyn Creek development area farther south of the lease boundary.

However, CNRL also stated that where SAGD operations did not overlie laterally continuous basal water sands, the potential for DCEL's project to be impacted by mine depressurization activities would be very low. CNRL argued that the diffusivity of the oil sands was so low that pressure transfer in the bitumen phase would be near zero. CNRL stated that the low permeability of oil sands was demonstrated during a 1996 pumping test at Syncrude Canada's Aurora mine and that this test was the basis for the hydraulic conductivity value CNRL used in its application. Furthermore, CNRL relied on a 1993 Alberta Research Council study to conclude that within the McMurray/Wabiskaw system, discontinuous sand and shale lenses and large areas of bitumen-saturated sands could act locally as flow barriers and, therefore, justify the use of lower hydraulic conductivity data.

CNRL acknowledged that there was a need for it and DCEL to gather additional information to better understand the impacts of depressurization on DCEL's lease. As a result, CNRL agreed to

- work with DCEL to develop a joint monitoring program at its lease boundary with DCEL, in order to establish baseline pressure conditions in the basal water sands,
- undertake continuous monitoring to detect any changes in baseline conditions as a result of CNRL's mine depressurization activities and to share this information with DCEL,
- file annually with the EUB the findings and programs associated with the monitoring, and
- prior to the start-up of formal dewatering activities, and if there were reason to do so, submit to the EUB and DCEL a report describing the steps, if any, that CNRL would undertake to prevent any adverse effects on DCEL's ability to recover its oil sands resources arising from depressurization activities by CNRL.

7.7.2 Views of DCEL

DCEL stated that it believed the mine depressurization activities of CNRL would have a detrimental effect on its proposed Joslyn Creek SAGD project. DCEL pointed out that its Joslyn lease was directly south and adjacent to CNRL's proposed project. DCEL stated that it did not believe other mining operations to the east and south of its lease would likely have any impact on its SAGD operations.

DCEL stated that CNRL's mine depressurization activities would result in a drawdown of water levels in the basal aquifer extending outward beyond CNRL's lease and into its Joslyn lease. DCEL claimed that this would result in a loss of hydraulic head to the basal water sands underlying its lease, and that this would lead to a pressure loss in the overlying bitumen zones. DCEL stated that reducing the reservoir pressure in the bitumen zones would render bitumen recovery through the use of SAGD uneconomic, resulting in the sterilization of significant bitumen resources.

DCEL acknowledged that the basal water sands were currently mapped as discontinuous, although it noted that drillhole information was continuing to be gathered. Nonetheless, DCEL concluded that the data presented by CNRL predicted a widespread, regional drawdown effect, despite the apparent discontinuous nature of the basal aquifer, and that this effect would occur regardless of the presence or absence of basal water sand.

DCEL argued that pressure changes in the basal water sands would move out into the bitumen zones (called cross-formational flow) and reduce the pressures in these zones. In support of its contention, DCEL stated that CNRL's information implied a hydraulic connectivity between the basal aquifer, Quaternary sediments, and surface water bodies, which indicated a strong downward hydraulic gradient from the water table across the bitumen zones into the basal water sands.

DCEL noted studies on basal water sands on the Albian lease east of DCEL/CNRL. Based on the measurement of tritium concentrations in the basal water, the studies indicated a higher hydraulic conductivity on a regional basis than used by CNRL in its analysis. This pointed to a significant concern for cross-formational flow of groundwater. DCEL also cited an Alberta Research Council publication that it argued implied that cross-formational flow existed in the McMurray and Wabiskaw aquifers.

DCEL stated that its situation was analogous to recent bitumen conservation issues in which pressure transmission through the bitumen zones was argued to occur due to overlying gas production. In this regard, DCEL cited EUB *Decisions 2000-22*[1] and *2003-23*[2] as support for the pressure transmission mechanism and the impact of pressure reductions on SAGD recovery and cited *General Bulletin (GB) 2003-12*,[3] *GB 2003-16*,[4] and *GB 2003-28*[5] as explaining the EUB's views on this issue.

DCEL requested that

- a monitoring program be implemented by CNRL at the DCEL/CNRL lease boundary to establish baseline pressure regimes in the basal aquifer and McMurray oil sands zones and to monitor changes in the baseline pressure regimes;
- both itself and CNRL share all monitoring data;
- CNRL acknowledge that it had an obligation to satisfy the EUB that its activities would not adversely affect the subsurface pressure regimes on the DCEL lease; and
- CNRL acknowledge that it had an obligation to prevent any adverse effects on the subsurface pressure regime on the DCEL lease caused by CNRL's activities.

7.7.3 Views of the Panel

The Panel notes that CNRL and DCEL agree that there is evidence to suggest that CNRL's basal aquifer depressurization activities could result in depressurization of laterally continuous basal water sands on DCEL's lease. As a result, there is a potential that pressure changes in the basal aquifer could transfer vertically through the overlying bitumen and affect the pressure in any overlying SAGD steam chamber. The Panel also notes that CNRL and DCEL disagree on whether or not SAGD operations that do not directly overlie basal water sands would be similarly impacted.

The Panel further notes that while hydraulic connectivity of the basal aquifer appears likely at the lease boundary between CNRL and DCEL, it is uncertain whether that connectivity exists in the region of DCEL's proposed SAGD project and, in the absence of connectivity, whether pressure changes through the bitumen zones would occur.

The Panel believes that careful monitoring of the impacts of CNRL's depressurization activities is important, given the implications for resource recovery on in situ bitumen deposits in the region and the possible need to undertake mitigation measures to ensure resource conservation and the protection of DCEL's correlative rights. The Panel expects that CNRL will ensure that timely mitigation steps are taken in the event that abnormal operating events are identified.

---

[1] *Decision 2000-22: Gulf Canada Resources Limited Request for the Shut-in of Associated Gas, Surmount Area*
[2] *Decision 2003-23: Chard Area and Leismer Field, Athabasca Oil Sands Area*
[3] *GB 2003-12: Gas Production in Oil Sands Areas*
[4] *GB 2003-16: Proposed Conservation Policy Affecting Gas Production in Athabasca Wabiskaw-McMurray Oil Sands Areas*
[5] *GB 2003-28: Bitumen Conservation Requirements Athabasca Wabiskaw-McMurray*

The Panel directs CNRL to

- provide the EUB, for its review and approval, with a monitoring plan to detect basal aquifer pressure changes at its lease boundary with DCEL six months prior to beginning its mine depressurization activities;
- provide a report to the EUB on or before February 28 of each year following start-up of mine depressurization activities, or on such other date as the EUB may stipulate, on the results of its lease boundary monitoring program; and
- satisfy the EUB within one year of project approval on the need, or otherwise, to monitor the effects of its depressurization and injection activities along the northern and western boundary of its mining activities.

The Panel also expects CNRL to honour its commitment to work with DCEL in developing an appropriate monitoring program, to share the results with DCEL, and to take corrective action where necessary.

8 BITUMEN PRODUCTION AND ASSOCIATED FACILITIES

8.1 Bitumen Recovery

8.1.1 Views of CNRL

CNRL selected a warm water extraction process for froth bitumen production. It stated that the process would incorporate primary separation cells, secondary and tertiary flotation, cycloning coarse sand tailings, and fine tailings thickening. CNRL had designed its extraction process to provide flexibility of operation and to optimize extraction and energy efficiencies while minimizing tailings production.

CNRL claimed that its extraction process would yield equal or higher bitumen recovery for equivalent oil sands feed than that recovered at existing oil sands processing facilities and that it would meet the guidelines of *ID 2001-7*. CNRL committed to 89.9 mass per cent extraction bitumen recovery at an average oil sands grade of 10.65 mass per cent.

CNRL selected a naphtha solvent-based process to produce bitumen from froth. It noted that further evaluations of inclined plate separators, centrifuges, cyclones, and other alternative processing equipment were ongoing.

CNRL stated that it had removed from its design the naphtha recovery unit (NRU) tailings thickener to recover heat energy in the tailings due to safety issues of residual solvent in the recovered water and to high capital and operating costs.

8.1.2 Views of the Panel

The Panel encourages oil sands developers to use new and modified technology that will maximize resource recovery, reduce energy and water consumption, and minimize fluid tailings production. The Panel believes that CNRL is attempting to meet these goals by its selection of a flexible extraction process and the use of thickeners. The Panel believes that the modified process will obtain acceptable bitumen recoveries and will enable CNRL to meet operating criteria.

8.2 Naphtha Recovery

8.2.1 Views of CNRL

CNRL stated that it would use hydrotreated diluent naphtha in its froth treatment plant and that the diluent naphtha would be recovered from tailings in the NRU prior to discharge to the tailings pond. CNRL committed to limit its annual average diluent losses to tailings to 4.3 volumes per 1000 volumes of bitumen produced, including vents, tankage, and other fugitive volatile organic compound (VOC) emissions. As a result, CNRL noted that the fugitive emissions, primarily VOCs, would be minimized from its tailings pond. CNRL committed not to send untreated froth treatment tailings to the tailings area during normal operations.

CNRL believed that its diluent losses in NRU tailings could be achieved with the use of two NRUs, each receiving 50 per cent of froth treatment plant tailings. CNRL stated that its NRUs were designed so that each could hydraulically handle all of the froth treatment tailings flow. With increased steam to the NRU and expected short, infrequent durations of one NRU operation, CNRL stated that it would still meet its diluent loss commitment on an annual average basis. CNRL's modelling showed that the number of occurrences of 100 per cent flow to one NRU would be so infrequent that CNRL would be able to meet its commitment.

8.2.2 Views of Alberta

AENV noted that VOCs could be a concern from the perspective of odours, human health, and environmental effects and could act as a catalyst in ground-level ozone formation. AENV stated that it expected the plant to be designed and operated in a manner that minimized the frequency of any odour incidents. AENV stated that it might include conditions in any EPEA approval that would require CNRL to provide 100 per cent NRU redundancy or to reduce throughput when necessary to ensure that no untreated tailings were sent to the tailings pond so that VOC emissions were minimized during all operating conditions.

8.2.3 Views of the Panel

The Panel notes CNRL's commitment that its site-wide, annual average diluent losses will not exceed 4.3 volumes per 1000 volumes of bitumen production, inclusive of normal, start-up, and upset conditions. The Panel also notes CNRL's commitment not to discharge untreated froth treatment tailings to the tailings area during normal operations.

The Panel notes AENV's concern about VOCs and the need for the plant to be designed and operated to minimize odour incidents. The Panel believes that the same approach to minimize odour incidents should be applied for all oil sands operations. The Panel notes that recent EUB approvals have set the limit on diluent losses at 4.0 volumes per 1000 volumes of bitumen production.

Therefore, the Panel directs that, on an annual average basis, CNRL limit site-wide diluent losses to 4.0 volumes per 1000 volumes of bitumen production, unless it can satisfy the Board that a limit of 4.3 is appropriate. The Panel recognizes that the lower limit may require CNRL to add additional equipment or modify its operating practices. The Panel also directs CNRL not to discharge untreated froth treatment tailings to the tailings area.

The Panel concludes that the diluent losses would not result in significant adverse environmental effects.

9 UPGRADING

9.1 Bitumen Conversion

9.1.1 Views of CNRL

CNRL stated that its selected upgrader process would use vacuum towers, delayed coking, and hydrotreating of distillate to produce an upgraded oil product and sulphur and coke by-products. It noted that it would improve the marketability of its upgraded product by increasing gas-oil hydrotreating severity. CNRL estimated an upgraded product yield of 86.3 volume per cent, including butanes.

CNRL stated that it would optimize energy efficiency through cogeneration for steam and electric power. It stated that it rejected coke to fuel cogeneration because of high capital, operating, and maintenance costs and increased air emissions. It considered gasifying coke to reduce or eliminate import of natural gas but rejected that on the basis of unfavourable economics. Imported natural gas would fuel gas turbine generators and plant fuel gas would be used for heaters, heat recovery steam generators, duct burners, and steam boilers. CNRL stated that the cost of natural gas had a relatively low impact on the overall sustainability of the project.

9.1.2 Views of WBFN

Wood Buffalo First Nation (WBFN) stated that CNRL was not proposing to use the most modern technology for its bitumen upgrading. WBFN believed that CNRL's technology seemed to leave a lot of toxic waste behind. In particular, WBFN was concerned that coke was stored and not used as fuel in the process. WBFN claimed that a more advanced upgrading process was available that produced less coke and consumed less water, but it provided no evidence. WBFN recommended that the Panel ensure that CNRL was using the most modern technology.

9.1.3 Views of the Panel

The Panel is satisfied that CNRL has assessed alternative technologies adequately and accepts the selected upgrading technology as discussed in Section 6. The Panel notes that delayed coking produces large quantities of coke, which CNRL does not consider an appropriate fuel source and for which there currently is no off-site market. The Panel accepts storage of coke but notes that it considers coke to be an energy resource with potential to replace natural gas as an alternative fuel and feedstock for hydrogen generation. It expects CNRL to continue to examine the economic and technical feasibility of using its coke production. The Panel directs CNRL to submit a report to the EUB on the feasibility of coke use and sales potential every five years commencing February 28, 2010, or such other date as the EUB may stipulate.

9.2 By-product Storage

9.2.1 Views of CNRL

CNRL stated that it would store its coke and sulphur production in a manner that was environmentally safe and so that it was accessible for recovery at a later date until a viable market was available. It would store 3.1 10^6 tonnes per year of coke and 549 thousand (10^3) tonnes per year of sulphur.

CNRL stated that it would stockpile the sulphur in solid blocks. The initial blocking facility would consist of a pad, runoff pond, and enclosing berm with a polyvinyl chloride liner. It would have a base of approximately 80 hectares (ha) and would reach a height of about 20 m in 20 years. It would neutralize runoff water collected in the runoff pond and discharge it into the recycle pond. CNRL noted that it would degas the liquid sulphur. It believed that once the sulphur was blocked, there would be no problems with sulphur dusting, vapour emissions, or odour off site. If sulphur storage were required beyond 20 years, CNRL would construct new storage facilities in the mined-out area.

CNRL stated that it proposed to develop the coke storage location northwest of the sulphur block as an integral part of Waste Area 3. The location had the advantages of

- shorter haul distances,
- containment within overburden waste, and
- accessibility for recovery should a market develop.

CNRL noted that the sulphur block would be about 100 m from the coke storage area and stated that it believed that the mitigative measure of removing all combustible materials between the two areas eliminated any chance of fires at the sulphur block. It stated that with the 100 m separation and the lining of the sulphur area, it believed that any concerns about leaching of heavy metals and contamination and cross-contamination were adequately addressed.

CNRL stated that it had designed a management system at the coke pile to prevent fires from spontaneous combustion caused by large clinker coke. The management system included track packing with large dozers in very thin lifts to eliminate or reduce clinker coke. In some rare instances, the clinker coke would be removed, laid in thin lifts, and capped with waste material. CNRL stated that its estimate of particulates from the project did not include emissions from fires at the coke pile, because it would put in place mitigative measures to prevent fires. CNRL stated that it had a dust suppression system to prevent dusting from the coke pile and that it would periodically reclaim the pile with grass to assist with dust control.

9.2.2 Views of WBFN

WBFN expressed concern that particulate matter had the potential to adversely affect human health and that the particulates from coke pile fires had not been included in CNRL’s estimate of particulate emissions from its project.

WBFN expressed concern about the potential for sulphur block fires resulting from sparks from coke pile fires, because the sulphur block would be close to and downwind of the coke pile.

WBFN expressed concern that the fugitive emissions assessment for the plant site did not include emissions from the sulphur blocking operation and that the emissions had not been included in the potential acid input (PAI) estimates.

9.2.3 Views of Alberta

AENV stated that runoff from aboveground sulphur block storage could be managed to prevent impacts on groundwater and surface water by capturing and neutralizing any runoff water. AENV stated that runoff or groundwater from coke storage was not of particular concern because of the limited solubility of coke. AENV stated that concerns about coke related to particulate matter being wind-blown off of the coke storage pile and management of coke to prevent fires. It stated that the proposed facilities were suitable for coke and sulphur storage and that the design of the storage facilities would be addressed in any EPEA approval.

9.2.4 Views of the Panel

The Panel notes that AENV considers the proposed facilities to be suitable for coke and sulphur storage. The Panel believes that the mitigative measures CNRL proposes for prevention of fires, runoff, and dust control will result in coke and sulphur being stored in an environmentally safe manner.

In response to WBFN concerns about coke pile and sulphur block fires, the Panel expects CNRL to produce and to follow its emergency response plan.

The Panel notes that the delayed coking process produces large amounts of coke, for which there currently is no off-site market. The Panel considers coke to be an energy resource and it expects CNRL to ensure that the coke is stored so as to maximize future recovery.

The Panel concludes that there are unlikely to be any significant adverse environmental effects associated with the storage of coke and sulphur, provided that the mitigation measures proposed by CNRL are implemented.

10 TAILINGS MANAGEMENT

10.1 Views of CNRL

CNRL stated that it required an external tailings pond for the first 10 years of operation. The pond would have sufficient capacity to store extraction process-affected recycle waters, Tar River water, possibly some basal aquifer water, extraction nonsegregating tails (NST), and segregating froth treatment tailings. CNRL stated that after it made sufficient in-pit space available, it would place NST in-pit. CNRL would continue to use the external pond for extraction water recycle inventory and storage of mature fine tailings (MFT) for the life of the project. CNRL stated that it would evaluate the feasibility of modifying the tailings operations and NST process and composition to consume more of the MFT formed to reduce the timing for both storage and reclamation of the external pond.

CNRL described NST as tailings resulting from a process in which the coarse sand stream and thickened tailings stream from the bitumen extraction plant would be mixed together at a sand-to-fines ratio ranging from 3.6 to 4.7 and pumped to the tailings area. If required, gypsum, carbon dioxide (CO_2), or another coagulant would be used to prevent segregation of fine and coarse particles. CNRL stated that NST would consume about 98 mass per cent of all the tailings solids. CNRL expected that NST would consolidate into a stable deposit in less than 10 years. It believed that this deposit, after appropriate capping, would be suitable for dry landscape reclamation.

CNRL stated that tailings research and development were continuing in the oil sands industry and that the use of thickeners to produce thickened fine tailings was undergoing field testing. CNRL stated that it had spent $7.8 million to date in tailings research and development. CNRL also stated that it had considered the use of paste stacking and filtered tailings to produce drier tailings and to reduce the size of the external tailings pond. However, CNRL rejected paste stacking due to its complexity, cost, and unproven performance. CNRL rejected filtration due to its mechanical complexity, the requirement to transport the filtered product, and high capital and operating costs.

CNRL concluded that in terms of technical and commercial development, NST was the most advanced demonstrated tailings management scheme available. CNRL indicated that currently there were no other economical tailings management schemes.

CNRL stated that the NRU tailings would not be thickened due to safety issues and high capital and operating costs. The NRU tailings, about 2 per cent of the total tailings solids, would be managed as segregating tailings for the duration of the mining operation. At the end of lease life, the residual NRU tailings and excess MFT, about 180 10^6 m^3, would be transferred to an end-pit lake (EPL). CNRL stated that this was a conservative number and that it had not taken into account any reduction from in situ consolidation or interlayering possibilities. CNRL stated that it would be evaluating the feasibility of modifying its NST composition to consume more of the MFT and to reduce the potential volume requiring transfer. This modification had the potential to substantially reduce the MFT to 20 10^6 m^3. CNRL noted that it would continue to work on tailings management alternatives with industry to evaluate in situ reclamation, volume reduction, and other techniques for MFT management.

10.2 Views of MCFN

MCFN expressed concerns about CNRL's need for large water withdrawals from the Athabasca River. It requested that a condition be added to any approvals requiring CNRL to commit to continued research towards reduction of water usage and elimination of massive tailing ponds.

10.3 Views of the Panel

The Panel believes that appropriate tailings management objectives for oil sands mines should be

- maximizing immediate process water recycle to increase energy efficiency and reduce fresh water import,
- reducing stored process-affected water volumes on site,
- eliminating or reducing containment of fluid fine tailings in an external tailings pond during operations,

- minimizing and eventually eliminating long-term storage of fluid tailings in the reclamation landscape, and
- creating a trafficable landscape at the earliest opportunity.

The Panel believes that CNRL's tailings management scheme is a positive development in the management of tailings. The Panel commends CNRL and believes that the proposed NST scheme takes positive steps towards achievement of many of the above objectives.

The Panel recognizes that CNRL's proposed scheme includes final storage of MFT in an EPL, and as a result the scheme will not meet the objective of eliminating long-term storage of fluid tailings in the reclamation landscape. The Panel recognizes that NST is in the development stage and that ongoing development and additional research efforts will be required to advance the NST technology to ensure that the above objectives are met.

The Panel believes that tailings management is one of the main challenges for the oil sands mining industry. This challenge remains, despite considerable efforts over more than 40 years to develop an alternative bitumen extraction or tailings management scheme that does not produce fluid fine tailings. Current tailings management results in tailings having to be impounded indefinitely and in some cases prevents reclamation of tailings areas. The challenge is more problematic since there is currently no demonstrated means to reclaim fluid fine tailings. The Panel notes that a reclamation scheme consisting of water capping of fluid fine tailings in an in-pit pond was applied for and endorsed by the EUB in *Decision 94-5: Syncrude Continuous Improvement and Development project, Mildred Lake Oil Sands Plant*, subject to successful demonstration. This demonstration is a major undertaking and is expected to occur over the next 20 years or so. In the absence of a demonstrated successful case of reclamation of fine tailings by water capping, the EUB has directed oil sands mining developers to continue to work on alternative technologies for bitumen extraction and tailings management to ensure that acceptable reclamation of all tailings deposits will be achieved.

The Panel expects CNRL to continue research and development on solid tailings technologies and to incorporate that into its existing tailings plan in order to ensure a trafficable landscape and rapid progressive reclamation (reclamation of land as soon after disturbance as is reasonably possible and in a manner consistent with the approved closure plan) and to eliminate the need for long-term storage of fluid fine tailings.

Therefore, the Panel directs CNRL to submit to the EUB on or before February 28, 2005, and every year thereafter, or such other date as the EUB may stipulate, a progress report summarizing

- research and development on solid tailings technologies, and
- modifications to the existing tailings plan to ensure a trafficable landscape, rapid progressive reclamation and to eliminate the need for long-term storage of fluid tailings.

The Panel believes that it is imperative to produce high-quality NST consistently to ensure that the objectives of a trafficable landscape that allows rapid progressive reclamation of tailings areas can be met. The Panel believes that use of 98 mass per cent of solids in NST while ensuring that the mixture consolidates and remains in a nonsegregated state would require close attention to equipment design and operation. This would require more equipment and a significantly higher service factor than is typical.

Therefore, the Panel directs CNRL to submit to the EUB two years prior to planned start-up, or such other date as the EUB may stipulate, a report summarizing the engineering design and operating plans for the NST system. The Panel also directs CNRL to submit to the EUB on or before February 28 of every year following start-up, or such other date or frequency as the EUB may stipulate, a report summarizing for the preceding year the performance of the NST system, including reasons for deviations from design.

The Panel recognizes that tailings management affects water management, energy efficiency, and the final landscape. The Panel believes that CNRL's proposed scheme is reasonable, based on current technology, but that there is a need for the regulators to ensure that CNRL and other oil sands developers manage tailings more effectively.

The Panel has considered a number of regulatory options to ensure that tailings are managed satisfactorily. In *Decision 2002-089,*[6] the EUB considered limiting the maximum amount of project disturbance, which had the effect of imposing tailings management performance requirements to some degree. In its deliberations regarding the proposed project, the Panel has considered regulating the percentage capture of tailings solids. Another option the Panel has considered is setting requirements on the utilization of the NST production system. However, after detailed review of the evidence provided, the Panel believes that it does not have adequate information to establish performance criteria for tailings management at this time. Additionally, the Panel is concerned about the potential for establishing an inconsistent set of requirements for various mineable oil sands operators by establishing criteria on a project-by-project basis. The Panel believes a uniform set of criteria would allow the EUB to regulate effectively in this area. Ideally, the criteria would be performance based, with the discretion left to operators as to how to meet them. The Panel is not in a position at this time to set such criteria, but believes that work should commence without delay to develop criteria. The Panel believes that this work could start by considering the feasibility of using factors that relate to fluid fine tailings consolidation, such as percentage of solids utilization in NST, quality of NST produced, and NST system service factor.

The Panel notes that the approval of discard management plans is the regulatory responsibility of the EUB, and therefore it is appropriate for EUB staff to lead the initiative and consult with the mineable oil sands developers as appropriate. Due to the close linkages between tailings performance and reclamation issues, the Panel believes that this initiative would benefit from the participation of AENV and ASRD, since both agencies have reclamation approval responsibilities under EPEA and the Public Lands Act (PLA) respectively. Therefore, the Panel will direct EUB staff to work with the mineable oil sands industry, AENV, and ASRD to develop performance criteria for tailings management. The Panel expects this work to provide a recommendation on the appropriate tailings management performance criteria to the Board by June 30, 2005.

[6] *Decision 2002-089: TrueNorth Energy Corporation Application to Construct and Operate an Oil Sands Mine and Cogeneration Plant in the Fort McMurray Area*

The Panel notes that research continues on water capping of fine tailings. The Panel believes that the ongoing tailings research will identify alternative means to reclaim fluid fine tailings, perhaps at a higher cost than water capping, should water capping prove to be unacceptable.

In conclusion, the Panel believes that close attention to design and operations supported by continued aggressive research by CNRL and continued monitoring by EUB and AENV will ensure that the proposed tailings management scheme is unlikely to have significant adverse environmental effects.

11 WATER MANAGEMENT

11.1 Project Water Balance, Use, and Need

11.1.1 Views of CNRL

CNRL stated that it would use the following water conservation principles for the project:

- minimizing water intake by recycling and reusing water,
- minimizing evaporation losses by reducing the surface area of water storage ponds,
- collecting seepage losses by constructing perimeter trenches to intercept seepage for reuse,
- supplementing withdrawals from the Athabasca River with runoff from developed areas and connate water in the mined ore, and
- releasing any water to the environment in accordance with the AENV *Surface Water Quality Guidelines for Use in Alberta*.

CNRL stated that it would require 29.6 10^6 m^3 of fresh water before start-up to build recycle water inventory in the external tailings pond and 89.6 10^6 m^3 per year during start-up operations to provide for start-up contingencies. It stated that at steady-state full production, before and after NST goes in-pit, 61.3 10^6 m^3 per year would be required. An additional 19.9 10^6 m^3 per year would be required for 8 years to fill the EPLs at reclamation.

CNRL stated that it required 2.68 volumes of fresh water per volume of synthetic crude oil to operate the process on a long-term sustainable basis.

CNRL stated that its licensed annual water withdrawal from all sources, including the Athabasca and Tar Rivers, should be set at 89.6 10^6 m^3 per year. It stated that its water management plan had been revised to reflect the new mine plan, adjustments to water in tailings, and increased usage from the upper Tar River. Therefore reduced diversion would be required from the Athabasca River. The maximum annual withdrawal volume was based on stream-day water requirements for

- start-up conditions that included external tailings pond buildup inventory,
- conditions of no runoff,
- contingencies for upset operations,
- uncertainties of technology and design, and

- incremental water requirement for 60 days per year for processing low-grade oil sands.

11.1.2 Views of the Panel

The Panel has reviewed CNRL's water balance and fresh water requirements. The Panel understands that CNRL's tailings management scheme results in denser tailings and faster release of water for recycle and, therefore, a lower total make-up water requirement. The Panel notes that the requested allocation does not appear to account for the lower make-up requirement. The 2.68 volumes of fresh water per volume of synthetic crude oil to operate the process on a long-term sustainable basis is not consistent with the requirement of 61.3 10^6 m^3 per year during steady-state full production. The Panel expects that AENV, in approving CNRL's water withdrawal licence, will consider this apparent inconsistency.

The Panel notes that CNRL's tailings management scheme has the potential to reduce water use. The Panel encourages CNRL and other operators to continue to place a priority on developing strategies and technologies to reduce fresh water use, maximize reuse of process-affected water, and reduce storage of process-affected waters.

11.2 Raw Water Storage

11.2.1 Views of CNRL

CNRL proposed on-site raw water storage to minimize the effects of water withdrawal from the Athabasca River during low-flow conditions. CNRL stated that the operating capacity of its raw water pond was 1 10^6 m^3 and provided approximately 3 to 4 days of water supply to the plant at a maximum rate of 3.1 m^3 per second (s), or 17 days of water supply at the minimum water rate. CNRL noted that it required the minimum raw water withdrawal for boilers, cooling systems, and domestic uses. It stated that it could not use untreated recycled water for these purposes and that treatment was expensive. As a result, CNRL stated that it must be allowed to draw water at all times from the Athabasca River or from other fresh water sources at rates of 0.6 m^3/s in Phase 1, 1.09 m^3/s in Phase 2, and 1.2 m^3/s in Phase 3.

CNRL committed to increase the capacity of its raw water storage to 1.5 10^6 m^3 without sterilizing any additional ore or expanding its development footprint. It stated that under normal stream-day operations, this volume of water would provide 25 days of operation with no withdrawal from the Athabasca River, and even longer with a minimum withdrawal or during winter operations, when less cooling water would be required. CNRL noted that 20 days of less than 100 m^3/s of flow in the Athabasca River had been observed in a year. CNRL's raw water capacity would generally sustain it over that time frame and beyond before water withdrawal would be required.

11.2.2 Views of MCFN

MCFN expressed concerns relating to water withdrawal from the Athabasca River during low-flow periods and requested that CNRL be required to construct a raw water pond with at least 1.5 10^6 m^3 capacity.

11.2.3 Views of the Panel

The Panel recognizes that a minimum raw water withdrawal is required from the Athabasca River to feed boilers, cooling systems, and domestic use.

The Panel recognizes the concern that there may be impacts on the aquatic environment in the Athabasca River during low flow and that there may be a need to restrict water withdrawals. The results of the IFN working group study will influence water allocations and allow CNRL to confirm whether the raw water storage capacity proposed by CNRL would be adequate. The Panel notes that AENV is aware of the concerns and that it has the responsibility to assess applications for water withdrawals from rivers and the ability to manage them.

The Panel notes that the increased use of the raw water storage pond as a water source during low-flow conditions may require the rapid withdrawal of water. The Panel therefore recommends that CNRL include an analysis of the effect of rapid water withdrawal on the stability of the raw water storage dikes as part of the raw water storage pond design report submitted to the Dam Safety Branch.

12 GROUNDWATER

12.1 Views of CNRL

CNRL indicated that during development and following closure, it expected water to seep from the ETA into the groundwater system and/or discharge into the mine surface water drainage system. CNRL stated that during development, ditches would capture some of the seepage flow and direct it back to the tailings or recycle water ponds. CNRL indicated that seepage rates would decline over time as tailings consolidated and that the environmental consequences of ETA seepage on groundwater were low.

CNRL indicated that in-pit tailings seepage would occur following placement of tailings into mined-out pits. CNRL stated that depressurization activities would potentially capture seepage during development. CNRL indicated that backfilling of the mine pits with tailings would have a moderate environmental consequence on groundwater levels, flows, and flow patterns and a low impact on water quality within the basal aquifer.

CNRL indicated that basal aquifer depressurization would be necessary throughout the mine’s lifetime to ensure a stable mine environment. CNRL stated that this activity would have a regional effect on groundwater levels and flows limited mostly to the western side of the Athabasca River. CNRL stated that depressurization would decrease groundwater levels in the basal aquifer, affect discharge from the basal aquifer into the Athabasca River, and induce flow from the Athabasca River into the basal aquifer between 2019 and 2036. CNRL indicated that it would mitigate the effect of depressurization by depressurizing only those areas of the basal aquifer necessary for the safe and efficient operation of the mine pits. CNRL stated that the environmental consequence of basal aquifer depressurization on groundwater flows and levels would be moderate. CNRL indicated that basal aquifer water quality within the project area might improve as a result of depressurization.

CNRL indicated that water within the basal aquifer was generally brackish to saline, in some instances would contain hydrogen sulphide gas, and was not considered a significant groundwater resource in the area. CNRL stated that it could not release this water without treatment. It proposed some combination of on-lease reinjection into the basal aquifer, treatment and use in the extraction process, and treatment and release as management options for this water. CNRL indicated that the preliminary assessment of the feasibility of basal water sands reinjection showed that the effects on groundwater were acceptable. CNRL predicted that the average depressurization rates at other developments within its groundwater RSA were predicted to increase by approximately 6 per cent because of its injection activities. CNRL stated that its predictions were based on conservative groundwater models.

CNRL stated that it would continue to gather data to evaluate and potentially reduce the uncertainties in its groundwater models and to confirm its EIA predictions through the continued investigation of the hydrogeology of the Quaternary deposits in the vicinity of the ETA and of the hydrogeology of the basal aquifer.

CNRL stated that it would undertake a comprehensive groundwater monitoring program and was willing to involve stakeholders in the design and implementation of the program, as well as to share the results of monitoring. CNRL stated that it was willing to participate in a regional groundwater-modelling program.

12.2 Views of OSEC

The Oil Sands Environmental Coalition (OSEC) indicated that it and CNRL agreed that any future plans to treat and release basal aquifer water to the Athabasca River would be subject to a separate application, require an EPEA approval, and be subject to OSEC review.

12.3 Views of MCFN

MCFN stated that it had concerns regarding the quality of the baseline groundwater data set and of the groundwater monitoring plan. MCFN indicated that a predevelopment or pristine baseline data set should have been developed for the project and that it was concerned that the groundwater monitoring program would not meet the EIA terms of reference. MCFN recommended that CNRL enhance research respecting groundwater resources in Alberta and monitoring within the project area, ensuring that MCFN was involved in the design of any groundwater monitoring programs and had access to the monitoring results.

12.4 Views of WBFN

In final argument and through questioning of both CNRL and AENV, WBFN expressed concerns that information on springs issuing from the McMurray Formation into the Athabasca River was not included in the assessment of impacts and that the springs were not monitored. WBFN indicated that it had concern that any reduction in the flow of the Athabasca River would reduce the dilution of spring flow into the river and therefore the spring flow would have a greater impact on water quality.

12.5 Views of Canada

EC noted deficiencies in CNRL's baseline water and sediment quality data set and recommended that CNRL conduct further baseline and operational water quality sampling to complete a predisturbance description of the quality of local groundwater. EC suggested that any monitoring plan should be based on a rigorous scientific design.

12.6 Views of Alberta

AENV indicated that it had several concerns regarding the potential environmental impacts of CNRL's basal aquifer depressurization activities and the management of the depressurization water. These concerns included

- the inherent level of uncertainty associated with predictive numerical modelling,
- the lack of contingency disposal options,
- the need for monitoring in order to verify the EIA depressurization and injection predictions, and
- the impact of depressurization on the Athabasca River between 2019 and 2027.

AENV agreed that CNRL incorporated conservative assumptions into its modelling, but noted that CNRL based its assumptions on limited information. AENV stated that the inclusion of certain terms and conditions in the EPEA approval relating to data collection, monitoring, and additional validation of existing modelling of impacts could address the uncertainties.

Under cross-examination, AENV addressed a number of questions regarding the impact of tailings seepage, the treatment of basal aquifer depressurization water, the impact of sulphur springs on water quality within the Athabasca River, and the responsible authority for groundwater monitoring. AENV generally agreed with CNRL that seepage from tailings areas would not significantly impact groundwater. AENV indicated that if treatment of the basal aquifer depressurization water were undertaken, the environmental impacts of the treatment system would have to be examined. AENV suggested that groundwater flow made up a small component of flow within the Athabasca River and even at low flow conditions it was unlikely that sulphur springs would have a significant effect on water quality within the river. AENV indicated that groundwater monitoring for project effects would be the applicant's responsibility.

12.7 Views of the Panel

The Panel notes that the water quality within the basal aquifer is brackish to highly saline. Whatever injection plans CNRL has for the depressurization water will require application, approval, and reporting under EUB *Guide 51: Injection and Disposal Wells*.

The Panel notes that both CNRL and AENV indicated that conservative assumptions are incorporated into the basal aquifer groundwater modelling but that uncertainties exist. The Panel is encouraged that CNRL will conduct follow-up work to better understand the hydrogeological impacts of its project and accepts that this additional work will help remove some of the uncertainties in the models. The Panel believes that activities such as depressurization and injection have the potential to affect the groundwater system within the LSA and RSA. Therefore, the Panel supports CNRL's commitment to undertake groundwater monitoring and follow-up work, as well as AENV's intentions to require CNRL to monitor and assess the impact of basal aquifer water management on the groundwater system.

The Panel notes that CNRL predicted that depressurization activities would induce flow from the Athabasca River into the basal aquifer and that AENV expressed concerns regarding this impact between 2019 and 2027. The Panel believes that the locations of the depressurization wells need to be chosen to ensure mine safety and accepts that depressurization could induce flow of water from the Athabasca River into the basal aquifer. However, the Panel notes that because CNRL predicted that depressurization volumes between 2019 and 2027 would exceed the available disposal capacity during that time period, CNRL committed either to treat and use any excess water in the process or treat and release it. The Panel believes that the disposition of the depressurization water produced between 2019 and 2027 needs to be optimized to limit any additional project impact on the Athabasca River.

The Panel concludes that with the implementation of the mitigation measure proposed by CNRL and the recommendations of the Panel, significant adverse environmental effects associated with basal aquifer depressurization and injection are unlikely.

The Panel notes that CNRL predicted that the need for depressurization would increase at other planned developments because of its injection activities. The Panel notes that CNRL believes that the predictions are conservative and that it will revise these predictions based on updated modelling. Notwithstanding, the Panel has concerns that the basal aquifer water management practices of other developers in the groundwater RSA could be negatively affected by CNRL's injection activities. The Panel directs CNRL, in consultation with developers within its groundwater RSA, to satisfy the EUB within one year of project approval on the need, or otherwise, to monitor for potential effects of its injection activities on the depressurization needs of other developments.

The Panel recognizes that both CNRL and AENV indicated that under the seepage modelling scenarios presented, ETA and in-pit tailings seepage would probably not have any significant impacts on groundwater quality. The Panel understands that groundwater monitoring will be implemented to assess the predictions regarding the impact of tailings seepage and that mitigation will be undertaken should any adverse effects be discovered. The Panel notes that CNRL indicated that it would conduct follow-up work on the hydrogeology of the Quaternary deposits in the vicinity of the ETA. The Panel recommends that AENV's Dam Safety Branch require CNRL to include updated seepage modelling results, Quaternary deposits mapping, groundwater monitoring plans, and mitigation measures as part of the ETA detailed design report.

The Panel concludes that with the implementation of the mitigation measure proposed by CNRL and the recommendation of the Panel, significant adverse environmental effects associated with tailings seepage are unlikely.

The Panel recognizes the commitment CNRL made to stakeholders regarding participation in the implementation and design of the monitoring program and sharing of monitoring results. The Panel notes that several interveners commented on groundwater data and monitoring needs and believes that AENV should address these concerns in any EPEA approval it might issue for this project. Therefore, the Panel recommends that AENV consider the involvement of stakeholders in the design and implementation of the groundwater monitoring program. The Panel notes that EC made recommendations regarding groundwater monitoring and encourages EC to provide AENV with additional information regarding its recommendations. The Panel recommends that AENV collaborate with EC in the design and implementation of the groundwater monitoring program.

The Panel notes that various groups are collecting data in order to assess the regional impact of development in the oil sands area on air, surface water, and wildlife, but that no group is currently assessing the regional impact of development on groundwater. In light of the number of developments in the area, as well as the scale of development, the Panel believes that such an initiative would be valuable in assessing all potential impacts. While the Panel recognizes CNRL's willingness to participate in the development of a regional groundwater model, cross-lease groundwater monitoring in conjunction with DCEL, and monitoring of project-scale impacts on groundwater, the Panel believes that no one organization should be tasked with undertaking a regional initiative. The Panel recognizes that an additional recommendation to regional working groups to undertake such an initiative may also not be feasible given their current workloads. The Panel recommends that AENV invite all interested stakeholders to participate in the process of assessing the need for a regional groundwater resource characterization initiative and, if the group concludes such an initiative is required, take action to have that need addressed.

13 SURFACE WATER QUANTITY

13.1 Views of CNRL

CNRL stated that the project maximized conservation and recycling of water and minimized water withdrawal from the Athabasca and Tar Rivers. CNRL concluded that the project would result in negligible adverse hydrologic effects on the Athabasca River flows and water levels due to the following mitigative measures:

- minimized water withdrawals from the Athabasca River by recycling tailings water, site runoff water, and seepage from mine pits;
- staged withdrawals from the Athabasca River during periods of low flow;
- minimized effects on flows in receiving streams by distributing muskeg drainage operations to avoid large increases in flow to receiving streams;
- minimized sediment load to receiving streams by routing surface water flows impacted by mine operations through polishing ponds prior to release to receiving streams; and
- diverting streams not disturbed by mining operations around the mining areas to receiving streams.

As a result of its mitigative measures, CNRL believed that the EIA estimated that only minor effects would occur as a result of water withdrawals from the Athabasca River, including during periods of low flow.

CNRL further described the strategies that it had considered to reduce its water withdrawal, including off-stream storage, minimization of water withdrawal during low-flow periods, and arrangements with other water licence holders. CNRL noted that it had increased the capacity of its storage pond to 25 days from 17 to address concerns about water withdrawals during low flow in the Athabasca River. As well, CNRL committed to pursuing Water Act licences that reflect long-term operational calendar-day water requirements; CNRL stated that short-term needs for start-up and commissioning would be addressed through temporary licences.

CNRL recognized and supported the work of the CEMA IFN subgroup, which was charged with determining the IFN of the Athabasca River required to sustain aquatic life and water quality. To meet possible IFN policies, CNRL committed to staged water withdrawal reduction strategies during low flows in the Athabasca River and stated that it expected any approvals that might be issued under the Water Act would include provisions to allow amendments should they be required when an IFN was determined. CNRL noted that the IFN subgroup was scheduled to complete its work by year-end 2005 and that AENV and DFO had assured the Panel that in the absence of an agreement or recommendation by the IFN subgroup, AENV and DFO had the authority to set whatever restrictions they deemed necessary. CNRL also committed to meeting IFN recommendations even if they were issued subsequent to receiving a Water Licence under the Water Act.

CNRL did not believe that it was appropriate to set an interim IFN, as there was an established CEMA process in place to address this issue. CNRL noted that the studies and consultations that were under way as part of the CEMA process would be significantly more advanced by year-end 2005, even if CEMA was not in a position to recommend an IFN as scheduled. Therefore, more information would be available to regulators at year-end 2005 if it became necessary for them to set the IFN. It was CNRL's position that a scientifically based interim IFN could not be set in the absence of these data. Further, CNRL noted that it would not require start-up water withdrawals from the Athabasca River until 2007.

CNRL stated that the EIA included a pre- and post-disturbance assessment of the hydrologic conditions within the project area, as required in the terms of reference for the EIA. The environmental baseline assessments included consideration of the cumulative effects of all existing and approved projects compared to an assessment of the potential residual effects of the project on surface water quality and quantity. Further, in response to comments that appropriate baseline conditions were not used, CNRL noted that for the Tar and Calumet watersheds, the pre-development and baseline conditions were identical. CNRL stated that the diversion of the Tar and Calumet Rivers would result in no net change in discharge to the Athabasca River. Therefore, CNRL was of the opinion that its definition of baseline conditions for its surface water assessment was appropriate. CNRL believed that the EIA predicted potential effects and addressed mitigative measures on the basis of sound baseline hydrologic data or, where data were scarce, by using conservative assumptions, such as that all land disturbances occurred at once.

CNRL was confident in the results of its flow estimates from the Hydrologic Simulation Program in Fortran (HSPF) model and asserted that it was an appropriate model for estimating long-term underlying changes in hydrologic indicators as mining activities progressed. It further explained that it selected this model because it was capable of generating flow statistics that closely approximated observed baseline conditions. Once calibrated, it used the model to generate expected future hydrologic statistics. It stated that the model was calibrated using observed flow data from 1975 to 1999 and climate data from 1953 to 1999. In response to comments that calibration using data from nonconcurrent periods was unusual, CNRL provided evidence that its method resulted in a better correlation between observed and simulated data and their confidence levels and that it predicted a drier landscape than did the more usual concurrent calibration approach. Therefore, CNRL maintained that its approach resulted in a more conservative prediction of flows and water quality and that where changes in the hydrologic regime affected water quality assessments, the model should not overpredict flow.

CNRL stated that there was no trend in lower flows in the Athabasca River as a result of climate change; it also noted that AENV had reached the same conclusion. CNRL noted that an assessment of the effects of climate change on stream flow was not required in the terms of reference for the EIA. Further, CNRL stated that current climate change models were unable to predict changes to stream flow on a watershed basis. It noted, however, that regional- or global-scale climate models generally predicted higher precipitation in the oil sands region, which was contrary to MCFN's theory of decreasing flows in the Athabasca River. CNRL stated that the suggestion that the HSPF model could be used to forecast the effects of temperature on stream flow was inappropriate, because increasing the input temperature ignored related changes to other model parameters.

CNRL responded in detail to the evidence MCFN presented to support its position that there was a decreasing trend in the lowest flow over seven consecutive days in a ten-year period (known as 7Q10) as a result of climate change. MCFN believed that CNRL's lack of consideration of climate change in its assessment called into question the conservatism in the flow estimates included in the EIA.

CNRL believed that the decreasing trend in 7Q10 asserted by MCFN resulted from the methodology used to analyze the data and was not reflective of an actual decrease in low flows. In this regard, CNRL noted that MCFN excluded data prior to 1960 due to small sample size (two points) but included data after 2000, which were of a similar sample size (three points), assumed that 7Q10 was the lowest flow in ten consecutive years, and plotted the 7Q10 against the mid-decade years, instead of the year in which they occurred. CNRL also noted that the low-flow value in the 2000/2009 decade could have a return period of greater than ten years and therefore should not have been included in the trend analysis.

CNRL noted that an appropriate trend analysis performed on annual low-flow values by fitting them to probability distributions showed no statistically significant trend. Additionally, CNRL pointed out that even if a trend were established using flow data from a specific monitoring station, the analysis should also be undertaken at additional stations to confirm the trend. It pointed out that multiple station trend analysis was performed under the Regional Aquatics Monitoring Program (RAMP) and that no trends in mean flood or low flow were identified on the Athabasca River. CNRL presented evidence that supported its position that the wide variability in historical stream-flow data made it unlikely that a trend in the data could be established over the life of the project.

With respect to hydrologic monitoring, CNRL noted that the terms of reference for the EIA did not require monitoring programs to be in place prior to receiving EPEA approvals. However, CNRL mentioned that climatic and hydrologic monitoring programs currently in place would continue at existing stations and that it would incorporate new stations to meet the requirements of its environmental approvals. CNRL noted that these approvals would contain requirements to monitor waters discharged from the project development area. This included monitoring of flows and sediment concentrations in discharge waters. Further, CNRL committed to continue its participation in the RAMP and CEMA regional programs.

CNRL indicated that it had not considered the impacts of the Bennett Dam on flows in the Athabasca River, as decreased flows in the Peace River resulting from the Bennett Dam did not impact the Athabasca River in the area of the project. CNRL noted that the RSA ended at the Embarrass Portage, as determined in consultation with regulators and stakeholders, because negligible water quality effects were predicted in the Athabasca River before the Embarrass Portage and the Peace-Athabasca Delta.

CNRL did not comment on the residual effect methodology employed in the EIA in all areas, but in response to comments on the methodology employed in CNRL's analysis of open water areas, it stated that it conducted its analysis in keeping with the guidance provided in Appendix D of the Regional Sustainable Development Strategy (RSDS). CNRL noted that the RSDS concerns about open water areas were related to changes in flow regime due to development. CNRL noted that in its closure drainage plan, open water areas were limited to 20 per cent of a watershed to ensure that evaporation did not dominate runoff and to ensure sustainability of engineered lakes and wetlands.

13.2 Views of MCFN

MCFN identified water as its primary concern about the project. MCFN was concerned that the influence of climate change on flows in the Athabasca River and the Peace-Athabasca Delta were not addressed by the EIA, as it believed that the effects of climate change would result in decreased flows in the Athabasca River. MCFN also stated that it believed that the incidence of extreme events, such as floods or droughts, would increase as a result of a warming climate.

MCFN believed that a significant decreasing trend was apparent in both mean stream flow and 7Q10 low flow in the Athabasca and that these trends were related to climate change. It believed that the omission of climate change data from the HSPF analysis made any future predictions of stream flows highly questionable. Therefore, MCFN stated that it was concerned about the impact of this project and other planned oil sands projects on the Athabasca River basin in light of the increasing trend in licences to withdraw water from the Athabasca. MCFN noted that continuation of its traditional way of life hinged on adequate water flow in the Athabasca River. MCFN stated that residents of Fort Chipewyan relied on the Athabasca River for many things, including food and transportation. Low flows could limit access to medicinal plants and herbs, spiritual and cultural sites, and trapping and hunting areas. MCFN stated that it believed that this was happening now and that the impacts would be magnified as water use by oil sands development increased.

MCFN stated that it realized that AENV had jurisdiction over the allocation of water licences. However, MCFN believed that this hearing was the only forum to voice its concerns with respect to water and to make recommendations to AENV that addressed these concerns. MCFN noted that AENV must consider the written decision of the Panel in any future review of a CNRL application under the Water Act to divert water from the Athabasca River. MCFN believed that it would not be able to appeal any future water licence that might be granted to CNRL because the issue had been previously raised at an EUB hearing.

MCFN requested a delay of CNRL's approvals and licences until an IFN had been established or an interim IFN was declared based on scientific evidence and the precautionary principle. MCFN also requested a delay in issuance of licences and approvals for the project until all outstanding gaps identified in the EIA by the MCFN were addressed. Alternatively, MCFN asked that the Panel recommend to other responsible agencies that all approvals and licences be conditioned to address gaps in the EIA and to assure prevention, mitigation, and compensation for adverse effects of the project alone or in conjunction with other projects. It specifically requested that CNRL be required to enter into cooperative management agreements with other operators and that CNRL be prohibited from withdrawing water from the Athabasca River during low-flow periods.

MCFN requested that the Panel recommend to AENV changes to the Water Act and ministerial regulation, such that

- cooperative management of water licences by oil sands operators was required,
- the transfer or sale of water licences among oil sands operators was prohibited,
- staged water licences were granted depending on applicant need and the results of the IFN, and
- no exceptions to withdrawal restrictions during low-flow periods were granted.

MCFN also requested that the Panel recommend to AENV the development of an Athabasca River Basin Regional Plan to establish policies for the management and conservation of the Athabasca River Basin, as another means of developing a cooperative water management strategy.

MCFN identified concerns about the calibration and validation of the HSPF model. It noted that the data received at the hearing satisfied many of its initial concerns about the HSPF modelling results but that this information should have been included in the EIA.

MCFN expressed concern about the methodology CNRL used to rank the impacts of the project on the environment. With respect to the hydrologic changes, MCFN noted that the EIA looked at changes in the local setting and compared these changes to a very large study area, resulting in the changes being ranked as negligible. MCFN believed that the changes should have been assessed on a more meaningful scale. For example, MCFN believed that the EIA employed an incorrect approach to calculate the net change of open water areas. It believed that the planned open water area should be compared to the current open water area, rather than to the LSA. MCFN believed that the EIA methodology resulted in an underappreciation of the magnitude of the change. To illustrate its concern, MCFN noted that the removal of the Tar and Calumet Rivers was ranked as negligible in terms of the entire study area. The MCFN also questioned the ranking of an 11 per cent decrease in flow to the Athabasca as negligible when the impact to the ecosystem was not addressed.

MCFN was also concerned about the RSA ending at the Embarrass Portage, which excluded the Peace-Athabasca Delta from the assessment area. MCFN believed that this was done to avoid the complexity of considering impacts on the Peace-Athabasca Delta.

MCFN requested that surface water monitoring programs be designed to address its questions regarding frequency and location of data collection and integrated traditional knowledge and that the data collected be accessible by MCFN. MCFN noted that it was vital to have standardized monitoring procedures in place to ensure that the project-induced changes to the hydrologic regime were captured and mitigated. MCFN also disputed the EIA position that monitoring instrumentation was unable to measure stream flow accurately due to the wide variability of the data, leading to the use of professional subjective judgement on the impact of the project. MCFN noted that although the measurement of stream flow was subject to the variability of that parameter, the measurement instrumentation was precise, and that an appropriate frequency of monitoring events reduced the need to apply subjective professional judgement.

13.3 Views of Fort McKay

The Fort McKay First Nation and Metis Local 122 noted that its agreement with CNRL contained commitments from CNRL related to surface water quantity, which included a basal water management strategy, no release of process-affected water during operations, support of the CEMA initiative to evaluate the need for an interim IFN by year-end 2003, optimization of off-stream water storage, and inclusion of Fort McKay in the design and construction of stream diversions for the project.

Additionally, Fort McKay requested that the Panel recommend to AENV that an interim IFN be established.

13.4 Views of ACFN

The Athabasca Chipewyan First Nation (ACFN) stated that it had not objected to the project application because it had reached an agreement with CNRL, which included recognition of traditional environmental knowledge (TEK) with respect to water levels in the Athabasca River, minimization of water withdrawals from the Athabasca River, compliance with the Athabasca River IFN, and no release of process-affected water during operation to surface water bodies.

Additionally, ACFN noted that it did not believe that CNRL should apply for exemptions from water withdrawal restrictions.

13.5 Views of WBFN

WBFN expressed concern that low flows in the Athabasca River had impacted the traditional way of life of its members. It believed that the impacts of the Bennett Dam should have been assessed in the EIA, as it believed that the dam was responsible for drier conditions in the Peace-Athabasca Delta. WBFN members noted that prior to flows being controlled by the dam, seasonally high water flows in the Peace River caused the Athabasca River to back up and flood the delta area, resulting in enhanced wildlife habitat.

WBFN also expressed concern that previous provincial and federal water sampling programs in the Peace-Athabasca Delta and Fort Chipewyan area were not communicated to residents in the area. WBFN also believed that CNRL could reduce demands on the Athabasca River by applying additional technology to treat water. WBFN further believed that the effects of climate change should have been considered in the EIA in order to address the observed decreasing flows in the Athabasca River.

13.6 Views of OSEC

OSEC believed that Albertans expected water to be responsibly and fairly allocated. Specifically, with respect to the oil sands area, OSEC expressed concern that Syncrude's and Suncor Energy Inc.'s (Suncor's) grandfathered water licences did not permit equitable management of water allocations in the oil sands area. OSEC believed that it was crucial that AENV treat all water users fairly in order that a consensus-based plan to manage the IFN of the Athabasca River could be established through the CEMA process. OSEC commented that the original timelines for the completion of this work would not be met and noted that a delay in establishing the IFN increased ecological and water quality risks to the Athabasca River. OSEC further explained that CNRL had addressed its concern in this area by being willing to accept a provision in its water licence that would accommodate future implementation of the IFN. OSEC also noted that CNRL had committed to pursue water licences that were in line with long-term requirements, and that CNRL would address its short-term requirements for start-up and commissioning through temporary, short-term licences. OSEC noted that this was in contrast to the current practice of including short-term water requirements on the 10-year water licence.

13.7 Views of Syncrude

In final argument, Syncrude stated that it was participating in the hearing to ensure that its approvals and investments were protected. Syncrude informed the Panel that water licences issued under the Water Act were subject to the principle of "first in time; first in right," which ensured that the allocations of earlier licensees were not impacted by future allocations. Syncrude stated that it had a statutory priority that could be overridden only in an emergency declared by the Lieutenant Governor in Council. Therefore, it was Syncrude's position that any water licence that might be issued to CNRL could not impact Syncrude's existing licence. Syncrude stated that it was its understanding that the only method by which CNRL could access existing licensed rights was by negotiating a voluntary transfer, as provided in the Water Act.

Syncrude stated that it believed that an IFN should be established through the CEMA process and that an interim IFN was not necessary, as proponents were aware that an IFN would ultimately be set and were incorporating this knowledge into future planning.

13.8 Views of Canada

DFO noted that CNRL's water withdrawal from the Athabasca River would contribute to changes in river flows and levels and therefore, recommended that the IFN for the Athabasca River be in place prior to CNRL being issued a licence for a permanent water intake from the river or allowed to operate any new permanent water intakes. DFO noted that it would cooperate with AENV in setting an IFN should the CEMA IFN subgroup be unable to fulfill its mandate on time, as preservation of fish habitat fell within its mandate under the Fisheries Act.

DFO expressed concern that CNRL used simulated and observed data from nonconcurrent time periods to calibrate the HSPF model. DFO believed that this increased the uncertainty of predictions related to flood return periods, low flows, water quality based on a changed volume of water, and fish health and tainting.

13.9 Views of Alberta

AENV stated that it believed that there were sufficient annual volumes of water in the Athabasca River to satisfy CNRL's allocation request and that of other potential users, because the withdrawals were a relatively low percentage of annual flow. However, it noted that timing of withdrawals during low flow might require careful management, as there was a potential for negative cumulative effects during low winter flows. AENV also stated that it did not detect a decreasing trend in actual stream flow from data for the Athabasca River at the Town of Athabasca or at Fort McMurray. It noted that the station at Athabasca records data similar to the station at Fort McMurray but had data available over a longer period.

AENV noted that recommendations from the CEMA IFN subgroup were expected by year-end 2005 and that an IFN strategy would be implemented soon after the conclusion of the subgroup's mandate. However, AENV also stated that it would take necessary action to ensure that IFN issues were addressed if this schedule could not be maintained. AENV also noted that it expected CNRL to continue its participation in the subgroup. AENV did not comment on the need for an interim IFN.

AENV further noted that all Water Act licences, including that of Syncrude, had some provision that allowed amendment of licence conditions to include IFN objectives. AENV indicated that any Water Act licence that might be issued to CNRL would include conditions to accommodate IFN management options in the Athabasca River. AENV did not comment on CNRL's ability to enter into a voluntary transfer with an existing Water Act licensee.

13.10 Views of the Panel

The Panel believes that the timely development of the IFN for the Athabasca River is needed to preserve the future integrity of the river. Further, the Panel believes that the current consultative process under way through the CEMA IFN subgroup is the most appropriate forum in which the scientific data can be gathered and all stakeholders' needs can be addressed. The Panel is satisfied that AENV and DFO will take appropriate action to ensure that IFN issues are addressed should the subgroup not achieve its mandate by the end of 2005, as planned. However, in view of the importance of this work, the Panel encourages all stakeholders to support the IFN process to ensure that the subgroup achieves its goal.

The Panel believes that the establishment of an IFN is critically important to mitigate against cumulative environmental effects associated with water withdrawal from the Athabasca River. The Panel notes that CNRL will not require permanent water withdrawal from the Athabasca River until 2007 and recommends that DFO and AENV assess the need to integrate the findings of the IFN subgroup into their respective authorizations that are required for the project. In view of AENV's and DFO's position on ensuring that an IFN will be established in a timely manner, the Panel does not believe that setting an interim IFN is necessary. In addition, the Panel believes that establishing an interim IFN might result in resources being diverted from the process of determining a permanent IFN. Therefore, the Panel recommends to AENV and DFO that they establish an IFN in the event that CEMA is unable to do so by the end of 2005.

With respect to Water Act licences, the Panel notes that CNRL's proposal to pursue a Water Act licence that reflects it long-term needs, while using short-term licences to address start-up and commissioning requirements, is a water management strategy that allows stakeholders, including the public, to see that allocated volumes are in line with long-term used volumes. The more common industry practice of applying for a total allocation to cover total project needs may lead some parties to believe that the entire allocated volume is being used for the entire life of the project.

The Panel notes Syncrude's argument that it has priority water rights under the Water Act for those licences it currently holds and that under the "first in time; first in right" principle, water licences issued after it was granted its licences cannot affect its earlier licences. The Panel notes that OSEC believed that this principle was contrary to the equitable use of water, but understands that AENV will recognize priority rights of all water users under the Water Act. It also notes that AENV has the ability to revise all water licences regardless of priority, should it become necessary to meet the requirements of the IFN.

The Panel also notes the concern of various parties with respect to the calibration, validation, and predictions associated with the HSPF model. The Panel believes that the initial predictions are acceptable, given the level of baseline hydrologic data currently available. However, the Panel views the modelling exercise as an iterative process that must be enhanced by additional baseline and operational data collection to ensure that appropriate mitigation can be planned. The Panel believes that the information presented throughout the hearing process indicates that additional monitoring work is necessary on a project and a regional scale to further augment hydrologic data. Therefore, the Panel concurs with the AENV, DFO, and EC position that acquisition of additional baseline hydrologic data is required to further verify the model results and recommends that any approvals that AENV and DFO might issue to CNRL include requirements for further hydrologic data collection and verification of HSPF model predictions.

On the basis of the available stream-flow data, the Panel agrees with the CNRL and AENV position that a decreasing trend in low flows is not apparent. From the evidence presented, the Panel believes that the trend presented by MCFN is a result of the manner in which the data were presented, rather than an actual feature of the data. The Panel is concerned that the trend analysis presented by MCFN was not subjected to a more rigorous statistical analysis. The Panel accepts CNRL's and AENV's position that given the natural variability of stream-flow data, it is unlikely that trends will be detected over the life of the project.

The Panel accepts CNRL's position that it is currently difficult, if not impossible, to incorporate climate change effects into watershed-scale models, but that current regional- or global-scale climate change models suggest that the climate in the project area will become wetter. The Panel accepts that these regional and global predictions will be refined as more data become available.

The Panel believes that consideration of the impacts of the Bennett Dam on the Peace River is beyond the scope of these proceedings. As the Panel understands it, these concerns are related to the impact of controlled flows on the Peace River and the effects on the Athabasca Delta, not the Athabasca River, which is the focus of the Panel's review.

The Panel notes the concern of MCFN regarding analysis of residual effects, specifically with respect to calculation of open water areas, definition of the RSA, and stream flow. The Panel believes that these concerns relate in part to the current levels of data available to assess the project and that the additional data collection and monitoring requirements that CNRL will be subject to under the conditions of its licences will assist in addressing these concerns.

Having regard for the data and analysis provided by CNRL and AENV, the implementation of mitigation measures proposed by CNRL, and the recommendation of the Panel, the Panel concludes that significant adverse environmental effects associated with water withdrawn from the Athabasca River for use in the project are unlikely.

14 SURFACE WATER QUALITY

14.1 Views of CNRL

CNRL stated that its water quality impact assessment considered all potential impacts associated with the construction, operation, and reclamation phases of its project, including cumulative effects from existing, approved, and planned projects. The assessment took into account water releases that might alter stream flows, thermal regimes and water quality in receiving waters, stream diversions and disruption of natural drainage, groundwater and surface water quality interactions, muskeg and overburden dewatering, external and in-pit tailings disposal areas, end-pit lakes, and air emissions.

CNRL used different water quality models to predict future conditions and the potential impact of the proposed project and reasonably foreseeable projects on water quality in the region. CNRL used a two-dimensional, steady-state dispersion model to predict water quality and mixing in the Athabasca River. It used the HSPF model to simulate water quality and temperature in small streams and water bodies. CNRL modelled EPLs using a flow and mass balance model. CNRL contended that the water quality component of the EIA was based on state-of-the-art modelling that incorporated conservative assumptions and accounted for any uncertainties. CNRL indicated that it performed a sensitivity analysis to determine the robustness of the HSPF water quality results and noted that the analysis considered the combined effects of all constituents. CNRL stated that this analysis further substantiated its predictions that the project would have negligible chronic toxicity effects on water quality. CNRL clarified that it used 7Q10 specifically for the worst-case design flow for water quality only, as recommended by AENV for steady-state modelling of effluent release. It stated that it made its predictions more conservative by assuming that maximum effluent flows would occur simultaneously.

Using the project development scenario to predict water quality conditions, CNRL determined that the project would either cause or contribute to some exceedances of water quality and/or human health guidelines during certain periods of time or under certain conditions in the regional watercourses. However, CNRL stated that the exceedances were primarily a result of muskeg and overburden drainage, local soil conditions, and high background concentrations of certain parameters. CNRL indicated that in the Athabasca River, all predicted concentrations would be within the range of observed natural variation. It also noted that water quality within EPLs would meet provincial regulatory requirements prior to the lakes releasing water. CNRL believed that the project was not a significant factor in causing certain predicted water quality parameter exceedances and concluded that the environmental consequences of the exceedances were negligible. It also indicated that the exceedances in water quality would not adversely affect fish or other aquatic biota according to its assessment of fish health, fish tainting, and fish tissue quality. CNRL stated that predicted exceedances of the water quality guidelines did not imply effects on aquatic biota. In order to ensure that the effects of the project releases on water quality of the Athabasca River were negligible throughout the life of the project, CNRL proposed a monitoring plan to detect changes in key water quality parameters for applicable surface waters, verify predictions, calibrate the models, and adaptively manage any changes in environmental variables.

With respect to acidification of water bodies, CNRL determined that the project would cause, or contribute to, the exceedances of the critical load[7] of the PAI in several lakes. However, CNRL noted that any potential impacts were considered reversible, as demonstrated by other studies of similarly affected lakes. The magnitude of predicted impacts on other potentially acidified lakes was negligible. CNRL acknowledged that the impact predictions on surface water acidification and aquatic life were subject to a moderate degree of uncertainty. It committed to monitor lake water quality in one of the lakes, as well as participate in RAMP's acid-sensitive lakes program, which currently samples two of the other larger lakes.

In response to criticisms that methyl mercury was not appropriately assessed, CNRL emphasized that the EIA assumed all mercury was methyl mercury, in its view an assumption that was extremely conservative in its view. CNRL indicated that it was aware of the concerns about mercury in reservoirs and acknowledged that this issue was widely known. It stated that mitigation measures were feasible, practical, and proven. CNRL would also test the vegetation and soil for mercury in the area of the proposed compensation lake prior to its filling, and it would strip and clear the area if necessary.

14.2 Views of OSEC

Acidifying emissions from the project was one of the concerns raised by OSEC. It stated that chemical changes caused by levels of acid deposition that exceeded the buffering capacity of receiving ecosystems could modify chemical and nutrient cycling and affect biota and ecosystem functioning. OSEC noted that the project would cause the critical load of one lake to be exceeded and would contribute to the critical load exceedances of 11 other lakes in the region. The majority of acidifying emissions from the project were attributed to the mining truck fleet. OSEC's favoured mitigation approach was to limit the output of PAIs.

14.3 Views of MCFN

MCFN identified water quality as an issue of concern. In its analysis, MCFN predicted that mercury levels in Calumet Lake and the proposed compensation lake would become elevated as a result of flooding the vegetation, similar to the effects observed in reservoir formation. Stripping of wetlands, which contained naturally high levels of mercury, would also result in higher mercury concentrations in receiving waters. MCFN contended that these effects were not addressed in the EIA. Consequently, MCFN questioned the ability of the proposed compensation lake to provide fish habitat. It did not consider the calculation of mercury in surface water quality samples an appropriate indicator of the potential concentrations of mercury in fish, particularly the amounts of methyl mercury. MCFN stated that methyl mercury, not total mercury, was the primary compound of concern because it was an established neurotoxin. Furthermore, small

[7] The level of acid deposition that will not cause long-term harmful effects on the receiving ecosystem.

amounts of methyl mercury could cause fish tissue to exceed consumption guidelines, because methyl mercury bioaccumulates in fish, particularly in predatory fish such as pike and walleye, which are common to the region. MCFN stated that no analysis of methyl mercury was undertaken in the EIA for either water quality purposes or content in fish.

MCFN disagreed with the evaluation of lake acidification in the EIA. MCFN stated that the forecasts were not reliable because the predictions were based on unverified models. MCFN argued that a re-evaluation of impacts on fish health was required. The EIA indicated that impacts from lake acidification were reversible. However, MCFN stated that the effects had been demonstrated to be only partially reversible and that this was substantiated by scientific literature that had not been cited by CNRL.

MCFN also questioned the predictions pertaining to water quality in EPLs. According to MCFN, the predictions were made using unverified models. It questioned the accuracy of those models and noted the lack of follow-up on previous predictions relative to past developments.

MCFN indicated that the continuation of its traditional way of life depended in part on adequate water quality in the Athabasca River. Elders noticed a change in the overall water quality over time, stating that people were no longer able to drink directly from surface water. MCFN had concerns about deteriorating water quality as a consequence of development, lack of consultation with MCFN regarding potential effects on water quality, and lack of environmental monitoring of potential effects. It recommended that additional baseline information be collected, a specific monitoring plan be established in which objectives, indicators, and performance measures were derived, and an analysis on the accumulation of methyl mercury due to wetland stripping and vegetation flooding be performed.

14.4 Views of Canada

EC explained that CNRL’s water quality modelling was based on outputs from HSPF and Monte Carlo simulations, which comprised relatively few real data and included analyses with detection limits above water quality guidelines in some cases. As such, EC was uncertain about the reliability of the surface water and sediment quality assessment in the EIA. It noted the importance of collecting additional data as part of an ongoing monitoring program to reduce uncertainty over time, allow effective comparisons of conditions both before and after disturbance, and evaluate the effectiveness of mitigation measures. EC recommended that the monitoring plan be based on a rigorous scientific design with sufficient statistical power. EC did not believe that CNRL had collected adequate predevelopment baseline water quality and sediment quality data to provide the basis for comparison and to determine future sampling intensity. It recommended that CNRL conduct further baseline and operational sampling, in addition to completing a monitoring plan.

EC acknowledged that the EIA predicted some exceedances of the water quality guidelines and the chronic effects levels for aquatic biota. However, EC was unable to assess the accuracy of those predictions because of the uncertainty inherent in the predictions themselves. Furthermore, EC stated that it could not agree or disagree with CNRL’s conclusion that the project would have a negligible effect on water quality due to the low number of baseline measurements and the subsequent uncertainty in predictions. It also stated that it could not be absolutely certain that the potential impacts on water quality could be mitigated. EC acknowledged the environmental risk of EPLs with respect to water quality but noted that there was legislation to ensure that poor quality water would not be released into fish-bearing waters. EC noted that any tailings release or seepage from EPLs into fish-bearing waters might constitute a violation of the Fisheries Act, which would warrant EC taking enforcement action.

EC explained that SO_2 contributed to the development of acidifying emissions in the atmosphere, and hence to acid deposition in water bodies. It emphasized the work CEMA was doing in developing a strategy to manage acidifying emissions from oil sands facilities in the region. However, EC concluded that the significant increase in SO_2 and nitrogen oxides (NO_x) emissions would increase acid deposition in the region. It recommended that all operators comply with the elements of the management strategy that would be developed by CEMA.

DFO stated that there was little information on the additive or multiplicative impacts of water quality parameter interactions. Furthermore, effects of widespread regional oil sands development on fish tainting and fish health continued to be poorly understood. It noted its concern about the release, treatment, and on-site storage of water from the basal aquifer, as those waters were highly saline and had the potential to affect fish habitat. DFO stated that if it approved the habitat alterations resulting from the project, it would include conditions to ensure that CNRL adhered to prescribed mitigation measures for the protection of fish and fish habitat, and to prescribed monitoring and follow-up studies to assess mitigation measures and verify impact predictions, and it would require CNRL to compensate for any unmitigated losses of fish habitat. DFO recommended that CNRL continue to participate in regional initiatives such as CEMA, RAMP, and the Canadian Oil Sands Network for Research and Development (CONRAD) to address water quality issues. DFO further advised CNRL to implement the recommendations and management strategies established by those groups.

DFO noted that increased water withdrawal from the Athabasca River and its tributaries would result in increased water quality impacts, particularly when combined with low-flow periods. DFO therefore recommended that CNRL undertake a site-specific long-term water quality monitoring program for the project.

14.5 Views of Alberta

AENV noted the uncertainties in water quality predictions and in landscape impacts that could affect surface waters. It also acknowledged that the water quality predictions relied on the HSPF water quantity modelling, which itself contained elements of uncertainty due to a lack of site-specific historical data and hydrologic-process information. However, Alberta believed that CNRL's predictions for the water quality characteristics were very conservative and that, as a result, the assessment identified more variables as exceeding guidelines or as being of possible concern than would actually be expected to occur. Additionally, Alberta indicated that these parameters were satisfactorily addressed in the fish health assessment. Alberta did not express concern regarding CNRL's predictions. Nevertheless, Alberta noted that monitoring was necessary to validate and calibrate the models and confirm water quality predictions. AENV indicated that it might include a monitoring condition in any Water Act or EPEA approval issued to CNRL.

14.6 Views of the Panel

The Panel notes that CNRL predicted that it would exceed several parameters of the provincial water quality guidelines for the protection of aquatic life and/or human health guidelines. However, the Panel also notes AENV's evidence that these predictions were the result of highly conservative modelling, which did not indicate an impact on receptors and did not raise a significant concern. The Panel is reassured by EC's evidence that there is adequate legislation in place to prohibit the release of poor quality water into fish-bearing waters. However, both agencies advocated a thorough monitoring program to identify and address any effects that might occur. Therefore, the Panel recommends that DFO and AENV include a condition in any approvals to be issued to CNRL that it develop and implement a comprehensive monitoring program. The Panel expects CNRL to develop such a program in consultation with EC and other affected stakeholders. The Panel supports the work being done in conjunction with RAMP; however, CNRL is ultimately responsible for implementing the monitoring program.

The Panel is aware that the water quality guidelines are intended to be broad and are not specific to the watercourses and water bodies within the oil sands region. However, the Panel notes that CEMA is currently developing site-specific water quality objectives for the lower Athabasca River. The Panel expects CNRL to support CEMA in its efforts to develop water quality objectives for the lower Athabasca River by continuing to participate and provide funding. The Panel also expects CNRL to adhere to the water quality objectives recommended by CEMA and implemented by regulators.

The Panel considered the issue of mercury and notes AENV's evidence that CNRL took a very conservative approach in its predictions. The Panel is satisfied with CNRL's proposed plan to test for mercury in soil and vegetation in the area of the proposed compensation lake and to strip and clear such soil and vegetation if necessary. The Panel expects CNRL to monitor for mercury in the proposed compensation lake from the time of filling until monitoring is no longer required by regulators.

With regard to acidifying emissions, the Panel notes that the project will contribute to the potential of water bodies in the region to be acidified. It recommends that AENV include a condition in its approval requiring CNRL to monitor for effects of acid deposition in regional water bodies.

Although there are some predicted exceedances of water quality guidelines, the Panel believes that by implementing a comprehensive monitoring plan and adaptive management strategies to ensure adherence to the water quality guidelines, the project is unlikely to result in significant adverse environmental effects on water quality.

15 AQUATIC RESOURCES

15.1 Views of CNRL

CNRL stated that its EIA included an evaluation of the baseline conditions for aquatic resources and an assessment of the potential effects of the project, in conjunction with other developments, on fish and aquatic resources. The EIA assessed fisheries habitat, water quality, and water flow levels in the Athabasca River and tributaries affected by the project, as well as potential acidifying effects on lakes and streams. CNRL stated that the project would result in the loss of parts of the Tar River and its tributaries, the Calumet River and its tributaries, a tributary to the Pierre River, an unnamed tributary to the Athabasca River, Calumet Lake, and an unnamed lake referred to as UN-7. CNRL acknowledged that the project would result in permanent alterations of some aquatic resources and have a significant impact on fish access due to the elimination of these watercourses and water bodies, but it considered the residual effects on fish habitat to be negligible based on its compensation for the productive capacity of those resources as outlined in its No Net Loss Plan (NNLP). It recognized the uncertainty associated with the effectiveness of fish habitat mitigation and compensation measures in the NNLP, but pointed out that these mitigation measures had been implemented successfully elsewhere. CNRL indicated that it did not know what effects the loss of benthic invertebrate and forage fish production would have on important domestic, commercial, and sport fish populations in the Athabasca River basin. However, CNRL believed that it would mitigate any residual losses by providing more than equivalent compensation for lost habitat.

CNRL provided a revised NNLP to the Panel and stated that its revised compensation plan would include one lake to be located on the western perimeter of the mine and within CNRL's leases. The proposed species assemblage consisted of 11 species found locally. CNRL planned to maintain its target compensation ratio of creating two habitat units for each habitat unit eliminated. It expected to construct the lake in 2005. CNRL indicated that it would form the lake by impounding the mainstem of the Tar River. The water would drain into the ETA for use as process water until closure in 2044, at which time CNRL would divert flow from the lake and discharge it into the Athabasca River. CNRL stated that it would construct a diversion channel that would facilitate fish passage. It committed to monitoring compensated fish habitats and making modifications as required.

CNRL sampled benthic invertebrates at three sites in each of the Tar and Calumet Rivers and at one site in the Ells River. It took samples from erosional and depositional sites in affected watercourses. CNRL determined from these sampling events that benthic invertebrate abundance and richness was low to moderate in these watercourses. It also examined benthic drift in the Tar River. CNRL indicated that drift density was relatively low and was generally similar to other streams in the oil sands region. It did not sample the Athabasca River directly for the project, but indicated that previous surveys of the reach adjacent to the project showed low to moderate invertebrate abundance. CNRL stated that it had not evaluated biodiversity of benthic invertebrates for the project or for the oil sands region as a whole, but noted that the data collected by RAMP could be used to estimate invertebrate biodiversity relative to other regional rivers.

CNRL indicated that the daily drift contribution from the Tar and Calumet Rivers to the Athabasca River was about 5 per cent of the Athabasca's background invertebrate drift abundance. In response to MCFN's criticisms that CNRL had not followed the requirements for identifying benthic invertebrates to the appropriate taxonomic level, CNRL indicated that MCFN had been mistaken about the requirement for species level assessments as a result of MCFN's reliance on outdated guidelines.

When questioned about its lack of specific monitoring plans, CNRL stated that there was adequate time to conduct consultation and develop appropriate programs to monitor the project effectively, verify predictions, and identify next steps. Furthermore, it argued that creating a monitoring plan before any approvals were issued was unworkable, as the monitoring program would typically be designed in concert with conditions set by both the EUB and AENV.

CNRL stated that it recognized the importance of determining IFN to assess the effects of water withdrawals from the Athabasca River on fish habitat. CNRL indicated that changes in stream flow during mine development and closure also had the potential to adversely affect benthic invertebrates, but it considered this unlikely. CNRL noted its commitment to a staged water withdrawal reduction strategy during low flows in the Athabasca River to meet possible IFN policies. CNRL also noted its commitment to regional initiatives such as the IFN subgroup of CEMA and RAMP, among others.

CNRL acknowledged that it predicted some chemical substances would exceed chronic effects levels for fish and other aquatic biota, but it did not believe that there would be any effects on fish health as a result of those exceedances. It explained that it screened the water quality predictions to determine risk to fish health by comparing indicators of toxicity to predicted substance concentrations. CNRL indicated that the fish health assessment also considered a number of other health indicators. However, CNRL noted that there were no chronic effects values for naphthenic acids and indicated that there were insufficient data to understand the toxicity of naphthenic acids. CNRL stated that fish would be exposed to higher concentrations in the Athabasca River than the concentrations of naphthenic acids predicted to come from the project. CNRL indicated that the parameters carried forward to the fish health assessment did exceed guidelines, but it stated that no parameters were excluded because data were lacking. CNRL examined those parameters assessed for their potential to affect fish on a chemical-by-chemical basis. CNRL then estimated the extent of exposure to individual fish and concluded that the project would result in negligible effects on fish health. CNRL committed to continue its participation in the Fish Tainting Working Group and to ongoing monitoring for fish tainting. CNRL stated that it would ensure that the project would not result in the tainting of fish.

When questioned by interveners about the proposed compensation lake, CNRL acknowledged that comparable compensation activities had not yet been undertaken in the region. It noted that although it had not fully determined the fish assemblage, it would include fish from a variety of sources, including native fish and potentially hatchery fish. It expected to establish the proposed compensation lake in 2005. The lake would contain self-sustaining fish populations by 2012 at the latest. CNRL stated that the compensation lake was a beneficial environmental effect of the project. It indicated that the area currently had no similarly sized lake supporting a fishery. Furthermore, it expected that the habitat created within the lake would provide habitat that was superior to that of the Tar and Calumet Rivers, which would be lost as a result of the project.

15.2 Views of OSEC

OSEC stated the importance of maintaining a minimum in-stream flow in the Athabasca River that would support fish. OSEC believed that there was a risk of losing fish habitat in the Athabasca River as a result of CNRL's water withdrawal from the river, especially during periods of low flow. It noted that the IFN subgroup of CEMA was collecting fisheries information to determine the IFN of the Athabasca River. However, it expressed concern that the results of the IFN study were not available to determine whether the predicted river flows during the life of the project would negatively affect overwintering fish habitat.

15.3 Views of MCFN

MCFN emphasized the importance of fish and fishing to its traditional lifestyle and its treaty rights to fish in traditional lands. MCFN stated that most, if not all, of its members subsisted a good portion of the time on fish and game harvested from traditional lands. MCFN indicated that its members had observed changes in the spring and fall spawning patterns of certain fish species in the Athabasca River, and it attributed this change to oil sands development. MCFN stated that fish abundance and the diversity of fish species were both declining. It expressed concern that the project would contribute additional pressure on fish populations due to increased fishing resulting from the growth in human population coupled with increased access to fishing sites. It also stated that the taste of certain fish had been affected by oil sands development and that it was concerned about the uptake of toxic pollutants by fish.

MCFN stated that CNRL's aquatic resources assessment lacked scientific rigour and that some information was inadequate, incorrect, or missing. MCFN also indicated that CNRL's assessment lacked evidence demonstrating that proposed mitigation measures would work. MCFN believed that the invertebrates collected in the assessment should have been identified to the species level, rather than the genus or family level, as was done in the EIA. MCFN stated that the science in the assessment was flawed and not defensible to the broader scientific community. Consequently, it stated that the preimpact assessment of invertebrates would be of little use in the future for evaluating the effects of oil sands development on the aquatic communities. MCFN indicated that identification to the species level would have allowed the data to be included in the RAMP database.

With regard to fish habitat in the EIA, MCFN indicated that the assessment caused MCFN to question the accuracy of the predictions because the assessment was conducted using large-scale maps and videotape recordings. Furthermore, MCFN disagreed with CNRL's conclusion that the loss of the Tar and Calumet Rivers would have a negligible impact on the Athabasca River. MCFN questioned whether destroying part of the two rivers, in an area that contained only four rivers, should be considered a negligible impact on biota. It stated that the loss of fish habitat was a certainty, but that the success of CNRL's NNLP was not. It considered the use of streams and river mouths for spawning by fish to be particularly important. It did not accept CNRL's conclusion that the NNLP resulted in positive environmental effects. It stated that the NNLP was not based on sound science and should be revisited. MCFN also took issue with CNRL's proposal to incorporate fish ladders in the NNLP. It noted that there was no evidence to support the premise that the existing fish species in the Athabasca River would successfully use the ladders.

MCFN proposed a number of recommendations pertaining to aquatic resources. MCFN requested that CNRL be required to consult with MCFN regarding any aspect of the project that might affect aquatic systems, including the design of mitigation and monitoring programs.

15.4 Views of Canada

DFO indicated that the destruction of fish habitat in the Tar and Calumet watersheds required its authorization.

DFO acknowledged that the issues it identified regarding CNRL's project reflected larger concerns common to the Alberta oil sands region, including

- incremental loss of aquatic habitat, including small watercourses, confluence habitats, wetlands, and riparian zones;
- changes in flow conditions of regional water bodies, including the diversion of water from the Athabasca River;
- changes in water quality of regional water bodies and the potential for fish health effects and fish tainting; and
- release of acidifying emissions associated with oil sands development.

DFO quantified the loss of aquatic habitat resulting from the project. It recommended that fish presence/absence be confirmed for the unnamed tributary affected by the project, Otasan Lake, Legend Lake, and Lake UN-7 prior to the start-up of the project to determine monitoring requirements. DFO indicated that it was concerned that the release, treatment, and on-site storage of the highly saline water associated with basal water sands depressurization had the potential to affect fish habitat. DFO stated that mining activities had the potential to impact riparian habitat and recommended that CNRL meet its commitment to provide a minimum setback of 250 m along the Athabasca River.

DFO noted that there were no functioning examples of EPLs on the landscape to verify the predictions made in the EIA. In the event that EPLs were not a viable option, DFO indicated the importance of developing and implementing alternative strategies prior to mine closure. DFO stated that it did not accept EPLs as compensation for fish habitat.

DFO stated that regional fish habitat would be affected as a consequence of the successive elimination of watercourses and water withdrawals from the Athabasca River. Those activities would cause a reduction in tributary habitat, reduction in benthic invertebrates, and changes in habitat as a result of decreased Athabasca River flows and water levels. Although CNRL had submitted an NNLP in accordance with DFO policy, DFO indicated its concerns regarding the high degree of uncertainty associated with predicting cumulative environmental effects. DFO also indicated that uncertainty existed in the predictions based on the hydrology assessment including fish and fish tainting. DFO believed that all incremental change predictions and concerns needed to be examined on a regional scale. It further recommended that CNRL continue to participate in existing and new regional initiatives to detect cumulative effects on the aquatic environment.

DFO believed that with the implementation of appropriate mitigation measures, follow-up and monitoring programs, and adequate compensation for habitat losses, the goal of no net loss of fish habitat could be achieved. It noted that any authorizations it issued would contain specific conditions to ensure that mitigation measures for the protection of fish and fish habitat were implemented, that monitoring and follow-up studies addressed the effectiveness of mitigation measures and verified impact predictions, and that identified habitat losses were adequately compensated for.

EC was concerned that the potential release of process-affected waters into fish-bearing watercourses and water bodies could cause fish tainting. EC noted its participation in the Fish

Tainting Committee under CONRAD. Although EC was encouraged by the progress made by the Fish Tainting Committee, it was concerned that the work of the committee would not adequately address the knowledge gaps and future research needs identified by EC.

EC noted that although analytical chemistry of naphthenic acids was lacking in the past, there had been recent progress pertaining to developments in the analysis and characterization of naphthenic acids. However, EC did not believe that there was enough information on naphthenic acids to accurately assess the effects of naphthenic acids on fish and indicated that considerably more could be done to understand the issue of fish tainting. It stated that naphthenic acids were one of the classes of compounds under consideration for research in the fish tainting program and there were ongoing discussions as to whether naphthenic acids were potent enough to cause fish tainting.

EC also emphasized the importance of understanding tainting caused by background or natural conditions and tainting from industrial sources. EC had tried to persuade the Fish Tainting Committee to advance its work in that regard. Finally, EC acknowledged the difficulty with this issue, as there was a lack of solid evidence of fish tainting and much of the evidence to date was anecdotal. EC suggested examining compounds in oil sands waste waters, as it did not believe that those waters had been previously been examined from a tainting perspective.

15.5 Views of Alberta

Alberta took the position that effects on fish populations and fish habitat would be negligible if CNRL could successfully compensate for loss of fish habitat through the NNLP. However, it noted that there was uncertainty associated with predicting project-specific and cumulative impacts on fish and fish habitat due to limitations in water quantity and water quality modelling, coupled with CNRL's evolving drainage plans and knowledge gaps in regional fish ecology. As a result, Alberta recommended that fish and fish habitat monitoring be continued through groups such as RAMP. When questioned whether RAMP conducted adequate monitoring, Alberta indicated that because RAMP was currently undergoing an academic review of its five-year report, it was reluctant to draw conclusions about the appropriateness of RAMP's program. Alberta was confident that the review would identify any gaps or deficiencies in the RAMP program.

Alberta believed that CNRL adequately addressed the water quality variables in the fish health assessments and indicated that the conclusions drawn by CNRL in its fish health and fish tissue quality assessments did not cause AENV or ASRD concerns.

15.6 Views of the Panel

The Panel recognizes that project-specific and cumulative fish habitat losses are of concern in the oil sands region. However, the Panel notes DFO's opinion that the impacts on fish habitat can be mitigated. The Panel notes that DFO expressed confidence that the goal of no net loss can be achieved. The Panel believes that a strong monitoring plan is critical to the success of CNRL's project, as was recommended by several interveners. The Panel recommends that DFO, ASRD, and AENV, in consultation with EC, include a requirement in any approval issued to CNRL to address uncertainties in the EIA by developing and implementing a comprehensive fish monitoring program.

The Panel notes that CNRL's proposed compensation lake would be the first of its kind in the oil sands region. The Panel is aware that similar lakes may be proposed in the region to compensate for other aquatic habitat loss due to oil sands development. As a result, the Panel recognizes the potential for this first large-scale example of a compensation lake to be a valuable source of information. Therefore, the Panel recommends that DFO require CNRL to share its monitoring results with other stakeholders in the region.

The Panel notes the uncertainty surrounding the issue of fish tainting. It notes evidence provided by EC regarding the difficulty in relying on predictions without having chronic effects data available and without having a good understanding of potential effects on fish due to tainting compounds. The Panel notes CNRL's participation in regional initiatives intended to address issues of water quality and fish health, and it is encouraged by the work of the Fish Tainting Committee under CONRAD. However, it also notes EC's evidence that the fish tainting program may not address knowledge gaps adequately. The Panel also recognizes that information is not being generated in a manner that sufficiently addresses current concerns. Therefore, the Panel recommends that DFO, ASRD, and AENV require CNRL to conduct follow-up studies on potential impacts of fish tainting compounds from its project on relevant fish species in any approvals issued to CNRL. Such studies would supplement existing work. Furthermore, the Panel encourages DFO and EC to increase their participation in the Fish Tainting Committee such that the information gaps and research needs identified by the Government of Canada are addressed.

The Panel notes that the issue of naphthenic acids and their potential impacts on water quality and fish tainting has been known for 20 years. While the Panel recognizes the complexity of this issue, it believes that a higher priority should be placed on understanding naphthenic acids and their impacts on fish tainting.

The Panel heard evidence that undisturbed riparian areas were necessary to mitigate the effects of the project on fish and fish habitat. The Panel notes that DFO provided evidence that a minimum setback of 250 m would protect riparian habitat. Accordingly, the Panel directs that the project area include a setback of a minimum of 250 m from the edge of the wetted width of the Athabasca River during spring flow, excluding the water intake facility. The Panel notes that other setback distances were suggested for the purposes of facilitating wildlife movement. This issue is addressed in Section 16.3 of this report.

The Panel concludes that with the implementation of CNRL's mitigation measures and the Panel's recommendations and proposed condition, the project is unlikely to result in significant adverse environmental effects on aquatic resources.

16 TERRESTRIAL RESOURCES

16.1 Land

16.1.1 Views of CNRL

CNRL noted that the project would result in the direct loss of 17 193 ha (62 per cent of the LSA) of terrestrial vegetation, wetlands, and forest resources, but that progressive reclamation would minimize the extent of surface disturbance at any one time.

CNRL noted that the reconstructed terrain would have a greater area of water and slopes that are more varied and steeper than the natural terrain. CNRL stated that 1271 ha of mineral and organic soils would be replaced permanently with EPLs at closure. CNRL expected mineral soils to increase following reclamation due to the creation of 3352 ha of reclaimed mineral soil; however, organic soils would be reduced by 4711 ha.

CNRL noted that only 10 ha of potential rare plant habitat in the LSA would be removed, representing a low environmental consequence. It also predicted negligible effects for old growth forest and changes in hydrology. The remaining terrestrial vegetation, wetlands, and forest resource components would either increase in habitat area or remain the same as a result of the project.

CNRL stated that changes in forest capability had a negligible impact over the long term, with minor short-term impacts that would be offset by the salvage of merchantable trees. It rated changes in forest capability as small, since there would be an increase in soils, which would support forestry after reclamation.

CNRL identified that there would be a loss of 3995 ha of peatlands and a gain of 1986 ha of wetlands (including a graminoid marsh) in the LSA, with a total loss of 2009 ha of wetlands (including peatlands) due to the project after reclamation. CNRL noted that the 2009 ha loss represented less than a 1 per cent change in the 1.4 million ha of wetlands (including peatlands) or the 2 277 376 ha RSA. CNRL noted that it would be replacing certain wetland types and that these would play an important role in the reclamation landscape, including attenuating floods and naturally treating water. CNRL stated that in terms of reclamation, muskeg would not be returned to the landscape in a functional capacity but would instead be intermixed with overburden and mineral soil and used as reclamation material.

CNRL stated that it considered cumulative effects to be moderate for the loss of both wetlands (including peatlands) and potential rare plant habitat. Wetlands and potential rare plant habitat would each experience a 3 per cent decrease in area in the RSA, with less than 1 per cent of this attributed to the project.

CNRL stated that it assessed fragmentation for undisturbed, forested, riparian, and old growth areas. The project resulted in an 11 per cent reduction of forested areas, an 11 per cent increase in riparian areas, and a 5 per cent decrease in old growth forest, measured as a percentage of the LSA. Reclaimed ecosystems would have a structure capable of supporting old growth forests beyond closure (100 to 140 years).

CNRL stated that it was committed to the environment and would actively participate in regional committees that addressed monitoring of terrestrial vegetation, wetlands, and forest resources in the oil sands region. Project-specific measures would include monitoring of soil and vegetation re-establishment on reclaimed sites and monitoring programs designed to provide feedback to management systems on the effects of development and mitigation activities.

CNRL also stated that it would be involved in research programs such as CONRAD to resolve uncertainties associated with reclamation. CONRAD's research would examine the benefits of shallow topsoil salvage, correlating and classifying reclamation soil prescriptions with land capability and forest development, reclamation techniques to return bog and fen peatlands, examining the effects of salinity from NST and process water, and assessing a model for determining the sustainability of reclaimed soil series.

CNRL noted that its C&R plan was a key mitigation strategy. It would be designed to minimize disturbance to terrestrial vegetation, wetlands, and forest resources and to re-establish resources to equivalent predevelopment capability. The closure landscape would reflect a diverse environment and would include varied topography, natural vegetation units, wetlands, and EPLs. It planned long-term monitoring as a part of the project to ensure that the soil reclamation procedures returned an equivalent capability.

Specific mitigation would include

- avoiding or reducing incremental impacts by reusing previously disturbed areas (e.g., linear corridors) where possible;
- practicing progressive reclamation techniques and direct placement of soils where practical to preserve the natural seed bank and viable root fragments, thereby enhancing diverse native vegetation regeneration;
- conserving, restoring, and replacing topsoil and surface organic material to specified depths to attain appropriate land and soil capability classes for forestry;
- leaving islands of undisturbed vegetation where practical for rapid recolonization; and
- reconstructing early successional ecosite phases that would succeed to sustainable vegetation communities.

16.1.2 Views of MCFN

MCFN stated that although the contribution of a single development probably had relatively little effect on ecosystem processes, as few as two projects could significantly push the ecosystem function in the area into a new ecosystem configuration.

MCFN noted that there was a distinct threshold of land cover cleared, approximately 50 per cent, at which point landscape configuration and ecosystem processes changed. As forests were cleared, forest patch numbers increased while patch size decreased until a maximum number of forest patches were reached at about 50 per cent. This affected the diversity of species across the landscape and might represent a sudden shift from one ecosystem to another that could be irreversible.

MCFN stated that the project would not be completed until 2045 and that reclamation would be complete within 80 years. In the meantime, the project lease would be reduced to craters and pits. Cumulatively, the disturbance could be as large as 4700 km^2.

MCFN stated that the importance of the current wetland types on the CNRL lease was their ability to hold water and act as a natural water treatment system for the environment. MCFN indicated that CNRL planned to replace the existing wetlands with cattail wetlands, which would not function in the same manner.

MCFN recommended a review of current wetland protection plans, policies, and legislation. It requested that MCFN be afforded an opportunity to provide input and review any changes that occurred as a result.

MCFN noted that CNRL's statement that "land productivity and diversity would be restored to predisturbance capability" remained unproven and unsubstantiated. It stated that some wetland types in particular had proven difficult to reclaim.

MCFN also noted that there was a limited ability to return land disturbed in oil sands mining operations to equivalent capability. It was concerned that this would be an economic decision for CNRL and not an environmental/reclamation question.

16.1.3 Views of OSEC

OSEC indicated that the cumulative surface disturbance in the oil sands region represented a significant impact on the boreal forest. OSEC was concerned that the cumulative disturbance in combination with the loss of wetlands in the Fort McMurray region could be significant. It noted that the CNRL mine would add 17 193 ha to the 180 000 ha of planned regional disturbance and that although CNRL planned to use progressive reclamation, the majority of reclamation was not scheduled to occur until after 2030.

16.1.4 Views of Canada

EC stated that wetlands and peat sequestered mercury and sulphate and that the lands in the area of wooded fens contained high dissolved organic compounds.

EC noted that the removal of wetlands would have a significant adverse environmental effect on wetland function at the local level. EC stated that monitoring would be important to confirm that wetland function would be restored and maintained in the reclaimed landscape to the greatest extent possible. EC stated that the EIA dealt with wetland issues adequately.

16.1.5 Views of Alberta

ASRD noted that it had responsibilities under the PLA to regulate and direct conservation and reclamation activities, authorize the use of public lands, regulate CNRL's vegetation removal, aggregate management, and conservation and reclamation activities, and manage the conservation and reclamation of CNRL's mineral surface leases in conjunction with AENV.

ASRD also noted that it had regulatory, resource management, and planning responsibilities to regulate the removal and use of forest resources and to provide direction for reforestation during reclamation under the Forests Act.

16.1.6 Views of the Panel

The Panel notes that CNRL's mitigation of environmental effects relies heavily on its C&R plan, which requires CNRL to succeed in reclaiming the landscape to equivalent land capability. The Panel also notes that there remains a significant amount of uncertainty in the ability of industry to achieve adequate reclamation. Further expectations of the Panel regarding reclamation are detailed in Section 16.4 on Reclamation.

The Panel notes the concerns of MCFN and EC about the loss of wetlands. The Panel believes this is necessary to recover the oil sands resource. The Board notes that 50 per cent of the wetlands area lost would be reclaimed as wetlands. The Panel also notes that the cumulative reduction of wetlands and areas of rare plant potential is small on a regional scale. The Panel recognizes that it is not possible to completely duplicate the functioning of the original wetland landscape through the current suite of reclamation techniques and that some loss of wetland function will occur in the reclaimed landscape. The Panel recommends that ASRD and AENV identify this area of wetlands research as a priority for CEMA to address. AENV should also consider requiring CNRL to develop and initiate programs to facilitate wetlands restoration. Should wetlands restoration methods prove to be technically and economically feasible using stripped organic matter, there is further potential for the seedbed to regenerate native and rare plants. However, the Panel notes that CONRAD and CEMA are currently working to develop new techniques and reclamation processes for maintaining, saving, and reclaiming fens and bogs. The Panel expects that as new techniques are developed, they will be adopted by industry and applied appropriately through EPEA approvals and C&R plans.

The Panel believes that CNRL adequately dealt with the issue of ecosystem shift. CNRL acknowledged that it would not be returning an identical ecosystem to the landscape, but rather an ecosystem with similar functions. The Panel notes that CNRL has made significant commitments to monitor for early detection of unexpected ecosystem responses and to mitigate and adaptively manage as required. The Panel supports the development of a comprehensive monitoring program to detect these changes.

The Panel concludes that with the successful implementation of CNRL's mitigation measures, further research, and the Panel's recommendations, it is unlikely that the project will have significant adverse effects on terrestrial resources.

16.2 Wildlife

16.2.1 Views of CNRL

CNRL stated that the wildlife assessment for the local and regional effects of the project considered changes to habitat (loss and fragmentation), barriers to movement, and wildlife mortality resulting during construction, operation, and reclamation. It conducted the assessment for 14 wildlife species that represented the key indicator resources (KIR).

CNRL stated that local habitat loss due to the project would be high for all wildlife KIRs, with habitat loss ranging from 60 per cent (Canadian toads) to 70 per cent (muskrats). However, habitat gains at closure, as a result of reclamation, would be high for most KIRs. CNRL stated that it expected habitat loss in the RSA under the Planned Case for all KIRs to have low effects.

CNRL stated that the residual impacts of barriers to wildlife movement would be negligible locally for most KIRs. CNRL stated that residual impacts of direct mortality from site clearing, increased potential for nuisance wildlife, and interaction with infrastructure would be negligible for all KIRs considered. CNRL noted that residual impacts of increased predation, hunting, and trapping from improved access would be negligible for all KIRs except for moose and bears, which would be low.

CNRL stated that it was committed to wildlife monitoring. A wildlife monitoring program would be developed in consultation with regulators and would include regional wildlife initiatives. The wildlife monitoring program would include monitoring for listed species, reclamation success, and wildlife movements.

CNRL stated that its key mitigation would be its C&R plan. It planned a diverse environment for the closure landscape, which would include a varied topography, natural vegetation units, wetlands, and EPLs.

CNRL stated that mitigation measures included

- avoiding or reducing effects on special status species where practical;
- reconstructing early successional ecosite phases that would sustain vegetation communities;
- minimizing the effects of barriers on wildlife movement;
- managing mortality for nuisance wildlife;
- minimizing the effects of wildlife interactions with infrastructure, including those put in place for transmission lines, communication towers, and tailings ponds;
- managing the effects of potential increased predation/hunting/trapping as a result of changes in access and human use; and
- reducing vehicle-wildlife collisions.

CNRL also stated that it intended to undertake additional mitigation measures to address potential bird mortality due to tailings ponds, including the installation of bird deterrent systems and specialized sound systems to deter nonwaterfowl bird species.

CNRL concluded that no residual significant adverse effects on wildlife would occur within the project area and that no significant effects on wildlife would occur within the region.

16.2.2 Views of MCFN

MCFN stated that it wanted CNRL to research the adverse effects the improved access for nontraditional users to remote areas would have on fish and wildlife populations and to propose a solution.

MCFN stated that cumulative oil sands activities in the mineable area could clear more than 50 per cent of the land cover over the next 20 to 40 years, causing fragmentation and possibly an ecosystem shift that would affect wildlife core security and composition in the area.

16.2.3 Views of Canada

EC stated that it had not identified any issues under the Species at Risk Act arising from the project. It was possible that there may be species at risk on the lease area, but in the unlikely event that one was encountered, CNRL was expected to take appropriate measures.

EC noted that the monitoring of the trend and populations of breeding birds in the RSDS study area was essential. EC stated that there were no timelines or work plans under CEMA's

Sustainable Ecosystems Working Group (SEWG) to undertake the completion of monitoring of bird indicator species. Therefore, EC recommended that prior to project construction, CNRL provide the design and implementation schedule of a long-term monitoring program for the LSA for listed species, and Priority 1 and 2 indicator species identified by the CEMA Wildlife and Fish subgroup.

EC stated that the final landscape contained EPLs and that if CNRL's modelling was incorrect, the water quality could be poorer than predicted and could lead to potential adverse effects on wildlife. EC recommended that CNRL conduct long-term monitoring of the buildup of contaminants in EPLs and the potential for effects on migratory birds.

EC commented that given the projected loss of forest bird habitat sites, CNRL's development activities should be timed to avoid critical periods for migratory birds and other wildlife. EC recommended that vegetation clearing activities avoid the April 1 to August 31 time period.

16.2.4 Views of Alberta

ASRD noted that under current regulations, policies, and the Wildlife Act, it would provide advice and direction to CNRL on mitigation and other measures to support the sustainability of wildlife resources. ASRD would also monitor CNRL's management strategies and practices.

16.2.5 Views of the Panel

The Panel notes that impacts of the project on wildlife KIRs are generally predicted to have a low environmental consequence in a regional context.

The Panel recognizes that active mining areas remove wildlife habitat for some time and that CNRL is depending on the effectiveness of reclamation to mitigate wildlife issues. The Panel believes that with the implementation of appropriate mitigative measures, impacts can be kept to an acceptable level. The Panel acknowledges that CNRL developed a general list of mitigation measures that may reduce impacts on wildlife.

The Panel recommends that AENV and ASRD include EC in their discussions with CNRL to determine acceptable monitoring and mitigation requirements for wildlife.

The Panel concludes that with the implementation of CNRL's mitigation measures and the recommendation of the Panel, the project is unlikely to result in significant adverse environmental effects on wildlife.

16.3 Wildlife Corridor

16.3.1 Views of CNRL

CNRL stated that the wildlife corridor described in its EIA was 250 m from the top of the escarpment to the mine pit boundary, with an additional 100 to 150 m buffer from the Athabasca River to the top of the escarpment. The 100 to 150 m distances between the river and the escarpment varied along the length of the Athabasca River. At some points along a 2 km stretch of the Athabasca River where the distance between the river and the escarpment was minimal, the total setback distance could be as narrow as 250 m. CNRL stated that the wildlife corridor did not include a provision for the permanent water intake structure that would be positioned within this buffer zone. However, CNRL noted that the intake structure could be built with minimal impact on the corridor.

CNRL noted that additional work was required to confirm that the proposed wildlife corridor would be sufficient and stated that it would not be encroaching on the corridor until 2015. CNRL committed to work with interested stakeholders to conduct additional work to either confirm or revise its wildlife corridor plan.

16.3.2 Views of OSEC

OSEC stated that oil sands developments, including the proposed project, would compromise the integrity of riparian habitat and wildlife movement corridors critical to the viability of many wildlife populations.

OSEC believed that CNRL recognized the importance of this issue because CNRL had committed to undertake a wildlife movement study. OSEC noted that this should be a scientifically defensible evaluation of the effective corridor width needed to allow wildlife movement. OSEC expected that the development of an effective corridor width would be represented in the annual mine plans presented to the EUB and that the annual mine plans would be approved accordingly.

16.3.3 Views of MCFN and WBFN

MCFN and WBFN indicated concern about the adequacy of the proposed wildlife corridor, since there was minimal science available. MCFN asked to be involved in the development of appropriate monitoring programs for wildlife corridors.

16.3.4 Views of Canada

EC stated that the lack of information on the characteristics of effective wildlife corridors in the boreal forest limited the ability of CNRL and regulators to be certain of the appropriateness of CNRL's wildlife corridor plans.

EC recommended a minimum no-development setback from the Athabasca River (including utility corridors) of 400 m of upland forest plus the sloping valley sides. EC also recommended that CNRL lead an effort, in partnership with other developers operating in the region, to collect baseline data on wildlife use of river valleys and adjacent upland habitats and to study wildlife use of corridors that have been and would soon be created during the construction of oil sands mines.

EC stated that it understood the need to balance social, economic, and environmental issues in determining the appropriate width of a wildlife corridor.

16.3.5 Views of Alberta

Alberta stated that river valley ecosystems were important habitats for many wildlife species. River valley setbacks and habitat corridors were considered to be important components of wildlife management, particularly in landscapes altered extensively by human activities.

ASRD noted that during the hearing, CNRL referred to a width of undisturbed corridor that was different from what was proposed in the application and that the corridor could be reduced to 250 m at some points. Alberta understood from CNRL's application that there would be an undisturbed 400 m wide corridor. Alberta would consider a 400 m setback a positive step towards maintaining wildlife habitat values and connectivity along the Athabasca River valley.

ASRD indicated that the project activity did not contribute significantly to cumulative effects on key habitats and habitat connectivity for key wildlife species. But it also stated that the increased level of disturbance coupled with the potential for long-term cumulative impacts on habitat connectivity was not well understood and could influence natural dispersal patterns and seasonal range distributions for some species of wildlife, in particular, medium to large mammals.

ASRD indicated that although a continuous, effective valley corridor had already been compromised along the Athabasca River, additional mining disturbance within and adjacent to the valley would add to the cumulative effect by increasing the total disturbance area and period of impact. Alberta recognized that while river valley ecosystems were important and the widest possible setback from disturbance would achieve the maximum benefit for wildlife and biodiversity, the decision on river valley habitat corridors must also consider the value of bitumen reserves in the same location.

ASRD requested that the Panel require CNRL to undertake and lead a research and monitoring program, preferably in cooperation with other oil sands developers and stakeholders, to examine wildlife responses and effective setback distances for movement corridors in the oil sands area and to examine other potential mitigation and reclamation measures. This program could be accomplished through existing regional stakeholder forums, such as CEMA. Alberta stated that CNRL must be held accountable to ensure that the research program was completed in a timely manner. In addition, findings of this study could be used to review and revise the proposed wildlife corridor or include other forms of mitigation for the project. Alberta suggested that such changes be explored collaboratively with CNRL, the EUB, and ASRD to ensure an adaptive approach that would maximize corridor benefits within the context of the project.

ASRD also recommended that the Panel require CNRL to submit a cooperative research proposal for review and acceptance by the Director of Wildlife Management and to initiate a program within 12 months after receiving regulatory approval from the EUB. Preliminary results of this research program should be made available within 48 months following regulatory approval to help direct decisions regarding effective setbacks and wildlife corridors for this project and other future oil sands mining applications.

16.3.6 Views of the Panel

The Panel notes that there is significant uncertainty regarding the appropriate width and design of wildlife corridors in the mineable oil sands area. It also notes that there was agreement among the interveners and CNRL that additional work is required before an appropriate width can be determined. The Panel acknowledges CNRL's commitment to undertake the work in a timely manner and to involve both regulators and stakeholders. The Panel supports Alberta's position to require CNRL to do a wildlife movement study.

The Panel notes that CNRL has committed to a 250 m buffer to protect riparian habitat along the Athabasca River. This buffer would also effectively provide a minimum 250 m wildlife corridor. The Panel acknowledges that CNRL would not be affecting the expected wildlife corridor area physically until 2015, leaving CNRL sufficient time to determine the width of its wildlife corridor. The Panel expects CNRL's annual mine plans to reflect any changes in mine design resulting from changes in wildlife corridor design and width.

The Panel acknowledges that there are a significant number of issues to be considered in the determination of an appropriate wildlife corridor width, including but not limited to the balance of resource recovery versus the effective protection of wildlife movement. The Panel expects that the EUB will provide oil sands resource information to assist CNRL's initiative.

The Panel concludes that with the implementation of CNRL's mitigation measures, additional research, and the implementation of the Panel's recommendations, the project is unlikely to result in significant adverse environmental effects on wildlife movement.

16.4 Reclamation

16.4.1 Views of CNRL

CNRL stated that it expected its current resource delineation and mine plan to disturb up to 17 193 ha of land over the life of the project. CNRL's progressive reclamation would commence within 10 years of mining, with the ultimate objective of tailings placement to create a stable trafficable deposit amenable to dry landscape reclamation as quickly as possible. Additional reclamation techniques that might be used to improve the likelihood of success included direct placement of surface materials, storage of woody debris for future reclamation, salvage of shallow soil layers, and conservation of peat materials.

CNRL committed to minimizing the surface disturbance footprint of the plant, mine, and tailings-handling facilities. CNRL expected that by 2030, up to 10 per cent of the disturbed area would be in various stages of reclamation. CNRL expected that through continued research, collaboration with industry, consultation with stakeholders, and ongoing monitoring and review, it would be able to restore the land to equivalent or better capability than the original.

CNRL committed to participate in reclamation research programs, improve reclamation practices continuously, undertake an integrated reclamation monitoring program, and participate in existing regional reclamation monitoring programs. CNRL committed to submit annual reports to AENV that documented development and reclamation activities at the project.

CNRL stated that its proposed NST tailings management disposal scheme was a significant advancement in the management of tailings. It had the benefits of

- minimization of surface land disturbances,
- a major reduction of MFT volumes,
- reduced water requirements and additional opportunities to recover waters suitable for reuse, and
- improved, more rapid reclamation to a trafficable and contoured landscape.

CNRL also indicated that there would be opportunities to review and revise its reclamation plans as development progressed and that it was committed to an open and transparent process involving all interested stakeholders.

CNRL stated that through progressive reclamation the land would be put back to an equivalent, or in some cases, better land-use capability. CNRL noted, however, that it could not duplicate the existing ecosystem and that reclamation of the project area would result in a change to the relative percentage of ecosystem types on the lease.

16.4.2 Views of OSEC

OSEC indicated that the cumulative surface disturbance in the oil sands region represented a significant impact on the landscape of the boreal forest. OSEC was concerned that the cumulative disturbance in combination with the loss of wetlands in the Fort McMurray region could be significant. OSEC noted that the CNRL mine would add 17 193 ha of disturbance and, although CNRL planned to use progressive reclamation, the majority of reclamation was not scheduled to occur until after 2030.

OSEC stated that to date very little area directly affected by oil sands mining operations had been restored to land with capability equivalent to the premining conditions and no oil sands operations had yet received a reclamation certificate from the Government of Alberta.

OSEC had concerns that decision-makers were allocating terrestrial resources to the oil sands industry in the absence of information on the region’s terrestrial carrying capacity or demonstrated ability to reclaim lands affected by oil sands mining to certification standards.

16.4.3 Views of MCFN

MCFN stated that it was concerned that there were no reclaimed pits in the oil sands region and that the government continued to approve mining projects. MCFN questioned when government would certify that the land could be reclaimed.

MCFN stated that CNRL’s commitment to design and implement a reclamation plan that would restore as many of the ecological components of the boreal environment and landscape as feasible was too vague. MCFN noted that there was a limited ability to return land disturbed in oil sands mining operations to equivalent capability, and it was concerned that this would be an economic decision for CNRL, not an environmental or reclamation question.

MCFN stated that CNRL did not adequately assess ecosystem shift and that the information about how ecosystem shifts affect reclamation success was incorrect, incomplete, or nonexistent.

MCFN noted that as a result of ecosystem process changes, ecosystem services were reduced or altered. The services could include the purification of air or water. MCFN stated that it had been determined that such shifts caused by humans could be irreversible and, therefore, in MCFN’s view, it would be prudent to avoid an ecosystem shift rather than attempt to deal with it afterwards.

16.4.4 Views of Alberta

Alberta stated that the project would be subject to existing legislative requirements to ensure minimal disturbance and successful conservation and reclamation to re-establish a landscape having land capability equivalent to predisturbance.

16.4.5 Views of the Panel

The Panel acknowledges that the reclamation of oil sands mines is a significant issue. It is encouraged that CNRL has adopted progressive reclamation and that it is proposing an NST management disposal scheme for the majority of its tailings.

It is the Panel's view that although land reclamation and associated issues are regulated under EPEA, the reclamation planning and final landscape objectives are important considerations when the Panel is determining whether an oil sands development is in the public interest.

The Panel is aware that while some overburden disposal sites within the mineable oil sands area have been reclaimed, none has been certified. The Panel also notes that no tailings sites within the mineable oil sands area have yet been reclaimed. However, the Panel also notes that the nature of oil sands mining development inherently requires large areas of disturbance that may remain on the landscape over an extended period of time.

The Panel understands that CNRL has put a great deal of reliance on its progressive reclamation plans to mitigate environmental impacts of the project. A large component of achieving progressive reclamation depends on successful tailings management, reducing or eliminating fluid-based tailings, and timely implementation of reclamation practices. This would facilitate reducing long-term environmental liabilities, improving water management, and increasing certainty in the near term that reclamation objectives can be achieved cost effectively. The Panel notes that in Section 10 of this report it directs EUB staff to initiate work with oil sands operators to develop performance criteria for tailings management. The Panel recommends that AENV and ASRD consider whether additional criteria could be developed for progressive reclamation to complement the proposed tailings management criteria.

The Panel notes that CNRL identified the potential to reclaim a portion of its tailings pond prior to the end of the project life, promoting additional progressive reclamation. The Panel encourages CNRL to continue to investigate this option and implement earlier reclamation.

In the absence of environmental thresholds or management objectives from CEMA, the Panel believes it prudent to adopt a precautionary approach on the issue of reclamation. The Panel believes that to the extent allowed by current technology, the oil sands industry should minimize the total amount of land disturbed at any given time and that operators should strive to reclaim disturbed lands as soon as possible.

The Panel notes that there are opportunities for CNRL to revise and improve its reclamation plan through the annual mine plan and 10-year C&R plans, as its project progresses and additional knowledge is gained through continued research and development on tailings.

16.5 End-Pit Lakes

16.5.1 Views of CNRL

CNRL stated that EPLs would be part of its reclaimed landscape. CNRL noted that EPLs in combination with wetlands had long retention times, allowing biodegradation of organic substances; large water volumes, providing dilution of reclamation waters; and low flow velocity, promoting settling of suspended particulate substances. CNRL committed to ensuring that any discharges from the EPLs would meet *Alberta Surface Water Quality Guidelines* or the guidelines in force at the time of release.

CNRL modelled EPLs using a flow and mass balance model. CNRL noted that the water quality component of the EIA was based on state-of-the-art modelling, which incorporated conservative assumptions and accounted for any uncertainties.

CNRL stated that the EPLs would support viable, self-sustaining sport fish populations and would be built according to the CEMA EPL Working Group design and operational specifications. CNRL stated that it was committed to participating in research programs through CEMA and CONRAD to ensure that its EPLs would meet all regulator and stakeholder goals.

16.5.2 Views of MCFN

MCFN questioned the predictions pertaining to water quality in EPLs. According to MCFN, the predictions were made using unverified models. It questioned the accuracy of those models and noted the lack of follow-up of previous predictions relative to past developments.

16.5.3 Views of Canada

EC acknowledged the environmental risk of EPLs with respect to water quality but noted that there was legislation to ensure that poor quality water would not be released into fish-bearing waters. EC noted that any tailings release or seepage from EPLs into fish-bearing waters might constitute a violation of the Fisheries Act, which would warrant EC taking enforcement action.

DFO stated that there were no functioning examples of EPLs from which to verify CNRL's EIA predictions. DFO stated that in the event that EPLs were not viable, sufficient time would be needed to develop and implement alternative strategies prior to mine closure. DFO expressed concern that the lack of empirical evidence supporting the performance of EPLs could lead to a lack of viable options at the time of mine closure unless all stakeholders made EPL research a priority.

DFO recommended that ongoing research into the design and function of EPLs be continued and expanded. DFO also recommended additional research on mining and recovery options to reduce or eliminate the need for EPLs.

16.5.4 Views of Alberta

Alberta stated that the viability of EPLs as a sustainable ecosystem in the closure drainage landscape had yet to be demonstrated. Uncertainty in EPL design, functionality, and water quality were identified under RSDS as significant issues. Alberta believed that the pace of work currently being carried out under CEMA on the theoretical development of EPLs and guidance document was appropriate.

Alberta stated that CNRL's predictions regarding the function of the closure drainage landscape were reasonable, based on the information currently available. Alberta stated that given the complexity and uncertainty about EPL function, continued priority should be given to ongoing research.

Alberta stated that validation of EPL models would require a physical test case and that it might request CNRL to provide a research schedule for the construction of a field pilot in partnership with other oil sands companies to test EPL predictions and design features.

16.5.5 Views of the Panel

The Panel acknowledges that EPLs are a complex and still relatively unproven reclamation method for dealing with process-affected water and tailings. The Panel recognizes that the oil sands industry as a whole needs to take greater responsibility in addressing the issue of EPLs and moving towards larger scale field testing.

The Panel agrees that a demonstration test is necessary to further advance knowledge about EPLs. The Panel supports AENV's intention to require CNRL to provide a research schedule that includes the testing of EPL predictions and design features with a physical test case in partnership with other oil sands companies. The Panel expects that this work would be completed in the next 15 years. Therefore, the Panel recommends that AENV monitor EPL development and testing.

The Panel concludes that with the implementation of CNRL's mitigation measures and the recommendation of the Panel, EPLs are unlikely to result in significant adverse environment effects.

17 AIR

17.1 Views of CNRL

CNRL stated that it modelled both project and regional emissions to evaluate the effects on humans, wildlife, and aquatic health, as well as the potential acidifying effect on lakes, streams, soils, and vegetation. It believed that there would be no unacceptable effects associated with its project. CNRL stated that the project design included several enhancements to address environmental effects that in some cases exceeded EUB requirements, including the following:

- It would design its sulphur recovery technology to achieve a 99.2 per cent sulphur recovery level. However, CNRL stated that this would be a design target and that it expected to receive approval for the lower regulatory recovery level of 98.8 per cent set out in EUB *ID 2001-3*.
- Mine vehicles would meet the U.S. Environmental Protection Agency Tier 2 emission standards for nitrogen oxide and that low NO_x burners would be used.

- It would install two NRUs and would hydrotreat make-up diluent to remove sulphur compounds. This would help to minimize odours and reduce tailings emissions.

CNRL stated that it would continue to review emissions control technology and implement those that had value and met economic criteria. It stated, for example, that CNRL and other industry members had put pressure on engine suppliers for better engine performance.

CNRL stated that there was a potential to exceed the one-hour Alberta Ambient Air Quality Guideline for SO_2 should acid gas be flared as a result of plant upsets. It stated that in the event of an upset, it planned to bring the plant back into operation quickly and flare the least amount possible. CNRL intended to have a monitoring trailer between its operations and Fort McKay, as well as a notification system as part of its emergency response plan to address potential risks associated with flaring.

CNRL stated that the project was designed to achieve industry-leading energy efficiency and sector-leading greenhouse gas emission intensity. It stated that it would review new technology for subsequent phases to realize continuous improvement in energy efficiency and emissions reductions; however, it did not commit to future targets.

17.2 Views of OSEC

OSEC stated that its bilateral agreement with CNRL included air emissions issues. It stated that it was concerned about increasing acidifying emissions in the oil sands region and the expanding area predicted to receive those emissions. It stated that best efforts should be made to reduce NO_x emissions. It noted that CNRL had committed to reviewing burner and mine fleet emissions control technologies.

OSEC pointed out that the majority of acidifying emissions from the project was attributed to the mobile mine equipment. OSEC stated that its favoured mitigation would be to limit acidifying emissions. It noted that CNRL had committed to purchase low NO_x and SO_2 emission engines in 2008. OSEC stated that the greenhouse gas management aspects of its agreement with CNRL were a step forward in addressing a significant deficiency of the application. It stated that CNRL had agreed to establish continuous improvement targets for reduction of greenhouse gas intensity by 2005.

17.3 Views of Canada

EC noted that emissions from oil sands mining activities contributed to a number of important air issues, including acid deposition, smog, toxic air contaminants, and climate change. It stated that the NO_x-SO_2 Management Working Group had completed and was continuing work to close knowledge gaps related to air issues. It stated that complex interrelationships with sources in the region made it difficult to evaluate impacts from individual emitters. EC stated that it was important to shift from project and individual emissions species evaluations to a broader cumulative effects approach.

EC recommended continuous monitoring of nitrogen dioxide (NO_2) and NO_x within the oil sands region to validate near-field modelling of baseline and cumulative environmental assessment conditions, as well as to assess the effectiveness of improved fleet emission controls and best management practices over time.

EC recommended that stakeholders within the oil sands region collectively review ozone and precursor monitoring and modelling results and formulate an action plan to fill in the remaining gaps with respect to cumulative impacts.

EC noted that a long-term series of chemical measurements at spatially representative sites was needed to provide a full picture of particulate matter formation, transport, trends, and impacts. EC recommended that regional stakeholders participate in programs to initiate particulate matter and precursor monitoring. It further stated that inventories of particulate matter ($PM_{2.5}$) and associated modelling should be enhanced, including assessment of potential secondary particulate matter formation and long-range transport.

EC stated that a computer model predicted total acid deposition by simulating wet and dry deposition of relevant compounds. Wet deposition compounds were obtained directly from sampling, whereas dry deposition compounds were calculated. EC requested that the Panel include a recommendation to CEMA to design and initiate a wet and dry acid deposition monitoring program within the oil sands region. EC also recommended that all operators, including CNRL, comply with the elements of the acid deposition management framework currently being developed by the NO_x-SO_2 Management Working Group.

EC stated that preliminary acid deposition modelling indicated that long-range transport into Saskatchewan was likely causing acid deposition at levels well below the threshold for harmful effects. It stated that AENV and EC had recently undertaken additional acid deposition modelling in Alberta with a 30-year time frame so that variations in patterns and a range of deposition rates could be evaluated over time. If this new modelling indicated that deposition in Saskatchewan was more significant, monitoring in Saskatchewan might be needed and mitigative solutions considered.

Natural Resources Canada (NRCAN) concluded that CNRL had reduced the greenhouse gas intensity of its existing operations and had committed to continue efforts in that regard. It stated that CNRL was proposing to use industry standard technology to reduce emissions and that CNRL's forecast emissions were consistent with the oil sands industry as a whole. It stated that CNRL would be assessed as part of the Large Industrial Emitters Group, which was responsible for establishing and administering emission intensity targets.

17.4 Views of Alberta

AENV stated that it would be unlikely that the Canada Wide Standard (CWS) for $PM_{2.5}$ would be exceeded. However, it also stated that there was a need for monitoring to confirm CNRL's predictions. It added that it might include conditions in its approval requiring CNRL to collaborate with the Wood Buffalo Environmental Association (WBEA) on enhanced monitoring.

AENV noted that the project would increase regional SO_2 emissions by 4 per cent to 316 tonnes per calendar day (t/cd). It noted that predicted 99.9 percentile one-hour SO_2 concentrations would not exceed Alberta Ambient Air Quality Guidelines. It stated that SO_2 emissions should be controlled to the lowest practicable level, and it viewed CNRL's plan to use tail gas cleanup as consistent with AENV's requirements. It stated that it expected the plant to be designed and operated to minimize upsets that could significantly increase SO_2 emissions.

AENV stated that CNRL's project would increase regional NO_x emissions by 22 per cent to 266 t/cd. It stated that although CNRL predicted exceedance of 24-hour and annual NO_2 Alberta Ambient Air Quality Guidelines, it predicted no exceedances for communities in the area. It stated that NO_2 predictions tended to be conservative (to overpredict actual concentrations). Alberta noted that CNRL committed to using low NO_x burners and using vehicles that met or exceeded applicable emissions standards at the time of purchase. It stated that NO_x emissions should be controlled to the lowest practicable level with appropriate technology, including burners that met Canadian Council of Ministers of the Environment (CCME) low NO_x guidelines and mine equipment that met latest vehicle emissions standards. It stated that CNRL's approval might be conditioned to require it to participate in regional environmental management and monitoring initiatives.

AENV noted that the project would increase areas predicted to be impacted by acid deposition in excess of provincial monitoring loads and provincial critical loads. It stated that AENV might require CNRL to evaluate increasing the height of the main stack to increase NO_x and SO_2 dispersion.

AENV stated that it expected CNRL's plant to be designed to minimize odour incidents related to volatile organic compounds (VOCs) and other odourous gases. It stated that AENV might require CNRL to add NRU redundancy or to reduce throughput during upsets to prevent release of untreated tailings.

AENV noted that the project would increase Alberta's annual greenhouse gas emissions by 7.7 10^6 t of CO_2 equivalent. It stated that AENV might require CNRL to submit an annual greenhouse gas emissions and intensity summary report. The report would also be required to address measures taken to meet predicted performance levels and continuous improvement. It stated that it might also require CNRL to participate in future greenhouse gas emissions reporting and sectoral emissions limits or targets.

17.5 Views of the Panel

The Panel believes that new oil sands projects must minimize acidifying emissions (SO_2 and NO_x) through the implementation of effective controls and project designs. CNRL's use of tail gas cleanup technology to minimize SO_2 emissions is an example of using best practicable technology that improves upon minimum regulatory standards. The Panel notes that CNRL has designed its project for a 99.2 per cent acid gas sulphur recovery target relative to a minimum regulatory requirement of calendar quarter-year 98.5 per cent sulphur recovery, as set out in *ID 2001-3*.

The Panel expects that CNRL will achieve its 99.2 per cent sulphur recovery target on a long-term basis. Since CNRL's environmental assessment was based on that recovery level, the Panel recommends that AENV consider conditions in its EPEA approval that limit longer term (quarter-year or annual average) SO_2 emissions to levels that correspond with 99.2 per cent sulphur recovery at full calendar-day production rates.

The Panel notes that CNRL requested that its approval reflect the 98.5 per cent sulphur recovery set out in *ID 2001-3*, notwithstanding that CNRL voluntarily proposed to use emission control technology capable of performing better than minimum regulatory standards. The Panel believes that it would be appropriate to require CNRL to meet the minimum calendar quarter-year 98.5

per cent sulphur recovery, as set out in *ID 2001-3*, on the basis of acid gas produced inclusive of flared volumes, provided that long-term SO_2 emission rates are not more than those set out in CNRL's EIA.

The Panel notes that acidifying emissions from CNRL's project will contribute to the potential for acidification of soils and water bodies in the region. The panel expects CNRL to monitor acid deposition in areas potentially affected by the project, either independently or through participation in expanded regional programs. The panel notes that monitoring requirements are addressed by AENV through its EPEA approvals.

The Panel believes that the cumulative impacts associated with industrial development in the region requires new project proponents to minimize emissions, monitor environmental quality, and participate in regional initiatives. In particular, the Panel expects that CNRL will develop and sustain an effective program of operations optimization, technology assessment, and implementation of cost-effective, best-available emissions control technologies to reduce air contaminant emissions, as well as reduce the energy and greenhouse gas emissions intensity of its operations. This program must be an integral part of planning for capital equipment replacements and expansions.

The Panel further expects that CNRL will support regional monitoring programs and related monitoring improvements should these be recommended by CEMA and subsequently adopted by regulators. The Panel expects that CNRL will contribute to future acidifying emissions reductions or constraints should the need for such actions arise from industry and regulator implementation of CEMA recommendations.

The Panel believes that it would be appropriate for AENV to consider measures in its EPEA approval to address the following matters:

- CNRL collaboration with WBEA on enhanced PM monitoring
- Use of appropriate technology to control NO_x emissions to the lowest practicable level, including burners that meet CCME low NO_x guidelines and mine equipment that meets the latest vehicle emissions standards
- CNRL participation in regional environmental management and monitoring initiatives related to NO_x emissions, acid deposition, anthropogenic ozone formation, and nitrogen eutrophication, including participation in ongoing research necessary to implement CEMA recommendations on acid deposition management
- Use of appropriate systems to minimize odour incidents related to VOCs and other odourous gases, including an adequate level of NRU redundancy or other measures to prevent release of untreated tailings during upsets
- CNRL reporting on annual greenhouse gas emissions and intensity, including review of measures taken to meet predicted performance levels and reporting on continuous improvement activities
- Future CNRL participation in sectoral emission limits or targets

The Panel notes that the potential impacts of acid deposition on receptors are addressed in other sections of this decision.

The Panel believes that the project is unlikely to result in significant adverse environmental effects on air quality, provided that CNRL fully implements its proposed air emissions control measures and that performance of those systems is consistent with or better than the assumptions used in the EIA. The Panel notes, however, that the project will contribute to potential cumulative effects in the region. The Panel believes that the potential contribution of the project's air emissions to adverse cumulative effects can be adequately managed with implementation of management frameworks resulting from regional initiatives, including the CEMA NO_x-SO_2 Management Working Group and the Trace Metals and Air Contaminants Working Group (TMAC). The Panel further believes that management of potential cumulative effects will also be addressed by effective implementation of enhanced monitoring by CNRL and/or regional programs administered by RAMP and WBEA.

18 HEALTH EFFECTS

18.1 Views of CNRL

CNRL's human health assessment evaluated the potential for adverse effects to health associated with emissions from the project in combination with existing, approved, and planned developments. It evaluated exposures to chemicals in air, water, soil, and food. CNRL indicated that the assessments were based on many conservative assumptions and that its analysis had likely overpredicted potential risks to human health. Nonetheless, CNRL rated the potential effects from the existing and planned developments as negligible for all routes of exposure in local and regional communities.

CNRL confirmed that it would contribute to regional monitoring programs for substances in air, water, and traditional foods by

- participating in RAMP, which monitors water and fish, and
- participating in WBEA, which conducts ambient air monitoring in local communities and studies the uptake of airborne chemicals through the terrestrial food chain.

18.2 Views of MCFN and WBFN

MCFN stated that it had concerns for its members' health. MCFN and WBFN elders expressed concerns about an apparent long-term decline in the health of aboriginal people generally since the advent of industrialization in the region, although it was not directly associated with any particular industrial activity. Elders' observations, which tended to be supported by the Fort McMurray Medical Staff Association (FMMSA), suggest that aboriginals appear to be particularly susceptible to life-threatening diseases, such as cancer and immune system problems. At the hearing two elders reported serious worries about a large number of deaths in a short period of time in Fort McKay and Fort Chipewyan from a range of different ailments.

MCFN questioned AHW about the feasibility of conducting a baseline health study, the likely form that such a study would take, and the input that would be required from MCFN members.

18.3 Views of FMMSA

FMMSA noted significant concerns regarding health care and the high incidence of serious illness in aboriginals, including First Nations, nontreaty, and Metis individuals. FMMSA expressed a need for more information with respect to community health and requested that a comprehensive health study be conducted to evaluate if apparent problems are part of a trend.

18.4 Views of Alberta

AHW stated that an interdepartmental review team, including representation from HC, with AHW as the lead agency, reviewed the EIA using a population health risk assessment process.

AHW stated that CNRL used an acceptable methodology for its human health risk assessment, noting that the conclusions drawn from the assessment were reasonable. AHW also noted that although there were predicted air quality guideline exceedances, they were likely the result of highly conservative modelling methods. AHW suggested that validation of the predictions made by CNRL would be a logical next step in further addressing the predicted exceedances. AHW indicated that it would collaborate with AENV to determine appropriate conditions for an EPEA approval, should one be issued for the project.

AHW stated that it had strongly encouraged WBEA to include a human health monitoring component to its monitoring programs in the region that would include Fort Chipewyan. AHW suggested that this monitoring component be based on the community exposure and health effects assessment model. AHW further stated that it had made several presentations to WBEA regarding this and it was AHW’s understanding that the item was currently on WBEA’s agenda.

AHW stated that one form of health study could consist of an analysis of the historical health records of specific aboriginal patients, if a list of such patients were provided.

AHW stated that the health of the public would not be compromised by the construction and operation of the project.

18.5 Views of Canada

HC indicated that it was generally satisfied with the EIA and had no outstanding concerns with respect to health or social issues. HC also stated that it was an active partner in the Human Health Monitoring Committee under WBEA.

18.6 Views of the Panel

Potential effects of the project on human health are considered in the Panel’s analyses for other sections of this report, particularly in the sections that relate to air and water quality. The Panel notes that AHW and HC raised no concerns with respect to the effect of the project on human health. The Panel has considered the information brought forward by CNRL and the interveners and concludes that there are unlikely to be significant adverse effects on human health.

In view of the number of concerns that were registered by interveners regarding their observations of declining health, the Panel recommends that AHW and HC consider undertaking a regional health study primarily dealing with First Nations, Metis, and other aboriginal people.

19 MEASURES TO ENHANCE BENEFICIAL ENVIRONMENTAL EFFECTS

19.1 Views of CNRL

CNRL stated that its sulphur recovery technology, the low CO_2 per unit of oil produced, the compensation lake, and the vegetation communities that would be established following reclamation were the beneficial environmental effects that would accrue as a result of the project being carried out.

19.2 Views of the Panel

With respect to CNRL's sulphur recovery technology, CO_2 production, revegetation of previously disturbed areas, and the compensation lake, the Panel views these actions as mitigative measures and not environmental benefits. The Panel expects CNRL to work closely with all stakeholders in finalizing and implementing mitigation measures to maximize any environmental benefits that may accrue as a result of the project being carried out.

20 REGIONAL INITIATIVES

20.1 Views of CNRL

CNRL stated that CEMA was an important and effective working group for dealing with the impacts of oil sands development in the region. CNRL indicated that it believed CEMA had done a substantial amount of work and would continue to be valuable in dealing with important regional issues. CNRL indicated that working through CEMA was a positive and effective method of bringing different stakeholders to the table to deal with important regional issues that may not have been otherwise identified.

CNRL stated that it had recently increased its funding of CEMA and that it was committed to continued participation in regional initiatives. CNRL noted that it would maintain its funding and participation level for both CEMA and RAMP regardless of whether the EUB conditioned it to participate or not.

CNRL stated that it participated in WBEA, a multistakeholder group with a mandate to conduct air quality and ecosystem and human health effects monitoring in the region. CNRL stated that it was committed to continue its participation in regional monitoring and assessment of air emissions in the oil sands region through WBEA.

20.2 Views of OSEC, Fort McKay, and ACFN

OSEC noted that the EUB had indicated with increasing urgency its concerns about the pace of CEMA in achieving the objectives set out in AENV's RSDS.

OSEC maintained that the continued issuance of approvals for oil sands projects in the absence of CEMA-determined management objectives and an established environmental management plan undermined the CEMA process.

OSEC stated that it was becoming increasingly apparent that the original timelines established by RSDS would not be met. It suggested that with the continued filing and consideration of oil sands project applications, CEMA members had less time to dedicate towards the work of CEMA. This was compounded by the fact that many of the experts and consultants required to conduct the work of CEMA had had limited availability due to their involvement in conducting EIAs for oil sands projects.

OSEC stated that the risk of irreversible impacts from oil sands developments was increasing. Given CEMA's difficulties in estimating timelines to collect adequate scientific information to define management objectives and the length of time needed to develop management objectives, OSEC concluded that it was inappropriate for CNRL to rely on the CEMA process to serve as mitigation for project-specific effects.

Fort McKay, OSEC, and ACFN noted that they were committed to CEMA and other regional multistakeholder initiatives, but stated that they were concerned about the lack of progress and resources to meet CEMA's goals. They believed that for CEMA to be effective, it needed a secure supply of sufficient resources, including people with appropriate expertise and funding, accountability by industry and regulators for effective participation, and strong leadership by the regulators who participated in the process. They requested that timelines be set or recommended by the Panel for CEMA to develop introductory or interim objectives for key resources: air, water quality, and water quantity.

20.3 Views of MCFN

MCFN stated that it was frustrated with CEMA's lack of progress and questioned how additional oil sands activities could be approved in the absence of many key CEMA recommendations. MCFN recommended that some interim thresholds be established prior to any further EPEA or Water Act approvals being issued.

MCFN was concerned about the inability of CEMA to meet its timelines, the lack of adequate funding, and the level and dedication of stakeholder participation in the CEMA process. MCFN's concerns were not limited to CNRL's participation, but included all members' commitment to the CEMA process.

MCFN stated that it would like the shortcomings of CEMA identified and minimum standards and policies developed to make CEMA more effective at delivering timely recommendations. In the event that the shortcomings could not be overcome in a timely fashion, MCFN would expect government to take additional control and develop alternatives to CEMA to address cumulative effects.

MCFN expressed its concern with the unequal representation of stakeholders on regional multistakeholder committees, particularly in the case of RAMP, where industry currently made up close to 50 per cent of its participants.

MCFN stated that the information provided by RAMP was difficult to use and in some cases was based on data collected using different methodologies and from different locations. MCFN expressed concern regarding the objectivity of the products produced for RAMP. MCFN noted that Golder and Associates had been the main consultant used by RAMP, and it was concerned that reports generated by RAMP predominantly cited previous Golder work, as opposed to other scientific literature.

MCFN stated that RAMP work should be peer reviewed and include people critical of the program to maximize the credibility of the final products. MCFN suggested that the work produced through RAMP should also be published in peer-reviewed journals and additional ground-truthing should be done to confirm data and validate models.

MCFN suggested that the government should manage data gathering and interpretation to ensure objectivity and quality.

20.4 Views of Canada

EC stated that it supported the CEMA initiative and would continue to participate as a stakeholder in the identification and prioritization of knowledge gaps, directing and undertaking research to fill the gaps and assessing and interpreting data and information collected through CEMA processes. EC acknowledged that the regional management objectives and activities recommended by CEMA would be reviewed and implemented by regulators.

EC noted that the pace of oil sands development may be exceeding the capacity of CEMA and RSDS to effectively develop management systems so that environmental thresholds and objectives could be established and environmental limits not be exceeded. EC, therefore, recommended the development of interim environmental thresholds and objectives by the CEMA working groups, stating that this would be consistent with applying the precautionary principle.

EC noted that CEMA did not intend to conduct long-term monitoring or carry out research beyond that needed to develop management recommendations. Therefore, the reliance of CNRL on CEMA to develop and implement monitoring programs might not be appropriate.

DFO recommended that CNRL continue to participate and abide by the recommendations and management strategies established through CEMA, RAMP, and CONRAD.

DFO stated that it understood that CNRL would monitor for effects from its project, but DFO was uncertain as to whether the actual monitoring would be done by RAMP, CNRL, or other regional monitoring groups. DFO expected that CNRL would add detail to its current monitoring plans and program to identify clearly where the data would come from (e.g., RAMP, provincial monitoring, CNRL, or any other high-quality monitoring system) to properly detect effects from the project.

20.5 Views of Alberta

AENV stated that RSDS provided a framework for balancing development with environmental protection using adaptive resource management objectives recommended by regional stakeholders. It added that the strategy supported the identification of priority regional environmental issues and the management of science and monitoring work needed to understand the issues.

AENV noted that RSDS was being implemented in partnership with CEMA, based upon the identification of priority issues and the development of recommendations for regional environmental management. It stated that recommendations brought forward by CEMA to AENV and ASRD would be considered and, if approved, implemented.

AENV noted a number of CEMA accomplishments:

- In August 2002, CEMA forwarded to regulators consensus recommendations for managing trace metals in the Regional Municipality of Wood Buffalo (RMWB), which AENV reviewed and endorsed. These recommendations included a goal, a management objective and actions, research, and monitoring activities, and an evaluation period.
- In July 2003, CEMA industry members voluntarily agreed to adopt three management tools to help minimize land disturbance related to industrial development and exploration.
- As of August 2003, CEMA had completed over 28 technical reports, with over 22 other reports in progress supporting the development of environmental management systems.

AENV stated that it might include conditions in the EPEA or Water Act approvals that required CNRL to

- participate in the activities of CEMA,
- support an ongoing research program to implement CEMA recommendations for an acidification management framework,
- support an ongoing research program to develop CEMA recommendations for developing an IFN assessment for the lower Athabasca,
- support an ongoing research program to develop CEMA recommendations for EPL, and
- submit plans demonstrating how the project could be adapted to meet future regional environmental objectives and environmental management systems.

AENV stated that CEMA's work was important to environmental management in the Athabasca oil sands and that stakeholder support for CEMA was critical to its success. AENV expected that CEMA recommendations accepted by AENV would be implemented industry-wide through industry-coordinated adaptive management activities.

20.6 Views of the Panel

The Panel notes that CNRL has identified the importance of regional initiatives to address adverse environmental effects of its project. It has also relied on monitoring, adaptive management, and reclamation activities to mitigate against these effects. In order for these mitigation measures to be successful, the Panel believes that the activities of CEMA must be strengthened and accelerated.

The Panel believes that CEMA's work is important and that the results will assist the EUB in meeting its regulatory mandate to ensure that energy developments are carried out in an orderly and efficient manner that protects the public interest. The Panel acknowledges the broad spectrum of regional environmental issues that CEMA is expected to manage as a consensus-based multistakeholder organization. CEMA's diverse membership of industry, First Nations, local aboriginal groups, regulatory agencies, nongovernmental organizations, and other stakeholders presents its own challenges respecting research, decision making, financial resourcing, and priority setting.

The Panel heard concerns relating to CEMA's funding, ability to obtain expert consultants, and ineffective participation of some CEMA members, which may have hampered CEMA work progress. In addition, the Panel heard that CEMA's recent restructuring and reprioritization would improve its ability to meet critical timelines. The Panel commends CEMA for its efforts to streamline and integrate its goals and organizational structure. Nevertheless, the Panel has concerns that CEMA's effectiveness may also be influenced by the volume and complexity of its work, multiple priorities of stakeholders, and funding mechanisms that may not keep pace with CEMA's increased workload from oil sands expansions, new oil sands mining and in situ projects, and other contributors of regional cumulative effects. The Panel also believes that greater dedication of technical experts would facilitate dealing with complex scientific issues. The Panel believes that restructuring and reprioritization are the first steps to ensuring that CEMA meets its goals and the expectations others have of it. The Panel believes it is important that RSDS expectations are clear and that CEMA's levels of funding and participation are sufficient to ensure that RSDS objectives are met.

The Panel notes that RSDS, initiated in 1999 to address environmental issues with Athabasca oil sands development, is led by AENV and ASRD and is being implemented in partnership with CEMA. RSDS initially expected to have environmental management objectives and management plans in two to five years. The Panel understands there is good support in general for CEMA but widespread concerns about delay in delivery of environmental management objectives and plans. The Panel recommends that AENV and ASRD provide stakeholders with an update on their expectations of RSDS, its deliverables, and the timing of those deliverables.

The Panel urges all CEMA participants to re-evaluate their financial support and staff resourcing allocated to CEMA and ensure that these are comparable to the amount of reliance they have put on the CEMA process to manage and mitigate the environmental effects of the project. The Panel also urges all CEMA participants to ensure that their staff are accountable for the completion of CEMA deliverables. CEMA participants may want to consider dedicating staff to this initiative. In addition, the Panel recommends that EC, DFO, AENV, and ASRD review and optimize their financial and human resourcing of CEMA to produce meaningful results in an earlier timeframe. The EUB will also examine its financial and human resourcing contribution to the CEMA process and make changes as needed.

The Panel has serious concerns about delays in the issuance of recommendations and the ability of CEMA to meet the proposed timelines. However, AENV's and DFO's statements that they would develop an IFN in the event that CEMA was not able to meet its deadlines largely addresses the Panel's concerns. The Panel also notes that AENV indicated that it would work to ensure that CEMA met its deadlines. Therefore, the Panel recommends to AENV that it develop and implement environmental management plans and objectives in the event that CEMA is unable to meet its timelines.

The Panel notes that CNRL has committed to participate in CEMA and that it would accept participation as a condition of approval. The Panel supports AENV's intention to condition CNRL's EPEA approval accordingly. It also supports DFO considering requiring CNRL to participate and support CEMA in its approval.

The Panel notes that recommendations from the IFN subgroup and the wildlife corridor subgroup are not yet available. As a result, the Panel expects CNRL to abide by the outcomes of these working groups, as well as other regional environmental management initiatives. Once CEMA or other regional initiatives have produced substantive results or AENV has set management objectives, the EUB will consider whether there is a need to review CNRL's and other oil sands approvals.

The Panel supports CNRL's commitment to participate in WBEA as an active funding member. The Panel believes that WBEA is an important component of the regional monitoring system in conducting air quality, ecosystem, and human health effects monitoring.

The Panel understands that RAMP is currently undergoing a peer review process and that recommendations will be received shortly. The Panel believes that RAMP is an important and valuable tool in regional monitoring in the oil sands region and expects that improvements to the program noted through the peer review will be implemented in a timely manner so as to maintain the effectiveness of RAMP.

The Panel understands that CNRL currently participates in and funds RAMP and expects CNRL to continue participating in this group. The Panel notes that recommendations made by the peer review process may require additional funds and expects CNRL to fully support those changes as needed to accomplish the revised mandate of RAMP.

The Panel supports DFO's recommendation that CNRL continue to participate in RAMP, CONRAD, and CEMA to address water quality issues and that CNRL implement the recommendations and management strategies established by these groups.

The Panel expects details of monitoring conditions to be determined in coordination with AENV and DFO. Conditions would be determined with the understanding that where RAMP is not providing appropriate levels of monitoring, CNRL would be expected to provide additional monitoring to ensure the completeness of the monitoring program.

21 SOCIAL AND ECONOMIC IMPACTS

21.1 Macroeconomic Impacts

21.1.1 Views of CNRL

In CNRL's view, the employment and income potential of the project suggested that it would be in the broad public interest. Of the project's estimated capital costs of $8 billion, about $3.5 billion would be spent on engineering and labour costs. Therefore, a significant number of employment opportunities would be created over the project's seven-year construction period, totalling about 20 000 person-years of employment. Long-term direct employment on the project would require approximately 2400 people per year. Both the estimates of short-term construction jobs and long-term operations jobs would be compounded by a multiplier effect.

As well, the fiscal impacts of the project would be significant. CNRL stated that the total direct revenues to governments should exceed $24 billion over the life of the project, with about $16 billion accruing to the federal government, $8 billion to the provincial government, and $700 million to RMWB.

21.1.2 Views of the Panel

The Panel accepts that the economic impacts on Canada as a result of the project would be in the order of magnitude estimated by CNRL. While the net impacts on taxes and royalties would be diminished somewhat, considering necessary public expenditures that would accompany such a large project, the Panel believes that the net benefits from taxes and royalties to Canada and Alberta would be significant. The Panel further acknowledges, as discussed elsewhere in this report, that although an increase in economic activity is generally considered to be a positive attribute of any project, certain sectors of the economy can be stressed with a substantial increase in the demand for manpower, goods, and services, particularly at the regional level.

21.2 Employment and Population

21.2.1 Views of CNRL

CNRL considered a number of potential impacts of oil sands development on the local and regional economies and on quality of life. CNRL stated that the proposed project would be one of a total of 26 different oil sands projects either operating or planned for the region, all of which add to the cumulative socioeconomic impact on Fort McMurray and the outlying communities. The project's construction workforce would peak at about 3500 people in the second half of 2006 and would exceed 2000 people for about five years over the construction time period. CNRL's permanent workforce is expected to number about 2500 people. Assuming that all of the projects planned for the region proceeded, CNRL estimated that the population increase in Fort McMurray would be significant, reaching a total population of 73 000 by the year 2010.

CNRL stated that the availability of skilled workers had become a factor in the timely completion and costs of large industrial projects. It stated that skilled workers may be in short supply in the 2006 to 2011 period and that most of its construction workers would need to be recruited from outside the Wood Buffalo region. CNRL stated that it intended to promote the use of local and regional contractors and businesses and to work with other stakeholders to maximize the potential for local involvement in the project.

With respect to employing local aboriginal people, CNRL stated it was committed to providing career opportunities for qualified aboriginal workers. CNRL also stated it would work with groups such as the Athabasca Tribal Council/Athabasca Resource Developers (ATC/ARD) and the Wood Buffalo Employment and Career Training Specialists to enhance aboriginal employment opportunities.

CNRL acknowledged that the rapid pace of oil sands expansion expected for the region could have a profound impact on First Nations, Metis, and other area aboriginal people. Although oil sands developments have increased aboriginal involvement in the industrial wage economy, this has also tended to decrease the involvement of aboriginal persons in traditional activities and has affected access to and the use of traditional lands. CNRL suggested that while some welcome the transition, others accept these changes with some misgivings. CNRL stated that it had negotiated a number of bilateral agreements with First Nations that address issues such as culture, employment, training, and business development opportunities to assist in this transition.

21.2.2 Views of MCFN

MCFN generally reflected the views as reported by CNRL in that the future of the MCFN youth must necessarily incorporate elements of formal education and involvement with the wage/industrial economy. However, again as identified in CNRL's application, MCFN was hopeful that a transition to a wage economy would not weaken the relationship of MCFN youth to their cultural identity and traditional ways of life, for this relationship had been fundamental to their cultural well-being. MCFN elders expressed the necessity of finding the proper balance between traditional ways and the demands of an industrial economy and were involved in negotiations with CNRL to attempt to come to terms with these issues. While MCFN was not opposed to industrial development in general, it thought that the project could be delayed and improved from the viewpoint of First Nations and other aboriginal people.

21.2.3 Views of WBFN

WBFN expressed similar views to those of MCFN, relating the difficulties that some aboriginal people had experienced in adjusting to a wage economy, while acknowledging the need for aboriginal youth to seek formal education and wage employment. WBFN described some of the negative aspects that tended to accompany industrial activity in rural areas, such as pollution and more intense hunting and recreational use of land as the nonaboriginal population increased.

21.2.4 Views of the Panel

The Panel recognizes that the regional social and economic impacts of oil sands developments are not always positive. The Panel believes that the CNRL project would be an important addition to the economic base of the Wood Buffalo region, generating new business opportunities and project-related construction and permanent jobs for residents, including First Nations, Metis, and other aboriginal people.

The Panel believes that CNRL's commitment to enhancing opportunities for training and access to project employment should ensure that those who want to participate in this type of work would have a reasonable opportunity of doing so. However, the Panel also appreciates that such participation may involve difficult decisions for some First Nations, Metis, and other aboriginal people, as participating in the market economy may mean less attention is paid to traditional culture and activities.

The Panel supports the cooperative ways that CNRL and the First Nations are working towards mutually satisfactory arrangements in many areas.

21.3 Public Infrastructure/Services

21.3.1 Views of CNRL

CNRL indicated that its project, along with others that are occurring or are planned, would contribute to a number of social and economic impacts in the RMWB. The impacts identified by CNRL related to housing, roads and traffic, emergency services, policing, hospital and medical services, education, social services, and municipal services and infrastructure.

CNRL noted that many of these impacts were not new and were associated with previous oil sands development activity in the region. CNRL recognized that its project would be part of the cumulative impacts of the industrial development and population changes that were taking place. CNRL noted that it had been working closely with the RMWB, Northern Lights Regional Health Services (NLRHS), various multistakeholder groups, First Nations, other resource developers, and provincial and federal government departments to understand and find solutions to many of the existing and evolving socioeconomic issues. CNRL also made direct financial contributions in some areas to alleviate certain strains, including the development of lower income housing in Fort McMurray, funding First Nations cultural activities, and providing funds to the ATC/ARD development agreement.

CNRL committed to a number of initiatives at its plant site during construction and operations in order to reduce a number of impacts on both Fort McKay and Fort McMurray. These included the development of a well-serviced medical clinic on site, control of road traffic near Fort McKay, using buses along with reduced and staggered traffic flows to the site, use of a fly-in program for workers, strong alcohol and drug use policies, and participating in a health study involving First Nations, Metis, and other aboriginal people.

CNRL also committed to being actively involved in the future in working on solutions to the various RMWB socioeconomic issues by actively participating in multistakeholder groups, such as RIWG and the Alberta Oil Sands Developer Committee, and to work with the RMWB and the relevant provincial government departments. However, CNRL also indicated that many socioeconomic issues were outside the normal scope of activities of individual private oil sands companies and involved provincial and federal responsibilities. Company-specific impacts were increasingly difficult to separate from cumulative effects.

21.3.2 Views of FMMSA

FMMSA did not take a position with respect to future oil sands development in Wood Buffalo. However, it expressed an urgent need for improvements in health care funding for the region. FMMSA noted that the current available resources were not sufficient to provide fair and equitable medical care access for the current population of the municipality and the numbers of workers at the existing and approved oil sands expansions. FMMSA noted that

- the number of hospital beds in Wood Buffalo was roughly only two-thirds of the provincial average;
- the ratio of doctors to population was about less than half the provincial average and less than 40 per cent of the national average; and
- The range of services offered by the NLRHS was limited by financial resources, resulting in, for example, the lack of an orthopaedic surgeon.

FMMSA also expressed an urgent need for improvements for rapid response emergency services with respect to both Fort McMurray and Edmonton. It stated that there had been avoidable deaths due to a lack of adequate services.

FMMSA identified the regional health authority’s funding model as the main contributing factor to the deficient level of health services in the region, stating that it had not provided an adequate level of services for the existing population, nor did it adequately account for the future requirements of significant imminent population increases. FMMSA requested that the Panel create a credible regulatory oversight committee to set standards and monitor minimal standards of fair and equitable access to health care in the Wood Buffalo region.

21.3.3 Views of OSEC

OSEC generally supported CNRL's evidence regarding the current shortage of many types of services, including health care provision, affordable housing, road improvements, sewage, waste disposal, water treatment, and education. OSEC stated that the prospect of a rapid expansion of oil sands activity in the region necessitated an expansion of all of these services in the near future. Further, OSEC noted that these same concerns had been identified in previous socioeconomic impact assessments (SEIAs) but there had been few successful or innovative approaches to dealing with them.

OSEC identified RIWG as the organization chosen by industry and relied upon by the government thus far to monitor, research, and coordinate responses to cumulative social effects of development. OSEC stated, however, that RIWG's membership was made up almost entirely of industry and government members. One effect of this appeared to be a focus on the needs of the oil sands industry and its employees, as opposed to the community as a whole. It stated that nonmembers could only attend RIWG meetings by invitation in a nonvoting capacity, thereby limiting their ability to effectively participate in the mitigation, monitoring, and management of the social effects of oil sands developments. OSEC stated that CNRL agreed that a multistakeholder consensus-based committee was needed to address community-based socioeconomic issues resulting from industrial growth in the region. In OSEC's view, a group such as this would bring a greater breadth of understanding of the issues and would be more effective in designing and implementing effective and comprehensive solutions that meet community needs.

21.3.4 Views of the Panel

With respect to socioeconomic impacts and the provision of public services, the Panel acknowledges, along with CNRL and the interveners, that the project is likely to compound shortages that were identified in some sectors in the Wood Buffalo region. As well, the Panel agrees with the general sentiment expressed by CNRL and the interveners that better communication among all the stakeholders, adequate planning and monitoring for future requirements, and additional investment where appropriate would help to minimize the stress on many public services.

Similar concerns regarding the current level and future direction of public services have been expressed in previous EUB proceedings on major energy facilities in the Wood Buffalo region. Previously, the Board has expressed the view that the responsible government agencies are aware of the concerns and that they are responding to them. The Panel expects that this is still the case. However, given that the same concerns continue to be expressed, by CNRL in its SEIA and by the interveners, the Panel believes that there may be insufficient communication from the relevant government departments and the many multistakeholder committees to the Panel, to First Nations and to the public. Whether it is ultimately a matter of more effective communication, more open consideration of socioeconomic and health impacts, or a re-evaluation of the adequacy of some existing public services, it appears to the Panel that neither CNRL nor the interveners are satisfied that the level of public services in the Wood Buffalo region is able to meet some of the current and future needs for area residents and newcomers.

While the Panel does recognize that governments and regional multistakeholder committees are tackling regional socioeconomic issues, it believes better coordination and communication could further enhance these efforts. Some of the interveners suggested that a new consensus-based multistakeholder committee was needed to address socioeconomic issues. The Panel agrees in principle that the process for addressing socioeconomic issues should involve all affected stakeholders, but it does not take a position on how this can best be accomplished (whether through a new committee or accommodated within the existing committees). The Panel recommends that governments and other stakeholders review these matters and provide a strong focus of attention for them.

21.4 Impact on the Dastous

21.4.1 Views of CNRL

CNRL identified the Dastous as a couple having a trapline adjacent to and partially within CNRL's lease boundaries. They had constructed a permanent residence close to the Athabasca River approximately 300 m north of CNRL's lease boundary.

CNRL stated that it had compensated the Dastous several times for the impacts it had had on their well-being and would continue to compensate them for damages caused to, or impacts on their well-being. CNRL noted that it did not yet have regulatory approval for the proposed project and therefore was unable to make a long-term commitment to the Dastous for what might happen 10 or 15 years in the future.

21.4.2 Views of the Dastous

Mr. and Mrs. Dastous stated that they built their permanent residence themselves and that it was to be their retirement home. Mrs. Dastous stated that the Fish and Wildlife Division office in St. Paul advised her that a trapper did not require a permit to build a cabin on his or her registered trapline and that there were no restrictions on the number or size of cabins a trapper could build. Mrs. Dastous also stated that the "Forestry" office in Fort McMurray advised her that only one cabin could be constructed and that it could not be larger than 24 feet by 24 feet or less than 1000 feet from the Athabasca River. Mr. Dastous stated that prior to completing construction, they sought and were given verbal permission to build the home. That evidence was not challenged in the hearing. Following the oral hearing, the Dastous provided the Panel with copies of the written permits for the trapline.

Mr. and Mrs. Dastous stated that CNRL had compensated them for losses resulting from CNRL's activities that affected the trapline, although they expressed some frustration because one of the compensation payments was offered on a "take-it-or-leave-it" basis. They also indicated that they had used the trapline as part of an ecotourism business, but after hosting about a dozen patrons they did not continue pursuing that business. Mr. and Mrs. Dastous had come to the area in 1985, and while they were aware of oil sands development in the general area, they did not anticipate that oil sands activity would come as close to their home as the proposed project would within its time frame.

Mr. and Mrs. Dastous were concerned over the loss of the lifestyle they currently enjoyed and expected to enjoy in the future in their retirement home. They stated that commencement of land clearing activities would be a sufficient impact on their lifestyle to cause them to leave the area. They indicated that they had already been affected by the operation of heavy equipment and by road cutting in the area. Most of all, they were concerned that CNRL did not appear to have immediate intentions to address their expected loss of lifestyle. They produced a letter from CNRL that indicated they would not be impacted for 15 or 20 years. They responded that they had already been affected by CNRL and that if the project proceeded, they would leave the area. Mr. and Mrs. Dastous asked the Panel to impose as a condition of approval that CNRL be required to reach an agreement to compensate them for the loss of their lifestyle.

21.4.3 Views of the Panel

The Panel notes that Mr. and Mrs. Dastous were the only witnesses to give evidence on the question of what approvals were necessary in order for them to construct a permanent residence in proximity to the project lease. The Panel also notes that the Dastous themselves were not certain exactly what approvals were required and from whom. The Panel further notes that the copies of the permits Mr. and Mrs. Dastous provided do not address the matter of a home being built on or near the trapline. Based on the evidence before the Panel, the only conclusions it can make are that Mr. and Mrs. Dastous received verbal approval to construct their home or that no approval was needed and there are no requirements or restrictions that the Dastous had to observe when building the home.

Without commenting directly on the Dastous' situation, the Panel is concerned that anyone would be permitted to build a permanent residence within or near an area leased for oil sands mining operation. Such conflicting uses would inevitably result in the difficulties and disappointment expressed by Mr. and Mrs. Dastous. It is not clear to the Panel what authorities, if any, have the jurisdiction to control or prohibit construction of a permanent residence in or near an area leased for oil sands mining operations. If such construction is regulated, the Panel strongly suggests that the authorities having jurisdiction over the matter reconsider allowing any permanent residence to be constructed within or in close proximity to an area leased for oil sands operations. The Panel also suggests that land users who are considering building in or near an area that may possibly become a site for oil sands operations carefully consider whether they are prepared to live in close proximity to such development.

CNRL acknowledges that Mr. and Mrs. Dastous' trapline has been affected by past activities, and it has compensated them for those effects. The Panel is encouraged that to date compensation relating to the trapline itself has been a matter the parties have resolved between themselves. The Panel notes that jurisdiction over the matter of trappers' compensation rests with the Trapper Compensation Board, and if necessary the parties have recourse to that board to resolve any dispute over compensation for impacts to the Dastous' trapline.

CNRL also stated that it would compensate Mr. and Mrs. Dastous for any future disturbance, damage, or impact that affects their well-being. Impacts on and the loss of lifestyle are Mr. and Mrs. Dastous' primary concern about the proposed project. It is apparent to the Panel that the uncertainty over when compensation discussions will take place is causing Mr. and Mrs. Dastous significant concern. This concern was not alleviated when CNRL provided a letter stating that in its view Mr. and Mrs. Dastous would not be impacted for 15 to 20 years and that CNRL would be prepared to initiate compensation discussions after regulatory approval was given. Mr. and Mrs. Dastous stated they have already been impacted by the proposed project and that future impacts, commencing with land clearing, will be sufficient to cause them to leave the area. For that reason, they are anxious to have the matter of compensation for their loss of lifestyle addressed by CNRL at an early date.

Assuming that the project proceeds, the Panel is of the view that Mr. and Mrs. Dastous' current lifestyle will be significantly affected some time prior to the day mine operations reach the northeastern limit of the proposed mine, being the point closest to the Dastous' permanent residence. CNRL estimated that it would be impacting the Dastous in 10 to 15 years. Mr. and Mrs. Dastous stated they will be impacted when land clearing commences. The Panel is not able to state with certainty at what point in time or development CNRL's proposed project will impact Mr. and Mrs. Dastous to the extent that their loss of lifestyle is significant. The Panel also notes that it has no jurisdiction on the issue of compensation for a party's loss of land or loss of use or enjoyment of land. However, the Panel expects CNRL to recognize the Dastous' desire to have the matter of compensation for their loss of lifestyle addressed at an early date. In its correspondence to Mr. and Mrs. Dastous, CNRL indicated that it would be prepared to discuss compensation matters once regulatory approval was given. The Panel expects CNRL to fulfill that representation and to begin consultations with Mr. and Mrs. Dastous without delay if and when approvals are issued. The Panel will not impose a condition requiring CNRL to reach an agreement with Mr. and Mrs. Dastous, but it expects both parties to consult in good faith with the common goal of reaching a mutually satisfactory compensation plan.

22 PUBLIC CONSULTATION

22.1 Views of CNRL

CNRL expressed concern that the consultation issues advanced by MCFN were not brought forward until the closing argument stage of the hearing. CNRL also asserted that MCFN's claim that insufficient consultation had occurred was inconsistent with the prehearing submissions and evidence of MCFN, which focused on concerns about gaps it had identified in the EIA. CNRL stated that it was also inconsistent with the sophistication of MCFN, as evidenced by its business holdings, and the fact that CNRL had provided funding to MCFN in excess of $155 000 so that MCFN could retain experts to review the EIA.

In response to MCFN's position that its members' rights under Treaty 8 could not be affected by the project before adequate government consultation had taken place, CNRL stated that the rights conferred in Treaty 8 were neither exclusive nor in all circumstances perpetual and that the wording of Treaty 8 left open the question of whether treaty rights would continue to extend to the area of the proposed project mine.

In response to MCFN's position that it was a holder of a licence or lease as those terms are used in Section 23 of the Fisheries Act, CNRL stated that as a matter of statutory interpretation it was abundantly clear that MCFN members were not holders of a license or lease as contemplated by that section of the statute. CNRL stated that the licence or lease referred to in Section 23 of the act was a licence or lease granted by the minister under the act.

Further, on the matter of consultation, CNRL indicated that it was not clear whether MCFN was raising the consultation issue in relation to Section 35 of the Constitution Act, 1982, whether it was arguing consultation in relation to the public interest question, or whether it was arguing consultation in relation to the terms of reference for the EIA. CNRL stated that it agreed with Alberta that the Panel did not have authority to deal with the constitutional consultation question, nor was it appropriate for the Panel to attempt to address that issue. With respect to consultation other than the constitutional question, CNRL stated that the Panel had more than adequate evidence that sufficient consultation had occurred to satisfy the public interest question and the consultation requirements arising under the terms of reference.

CNRL stated that it was prepared to continue into negotiations with MCFN in order to resolve their outstanding concerns as it had done with other First Nations groups. However, CNRL indicated that it was unable to negotiate while the hearing was under way. It stated that it was prepared to continue discussions and negotiations following the hearing.

CNRL stated that it had met with elders and other community residents in Fort Chipewyan a number of times in relation to the project and had made project design changes as a result of those meetings. It had also had discussions with WBFN, and CNRL indicated that it was prepared to have further discussions. CNRL stated that on June 13, 2003, it and other oil sands developers had signed a Metis industry consultation agreement with six RMWB Metis locals.

22.2 Views of MCFN

MCFN stated that it had not been consulted separate and apart from the public consultation process and because of this MCFN was not in a position to say whether the proposed project would impact its members' rights as little as possible. MCFN did acknowledge that some level of consultation had occurred between it and CNRL, but stated that the environmental and social issues arising from the project had not yet been adequately addressed. MCFN stated that any approvals or rights required by CNRL for the project would be subordinate to the constitutionally guaranteed treaty rights of MCFN. To the extent that the governments and CNRL had failed to fulfill their respective obligations to consult with MCFN, the approvals and rights acquired by CNRL would not supplant MCFN's rights to occupy traditional lands and carry out traditional practices thereon.

MCFN also stated that the Panel agreement and CEAA provided the Panel with authority to decide whether Canada and Alberta had satisfied the obligation imposed on each of them by Section 35 of the Constitution Act, 1982, to consult with MCFN in relation to the project. MCFN stated that such consultation had to occur separate and apart from the public consultation that normally took place as part of the regulatory process and there was no evidence that it had taken place in the course of these applications.

During closing argument, MCFN stated that it was not asking the Panel to make a finding that a legislative provision conflicted with Section 35 of the Constitution Act. MCFN stated that it was asking the Panel to confirm that MCFN's treaty rights existed in preference to any licence or approval that may be issued by government. In also asked the Panel to rule on whether Alberta and Canada had carried out their consultation obligations under the Canada-Alberta Agreement for Environmental Assessment Cooperation. MCFN stated that the Panel had to determine whether the project was in the public interest and that the absence of adequate, meaningful consultation between CNRL and MCFN or the regulators and MCFN required the Panel to assume that the public interest test under EUB legislation had not been met.

During the hearing, MCFN stated that it was prepared to negotiate an agreement with CNRL to resolve its concerns.

22.3 Views of the Dastous

To the extent the matters raised by Mr. and Mrs. Dastous included concerns about consultation, their and the Panel's views are contained in Section 21.4 of this report.

22.4 Views of WBFN

WBFN stated that it did not oppose development as such but opposed haphazard development. It stated that it was a First Nation and was entitled to be consulted in the same manner as other First Nations. WBFN stated that its goal was to be consulted in a meaningful manner by oil sands developers and by CNRL. WBFN stated that meaningful consultation meant WBFN participating in the consultation process without incurring a financial cost to do so. Consultation also meant identifying issues working with parties, and coming to agreement on those issues, even if that meant some amount of compromise. With respect to consultation with CNRL regarding the proposed project, Mr. Malcolm stated that when he asked CNRL to provide him with the application materials, he was provided instead with a CD-ROM version that he could not read because he had no computer and CNRL refused to supply him with one.

22.5 Views of Canada

Canada stated that MCFN did not distinguish between consultation as it related to CEAA or the Panel agreement and consultation as it related to Section 35 of the Constitution Act, 1982. Canada stated that the obligation of a federal authority to undertake constitutional consultation arose when it took actions that directly affected First Nations. In the case of the applications for the project approvals, the consultation process had not ended and DFO, as the responsible authority, would be considering whether sufficient consultation had taken place prior to issuing any type of authorization.

Canada also stated that Indian and Northern Affairs Canada did not recognize WBFN as a band under the Indian Act.

22.6 Views of Alberta

Alberta, as represented by the Minister of Justice for Alberta and the Attorney-General for Alberta, stated that the Panel should not consider the constitutional consultation issues raised by MCFN. Alberta stated there were three bases for that, the first of which was an absence of proper notice of the issue. Alberta stated that notice of intention to raise the issue was required not only as a matter of procedural fairness, but also as a specific requirement under Section 24 of the Judicature Act. Alberta stated that such notice had not been provided in this case.

Second, Alberta stated that the Panel had no authority to determine constitutional issues. Alberta stated that the powers conferred on the Panel by the provincial and federal statutes governing the proceedings and the application did not include the power to determine questions of law or constitutional issues. Given the absence of that power, the Panel was not entitled to determine whether the proposed project would infringe upon rights arising under Section 35 of the Constitution Act, 1982, or whether such infringement could be justified.

Alberta also stated that if the Panel decided it did have jurisdiction to consider the constitutional consultation issues, in Alberta's view the Panel should decline that jurisdiction in favour of the Courts, which are much better suited to deal with the complicated and timely process of deciding constitutional questions.

22.7 Views of the Panel

The Panel notes that CNRL undertook an extensive consultation process in relation to the proposed project and the Panel commends CNRL for its efforts. This is clear from the evidence provided by CNRL, in particular its detailed List of Stakeholder Consultation, and by other parties' witnesses. The Panel notes the agreements made between CNRL and Fort McKay and between CNRL and ACFN, and it commends the parties for achieving those agreements. The Panel also notes the technical review that was undertaken by MCFN, which in the Panel's view demonstrates a comprehensive understanding of the proposed project.

CNRL stated that it had consulted with WBFN and that it was prepared to have further meetings with WBFN to discuss the project. WBFN's consultation efforts appear to have stalled when it was provided with a CD-ROM version of the application but not with a computer. The Panel notes that the application materials were available for public viewing at the EUB office in Fort McMurray and notice of this was provided in the Notice of Joint Panel Agreement. The Panel believes that all affected parties have an obligation to participate in the consultation process, and this requires them to each make a reasonable effort to engage the process.

The Panel is of the view that the consultation requirements applicable to the EUB application before the Panel have been met by CNRL and, therefore, the Panel is not prepared to condition or delay issuing EUB approvals on the basis of inadequate consultation.

MCFN addressed the question of consultation with First Nations. The Panel agrees with Canada and Alberta that the consultation issue was not raised prior to the hearing to the same extent that MCFN argued the issue at the closing of the hearing. MCFN's prehearing submissions focused on its gap analysis of the EIA.

WBFN did not make a prehearing submission, but during the hearing it stated that it wished to be consulted in a meaningful manner by CNRL. During its closing argument, WBFN stated that the hearing being conducted by the Panel was not the proper forum in which to determine WBFN's constitutional consultation issues, but that it wanted the Panel to take note of WBFN's position on that matter.

With respect to the request by MCFN that the Panel confirm that MCFN's treaty rights exist in preference to any licence or approval that may be issued by government, the Panel is not prepared to make that confirmation, nor is it satisfied that such confirmation by the Panel is needed to preserve whatever MCFN treaty rights may be affected by future government action. The Panel notes that Canada stated that the consultation process had not ended and that DFO would be reviewing the matter of consultation prior to issuing any type of authorization.

The Panel is also of the view that it does not have sufficient evidence on the constitutional question to allow it to make a recommendation on that issue. Little or no evidence was provided to indicate what, if any, specific treaty rights would be affected if the project were to proceed, and no evidence was provided that would enable the Panel to decide whether an infringement of treaty rights would occur, and if so whether it could be justified in this case.

With respect to MCFN's position regarding Section 23 of the Fisheries Act, the Panel is not prepared to make the recommendation requested by MCFN.

During closing argument, counsel for MCFN cited Clause 12 of the Canada-Alberta Agreement for Environmental Assessment Cooperation, which is referred to in the recitals to the Panel agreement. In the Panel's view, the consultation requirements under Clause 12 of the Environmental Assessment Cooperation Agreement are that potentially affected aboriginal people must be notified of the project and be given the opportunity to provide input on the terms of the EIA, to comment on the EIA itself, and to appear at a public hearing if one is convened. MCFN's witnesses confirmed that MCFN was notified of the proposed project and was given an opportunity to comment on the terms of reference for the EIA. MCFN made prehearing submissions on the EIA and participated fully in the hearing. The Panel is of the view that MCFN was afforded all the consultation opportunities referred to in Clause 12 of the Canada-Alberta Agreement for Environmental Assessment Cooperation.

23 CAPACITY OF RENEWABLE RESOURCES

23.1 Views of CNRL

CNRL assessed the potential for its project to have an adverse environmental effect on the capacity of renewable resources, such as fishing, forestry, trapping, berry picking, hunting, outdoor recreation, and tourism. Because the project would be located in an area where other resource uses occurred, CNRL conducted an assessment to identify the potential effects of the project on other resource use. CNRL indicated that site clearing for the mine site, plant site, tailings pond, dumps, and infrastructure corridors for the project may reduce resource availability, while the construction of roads could increase access to resources. CNRL determined that an increase in the local workforce could increase competition for resources.

CNRL's assessment involved identifying and comparing possible interactions between resource uses and its proposed development. It identified issues to develop key questions and linkages that detailed potential impacts of the project on resource use. It developed and then assessed linkages between project activities and environmental changes that affected each of the key questions.

CNRL evaluated the project's construction and operation activities, as well as social changes, such as an increased regional population, to determine potential impacts. Following this, CNRL developed mitigation strategies for each valid linkage. It assessed residual impacts with regard to direction, magnitude, geographic extent, duration, frequency, and reversibility.

CNRL considered the accessibility of each of the renewable resources, changes to the resources due to clearing and development, and population pressure on each resource. For each type of resource use, it identified relevant government guidelines, available resource use statistics, and important locations in which resources were located in the RSA and LSA. It investigated three cases: an existing/approved case, a project development case, and a planned case.

CNRL indicated that the existing/approved case included an assessment of the cumulative effects from existing and approved developments within the defined study areas, including communities.

CNRL's project development case included the existing/approved case developments in combination with the potential effects of the project. This scenario represented the cumulative effects should the project become operational. Since the project, as well as several of the approved developments, had not yet been constructed, it would be several years before predicted environmental impacts reached the levels used for the project development case.

CNRL's planned case included all of the existing and approved projects in the region, the project, and other planned regional developments. The planned case included planned projects publicly disclosed at least six months prior to the submission of the project EIA, none of which had received approval to operate and many of which had yet to apply for approval. The environmental impacts used in the planned case represented speculative levels. The assessed impacts could be greater than those realistically attained in the future.

Increases in the region's population under both the project development case and the planned case would have implications for all types of resources in the RSA. Effects would include increased demand for fishing, hunting, berry picking, and recreation. For Fort McMurray, CNRL estimated a population increase of 21 per cent over the existing/approved case under the project development case and a population increase of 62.5 per cent over the existing/approved case for the planned case. CNRL stated that it expected that both changes would cause increases in demand for resources.

Impacts on environmentally important areas and resource use of all types would be mitigated under NNLPs (i.e., for fisheries), during reclamation (i.e., for forestry, berry picking, and hunting locations) and minimization of the area to be cleared (especially in environmentally important areas). Exploring for new resource sources, such as aggregate deposits, or building new venues for nonconsumptive resource use, such as recreation, could also represent effective mitigation options.

CNRL determined that agricultural activity would not be affected under the project development case or the planned case because there was no agricultural activity occurring within the LSA.

CNRL identified that forestry was a relatively important extractive industry in the RSA and some forestry companies had been negatively affected by previous oil sands developments. Effects on forestry as a result of the project would occur due to clearing of forests in the LSA. CNRL analyzed this issue by assessing the effects of the project on merchantable timber. Trees would be lost from the development footprint for the life of the project. Following closure, the productive forest stands would be restored through reclamation. CNRL considered that the effects on forestry resulting from the project under the project development case would be negligible. In the current five-year plan, compensation for lost timber allocations was being provided, and the loss of forested lands was reversible. CNRL indicated that long-term effects could be mitigated by reclamation of development areas, with a return of equivalent or greater capability for forestry.

CNRL indicated that potential berry harvesting areas would be affected by site clearing activities. It assessed berry picking by analyzing the impacts to the berry producing plants. Approximately 8100 ha (56 per cent) of potential berry picking habitat in the LSA would be affected by the project. More than 99 per cent of this area would be restored to potential berry picking habitat following closure. Effects on berry picking could also occur due to changes in access to the south of the project. The effects of improvements in access in this area would be positive wherever a new access route traversed potential berry picking habitat. CNRL determined that the LSA was rarely used for berry picking in practice. As a result, CNRL concluded that the effects on berry harvesting would be negligible.

CNRL indicated that hunting and trapping did occur in the LSA and would be negatively affected by the project. The project would result in a temporary loss of wildlife habitat during and in some cases past the life of the project. Hunting in the LSA by nonaboriginal people had historically been very limited, although recent access improvements could have encouraged a short-term increase in hunting activity. As a result, CNRL concluded that the effects on hunting and trapping would be negligible.

CNRL concluded that the project would result in a temporary loss of furbearer habitat during and in some cases extending several years past the life of the project. This localized habitat loss would have the potential to affect some trappers in the region. The overall environmental consequence to trapping was negligible. However, consequences could be greater for the trappers directly affected.

CNRL stated that fishing was an important recreational activity in the RSA and that two sport fish-bearing watercourses, the Tar and Calumet Rivers, would be diverted as part of the project. However, it noted that relatively small numbers of anglers used these watercourses for fishing, as there had historically been a lack of access to the area. CNRL stated that these fishing areas would be replaced with equivalent or better habitat, including the new Horizon Lake, which would be accessible to the public. The project would result in a loss of some potential fishing areas in the LSA (most important, segments of the Tar and Calumet Rivers). However, implementation of an approved No Net Loss Fisheries Habitat Plan would ensure that there was ultimately no net loss in fish habitat, and habitat for some sport fish species could improve. CNRL concluded that the overall environmental consequence to fishing would be low.

23.2 Views of the Panel

The Panel is of the view that for each renewable resource that could be affected, CNRL has proposed adequate mitigation. The Panel believes that given the nature of the project and the mitigation measures that will be implemented, the project is not likely to cause significant adverse environmental effects on renewable resources. Accordingly, the Panel concludes that the capacity of those resources to meet the needs of the present and those of the future is not likely to be significantly affected.

24 TRADITIONAL USE AND CULTURAL RESOURCES

24.1 Views of CNRL

CNRL stated that important historic resources within the project area would be subject to permanent impacts. CNRL proposed that its mitigative measures would include resource avoidance and information recovery. CNRL undertook a Historical Resources Impact Assessment (HRIA) in consultation with Alberta Community Development (ACD). The assessment included interviews and mapping studies with affected stakeholders to identify historical resource sites and areas of cultural concern.

Several sites were identified within the proposed project area, including camps, hunting blinds, cabins, and trails. CNRL proposed that effective mitigation strategies would be established that would result in negligible negative effects on historical resources.

CNRL evaluated the potential impacts to traditional land use based on an understanding of how aboriginal peoples had been using the land and resources within the area. CNRL indicated that traditional land-use patterns would continue to be affected by a wide variety of regional developments, including oil sands projects and their associated infrastructure, forestry operations, commercial developments, government projects, and municipal expansions. CNRL stated that these effects would result from landscape disturbance and ecological disruption, as well as from restrictions that would be placed on access to areas containing industrial facilities. Local and regional development would also indirectly affect existing traditional land-use patterns as a result of increased noise, traffic, dust, and increased access for competing resource use. CNRL stated that these effects were likely to have a wide variety of social and cultural consequences, most of which would negatively affect traditional land use.

CNRL stated that it was committed to successful implementation of a comprehensive series of mitigative strategies to offset the effects of the project on traditional land use. These strategies included access control, consultation with directly affected trappers, and a reclamation plan that would restore traditional land-use opportunities as soon as possible.

24.2 Views of the Panel

The Panel accepts CNRL's evidence and notes that interveners did not raise any objections to CNRL's methodology, proposed mitigation measures, and conclusions. With appropriate and effective mitigation strategies, the Panel believes there would be no significant adverse environmental effects on historical and cultural resources.

With respect to the effects of the project on traditional uses, previous sections of this report discuss the general effect the project would have on lands and resources. The Panel notes that CNRL has committed to ongoing consultation with trappers and aboriginal users in the project area. The Panel concludes that there is unlikely to be significant adverse effects to the resources and lands used for traditional purposes, provided that the mitigation measures proposed by

CNRL are implemented. The Panel expects CNRL to keep its commitments as negotiated with First Nations, Metis, and other aboriginal people.

Dated in Calgary, Alberta, on January 27, 2004.

ALBERTA ENERGY AND UTILITIES BOARD
CANADIAN ENVIRONMENTAL ASSESSMENT AGENCY

J. D. Dilay, P.Eng.
Presiding Member

R. Houlihan, Ph.D., P.Eng.
Panel Member

G. Kupfer, Ph.D.
Panel Member

APPENDIX 1 SUMMARY OF APPROVAL CONDITIONS AND COMMITMENTS

APPROVAL CONDITIONS

CNRL must do the following as conditions of approval:

On or before December 31, 2007, submit to the EUB for its review and approval a report on the southwest area lease boundary containing a comprehensive evaluation of the lease boundary geology and reserves, geotechnical conditions, alternative mining scenarios and impacts, and associated costs, in accordance with Section 3.1 of EUB *ID 2001-7* (Section 7.1.3).

At least five years prior to mining at the southeast lease boundary but no later than December 31, 2010, submit to the EUB for its review and approval a report on the southeast area lease boundary containing a comprehensive evaluation of the lease boundary geology and reserves, geotechnical conditions, alternative mining scenarios and impacts, and associated costs, in accordance with Section 3.1 of *ID 2001-7* (Section 7.1.3).

At least six months prior to the construction of the plant site, submit to the EUB for its review and approval a report documenting efforts that have been taken to optimize the plant site area with respect to the minimization of resource sterilization (Section 7.2.2).

At least six months prior to field preparation, submit to the EUB for its review and approval detailed geotechnical designs for all external overburden disposal areas (Section 7.3.2).

At least five years prior to mining at the final pit wall but no later than December 31, 2016, submit to the EUB for its review and approval a report evaluating the mineable oil sands ore quality and nonrecoverable quantity in the east final pit wall area adjacent to the Athabasca River, and a detailed geotechnical stability evaluation of the final east pit wall location (Section 7.5.2).

Beginning with the September 2004 annual mine plan, submit to the EUB the details of the MOPP testing (Section 7.6.2).

At least six months prior to beginning mine depressurization activities, submit to the EUB for its review and approval a monitoring plan to detect basal aquifer pressure changes at the lease boundary with DCEL (Section 7.7.3).

On or before February 28 of each year following start-up of mine depressurization activities, or such other date as the EUB may stipulate, submit to the EUB a report on the results of the basal aquifer monitoring program at the lease boundary with DCEL (Section 7.7.3).

Within one year of project approval, satisfy the EUB on the need, or otherwise, to monitor the effects of depressurization and injection activities along the northern and western boundary of mining activities (Section 7.7.3).

On an annual average basis, limit diluent losses to tailings and the scheme to not more than 4.0 volumes per 1000 volumes of bitumen production, unless it can satisfy the Board that a limit of 4.3 volumes per 1000 volumes of bitumen production is appropriate (Section 8.2.3).

Not discharge any untreated froth treatment tailings to the tailings area (Section 8.2.3).

Every five years commencing February 28, 2010, or such other date as the EUB may stipulate, submit to the EUB a report on the feasibility of coke use and sales potential (Section 9.13).

On or before February 28, 2005, and every year thereafter, or such other date as the EUB may stipulate, submit to the EUB a progress report summarizing

- research and development on solid tailings technologies, and
- modifications to the existing tailings plan to ensure a trafficable landscape, rapid progressive reclamation and to eliminate the need for long-term storage of fluid tailings (Section 10.1.3).

Two years prior to planned start-up, or such other date as the EUB may stipulate, submit to the EUB a report summarizing the engineering design and operating plans for the NST system (Section 10.1.3).

On or before February 28 of every year following start-up, or such other date or frequency as the EUB may stipulate, submit to the EUB a report summarizing for the preceding year the performance of the NST system, including reasons for deviations from design (Section 10.1.3).

Within one year of project approval, satisfy the EUB on the need, or otherwise, to monitor for potential effects of injection activities on the depressurization needs of other developments in the regional study area (Section 12.7).

Include in the project area a minimum setback of 250 m from the edge of the wetted width of the Athabasca River during spring flow, excluding the water intake facility (Section 15.6).

Commitments

The Panel notes throughout the decision report that CNRL has undertaken to conduct certain activities in connection with its operations that are not strictly required by the EUB's regulations or guidelines. These undertakings are described as commitments.

It is the Panel's view that when a company makes commitments of this nature, it has satisfied itself that these activities will benefit both the project and the public, and the Panel takes these commitments into account when arriving at its decision. The Panel expects the applicant, having made the commitments, to fully carry out the undertaking to the extent that those commitments do not conflict with the terms of any approval or licence affecting the project or any law, regulation, or similar requirement CNRL is bound to observe, or to advise the EUB if, for whatever reasons, it cannot do so. The EUB would then assess whether the circumstances regarding the failed commitment warrant a review of the original approval. The Panel also notes that the affected parties also have the right to request a review of the original approval if commitments made by the applicant remain unfulfilled.

In addition to commitments made at the hearing, CNRL filed three documents listing in detail its commitments to stakeholders and regulators in the areas of operational management, environmental management, socioeconomic initiatives, and consultation. These documents are a matter of public record and were filed as exhibits 9, 22, and 48.

APPENDIX 2 PANEL AGREEMENT

AGREEMENT

To Establish a Joint Review Panel for the Horizon Oil Sands Project

Between

The Minister of the Environment, Canada

- and -

The Alberta Energy and Utilities Board

PREAMBLE

WHEREAS the Alberta Energy and Utilities Board (the AEUB) has statutory responsibilities pursuant to the *Alberta Energy and Utilities Board Act* and the *Energy Resources Conservation Act*; and

WHEREAS the Minister of the Environment, Canada (the Federal Minister) has statutory responsibilities pursuant to the *Canadian Environmental Assessment Act*; and

WHEREAS the Horizon Oil Sands Project (the Project) requires a public hearing and approvals from the AEUB pursuant to the *Alberta Energy and Utilities Board Act* and the *Energy Resources Conservation Act* and is subject to an assessment under the *Canadian Environmental Assessment Act*; and

WHEREAS the Minister of Fisheries and Oceans has referred the environmental assessment in respect of the Project to the Federal Minister in accordance with section 21 of the *Canadian Environmental Assessment Act*; and

WHEREAS the Federal Minister has referred the project to a review panel in accordance with section 29 of the *Canadian Environmental Assessment Act*; and

WHEREAS the Government of the Province of Alberta and the Government of Canada established a framework for conducting joint panel reviews through the *Canada-Alberta Agreement for Environmental Assessment Cooperation* signed on June 30, 1999; and

WHEREAS the AEUB and the Federal Minister have determined that a joint panel review of the Project will ensure that the project is evaluated according to the spirit and requirements of their respective authorities while avoiding unnecessary duplication, delays and confusion that could arise from separate reviews by each government; and

WHEREAS the AEUB and the Federal Minister have determined that a joint panel review of the Project should be conducted in a manner consistent with the provisions of the *Subsidiary Agreement on Joint Review Panels*, attached as Appendix 2 of the *Canada-Alberta Agreement for Environmental Assessment Cooperation*; and

WHEREAS the Federal Minister has determined that a joint review panel should be established pursuant to paragraph 40(2) of the *Canadian Environmental Assessment Act* to consider the Project;

THEREFORE, the AEUB and the Federal Minister hereby establish a joint review panel for the Project in accordance with the provisions of this Agreement and the Terms of Reference attached as an Appendix to this Agreement.

1. Definitions

For the purpose of this Agreement and of the Appendix attached to it,

"**Agency**" means the Canadian Environmental Assessment Agency.

"**EIA Report**" means an Environmental Impact Assessment report prepared in accordance with the Terms of Reference issued for the Project by the Director of Alberta Department of the Environment.

"**Environment**" means the components of the Earth, and includes
(a) land, water and air, including all layers of the atmosphere;
(b) all organic and inorganic matter and living organisms; and
(c) the interacting natural systems that include components referred to in (a) and (b)."

"**Environmental Effect**" means, in respect of the Project,
(a) any change that the Project may cause in the Environment, including any change it may cause to a listed wildlife species, its critical habitat or the residence of individuals of that species, as those terms are defined in subsection 2(1) of the *Species at Risk Act*,
(b) any effect of any change referred to in paragraph (a) on
 (i) health and socio-economic conditions
 (ii) physical and cultural heritage
 (iii) the current use of lands and resources for traditional purposes by aboriginal persons
 (iv) any structure, site or thing that is of historical, archeological, paleontological or architectural significance, or
(c) any change to the project that may be caused by the environment

whether any such change or effect occurs within or outside Canada.

“**Federal Authority**” refers to such an authority as defined in the *Canadian Environmental Assessment Act.*

"**Final Report**" is the document produced by the Joint Panel, which contains decisions pursuant to the *Energy Resources Conservation Act* and the Joint Panel's conclusions and recommendations pursuant to the *Canadian Environmental Assessment Act* with respect to the environmental assessment of the Project.

"**Follow-up Program**" means a program for

(a) verifying the accuracy of the environmental assessment of the Project, and

(b) determining the effectiveness of any measures taken to mitigate the adverse environmental effects of the Project.

"**Joint Panel**" refers to the joint panel established by the AEUB and the Federal Minister through this Agreement.

"**Mitigation**" means, in respect of the Project, the elimination, reduction or control of the adverse environmental effects of the project, and includes restitution for any damage to the environment caused by such effects through replacement, restoration, compensation or any other means.

“**Parties**” means the signatories to this Agreement.

"**Responsible Authority**" refers to such an authority as defined in the *Canadian Environmental Assessment Act*.

2. Establishment of the Panel

2.1. A process is hereby established to create a Joint Panel, pursuant to section 22 of the *Energy Resources Conservation Act* with the authorization of the Lieutenant Governor in Council of Alberta, and Sections 40, 41 and 42 of the *Canadian Environmental Assessment Act*, for the purposes of the review of the Project.

2.2. The AEUB and the Agency will make arrangements to coordinate the announcements of a joint review of the Project by both Alberta and Canada.

3. Constitution of the Panel

3.1. The Joint Panel will consist of three members. Two members, including the Joint Panel Chair, will be appointed by the Chair of the AEUB with the approval of the Federal Minister. The third Joint Panel member will be appointed by the Federal Minister in accordance with article 3.2 of this Agreement.

3.2. The Federal Minister will select the third Joint Panel member and recommend the selected candidate as an individual who may serve as a potential acting member of the AEUB. If acceptable to the Lieutenant Governor in Council of Alberta and the Chairman of the AEUB, the Lieutenant Governor in Council of Alberta will nominate this candidate to serve as an acting member of the AEUB and the Chairman of the AEUB will appoint this candidate as a member of the Joint Panel. The selected candidate will then be appointed by the Federal Minister as a member of the Joint Panel.

3.3. The Joint Panel members shall be unbiased and free from any conflict of interest relative to the Project and are to have knowledge or experience relevant to the anticipated Environmental Effects of the Project.

4. Conduct of Assessment by the Panel

4.1. The Joint Panel shall conduct its review in a manner that discharges the responsibilities of the AEUB under the *Alberta Energy and Utilities Board Act* and the *Energy Resources Conservation Act*.

4.2. The Joint Panel shall conduct its review in a manner that discharges the requirements set out in the *Canadian Environmental Assessment Act* and in the Terms of Reference attached as an Appendix to this Agreement.

4.3. All Joint Panel hearings shall be public and the review will provide for public participation.

4.4. The Joint Panel shall have all the powers and duties of a panel described in Section 35 of the *Canadian Environmental Assessment Act* and in Section 10 of the *Alberta Energy and Utilities Board Act*.

5. Secretariat

5.1. Administrative, technical, and procedural support requested by the Joint Panel shall be provided by a Secretariat, which shall be the joint responsibility of the AEUB and the Agency.

5.2. The Secretariat will report to the Joint Panel and will be structured so as to allow the Joint Panel to conduct its review in an efficient and cost-effective manner.

5.3. The AEUB will provide its offices for the conduct of the activities of the Joint Panel and the Secretariat.

6. Record of Joint Review and Final Report

6.1. A public registry will be maintained by the Secretariat during the course of the review in a manner that provides for convenient public access, and for the purposes of compliance with section 55 of the *Canadian Environmental Assessment Act*. This registry will be located in the offices of the AEUB.

6.2. On completion of the assessment of the Project, the Joint Panel will prepare a Final Report.

6.3. Once completed, the Final Report will be conveyed, in both official languages simultaneously, by the Joint Panel to the Government of Alberta, to the Federal Minister, the Minister of Fisheries and Oceans, and to the public.

6.4. Once the Final Report is submitted to the Federal Minister, the responsibility for the maintenance of the public registry will be transferred to the Responsible Authority. The AEUB will continue to maintain records of the proceedings and the Final Report, as per the AEUB Rules of Practice.

7. Other Government Departments

7.1. At the request of the Joint Panel, Federal Authorities and provincial authorities having specialist knowledge with respect to the Project will provide available information and knowledge in a manner acceptable to the Joint Panel.

7.2. Nothing in this agreement will restrict the participation by way of submission to the Joint Panel by other federal or provincial government departments or bodies**,** subject to article 7.1, above, section 12(3) of the *Canadian Environmental Assessment Act* and the AEUB Rules of Practice.

8. Participant Funding

8.1. Decisions regarding participant funding by the Agency under the federal Participant Funding Program, and decisions on intervener funding by the AEUB as provided for in the *Energy Resources Conservation Act*, AEUB Rules of Practice and the AEUB Guidelines for Energy Cost Claims (Guide 31A) will, to the extent practicable, take into account decisions of the other party**.**

9. Cost Sharing

9.1. The AEUB, as lead party, will develop a budget estimate of expenses agreeable to both parties prior to initiation of Joint Panel activities.

- 6 -

9.2. The costs of the review will be apportioned between the AEUB and the Agency in the manner set out in articles 9.3, 9.4 and 9.5.

9.3. The AEUB will be solely responsible for the following costs:

- salaries and benefits of the Joint Panel Chairman and the member of the Joint Panel not appointed in accordance with article 3.2; and
- salaries and benefits of AEUB staff involved in the joint review.

9.4. The Agency will be solely responsible for the following costs:

- per diems of the Joint Panel member appointed in accordance with article 3.2;
- salaries and benefits of Agency staff involved in the joint review;
- all costs associated with the federal Participant Funding Program; and
- French translation requirements.

9.5. The AEUB and the Agency agree to share equally all those costs listed below, incurred as part of the Joint Panel review from the signing of this Agreement to the date the Final Report is issued by the Joint Panel. The shareable costs are as follow:

- travel-related expenses associated with the review incurred by the Joint Panel members, and by AEUB and Agency staff in fulfilling the Secretariat functions;
- per diems and associated expenses of independent/non-government expert consultants or communications specialists retained by the Joint Panel;
- printing of any reports or documents distributed by the Joint Panel necessary for the Joint Panel's work;
- the publication of notices;
- photocopying and postage related to the review;
- production of one electronic and one paper copy of the transcripts prepared by court reporters as required by the Joint Panel;
- rental of hearing and public meeting facilities and equipment;
- sound services at the hearing and public meetings; and
- miscellaneous expenditures up to a maximum of 5 percent of the total budget for the review.

9.6. Shareable costs of the joint review as detailed in article 9.5 will be incurred at the sole discretion of the Joint Panel with due regard to economy and efficiency.

9.7. All expenses not listed above will need prior approval of both parties if they are to be equally shared.

9.8. To facilitate the delivery of payment of per diems of the Joint Panel member appointed in accordance with article 3.2 the AEUB will pay the individual in response to appropriate invoices and will invoice the Agency for the reimbursement of such payments.

10. Amending this Agreement

10.1. The terms and provisions of this agreement may be amended by written memorandum executed by both the Federal Minister and the Chairman of the AEUB. Subject to section 27 of the *Canadian Environmental Assessment Act*, upon completion of the joint review, this Agreement may be terminated at any time by an exchange of letters signed by both parties.

11. Signatures

WHEREAS the parties hereto have put their signatures this 18th day of August 2003.

<original signed by>	<original signed by>
The Honourable David Anderson Minister of the Environment Chairman	Neil McCrank Alberta Energy and Utilities Board

Appendix
Terms of Reference

Part I - Project Description

Canadian Natural Resources Limited (CNRL) is proposing to construct and operate an oil sands mining, extraction and upgrading facility in the Fort McMurray area, the Horizon Mine. The proposed project is located approximately 70 kilometres north of Fort McMurray in Townships 96 and 97, Ranges 11 to 13, West of the 4th Meridian. The proposed project includes an open pit, truck and shovel mine, four bitumen processing trains, three upgrading trains, associated utilities and infrastructure, water and tailing management plans, and an integrated development and reclamation plan. The project is designed to produce approximately 43 000 cubic metres per day of bitumen and approximately 37 000 cubic metres per day of upgraded bitumen product. Construction is scheduled to commence in 2004, initial production in 2007, and full production is expected by 2011.

Part II - Scope of the Environmental Assessment

1. The Joint Panel will conduct an assessment of the Environmental Effects of the Project based on the Project Description (Part I).

2. The assessment will include a consideration of the factors listed in subsection 16(1)(a) to (d) and 16(2) of the *Canadian Environmental Assessment Act*, namely:

- **a)** The environmental effects of the Project, including the environmental effects of malfunctions or accidents that may occur in connection with the Project and any cumulative environmental effects that are likely to result from the Project in combination with other projects or activities that have been or will be carried out;
- **b)** The significance of the effects referred to in paragraph a;
- **c)** Comments from the public that are received during the review;
- **d)** Measures that are technically and economically feasible and that would mitigate any significant adverse environmental effects of the Project;
- **e)** The purpose of the Project;
- **f)** Alternative means of carrying out the Project that are technically and economically feasible and the environmental effects of any such alternative means;
- **g)** The need for, and the requirements of, any follow-up program in respect of the Project; and
- **h)** The capacity of renewable resources that are likely to be significantly affected by the Project to meet the needs of the present and those of the future.

3. Pursuant to subsection 16(1)(e) of the CEAA, the assessment by the Joint Panel will also include a consideration of the additional following matters:

- **a)** Need for the Project;
- **b)** Alternatives to the Project; and
- **c)** Measures to enhance any beneficial Environmental Effects.

4. The Review will consider the Environmental Effects of the proposed Project within spatial and temporal boundaries which encompass the periods and areas during and within which the Project may potentially interact with, and have an effect on, components of the environment. These boundaries may vary with the issues and factors considered, and with the different phases in the life cycle of the project. The boundaries will reflect:

- the natural variation of a population or ecological component;
- the timing of sensitive life cycle phases in relation to the scheduling of the Project;
- the time required for an effect to become evident;
- the time required for a population or ecological component to recover from an effect and return to a pre-effect condition, including the estimated degree of recovery;
- the area affected by the Project; and
- the area within which a population or ecological component functions and within which a Project effect may be felt.

APPENDIX 3 HEARING PARTICIPANTS

Principals and Representatives (Abbreviations used in report)	Witnesses
Canadian Natural Resources Limited (CNRL)	
D. A. Holgate	P. Keele, P.Eng.
J. D. Brett	T. Dereniwski, P.Eng.
	J. Romero, P.Eng.
	C. Kean, P.Eng.
	R. Doucet, P.Eng.
	C. Duane, P.Ag.
	I. Mackenzie
	A. Takyi, Ph.D., P.Eng.
	N. Schmidt, Ph.D., P.Eng.
	S. McCutcheon, Ph.D.
	S. McKenzie, P.Biol.
	A. Beersing, Ph.D.
	T. Y. Gan, Ph.D.
	S. Swanson, Ph.D.
	M. Rawlings, P.Eng.
	T. Davidson, P.Geol.
	A. Thomson
	M. Ingen-Housz
Deer Creek Energy Limited (DCEL)	
D. Thomas, Q.C.	D. Theriault, P.Eng.
M. Ignasiak	M. Montemurro, P.Eng.
	D. Hackbarth, Ph.D., P.Geol.
Mikisew Cree First Nations (MCFN)	
D. Mallon	D. Schindler, Ph.D.
R. Salamucha	J. Byrne, Ph.D.
	J. Brownlee
	S. Kienzle, Ph.D.
	P. Komers, Ph.D.
	Chief A. Waquan
	W. Courtorielle
	S. Courtorielle
	R. McKay
	M. R. Waquan
	T. Marten
Oil Sands Environmental Coalition (OSEC)	
K. Buss	M. Kitagawa
	D. Woynillowicz
	A. Dort-McLean

(continued)

APPENDIX 3 HEARING PARTICIPANTS (continued)

Principals and Representatives (Abbreviations used in report)	Witnesses
Fort McKay First Nation and Metis Local 122 (Fort McKay)	
K. Buss	
S. Laurent	
Athabasca Chipewyan First Nation (ACFN)	
K. Buss	
L. Flett	
Fort McMurray Medical Staff Association (FMMSA)	
M. Sauvé, M.D.	
Marlboro Environmental Committee (MEC)	
G. Brandenburg	G. Brandenburg
Sierra Club of Canada (SCC)	
S. P. Stensil	
Dastous	
C. Dastous	C. Dastous
M. Dastous	M. Dastous
Shell Canada Limited (Shell)	
S. Denstedt	
K. Lozynsky	
Suncor Energy Inc. (Suncor)	
D. Thomas, Q.C.	
M. Ignasiak	
Imperial Oil Resources and ExxonMobil Canada (IOR)	
K. Sury	
Syncrude Canada (Syncrude)	
B. J. Roth	
D. Bercov	
UTS Energy Corp. (UTS)	
D. McDonald	

(continued)

APPENDIX 3 HEARING PARTICIPANTS (continued)

Principals and Representatives (Abbreviations used in report)	Witnesses
Birch Mountain Resources Ltd. (BMRL) D. Dabbs	
Government of Canada (Canada) B. Hughson D. Mueller	Environment Canada (EC) M. Fairbairn L. Bates-Frymel M. R. Norton B. Brownlee, Ph.D. D. Lindeman, Ph.D. Department of Fisheries and Oceans (DFO) D. Majewski A. Thomson, P.Eng. R. Courtney, P.Biol. B. Makowecki J. Shamess D. Walker W. Huber, Ph.D. Natural Resources Canada (NRCAN) G. R. Browning M. K. Cliffe
Her Majesty the Queen in Right of Alberta (Alberta) H. Veale D. Stepaniuk K. Sandstrom	D. Yoshisaka C. de la Chevrotiere, P.Eng. P. Marriott, P.Eng. M. Boyd R. Barrett K. Bodo, Ph.D. R. Chabaylo, P.Biol. L. Rhude, P.Biol. P. McEachern, Ph.D. K. Singh, P.Eng. C. Hale, RPF

(continued)

APPENDIX 3 HEARING PARTICIPANTS (continued)

Principals and Representatives (Abbreviations used in report)	Witnesses
Wood Buffalo First Nation (WBFN)	
J. Malcolm	R. S. J. Campbell W. Castor E. Cree R. Woodward D. McDonald
Chipewyan Prairie First Nation Industrial Relations Corporation (CPFN)	
B. Kennedy	
Alberta Energy and Utilities Board (EUB) staff	
G. Perkins, Board Counsel R. Germain, P.Eng. K. Geekie B. Austin, P.Geol. M. Dmytriw, R.E.T. J. Farnell, C.E.T. C. Brown. P.Biol. T. Lemay K. Johnston	
Canadian Environmental Assessment Agency (CEAA) staff	
S. Chapman	

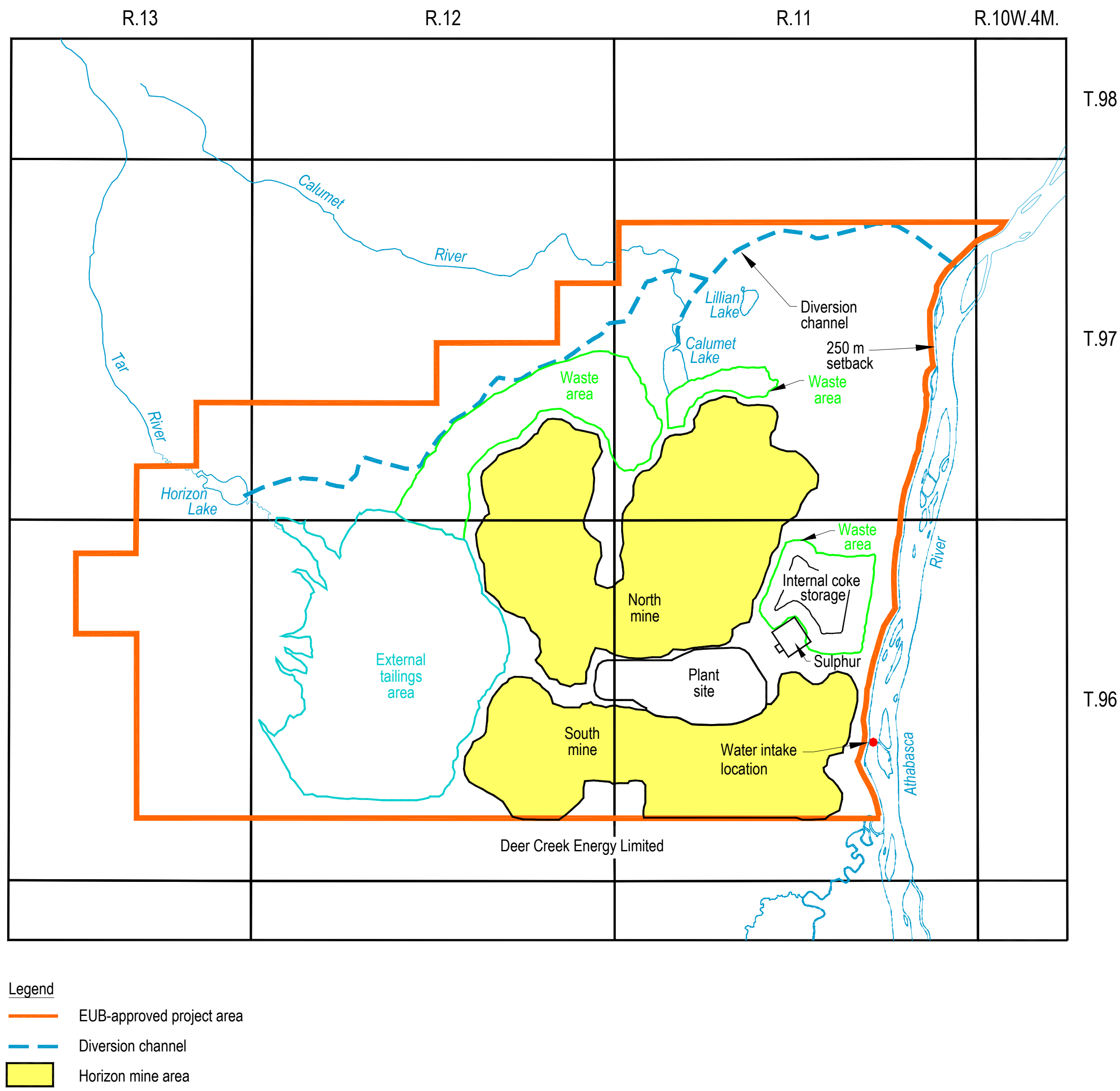


Figure 1. Horizon oil sands project area

Appendix XVIII:

"Memorandum to the Minister: Oil Sands Tailings Ponds"
(Environment Canada, 19 January 2009)

MIN-118731

MEMORANDUM TO THE MINISTER

OIL SANDS TAILING PONDS

(For Information)

PURPOSE

To inform you of the environmental impact of oil sands tailing ponds. *(revised Jan. 19, 2009)*

SUMMARY

- Tailing ponds are large bodies of water and sludge-like sediments formed as a result of the hot water process that separates bitumen from sand. Most of the water is trapped in the sediments that make up most of the tailing pond's contents. The water is contaminated with bitumen and other toxics and cannot be released to the natural environment. The surface area and volume of tailing ponds have grown substantially over the past three decades and are expected to continue to grow over the next several decades. These tailings ponds are one of the few man-made features that can be seen from space.

- Tailing ponds have environmental effects on water, land, wildlife and air. Some of these effects are potentially significant. There is considerable international media attention to the environmental performance of the oil sands, and the size and toxicity of the tailing ponds features prominently in that coverage.

- Environment Canada does not issue any approvals for the oil sands projects. There are no federal triggers under the *Canadian Environmental Assessment Act* for Environment Canada. The Department of Fisheries & Oceans and Transport Canada have such triggers that result in those departments issuing either authorizations or permits. Environment Canada participates in the environmental assessment process as a Federal Authority providing scientific, expertise, information and knowledge to the Responsible Authorities (i.e., Fisheries & Oceans and Transport Canada).

- Oil sands projects are subject to various licenses and approvals from several departments and agencies of the Government of Alberta, including the Energy Resources Conservation Board and the Department of the Environment. Under Alberta's *Environmental Enhancement and Protection Act*, an environmental assessment must be completed, and the resulting permit is typically associated with a long list of conditions related to environmental performance. A permit under the *Water Act* is required for withdrawals of surface water. Alberta has a zero-discharge policy for oil sands tailing ponds.

- The Department administers and enforces a number of acts and regulations which could impose some requirements on oil sands tailings ponds. These are the *Fisheries Act*, the *Species at Risk Act*, and the *Migratory Birds Convention Act* and its associated *Migratory Birds Regulations*. In addition, air emissions from tailings ponds could be covered by the *Canadian Environmental Protection Act*, if regulations are put into place.

CURRENT STATUS

Alberta's oil sands are a strategic energy resource for Alberta and Canada. The oil sands are the largest developed bitumen deposits in the world. The proven oil reserves from them are second in the world only to Saudi Arabia. Small oil sands deposits in northwest Saskatchewan are also being developed. Oil from conventional oil production is falling in Canada, whereas bitumen production is expected to triple by 2020. The production of oil from the oil sands is already over half of Canada's total oil production and this will likely increase to three-quarters of Canadian oil production by 2020.

The separation of bitumen from bitumen-containing sand extracted using open pit mining techniques requires a significant quantity of water. It requires between 2 to 4 barrels of water to create one barrel of synthetic crude oil. After the extraction, the water used is contaminated with hydrocarbons and other substances and is toxic.

Alberta has a policy of zero discharge of this water to the natural environment, so the water must be stored. This water is permanently stored in "tailing ponds", which are large bodies of standing water contained behind man-made dykes or dams that are constructed from sand and overburden excavated as part of the mining process. Some water from the tailing ponds can be recycled for the extraction processes, and additional water requirements are drawn from fresh water sources such as the Athabasca River or possibly in the future from saline groundwater. Based on historical performance, generally the industry has been unable to meet its own predictions for performance of tailings management systems with the result that larger volumes of tailings need to be stored in ponds than has been predicted during regulatory review and approval processes.

There are currently four open-pit oil sands mines operating in northeast Alberta, each with substantial tailings ponds, and a fifth mine has just commenced operations this year. The tailings ponds currently cover an area of about 63,000 acres or 250 km^2 (refer to map in the Annex). Over the next decade or so, it is expected that there will be six new mines and a number of major expansions to existing mines.

ISSUES

Water

The water in the tailings ponds is highly contaminated and not suitable for release to the natural environment without expensive chemical, physical or biological treatment. The toxicity of water is due primarily to high concentrations of naphthenic acids, salts, polycyclic aromatic hydrocarbons and some metals. The water trapped in the fine tailings cannot be treated until it has been separated from the sediments. The industry, in conjunction with Natural Resources Canada and universities, is developing technologies (e.g., "Consolidated Tailings") which reduce the amount of water in the fine material deposited in the tailings ponds.

Adding a surface layer of 3 to 5 metres or more of fresh water to the tailings ponds has been proposed by industry as a viable mitigation measure for tailings, but such an approach has not yet been commercially demonstrated to segregate toxic tailings from the overlying fresh water. One issue is that after 15 to 20 years the sediments of tailings ponds began to generate methane gas bubbles that could re-suspend tailings and prevent settling and potentially mix fine tailings into this proposed water cap.

A December 2008 report by the environmental group Environmental Defence estimated that liquid contents (water plus toxics) of the tailing ponds are seeping out at a rate of 11 million litres per day in 2007, growing to over 72 million litres per day within a decade. This was estimated by using industry data from their environmental assessment submissions and allowing for the industry-proposed concept that the lakes "seal" themselves over time though the deposition of fine particles (which may not be a completely impermeable seal).

Seepage would not likely be directly into surface waters, but move first into groundwater. It may take decades to reach surface waters. In their environmental assessments, many oil sands companies acknowledge that this may occur. Natural Resources Canada possesses considerable technical expertise in this area, and is reviewing the validity of Environmental Defence's conclusions.

Wood Buffalo National Park is downstream of the oil sands developments. Environment Canada samples the Athabasca River at the southern boundary of Wood Buffalo National Park every month; however, this is a small, funding-limited program associated with identifying cumulative effects of pulp mill. It does not at present test for particular parameters (e.g., naphthenic acids and possibly others) which could be used as definitive indicators for oil sands related activities, but tend to be expensive to test for. The samples are used to monitor several total and dissolved metals, including arsenic, chromium and lead. Although some results exceed Canadian Council of Ministers of the Environment's *Canadian Water Quality Guidelines for the Protection of Aquatic Life* (i.e., for lead, copper, iron, aluminum and zinc), the high levels of metals are attributed to sediment loading in the river and they cannot be traced to deposition from oil sands tailings ponds.

Land Reclamation

The reclamation of the land covered by tailing ponds depends on the ability to contain fine particles present in tailings ponds and to eliminate toxicity of overlying water and associated sediments for their return to the natural environment. Research into reclamation of tailings ponds water through chemical, physical and biological (e.g., constructed wetlands) treatment is underway through industry-sponsored initiatives in university, government, and industry laboratories. To date, very little (0.2%) of the total mined land has been certified as reclaimed by the Government of Alberta, although industry claims that they have reclaimed up to 30% to some level of natural environment. The criteria for certifying land as being reclaimed are the subject of ongoing debate.

Many stakeholders doubt the ability of industry to reclaim tailings ponds to some degree of natural environment following closure of mining operations. Questions are often raised by stakeholders as to whether industry is committing sufficient resources to research and development in this area. The Alberta Energy Resource Conservation Board recently proposed requirements to decrease the ratio of wet to dry fine particles in the discharge to the tailing ponds, with a final requirement expected soon. These requirements will likely require the widespread adoption of the Consolidated Tailings technology or a similar type of technology.

Wildlife

Habitat loss from oil sands development (including the creation of tailings ponds) is currently the greatest concern to migratory birds (particularly the whooping crane) and to the woodland caribou due to severe challenges for landscape restoration and reclamation. By combining the various estimates of the loss of birds from mining and in-situ operations (including tailings ponds), a recent report by the Natural Resources Defence Council projects a cumulative impact over the next 30 to 50 years ranging from a low of about 6 million birds lost to as high as 166 million birds lost. Modelling by the Cumulative Environmental Management Association (CEMA) has indicated that the herds of woodland caribou in the region will be significantly affected by the development of in-situ facilities and their extensive linear disturbances (there are no herds in the surface mining area of the oil sands).

Birds that land on tailings ponds can also become oiled or ingest toxic material, both of which can be detrimental or fatal. Tailing ponds can become biological traps for species, as passing or migrating birds mistake them for natural bodies of water. Some endangered and threatened species of migratory birds are also known to occur and migrate over the oil sands tailings ponds. Examples include Whooping Cranes and Peregrine Falcons. The recent report by the Natural Resources Defence Council estimated an annual mortality of 8,000 to 100,000 birds due to direct bird contact with tailings ponds (a part of the overall oil sands impact noted above). The report also anticipated that a doubling of tailings ponds would increase projections to 17,000 to 300,000 birds. Experts in Canadian Wildlife Service concluded that estimates of landings on tailings ponds are reasonable, but such estimates of mortality are highly speculative.

In April 2008, approximately 500 migratory ducks became oiled and died when they landed on a tailings pond at Syncrude's Aurora mine. The company's normal noise-making deterrent equipment was not functioning at the time. This is the largest single number of birds reported oiled in past years, and the incident became international news. It should also be noted that small numbers of bird losses have been documented in the tailings ponds for many years, even with bird deterrents in place.

Air

Any hydrocarbons (bitumen, extraction solvents or diluent) not recovered in the mining process generally end up in the tailings ponds. Heating from the sun, surface agitation from the wind and microbial breakdown of these residual hydrocarbons results in emissions to the atmosphere.

Tailings ponds are an important source of emissions of smog-forming volatile organic compounds, methane (a greenhouse gas) and benzene (a toxic, carcinogenic volatile organic compound) from oil sands mines, accounting for more than 70% of a facility's total. In 2006, this represented approximately 100,000 tonnes of emissions of volatile organic compounds and methane to the atmosphere; however, these emissions estimates are calculated from emission factors derived from limited observations and actual emissions may in fact be larger.

CONSIDERATIONS

Media Attention

There is considerable international media attention to the environmental performance of the oil sands, and the size and toxicity of the tailing ponds features prominently in that coverage. The environmentalist's message of Canada's "dirty oil" has gained significant attention abroad.

Alberta Regime

Oil sands projects are subject to various licenses and approvals from several departments and agencies of the Government of Alberta. Prominent among those is the need for a license from the Energy Resources Conservation Board, the provincial energy regulator. The Board imposes several performance and reporting requirements, for example on sulfur recovery and proposed performance requirements for oil sands tailings.

Under Alberta's *Environmental Enhancement and Protection Act*, an environmental assessment must be completed, and the resulting permit is typically associated with a long list of conditions related to environmental performance (water removal, water quality of non-tailing pond discharges, land and land reclamation, air emissions standards, environmental equipment performance, solid waste). A permit under the *Water Act* is required for withdrawals of surface water. Alberta has an enforceable requirement for oil sands tailing ponds that does not allow companies to discharge any untreated water. Other permits regulate use of crown land, infrastructure and other aspects of a project.

Environment Canada's Authorities

Because the tailing ponds do not discharge into fish-bearing bodies of water, Environment Canada has not regulated tailings ponds through the *Fisheries Act* (although it might be able to if it there was seepage from the tailing ponds into fish-bearing bodies of water). As a result, the Department does not actively monitor tailings management systems or the ponds themselves. However, Environment Canada administers and enforces a number of acts and regulations which could impose some requirements over oil sands tailing ponds. These are the *Fisheries Act*, the *Species at Risk Act*, and the *Migratory Birds Convention Act* and its associated *Migratory Birds Regulations*. In addition, releases of toxics substances from tailings ponds (either to the air or to water) could be covered by the *Canadian Environmental Protection Act*. Many toxics substances found in tailing ponds (e.g., VOCs, PAHs, benzene) are on Schedule 1 of CEPA, but currently there are no federal regulations to control their releases from tailings ponds. Under the Clean Air Regulatory Agenda, the feasibility of a regulated code of practice for reducing fugitive emissions from tailing ponds is to be assessed.

Environment Canada does not issue any approvals for the oil sands projects. There are no federal triggers under the *Canadian Environmental Assessment Act* for Environment Canada. The

Department of Fisheries & Oceans and Transport Canada have such triggers that result in those departments issuing either authorizations or permits. Environment Canada participates in the environmental assessment process as a Federal Authority providing scientific, expertise, information and knowledge to the Responsible Authorities (i.e., Fisheries & Oceans and Transport Canada). As well, the Province of Alberta issues approvals for oil sands projects.

The Department has only limited science capacity related to tailings management. However, broad questions of water use and protection of surface water quality related to the oil sands industry are of interest to the Department.

Ian Shugart

c.c.: Associate Deputy Minister

Attachments (2)

Revised January 19, 2009

Appendix XIX:

Correspondence between the Submitter Environmental Defence and Environment Canada (January 2009 - March 2010)

ENVIRONMENTAL | DEFENCE
317 Adelaide Street West Suite 705 • Toronto Ontario Canada • M5V 1P9 • tel 416 323 9521 fax 416 323 9301 • www.environmentaldefence.ca

Ian Shugart, Deputy Minister
Environment Canada
Gatineau, Quebec
K1A 0H3

January 26, 2009

Dear Mr. Shugart:

This letter seeks action from your Department regarding the enforcement of s.36(3) of the *Fisheries Act* with regard to widespread toxic leakage from tar sands tailings ponds.

Please find attached a copy of our recent report "11 Million Litres a Day: The Tar Sands Leaking Legacy." The report uses data from tar sands companies to estimate for the first time the overall leakage of contaminated tailings water into the groundwater of the Athabasca watershed.

We have also enclosed the calculations, and as you will see, we believe that the figures we used in the report are in fact overly conservative. Moreover, in the next several years the overall leakage rate is set to increase five-fold with new projects.

As your Department itself notes, assuming that contaminants will stay in the groundwater is "wishful thinking." S.36(3) clearly anticipates indirect deposition of substances into waters that connect with fish bearing waters, and it is solidly established that leaking tailings water contains substances harmful to fish.

Leakage of contaminated tailings water is acknowledged by the tar sands companies in their applications for new projects, yet there are no permits given to waive enforcement of s.36(3), nor are there regulations under the *Fisheries Act* that would exempt the need for companies to acquire such permits.

The existence of a Canada-Alberta agreement on coordinating activities on deleterious substances does not relieve responsibility to enforce the relevant provisions of the *Fisheries Act*. Indeed, in this situation there are several factors that warrant an increased federal role, including:

- Expressions by federal officials of concern over weakness of information, modeling, standards, and monitoring with regards to water quality issues in the tar sands;

- The trans-boundary nature of this problem given the proximity of the downstream jurisdictions of Saskatchewan and the Northwest Territories;
- The double standard of having specific federal regulation of metals mining and tailings ponds, but not for tar sands mining and tailings ponds; and
- The fiduciary duty the federal government has to First Nations who have heightened concerns regarding water quality and health issues in the tar sands

We therefore ask that you exercise your authority to effectively enforce s.36(3) of the *Fisheries Act* in order to bring an end to the practice of the massive leakage of contaminated water from the tailings ponds.

Yours sincerely,

Matt Price
Project Manager

cc Marcelle Marion, SEM Legal Advisor, Commission for Environmental Cooperation
Sean Nixon, Staff Lawyer, Ecojustice

Environment Canada | Environnement Canada
Deputy Minister | Sous-ministre

Mr. Matt Price
Project Manager
Environmental Defence
317 Adelaide Street West, Suite 705
Toronto ON M5V 1P9

Dear Mr. Price:

Thank you for your correspondence of January 26 and copy of your report, *11 Million Litres a Day: The Tar Sands' Leaking Legacy*, regarding the Alberta oil sands tailings ponds.

The general prohibition in the federal *Fisheries Act*, which you cite in your letter, is triggered by the release of a deleterious substance in waters frequented by fish. In order to take enforcement action, the Crown must be able to demonstrate that a particular person caused such a release, in this case in the Athabasca watershed.

To determine whether evidence exists that groundwater contamination from oil sands tailings ponds is leaking into the Athabasca watershed, and whether contamination from direct leaking of tailings ponds into the Athabasca watershed is occurring, Environment Canada reviewed information from a variety of sources, including: your report; the *Regional Aquatics Monitoring Program (RAMP) Technical Report 2006*; the final report on the Athabasca Chipewyan First Nation Fresh Water Mussel Contaminant Project 2001; a report on the Near Fields Aquatics Effects Monitoring Study, Athabasca River, Fall 2001; a report on the Aquatic Effects Monitoring Study in the Athabasca River, Fall 2004; a report on the 10-Year Technical Review of Aquatic Effects Monitoring Studies on the Athabasca River March 2006; and the 2007 annual groundwater monitoring reports from Syncrude Canada Ltd., Albian Sands Energy Inc. and Suncor Energy Inc. To date, we have no evidence of any particular point where such leaking into the Athabasca watershed is occurring.

In May and June 2009, departmental officials will visit four oil sands companies in Alberta, to review their operations and monitor any discharges from those operations directly into fish-bearing water. If required, the officials will evaluate the potential indirect impacts of any such discharges. As Alberta Environment regulates the control of the construction of tailings ponds, the deposit of waters into the existing tailings ponds, and the monitoring of these activities, we will advise the Province ahead of time of our site visits and invite them to join us.

/2

If any person has evidence of a contravention of subsection 36(3) of the *Fisheries Act*, the evidence can be brought to the attention of a *Fisheries Act* inspector via a 24-hour complaint line (1-800-222-6514) supported by the Department. Such evidence can also be brought in person or mailed to Environment Canada, Environmental Enforcement Division, Room 200, 4999 – 98 Avenue, Edmonton AB T6B 2X3.

With respect to your comment regarding the metal mining industry, the *Metal Mining Effluent Regulations* deal with an industry in cases where there is a surface discharge directly into fish-bearing waters. Environment Canada is not aware of any such issue with respect to the oil sands industry, and there is no surface discharge from the tailings ponds. Should this change, we will revisit the issue.

I appreciate your organization's continuing interest in protecting the environment.

Sincerely,

Ian Shugart

ENVIRONMENTAL | DEFENCE
317 Adelaide Street West Suite 705 • Toronto Ontario Canada • M5V 1P9 • tel. 416.323.9521 fax. 416.323.9301 • www.environmentaldefence.ca

May 8, 2009

Ian Shugart, Deputy Minister
Environment Canada
10 Wellington Street
Gatineau, Quebec K1A 0H3

Dear Mr. Shugart:

Thank you for your reply of April 8 regarding s. 36(3) of the *Fisheries Act* and tailings ponds leakage in the tar sands.

As you recommend in your letter, please find enclosed a copy of a letter to the Environmental Enforcement Division in Edmonton regarding documented instances of deposition of deleterious substances from tailings ponds into fish bearing surface waters in the Athabasca watershed. We are concerned that your Ministry would not have routine access to such information and believe this lack of information in itself reflects a significant gap in the enforcement of the *Fisheries Act* in the largest industrial enterprise in the country.

We are also concerned with the narrow focus of your response on documented instances of deposition of deleterious substances when it is clear, as the attached letter outlines, that sub-section 36(3) of the *Fisheries Act* clearly refers to indirect deposition, of which the contaminated water entering the groundwater systems of the Athabasca is already one of the biggest in Canada, and set to explode in size.

We have requested a reply in the attached letter that may involve issues that fall beyond the scope of your Enforcement Division, so would also request your reply to any such issues so that the current position of Environment Canada on this matter is fully understood.

Sincerely,

Matt Price
Project Manager

cc: Doris Millan, Submissions on Enforcement Matters Unit, Commission for Environmental Cooperation
Barry Robinson, Counsel, Ecojustice

ENVIRONMENTAL | DEFENCE
317 Adelaide Street West Suite 705 • Toronto Ontario Canada • M5V 1P9 • tel: 416.323.9521 fax: 416 323 9301 • www.environmentaldefence.ca

May 8, 2009

Environment Canada
Environmental Enforcement Division
Room 200, 4999 – 98 Avenue
Edmonton, AB T6B 2X3

Dear Sir/Madam:

Re: Request for Investigation
Subsection 36(3) of the *Fisheries Act*

Environmental Defence is a non-profit environmental organization that works to protect the environment and human health. Over the past year, Environmental Defence has conducted research into the leakage of process waters from oil sands tailings ponds in the Athabasca region of Alberta.

The purpose of this letter is to provide you with evidence of alleged contraventions of subsection 36(3) of the *Fisheries Act*. Groundwater and surface water monitoring reports prepared by Syncrude Canada Limited ("Syncrude") indicate that oil sands process waters are leaking from tailings ponds into Bridge Creek and Beaver Creek in the Athabasca region. Further, process waters are leaking from tailings ponds into groundwater aquifers connected to surface waters frequented by fish. These deposits into waters frequented by fish and into locations that may enter such waters are not authorized by any regulation or approval under the *Fisheries Act*.

By this letter, we are requesting that the Enforcement Division of Environment Canada investigate these alleged offences and take appropriate enforcement action.

A. The Law

Subsection 36(3) of the *Fisheries Act* provides that:

> 36(3) Subject to subsection (4), no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter any such water.

Our understanding of subsection 36(3) of the *Fisheries Act* includes the following:

1. A "deleterious substance" is any substance that, if added to any water, would degrade the quality of that water so that it is rendered deleterious to fish. It is not necessary that the deleterious substance render the receiving watercourse deleterious to fish.

"Deleterious substance" is defined in subsection 34(1) of the *Fisheries Act*:

> 34. (1) "deleterious substance" means
>
> (*a*) any substance that, if added to any water, would degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water, or
>
> (*b*) any water that contains a substance in such quantity or concentration, or that has been so treated, processed or changed, by heat or other means, from a natural state that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water so that it is rendered or is likely to be rendered deleterious to fish or fish habitat or to the use by man of fish that frequent that water,
>
> and without limiting the generality of the foregoing includes
>
> (*c*) any substance or class of substances prescribed pursuant to paragraph (2)(*a*),
>
> (*d*) any water that contains any substance or class of substances in a quantity or concentration that is equal to or in excess of a quantity or concentration prescribed in respect of that substance or class of substances pursuant to paragraph (2)(*b*), and
>
> (*e*) any water that has been subjected to a treatment, process or change prescribed pursuant to paragraph (2)(*c*).

In *R. v. Kingston (Corporation of the City)*, (2004) 70 O.R. (3d) 577, (2005) D.L.R.(4th) 734 (Ont. C.A.) ("*Kingston*"), the Court stated:

> [63] On an ordinary and plain reading of paragraph [34(1)](a) [defining "deleterious substance"], a substance is deleterious if, when added to *any water*, it would alter the quality of the water such that it is likely to render the water deleterious to fish, fish habitat or to the use by man of fish that frequent the water. There is no stipulation in paragraph (a) that the substance must be proven to be deleterious to the receiving water. There is no reference to the receiving water in paragraph (a). On the contrary, the language makes it clear that the substance is deleterious if, when added to any water, it degrades or alters the quality of the water to which it has been added. The "any water" referred to in paragraph (a) is not the receiving water. Rather, it is any water to which the impugned substance is

added, after which it can be determined whether the quality of that water is rendered deleterious to fish, fish habitat or the use by man of fish that frequent that water.

[64] I agree with the interpretation of s. 36(3) given by Seaton J.A. in *MacMillan Bloedel* [*R. v. MacMillan Bloedel (Alberni) Ltd.* (1979) 47 C.C.C. (2d) 118 (B.C.C.A.)]. As he noted at pp. 121-22: "What is being defined is the substance that is added to the water, rather than the water after the addition of the substance."

[65] The focus of s. 36(3) is on the substance being added to water frequented by fish. It prohibits the deposit of a deleterious substance in such water. It does not prohibit the deposit of a substance that causes the receiving water to become deleterious. It is the substance that is added to water frequented by fish that is defined, not the water after the addition of the substance. A deleterious substance does not have to render the water into which it is introduced poisonous or harmful to fish; it need only be likely to render the water deleterious to fish. The *actus reus* is the deposit of a deleterious substance into water frequented by fish. There is no requirement in s. 36(3) or paragraph (a) of the definition of the term "deleterious substance" in s. 34(1), of proof that the receiving waters are deleterious to fish.

Therefore, it is clear that, to find an offence under subsection 36(3), it is not necessary that the deleterious substance render the receiving water deleterious to fish. It is sufficient that the deleterious substance, when added to any water, would render the water deleterious to fish.

In the case of tailings ponds leakage, it is therefore sufficient to establish that oil sands process waters are deleterious to fish and are entering or may enter water frequented by fish. It is not necessary that the leakage of tailings process water render the receiving waters deleterious to fish.

2. "Deposit" includes leakage or seepage.

"Deposit" is defined in subsection 34(1) of the *Fisheries Act*:

"deposit" means any discharging, spraying, releasing, spilling, **leaking, seeping**, pouring, emitting, emptying, throwing, dumping or placing.

(Emphasis added.)

Contravention of subsection 36(3) of the *Fisheries Act* does not require the direct deposit of the deleterious substance into water frequented by fish. Indirect leakage or seepage of the deleterious material into the waters is sufficient.

The courts have confirmed that the leakage or seepage of the deleterious substance is sufficient to find a contravention of subsection 36(3) in a number of situations: seepage of leachates from landfill sites (*Kingston*; *Gemtec v. R.*, 2007 NBQB 1999); leakage from an underground pipe through soil (*R. v. MacMillan Bloedel Ltd.*, 2002 BCCA 510); and, leakage through or across land (*R. v. Rivtow Straits Limited*, 1993 CanLII 1769).

Therefore, any leakage or seepage of process waters from oil sands tailings ponds that enters or may enter water frequented by fish would constitute a deposit.

3. It is not necessary that the deleterious substance enter water frequented by fish to find an offence under subsection 36(3) of the *Fisheries Act.* It is sufficient that the deleterious substance is deposited in a location that <u>may</u> enter water frequented by fish.

Subsection 36(3) of the *Fisheries Act* provides that:

> 36(3) Subject to subsection (4), no person shall deposit or permit the deposit of a deleterious substance of any type in water frequented by fish or **in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance <u>may</u> enter any such water.**
>
> (Emphasis added.)

This latter phrase of subsection 36(3) confirms that enforcement should take place proactively, requiring any proponent of groundwater contamination to offer definitive evidence that the contamination will not reach water frequented by fish.

There has been no such evidence presented by oil sands companies that the deleterious substances they are leaking into the groundwater will not enter waters frequented by fish, and indeed documented below are instances where this has taken place. Given the planned expansion of leakage of contaminated waters into groundwater by oil sands companies over the next decade, the risks and occasions of surface water contamination through this pathway will only grow, in direct contravention of the second part of subsection 36(3).

B. The Evidence

1. Deleterious Substance

In a recent scientific article, Erik W. Allen, "Process water treatment in Canada's oil sands industry: I. Target pollutants and treatment objectives", (J. Environ. Eng. Sci. 7:123-138), the author compiles the results of several studies of the inorganic chemistry, organic chemistry and toxicity of oil sands process waters, including process waters from Syncrude's Mildred Lake Settling Basin ("MLSB") and Suncor Energy's tailings ponds. The article indicates that oil sands process waters exceed the Canadian Council of

Ministers of the Environment ("CCME") *Canadian Environmental Quality Guidelines: Surface Water Quality Guidelines for the Protection of Aquatic Life* (CCME, 2005) for several substances including ammonia, benzene, cyanide, oil and grease, phenols, toluene, polycyclic aromatic hydrocarbons, arsenic, copper and iron. The author concludes that:

> Chemicals of environmental concern in oils sands process water include NA's [naphthenic acids], bitumen, ammonia, sulphate, chloride, aromatic hydrocarbons, and trace metals. While NA's are the main contributors of acute toxicity to aquatic biota, various compounds have exceeded CCME water quality guidelines at some point during oil sands operations and could contribute to chronic toxicity in reclaimed aquatic environments.

While Mr. Allen's focus was on the impact of contaminated process waters on the reclamation of tailings ponds, the article provides clear evidence that oil sands process water may be acutely toxic and chronically harmful to fish.

We request that Environment Canada conduct additional sampling of oil sands tailings ponds to confirm that oil sands process waters are deleterious to fish.

2. Syncrude's Mildred Lake Settling Basin

Syncrude is the operator of the Mildred Lake oil sands mine. The mine site includes three tailings areas: the Mildred Lake Settling Basin ("MLSB"), the Southwest Sand Storage Site (SWSS) and an in-pit tailings area.

The Mildred Lake East Toe Berm ("MLETB") was constructed on the east side of the MLSB. According to the *2007 Groundwater Monitoring Report, Syncrude Canada Ltd., Mildred Lake Site* ("*2007 Mildred Lake Report*"), submitted by Syncrude to Alberta Environment on March 15, 2008, at subsection 5.2.2.1.2:

> The MLETB was constructed with hydraulically placed sand, and so when initially placed, the deposit was fully saturated. Characteristics unique to the MLETB have allowed it to drain and flush significantly faster than Syncrude's other tailings deposits. In particular, the volume of pond water within the MLETB is minimal and has likely been diluted by surface runoff and precipitation over the years. There is therefore no constant or fresh source of process affected water over the entire deposit. The MLETB is also constructed on a foundation having relatively high hydraulic conductivity, and contains a number of finger drains within the foundation of its perimeter.
>
> The evidence indicating that the MLETB has been drained and flushed of contaminants is as follows:
>
> - The total flow from the finger drains has decreased to zero, indicating that the perimeter of the MLETB has drained, in those locations where the

finger drains exist. Currently, all ten finger drains along the north side and the seventeen finger drains along the east side of the MLETB are dry. The only flow from the MLETB is from the toe at ETB-GD (granular drain) section. Flow rates are usually monitored at the finger drains, whereas the ETB drains are only monitored for water level and chemistry. However, the trend of finger drain flow rate from last two years till now has not reported any flow, which is substantiated by the record of no-flow condition from the finger drains this year (Figure 5.6). Syncrude is considering stopping monitoring the finger drains for flow since (the drains are dry) monitoring at the toe is now basically the natural groundwater elevation in the area.

- The general trend of the standpipes water elevations was slightly lower than previous year and constant in a few locations while the surrounding ditches are virtually dry. Figure 5.7 shows the locations of the standpipes and finger drains, the current elevation of the water table and the original ground elevation in the MLSB relative to the standpipes, finger drains and ditches.

- The concentration of the major ions sampled from the MLETB appears steady over a five-year period with a slight drop at the later years. This follows a steady state concentration in the MLETB and a subsequent natural attenuation of the contaminant as observed in the declining trend.

With the little or no-flow of process water within the MLETB structure, the flux of water moving beyond the perimeter ditch is expected to decrease, and invariably the potential for influence on the surrounding environment. **Provided that the current ditch system is maintained, the flux of contaminated MLETB seepage water reaching the ditch, moving past the ditch and entering Beaver Creek are all expected to decline.**

(Emphasis added.)

This passage clearly indicates that the contaminated process waters, originally found in the hydraulic slurry used to construct the MLETB, were allowed to flow into the groundwater aquifer and into the nearby Beaver Creek. While the contaminated process waters have now migrated out of the MLETB and beyond the perimeter ditch, flow through the groundwater aquifer into Beaver Creek continues. It is not clear from the *2007 Mildred Lake Report* how much longer the process water will continue to enter Beaver Creek.

The results of surface water monitoring, found in the *2007 Mildred Lake Report* at subsections 5.2.2.3.2 and 5.2.2.3.3, further confirm that oil sands process waters are reaching both Bridge Creek and Beaver Creek:

5.2.2.3.2 Bridge Creek
The concentrations of major ions reduced at OW99-27 except for chloride while the surface water quality sample at the west interceptor ditch (WID) indicated a reduced concentrations [sic] of major ions, selected metals and naphthenic acid. This reflected a down-stream effect of the low flow from the MLSB (source).

5.2.2.3.3 Beaver Creek
Beaver Creek is routinely sampled at two locations, downstream of the Lower Seepage Dam (TBC-1B) and at Highway 63 (TBC-3). Both locations continue to show a consistent flat and steady trend except for sodium and chloride at TBC-1B. This observation is as a result the [sic] reduced actual volume of seepage into Beaver Creek, following the (no-flow) trend from the finger drains, adjacent sampling locations (SG0122-01) and reported low flow in the dyke.

Bridge Creek and Beaver Creek are both tributaries to the Athabasca River.

Further, the *2007 Mildred Lake Report* indicates, at subsection 5.2.2.2.2, that a plume of contaminated groundwater continues to expand east of the MLSB and southeast of the MLETB:

> Another seven wells (OW99-15, OW99-16, OW99-17, OW98-08, OW98-20, OW01-03 and OW98-27) show influence of process-affected water, which is due to their proximity to the MLSB. However, the trend of the concentrations of major ions and selected metals at these wells are flat and stable. Moreover, the chloride concentration is also retarding and shrinking within these areas. **Results from another four wells (OW99-12, OW99-18, OW98-21 and OW98-26B) show a steady flat trend in major ions and selected metals while a slight increase of major ions was noticed at two wells due to their proximity to the MLSB, OW98- 22 and OW98-28 consequently the chloride concentration trend within these areas indicated a forward migration.** Moreover, groundwater well OW03-03 is also impacted with increased concentration, which is indicative of some variability in the trending. This area shall be closely monitored in the 2008 in order to stabilize the plume.
>
> (Emphasis added.)

In a letter dated June 9, 2008 from Kem Singh, Alberta Environment to Nathalie Berube, Syncrude in response to the submission of the *2007 Mildred Lake Report*, Alberta Environment stated that:

> Monitoring wells OW80-14 and OW03-03 continue to clearly show increasing chloride concentrations not reflective of background chemistry. In addition, monitoring well OW99-14 is showing an increase. This is all indicative of an advancing plume.

Therefore, it is our belief that there is evidence of oil sands process water reaching both Bridge Creek and Beaver Creek, and that there is an expanding plume of contaminated groundwater east of the MLSB that may reach Bridge Creek, Beaver Creek and/or the Athabasca River. As discussed in Part A, Section 1 of this letter above, it is not necessary that the deleterious substance render the receiving waters deleterious to fish in order to take enforcement action. It is sufficient that the deleterious substance is entering or may enter the receiving waters.

We therefore request that Environment Canada consider this evidence and carry out the investigations necessary to confirm whether Syncrude has deposited a deleterious substance, namely oil sands process water, at its Mildred Lake mine site in locations where that deleterious substance is entering or may enter water frequented by fish.

3. Syncrude's Aurora Tailings Pond

Syncrude operates the Aurora North mine site. The site includes an external tailings pond known as the Aurora North Settling Basin ("ANSB"). The Muskeg River lies within 1 kilometre to the east of the ANSB.

The *2007 Groundwater Monitoring Report, Syncrude Canada Limited, Aurora* ("*2007 Aurora Report*"), submitted by Syncrude to Alberta Environment on March 28, 2008, indicates at section 3.5 that there are four areas where contamination from process water has been identified beyond the perimeter containment ditch of the ANSB:

(i) South Seepage Sump Area: The South Seepage Sump Area ("SSSA") lies to the southeast of the ANSB, between the ANSB and the Muskeg River. The *2007 Aurora Report* states:

> The water chemistry of monitoring well OWS0134-11 near the south seepage sump has shown similarity with the type of water influenced by process water. A significant increase in the chloride concentration occurred from 2006 (92 mg/l) to 2007 (178 mg/l). The sodium concentration also increased from previous years samples. The chloride concentrations in monitoring well OWS0434-16 continued to increase in 2007 to 148 mg/l from a value of 62 mg/l in 2006. These concentrations are becoming closer to typical process water concentrations.

In a letter dated June 9, 2008 from Kem Singh, Alberta Environment to Nathalie Berube, Syncrude in response to the submission of the *2007 Aurora Report* (the "*Aurora Response Letter*"), Alberta Environment stated:

> Continued increasing concentrations (chloride) in monitor wells OWS0134-11 and OWS0434-16 are observed. Additionally, monitor well OWS0134-12 and recently installed (2007) monitor well OWS0734407 show signs of impact, based on chloride concentrations. It is our understanding that Syncrude believes that operating the south seepage sump with a maximum water level elevation of 280masml will curtail the movement of process affected waters. If required, in

addition to the south seepage sump, what other mitigative means may Syncrude implement to prevent process water from reaching the Muskeg River?

(ii) East Side: On the east side of the ANSB, process water was migrating beyond the perimeter ditch in 2001. Syncrude constructed a sump in 2002 and a bentonite cut-off wall in 2005 in an attempt to reduce the migration of the plume towards the Muskeg River. In 2007, the sump was not operated for most of the year due to equipment failures. The *2007 Aurora Report* indicates that, "[t]his changed the direction of the gradient from into the perimeter ditch out towards the Muskeg River." The *2007 Aurora Report* also notes that seepage continues beyond the cut-off wall.

(iii) Northeast Pit: A proposed mining area, the Northeast Pit, lies to the northeast of the ANSB. Stanley Creek drains the Northeast Pit area and flows into the Muskeg River. The Northeast Pit is proposed to be mined beginning in 2035. The *2007 Aurora Report* indicates that seepage is occurring outside of the containment system on the northeast side of the ANSB:

> Syncrude's experience and previous chemistry results indicated that the current plume will remain outside of the cut-off wall, and will slowly be diluted by advection, dispersion and potentially degradation of the organic components. The future migration of this plume is expected to be in an overall east or south-easterly direction [towards the Muskeg River]. There was no increase in the ion concentrations of the surrounding monitoring wells to suggest any migration of the contaminant plume occurred in 2007. There was evidence that the plume is being influenced by additional process water though. The chemistry results from 2007 suggest that process affected water from the tailings pond or perimeter ditch is recharging the plume. Syncrude will be looking into the issue and continue tracking the movement of process affected waters in the area.
>
> At this time, Syncrude does not see the need to immediately recover the plume that remains outside the cut-off wall. The current mining sequence for the Aurora site identifies that the mining of the area north of the tailings pond (Northeast Pit) begins in 2035. The area would have to be dewatered in preparation for mining; therefore recovery of the plume could take place at this time, if it is deemed necessary. In the interim Syncrude will continue to monitor the movement of this plume. Syncrude Research is conducting research on process water constituents including the degradation process within environmental waters.

In the *Aurora Response Letter*, Alberta Environment questioned Syncrude's plan to leave the dewatering of this plume until 2035, stating:

> A significant delay in dewatering may provide an opportunity for the plume to reach surface water receptors.

(iv) East Pit Passage Area: The East Pit Passage Area ("EPP"), to the northwest of the ANSB, is being dewatered in advance of mining. Water is pumped from the EPP into a polishing pond and subsequently into the Stanley Creek drainage. The *2007 Aurora Report* indicates that the quality of the discharged water was similar to background water chemistry.

The *2007 Aurora Report* indicates that monitoring of the Muskeg River has not yet identified any impact from leakage from the ANSB. However, as discussed above, there is evidence of contaminated groundwater plumes migrating beyond the containment systems and towards the Muskeg River at the SSSA, at the east side of the ANSB and at the Northeast Pit. As discussed in Part A, Section 3 of this letter above, it is not necessary that deleterious substances reach water frequented by fish before Environment Canada may take enforcement action. Environment Canada may take proactive enforcement action to prevent contaminated groundwater from reaching surface waters frequented by fish. The *2007 Aurora Report* provides evidence of contamination plumes migrating towards Stanley Creek and the Muskeg River. Given the hydrology of this area, it is likely that these plumes will continue to migrate for decades after the source of contamination has been eliminated.

We therefore request that Environment Canada consider this evidence and carry out the investigations necessary to confirm whether Syncrude has deposited a deleterious substance, namely oil sands process water, at its Aurora North mine site in locations where that deleterious substance may enter water frequented by fish.

C. Conclusion

Environment Canada's *Compliance and Enforcement Policy for the Habitat Protection and Pollution Prevention Provisions of the Fisheries Act (November 2001)* ("*Enforcement Policy*") states that compliance with the pollution prevention provisions of the *Fisheries Act* is mandatory. Further, the *Enforcement Policy* indicates that Environment Canada will administer the provisions of the *Fisheries Act* with an emphasis on preventing harm. The predicted life of oil sands tailings ponds is in some cases up to sixty years after mining operations have ceased, and the life of contaminants like napthenic acids also extend well beyond that point. Therefore, it is essential that Environment Canada act now to address tailings pond leakage and to prevent long term degradation of the fish bearing watercourses in the Athabasca region.

Based on the evidence provided above, Environmental Defence requests that Environment Canada conduct the investigations necessary to determine if contraventions of subsection 36(3) of the *Fisheries Act* have occurred or are occurring as a result of tailings pond leakage. Further, Environmental Defence requests that Environment Canada take enforcement action where contraventions of subsection 36(3) are found.

We respectfully request a response to this letter outlining your plan of action at your earliest convenience. Thank you for your assistance.

Sincerely,

Matt Price
Project Manager

cc: Ian Shugart, Deputy Minister, Environment Canada
Doris Millan, Submissions on Enforcement Matters Unit, Commission for Environmental Cooperation
Barry Robinson, Counsel, Ecojustice

ENVIRONMENTAL | DEFENCE
317 Adelaide Street West Suite 705 • Toronto Ontario Canada • M5V 1P9 • tel: 416.323.9521 fax: 416.323.9301 • www.environmentaldefence.ca

May 29, 2009

Ian Shugart, Deputy Minister
Environment Canada
10 Wellington Street
Gatineau, Quebec K1A 0H3

Michel Labossiere, Manager
Environment Canada
Environmental Enforcement Division
Room 200, 4999 – 98 Avenue
Edmonton, AB T6B 2X3

Via e-mail

Dear Mr. Shugart and Mr. Labossiere

Re: Request for Investigation
Subsection 36(3) of the *Fisheries Act*

By letter dated May 8, 2009, we requested an investigation of alleged contraventions of Subsection 36(3) of the *Fisheries Act* resulting from leakage from Syncrude's Mildred Lake Settling Basin and Aurora North Tailings Pond. We are attaching additional information that would suggest that your investigation of tailings pond leakage should be expanded to include other oil sands operations.

We have attached the Albian Sands Energy Inc. *2008 Groundwater Monitoring Program: Muskeg River Mine* report prepared by Worley Parsons (the "*Albian Sands Report*"). This report indicates increasing total dissolved solids, chloride, sulphate, sodium, calcium, magnesium and bicarbonate concentrations in some groundwater monitoring wells downgradient of the Albian Sands Muskeg River tailings pond. The increasing concentrations are observed primarily in wells in shallow Quaternary deposits located between the tailings pond and the Muskeg River. This would indicate the possibility of the contaminants reaching the Muskeg River.

The *Albian Sands Report* claims that the observed effects do not appear to be associated with the seepage of process waters from the tailings pond but may be from the use of road salts or ground disturbance in the vicinity of the wells. Regardless of the source, the observed effects indicate an impact on the shallow aquifer close to the Muskeg River. The *Albian Sands Report* recommends further investigation to confirm the source of these increases.

We request that Environment Canada include the Albian Sands Muskeg River tailings pond in its investigations and conduct further investigations to confirm the source of the groundwater changes.

We have also attached a copy of a report titled *The Sustainable Management of Groundwater in Canada* (2009) prepared by the Expert Panel on Groundwater of the Council of Canadian Academies. This peer-reviewed report was prepared by fifteen Canadian and American experts on groundwater. While the report does not address any specific oil sands operation, it concludes at lines 3962-3969:

> Roughly two tons of oil sands are excavated to produce one barrel of oil, and the sand and associated process water is discharged to large tailings ponds. The tailings-pond dams may be constructed out of some of this processed sand. There is a concern that this has resulted in more-permeable zones in the dams that may leak and act as migration pathways for the contaminants in the tailings water. Of particular concern is the proximity of the tailings ponds to the Athabasca River, with a potential to detrimentally affect both human and aquatic ecosystem health downstream.

We believe that this conclusion supports our contention that oil sands operators cannot demonstrate compliance with the prohibition on the indirect deposition of deleterious substances in the second part of s.36(3) of the *Fisheries Act*.

We look forward to the results of your investigations and request that we be advised of the results of any investigation. Thank you for your assistance.

Sincerely,

Matt Price
Project Manager
Environmental Defence

cc: Doris Millan, Submissions on Enforcement Matters Unit, Commission for Environmental Cooperation
Barry Robinson, Counsel, Ecojustice

Environment Canada Environnement Canada

Deputy Minister Sous-ministre

JUL 0 6 2009

Mr. Matt Price
Project Manager
Environmental Defence
317 Adelaide Street West, Suite 705
Toronto ON M5V 1P9

Dear Mr. Price:

Thank you for your correspondence of May 8 and 29 regarding alleged contraventions of subsection 36(3) of the *Fisheries Act* by Alberta oil sands operations in the Fort McMurray area.

On May 26, 27 and 28 Environment Canada conducted preliminary on-site inspections of five oil sands operations in the Fort McMurray area, to address the concerns identified in your letter and determine what evidence existed that would indicate potential violations under the *Fisheries Act*. Inspections were conducted at Suncor Energy Inc., Syncrude Canada Ltd. (Aurora and Mildred Lake operations), Albian Sands Energy Inc., and Canadian Natural Resources Ltd. (Horizon Oil Sands Project). To date, the findings are inconclusive, and further initiatives are being planned.

Environment Canada has decided to obtain independent verification of whether oil sands components are leaking from tailings ponds into surface water in the Athabasca Region in concentrations that are deleterious to fish. To accomplish this, the Department is collaborating with Alberta Environment to conduct independent monitoring of selected groundwater monitoring wells in the area. We are also examining research options to assist in distinguishing the high background levels in the groundwater from those that could be coming from the tailings ponds. In addition, we will be looking at research to determine the impacts on the native aquatic biota from natural versus oil sands–derived contaminants.

The information collected through this research will be used to determine if the elements of an offence are present. If it is concluded that such elements are present, the Department will assess if the companies are being duly diligent in preventing the deposits.

.../2

Environment Canada has made inspections of the oil sands area a priority. Accordingly, we take your concerns seriously, and are working diligently to assess the information and take the appropriate actions. Should you require additional information, please contact Mr. Hal Sommerstad, Regional Director, Environmental Enforcement Directorate, Prairie and Northern Region, at 780-951-8861 or *hal.sommerstad@ec.gc.ca*.

I trust that the information provided is of assistance, and extend my best regards.

Sincerely,

Ian Shugart

From:	"Ladouceur,Sylvie [NCR]" <Sylvie.Ladouceur@ec.gc.ca>
Subject:	Tailings ponds leakage
Date:	Mon, September 28, 2009 5:43 pm
To:	mjprice@environmentaldefence.ca

Hello,

Unfortunately, Ian Shugart will not be able to meet with Rick Smith on October 2. Currently there is an inspection program underway related to the tailing ponds. As such, it would be inappropriate for the Deputy Minister to comment or provide any specific information related to these inspections or any enforcements activities related to this issue.

Sylvie Ladouceur
Executive Assistant to the DM
Adjointe exécutive au sous-ministre
819-994-5020

Attachments:

untitled-2	
Size:	1.2 k
Type:	text/html

ENVIRONMENTAL | DEFENCE
317 Adelaide Street West Suite 705 • Toronto Ontario Canada • M5V 1P9 • tel: 416.323.9521 fax: 416.323.9301 • www.environmentaldefence.ca

January 13, 2010

Ian Shugart, Deputy Minister
Environment Canada
10 Wellington Street
Gatineau, Quebec K1A 0H3

Dear Mr. Shugart:

I am writing to follow up on your letter of July 6, 2009 in which you indicated that Environment Canada had conducted preliminary investigations with respect to tailings pond leakage in the Alberta oil sands on May 26, 27 and 28, 2009, and that Environment Canada intended to conduct further verification of tailings pond leakage in collaboration with Alberta Environment.

I am writing to request an update on the findings of those studies. Please provide me with the results of any studies conducted by or on behalf of Environment Canada to date with respect to tailings pond leakage. Also, please advise me as to Environment Canada's current intentions with respect to enforcement under section 36(3) of the *Fisheries Act* with respect to tailings pond leakage.

You may be aware of recent research findings by researchers at the University of Alberta with respect to polycyclic aromatic compounds ("PAC's) found in the Athabasca River and its tributaries.[1] These researchers concluded, amongst other findings, that:

- PAC concentrations were increased below oil sands mining developments, upgrading facilities and tailings ponds;
- Where oil sands development was insignificant, the flow of water through the oil sands-bearing McMurray Formation did not significantly affect PAC concentrations, indicating that natural sources did not contribute significantly to increased PAC levels; and
- PAC levels below oil sands mining developments, upgrading facilities and tailings ponds were at levels that are toxic to fish embryos.

---

[1] Erin N. Kelly et al., "Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries", Proc. Ntl. Acad. Sci., Dec. 2009, on-line at www.pnas.org/cgl/dol/10.1073/pnas.0912050106.

We are also in receipt of a document obtained under the *Access to Information Act* that states that while Alberta Environment inspectors are not designated as Fishery Inspectors under the *Fisheries Act*, at that time (March, 2009) it was the practice of Environment Canada to wait for referrals from Alberta Environment before initiating action.[2]

We believe that the evidence we have provided you of leakage of deleterious substances into fish bearing waters (eg. Tar Island Dyke and Syncrude into Beaver Creek), as well as evidence of widespread leakage into groundwater that "may" enter fish bearing waters, as per the second half of section 36(3), warrants a change in enforcement practices by Environment Canada in spite of the silence of Alberta Environment, which is likely to continue indefinitely.

I look forward to your timely response.

Sincerely,

Matt Price
Project Manager

cc: Doris Millan, Submissions on Enforcement Matters Unit, Commission for Environmental Cooperation
Barry Robinson, Counsel, Ecojustice

[2] "Follow up on Committee Hearings," by Pierre Boucher, Environment Canada, March 20, 2009

Environment Canada | Environnement Canada
Deputy Minister | Sous-ministre

FEB 2 2 2010

FEB 2 4 2010

Mr. Matt Price
Project Manager
Environmental Defence
317 Adelaide Street West, Suite 705
Toronto ON M5V 1P9

Dear Mr. Price:

Thank you for your follow-up letter of January 13 in which you request additional information concerning the inspections being conducted on oil sands operations in the Fort McMurray area.

Following the May 2009 preliminary on-site inspections of five oil sands operations in the Fort McMurray area, Environment Canada obtained samples from two active tailings ponds in September 2009, in an effort to verify compliance with the *Fisheries Act*. Comprehensive analytical testing is being done on these samples and their potential toxicity to fish and fish habitat, and the results are expected by spring 2010.

In addition, Environment Canada obtained samples from selected groundwater wells within the oil sands area in November 2009. Extensive testing is being done on these samples to determine the concentration of any contaminants that may be present. Results to date show less than detectable levels for polycyclic aromatic hydrocarbon compounds for one of the groundwater wells sampled, and further analysis is under way. Additional sampling of surface water and groundwater wells in the oil sands area is expected this year, and should include Beaver Creek and wells around Tar Island Dyke.

As noted above and in my July 6, 2009 reply to you, the information collected through these inspections will be used to assess compliance with the *Fisheries Act*. In the event that the samples reveal a potential violation of the Act, an investigation will be initiated. Please be assured that the oil sands operations continue to be a priority for Environment Canada.

.../2

I trust that the information provided is of assistance, and extend my best wishes.

Sincerely,

Ian Shugart

ENVIRONMENTAL | DEFENCE
317 Adelaide Street West Suite 705 • Toronto Ontario Canada • M5V 1P9 • tel. 416.323.9521 fax. 416.323.9301 • www.environmentaldefence.ca

March 25, 2010

Ian Shugart, Deputy Minister
Environment Canada
10 Wellington Street
Gatineau, Quebec K1A 0H3

Dear Mr. Shugart:

Thank you for your letter of February 22. We are writing again because we believe that our correspondence to date has not taken us further towards the goal of effective enforcement of Section 36(3) of the *Fisheries Act* with regards to tailings pond leakage, and we believe we should spell out what this would look like.

The sampling by Environment Canada now underway as described in your February 22 letter would seem to be investigating possible violations some years after surface water impacts have taken place. The height of the Syncrude Beaver Creek incident, for example, would appear to be around 2004, and with regards to Tar Island Dyke, Suncor has been moving to close this pond over the past years.

For us, this is an indication of the systemic nature of the failure to enforce Section 36(3), because Environment Canada is not keeping current with what tailings leakage data does exist via industry self-reporting due to a failure to exercise a regulatory interest in doing so.

The federal government has known about the leakage problem and its relationship to surface water contamination for several years, yet has still not stepped in to regulate. As far back as 2004 the National Energy Board stated:

> …the principal environmental threat from tailings ponds are the migration of pollutants through the groundwater system and the risk of leaks to the surrounding soil and surface water…the scale of the problem is daunting...[i]

Also, successive Canadian Environmental Assessment Act hearings for oil sands mines and associated tailings ponds have seen the companies themselves project surface water contamination and impacts on water quality, yet Environment Canada officials present at those hearings have not taken regulatory action to enforce pollution prevention provisions of the *Fisheries Act*. As you are aware, Canadian case law has established that the receiving waters need not be rendered harmful to fish on these occasions – it is the deleterious substance itself that is subject to the test. Arguments made regarding dilution at these hearings therefore do not excuse the need to regulate or prosecute.

With the weight of evidence dating back several years, we therefore believe that there already exist ample grounds for Environment Canada to enforce the law. While further sampling is meritorious, it should not serve to delay action.

It is our opinion that effective enforcement of Section 36(3) would involve:

1. The creation of regulations specific to oil sands tailings ponds as enabled by Sections 36(4) and 36(5). This would an acknowledgement that tailings ponds are today routinely leaking deleterious substances "in any place under any conditions where the deleterious substance or any other deleterious substance that results from the deposit of the deleterious substance may enter" waters frequented by fish, as per Section 36(3). Such regulation would ensure that Environment Canada be the routine recipient of groundwater monitoring reports as part of compliance. Environment Canada should also be notified immediately should they gain knowledge of surface water deposition.

2. Active prosecution of all incidents of tailings materials entering surface waters, as per Canadian case law – ie. dilution cannot serve as a legal defence to Section 36(3). Prosecution should take place soon following the violation, as enabled by 1, above.

3. Withdrawal of Environment Canada from the discredited Regional Aquatic Management Program (RAMP) in favour of a government-run (arms length from industry) surface and groundwater monitoring program for the region that is scientifically defensible and transparent to the public.

We therefore seek your commitment to these three steps at the earliest convenience, since several years have now passed without Section 36(3) being enforced.

Yours sincerely,

Matt Price
Policy Director

cc: Doris Millan, Submissions on Enforcement Matters Unit, Commission for Environmental Cooperation
Barry Robinson, Counsel, Ecojustice

[1] "Canada's Oil Sands: Opportunities and Challenges to 2015," National Energy Board, 2004.

Appendix XX:

Aurora Mine: 2007 Annual Groundwater Monitoring Report, Syncrude Canada Limited (March 2008)

Syncrude
Environmental Services

March 28, 2008

Alberta Environment
Enforcement and Monitoring Division
11th Floor, Oxbridge Place
9820-106 Street
Edmonton, Alberta
T5K 2J6

Dear Sir/Madam:

RE: AURORA MINE - 2007 ANNUAL GROUNDWATER MONITORING REPORT
SYNCRUDE CANADA LIMITED

Attached, please find two copies of our Annual Compliance Report for 2007 pursuant to clause 4.6.7 of Approval 26-02-00 under the Environmental Protection and Enhancement Act. We trust that the report is satisfactory at this time.

Yours truly,

Nathalie Berube

Environmental Services and Regulatory Approvals
Syncrude Canada Limited
P.O. Bag 4009, M.D. 4160
Fort McMurray, Alberta, T9H 3L1
Ph: (780) 790-4544 Fax: (780) 790-4105
E-mail: berube.nathalie@syncrude.com

REPORT DISTRIBUTION:

2 COPIES: ALBERTA ENVIRONMENT
1 COPY: ALBERTA ENERGY AND UTILITIES BOARD
1 COPY: DALLAS HEISLER, AURORA TECHNICAL
1 COPY: SANIL SIVARAJAN, DEVELOPMENT GEOLOGY
1 COPY: GURINDER NATT, AURORA TECHNICAL LEADER
1 COPY: PAUL KEARNEY, MANAGER AURORA
2 COPIES: NATHALIE BERUBE, ENVIRONMENTAL SERVICES
1 COPY: SCL RESEARCH LIBRARY, EDMONTON
1 COPY: TAILINGS LIBRARY

Table of Contents

List of Tables

List of Figures

1 Introduction

This Syncrude Canada Ltd. report is completed and submitted in compliance with Clause 4.6.7 of Approval 26-02-00 under the Environmental Protection and Enhancement Act. The report outlines and summarizes the results from the 2007 groundwater monitoring program at Syncrude's Aurora North site.

2 Background Information

2.1 Site Location

Syncrude's Aurora North site is located approximately 70 kilometres north of the City of Fort McMurray in the Regional Municipality of Wood Buffalo. Aurora North is a satellite operation for the Mildred Lake Facility. The site is situated on Oilsand leases 10, 12 and 34, Mineral Surface Lease No. 973220. The legal descriptions of various areas are provided in Table 2.1 and shown on Figure 2.1.

Table 2.1: Legal Description of the Aurora Site

Area Description	Sections	Township	Range
Tailings	4 to 9, 16 to 18	96	9
Mine Pit and Dumps	1, 12	96	10
	7, 18, 19	96	9
	1 to 3, 10 to 15, 22 to 24	96	10
Plant	2, 16	96	10

All sections are west of the Fourth Meridian

2.2 Industrial Activity

Overburden and the bitumen-saturated ore body are mined by a truck and shovel fleet. The ore is fed through a crusher and slurry-preparation process. The oilsand slurry is then transported to the Aurora North Plant site, through a hydrotransport pipeline. The bitumen is separated from the sand in primary separation vessels (PSVs). From the PSVs, sand, water and un-recovered bitumen are transported by pipeline to the external tailings pond. An inter-site pipeline transports bitumen froth from the Aurora North PSVs to the Mildred Lake Site. A satellite photograph of the Aurora North site is shown on Figure 2.2.

An on-site natural gas fired co-generator provides electrical power and thermal energy. Hot water, for use in the extraction process, is also imported from the Mildred Lake site via an inter-site pipeline. The Aurora Thermal Block supplies additional hot water.

Overburden material and low-grade oilsand rejects are placed in the Fort Hills and Moose Mountain Dumps, or used for tailings dyke construction.

Depressurization of the basal aquifer, which underlies the ore body, is required to ensure pit floor stability and prevent flooding of the mine. Depressurization is accomplished by pumping a number of wells. Some of the water from these wells is used in the plant and the rest is transported via ditches and sumps to the tailings pond, where it is retained and recycled through the extraction process. Syncrude will begin to pump some of the wells to an aeration pond for treatment and then return the water back to the environment in 2008.

Figure 2.1 – Aurora North and Surrounding Water Users

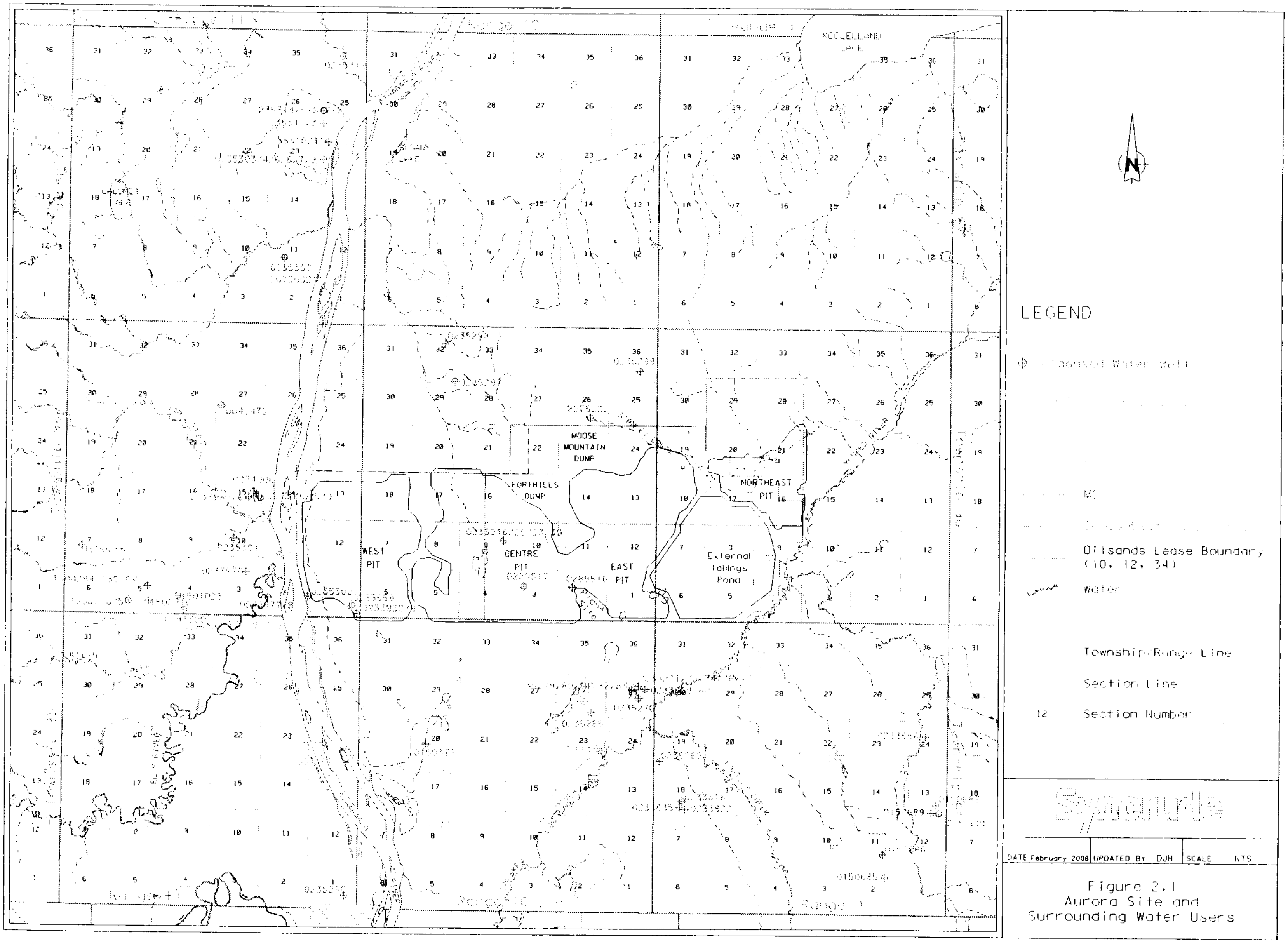


Figure 2.2 – Aurora North 1 m IKONOS Satellite Image, May 2007

2.3 Topography and Drainage

Most of the Aurora North site slopes gently towards the Muskeg River in the southeast. At the northern edge of the site, the Fort Hills rise above 330 metres above mean sea level (mamsl). Originally, natural drainage of the site was controlled by topography. The Muskeg River was the dominant drainage feature. Other minor features include: Stanley Creek at the south edge of the Fort Hills, that flows to the Muskeg River; and Fort Creek, that flows to the Athabasca River, in the northern portion of the Centre Pit.

At present, the topography has been altered by mining activities. The mine pit has been excavated to approximately 220 mamsl, which is approximately 80 metres below original ground. The external tailings pond has been constructed to approximately 30 metres above original ground, the Fort Hills Dump has been built to 350 mamsl, approximately 40 metres above original ground, and the Moose Mountain Dump has been built to 393 mamsl that is approximately 70 metres above original ground.

Site drainage is now predominantly controlled by a series of ditches and sumps. Dirty-water ditches carry water that is retained on site. The dirty-water ditches intercept runoff from the mine, plant, and tailings areas. These ditches also carry depressurization water to the tailings pond. Clean groundwater coming from north of the mine area is intercepted by the East Pit Passage (EPP) and the 1-04 Pond which is then diverted to the Muskeg River through Stanley Creek. The site topography and drainage are depicted on Figure 2.3.

2.4 Regional Hydrogeology

Hackbarth and Nastasa (1979) identified three main hydrostratigraphic units above the Precambrian surface:

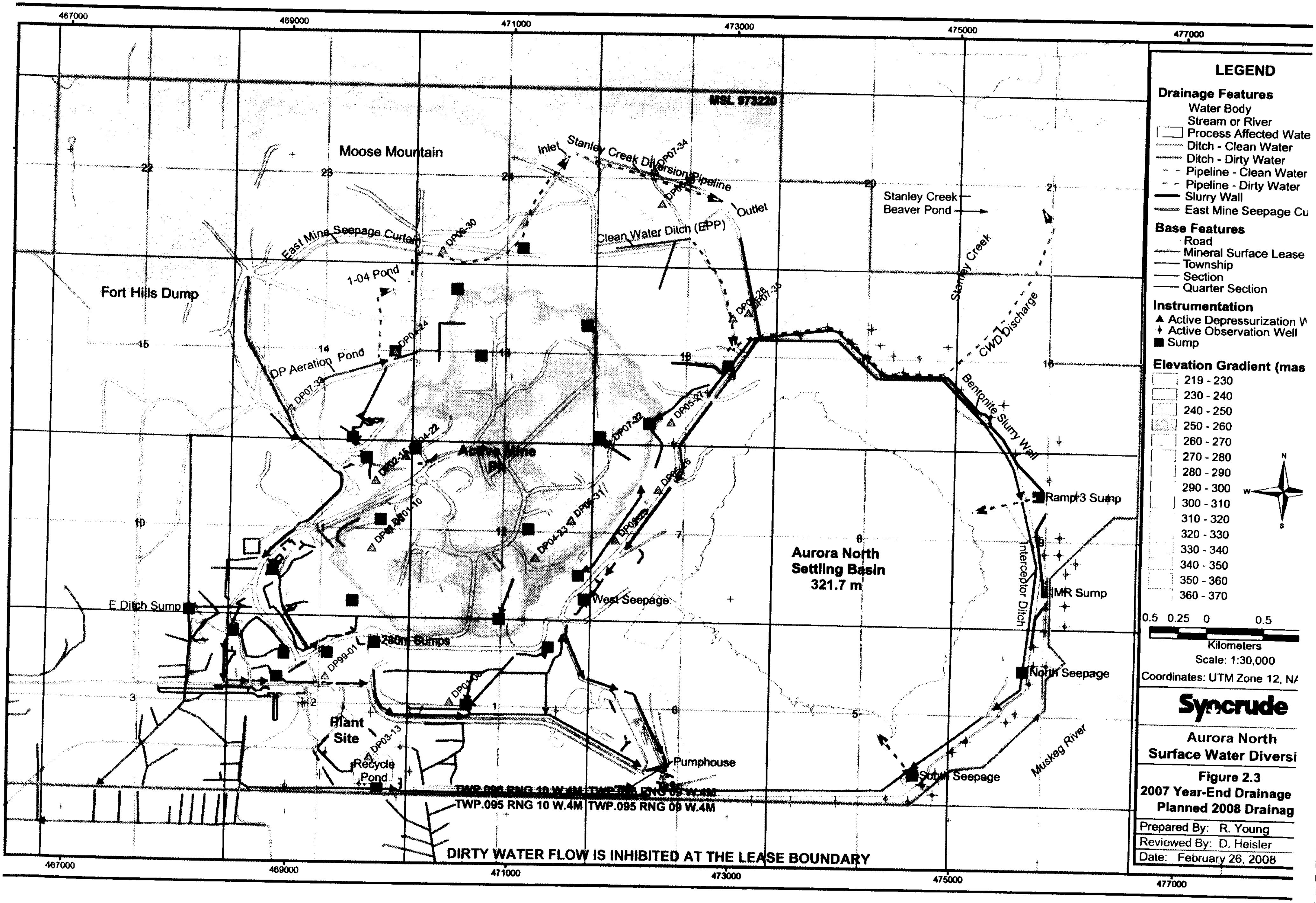
- K-Q Pleistocene and Recent deposits, and Cretaceous formations.
- D2 – Upper Devonian or Woodbend Group.
- D1 – Methy, McLean, and LaLoche Formations

The evaporite sequence separating the D1 and D2 hydrostratigraphic units thins to the east of the Athabasca River and behaves like one unit.

The K-Q unit is characterized as being heterogeneous, with alternating layers of highly contrasting hydraulic conductivities. As a result of the heterogeneity and topographic relief, high vertical hydraulic gradients are observed in this unit. Groundwater flow is typically horizontal in the higher hydraulic conductivity units, and vertical through the lower hydraulic conductivity units. In the upper members of the K-Q unit, groundwater flow is typically controlled by local topography, with discharge to major rivers and tributaries. In the lower members of the K-Q unit, north of Fort McMurray and east of the Athabasca River, groundwater flow is typically westerly from the Muskeg Mountains to the Athabasca River. Water-saturated sands of the Lower McMurray Formation form a regional aquifer, called the basal aquifer. The structural top of the underlying Devonian surface controls the thickness of the aquifer, the thickest parts of the basal aquifer coinciding with Devonian topographic lows.

The D1/D2 hydrostratigraphic unit, north of Fort McMurray and East of the Athabasca River, is characterized as having hydraulic heads similar to the lower members of the K-Q unit (basal water sand).

The regional hydrogeology is described in detail by Hackbarth and Nastasa (1979), and is also discussed in Golder (1996).


LEGEND
Drainage Features
Water Body
Stream or River
Process Affected Wate
Ditch - Clean Water
Ditch - Dirty Water
Pipeline - Clean Water
Pipeline - Dirty Water
Slurry Wall
East Mine Seepage Cu
Base Features
Road
Mineral Surface Lease
Township
Section
Quarter Section
Instrumentation
Active Depressurization W
Active Observation Well
Sump
Elevation Gradient (mas
219 - 230
230 - 240
240 - 250
250 - 260
260 - 270
270 - 280
280 - 290
290 - 300
300 - 310
310 - 320
320 - 330
330 - 340
340 - 350
350 - 360
360 - 370
0.5 0.25 0 0.5
Kilometers
Scale: 1:30,000
Coordinates: UTM Zone 12, NA
Syncrude
Aurora North
Surface Water Diversi
Figure 2.3
2007 Year-End Drainage
Planned 2008 Drainag
Prepared By: R. Young
Reviewed By: D. Heisler
Date: February 26, 2008
Moose Mountain
Fort Hills Dump
MSL 973220
Inlet
Stanley Creek Diversion Pipeline
Outlet
Clean Water Ditch (EPP)
East Mine Seepage Curtain
1-04 Pond
DP Aeration Pond
Stanley Creek
Stanley Creek Beaver Pond
CWD Discharge
Bentonite Slurry Wall
Ramp 3 Sump
Interceptor Ditch
MR Sump
North Seepage
South Seepage
Muskeg River
Aurora North Settling Basin 321.7 m
Active Mine Pit
West Seepage
E Ditch Sump
280m Sumps
Plant Site
Recycle Pond
Pumphouse
TWP.096 RNG 10 W.4M TWP.096 RNG 09 W.4M
TWP.095 RNG 10 W.4M TWP.095 RNG 09 W.4M
DIRTY WATER FLOW IS INHIBITED AT THE LEASE BOUNDARY
467000
469000
471000
473000
475000
477000

2.5 Regional Surface Water and Groundwater Users

Aurora North is situated in a largely undeveloped area. Albian Sands Energy Inc.'s oilsand mining facility is located immediately to the south. Petro Canada's oilsand mining facility is in development to the north. A commercial sand and gravel pit, Susan Lake Gravel Pit, is in operation in the southwest. There is little demand for potable surface water or groundwater around the Aurora Site due to the lack residential communities in the area. Potable water for the Aurora site is transported from Fort McMurray to site.

The following searches covered the area outlined in Table 2.2, extending over five kilometres from the Aurora North site (MSL Limit). A search was completed for licensed water wells in the surrounding area through the Alberta Environment Groundwater Information System web site. Seventy-Seven (77) wells, including observation and industrial wells were identified within this search area as shown below in Table 2.3. An additional search for licenced surface water/groundwater users was completed through the Northeast Boreal Regional office of Alberta Environment. Twenty-four (24) active approvals for surface water/groundwater use were identified within this search area as shown in Table 2.4. All licenced surface water and groundwater wells do not have coordinates associated with them. Wells that have coordinates are shown on Figure 2.1.

The basal aquifer at Aurora North is being depressurised to allow mining of the entire ore body. Depressurization could influence the water elevation in other wells in the immediate vicinity of the site; however it is not likely to significantly impact the well yield. Wells owned by Total E&P Canada and CNRL are located west of the Athabasca River and are unlikely to be affected by Syncrude's activities because the Athabasca is the sink for groundwater flow in the region. Wells that are screened in the surficial aquifer would also be less affected by mining activities at Aurora North because typically the lateral extent of drawdown in unconfined aquifers is short. These types of wells are not likely to be negatively impacted by activities at Syncrude's Aurora North site. The licenced groundwater users identified in Table 2.4 are "fenceline" approvals for diversion control and use of water, as well as construction, operation, and maintenance of related structures. Activity on the Aurora North site is not expected to negatively impact any of the surrounding licences. The location of all active surface water/groundwater licences around the Aurora site are identified in Figure 2.1.

Table 2.2: Search Area for Surface Water and Groundwater Users

Sections	Township	Range
1 to 36	95	9, 10, 11
1 to 36	96	9, 10, 11
1 to 36	97	9, 10, 11

All Sections are west of the Fourth Meridian

Table 2.3: Summary of Wells Located Around the Aurora Site

Well ID	Owner	Use	Drill Date
0042477	CNRL	Industrial	03/04/02
0042478	CNRL	Observation	03/05/02
0042479	CNRL	Industrial	03/02/02
0150377	Alberta Forestry	Domestic	03/05/90
0150685	Esso	Observation	02/21/90
0150686	Esso	Observation	02/21/90
0150687	Esso	Observation	02/18/90
0150688	Esso	Observation	02/19/90
0150689	Esso	Observation	02/20/90
0233818	Alberta Research Council	Observation	02/18/75*
0233822	Alberta Research Council	Observation	02/08/75
0233835	Alberta Research Council	Observation	02/01/75
0233856	Shell	Observation	08/10/72*
0233859	Shell	Observation	02/02/75*
0233860	Shell	Observation	08/17/75*
0233916	Petrofina	Industrial	02/26/74
0233920	Petrofina	Observation	03/24/74
0233923	Petrofina	Observation	Unknown
0233930	Petrofina	Observation	03/23/74*
0233932	Petrofina	Observation	03/30/74
0233939	Petrofina	Observation	03/30/72*
0233959	Petrofina	Observation	02/01/74
0233976	BP	Observation	03/01/75*
0233982	Alberta Research Council	Observation	01/01/75
0233986	Alberta Research Council	Observation	03/01/75
0233990	Alberta Research Council	Observation	01/01/75
0233995	Alberta Research Council	Observation	03/01/75
0233999	Alberta Research Council	Observation	03/01/75
0234006	Alberta Research Council	Observation	02/01/76
0235269	Shell	Unknown	Unknown
0235270	Shell	Industrial	08/22/75
0235271	Shell	Industrial	10/10/72*
0235272	Shell	Observation	01/01/72
0235274	Shell	Observation	10/01/73
0235276	Shell	Observation	01/01/72
0235277	Shell	Observation	01/01/72
0235279	Shell	Observation	01/01/72
0235280	Shell	Observation	01/01/72
0235281	Shell	Observation	01/01/72
0235282	Shell	Observation	01/01/72
0235283	OBS 439	Observation	01/01/73
0235285	Shell	Industrial	09/07/71*
0235286	Grant Nielson	Unknown	09/19/69*
0235297	INTL Bitumen	Unknown	01/29/01
0235298	INTL Bitumen	Unknown	01/01/27
0235299	INTL Bitumen	Unknown	01/01/28
0235300	Athabasca Oils	Industrial	01/01/14
0235301	Hudson's Bay Oil & Gas	Industrial	01/01/73
0235302	Unknown	Unknown	05/13/75*
0235303	Canstar Oilsands	Observation	09/22/81

0235304	Canstar Oilsands	Observation	09/20/81
0235306	Canstar Oilsands	Observation	09/26/81
0235307	Canstar Oilsands	Observation	09/05/81
0235308	Canstar Oilsands	Observation	09/20/81
0235309	Canstar Oilsands	Other	09/18/81
0235310	Canstar Oilsands	Observation	09/03/81
0235311	Canstar Oilsands	Domestic	09/23/81
0235312	Canstar Oilsands	Domestic	09/01/81
0235313	Canstar Oilsands	Domestic	08/31/81
0235314	Canstar Oilsands	Domestic	09/08/81
0235315	Canstar Oilsands	Observation	09/12/81
0235316	Canstar Oilsands	Investigation	09/14/81
0235317	Canstar Oilsands	Observation	09/08/81
0235318	Canstar Oilsands	Observation	09/15/81
0235319	Canstar Oilsands	Unknown	01/29/82*
0289516	Syncrude	Industrial	04/11/96
0289517	Syncrude	Industrial	04/12/96
0291300	Deer Creek Energy	Domestic	01/15/99
1500035	CNRL	Observation	01/17/04
1500216	Deer Creek Energy	Other	02/05/03
1500220	Deer Creek Energy	Other	02/05/03
1500225	Deer Creek Energy	Unknown	02/05/03
1500289	Deer Creek Energy	Other	02/06/03
1501023	Deer Creek Energy	Observation	02/04/03
1501041	Deer Creek Energy	Other	12/14/03
2075000	Petro Canada	Other	10/16/06
2075002	Petro Canada	Other	10/26/06

Information from Alberta Groundwater Information System Website (February 2008)

* Date Reported shown; Date drilled unknown

Table 2.4: Summary of Active Groundwater and Surface Water Licences

Approval #	Owner	Source
F27570	Syncrude Canada Ltd	Surface Runoff
F27570	Syncrude Canada Ltd	Unnamed Aquifer - Potable
*	Syncrude Canada Ltd	Unnamed Lake - Unclassified
F60131	Shell Canada Limited	Mill Creek
F00071821 *	Shell Canada Limited	Athabasca River
F00071821 *	Shell Canada Limited	Unnamed Aquifer - Unclassified
F00071821 *	Shell Canada Limited	Surface Runoff
*	Shell Canada Limited	Muskeg River
*	Shell Canada Limited	Muskeg River
*	Shell Canada Limited	Muskeg River
F00186157	Shell Canada Limited (Jackpine)	Athabasca River
F00186157	Shell Canada Limited (Jackpine)	Unnamed Aquifer - Unclassified
F00186157	Shell Canada Limited (Jackpine)	Muskeg River
F16192	Regional Municipality of Wood Buffalo	Ells River
F00198976	Deer Creek Energy Limited	Athabasca River
F00198976	Deer Creek Energy Limited	Athabasca River
F00198976	Deer Creek Energy Limited	Athabasca River
27271	Solv-Ex Corporation	Athabasca River
F00151636	True North Energy	Athabasca River
F00186921	Canadian Natural Resources Limited	Athabasca River
F00186921	Canadian Natural Resources Limited	Unnamed Aquifer - Unclassified
F00186922	Canadian Natural Resources Limited	Tar River
F00186923	Canadian Natural Resources Limited	Tar River
F00186924	Canadian Natural Resources Limited	Tar River

Information from Alberta Environment (February 2008); does not include TWP 97

* No Approval Number supplied

2.6 Aurora Site Hydrogeology

There are four main hydrostratigraphic sub-units within the K-Q unit at the Aurora North site:

- **Overburden** Holocene and Pleistocene Deposits (and Cretaceous Clearwater Formation where present).
- **Oilsand** Upper and Middle McMurray Formation bitumen-saturated sands and interbedded clays.
- **Basal Clays** Lower McMurray Formation Clays and silty-clays (referred to as non-water sands in Golder (1996))
- **Water sand** Lower McMurray Formation water saturated sands, basal aquifer

Overburden sub-units vary locally, however most of the Aurora North overburden forms a continuous unconfined to semi-confined aquifer. Pleistocene and Holocene sands blanket most of the site. In some areas, silty or clayey Holocene deposits overlie the sand. Thick deposits of muskeg occur in topographic lows. The Pleistocene sand is generally underlain by till or McMurray Formation oilsand. The Clearwater Formation shales are present over a limited portion of the site, generally to the northwest. The hydraulic conductivities of the Holocene and Pleistocene sands are generally high, in the order of $1x10^{-3}$ to $1x10^{-5}$ m/s. Groundwater flow in the sand is horizontal, with the direction controlled by the local topography and aquifer hydraulic conductivity. Groundwater generally discharges to local creeks.

Oilsand sub-unit forms a regional aquitard, having a hydraulic conductivity in the order of $1x10^{-9}$ m/s. The hydraulic conductivity is significantly influenced by the bitumen saturation. Zones with low bitumen saturation form isolated aquifers of limited vertical and horizontal extent.

Basal Clays, part of the Lower McMurray generally occur directly below the Middle McMurray Formation oilsand and directly above the water sand. The hydraulic conductivity of this unit is typically in the range of $5x10^{-8}$ to $1x10^{-10}$ m/s. This unit acts to increase the effective thickness of the aquitard separating the overburden aquifer and basal aquifer.

Water sand of the Lower McMurray Formation forms a regional aquifer (basal aquifer) east of the Athabasca River. The aquifer is confined between the overlying oilsand or basal clays, and the underlying Devonian, limy shales. Locally, the structural top of the underlying Devonian surface controls the extent of the aquifer.

The hydrostratigraphic subunits of the K-Q unit are depicted on geological cross-sections in Figure 2.4 and Figure 2.5, section locations are shown on Figure 2.1. The Aurora North overburden facies chart is also included as Table 2.5 for reference.

Figure 2.4 - Overburden Cross-Section, Aurora North

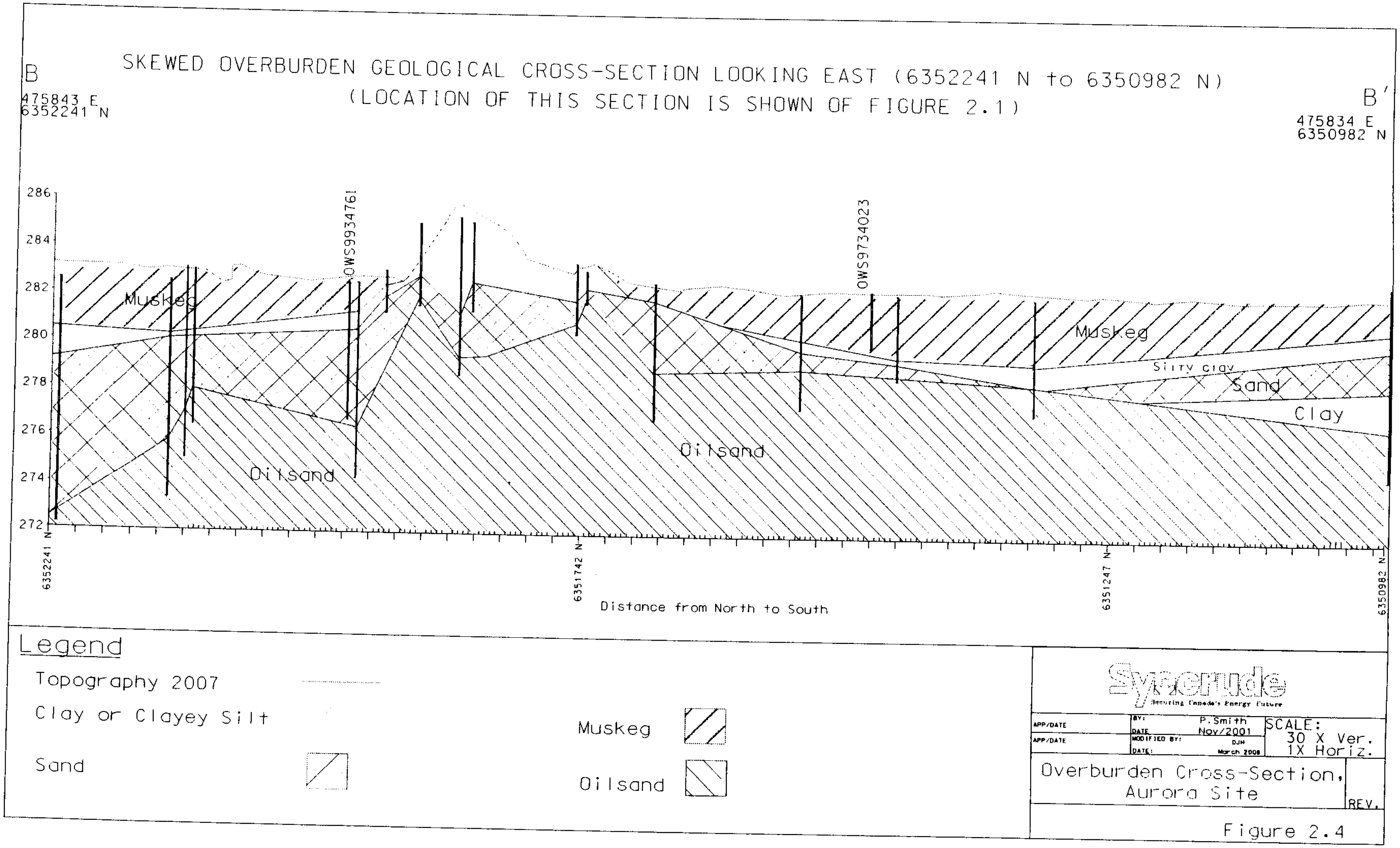


Figure 2.5 - Geological Cross-Section, Aurora North

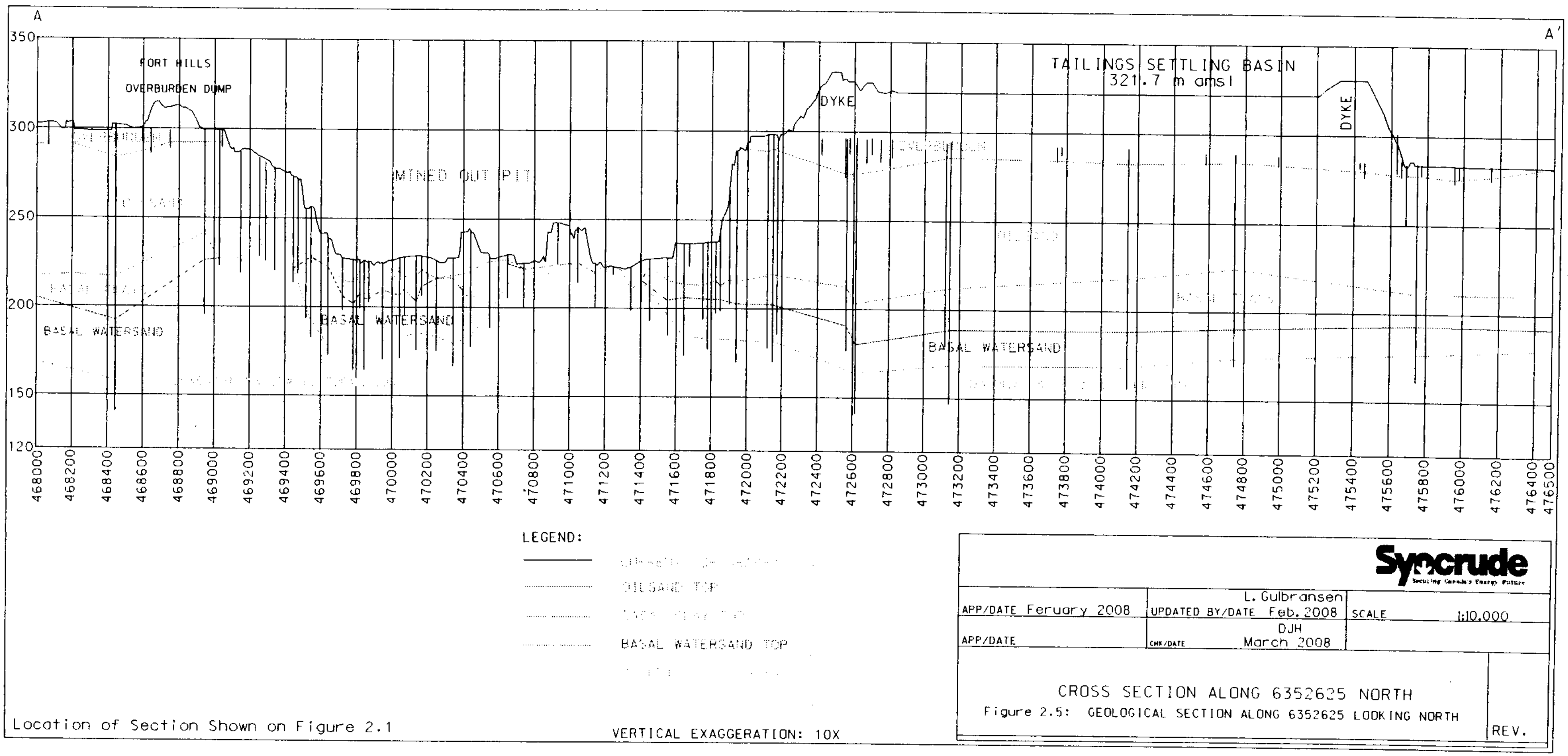


Table 2.5: Aurora - Quaternary Overburden Soils

	Depositional Environment & Soil Type	UNIT	USC Code	DESCRIPTION	% Grav	% Sand	% Fines	Geology Note
HOLOCENE	Muskeg	HO2	PT	Muskeg; plant debris and wood fragments near surface; amorphous peat often at depths >1m. Dark brown to black.	-	-	-	Widespread; near surface; corresponds with vegetation (bl. and white spruce) Often absent on sand ridges of greater than 2m relief above surrounding ground; similar to Base Mine
	Organic Mineral Soil	HO1	PT OL	Mineral Soil with organics; dark brown to black.	-	-	-	Mineral soil; may often be logged as HO2 or HF1
	Colluvium	HE1	CL-ML	Variable, silty-clay matrix with organic debris, possible pebbles or occ. Cobbles, disturbed.	1	43	56	Colluvium, variable lithology depending on locally derived intact soils; expected to be more abundant ot the west in gully areas
	Aeolian Sand	HAE	SP SP-SM	SAND, fine grain, uniform, fines up to 20%, occ. organic contamination, often tan colour.	1	80	19	Near surface; Often occurs as veneer on sand ridges with Jack pine. Often very dry; uniform
	Fluvial Sand with fines	HF1	SW-SM	SAND, fine grain, moderately sorted, fines often 25%, usually some organic content, tan-orange colour.	7	69	24	Often occurs near surface immediately above PF sand in areas of minor or zero muskeg thickness; commonly 0.5m-1.5m thick with organics. May also occur as thin beds within muskeg.
	Pond Marl clayey Silt	HL1	OL-ML	SILT, clayey; 20% clay and 15% fine sand, white-cream colour, up to 10% organics, minor gastropods up to 10mm diam., high moisture content.	0	16	84	Occurs within muskeg and at base of muskeg; may also be found above muskeg in present-day sloughs.
	Pond Marl silty Sand	HL2	OL-ML	FINE SAND, silty; tan to cream colour, organics, shell fragments, high moisture content.	3	50	47	Occurs within muskeg and at base of muskeg; may also be found above muskeg in present-day sloughs; slightly coarser than HL1.
	Ridge silty Clay (lacustrine clay)	HX1	CL-CH	CLAY, silty, <12% fine sand; tan-cream colour, firm/dense, moderate moisture content, often oxidized.	0	12	88	Observed in Eastern Lease 34 immediately adjacent to Muskeg River valley along discrete ridges; interpreted as Holocene Lacustrine--likely similar or the same unit as HL3A based on XRD and test pits.
	Lacustrine silty Clay	HL3A	CL	CLAY, silty, with occ. fine sand beds; plastic, dark olive green/black, organic odour, occ. small white/bluish-white gastropod shells, 1mm-8mm. May have fibrous organics and black organic streaks.	0	18	82	East portion of Lease 34 along Muskeg River; usually occurs immediately below base of muskeg in areas of >1m muskeg thickness, usually below 280m.
	Lacustrine silty Sand	HL3B	SC SC-SM	SAND, silty, with some clay; mod. plasticity, dark olive green/black or grey, often has organic odour, small white, bluish-white gastropod shells, 1mm-5mm. May have fibrous organics and black organic streaks. Occ. cm scale clay beds within.	1	57	42	Coarser fraction related to HL3A.
	Oxbow Lake silty Clay	HF2A	CL	CLAY with organics; silty clay with organics and twigs; occ. charcoal fragments.	0	22	78	Commonly observed in western lease 34 within 1km of Muskeg River and within Stanley Flats area. Interpreted as oxbow lake/abandoned channel and last phase of fluvial fining upward sequence
	Fluvial silty Sand	HF2B	SC SC-SM	SAND, with CLAY BEDS; fine to med. grain sand interbedded with cm scale clay beds; Clays are light to med. grey clay, firm, well-defined. Sand and clay interbeds are horizontal. Similar to HL3B.	2	61	37	Fluvial sand; same sequence as HF2A but coarser fraction r
	Fluvial Sand	HF2C	SW SW-SM	SAND, fine to coarse grain, may have minor gravel, occ. light grey clay clasts, occ. cm-scale clay beds, occ. organic clasts. Less Sorted and more quartz than PF4 sand.	3	84	13	Fluvial sand with some gravel; same sequence as HF2A but coarser fraction.
	Fluvial gravelly Sand	HF2D	SW, GW SW-SM	SAND and GRAVEL, coarse grain sand and gravel. Less quartz but similar grain size distribution to PF4 and PF5A & B.	38	52	11	Lowermost interval of fining upward fluvial sand sequence.
PLEISTOCENE	Glaciofluvial Sand	PF4	SP SP-SM	SAND, med. grain, uniform to well-sorted, often orange-tan coloured above long-term watertable, often loose.	3	90	7	Widespread; Often occurs above PL clays or PG tills
	Glaciofluvial gravelly Sand	PF5A	SP SP-SM	SAND, gravelly up to 35%, % fines often <8%	17	75	8	Widespread; Often occurs above PL clays or PG tills
	Glaciofluvial sandy Gravel	PF5B	SW, SP GW	GRAVEL, sand from 35% to 65%, %fines often <8%	46	47	7	Often occurs as gravel lag in 0.15m to 1m thick interval directly above Km Top surface or in discrete granular ridges in L12 area.
	Glaciofluvial Gravel	PF3	GW, SW	GRAVEL, sand up to 35%, %fines often <8%	65	30	6	Often occurs as gravel lag in 0.15m to 1m thick interval directly above Km Top surface or in discrete granular ridges in L12 area.
	Glaciolacustrine silty Clay	PL1	CL	CLAY, silty, up to 40% silt, up to 20% fine sand, plastic, green to black	1	21	77	Problematic, may have been dark PG2; may exist in L12 area.
	Glaciolacustrine silty Clay	PL2	CL, CH	CLAY, siltey, up to 40% clay, up to 40% fine sand with occ. med. to coarse sand lens, pink to brownish pink to occ. brown in colour, stiff, plastic	2	26	72	Uncommon; found within well defined zero edge in SE corner of L34. Often occurs immediately below PF sand and above PG1 or KM; distinguised from PL2 by well-defined bedding and occ. Sand lenses.
	Disturbed Glaciolacustrine silty clay	PG2	CL, CH	CLAY, siltey, up to 40% clay, up to 40% fine sand, pink to brownish pink to occ. brown in colour, stiff to very stiff, plastic, disturbed bedding, minor very soft pink or white clay clasts up to 5mm throughout; within sandy silt matrix. Often distorted bedding with occ. pebbles and angular cobbles.	2	28	70	Same as PL2 occurrence. Distinct features are diagnostic clay mm-scale clasts and pink/brown colour; lack of well-defined bedding and unlike PL2.
	Glaciolacustrine Deltaic silty sand	PL3	SP SP-SM	SAND, fine-grain, up to 30% fines, occ. med. to coarse sand up to 20%, often clean with no contamination, very uniform.	1	81	18	Occurs primarily in Stanley Flats area within Eastern L34 and L10. Often occurs within PL2. PL3 has likely been mis-identified as PF1 in the past. PL3 has been observed in outcrop in East pit below PF4 sand.
	Glacial Kame Fluvial sand	PF1	SP SP-SM	SAND, fine to med. grain, uniform to well-sorted, often white, >90% quartz, cm-scale bedding	1	92	7	Fort Hills Kame Sand underlying all Quaternary units except PG1. May have stringers of pink clay within. Has been recorded as PF4 in many holes. Most common above areas with ground elevation >305m.
	Ablation Till	PG3	CL	Variable, silty-clay matrix with angular pebbles and occ. cobbles to pebbly-gravel with 10-20 % fines.	5	38	57	Likley PG2 in most holes that has been confirmed with redrills; may exist to the west.
	Lodgment Till	PG1	SC-SM CL, ML	SAND, fine-grain, silty, up to 50% fines, occ. med. to c. grain sand, poorly sorted, black, angular pebbles up to 5mm, slight bitumen odour, very dense.	6	46	48	Firebag Till; Widespread; always occurs directly overlying Cretaceous where it does occur.
	Rafted Clearwater Clays	PGKC	CL	KC clay clast >0.3m within Quaternary solid unit; interpreted as rafting.				Rafted Clearwater clays found within Quaternary interval
	Rafted McMurray Oil Sand	PGKM	variable	KM clays >0.3m within a Quaternary solid unit; interpreted as rafting.				Rafted McMurray oil sand found within Quaternary interval
	Undifferentiated Pleistocene	PUG	variable	Problematic soil with poorly understood or unknown depositional environment.				Unknown
CRET.	Glauconitic silty Sand; Clearwater Fm.	KCW	CL, SC	Sand, silty with glauconite; wavey laminae often observed				Clearwater Fm; Wabisco Member
	Massive Clay; Clearwater Fm.	KC	CH, CL	Undifferentiated Clearwater Clay (e.g. KCA, KCB etc)				Undifferentiated Clearwater clays: e.g. KCA, KCB etc
	Oil Sand; McMurray Fm.	KM		Undifferentiated Oil Sand; Facies 98 in SCL Database				Undifferentiated McMurray Fm; recorded as 98 in database
		SOIL UNIT QUALIFIERS						
		OILY		Bitumen within soil unit, commonly found as "tar balls"				
		KC		Quaternary soil unit with >50 % KC clays as matrix				
		DIST		Disturbed, churned or mildly contaminated by another soil unit, (e.g. pebbles found within churned Kc)				
		QUES		Depth and lithology questionable				

3 Groundwater Monitoring Program

3.1 Program Description

The groundwater monitoring program was first outlined in the "Groundwater Monitoring Proposal for Aurora North Mine" (Kampala 1999) and submitted to Alberta Environment. Several changes to the monitoring network have been implemented since that time, as outlined in subsequent Annual Groundwater Reports. The current network of monitoring sites is shown in Figure 3.1. The proposed program for 2007 was outlined in the 2006 Monitoring Report. The analytical schedule used in 2007 is outlined in Table 3.1.

Table 3.1: 2007 Analytical Schedule

Parameter	Monitoring Locations	Frequency
Field Conductivity, pH, and Temperature	All	Semi-annually
Major Cations and Anions	All	Semi -annually
Total Dissolved Solids	All	Semi -annually
Total Suspended Solids	All	Semi -annually
Dissolved Organic Carbon	All	Semi -annually
Phenols	All	Semi -annually
Laboratory pH and Conductivity	All	Semi -annually
Metals (Al, As, Cd, Cr, Cu, Fe, Hg, Pb, Ni, Zn)	All monitoring wells and river locations	Every 5-years**
Metals (Al, As, Cd, Cr, Cu, Fe, Hg, Pb, Ni, Zn)	Surface samples of dirty water	Annually
Naphthenic Acids	Selected	Annually
Total Extractable Hydrocarbons (TEH)	Selected	Annually
Polyaromatic Hydrocarbons (PAH)	Selected	Annually

** Next analysis for Metals will be done in 2008. New locations to be sampled during first year of monitoring

Selected analysis were conducted at specific monitoring well locations based on the historical data and the proximity of monitoring well locations to potential sources of influence especially at the plant emergency dump pond where prior contamination was detected.

3.2 Sampling Procedures

All monitoring wells are equipped with dedicated inertia pumps. Inertia pumps are used for both purging and sampling. Syncrude contracted the sampling of all monitoring wells to Golder Associates in 2007. The sampling procedures and protocols that Golder and Syncrude follow are presented in Appendix D. The following paragraphs summarise what is covered in the Appendix D.

ALS Laboratory Group conducted all analyses for the two scheduled sampling periods in 2007. Eight blind duplicate samples were collected in the summer, and nine were collected in the fall to ensure that the lab analysis were accurate and repeatable. ALS Laboratory Group analyzed the duplicate samples.

Purging

Static water level measurement was taken prior to well purging. During well purging three well volumes were pumped from the well. Wells that were installed in units of lower hydraulic conductivity were purged by pumping the well dry. The well was then allowed to recover until sufficient water was available for sampling.

Sampling

Latex gloves were worn during sampling to protect the integrity of the sample. Sample bottles were rinsed with well water (with the exception of BTEX bottles, which contain a powdered preservative, $NaHSO_4$). The rinsed bottles were then filled to overflowing and immediately capped. For analyses that require preserved samples, the preservative was added to the bottle when it was approximately half full. Samples for analysis of dissolved species (requiring preservation) were filtered using a single-use 45-micron on-line filter, before the preservative was added. Field measurements for pH, conductivity and temperature were completed after all sample bottles were filled. Sample bottles were labelled and stored in a cooler until they were delivered to the contract laboratory (in person or via courier). Chain of custody paperwork accompanied all samples.

3.3 Summary of Changes Since 2006

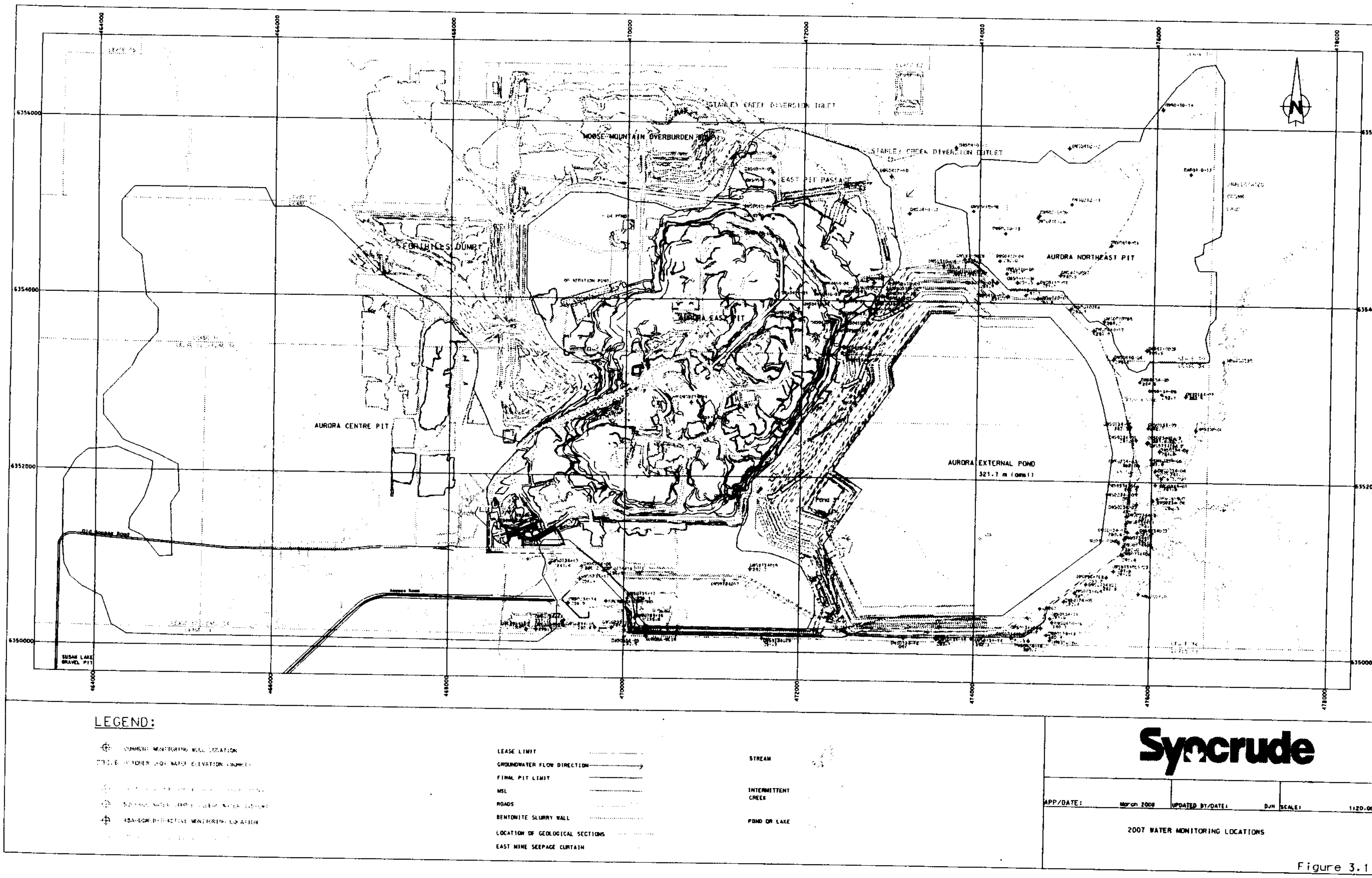
The following changes were made to the groundwater monitoring program in 2007:

- Five additional wells (OWS0734413, OWS0734414, OWS0734416, OWS0734417, and OWS0734418) were installed in the Plant area.
- Nine additional wells (OWS0734400, OWS0734405, OWS0734406, OWS0734407, OWS0734408, OWS0734409, OWS0734410, OWS0734411, and OWS0734412) were installed in the area of South Seepage and along the East Side of tailings.

The following changes will occur in the groundwater monitoring program in 2008.

- Wells OWS0310-01, OWS0410-32 and OWS0410-34 will be abandoned due to the advancement of mine operations.
- East Pit Passage Polishing Pond (EPP-PP) will be converted into a dirty water sump and a new clean water sump will be developed.

Figure 3.1 - Monitoring Locations



3.4 Surface Water within the Dirty Water System

Six locations within the dirty water system (AN-SIPHON, RECYCLPOND, A6202, SOUTHPOND, MRSUMP, RAMP3POND), shown on Figure 3.1, were sampled as part of the groundwater monitoring program in 2007. Additional data from SCL Research is included for the Aurora Tailings Pond (ATP) site. Table 3.2: Summary of Surface Water Chemistry (Dirty Water) provides a summary of active surface sampling locations for the past eight years. Samples from the dirty water system provide an indication of potential contaminant sources. The analytical results from the 2007 sampling are summarized in Table 3.3. Complete results are included in Appendix A and trend plots are included in Appendix B.

Discussion

Generally, the concentration of major ions is increasing in process water. This trend will continue, as water is recycled through the extraction process, dissolving salts from the ore. The majority of ion concentrations have remained lower at the Aurora North site than at Syncrude's Mildred Lake Site, primarily due to the large import of clean water from depressurization wells and surface drainage. The import of captured water has lead to higher concentrations of calcium, magnesium, and potassium in the Aurora process water than at the Mildred Lake Site. All locations within the dirty water system showed little change over the years. The following samples are collected from the seepage sumps and other sources around the tailings pond.

A6202, AN-SIPHON, ATP, and RECYCLPOND

These sample locations assess the water chemistry of the tailings pond and as such all share similar water chemistry. The results are consistent with historical data. The exception is ATP which shows a steady increase in the concentration of naphthenic acids, sulphate and zinc. Additional data collected by Syncrude Research are included in Appendix C.

SOUTH POND

The south seepage pond (sump) receives tailings seepage water, intercepted clean groundwater, as well as mine water (including depressurization water, intercepted shallow groundwater, precipitation, and runoff). The salinity concentrations were in the general range of the previous years.

RAMP 3 POND

Ramp 3 Pond is a sump that receives tailings seepage water, intercepted clean groundwater, and periodically depressurization water. It is located between the 2004 and 2005 cut-off walls (Figure 3.1). Water from this sump is pumped directly over the Aurora Settling Basin and back into the tailings pond.

The construction of a soil-bentonite cut-off wall north and south of Ramp 3 Pond was expected to alter water chemistry in the sump in 2006 and beyond but the chemistry has continued to follow historical trends. As a result, Syncrude expects the water chemistry to continue to resemble diluted process water in 2008. Also with the advancement of the East Pit north, the volume of water reporting to Ramp 3 Pond will continue to increase as more mine water is directed to the sump.

MR SUMP

Active pumping of the MRSUMP stopped in May 2006. Wells in the area have started to show influence from process water, specifically OWS0234-03 and OWS9934761. Active pumping of MRSUMP has resumed mitigating the process water influence. The chemistry in the sump has returned to near historical values. Generally the elevated Chloride and Sodium ions, from process water, have shown a slight increase while the Calcium ions, associated with clean water, have shown a slight decrease. The change in chemistry can be attributed to the installation of the 2005 cut-off wall that is now preventing the influx of clean water from the Muskeg River.

Table 3.2: Summary of Surface Water Monitoring Locations (Dirty Water)

ID	Water Type	1999 Proposal	1999	2000	2001	2002	2003	2004	2005	2006	2007
A6202	Tailings filter drain	-	-	-	-	A	A	A	A	A	A
AN-SIPHON	Siphon Removes water from tailings pond	-	-	-	-	-	A-F	A	A	A	A
ATP*	Tailings pond Surface water	-	-	-	-	-	A-S	A	A	A	A
FWATERPOND	Fresh water pond Water used in plant	-	A	A	A	A	U	-	-	-	-
L6203	Tailings filter drain	-	-	A	A	U	-	-	-	-	-
MRSUMP	Seepage control sump east of the tailings dyke	-	-	-	A-F	A	A	A	A	A	A
NORTHPOND	North Sump Collects tailings seepage water	P	A	A	A	A-S U-F	-	-	-	-	-
PP-1	Collects tailings seepage water	-	A	A	A	U	-	-	-	-	-
RAMP3POND	Ramp 3 Seepage Sump Collects tailings seepage water	-	-	-	-	A	A	A	A	A	A
RECYCLPOND	Recycle Pond Process water used in plant	-	A	A	A	A	A	A	A	A	A
SOUTHPOND	South Sump – Collects tailings seepage water, dirty water from the mine, and depressurization water	P	A	A	A	A	A	A	A	A	A
Total Proposed		2	-	-	-	-	-	-	-	-	-
Total Active		-	5	6	6	5	7	7	7	7	7

P = Proposed, A = Active, R = Replaced, U = Suspended, -F = Fall, -S = Summer
* sampled by SCL research annually

Table 3.3: Summary of Surface Water Chemistry (Dirty Water Major Ions)

ID	Sample Date	HCO_3	Cl	SO_4	Ca	Mg	K	Na	pH	Cond	TDS	DOC
A6202	24-Jun-07	761	410	286	98	33	16	505	8.0	3335	1780	45
A6202	15-Oct-07	692	395	289	88	30	16	474	8.4	2750	1780	46
ANSIPHON	26-Jun-07	685	402	320	27	17	22	602	8.4	3012	1700	56
ANSIPHON	15-Oct-07	628	388	334	31	17	23	554	8.7	2880	1850	60
ATP	27-JuL-07	691	380	337	21	13	18	613	8.4	2980	0.175^	45
MRSUMP	24-Jun-07	359	108	142	109	25	3	113	8.2	1374	710	18
MRSUMP	15-Oct-07	392	145	164	127	26	3	122	8.3	1290	885	23
RAMP3POND	24-Jun-07	640	238	140	134	24	5	266	8.0	2197	1390	33
RAMP3POND	15-Oct-07	614	265	185	132	24	7	284	8.3	2060	1240	34
RECYCLPOND	26-Jun-07	674	395	317	27	17	23	599	8.5	2979	1700	57
RECYCLPOND	15-Oct-07	649	372	340	32	18	23	548	8.7	2660	1830	60
SOUTHPOND	24-Jun-07	702	321	345	100	31	12	456	8.1	3026	1600	36
SOUTHPOND	15-Oct-07	625	261	451	125	34	13	391	8.2	2490	1730	38
SOUTHPOND*	15-Oct-07	609	263	455	123	34	13	398	8.2	2360	1730	34

Abbreviations: HCO3 - Bicarbonate (mg/l), Cl - Chloride (mg/l), SO4 - Sulphate (mg/l), Ca - Calcium (mg/l), Mg - Magnesium (mg/l), K - Potassium (mg/l), Na - Sodium (mg/l), Cond. - Conductivity (mS/cm), TDS - Total Dissolved Solids (mg/l), DOC - Dissolved Organic Carbon (mg/l)

* Duplicate Sample

^ TDS reported as % weight

3.5 Surficial Aquifer and Surface Water Monitoring

In the fall of 2007 fourteen monitoring wells were added to the fall sampling campaign. Five monitoring wells were installed in the plant area and the remaining nine wells were installed around South Seepage and the East Side of the tailings pond. There were a total of fifty-six active wells during the summer sampling program, and sixty-eight active wells in the fall sampling program. Summer sampling was carried out in June and July. Fall sampling was carried out in October. The following wells were dry for both summer and fall sampling programs: OWS0134-16, OWS0310-01, OWS0410-32 and OWS0410-34. During summer sampling program OWS0134-12 was frozen. During fall sampling program OWS0234-10 was dry. Table 3.4 provides a summary of the status of each monitoring well since 1999.

The groundwater monitoring network focuses on the tailings area, in particular the north and east side where the majority of monitoring wells are located. There were twelve monitoring wells in the vicinity of the plant site during the 2007 sampling programs.

Currently, there are six active surface water sampling locations along the Muskeg River. The East Pit Passage (EPP) polishing pond is also considered as a clean water sampling location and is discharged into Stanley Creek. During 2007 the discharge of clean water to the environment was continuous with only a few reportable incidents of elevated total suspended solids due to construction activities from expanding the clean water collection system. Table 3.5 provides a summary of all active surface water sampling locations outside the dirty water system over the past nine years.

Table 3.4: Status Summary of the Aurora North Monitoring Wells

ID	1999 Proposal	1999	2000	2001	2002	2003	2004	2005	2006	2007
OWS9734004	P	A	A	D	-	-	-	-	-	-
OWS9734006	P	A	A	D	-	-	-	-	-	-
OWS9734008	-	-	-	A-F	D	-	-	-	-	-
OWS9734012	P	A	A	A	D	-	-	-	-	-
OWS9734015	P	A	A	A	A	A	A	A	A	A
OWS973416B	P	A	A	A	R	-	-	-	-	-
OWS9734017	-	A	A	A	D	-	-	-	-	-
OWS9734018	P	A	A	A	A	A	A	A	A	A
OWS9734021	P	A	A	A	A	A	A	A	A	A
OWS9734022	P	A	A	A	A	A	A	A	A	A
OWS9734023	P	A	A	A	A	A	A	A	A	A
OWS9710026	P	A	A	A	A	A	A	A	A	A
OWS9710027	P	A	A	A	A	A	A	A	A	A
OWS9710028	-	-	-	A-F	A	A	A	A	A	A
OWS9834755	P	A	D	-	-	-	-	-	-	-
OWS9934761	P	A	A	A	A	A	A	A	A	A
OWS9934762	P	A	A	A	A	A	A	A	A	A
SP9834-505	-	-	A	A	R	-	-	-	-	-
Well-4	P	P	-	-	-	-	-	-	-	-
OWS0010765	P	P	A	A	A	A	A	A	A	A
OWS0010766	-	-	A	A	A	A	A	A	A	A
OWS0110-01	P	P	P	A	A	A	A	A	A	A
OWS0110-02	-	-	P	A	A	A	A	A	A	A
OWS0110-03	-	-	P	A	A	A	A	A	A	A
OWS0110-04	P	P	P	A	A	A	A	A	A	A
OWS0134-05	-	-	P	A	A	A	A	A	A	A
OWS0134-06	-	-	P	A	A	A	A	A	A	A
OWS0134-07	-	-	P	A	A	A	A	A	A	A
OWS0134-08	-	-	P	A	A	A	A	U-S A-F	A	A
OWS0134-09	-	-	P	A	A	A	A	A	A	A
OWS0134-10	-	-	P	A	A	A	A	A	A	A
OWS0134-11	P	P	P	A	A	A	A	A	A	A
OWS0134-12	-	-	P	A	A	A	U	A	A	U-S A-F
OWS0134-13	-	-	P	A	A	A	U-S A-F	A	A	A
OWS0134-14	P	P	P	A	A	A	A	A	A	A
OWS0134-15	-	-	P	A	A	A	A	A	A	A

P = Proposed, A = Active, R = Replaced, D = Abandoned, U = Suspended, -F = Fall, -S = Summer

Table 3.4: Status Summary of the Aurora North Monitoring WellStatus Summary of the Aurora North Monitoring Wells (continued)

ID	1999 Proposal	1999	2000	2001	2002	2003	2004	2005	2006	2007
OWS0134-16	P	P	P	A	A	A	U	U	U	U
OWS0134-17	-	-	P	A	A	D	-	-	-	-
OWS0234-01	-	-	-	-	A	A	A	A	A	A
OWS023402A	-	-	-	-	A	A	A	A	A	A
OWS023402B	-	-	-	-	A	A	A	A	A	A
OWS0234-03	-	-	-	-	A	A	A	A	A	A
OWS0234-04	-	-	-	-	A	A	A	A	A	A
OWS0234-05	-	-	-	-	A	A	A	A	A	A
OWS0234-06	-	-	-	-	A	A	A	A	A	A
OWS0234-07	-	-	-	-	A	A	A	A	A	A
OWS0234-08	-	-	-	-	A	A	A	A	A	A
OWS0234-09	-	-	-	-	A	A	A	A	A-S U-F	A
OWS0234-10	-	-	-	-	A	A	A	A	U	A-S U-F
OWS0210-11	-	-	-	-	A	U-S A-F	U	U	U	U
OWS021012A	-	-	-	-	A	U-S A-F	U	U	U	U
OWS021012B	-	-	-	-	A	U-S A-F	U	U	U	U
OWS0210-13	-	-	-	-	A	U-S A-F	U	U	U	U
OWS0234-14	-	-	-	-	A	A	A	A	A	A
OWS0234-15	-	-	-	-	A	A	A	A	A	A
OWS0234-16	-	-	-	-	A	A	A	A	A	A
OWS0234-17	-	-	-	-	A	A	A	A	A	A
OWS0310-01	-	-	-	-	-	A-F	A	A	U	U
OWS0310-02	-	-	-	-	-	A-F	U	U	U	U
OWS0310-03	-	-	-	-	-	A-F	U	U	U	U
OWS0310-04	-	-	-	-	-	P	A	A	A	A
OWS0334-06	-	-	-	-	-	P	A	A	A	A
OWS0334-07	-	-	-	-	-	P	A	A	A	A
OWS0334-09	-	-	-	-	-	P	A	A	A	A
OWS0410-01	-	-	-	-	-	-	A	A	A	A
OWS0410-02	-	-	-	-	-	-	A	A	A	A
OWS04103A	-	-	-	-	-	-	A	A	A	A
OWS04103B	-	-	-	-	-	-	A	A	A	A
OWS0410-04	-	-	-	-	-	-	A	A	A	A
OWS0410-05	-	-	-	-	-	-	A	A	A	A
OWS0410-06	-	-	-	-	-	-	A	A	A	A
OWS0410-07	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U

P = Proposed, A = Active, R = Replaced, D = Abandoned, U = Suspended, -F = Fall, -S = Summer

Table 3.4: Status Summary of the Aurora North Monitoring Well(continued)

ID	1999 Proposal	1999	2000	2001	2002	2003	2004	2005	2006	2007
OWS0410-08	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U
OWS0410-09	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U
OWS0410-10	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U
OWS0410-11	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U
OWS0410-12	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U
OWS0410-13	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U
OWS0410-14	-	-	-	-	-	-	A-S U-F	A-S U-F	U	U
OWS0410-17	-	-	-	-	-	-	A	A	A	A
OWS0410-19	-	-	-	-	-	-	A-S U-F	U	U	U
OWS0410-20	-	-	-	-	-	-	A-S U-F	U	U	U
OWS0410-21	-	-	-	-	-	-	A-S U-F	U	U	U
OWS0410-22	-	-	-	-	-	-	A	A	A-S D-F	D
OWS0410-23	-	-	-	-	-	-	A-S U-F	U	D	D
OWS0410-24	-	-	-	-	-	-	A	A	D	D
OWS0410-25	-	-	-	-	-	-	A	A	D	D
OWS0410-26	-	-	-	-	-	-	A	A	U-S D-F	D
OWS0410-27	-	-	-	-	-	-	A	A	D	D
OWS0410-28	-	-	-	-	-	-	A	A	D	D
OWS0410-29	-	-	-	-	-	-	A-S U-F	D	D	D
OWS0410-30	-	-	-	-	-	-	A	D	D	D
OWS0410-31A	-	-	-	-	-	-	A–S U-F	D	D	D
OWS0410-31B	-	-	-	-	-	-	A	A	D	D
OWS0410-32	-	-	-	-	-	-	A	A	U	U
OWS0410-34	-	-	-	-	-	-	A	A	A-S U-F	U
OWS0434-15	-	-	-	-	-	-	A	A	A	A
OWS0434-16	-	-	-	-	-	-	A	A	A	A
OWS0734400	-	-	-	-	-	-	-	-	-	A-F
OWS0734405	-	-	-	-	-	-	-	-	-	A-F
OWS0734406	-	-	-	-	-	-	-	-	-	A-F
OWS0734407	-	-	-	-	-	-	-	-	-	A-F
OWS0734408	-	-	-	-	-	-	-	-	-	A-F

P = Proposed, A = Active, R = Replaced, D = Abandoned, U = Suspended, -F = Fall, -S = Summer

Table 3.4: Status Summary of the Aurora North Monitoring WellStatus Summary of the Aurora North Monitoring Wells (continued)

ID	1999 Proposal	1999	2000	2001	2002	2003	2004	2005	2006	2007
OWS0734409	-	-	-	-	-	-	-	-	-	A-F
OWS0734410	-	-	-	-	-	-	-	-	-	A-F
OWS0734411	-	-	-	-	-	-	-	-	-	A-F
OWS0734412	-	-	-	-	-	-	-	-	-	A-F
OWS0734413	-	-	-	-	-	-	-	-	-	A-F
OWS0734414	-	-	-	-	-	-	-	-	-	A-F
OWS0734416	-	-	-	-	-	-	-	-	-	A-F
OWS0734417	-	-	-	-	-	-	-	-	-	A-F
OWS0734418	-	-	-	-	-	-	-	-	-	A-F
Total Proposed	21	-	-	-	-	4	-	-	-	-
Total Active	-	15	17	34	47	42-S 50-F	79-S 66-F	73-S 66-F	58-S 54-F	56-S 68-F

P = Proposed, A = Active, R = Replaced, D = Abandoned, U = Suspended, -F = Fall, -S = Summer

Table 3.5: Summary of Surface Water Monitoring Locations

ID	Water Type	1999 Proposal	1999	2000	2001	2002	2003	2004	2005	2006	2007
AUR_WEIR	Aurora Weir - Clean water Discharged to Muskeg River	-	A	A	A	A	D	-	-	-	-
CWD-PP	Clear Water Ditch Polishing Pond	-	-	-	-	-	-	A	A	A	D
EPP-PP	East Pit Passage Polishing Pond	-	-	-	-	-	-	-	-	A	A
MR6350190	Muskeg River	-	-	-	A-F	A	A	A	A	A	A
MR6350775	Muskeg River	-	-	-	A-F	A	A	A	A	A	A
MUSK_UPST/ MR6351800	Muskeg River	-	A	A	A	A	A	A	A	A	A
MRT6352090	Tributary to the Muskeg River	-	-	-	A-F	A	A	A	A	A	A
MR6352600	Muskeg River	-	-	-	A-F	A	A	A	A	A	A
MR6353330	Muskeg River	-	-	-	A-F	A	A	A	A	A	A
Total Proposed		0	-	-	-	-	-	-	-	-	-
Total Active		-	2	2	2+5	7	6	7	7	8	7

P = Proposed, A = Active, R = Replaced, D = Abandoned, U = Suspended, -F = Fall, -S = Summer

Typically, the surficial aquifer and natural surface waters around the Aurora North site have very low concentrations of major ions. Interpretation of the analytical results may be simplified by examining chloride concentrations. Chloride is a very good indicator of influence from process water due to its conservative behaviour in groundwater, and low background concentrations in the aquifer. Typically background chloride concentrations are less than 10 mg/l in the surficial aquifer. As a conservative ion in groundwater, chloride is found at the leading edge of a process water plume, arriving before organics or most other ions. Analytical results from the sampling program collected from monitoring wells in 2007 are summarized in Table 3.6. Results for natural surface waters are summarized in Table 3.7. Complete results are included in Appendix A with the trend plots included in Appendix B.

External Tailings Pond Area

An integral part of the external tailings pond design is the perimeter ditch, which was designed to act as a hydraulic sink. The ditch was excavated below the local groundwater table, to create a gradient towards the ditch from both the tailings pond and the surrounding environment. The perimeter ditch flows into sumps at various locations, from which water is pumped back into the tailings pond. The system has operated effectively in most areas over the past nine years and has reduced the import of significant volumes of water from the environment. This imported water becomes part of Syncrude's dirty water inventory, which must be stored. The management of the dirty water inventory continues to be a significant challenge for Syncrude.

During 2007 there were multiple pipeline ruptures along the perimeter ditch system. This caused the perimeter ditch and in some instances the sumps to be filled with tailings sand. This lead to an increase in the water table and reversed the hydraulic gradient of the process contaminated water in the perimeter ditch and sumps towards the Muskeg River. Elevated ion concentrations were observed in areas of the events. The perimeter ditch and sumps have been cleaned out and are now operating properly.

Due to Environmental concerns Syncrude has continued initiatives to reduce water import in 2007. These initiatives included acquiring regulatory approval to discharge basal water back to the environment, construction of horizontal and vertical dewatering wells along the north side of East Pit (East Mine Seepage Curtain) and the addition of two new clean water discharge locations on Stanley Creek. It is expected that these initiatives will reduce the amount of clean water entering the dirty water system.

There are four areas where contamination from process water has been identified beyond the perimeter ditch. These areas are discussed in the following sections. All other monitoring wells continue to indicate background conditions.

In the fall of 2007 thirteen boreholes were drilled to help delineate the aquifer and acquire a better understanding of the geology around South Seepage and along the lower East Side of tailings. Wells were installed in nine of the boreholes where sufficient aquifer thickness was present.

South Seepage Sump Area

The water chemistry of monitoring well OWS0134-11 near the south seepage sump has shown similarity with the type of water influenced by process water. A significant increase in the chloride concentration occurred from 2006 (92 mg/l) to 2007 (178 mg/l). The sodium concentration also increased from previous years samples. The chloride concentrations in monitoring well OWS0434-16 continued to increase in 2007 to 148 mg/l from a value of 62 mg/l in 2006. These concentrations are becoming closer to typical process water concentrations.

Despite the localized change in water chemistry, Syncrude believes that there are adequate measures in place to monitor and control seepage in this area. The south seepage sump is to be operated with a maximum water elevation of 280masml although during 2007 it was operated above the 280masml mark due to the tailing pipeline ruptures and sanding of the perimeter ditch and sump. This elevation is below the mean Muskeg River elevation and approximately equal to the seasonal low river elevation.

In the fall of 2007 eight boreholes were drilled in the area. Four were suitable for monitoring wells installation (OWS0734400, OWS0734405, OWS0734406 and OWS0734407). The wells exhibited chemistry typical of background conditions expect for OWS0734407 that had a chloride concentration of 48 mg/l.

All other monitoring wells in the area exhibit water chemistry typical of background conditions. Syncrude believes that the hydraulic control provided by the sump combined with the limited aquifer thickness in the area; provide reasonable containment of the process water. The location of monitoring wells in this area, and the aquifer isopach are shown on Figure 3.2.

East Side

Process water was identified migrating beyond the perimeter ditch on the east side of the Aurora tailings pond during 2001. The MR Sump was constructed to intercept the seepage and return the water to the perimeter ditch. Since 2002, Syncrude has conducted increased monitoring in the surrounding area to assess the performance of the seepage sump.

In the fall of 2007 five additional monitoring wells (OWS0734408, OWS0734409, OWS0734410, OWS0734411 and OWS0734412) were installed on the southern end of the East Side, just south of the 2005 cut-off wall. The location of the monitoring wells in this area and the aquifer isopach are shown on Figure 3.3. The new monitoring well locations all showed elevated water chemistry with chloride concentrations ranging from 46 mg/l to 223 mg/l. The monitoring wells are located near the North Pond, which did not operate properly in 2007 due to the tailings pipeline ruptures. For a good portion of the year the sump was full of tailings sand and this increased the operational water level. This changed the direction of the gradient from into the perimeter ditch to out towards the Muskeg River. Proper operation of the North Pond in 2008 should lead to a decrease in the chemistry observed in the new monitoring wells. All other monitoring wells in the area exhibit water chemistry typical of background conditions.

In 2005 a cut-off wall was constructed south of Ramp 3. Syncrude is satisfied that the cut-off wall is impeding the influx of clean water but is permitting the egress of process influenced waters. Pumping of the MR Sump to the perimeter ditch has commenced again to mitigate the influence of process water in the area. Elevated water chemistry was observed in OWS0234-03 (91 mg/l chlorides) and OWS9934761 (178 mg/l chlorides). These two monitoring wells are located near the MR Sump. It is believed that the chemistry will return to historical values upon pumping the MR Sump again.

Since the construction of the cut-off wall, groundwater chemistry in the MR Sump has migrated back towards the characteristics of process water. The water chemistry has increased and will continue to trend towards process water throughout 2008. Water chemistry changes have not been noticed in the surrounding wells, both inside and outside of the wall. The current results are near or slightly above the historical values. Syncrude expects to see the effects of prolonged periods with low river levels, typically during winter flow conditions to have less impact on the water table west of the cut-off wall.

North Tailings Area

Groundwater contamination was identified north of the tailings dyke in monitoring well OWS0110-01 in 2003. The monitoring network has since been expanded to identify the extent of the contamination that has now been identified in OWS0110-03, OWS0410-01, OWS0410-02, OWS041003A, OWS041003B, OWS0410-05, and OWS0410-06. These monitoring wells showed an increase in water chemistry and returned to the 2004 or remained at historical levels in water chemistry. OWS0110-01 showed an increase in chloride concentration in the spring but returned to 2006 levels in the fall. All the remaining wells in the area are at historical chemistry values. The location of monitoring wells in this area, and the aquifer isopach are shown on Figure 3.4.

Syncrude's experience and previous chemistry results indicated that the current plume will remain outside of the cut-off wall, and will slowly be diluted by advection, dispersion and potentially degradation of the organic components. The future migration of this plume is expected to be in an overall east or south-easterly direction. There was no increase in the ion concentrations of the surrounding monitoring wells to suggest any migration of the contaminant plume occurred in 2007. There was evidence that the plume is being influenced by additional process water though. The chemistry results from 2007 suggest that process affected water from the tailings pond or perimeter ditch is recharging the plume. Syncrude will be looking into the issue and continue tracking the movement of process affected waters in the area.

At this time, Syncrude does not see the need to immediately recover the plume that remains outside the cut-off wall. The current mining sequence for the Aurora site identifies that the mining of the area north of the tailings pond (Northeast Pit) begins in 2035. The area would have to be dewatered in preparation for mining; therefore recovery of the plume could take place at this time, if it is deemed necessary. In the interim Syncrude will continue to monitor the movement of this plume. Syncrude Research is conducting research on process water constituents including the degradation process within environmental waters.

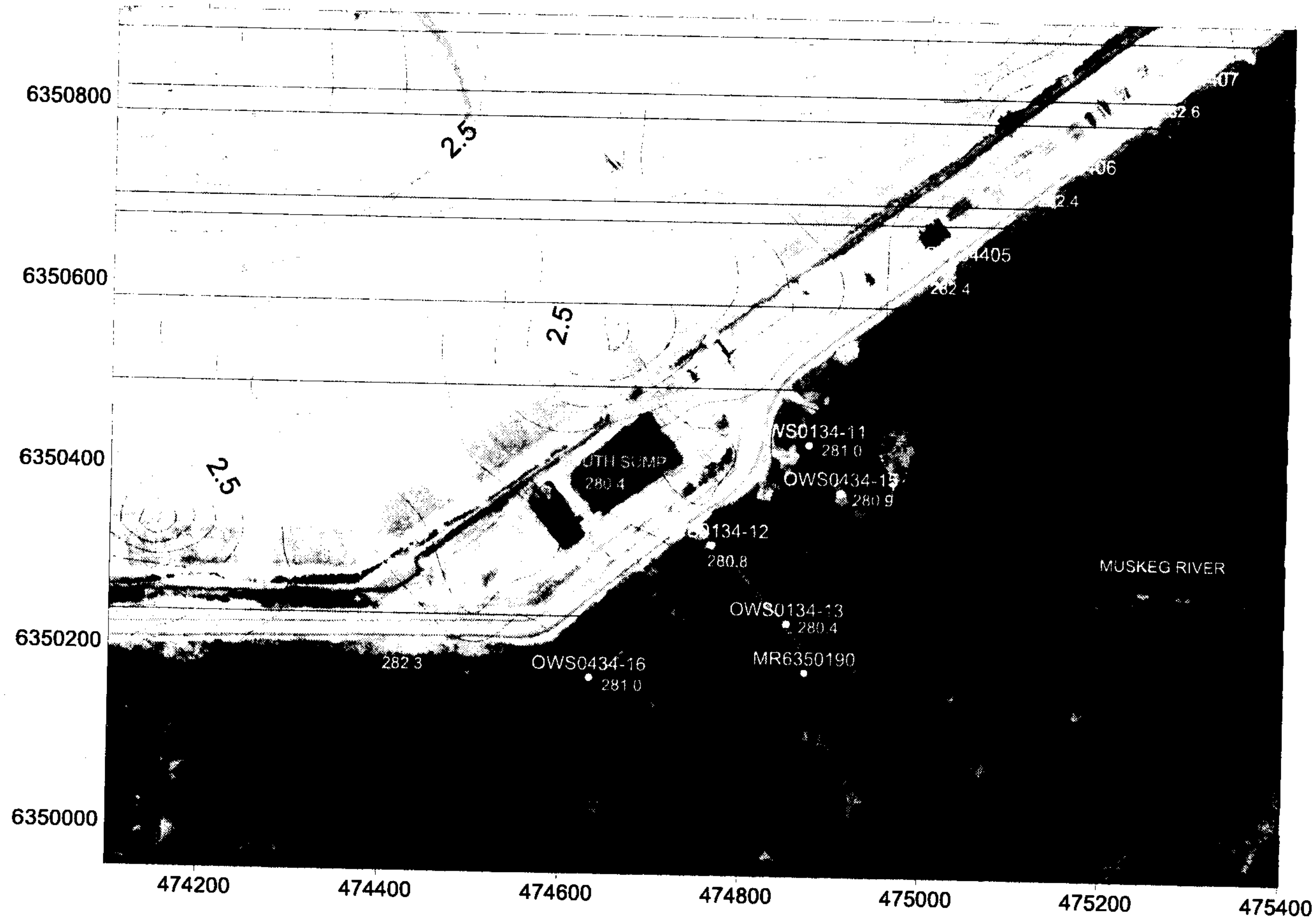
East Pit Passage Area

Dewatering of the overburden in advance of mining operations is carried out with a ditch system. The EPP flows into a polishing pond located to the northwest of the tailings pond. Water is pumped from the polishing pond to the Stanley Creek discharge area. The EPP became fully operational in 2006. The chemistry of the groundwater collected by the EPP was similar to the background water chemistry. The EPP can be seen on Figure 3.1

Muskeg River Monitoring

The Muskeg River was sampled at five locations (Figure 3.1) and in one small inlet (MRT6352090) during 2007. The water chemistry continues to show seasonal variability that corresponds with river flows. The water monitoring has not identified any impact from the Aurora Site facilities.

Figure 3.2 - South Seepage Sump Area Monitoring – aquifer thickness

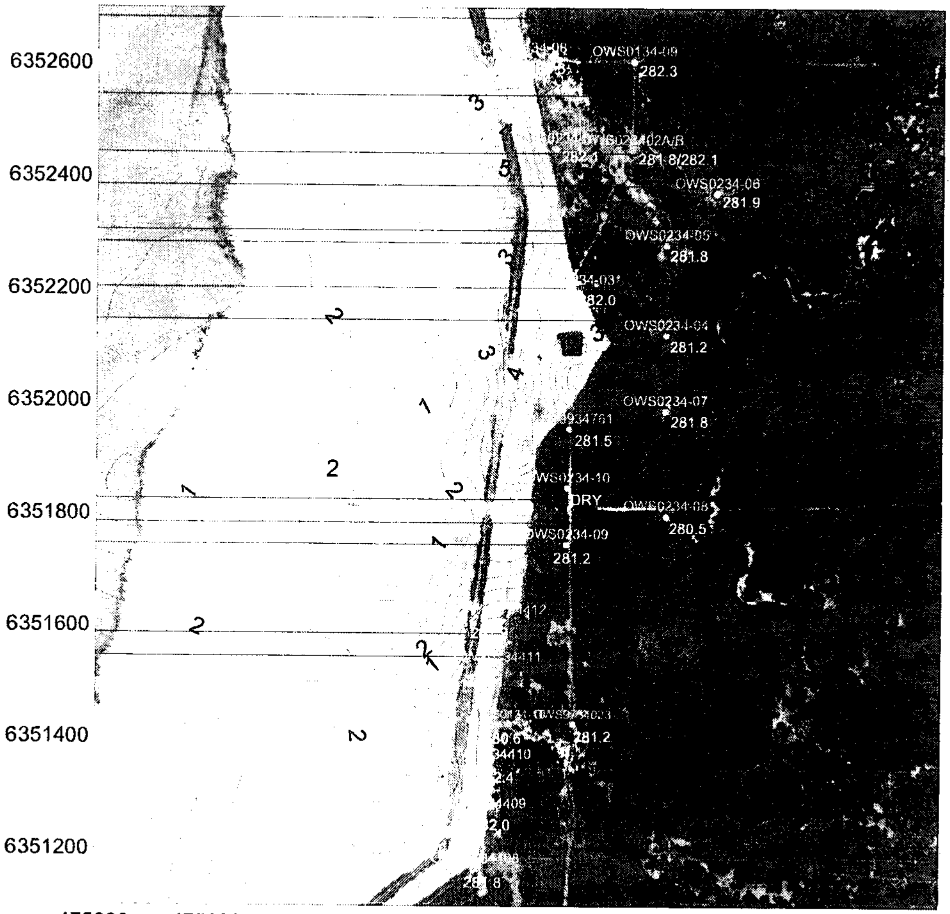


- Geological hole or test pit

Current Monitoring Well Location, Fall 2007 Water Elevation

Contour interval 0.5 metres, aquifer thickness

Figure 3.3 - East Tailings Area Monitoring – aquifer thickness



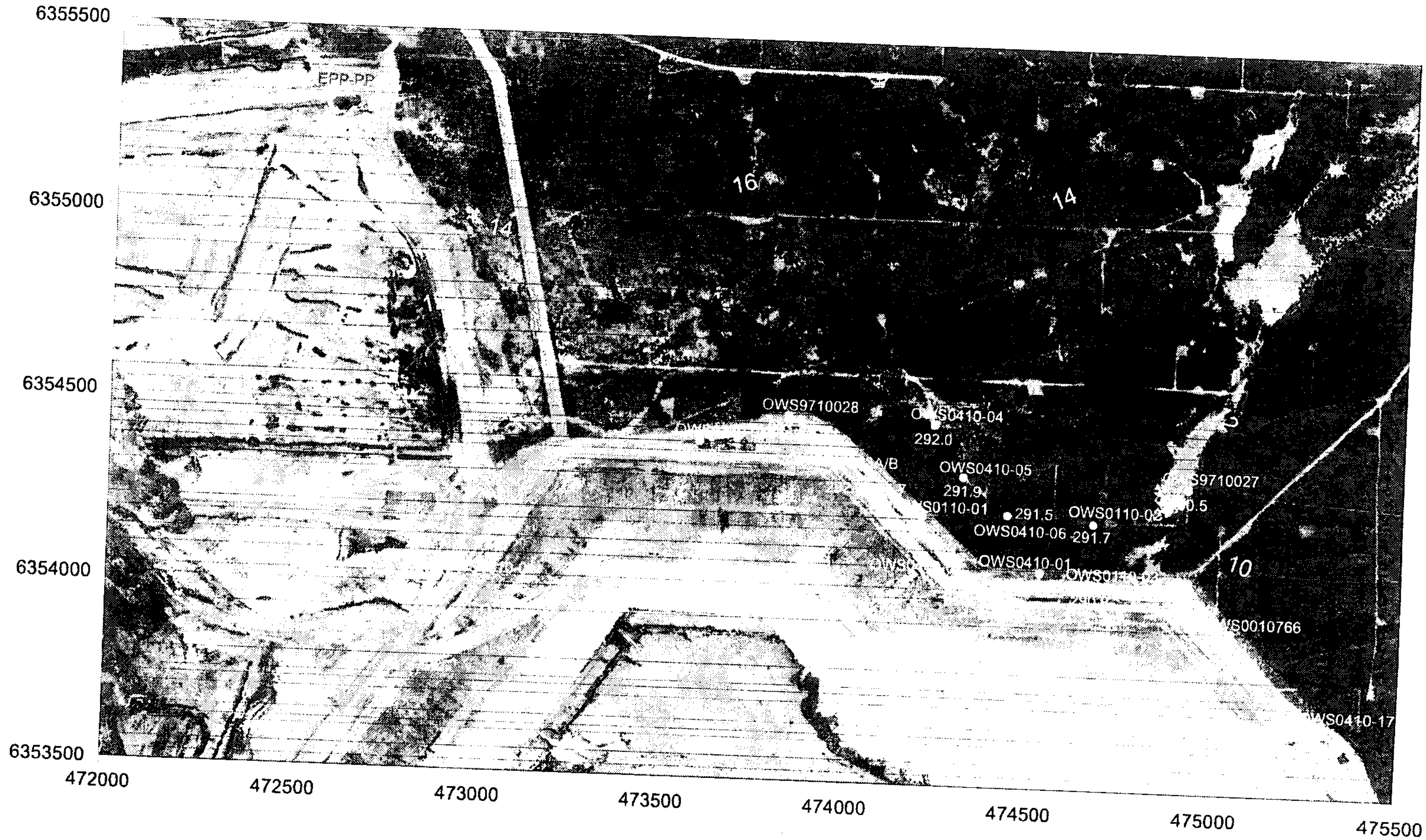
- Geological hole or test pit

Current Monitoring Well Location, Fall 2007 Water Elevation

Soil-Bentonite Slurry Wall

Contour interval 1 metre, aquifer thickness

Figure 3.4 - North Tailings Area Monitoring – aquifer thickness



Current Monitoring Well Location, Fall 2007 Water Elevation

Soil-bentonite Slurry wall

Aquifer isopach, contour interval =1 metre

Plant Area Monitoring

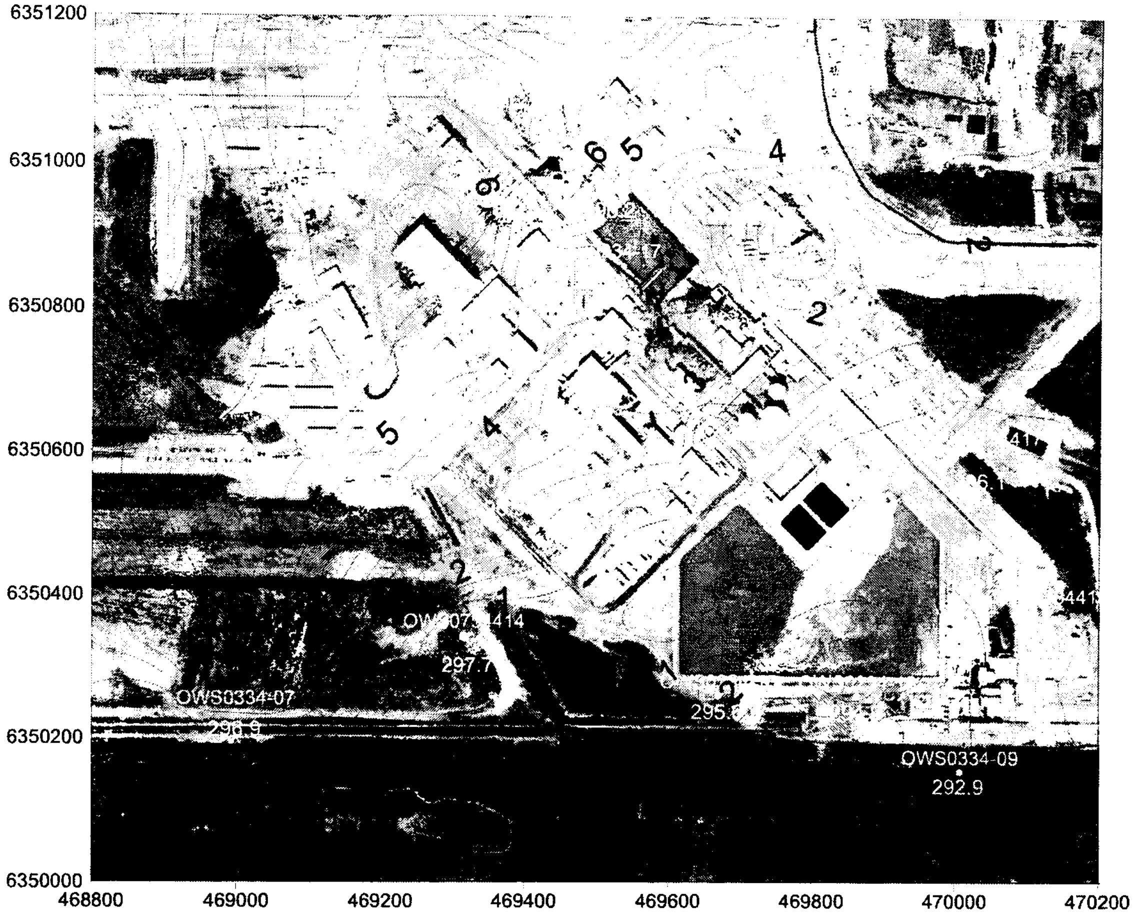
Due to concerns raised by AENV an additional five monitoring wells were installed to bring the well total to twelve in the vicinity of the Aurora Plant site. The new monitoring wells were OWS0734413, OWS0734414, OWS0734416, OWS0734417 and OWS0734418.

Historical monitoring in the plant area has shown higher background concentrations of calcium and sulphate than in other areas. The 2007 chemistry results for monitoring wells OWS0234-15, OWS0234-16, OWS0334-07, OWS0334-09, OWS0734414 and OWS0734417 are consistent with historical trends, indicating background chemistry. All of these wells are located near the boundary between Aurora North and Albian Sands. This shows that process affected water is not migrating offsite.

OWS0234-14, OWS0234-17, and OWS0334-06 continued to show elevated water chemistry and remained similar to the chemistry from 2006. OWS0734413 and OWS0734418 have water chemistry that is similar to the above wells. OWS0234-17 and OWS0334-06 are located adjacent to the emergency dump pond. OWS0734413 and OWS0734418 are located relatively close to the emergency dump pond. The emergency dump pond is located near the Primary Separation Vessels. The emergency dump pond is used as a sump which oilsand-bitumen-water slurry is periodically dumped from the PSVs when the unit have to be shutdown. The emergency dump pond is believed to be the source of contamination identified in the wells because of the bitumen in the pond. OWS0234-14 is adjacent to a ditch, which carries process water from the emergency dump pond to the recycle pond. Local effects on the well should be expected from this shallow ditch. OWS0734416 is located near the Tailings Distributor emergency dump pond. Overall groundwater flow in the plant area is expected to be toward the mine pit. This local contamination is therefore not considered a significant concern.

The underlying geology at the plant site helps to minimize and control the movement of process-affected water. The aquifer thins to the south. The mine area to the north has effectively been dewatered. This limits the movement of groundwater to the south (Figure 3.5). All water collected in the mine pit is considered dirty water and is retained on site. Extensive effort to protect groundwater within the plant site is therefore not considered a priority. Syncrude's current focus is to ensure that the contamination within the plant site is not in any way released to the surrounding environment.

Figure 3.5 - Plant Area Monitoring – aquifer thickness



Ditch from emergency dump to recycle water pond

Aquifer isopach, 0.5 metre contour interval

• Geological hole or test pit

Current Monitoring Well Location, Fall 2007 Water Elevation

Table 3.6: Summary of Groundwater Chemistry (Major Ions)

ID	Sample Date	HCO_3	Cl	SO_4	Ca	Mg	K	Na	pH	Cond	TDS	DOC
OWS9710026	27-Jun-07	391	<1	1.4	101	14	0.8	4	8	703	370	12
OWS9710026	22-Oct-07	384	<1	0.9	98.9	12.2	0.9	3	7.6	565	354	11
OWS9734015	29-Jun-07	493	5	37.4	137	16.1	0.7	13	7.9	866	480	14
OWS9734015	23-Oct-07	496	5	39.2	146	16	1.5	12	7.1	778	481	12
OWS9734018	29-Jun-07	465	2	3.7	119	16.6	<0.5	4	7.9	617	410	32
OWS9734018	18-Oct-07	440	2	4.5	114	15	1.2	4	7.1	625	407	32
OWS9734021	26-Jun-07	291	1	11.2	85	8.9	0.5	11	7.7	482	320	24
OWS9734021	17-Oct-07	313	3	7.9	94.3	9	<0.5	7	7.5	481	334	29
OWS9734022	26-Jun-07	368	4	3.7	90.4	9.8	1.6	28	7.8	583	370	28
OWS9734022	17-Oct-07	330	6	3.9	89.5	9.2	1	13	7.5	497	388	28
OWS9734023	26-Jun-07	262	2	29.2	82.4	9.7	1.9	9	7.9	470	340	23
OWS9734023	15-Oct-07	414	2	3.9	116	11.6	1.5	7	8.3	606	392	21
OWS9710027	27-Jun-07	291	<1	19.3	81.3	10.8	0.6	3	8	577	290	11
OWS9710027	22-Oct-07	305	2	23.3	90	10.3	1.1	3	7.7	502	317	10
OWS9710028	24-Jun-07	332	<1	1.5	84.9	15	<0.5	5	7.8	597	280	14
OWS9710028	14-Oct-07	281	1	25.5	75.7	12.8	1.3	7	7.7	461	303	12
OWS9934761	25-Jun-07	636	233	276	213	26.7	1.6	176	7.6	2240	1450	32
OWS9934761	15-Oct-07	566	179	221	222	21.9	2.3	143	8.2	1760	1150	31
OWS9934762	28-Jun-07	662	30	6.9	115	17.2	5.2	108	8	1020	630	26
OWS9934762*	28-Jun-07	660	30	6.9	116	17.2	4.9	109	8	1020	620	26
OWS9934762	23-Oct-07	618	20	1.5	112	15.9	3.9	85	7.4	923	588	26
OWS0010765	28-Jun-07	353	<1	1.6	89.2	12.4	0.9	4	8.1	591	360	11
OWS0010765	14-Oct-07	347	2	2.8	91.3	11.9	1.4	6	7.8	509	294	10
OWS0010766	25-Jun-07	284	1	16.9	68.4	10.9	1.2	7	7.8	580	280	10
OWS0010766	14-Oct-07	286	2	25.7	82.9	10.5	1.1	7	7.8	465	295	11
OWS0010766*	14-Oct-07	278	1	30	82.1	10.4	1.3	6	7.8	468	303	10
OWS0110-01	25-Jun-07	591	300	277	196	27.7	2.4	261	7.6	2383	1230	28
OWS0110-01	14-Oct-07	573	215	409	210	27.7	2.5	235	7.7	2060	1390	30
OWS0110-02	27-Jun-07	299	2	29.1	87.7	11.1	0.9	4	8	594	290	9
OWS0110-02	22-Oct-07	283	21	38.6	96	11	2	5	7.8	556	354	11
OWS0110-03	25-Jun-07	574	310	273	210	28.7	2.6	245	7.6	2506	1420	33
OWS0110-03	14-Oct-07	604	304	344	194	25.4	2.6	267	7.6	2320	1530	33
OWS0110-04	25-Jun-07	534	2	139	179	24.9	1.2	5	7.5	1132	710	14
OWS0110-04	14-Oct-07	514	2	171	187	25.6	1.8	8	7.5	991	684	15
OWS0134-05	28-Jun-07	472	<1	1.7	124	14.4	0.6	4	8.1	770	430	14
OWS0134-05	22-Oct-07	463	1	0.7	132	13.6	0.8	3	7.8	676	413	11
OWS0134-06	27-Jun-07	452	1	2.3	121	15.3	2.6	7	8	742	390	11
OWS0134-06	22-Oct-07	444	1	0.5	119	14.3	0.9	4	7.7	652	396	9
OWS0134-07	27-Jun-07	483	1	1.4	121	17.7	<0.5	5	7.9	763	400	13
OWS0134-07	22-Oct-07	469	1	0.7	121	16.7	0.9	4	7.6	685	409	10

Abbreviations: HCO3 - Bicarbonate (mg/l), Cl - Chloride (mg/l), SO4 - Sulphate (mg/l), Ca - Calcium (mg/l), Mg - Magnesium (mg/l), K - Potassium (mg/l), Na - Sodium (mg/l), Cond. - Conductivity (mS/cm), TDS - Total Dissolved Solids (mg/l), DOC - Dissolved Organic Carbon (mg/l)

* Duplicate Sample

Table 3.6: Summary of Groundwater Chemistry (Continued)

ID	Sample Date	HCO_3	Cl	SO_4	Ca	Mg	K	Na	pH	Cond	TDS	DOC
OWS0134-08	25-Jun-07	545	18	9.5	147	19.7	<0.5	6	7.7	835	520	17
OWS0134-08*	25-Jun-07	543	18	8.5	134	20.8	0.7	8	7.7	833	530	16
OWS0134-08	15-Oct-07	539	26	13.9	159	20.5	2	9	8.2	871	537	17
OWS0134-09	28-Jun-07	465	<1	1.3	110	13.9	0.5	6	8	750	400	14
OWS0134-09	23-Oct-07	496	<1	<0.5	126	13.9	1.2	7	7.5	676	410	10
OWS0134-10	26-Jun-07	370	22	14.9	101	13	1.2	18	7.6	662	380	23
OWS0134-10	15-Oct-07	352	10	6.1	95.4	10.7	3.2	11	7.9	567	412	20
OWS0134-11	26-Jun-07	694	181	8.3	171	27.8	1.7	109	7.7	1653	830	24
OWS0134-11	17-Oct-07	674	172	5.3	177	27.6	1.1	102	7.7	1450	880	23
OWS0134-11*	17-Oct-07	677	178	5	176	27.7	1	102	7.7	1450	880	24
OWS0134-12	17-Oct-07	500	34	38.4	159	23.4	<0.5	11	7.6	883	576	19
OWS0134-13	29-Jun-07	458	3	4.7	103	16.7	0.7	24	8	668	410	20
OWS0134-13	17-Oct-07	448	5	9.8	106	17.9	1.2	30	7.8	675	422	17
OWS0134-14	26-Jun-07	463	1	2.3	99.2	16.4	0.8	18	7.6	731	430	21
OWS0134-14	17-Oct-07	462	1	2.9	116	17	<0.5	14	7.6	677	516	17
OWS0134-15	29-Jun-07	697	6	29.5	169	30.9	<0.5	4	8	1030	660	14
OWS0134-15*	29-Jun-07	692	7	30.8	181	32.6	<0.5	4	8	1020	720	16
OWS0134-15	17-Oct-07	733	10	65.9	206	37.8	<0.5	4	7.6	1140	742	11
OWS0234-01	25-Jun-07	483	5	1.7	129	18.1	0.8	18	7.7	707	670	13
OWS0234-01*	25-Jun-07	484	5	1.8	119	16.4	0.8	9	7.8	706	440	13
OWS0234-01	15-Oct-07	465	2	2.5	125	17	1.6	9	8.3	691	422	14
OWS023402A	28-Jun-07	465	1	2.1	122	15.9	0.6	6	8	760	410	11
OWS023402A	23-Oct-07	481	1	<0.5	122	14.2	1.5	6	7.8	657	399	10
OWS023402A*	23-Oct-07	487	<1	<0.5	122	14.5	1.7	6	7.6	664	397	11
OWS023402B	28-Jun-07	469	1	0.8	120	15.9	<0.5	6	8	763	410	11
OWS023402B	23-Oct-07	488	1	<0.5	123	14.3	1.6	6	7.4	667	398	10
OWS0234-03	25-Jun-07	505	59	2.1	135	17.5	0.9	24	7.7	1037	620	14
OWS0234-03	15-Oct-07	533	91	3.1	152	19.6	1.9	45	8.2	1060	628	18
OWS0234-04	28-Jun-07	496	2	2.2	121	24.6	3.4	10	8	809	420	16
OWS0234-04	23-Oct-07	528	1	<0.5	120	23.3	2.3	8	7.5	700	415	14
OWS0234-04*	23-Oct-07	513	1	<0.5	119	23.3	2.3	8	7.5	697	316	13
OWS0234-05	28-Jun-07	475	1	1.7	121	16.1	0.5	6	8	776	430	11
OWS0234-05	23-Oct-07	479	1	<0.5	123	15	1.5	6	7.5	662	391	11
OWS0234-06	28-Jun-07	490	1	1.4	118	15.8	<0.5	6	8	771	430	12
OWS0234-06	23-Oct-07	498	1	<0.5	127	15.2	1.4	7	7.4	692	418	11
OWS0234-07	28-Jun-07	359	4	14.4	101	10.5	1	6	8	632	350	22
OWS0234-07	22-Oct-07	338	4	5	95.6	8.3	1.8	7	7.6	500	329	21
OWS0234-08	26-Jun-07	505	3	5.6	98.4	24	1.7	18	7.6	728	420	37
OWS0234-08*	26-Jun-07	504	3	3.4	104	23.5	1.9	19	7.6	727	470	39
OWS0234-08	15-Oct-07	480	3	4.5	98.8	18.4	3.4	24	7.6	674	440	37
OWS0234-08*	15-Oct-07	460	3	2.9	98.9	18.8	3.4	24	7.7	668	440	35

Abbreviations: HCO3 - Bicarbonate (mg/l), Cl - Chloride (mg/l), SO4 - Sulphate (mg/l), Ca - Calcium (mg/l), Mg - Magnesium (mg/l), K - Potassium (mg/l), Na - Sodium (mg/l), Cond. - Conductivity (mS/cm), TDS - Total Dissolved Solids (mg/l), DOC - Dissolved Organic Carbon (mg/l)

* Duplicate Sample

Table 3.6: Summary of Groundwater Chemistry (Continued)

ID	Sample Date	HCO_3	Cl	SO_4	Ca	Mg	K	Na	pH	Cond	TDS	DOC
OWS0234-09	25-Jun-07	947	1	1210	586	96	4.4	21	7.2	3246	2580	9
OWS0234-09	15-Oct-07	779	1	1370	663	99.2	7.5	25	7.7	2610	2740	7
OWS0234-10	25-Jun-07	964	1	1250	632	74.7	2.1	11	7.4	3312	2890	13
OWS0234-14	29-Jun-07	551	117	1250	602	64.3	8.5	129	7.5	3057	2720	27
OWS0234-14	18-Oct-07	454	88	1340	577	61.1	9.3	103	7.4	2880	2560	28
OWS0234-15	3-Jul-07	695	44	1310	650	118	2.9	18	7.5	3658	2740	42
OWS0234-15	18-Oct-07	733	54	1350	651	114	3.1	17	7.5	3000	2790	36
OWS0234-16	3-Jul-07	687	19	1540	620	175	12.7	19	7.3	3857	3000	58
OWS0234-16	18-Oct-07	769	21	1570	626	172	13.5	24	7.3	3250	3080	57
OWS0234-17	29-Jun-07	697	393	481	140	26.3	6.6	537	7.8	2987	1960	47
OWS0234-17	18-Oct-07	903	344	608	145	24	7.5	623	7.9	3390	2230	37
OWS0310-04	24-Jun-07	302	1	4.8	77.8	12.7	<0.5	5	7.9	569	250	11
OWS0310-04	14-Oct-07	290	<1	9.7	75	11	1.5	7	7.8	444	281	12
OWS0334-06	29-Jun-07	726	374	494	135	28	14.7	530	7.9	3040	2010	44
OWS0334-06	18-Oct-07	750	368	717	223	49.8	14	511	7.7	3380	2310	38
OWS0334-07	3-Jul-07	413	2	1240	556	80	7	5	7.7	3036	2320	25
OWS0334-07	18-Oct-07	483	4	1010	493	61.8	7.2	2	7.3	2210	2000	25
OWS0334-09	3-Jul-07	649	2	12.9	40.9	13.5	5.7	167	8	1200	580	16
OWS0334-09	19-Oct-07	624	2	7.5	37.4	12.8	5.6	158	7.7	883	544	14
OWS0410-01	25-Jun-07	621	332	362	173	32.6	1.6	309	7.6	2765	1590	36
OWS0410-01	14-Oct-07	648	325	328	200	27.8	2.2	277	7.6	2430	1590	34
OWS0410-02	25-Jun-07	505	173	258	99.2	22.5	1.9	234	7.7	1869	1320	30
OWS0410-02	14-Oct-07	636	290	312	199	30.7	3	256	7.6	2290	1560	34
OWS041003A	24-Jun-07	594	123	230	190	26	0.6	169	7.7	1988	1020	31
OWS041003A	14-Oct-07	573	143	246	217	31.2	2.7	112	7.6	1610	1070	26
OWS041003B	24-Jun-07	487	99	88.6	158	35.5	4.1	46	7.8	1387	700	16
OWS041003B	14-Oct-07	479	86	95.7	151	33	5.1	46	7.8	1100	732	17
OWS0410-04	27-Jun-07	400	9	58.7	128	19	2.9	13	7.9	709	460	16
OWS0410-04*	27-Jun-07	400	10	58.1	127	19	2.8	13	8.0	705	460	14
OWS0410-04	22-Oct-07	370	16	45.6	114	16.4	1.7	9	7.6	674	423	14
OWS0410-05	27-Jun-07	519	236	232	234	31.7	3.3	150	7.9	2118	1200	29
OWS0410-05	22-Oct-07	532	262	248	214	27.7	1.8	197	7.6	2000	1270	30
OWS0410-05*	22-Oct-07	536	263	240	208	26.7	2	196	7.6	2000	1280	28
OWS0410-06	27-Jun-07	502	228	242	210	28.6	2.9	171	7.9	2079	1190	28
OWS0410-06	22-Oct-07	541	282	298	223	29.1	2.4	225	7.5	2140	1460	30
OWS0434-15	26-Jun-07	422	2	3.2	107	14.6	<0.5	11	7.7	679	370	19
OWS0434-15	17-Oct-07	436	3	4.4	117	16.3	<0.5	10	7.7	641	390	17
OWS0434-16	26-Jun-07	546	82	46.6	162	18.2	<0.5	44	7.7	1099	660	18
OWS0434-16	17-Oct-07	582	144	59.5	180	20	<0.5	87	7.6	1310	844	23

Abbreviations: HCO3 - Bicarbonate (mg/l), Cl - Chloride (mg/l), SO4 - Sulphate (mg/l), Ca - Calcium (mg/l), Mg - Magnesium (mg/l), K - Potassium (mg/l), Na - Sodium (mg/l), Cond. - Conductivity (mS/cm), TDS - Total Dissolved Solids (mg/l), DOC - Dissolved Organic Carbon (mg/l)

* Duplicate Sample

Table 3.6: Summary of Groundwater Chemistry (Continued)

ID	Sample Date	HCO_3	Cl	SO_4	Ca	Mg	K	Na	pH	Cond	TDS	DOC
OWS0410-17	28-Jun-07	354	2	6.6	93.4	12.4	1.3	4	8.1	597	350	13
OWS0410-17	14-Oct-07	354	1	9	95.3	11.9	2	6	7.9	531	376	9
OWS0734400	24-Oct-07	773	4	2.2	179	31.3	6.1	10	7.1	1010	672	35
OWS0734400*	24-Oct-07	731	4	1.9	178	31.2	5.8	10	7.2	1000	664	35
OWS0734405	19-Oct-07	681	9	386	314	43.5	3.5	12	7.4	1590	988	28
OWS0734406	17-Oct-07	973	12	851	528	83	7	7	7.2	2560	2240	40
OWS0734407	17-Oct-07	680	48	190	246	32.6	2.2	24	7.3	1390	992	23
OWS0734408	19-Oct-07	639	223	176	205	25.5	3.4	164	7.6	1860	1040	29
OWS0734409	23-Oct-07	767	46	90.7	250	28.5	5.8	28	7.4	1290	952	28
OWS0734410	19-Oct-07	619	151	49.8	153	16.8	2.3	126	7.5	1380	896	27
OWS0734411	19-Oct-07	533	67	60.5	173	18.9	1.9	37	7.5	1080	668	19
OWS0734412	15-Oct-07	612	78	184	205	20.6	4.7	86	8.2	1390	908	24
OWS0734413	24-Oct-07	569	175	1440	674	118	13.8	54	7.5	3210	2820	18
OWS0734414	24-Oct-07	992	19	1430	675	117	12.8	54	7.3	2440	2220	58
OWS0734416	24-Oct-07	760	53	1770	709	109	12.7	211	7.2	3320	2850	58
OWS0734417	24-Oct-07	896	12	1440	698	119	13.3	55	7.6	2010	1790	23
OWS0734418	24-Oct-07	722	216	1660	677	61.7	11.9	354	7.3	3930	3590	36

Abbreviations: HCO3 - Bicarbonate (mg/l), Cl - Chloride (mg/l), SO4 - Sulphate (mg/l), Ca - Calcium (mg/l),
Mg - Magnesium (mg/l), K - Potassium (mg/l), Na - Sodium (mg/l),
Cond. - Conductivity (mS/cm), TDS - Total Dissolved Solids (mg/l),
DOC - Dissolved Organic Carbon (mg/l)

*** Duplicate Sample**

Table 3.7: Summary of Surface Water Chemistry (Major Ions)

ID	Sample Date	HCO_3	Cl	SO_4	Ca	Mg	K	Na	pH	Cond	TDS	DOC
EPPPP	24-Jun-07	287	1	123	115	22	1.4	6	8.1	657	390	10
EPPPP*	24-Jun-07	287	2	117	111	21	1.4	6	8.1	661	430	10
EPPPP	15-Oct-07	273	<1	51	85	16	2.1	5	8.3	513	323	10
MR6350190	26-Jun-07	210	2	4	48	13	0.9	12	8.2	344	230	25
MR6350775	28-Jun-07	215	2	4	49	12	2.1	13	8.3	366	250	27
MR6351800	26-Jun-07	266	2	4	64	15	1.3	9	8.2	401	310	21
MR6351800*	26-Jun-07	267	2	4	64	16	1.1	9	8.2	401	280	23
MR6352600	28-Jun-07	276	2	6	67	15	2.6	10	8.3	465	280	24
MR6353330	27-Jun-07	285	2	4	66	15	<0.5	6	8.2	513	280	23
MRT6352090	28-Jun-07	320	2	4	77	18	2.2	10	8.2	660	280	26

Abbreviations: HCO3 - Bicarbonate (mg/l), Cl - Chloride (mg/l), SO4 - Sulphate (mg/l), Ca - Calcium (mg/l), Mg - Magnesium (mg/l), K - Potassium (mg/l), Na - Sodium (mg/l), Cond. - Conductivity (mS/cm), TDS - Total Dissolved Solids (mg/l),

* Duplicate Sample

4 Basal Aquifer, Groundwater Monitoring

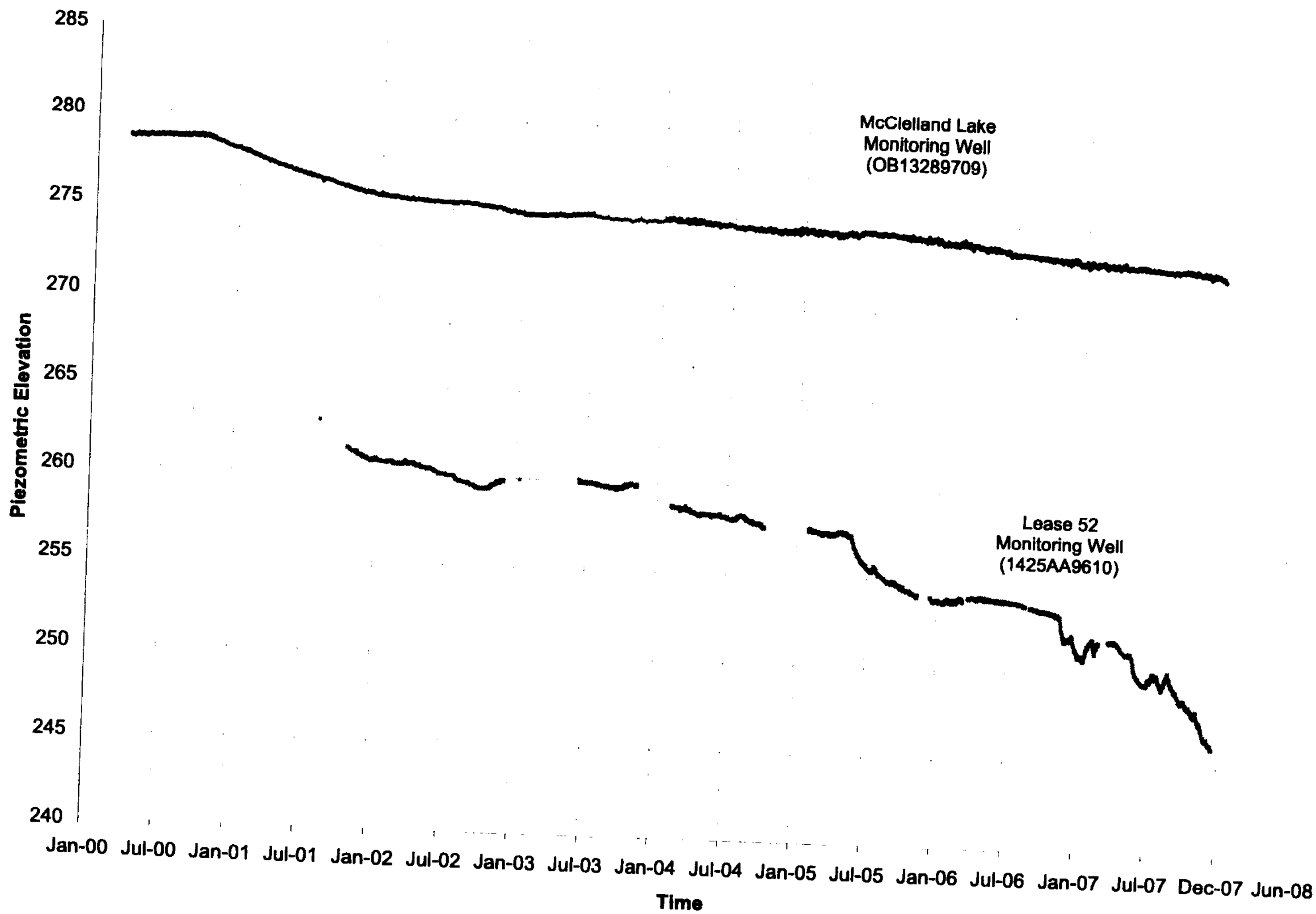
Monitoring the impact of depressurisation of the basal aquifer is conducted regularly for mining purposes and as required under the Water Act. The information is included in this report as requested by Alberta Environment. Locations of all active and inactive depressurisation wells are shown on Figure 2.3. Not all depressurisation wells shown are operating at any one time. Wells operate only in areas where active mining is in progress. Regional basal aquifer monitoring wells are located on Oilsands Lease 52 (1425AA9610) approximately 2.5 km north of the mine pit and near McClelland Lake (OB13289709) approximately 15 km north of the mine pit, Figure 2.1. Both wells are screened in the basal aquifer.

Monitoring on lease 52 began in November 2001. Cumulative drawdown since that time has been approximately 16.96 metres, to 246.05 metres elevation. The rapid drawdown that occurred during 2007 can be accounted for by the installation and pumping of new depressurisation wells in the vicinity of Lease 52.

Near McClelland Lake, the hydraulic head has declined to 272.40 metres elevation, approximately, since the start-up of the Aurora depressurisation in September 2000. Between December of 2006 and 2007, the head declined approximately 0.72 metres. This represents a total drawdown of about 6.15 metres since the start of depressurization (Figure 4.1).

The declining piezometric heads are consistent with predictions made in the Aurora Environmental Impact Assessment (EIA). Groundwater modelling completed for the 1996 Aurora EIA predicted the hydraulic head drop within the basal aquifer in the McClelland Lake area to be between 5 and 10 metres (Figure 3.1.3, page D-40 of the Aurora EIA) after full development of East Pit. East Pit has almost reached full development and the drawdown recorded near McClelland Lake is closer to the full development range than the expected drawdown range of 2 and 5 metres during the initial East Pit development (Figure 3.1.2, page D-39 of the Aurora EIA). The potential impact of this drop in basal hydraulic head on McClelland Lake itself as a result of deep percolation rates was estimated to be in the order of 2.2 mm/year.

Figure 4.1 - Response to Pumping in the Basal Aquifer



5 Proposed Monitoring Program for 2008

Syncrude proposes to monitor the current groundwater wells and surface water sampling locations in 2008. Syncrude may also install new monitoring wells in locations where concern has been noted or a clearer picture of the groundwater chemistry is required. The new wells will be included in the 2008 Groundwater Monitoring Report. Table 5.1 provides a summary of the proposed analytical schedule for 2008.

Table 5.1: Proposed Analytical Schedule for 2008

Parameter	Monitoring Locations	Frequency
Field Conductivity, pH, and Temperature	All	Bi-annually
Major Cations and Anions	All	Bi-annually
Total Dissolved Solids	All	Bi-annually
Total Suspended Solids	All	Bi-annually
Dissolved Organic Carbon	All	Bi-annually
Phenols	All	Bi-annually
Laboratory pH and Conductivity	All	Bi-annually
Metals (Al, As, Cd, Cr, Cu, Fe, Hg, Pb, Ni, Zn)	All monitoring wells and river locations	Every 5-years (2008)
Metals (Al, As, Cd, Cr, Cu, Fe, Hg, Pb, Ni, Zn)	Surface samples of dirty water	Annually
Naphthenic Acids	Selected	Annually
Total Extractable Hydrocarbons (TEH)	Selected	Annually
Polyaromatic Hydrocarbons (PAH)	Selected	Annually

Table 5.2: Proposed Monitoring Locations for 2008

OWS9734015	OWS0134-13	OWS0410-01	**Surface Water Samples (Clean Water)**
OWS9734018	OWS0134-14	OWS0410-02	MR6350190
OWS9734021	OWS0134-15	OWS041003A	MR6350775
OWS9734022	OWS0134-16	OWS041003B	MR6351800
OWS9734023	OWS0234-01	OWS0410-04	MRT6352090
OWS9710026	OWS023402A	OWS0410-05	MR6352600
OWS9710027	OWS023402B	OWS0410-06	MR6353330
OWS9710028	OWS0234-03	OWS0434-15	1-04-PP
OWS9934761	OWS0234-04	OWS0434-16	-
OWS9934762	OWS0234-05	OWS0410-17	-
OWS0010765	OWS0234-06	OWS0734400	**Surface Water Samples (Dirty Water)**
OWS0010766	OWS0234-07	OWS0734405	
OWS0110-01	OWS0234-08	OWS0734406	A6202
OWS0110-02	OWS0234-09	OWS0734407	SOUTHPOND
OWS0110-03	OWS0234-10	OWS0734408	RAMP3POND
OWS0110-04	OWS0234-14	OWS0734409	RECYCLEPOND
OWS0134-05	OWS0234-15	OWS0734410	MRSUMP
OWS0134-06	OWS0234-16	OWS0734411	AN-SIPHON
OWS0134-07	OWS0234-17	OWS0734412	ATP*
OWS0134-08	OWS0310-01	OWS0734413	-
OWS0134-09	OWS0310-04	OWS0734414	-
OWS0134-10	OWS0334-06	OWS0734416	-
OWS0134-11	OWS0334-07	OWS0734417	-
OWS0134-12	OWS0334-09	OWS0734418	-

* Annual Sampling conducted by SCL research

6 Response to Alberta Environment's Comments from the 2006 Report

This section of the report provides a response to comment from Alberta Environment (AENV) on the 2006 Groundwater Monitoring Report. AENV's comments from 2006 are shown below in italics, Syncrude's response follows.

1. ***"Page 14 – Summary of Changes Since 2005 – Some monitoring wells have been abandoned and removed by the advancement of mine operations. What plans does Syncrude have to replace these monitoring wells?"***

Syncrude has no current plan to replace these wells as the area of concern has been removed by mining operations.

2. ***"Page 16 – MR SUMP – Active pumping of the MR SUMP stopped in May 2006. Should the chemistry in the sump show sign of increasing concentrations, it would be expected that active pumping would once again start."***

Syncrude has observed increasing concentrations in the area and active pumping of the MR Sump has begun again.

3. ***"Page 18 – Table 3.3 – Chemistry results were not provided for the ID – South Pond."***

Table 6.1: Summary of Surface Water Chemistry (Dirty Water Major Ions) - SOUTHPOND

ID	Sample Date	HCO_3	Cl	SO_4	Ca	Mg	K	Na	pH	Cond	TDS	DOC
SOUTHPOND	23-Jun-06	682	264	366	137	37.3	12.7	363	8.1	2320	1600	23
SOUTHPOND	8-Oct-06	717	277	412	168	39.4	12	408	8.1	2590	1750	29

4. ***"Page 23 – Continued increasing concentrations (chloride) in monitor wells OWS0134-11 and OWS0434-16 will require Syncrude to address the matter through some other means in addition to the south seepage sump"***

Syncrude is currently reviewing all information in the area. The noted elevated concentrations seem to be isolated to these two monitoring wells. The aquifer thickness in the area is thin to non existent. Additional boreholes and monitoring wells were drilled and installed in 2007 as detailed in the report.

5. ***"It is our understanding that Syncrude will monitor the current plume that exists outside the cut-off wall. No planned further remedial action is planned because the area will be dewatered in preparation for mining of the Northeast Pit (area immediately north of tailings pond) beginning in 2012. It is our understanding that the isolated plume may provide Syncrude an opportunity to advance the understanding of the potential for degradation of process water constituents within a Pleistocene aquifer. Syncrude shall provide an update on the assessment of viable options for research work and who will conduct the work. AENV supports this initiative provided Syncrude ensures the plume does not migrate past the outer limits of the planned mined out area."***

Syncrude has decided against any research work as "Previous and ongoing studies show that little or no attenuation of constituents in oilsand process affected waters (OSPW) will occur and that most, if not all, the changes being observed in OSPW in groundwater transport in

Pleistocene sands layers will be as a result of dilution and mixing rather than biological or adsorptive processes" Mike MacKinnon, Syncrude Research.

6. ***"Page 28 – The sudden changes in concentrations observed for OWS0334-07 and OWS0234-17 are abnormal and shall be further investigated. Perhaps there was a sampling and/or labeling error."***

The chemical concentrations observed in 2006 are similar to the results from 2007. OWS0334-07 does not show the characteristics of being influenced by process affected waters. The reason for the elevated Calcium and Sulphate is unknown.

7. ***"AENV is supportive of Syncrude's plans that additional monitoring locations may be installed to ensure that process affected groundwater from the plant area does not move offsite."***

Syncrude has installed five monitoring wells in the plant area to provide additional monitoring in the plant area.

References

Hackbarth, D.A., Nastasa, N. 1979. The Hydrogeology of the Athabasca Oil Sands Area, Alberta (Bulletin 38). Alberta Research Council. Edmonton. 39p.

Golder Associates Ltd. 1996. Hydrogeology Baseline Study, Aurora Mine. Prepared for Syncrude Canada Ltd.

Kampala, G., Syncrude Canada Ltd. 1999. Groundwater Monitoring Proposal for Aurora North Mine. Submitted to Alberta Environment.

Kampala, G., Syncrude Canada Ltd. 2000. Groundwater Monitoring Program Report (1999). Submitted to Alberta Environment.

Kampala, G., Syncrude Canada Ltd. 2001. 2000 Report on Groundwater Monitoring at Aurora Mine North. Submitted to Alberta Environment.

Esford, B., Syncrude Canada Ltd. 2002. 2001 Groundwater Monitoring Report, Aurora North. Submitted to Alberta Environment.

Esford, B., Syncrude Canada Ltd. 2003. 2002 Groundwater Monitoring Report, Aurora. Submitted to Alberta Environment.

Esford, B., Syncrude Canada Ltd. 2004. 2003 Groundwater Monitoring Report, Aurora. Submitted to Alberta Environment.

Kampala, G., Syncrude Canada Ltd. 2005. 2004 Groundwater Monitoring Report, Aurora. Submitted to Alberta Environment.

Heisler, D., Livingstone, G., Syncrude Canada Ltd. 2006. 2005 Groundwater Monitoring Report, Aurora. Submitted to Alberta Environment.

Heisler, D., Sivarajan, S., Syncrude Canada Ltd. 2007. 2006 Groundwater Monitoring Report, Aurora. Submitted to Alberta Environment.

APPENDIX A: ANALYTICAL DATA AND WATER ELEVATIONS

Aurora – Surface Water Samples (Dirty Water)

ID	A6202		AN-SIPHON		MRSUMP		RAMP3POND	
Sample Date	24-Jun-07	15-Oct-07	26-Jun-07	15-Oct-07	24-Jun-07	15-Oct-07	24-Jun-07	15-Oct-07
Field pH	7.27	9.85	7.68	10.12	7.85	10	7.42	9.1
Field Conductivity	3335	2780	3012	2780	1374	1345	2197	1976
Field Temperature	20.94	9.83	22.09	11.28	19.2	6.37	14.55	7.11
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	761	692	685	628	359	392	640	614
CO_3	<5	25	10	43	<5	<5	<5	8
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	410	395	402	388	108	145	238	265
SO_4	286	289	320	334	142	164	140	185
Ca	97.8	88.1	27.1	30.7	109	127	134	132
Fe	2.24	1.25	3.98	<0.05	0.07	0.52	6.09	4.38
Mg	33.2	29.9	17.2	17.2	24.8	26.4	23.6	24.4
Mn	0.33	0.3	0.15	0.11	0.05	0.16	0.59	0.54
K	16.4	15.7	21.6	23	2.7	2.8	4.9	7.3
Na	505	474	602	554	113	122	266	284
Al		<0.01		0.1		<0.01		<0.01
As		0.003		0.0039		0.001		0.0015
B		1.5		1.88		0.213		0.71
Cd		<0.0001		0.0001		<0.0001		<0.0001
Cr		0.007		0.0083		0.0036		0.0059
Cu		0.0008		0.001		0.0009		0.0006
Pb		0.0001		0.0002		<0.0001		<0.0001
Hg		<0.0001		<0.0001		<0.0001		<0.0001
Ni		0.0124		0.0116		0.0051		0.0088
Zn		0.014		0.008		0.015		0.012
Ion Balance	100	95	99.7	93.2	105	99.7	101	97.6
Lab pH	8	8.4	8.4	8.7	8.2	8.3	8	8.3
Lab Conductivity		2750		2880		1290		2060
TDS	1780	1780	1700	1850	710	885	1390	1240
TSS	6	5	76	45	17	4	207	10
NO_3		<0.1		0.2		<0.1		<0.1
NO_2		<0.05		0.24		<0.05		<0.05
DOC	45	46	56	60	18	23	33	34
Phenols	0.013	0.013	0.008	0.014	0.008	0.01	0.008	0.01
Naphthenic Acid								

APPENDIX A

Aurora – Surface Water Samples (Dirty Water)

ID	RECYCLEPOND		SOUTHPOND	
Sample Date	26-Jun-07	15-Oct-07	24-Jun-07	15-Oct-07
Field pH	7.63	10.35	7.76	10.13
Field Conductivity	2979	2743	3026	2528
Field Temperature	18.96	11.05	17.79	10.63
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method				
HCO_3	674	649	702	625
CO_3	17	45	<5	<5
OH	<5	<5	<5	<5
Cl	395	372	321	261
SO_4	317	340	345	451
Ca	27	32.4	99.7	125
Fe	<0.05	0.24	1.77	0.37
Mg	17.3	17.7	31	33.7
Mn	0.02	0.13	0.45	0.54
K	22.5	23.3	12.3	12.7
Na	599	548	456	391
Al		0.12		0.01
As		0.0037		0.0022
B		1.85		1.34
Cd		0.0002		<0.0001
Cr		0.0081		0.0051
Cu		0.001		0.0009
Pb		0.0001		<0.0001
Hg		<0.0001		<0.0001
Ni		0.0115		0.0111
Zn		0.007		0.01
Ion Balance	100	92.5	99.7	97.6
Lab pH	8.5	8.7	8.1	8.2
Lab Conductivity		2660		2490
TDS	1700	1830	1600	1730
TSS	48	39	149	12
NO_3		0.2		0.1
NO_2		0.24		<0.05
DOC	57	60	36	38
Phenols	0.009	0.014	0.009	0.01
Naphthenic Acid				

Aurora – Surface Water Samples (Clean Water)

APPENDIX A

ID	EPP-PP		MR6350190	MR6350775	MR6351800	MR6352600	MR6353330	MRT6352090
Sample Date	24-Jun-07	15-Oct-07	26-Jun-07	28-Jun-07	26-Jun-07	28-Jun-07	27-Jun-07	28-Jun-07
Field pH	7.58	9.14	7.11	7.74	7.15	7.35	7.09	7.1
Field Conductivity	778	516	344	366	430	465	513	660
Field Temperature	na	5.84	16.16	18.04	15.09	16.5	15.89	15.07
Sampled By	AW/BS	DB/AW	AW/BS	AW/BS	AW/BS	AW/BS	AW/BS	AW/BS
Sample Method								
HCO_3	287	273	210	215	266	276	285	320
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	1	<1	2	2	2	2	2	2
SO_4	123	51.1	4.4	4.4	4.4	6.1	3.8	4
Ca	115	84.9	48	48.9	64	66.6	66.3	77.1
Fe	0.72	1.69	0.1	0.83	0.51	1.23	1.58	1.54
Mg	21.6	15.5	12.5	11.8	15.3	15.4	15.3	17.9
Mn	0.52	0.48	<0.01	<0.01	<0.01	<0.01	0.13	0.07
K	1.4	2.1	0.9	2.1	1.3	2.6	<0.5	2.2
Na	6	5	12	13	9	10	6	10
Al		0.01						
As		<0.0004						
B		0.047						
Cd		<0.0001						
Cr		0.0005						
Cu		<0.0006						
Pb		<0.0001						
Hg		<0.0001						
Ni		0.0031						
Zn		0.054						
Ion Balance	107	104	111	110	108	108	100	108
Lab pH	8.1	8.3	8.2	8.3	8.2	8.3	8.2	8.2
Lab Conductivity		513						
TDS	390	323	230	250	310	280	280	280
TSS	47	4	<3	<3	6	<3	<3	5
NO_3		<0.1						
NO_2		<0.05						
DOC	10	10	25	27	21	24	23	26
Phenols	0.004	0.004	0.005	0.005	0.004	0.004	0.002	0.005
Naphthenic Acid		<1						

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0010765		OWS0010766		OWS0110-01		OWS0110-02	
Sample Date	28-Jun-07	14-Oct-07	25-Jun-07	14-Oct-07	25-Jun-07	14-Oct-07	27-Jun-07	22-Oct-07
Field pH	7.54	8.61	7.22	8.12	na	8.78	7.58	7.66
Field Conductivity	591	547	580	504	2383	2070	594	591
Field Temperature	5.08	5.25	5.29	5.78	7.05	6.67	5.82	4.86
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
$HC0_3$	353	347	284	286	591	573	299	283
$C0_3$	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	<1	2	1	2	300	215	2	21
SO_4	1.6	2.8	16.9	25.7	277	409	29.1	38.6
Ca	89.2	91.3	68.4	82.9	196	210	87.7	96
Fe	16.3	11.6	8.38	10.8	17.9	16	15.2	22.8
Mg	12.4	11.9	10.9	10.5	27.7	27.7	11.1	11
Mn	0.7	0.46	0.3	0.43	0.4	0.33	0.48	0.88
K	0.9	1.4	1.2	1.1	2.4	2.5	0.9	2
Na	4	6	7	7	261	235	4	5
Al						0.06		
As						0.0008		
B						0.326		
Cd						<0.0001		
Cr						0.001		
Cu						0.0011		
Pb						0.0004		
Hg						<0.0001		
Ni						0.0039		
Zn						0.015		
Ion Balance	97.4	101	92.3	101	98.2	96.1	98.6	98.8
Lab pH	8.1	7.8	7.8	7.8	7.6	7.7	8	7.8
Lab Conductivity		509		465		2060		556
TDS	360	294	280	295	1230	1390	290	354
TSS	616	414	26	54	164	76	478	3210
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	11	10	10	11	28	30	9	11
Phenols	0.002	0.002	0.002	0.003	0.004	0.006	0.001	<0.001
Naphthenic Acid						14		

Aurora – Surficial Aquifer Monitoring Wells

ID	OWS0110-03		OWS0110-04		OWS0134-05		OWS0134-06	
Sample Date	25-Jun-07	14-Oct-07	25-Jun-07	14-Oct-07	28-Jun-07	22-Oct-07	27-Jun-07	22-Oct-07
Field pH	6.91	7.81	6.45	8.05	7.54	7.81	7.49	7.69
Field Conductivity	2506	2318	1132	1027	770	716	742	674
Field Temperature	5.91	7.5	7.04	7.33	5.83	6.15	7	4.56
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	574	604	534	514	472	463	452	444
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	310	304	2	2	<1	1	1	1
SO_4	273	344	139	171	1.7	0.7	2.3	0.5
Ca	210	194	179	187	124	132	121	119
Fe	10	20.3	17.7	27.8	2.08	3.33	8.17	10.1
Mg	28.7	25.4	24.9	25.6	14.4	13.6	15.3	14.3
Mn	0.13	0.87	0.59	1.22	0.3	0.33	0.61	0.72
K	2.6	2.6	1.2	1.8	0.6	0.8	2.6	0.9
Na	245	267	5	8	4	3	7	4
Al		0.02						
As		0.0008						
B		0.256						
Cd		<0.0001						
Cr		0.0012						
Cu		0.0009						
Pb		<0.0001						
Hg		<0.0001						
Ni		0.004						
Zn		0.013						
Ion Balance	98.9	91.5	96	98.3	97.3	103	102	100
Lab pH	7.6	7.6	7.5	7.5	8.1	7.8	8	7.7
Lab Conductivity		2320		991		676		652
TDS	1420	1530	710	684	430	413	390	396
TSS	40	44	3680	2980	50	20	187	510
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	33	33	14	15	14	11	11	9
Phenols	0.006	0.007	0.002	0.003	0.003	0.002	0.002	0.002
Naphthenic Acid		18						

Aurora – Surficial Aquifer Monitoring Wells

ID	OWS0134-07		OWS0134-08		OWS0134-09		OWS0134-10	
Sample Date	27-Jun-07	22-Oct-07	25-Jun-07	15-Oct-07	28-Jun-07	23-Oct-07	26-Jun-07	15-Oct-07
Field pH	6.97	7.63	6.92	8.87	6.99	8.11	na	10.55
Field Conductivity	763	717	1002	914	750	705	662	549
Field Temperature	5.82	4.54	6.34	6	5.83	3.69	4.62	6.65
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	483	469	545	539	465	496	370	352
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	1	1	18	26	<1	<1	22	10
SO_4	1.4	0.7	9.5	13.9	1.3	<0.5	14.9	6.1
Ca	121	121	147	159	110	126	101	95.4
Fe	7.22	7.43	14.3	24.3	5.23	6.38	5.47	4.98
Mg	17.7	16.7	19.7	20.5	13.9	13.9	13	10.7
Mn	0.4	0.41	0.15	0.64	0.34	0.37	0.22	0.55
K	<0.5	0.9	<0.5	2	0.5	1.2	1.2	3.2
Na	5	4	6	9	6	7	18	11
Al								
As								
B								
Cd								
Cr								
Cu								
Pb								
Hg								
Ni								
Zn								
Ion Balance	96.7	98.5	95.6	102	90.3	95.5	99	100
Lab pH	7.9	7.6	7.7	8.2	8	7.5	7.6	7.9
Lab Conductivity		685		871		676		567
TDS	400	409	520	537	400	410	380	412
TSS	370	186	352	164	39	49	2780	3780
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	13	10	17	17	14	10	23	20
Phenols	0.008	0.002	0.002	0.007	0.001	0.003	0.003	0.008
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

ID	OWS0134-11		OWS0134-12	OWS0134-13		OWS0134-14	
Sample Date	26-Jun-07	17-Oct-07	17-Oct-07	29-Jun-07	17-Oct-07	26-Jun-07	17-Oct-07
Field pH	6.39	8.75	8.2	6.65	8.19	6.16	7.96
Field Conductivity	1653	1514	932	668	715	731	711
Field Temperature	5.01	4.73	5.25	3.59	4.98	4.71	5.15
Sampled By	AW/BS	DB/AW	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method							
HCO_3	694	674	500	458	448	463	462
CO_3	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5
Cl	181	172	34	3	5	1	1
SO_4	8.3	5.3	38.4	4.7	9.8	2.3	2.9
Ca	171	177	159	103	106	99.2	116
Fe	11.2	13.5	9.5	15.4	6.4	3.37	7.98
Mg	27.8	27.6	23.4	16.7	17.9	16.4	17
Mn	0.26	0.39	0.44	0.54	0.4	0.29	0.37
K	1.7	1.1	<0.5	0.7	1.2	0.8	<0.5
Na	109	102	11	24	30	18	14
Al		0.03	0.02		0.04		
As		0.0006	0.0004		<0.0004		
B		0.124	0.075		0.182		
Cd		<0.0001	<0.0001		<0.0001		
Cr		0.0013	0.0007		0.001		
Cu		0.0008	<0.0006		<0.0006		
Pb		<0.0001	<0.0001		0.0002		
Hg		<0.0001	<0.0001		<0.0001		
Ni		0.0049	0.004		0.0025		
Zn		0.019	0.011		0.01		
Ion Balance	93.7	97.3	104	98.5	105	92.7	102
Lab pH	7.7	7.7	7.6	8	7.8	7.6	7.6
Lab Conductivity		1450	883		675		677
TDS	830	880	576	410	422	430	516
TSS	1210	1030	1490	536	858	208	796
NO_3		<0.1	<0.1		<0.1		<0.1
NO_2		<0.05	<0.05		<0.05		<0.05
DOC	24	23	19	20	17	21	17
Phenols	0.004	0.009	0.007	0.005	0.005	0.009	0.007
Naphthenic Acid		4	1		2		

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0134-15		OWS0234-01		OWS023402A		OWS023402B	
Sample Date	29-Jun-07	17-Oct-07	25-Jun-07	15-Oct-07	28-Jun-07	23-Oct-07	28-Jun-07	23-Oct-07
Field pH	6.63	8.11	9.86	4.31	6.89	7.36	6.9	7.18
Field Conductivity	1026	1166	838	724	760	687	763	698
Field Temperature	5.35	5.86	4.96	4.31	6.1	4.48	5.14	4.52
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	697	733	483	465	465	481	469	488
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	6	10	5	2	1	1	<5	<5
SO_4	29.5	65.9	1.7	2.5	2.1	<0.5	1	1
Ca	169	206	129	125	122	122	0.8	<0.5
Fe	4.84	4.21	10.5	19.2	7.6	10.6	120	123.
Mg	30.9	37.8	18.1	17	15.9	14.2	0.21	6.14
Mn	0.39	0.35	0.09	0.65	0.41	0.5	15.9	14.3
K	<0.5	<0.5	0.8	1.6	0.6	1.5	0.34	0.4
Na	4	4	18	9	6	6	<0.5	1.6
Al							6	6
As								
B								
Cd								
Cr								
Cu								
Pb								
Hg								
Ni								
Zn								
Ion Balance	91.4	99.3	108	104	99.7	95.4	97.8	94.9
Lab pH	8	7.6	7.7	8.3	8	7.8	8	7.4
Lab Conductivity		1140		691		657		667
TDS	660	742	670	422	410	399	410	398
TSS	196	534	308	145	142	327	127	41
NO_3		<0.1		<0.1		0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	14	11	13	14	11	10	11	10
Phenols	0.005	0.006	0.002	0.008	0.001	0.003	<0.001	0.004
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0234-03		OWS0234-04		OWS0234-05		OWS0234-06	
Sample Date	25-Jun-07	15-Oct-07	28-Jun-07	23-Oct-07	28-Jun-07	23-Oct-07	28-Jun-07	23-Oct-07
Field pH	6.76	10.53	6.94	7.2	6.84	6.59	6.86	7.54
Field Conductivity	1037	1064	809	747	776	700	771	708
Field Temperature	5.71	6.1	6.36	5.62	6.05	4.31	7.41	3.48
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	505	533	496	528	475	479	490	498
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	59	91	2	1	1	1	1	1
SO_4	2.1	3.1	2.2	<0.5	1.7	<0.5	1.4	<0.5
Ca	135	152	121	120	121	123	118	127
Fe	10.4	16.3	7.93	10.6	4.58	7.75	3.23	5.24
Mg	17.5	19.6	24.6	23.3	16.1	15	15.8	15.2
Mn	0.12	0.6	0.44	0.43	0.49	0.53	0.39	0.41
K	0.9	1.9	3.4	2.3	0.5	1.5	<0.5	1.4
Na	24	45	10	8	6	6	6	7
Al				0.01				
As				<0.0004				
B				0.058				
Cd				<0.0001				
Cr				0.0023				
Cu				<0.0006				
Pb				<0.0001				
Hg				<0.0001				
Ni				0.0023				
Zn				0.005				
Ion Balance	92.6	98.6	104	95.8	97.3	97.4	92.1	96.8
Lab pH	7.7	8.2	8	7.5	8	7.5	8	7.4
Lab Conductivity		1060		700		662		692
TDS	620	628	420	415	430	391	430	418
TSS	64	57	110	310	71	103	54	14
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	14	18	16	14	11	11	12	11
Phenols	0.002	0.009	0.003	0.003	0.001	0.004	0.002	0.004
Naphthenic Acid				<1				

Aurora – Surficial Aquifer Monitoring Wells

ID	OWS0234-07		OWS0234-08		OWS0234-09		OWS0234-10
Sample Date	28-Jun-07	22-Oct-07	26-Jun-07	15-Oct-07	25-Jun-07	15-Oct-07	25-Jun-07
Field pH	7.17	7.4	5.84	9.93	6.27	8.4	6.53
Field Conductivity	632	531	831	706	3246	2918	3312
Field Temperature	6.87	5.96	3.68	6.57	4.81	7.79	9.98
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS
Sample Method							
HCO_3	359	338	505	480	947	779	964
CO_3	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5
Cl	4	4	3	3	1	1	1
SO_4	14.4	5	5.6	4.5	1210	1370	1250
Ca	101	95.6	98.4	98.8	586	663	632
Fe	1.32	2.25	12.8	14.4	2.52	9.25	8.14
Mg	10.5	8.3	24	18.4	96	99.2	74.7
Mn	0.13	0.26	0.37	1.06	1.6	6.68	1.78
K	1	1.8	1.7	3.4	4.4	7.5	2.1
Na	6	7	18	24	21	25	11
Al							
As							
B							
Cd							
Cr							
Cu							
Pb							
Hg							
Ni							
Zn							
Ion Balance	98.3	101	91	94.2	93.7	103	91.3
Lab pH	8	7.6	7.6	7.6	7.2	7.7	7.4
Lab Conductivity		500		674		2610	
TDS	350	329	420	440	2580	2740	2890
TSS	8	11	3270	5020	762	1200	3220
NO_3		0.1		<0.1		<0.1	
NO_2		<0.05		<0.05		<0.05	
DOC	22	21	37	37	9	7	13
Phenols	0.004	0.006	0.004	0.01	0.002	0.008	0.003
Naphthenic Acid							

Aurora – Surficial Aquifer Monitoring Wells

ID	OWS0234-14		OWS0234-15		OWS0234-16		OWS0234-17	
Sample Date	29-Jun-07	18-Oct-07	3-Jul-07	18-Oct-07	3-Jul-07	18-Oct-07	29-Jun-07	18-Oct-07
Field pH	6.39	7.57	6.14	7.65	6.39	8.15	6.88	7.32
Field Conductivity	3057	2977	3658	3100	3857	3284	2987	3461
Field Temperature	9.59	9.58	9.73	8.8	9.02	8.63	21.73	16.75
Sampled By	AW/BS	DB/AW	AW/YW	DB/AW	AW/YW	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	551	454	695	733	687	769	697	903
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	117	88	44	54	19	21	393	344
SO_4	1250	1340	1310	1350	1540	1570	481	608
Ca	602	577	650	651	620	626	140	145
Fe	14.5	15.6	5.49	0.32	7.33	13.8	2.94	3.43
Mg	64.3	61.1	118	114	175	172	26.3	24
Mn	2.92	2.45	6.63	9.26	3.93	4.02	0.42	0.26
K	8.5	9.3	2.9	3.1	12.7	13.5	6.6	7.5
Na	129	103	18	17	19	24	537	623
Al		0.03						0.06
As		0.002						0.0039
B		0.144						1.21
Cd		<0.0001						<0.0001
Cr		0.0047						<0.005
Cu		0.0018						0.0022
Pb		0.0006						0.0004
Hg		<0.0001						<0.0001
Ni		0.032						0.0147
Zn		0.011						0.011
Ion Balance	107	102	108	103	106	102	100	98.2
Lab pH	7.5	7.4	7.5	7.5	7.3	7.3	7.8	7.9
Lab Conductivity		2880		3000		3250		3390
TDS	2720	2560	2740	2790	3000	3080	1960	2230
TSS	292	605	966	364	89	736	103	168
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	27	28	42	36	58	57	47	37
Phenols	0.006	0.008	0.008	0.013	0.012	0.014	0.01	0.007
Naphthenic Acid		11						17

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0310-04		OWS0334-06		OWS0334-07		OWS0334-09	
Sample Date	**24-Jun-07**	**14-Oct-07**	**29-Jun-07**	**18-Oct-07**	**3-Jul-07**	**18-Oct-07**	**3-Jul-07**	**19-Oct-07**
Field pH	7.01	9.06	6.87	7.51	6.9	7.74	7.1	9.69
Field Conductivity	569	472	3040	3443	3036	2265	1200	893
Field Temperature	5.46	5.12	12.93	13.85	13.12	9.57	9.51	4.95
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/YW	DB/AW	AW/YW	DB/AW
Sample Method								
$HC0_3$	302	290	726	750	413	483	649	624
$C0_3$	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	1	<1	374	368	2	4	2	2
SO_4	4.8	9.7	494	717	1240	1010	12.9	7.5
Ca	77.8	75	135	223	556	493	40.9	37.4
Fe	6.51	7.83	9.8	15.3	17.1	14.5	4.87	0.97
Mg	12.7	11	28	49.8	80	61.8	13.5	12.8
Mn	0.64	0.63	0.48	1.08	5.64	3.66	0.51	0.24
K	<0.5	1.5	14.7	14	7	7.2	5.7	5.6
Na	5	7	530	511	5	2	167	158
Al				0.06				
As				0.0058				
B				1.21				
Cd				<0.0001				
Cr				<0.005				
Cu				0.0022				
Pb				0.0001				
Hg				<0.0001				
Ni				0.0216				
Zn				0.013				
Ion Balance	101	101	99.2	101	106	103	96.4	95.2
Lab pH	7.9	7.8	7.9	7.7	7.7	7.3	8	7.7
Lab Conductivity		444		3380		2210		883
TDS	250	281	2010	2310	2320	2000	580	544
TSS	136	71	434	654	686	216	972	444
NO_3		<0.1		0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	11	12	44	38	25	25	16	14
Phenols	0.013	0.007	0.01	0.006	0.006	0.01	0.006	<0.001
Naphthenic Acid				17				

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0410-01		OWS0410-02		OWS041003A		OWS041003B	
Sample Date	25-Jun-07	14-Oct-07	25-Jun-07	14-Oct-07	24-Jun-07	14-Oct-07	24-Jun-07	14-Oct-07
Field pH	7.05	7.73	7.1	8.15	7.26	8.47	7.12	8.9
Field Conductivity	2765	2463	1869	2029	1988	1566	1387	1107
Field Temperature	6.12	8.55	7.77	9.8	7.49	8.73	7.37	5.92
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	621	648	505	636	594	573	487	479
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	332	325	173	290	123	143	99	86
SO_4	362	328	258	312	230	246	88.6	95.7
Ca	173	200	99.2	199	190	217	158	151
Fe	21	24.6	16.7	25.5	21.7	20.3	14.2	14.3
Mg	32.6	27.8	22.5	30.7	26	31.2	35.5	33
Mn	0.55	0.79	0.64	1.15	0.93	0.87	0.81	0.78
K	1.6	2.2	1.9	3	0.6	2.7	4.1	5.1
Na	309	277	234	256	169	112	46	46
Al								
As								
B								
Cd								
Cr								
Cu								
Pb								
Hg								
Ni								
Zn								
Ion Balance	91.6	91.6	91.9	94.3	106	98.9	102	101
Lab pH	7.6	7.6	7.7	7.6	7.7	7.6	7.8	7.8
Lab Conductivity		2430		2290		1610		1100
TDS	1590	1590	1320	1560	1020	1070	700	732
TSS	1320	921	1500	2580	612	560	2100	2850
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	36	34	30	34	31	26	16	17
Phenols	0.006	0.008	0.005	0.007	0.002	0.009	0.002	0.005
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0410-04		OWS0410-05		OWS0410-06		OWS0410-17	
Sample Date	27-Jun-07	22-Oct-07	27-Jun-07	22-Oct-07	27-Jun-07	22-Oct-07	28-Jun-07	14-Oct-07
Field pH	5.38	6.3	7.62	6.98	7.43	6.72	7.1	8.22
Field Conductivity	825	706	2118	2038	2079	2188	597	528
Field Temperature	7.5	3.82	5.77	4.27	5.82	4.41	5.88	6.24
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	400	370	519	532	502	541	354	354
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	9	16	236	262	228	282	2	1
SO_4	58.7	45.6	232	248	242	298	6.6	9
Ca	128	114	234	214	210	223	93.4	95.3
Fe	6.63	9.45	18.4	23	15	29	18.2	22.5
Mg	19	16.4	31.7	27.7	28.6	29.1	12.4	11.9
Mn	0.75	0.76	1.02	0.85	0.86	1.26	1.16	1.48
K	2.9	1.7	3.3	1.8	2.9	2.4	1.3	2
Na	13	9	150	197	171	225	4	6
Al								
As								
B								
Cd								
Cr								
Cu								
Pb								
Hg								
Ni								
Zn								
Ion Balance	107	100	105	101	103	102	98.2	100
Lab pH	7.9	7.6	7.9	7.6	7.9	7.5	8.1	7.9
Lab Conductivity		674		2000		2140		531
TDS	460	423	1200	1270	1190	1460	350	376
TSS	48	16	4580	461	5310	2440	1970	3180
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	16	14	29	30	28	30	13	9
Phenols	0.001	0.002	0.004	0.006	0.005	0.004	0.002	0.002
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0434-15		OWS0434-16		OWS0734400	OWS0734405	OWS0734406	OWS0734407
Sample Date	26-Jun-07	17-Oct-07	26-Jun-07	17-Oct-07	24-Oct-07	19-Oct-07	17-Oct-07	17-Oct-07
Field pH	6.37	7.37	6.37	8.11	7.4	9.35	7.51	8.15
Field Conductivity	679	679	1099	1309	1010	1653	2567	1458
Field Temperature	5.93	6.36	4.49	5.22	7.12	6.24	5.19	4.8
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	DB/AW	DB/AW	DB/AW	DB/AW
Sample Method								
HCO_3	422	436	546	582	773	681	973	680
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	2	3	82	144	4	9	12	48
SO_4	3.2	4.4	46.6	59.5	2.2	386	851	190
Ca	107	117	162	180	179	314	528	246
Fe	6.53	9.05	11.2	5.75	14	21	11.9	53.1
Mg	14.6	16.3	18.2	20	31.3	43.5	83	32.6
Mn	0.31	0.32	0.58	0.63	1.45	5.36	7.09	2.99
K	<0.5	<0.5	<0.5	<0.5	6.1	3.5	7	2.2
Na	11	10	44	87	10	12	7	24
Al					1.3	1.12	0.11	0.49
As					0.0023	0.0036	0.0021	0.0032
B					0.055	0.081	0.06	0.085
Cd					0.0003	0.0004	<0.0001	<0.0001
Cr					0.0045	<0.005	0.0008	0.0025
Cu					0.0018	0.0047	0.0021	0.0021
Pb					0.0036	0.0026	0.0009	0.0044
Hg					<0.0001	<0.0001	<0.0001	<0.0001
Ni					0.015	0.0539	0.0425	0.0239
Zn					0.039	0.05	0.035	0.024
Ion Balance	99.7	104	94	97.1	94.2	102	99	97.6
Lab pH	7.7	7.7	7.7	7.6	7.1	7.4	7.2	7.3
Lab Conductivity		641		1310	1010	1590	2560	1390
TDS	370	390	660	844	672	988	2240	992
TSS	1130	562	2680	4460	7610	13300	8460	9280
NO_3		<0.1		<0.1	0.1	<0.1	<0.1	<0.1
NO_2		<0.05		<0.05	0.07	<0.05	<0.05	<0.05
DOC	19	17	18	23	35	28	40	23
Phenols	0.006	0.009	0.003	0.005	0.012	0.016	0.028	0.022
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0734408	OWS0734409	OWS0734410	OWS0734411	OWS0734412	OWS0734413	OWS0734414	OWS0734416
Sample Date	19-Oct-07	23-Oct-07	19-Oct-07	19-Oct-07	15-Oct-07	24-Oct-07	24-Oct-07	24-Oct-07
Field pH	7.56	8.2	7.42	6.76	9.48	7.97	7.82	7.55
Field Conductivity	1934	1332	1417	1090	1380	3234	2471	3386
Field Temperature	4.48	7.27	5.53	5.89	10.05	7.04	8.52	8.05
Sampled By	DB/AW	DB/AW	DB/AW	DB/AW	DB/AW	DB/AW	DB/AW	DB/AW
Sample Method								
HCO_3	639	767	619	533	612	569	992	760
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	223	46	151	67	78	175	19	53
SO_4	176	90.7	49.8	60.5	184	1440	1430	1770
Ca	205	250	153	173	205	674	675	709
Fe	24.5	19.4	7.91	67.7	99.5	98.5	64.4	159
Mg	25.5	28.5	16.8	18.9	20.6	118	117	109
Mn	2.06	1.2	0.66	3.2	2.86	10	5.23	17.2
K	3.4	5.8	2.3	1.9	4.7	13.8	12.8	12.7
Na	164	28	126	37	86	54	54	211
Al	0.16	0.13	0.58	3.34	0.23	5.1	0.25	1.1
As	0.003	0.0008	0.0024	0.0055	0.0061	0.0039	0.0014	0.0025
B	0.11	0.189	0.222	0.082	0.213	0.086	0.09	0.182
Cd	0.0001	<0.0001	<0.0001	0.0007	<0.0001	0.0003	0.0001	0.0002
Cr	<0.005	0.0013	<0.005	<0.005	0.0023	0.012	0.0024	0.004
Cu	0.003	0.0011	0.0019	0.0062	0.002	0.0258	0.0099	0.0047
Pb	0.0008	0.0004	0.0009	0.012	0.0042	0.0154	0.0013	0.0074
Hg	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Ni	0.046	0.0059	0.0118	0.0502	0.0255	0.039	0.0244	0.0206
Zn	0.018	0.008	0.016	0.062	0.03	0.069	0.019	0.04
Ion Balance	95.7	103	94.3	99.6	98.3	104	98.7	106
Lab pH	7.6	7.4	7.5	7.5	8.2	7.5	7.3	7.2
Lab Conductivity	1860	1290	1380	1080	1390	3210	2440	3320
TDS	1040	952	896	668	908	2820	2220	2850
TSS	4030	3550	5540	10400	14700	35400	10100	26800
NO_3	<0.1	<0.1	<0.1	0.1	<0.1	0.2	0.1	0.1
NO_2	<0.05	0.08	<0.05	<0.05	<0.05	<0.05	<0.05	0.09
DOC	29	28	27	19	24	18	58	58
Phenols	0.009	0.016	0.01	0.008	0.009	0.004	0.012	0.013
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

APPENDIX A

ID	OWS0734417	OWS0734418	OWS9710026		OWS9710027		OWS9710028	
Sample Date	24-Oct-07	24-Oct-07	27-Jun-07	22-Oct-07	27-Jun-07	22-Oct-07	24-Jun-07	14-Oct-07
Field pH	8.08	6.85	7.24	7.47	7.52	7.21	7.06	8.97
Field Conductivity	2001	3944	703	637	577	567	597	476
Field Temperature	7.57	8.07	4.86	5.92	5.44	4.83	4.89	6.62
Sampled By	DB/AW	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
$HC0_3$	896	722	391	384	291	305	332	281
$C0_3$	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	12	216	<1	<1	<1	2	<1	1
SO_4	1440	1660	1.4	0.9	19.3	23.3	1.5	25.5
Ca	698	677	101	98.9	81.3	90	84.9	75.7
Fe	47.6	29.3	14.1	19.7	9.4	16	5.49	5.2
Mg	119	61.7	14	12.2	10.8	10.3	15	12.8
Mn	4.85	4.52	0.59	0.79	0.57	0.66	0.52	0.44
K	13.3	11.9	0.8	0.9	0.6	1.1	<0.5	1.3
Na	55	354	4	3	3	3	5	7
Al	0.29	0.01						
As	0.0024	0.0011						
B	0.064	0.133						
Cd	0.0002	<0.0001						
Cr	0.0013	0.0015						
Cu	0.0016	0.0029						
Pb	0.0014	<0.0001						
Hg	<0.0001	<0.0001						
Ni	0.0315	0.0212						
Zn	0.03	0.004						
Ion Balance	105	104	99.2	96.5	98.5	99.2	104	100
Lab pH	7.6	7.3	8	7.6	8	7.7	7.8	7.7
Lab Conductivity	2010	3930		565		502		461
TDS	1790	3590	370	354	290	317	280	303
TSS	3520	6880	184	438	65	65	249	11
NO_3	0.1	<0.1		<0.1		<0.1		<0.1
NO_2	<0.05	0.1		<0.05		<0.05		<0.05
DOC	23	36	12	11	11	10	14	12
Phenols	0.015	0.005	0.001	0.004	<0.001	0.002	0.019	0.004
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

ID	OWS9734015		OWS9734018		OWS9734021		OWS9734022	
Sample Date	29-Jun-07	23-Oct-07	29-Jun-07	18-Oct-07	26-Jun-07	17-Oct-07	26-Jun-07	17-Oct-07
Field pH	6.85	6.62	6.63	8.99	6.49	8.28	6.6	9.59
Field Conductivity	866	833	617	692	482	536	583	518
Field Temperature	5.66	6.31	6.03	4.9	2.88	4.34	3.88	3.63
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method								
HCO_3	493	496	465	440	291	313	368	330
CO_3	<5	<5	<5	<5	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5	<5	<5
Cl	5	5	2	2	1	3	4	6
SO_4	37.4	39.2	3.7	4.5	11.2	7.9	3.7	3.9
Ca	137	146	119	114	85	94.3	90.4	89.5
Fe	15.7	14.9	16.3	17.2	2.79	4.87	3.84	4.17
Mg	16.1	16	16.6	15	8.9	9	9.8	9.2
Mn	0.85	0.67						
K	0.7	1.5	<0.5	1.2	0.5	<0.5	1.6	1
Na	13	12	4	4	11	7	28	13
Al								
As								
B								
Cd								
Cr								
Cu								
Pb								
Hg								
Ni								
Zn								
Ion Balance	97.2	101	96.4	96.8	109	107	106	103
Lab pH	7.9	7.1	7.9	7.1	7.7	7.5	7.8	7.5
Lab Conductivity		778		625		481		497
TDS	480	481	410	407	320	334	370	388
TSS	1500	967	628	168	1180	140	3320	1470
NO_3		<0.1		<0.1		<0.1		<0.1
NO_2		<0.05		<0.05		<0.05		<0.05
DOC	14	12	32	32	24	29	28	28
Phenols	0.012	0.01	0.012	0.013	0.004	0.007	0.004	0.01
Naphthenic Acid								

Aurora – Surficial Aquifer Monitoring Wells

ID	OWS9734023	OWS9734023	OWS9934761	OWS9934761	OWS9934762	OWS9934762
Sample Date	26-Jun-07	15-Oct-07	25-Jun-07	15-Oct-07	28-Jun-07	23-Oct-07
Field pH	6.63	9.45	6.61	9.89	7.12	7.76
Field Conductivity	470	646	2240	1703	1145	951
Field Temperature	5.28	7.47	5.77	4.98	4.74	3.93
Sampled By	AW/BS	DB/AW	AW/BS	DB/AW	AW/BS	DB/AW
Sample Method						
HCO_3	262	414	636	566	662	618
CO_3	<5	6	<5	<5	<5	<5
OH	<5	<5	<5	<5	<5	<5
Cl	2	2	233	179	30	20
SO_4	29.2	3.9	276	221	6.9	1.5
Ca	82.4	116	213	222	115	112
Fe	0.8	5.11	1	5.63	6.15	5.6
Mg	9.7	11.6	26.7	21.9	17.2	15.9
Mn			0.21	0.57	0.33	0.34
K	1.9	1.5	1.6	2.3	5.2	3.9
Na	9	7	176	143	108	85
Al						
As						
B						
Cd						
Cr						
Cu						
Pb						
Hg						
Ni						
Zn						
Ion Balance	108	99.5	90.2	101	101	99.5
Lab pH	7.9	8.3	7.6	8.2	8	7.4
Lab Conductivity		606		1760		923
TDS	340	392	1450	1150	630	588
TSS	320	264	60	44	88	114
NO_3		<0.1		<0.1		0.3
NO_2		<0.05		<0.05		<0.05
DOC	23	21	32	31	26	26
Phenols	0.003	0.012	0.005	0.016	0.006	0.007
Naphthenic Acid						

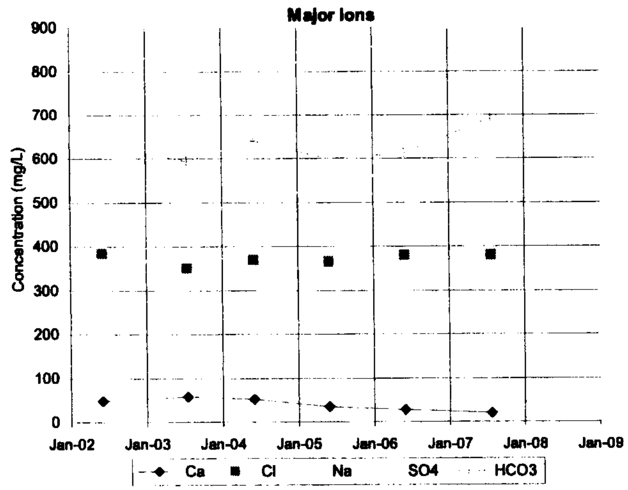
Aurora – Surficial Aquifer Monitoring Wells

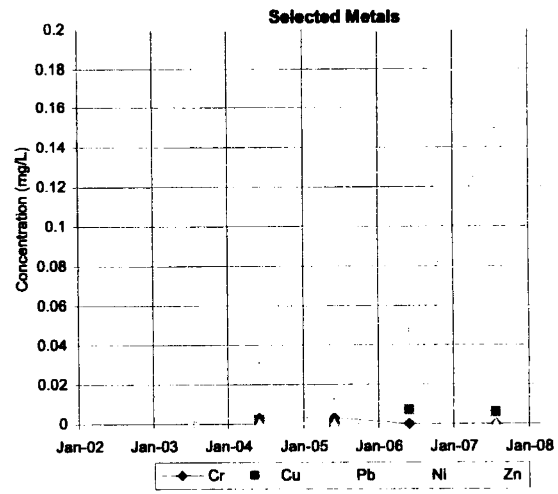
2007 TEH and PAH parameters

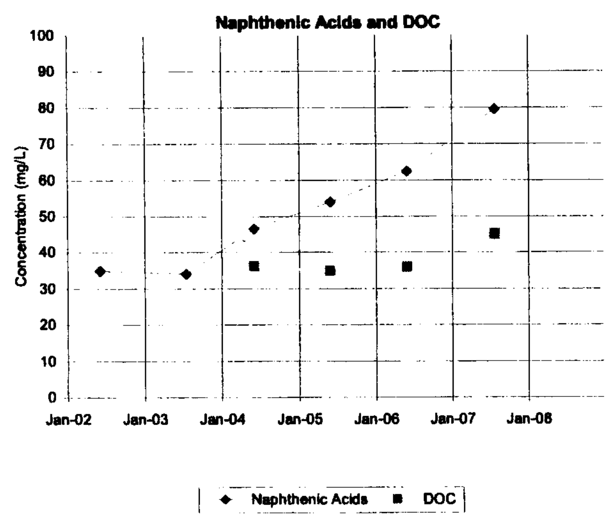
	OWS0110-01	OWS0110-03	OWS0134-11	OWS0134-12	OWS0134-13	OWS0234-04	OWS0234-14	OWS0234-17	OWS0334-06	EPP-PP
TEH (C11-C30)	<0.05	<0.05	17	<0.05	120	<0.05	5	2.3	1.3	<0.05
Naphthalene	<0.00001	<0.00001	0.00002	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Acenaphthene	<0.00001	<0.00001	0.00009	<0.00001	0.00096	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Fluorene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Phenanthrene	<0.00001	<0.00001	0.00015	0.00002	0.0015	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Anthracene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Fluoranthene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Pyrene	<0.00001	<0.00001	0.00004	<0.00001	0.0011	0.00002	<0.00001	<0.00001	<0.00001	<0.00001
Benzo(a)anthracene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Chrysene	<0.00001	<0.00001	0.00002	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Benzo(b)fluoranthene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Benzo(k)fluoranthene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Benzo(a)pyrene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Indeno(1,2,3-cd)pyrene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Dibenzo(a,h)anthracene	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Acridine	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001
Quinoline	<0.00001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.00001	<0.00001	<0.00001	<0.00001

APPENDIX B: HISTORICAL TREND PLOTS

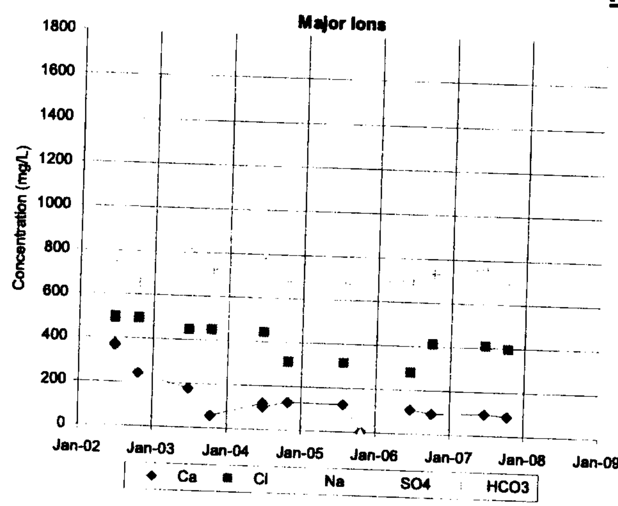
ATP

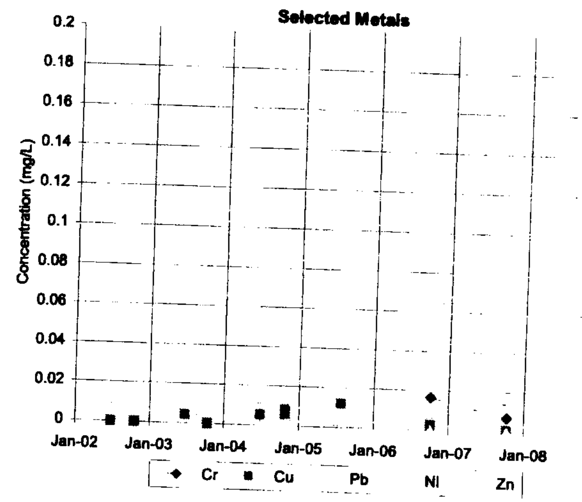

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Ca Cl Na SO4 HCO3

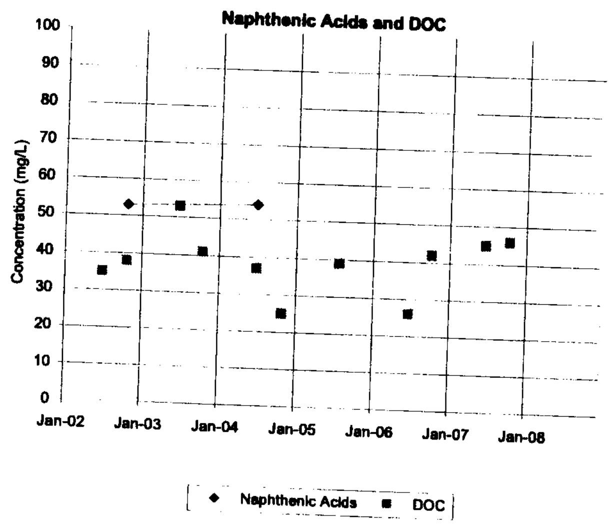

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Cr Cu Pb Ni Zn


Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Naphthenic Acids DOC

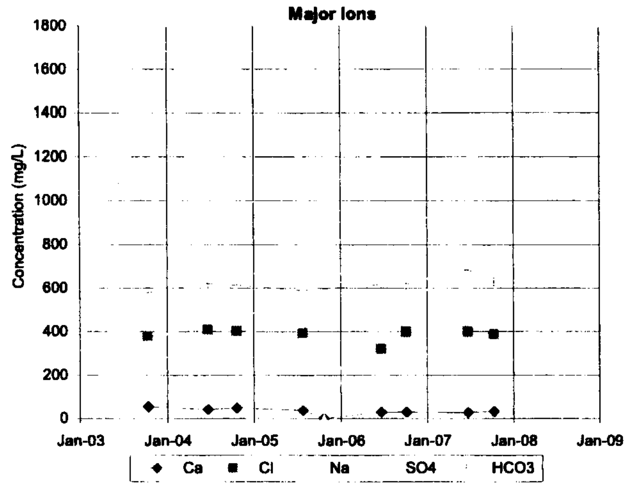
A6202

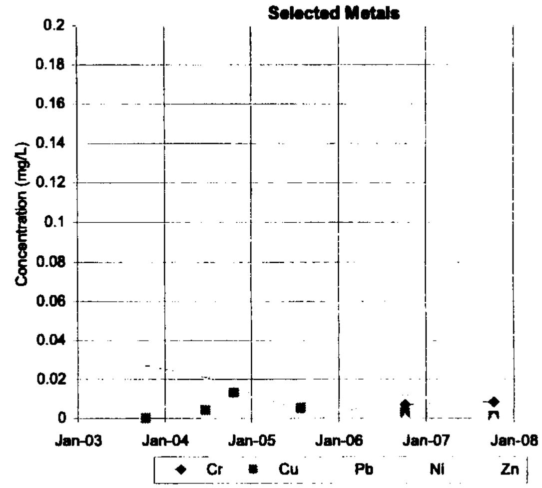

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Ca
Cl
Na
SO4
HCO3

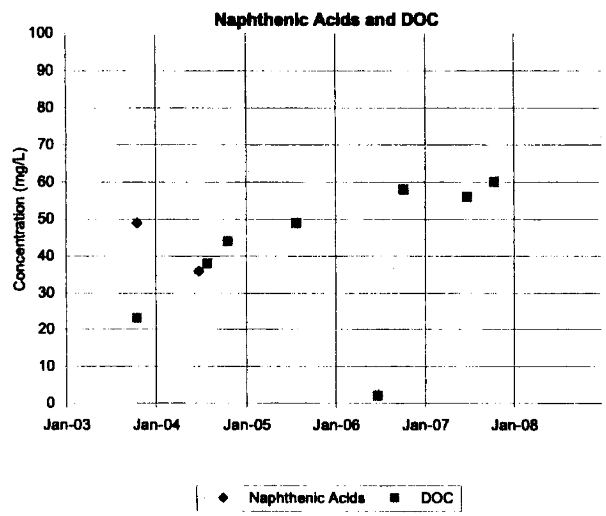

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn


Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

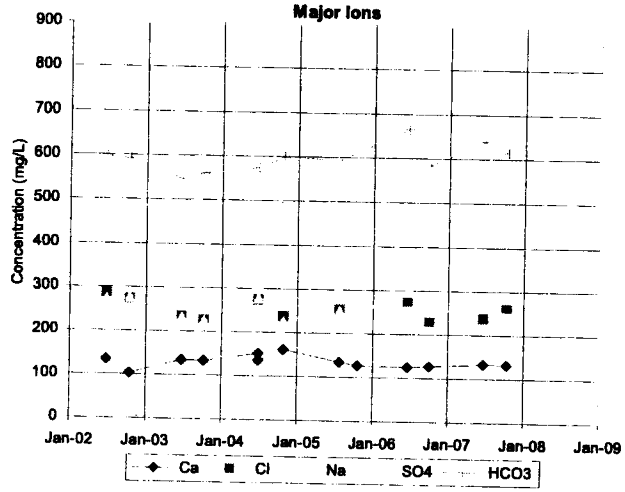
AN-SIPHON

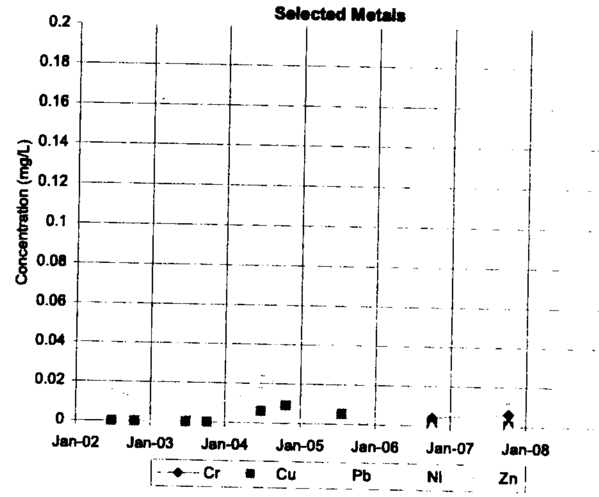

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Ca Cl Na SO4 HCO3

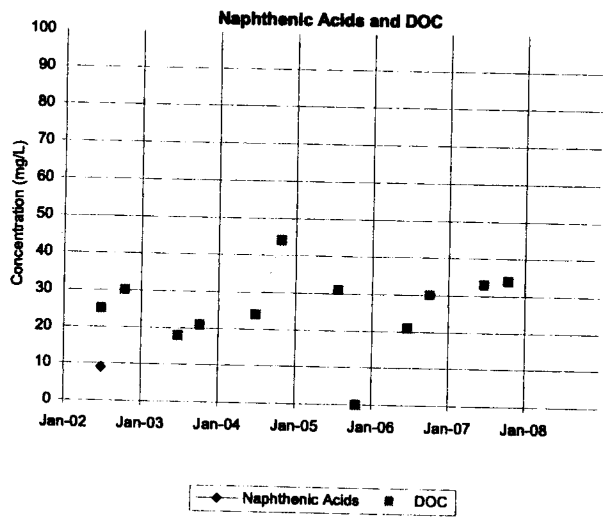

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Cr Cu Pb Ni Zn


Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Naphthenic Acids DOC

RAMP3POND

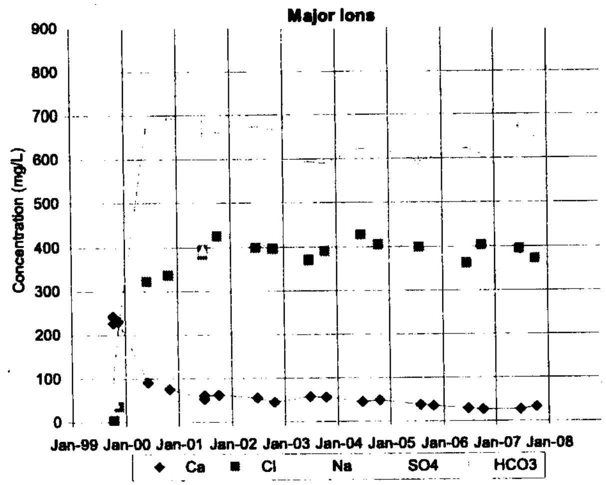

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Ca
Cl
Na
SO4
HCO3

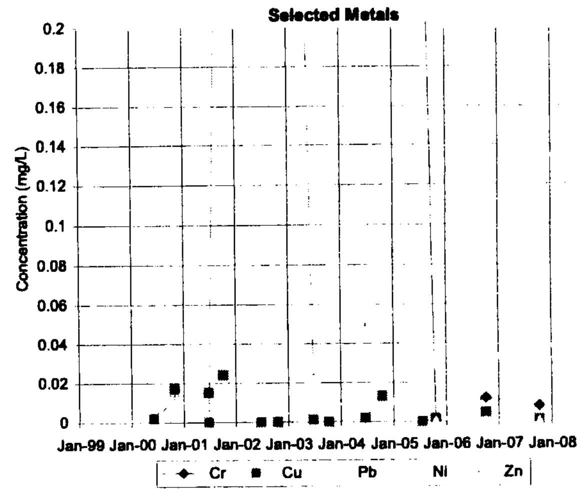

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

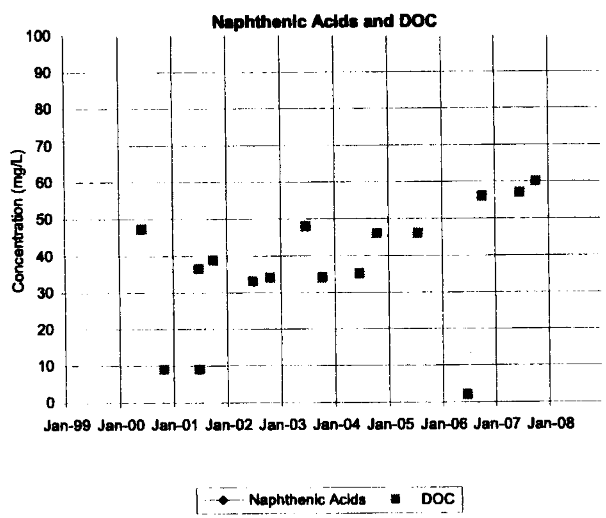

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

Aurora – Surface Water Samples (Dirty Water)

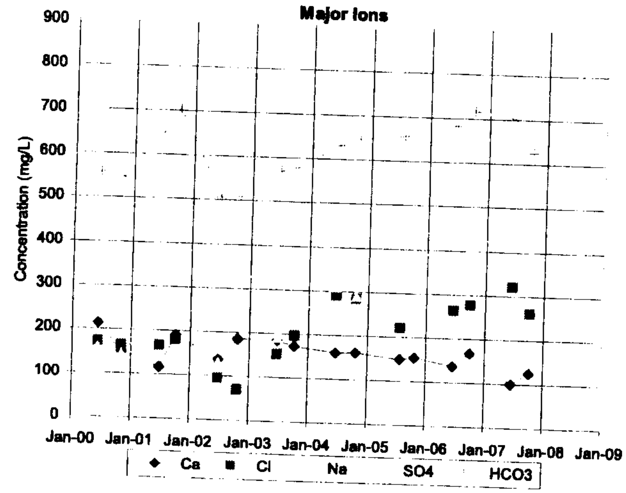
RECYCLEPOND

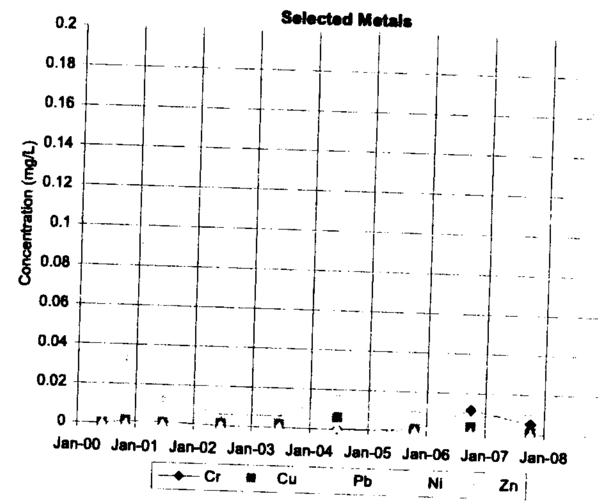


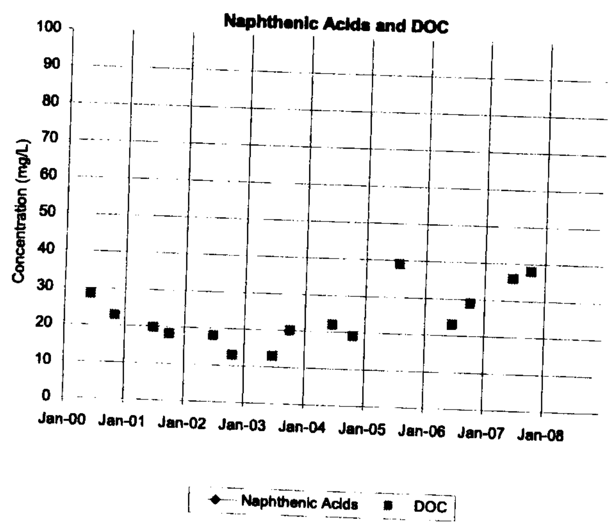




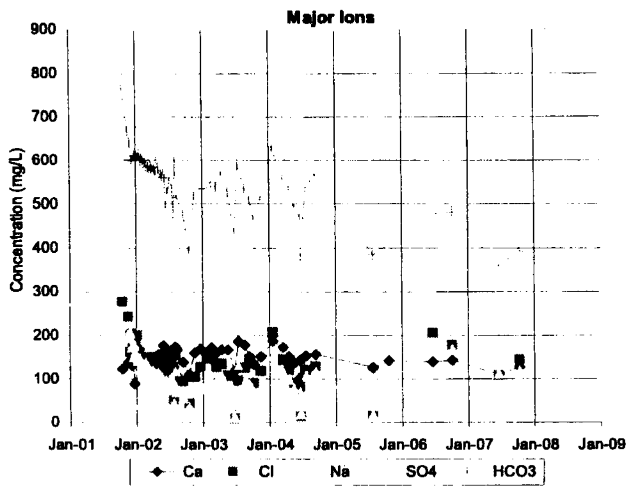
SOUTHPOND

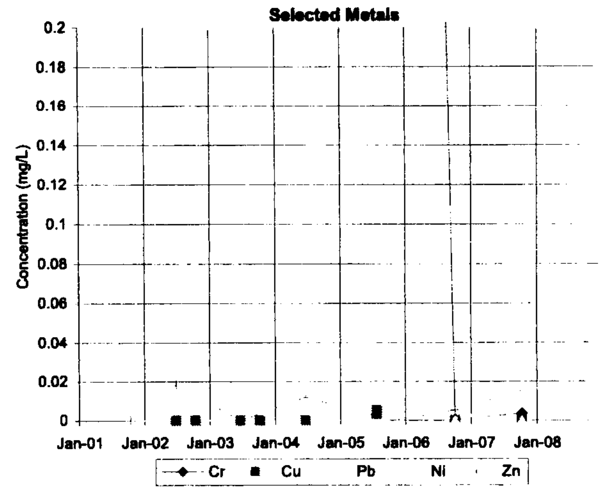

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Ca Cl Na SO4 HCO3

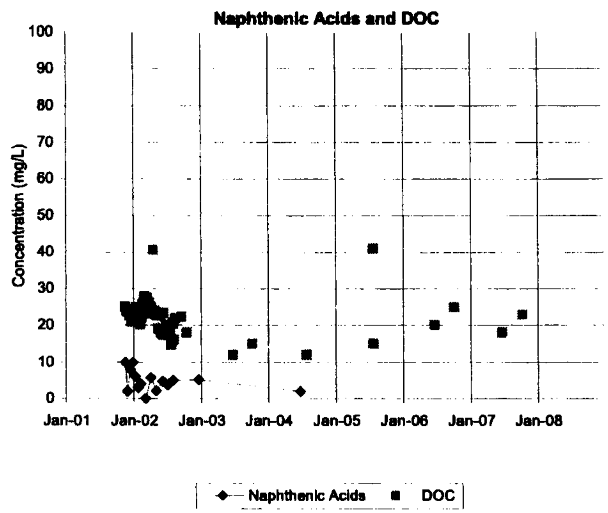

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Cr Cu Pb Ni Zn


Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-00 Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Naphthenic Acids DOC

MRSUMP

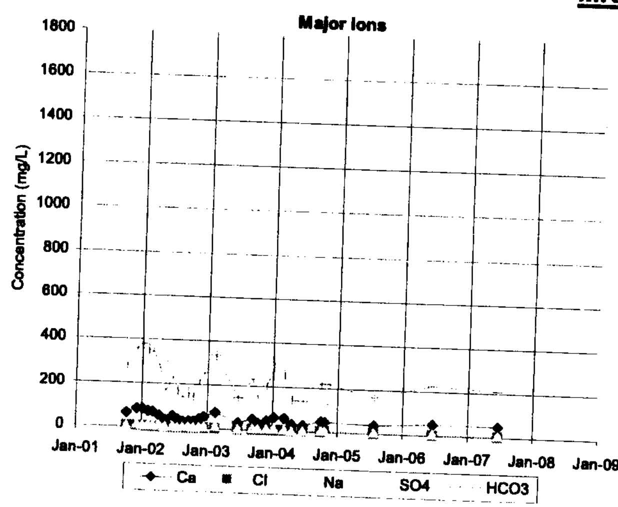

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Ca Cl Na SO4 HCO3

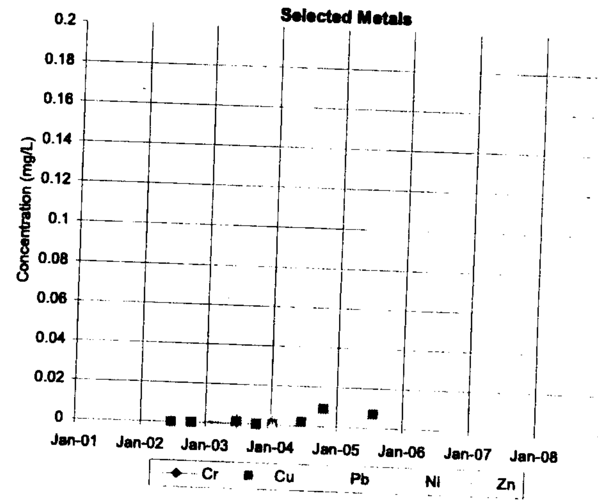

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Cr Cu Pb Ni Zn

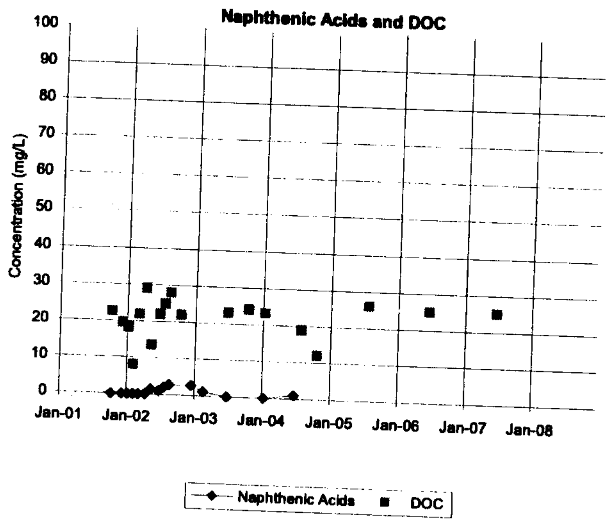

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Naphthenic Acids DOC

Aurora – Surface Water Samples (Clean Water)

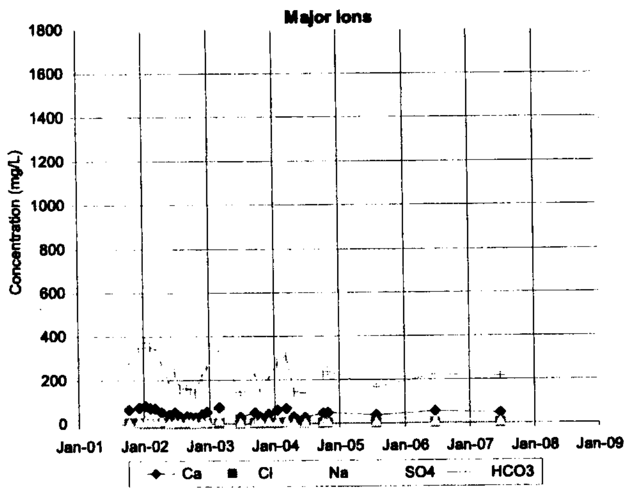
MR6350190

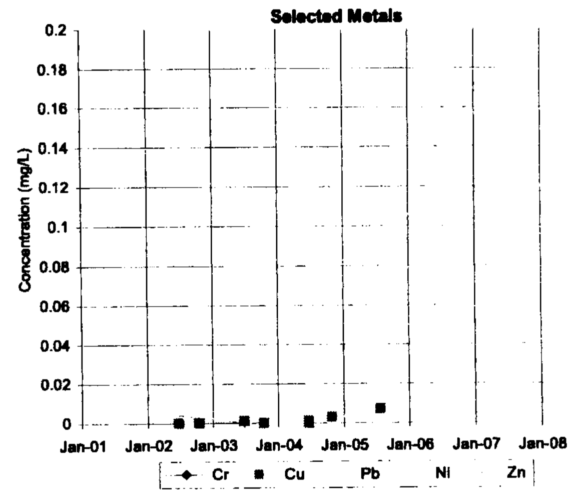


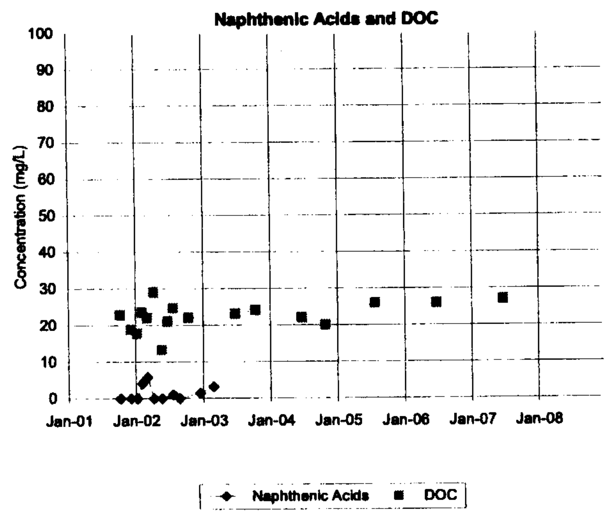




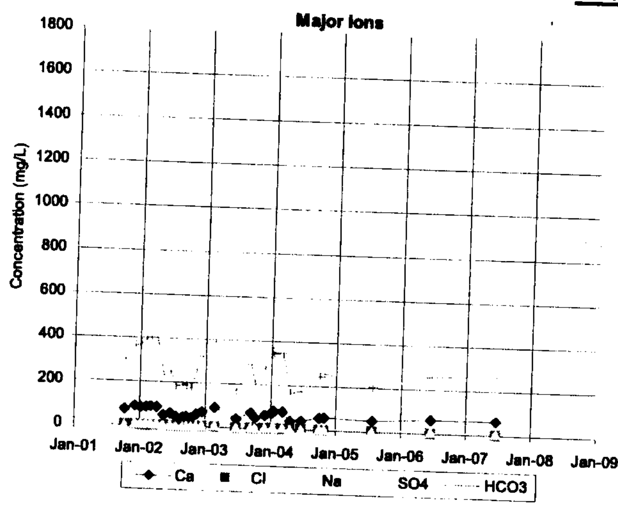
MR6350775

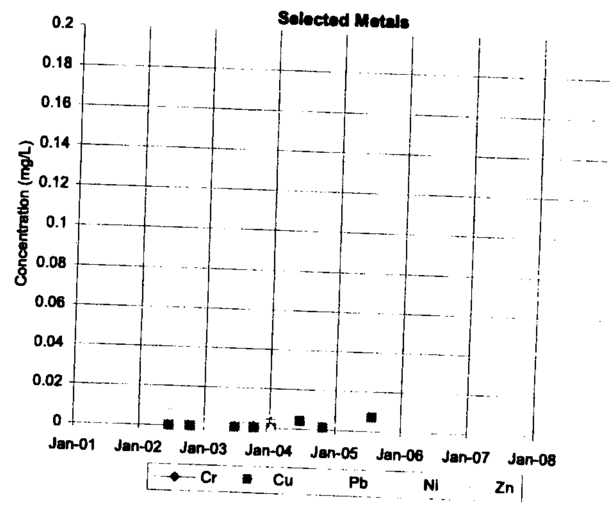

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Ca
Cl
Na
SO4
HCO3

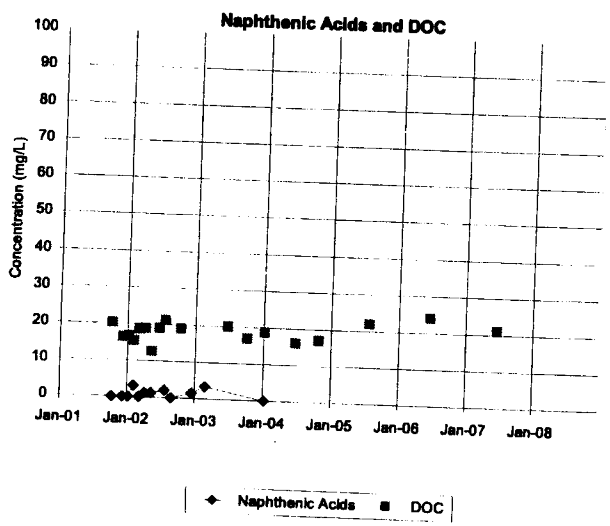

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Cr
Cu
Pb
Ni
Zn


Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Naphthenic Acids
DOC

MR6351800

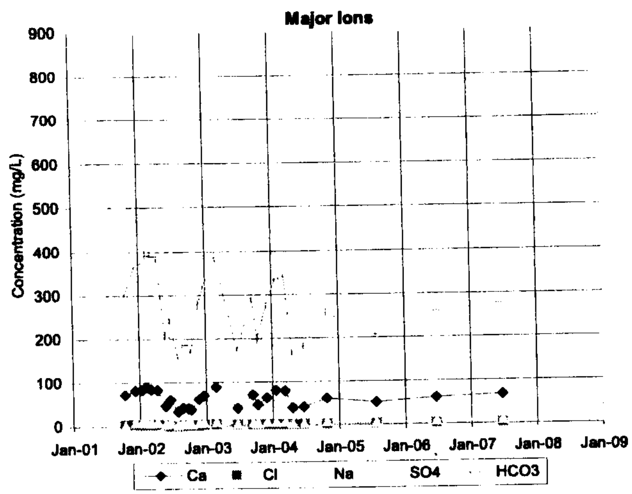

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Ca
Cl
Na
SO4
HCO3

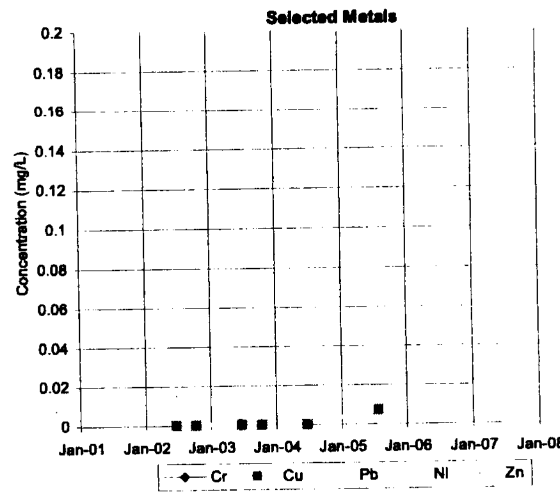

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Cr
Cu
Pb
Ni
Zn

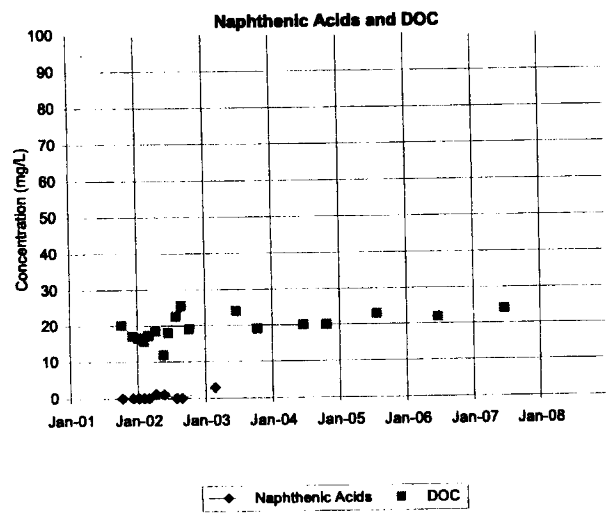

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Naphthenic Acids
DOC

Aurora – Surface Water Samples (Clean Water)

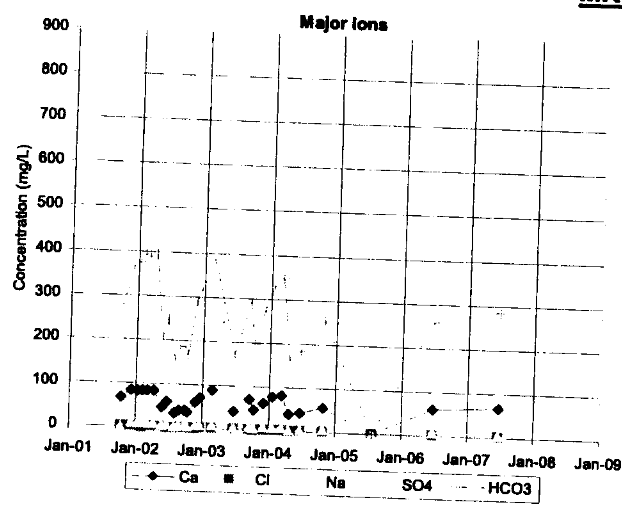
MR6352600

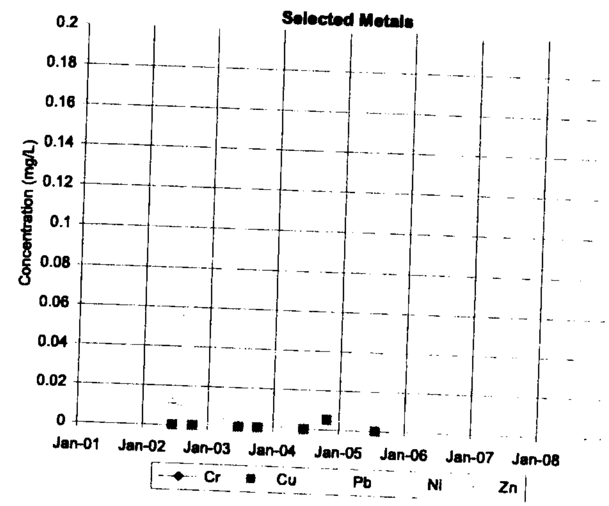


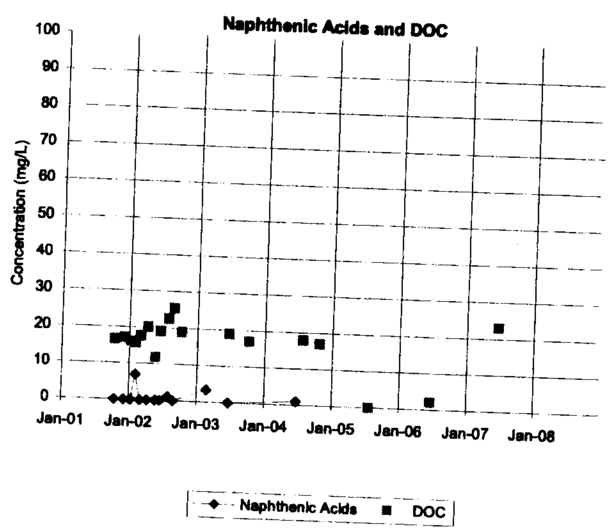




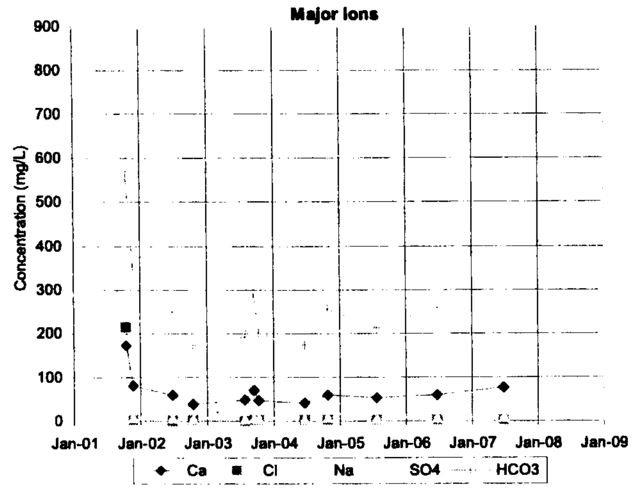
MR6353330

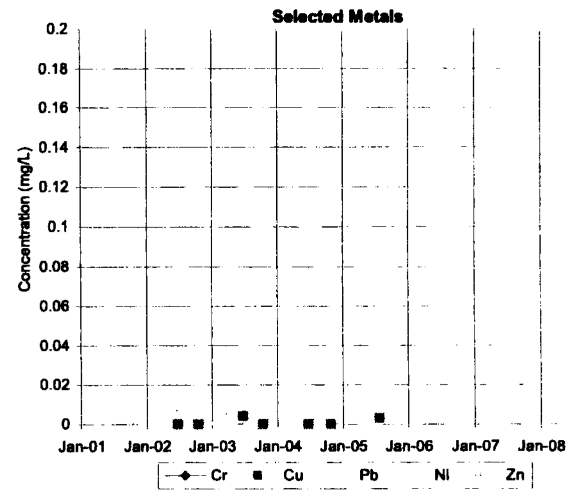

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Jan-09
Ca
Cl
Na
SO4
HCO3

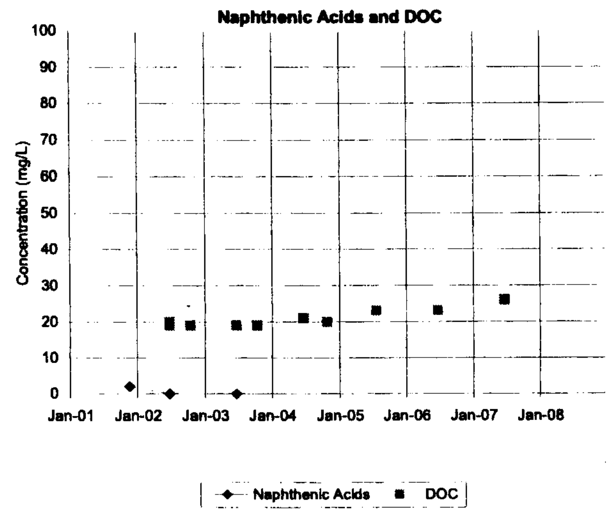

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn


Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-01
Jan-02
Jan-03
Jan-04
Jan-05
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

MRT6352090

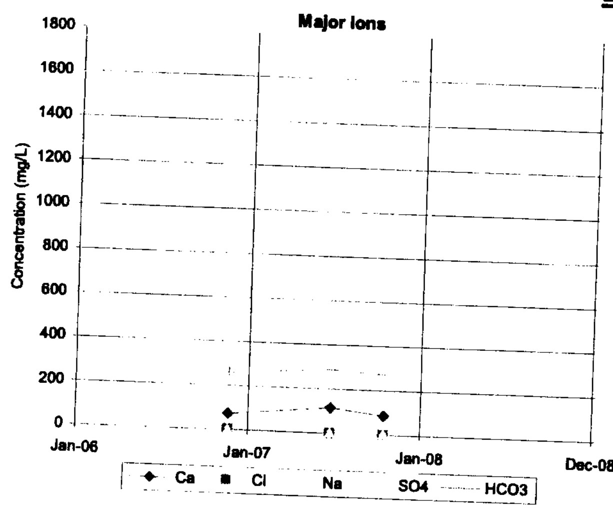

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08 Jan-09
Ca Cl Na SO4 HCO3

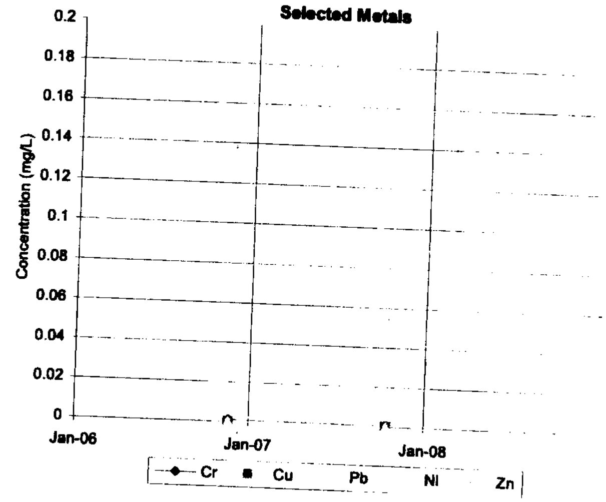

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Cr Cu Pb Ni Zn

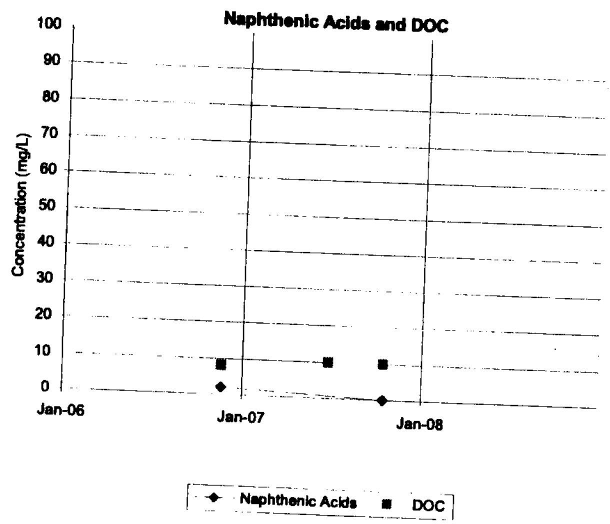

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-01 Jan-02 Jan-03 Jan-04 Jan-05 Jan-06 Jan-07 Jan-08
Naphthenic Acids DOC

Aurora – Surface Water Samples (Clean Water)

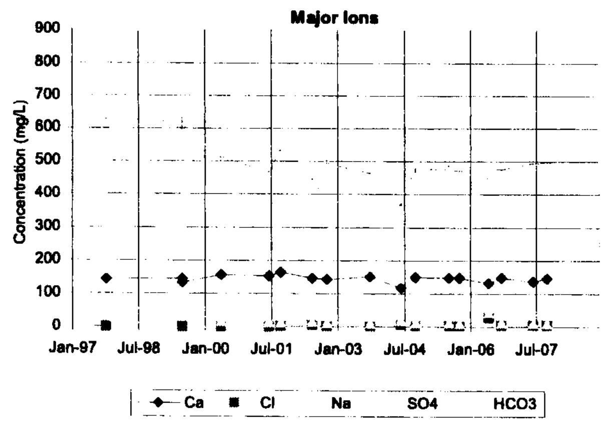
EPP-PP

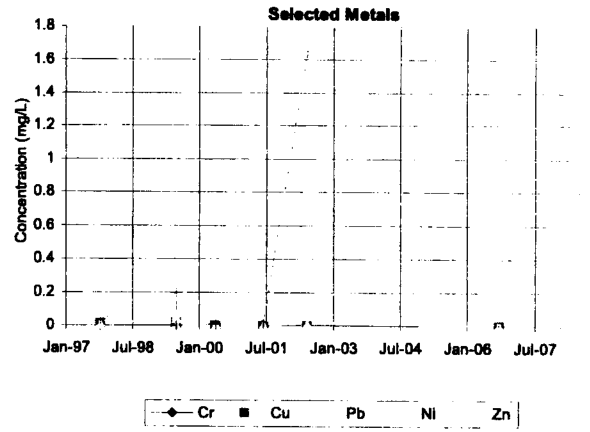


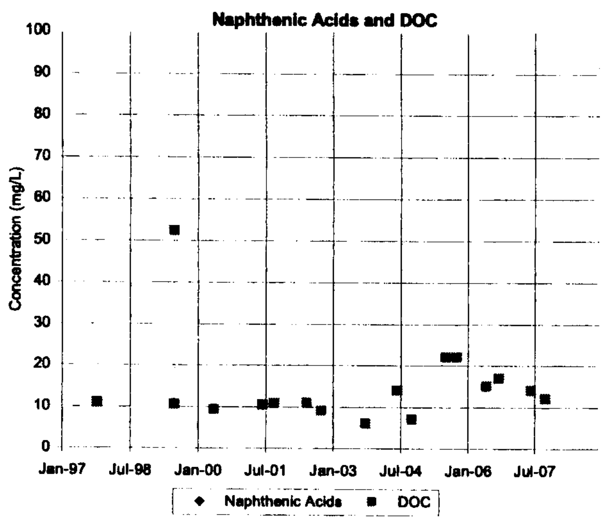


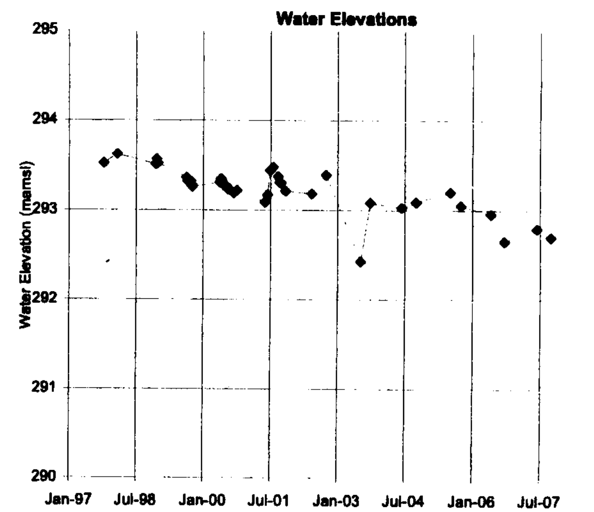


OWS9734015

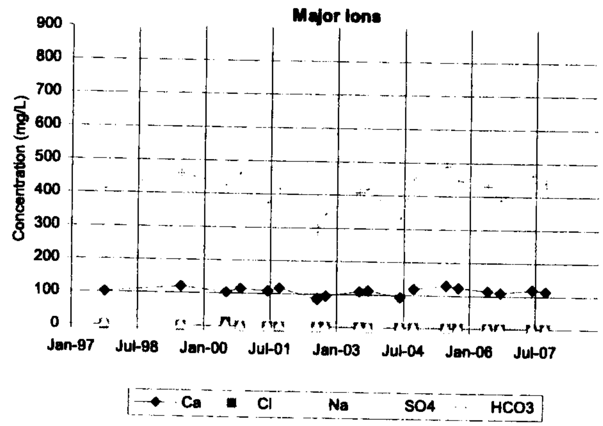

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

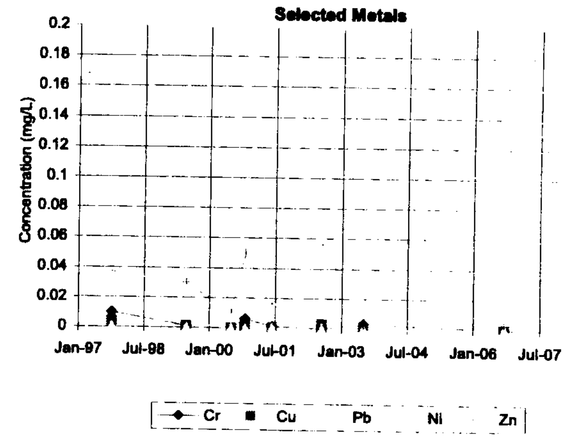

Selected Metals
Concentration (mg/L)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

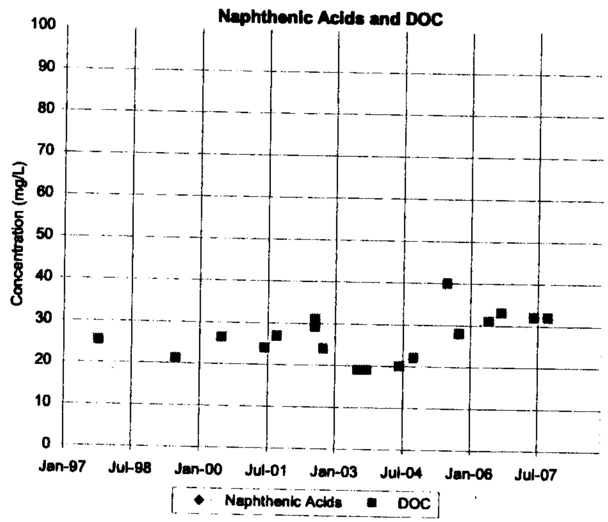

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

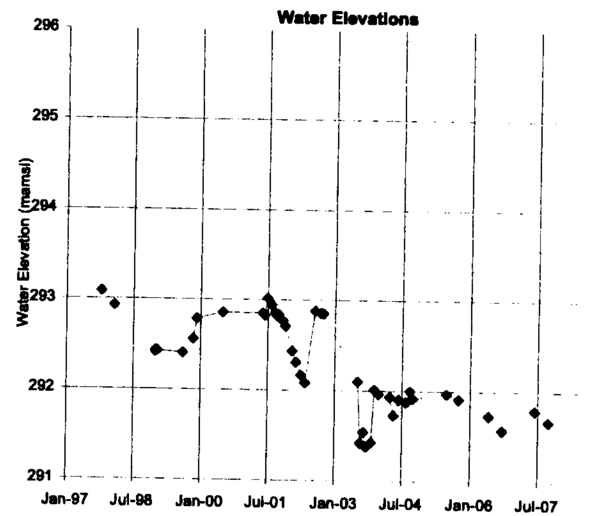

Water Elevations
Water Elevation (mamsl)
295
294
293
292
291
290
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS9734018


Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

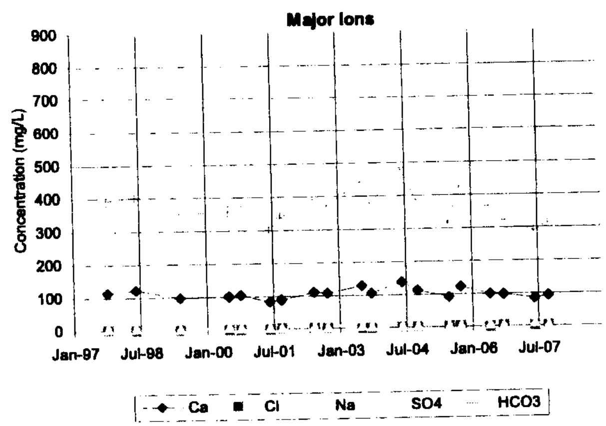

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

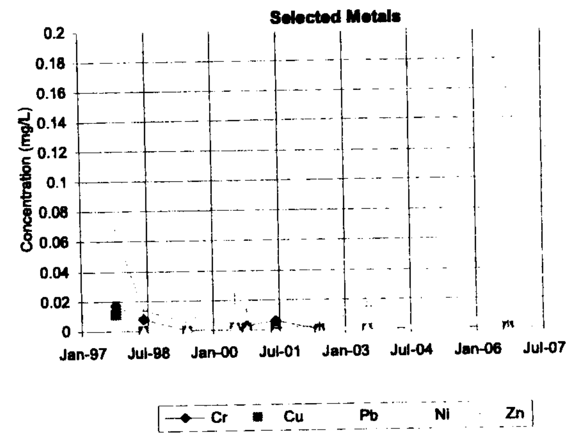

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

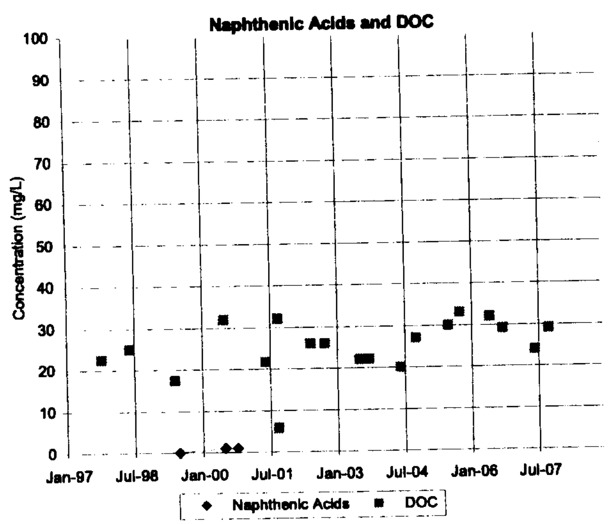

Water Elevations
Water Elevation (mamsl)
296
295
294
293
292
291
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

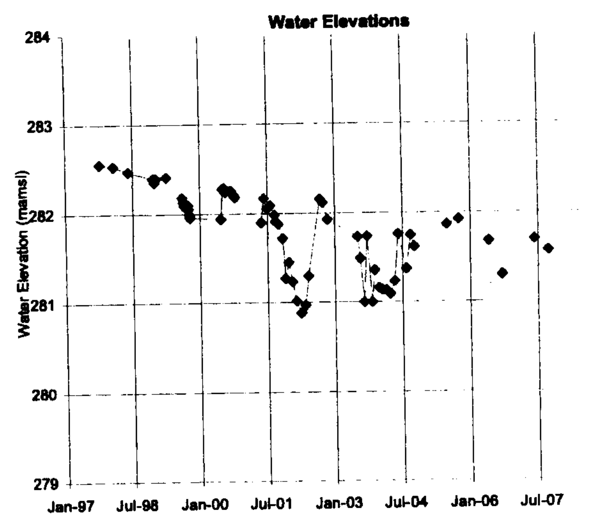
Aurora – Groundwater Monitoring Wells

OWS9734021

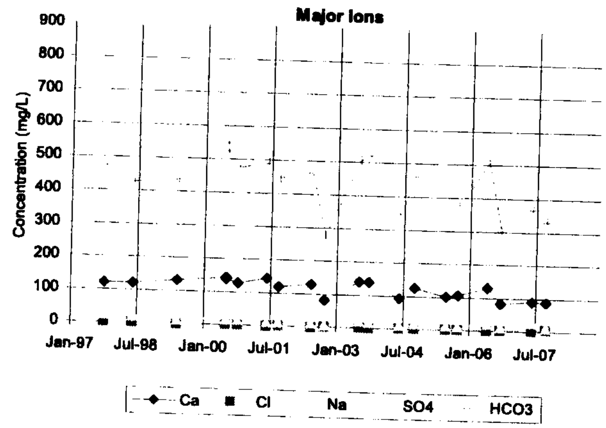


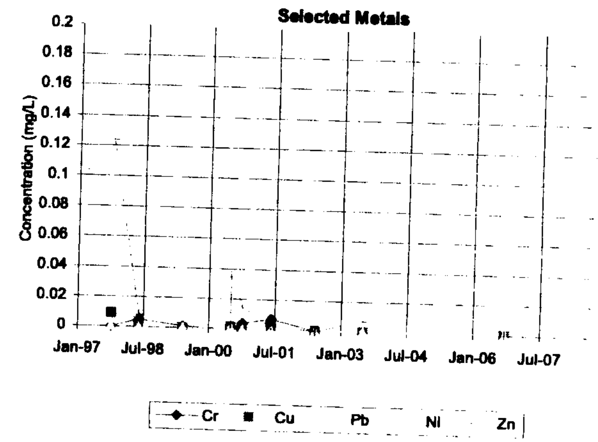


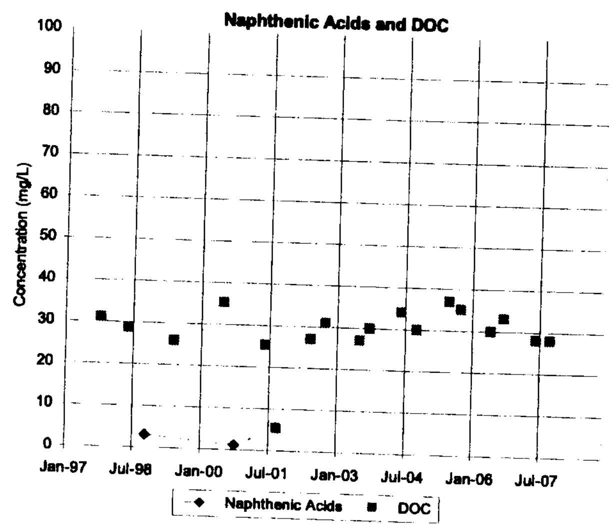


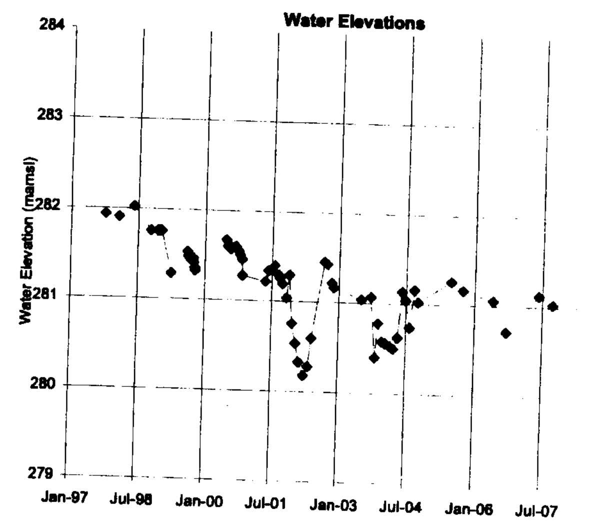


OWS9734022

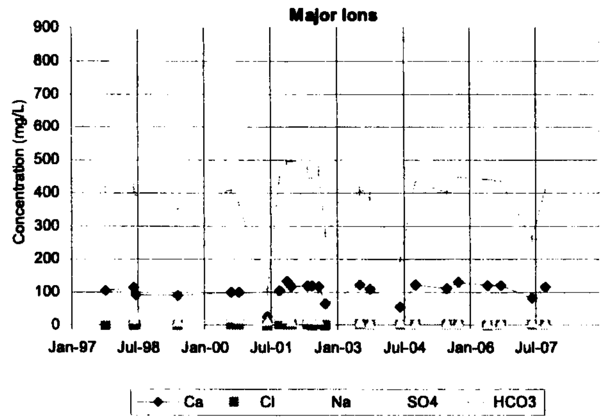

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

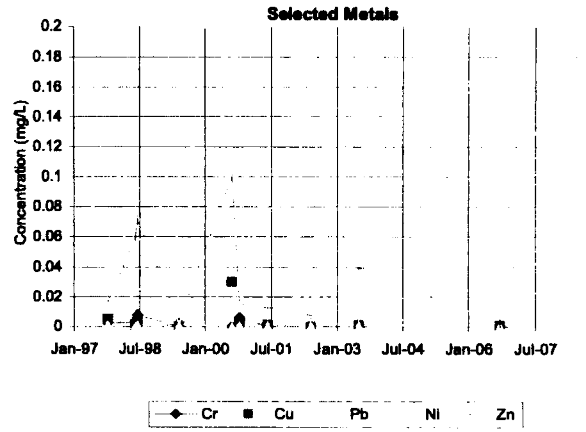

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

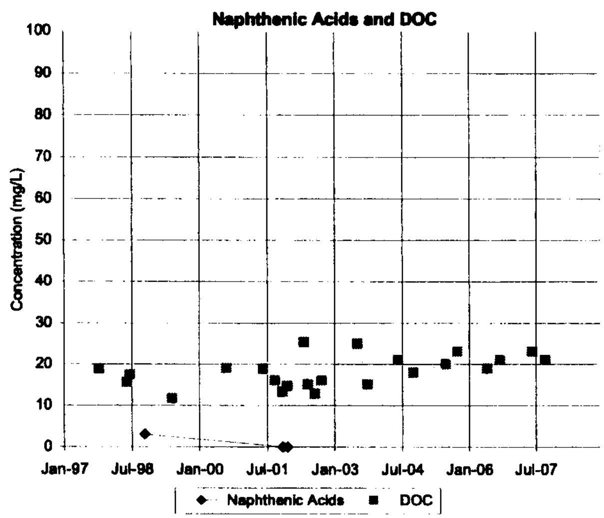

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

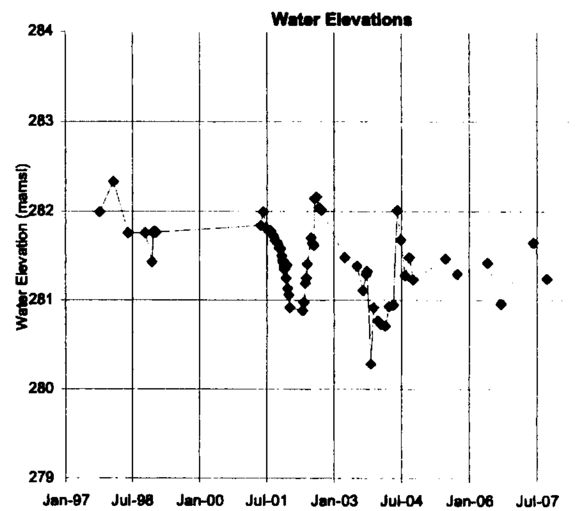

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS9734023

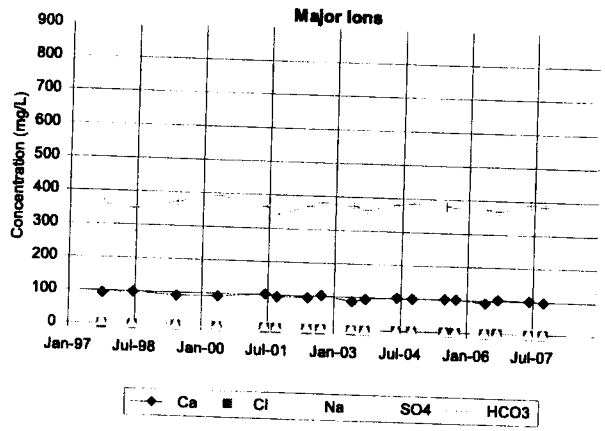

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

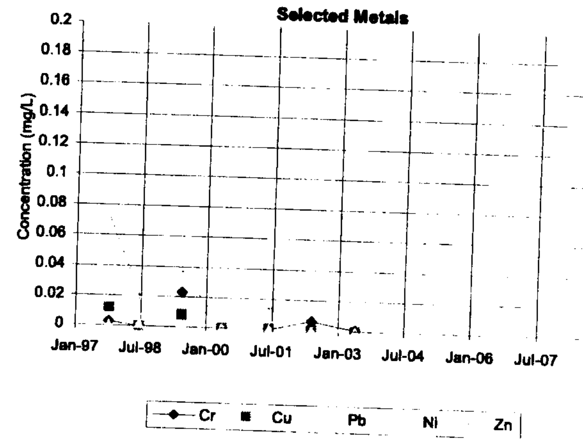

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

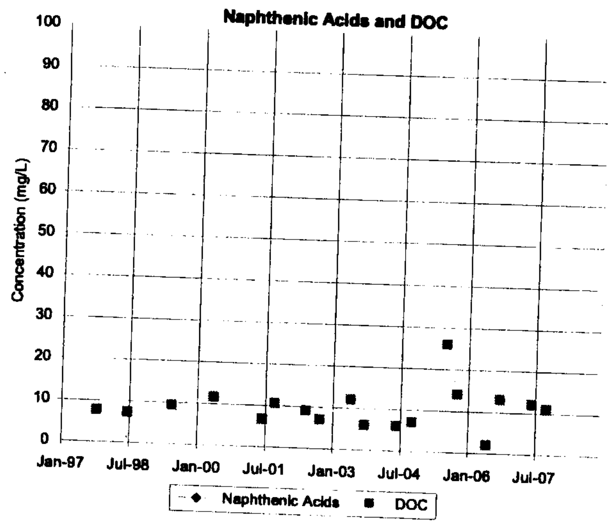

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

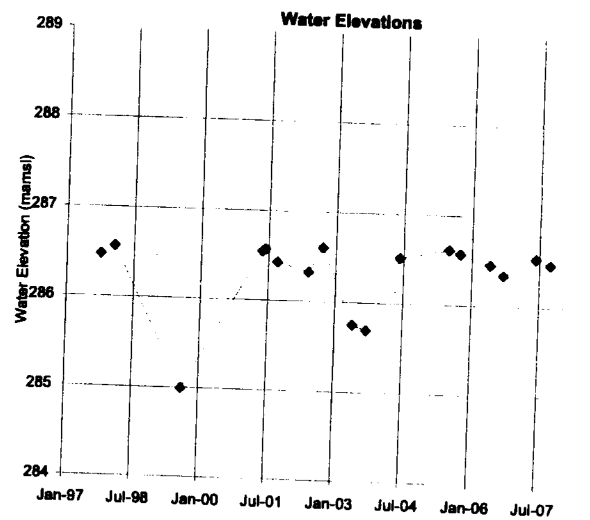

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS9710026

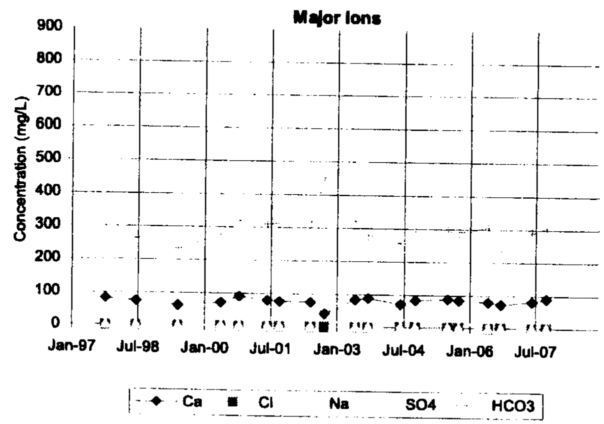

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

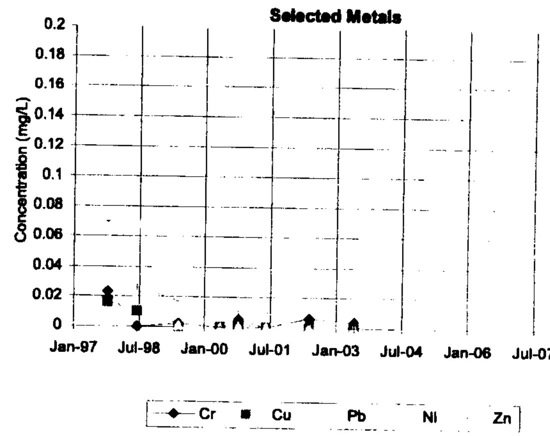

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

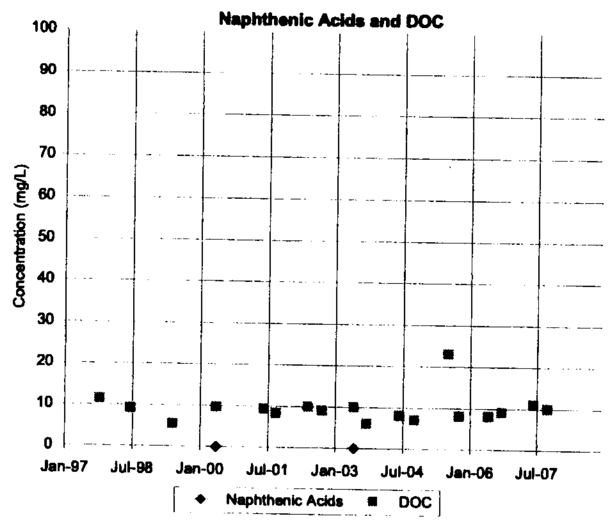

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

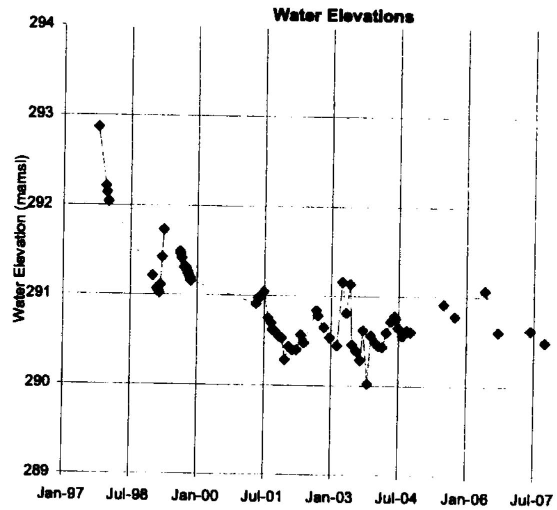

Water Elevations
Water Elevation (mamsl)
289
288
287
286
285
284
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS9710027

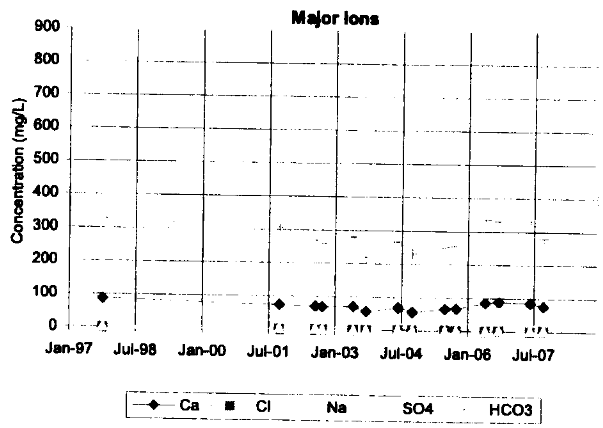

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

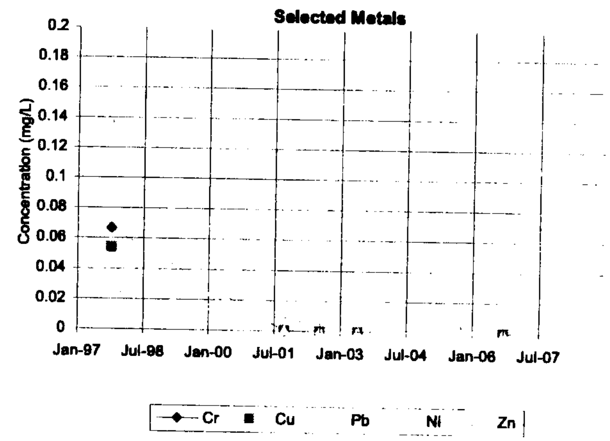

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

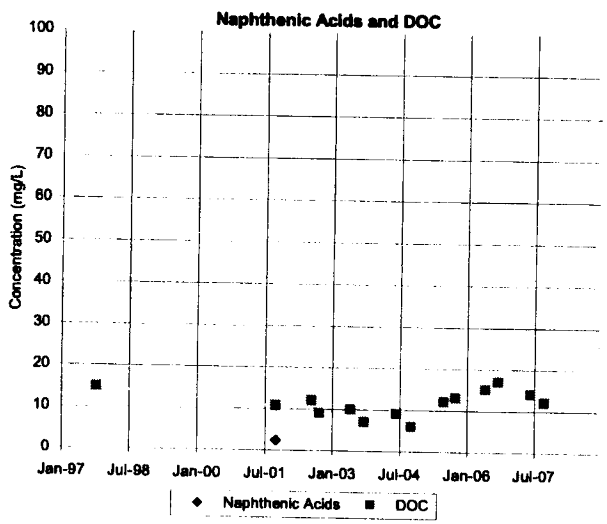

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

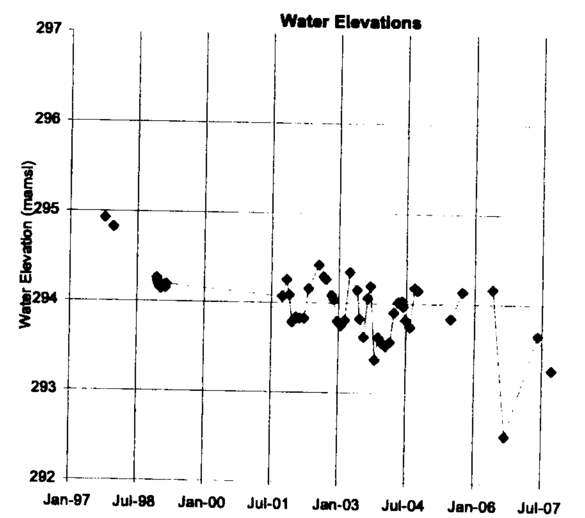

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS9710028


Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

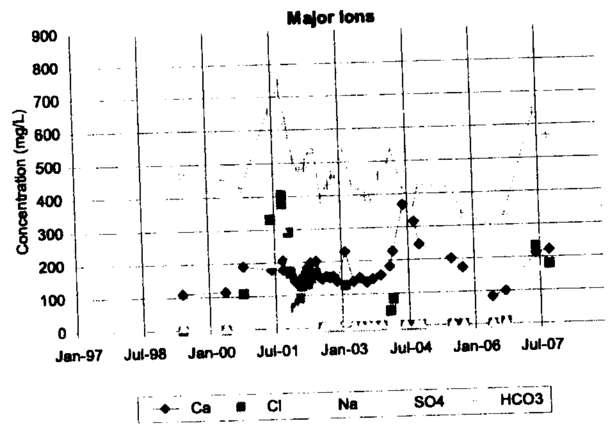

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

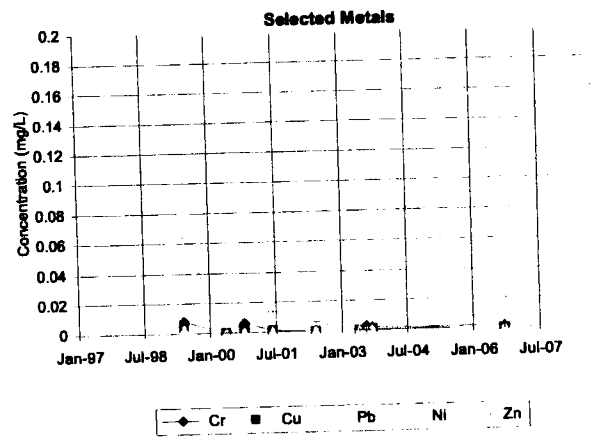

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

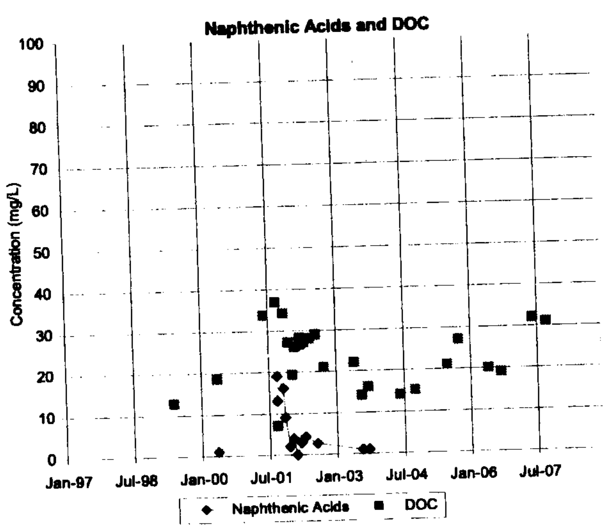

Water Elevations
Water Elevation (mamsl)
297
296
295
294
293
292
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

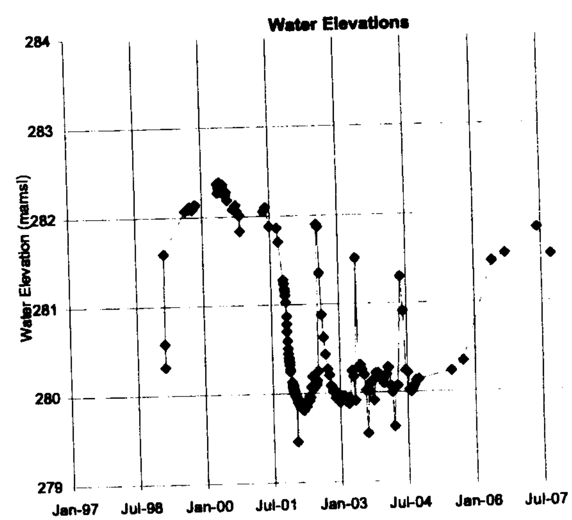
Aurora – Groundwater Monitoring Wells

OWS9934761

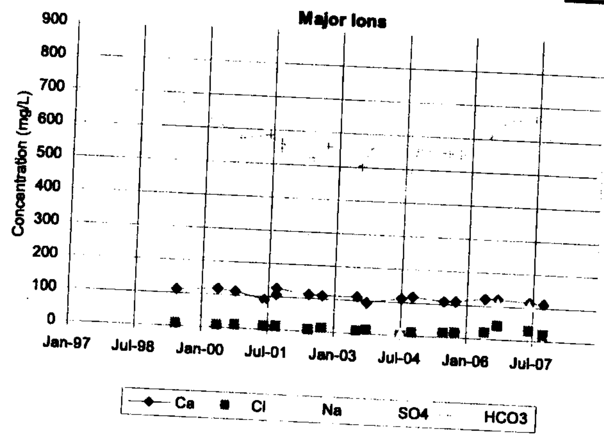


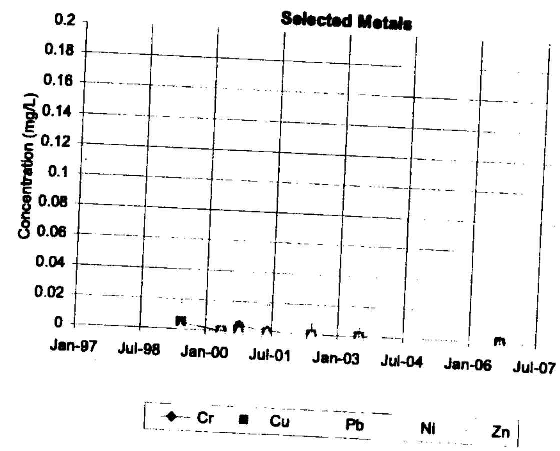


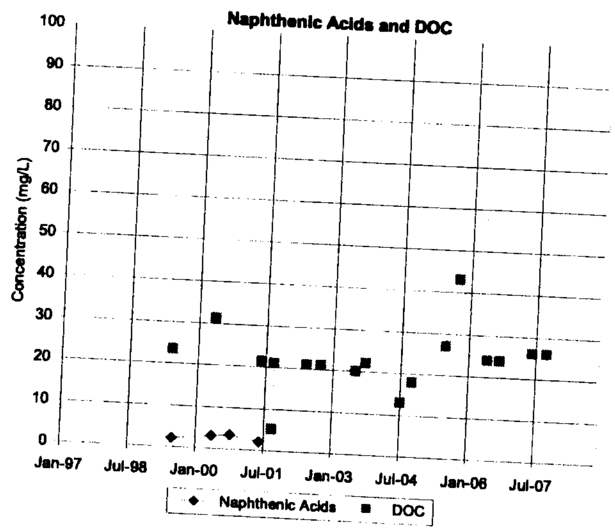


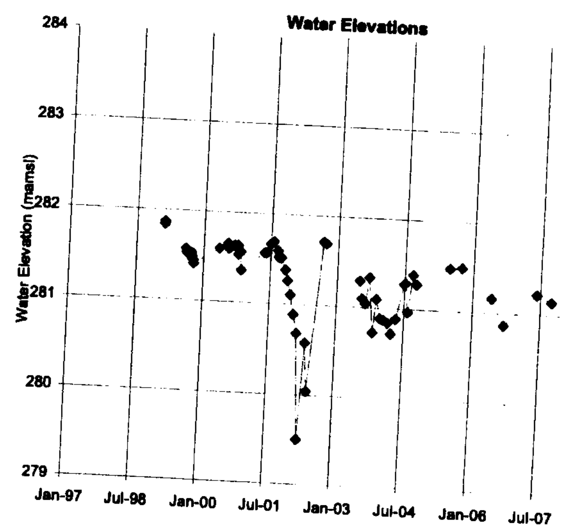


OWS9934762


Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

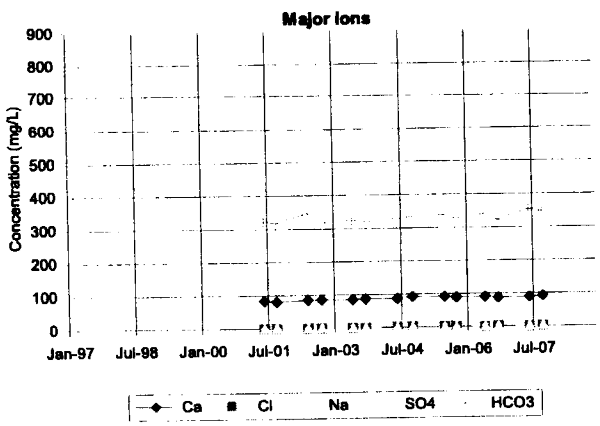

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

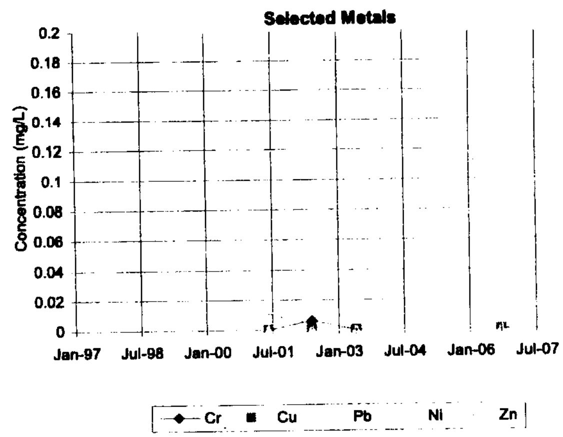

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

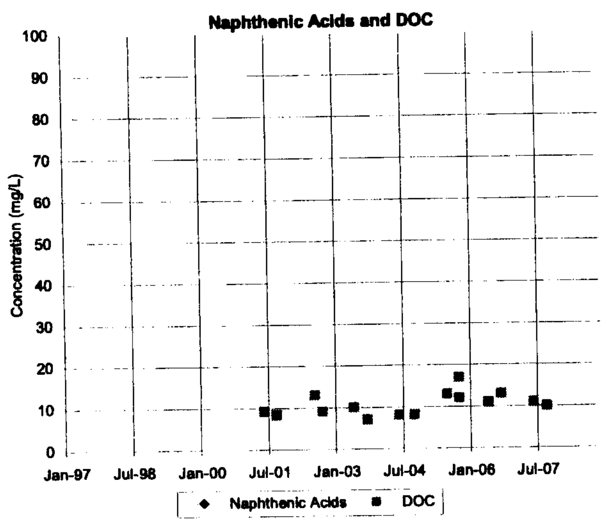

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

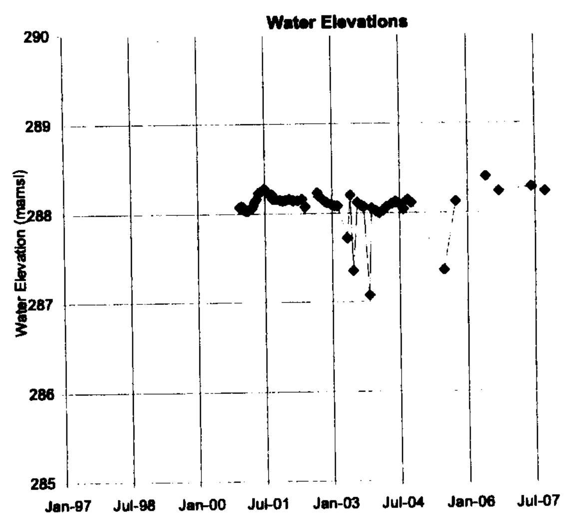
Aurora – Groundwater Monitoring Wells

OWS0010765

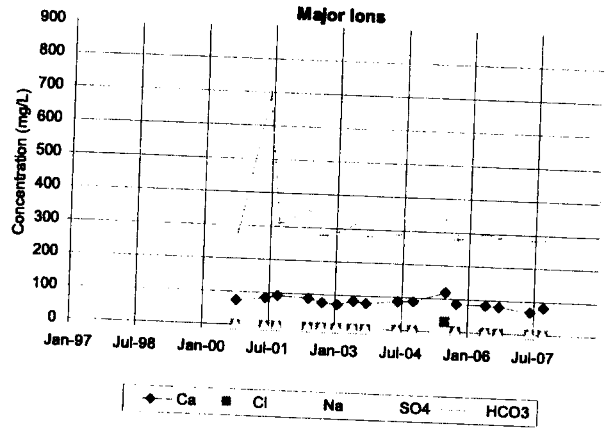


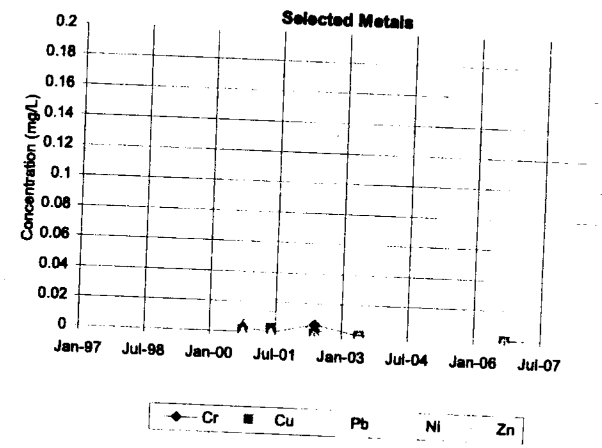


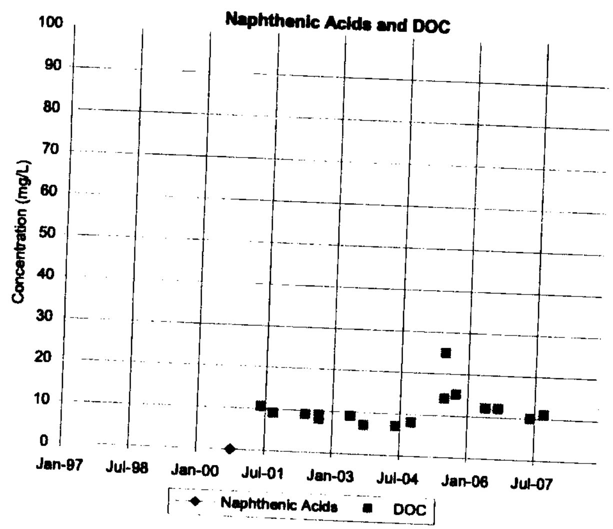


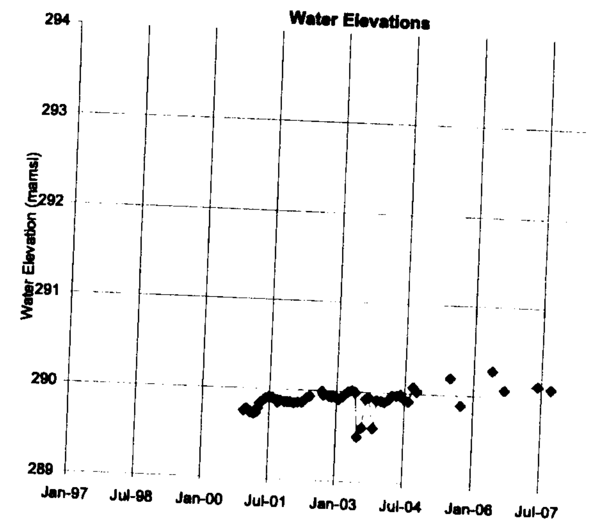


OWS0010766

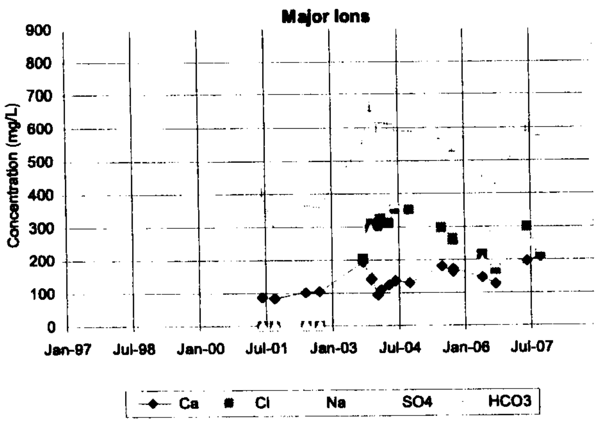

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca
Cl
Na
SO4
HCO3

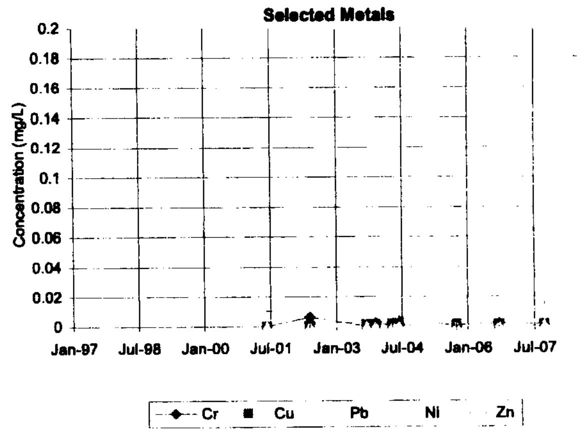

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr
Cu
Pb
Ni
Zn

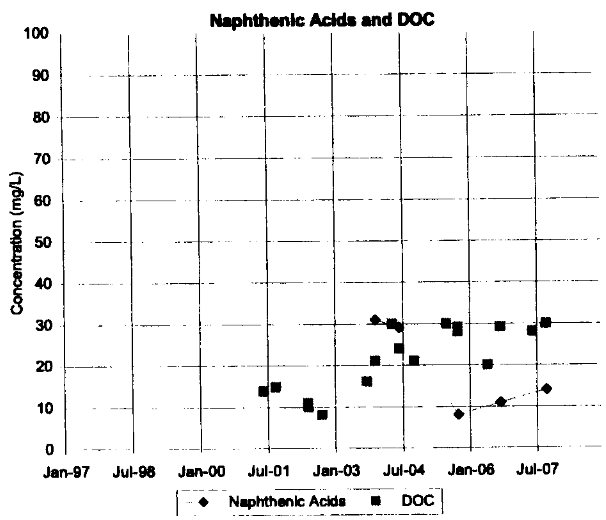

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids
DOC

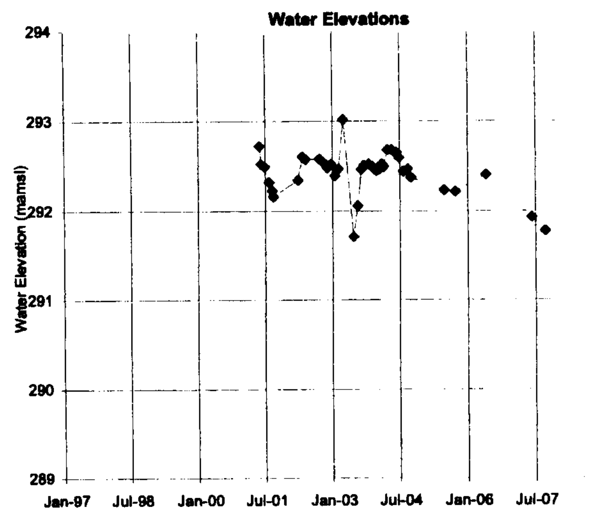

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0110-01

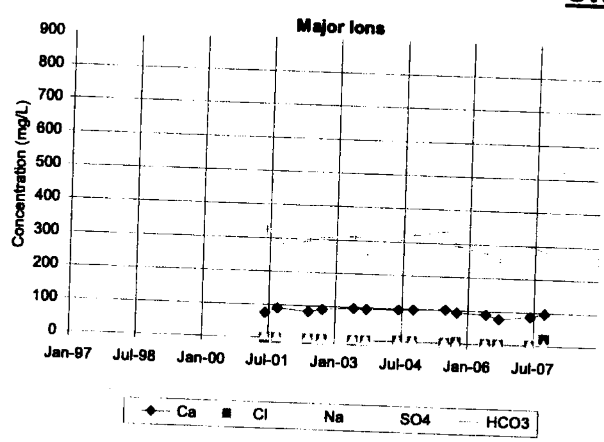

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

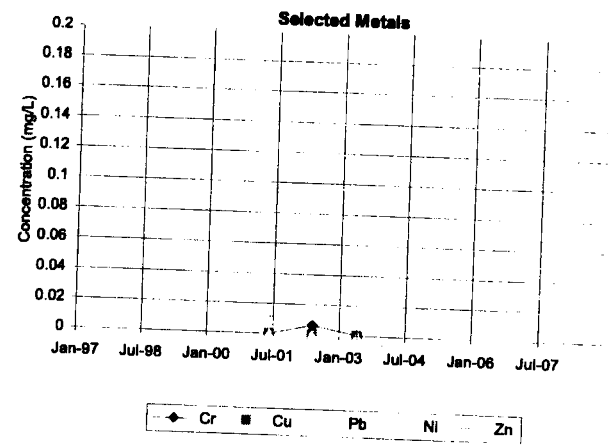

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

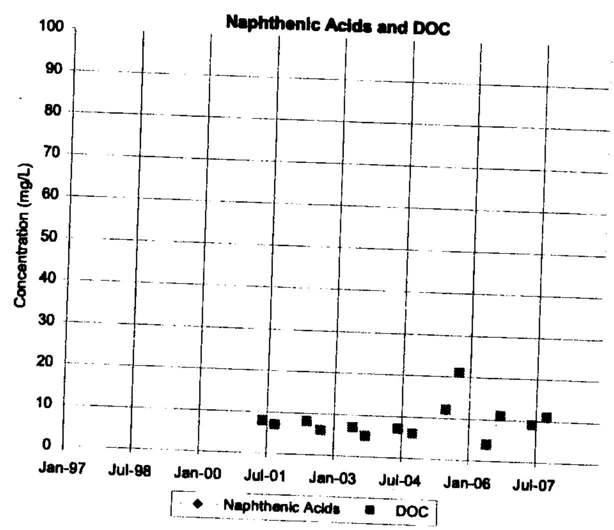

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

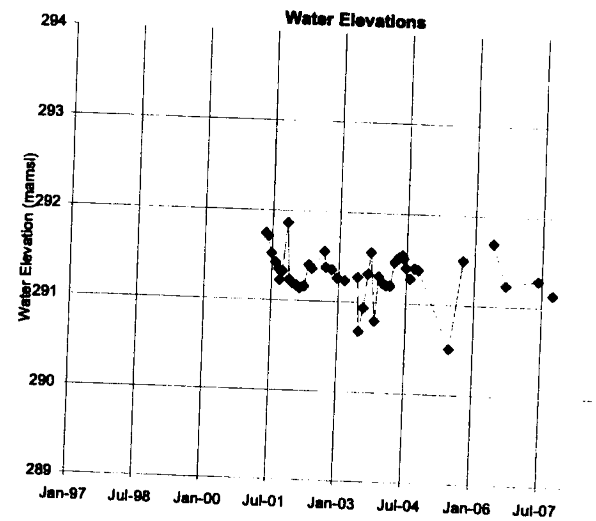

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0110-02

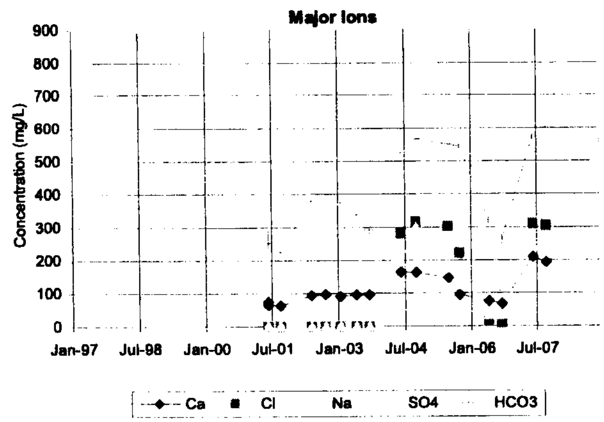

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

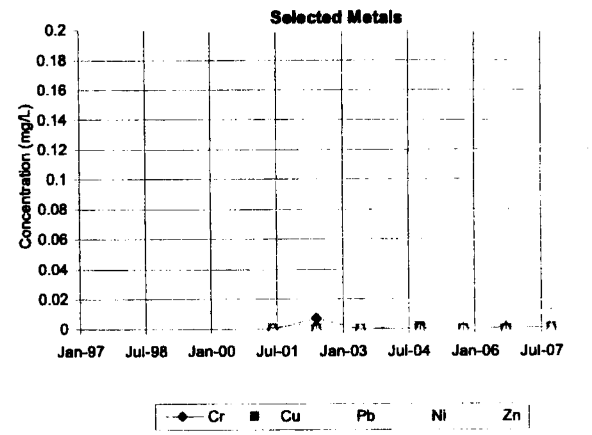

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

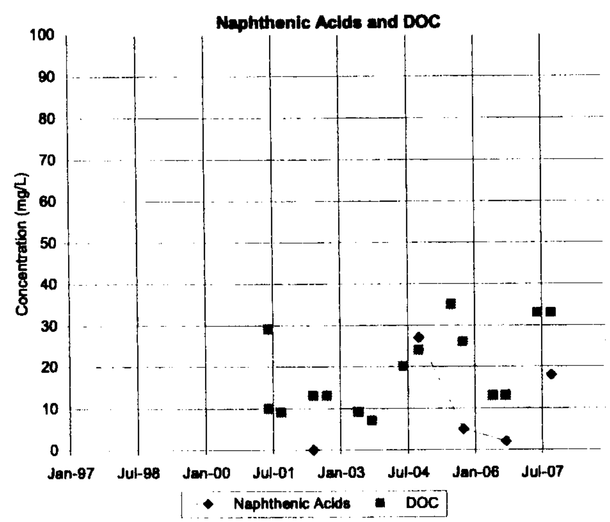

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

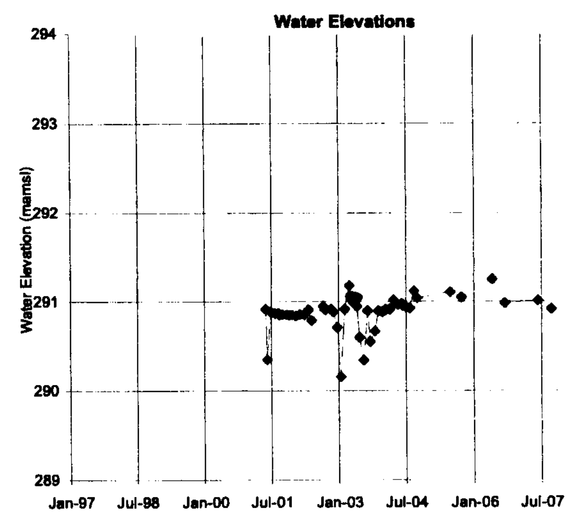

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0110-03

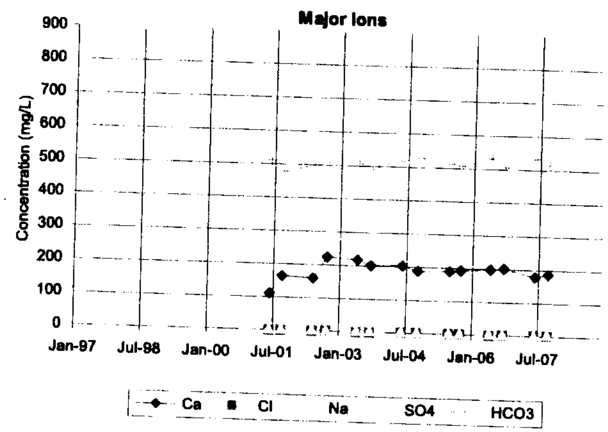

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

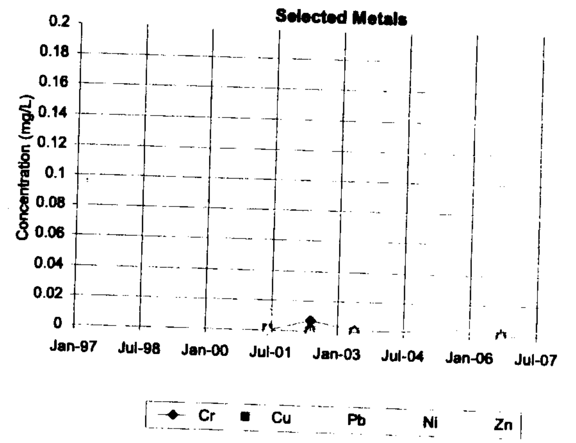

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

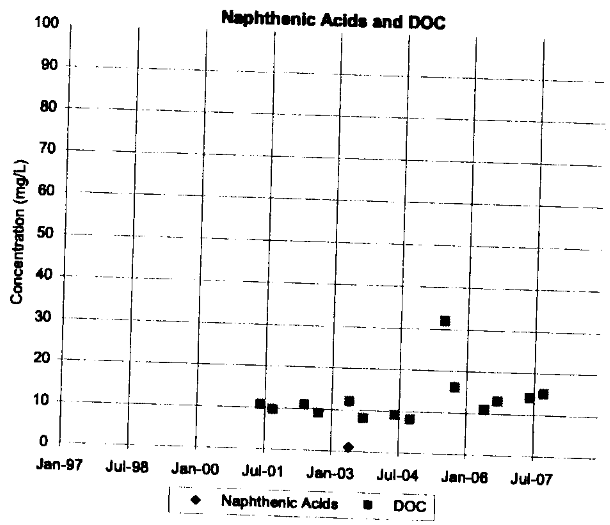

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

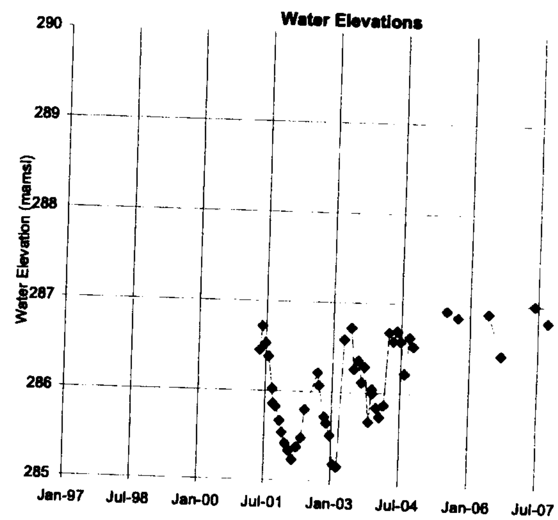

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0110-04


Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

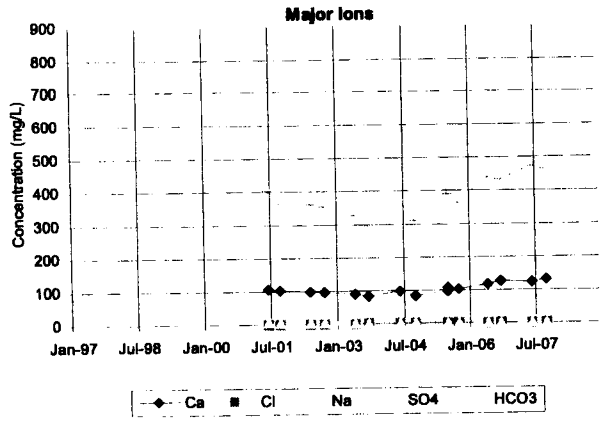

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

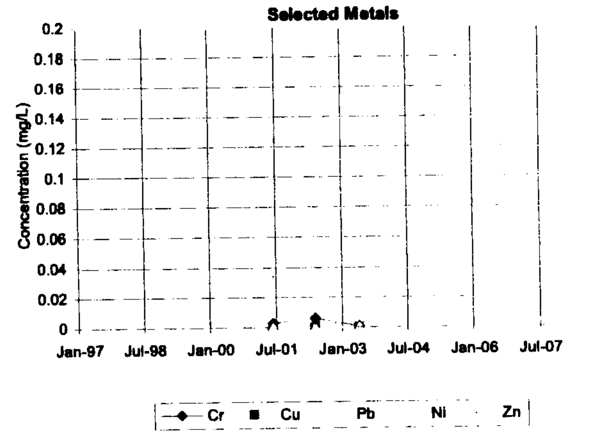

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

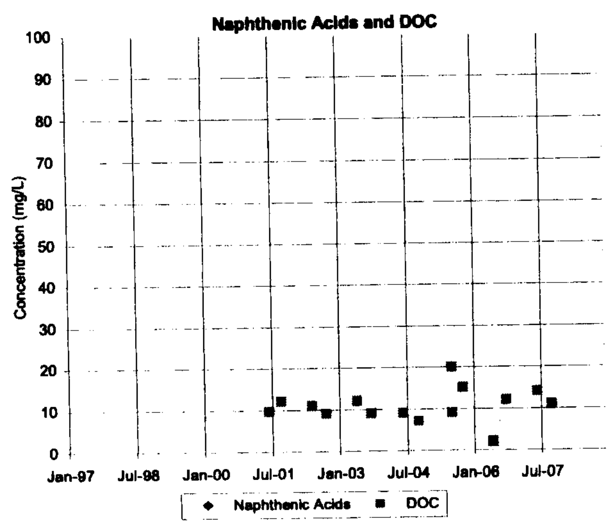

Water Elevations
Water Elevation (mamsl)
290
289
288
287
286
285
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

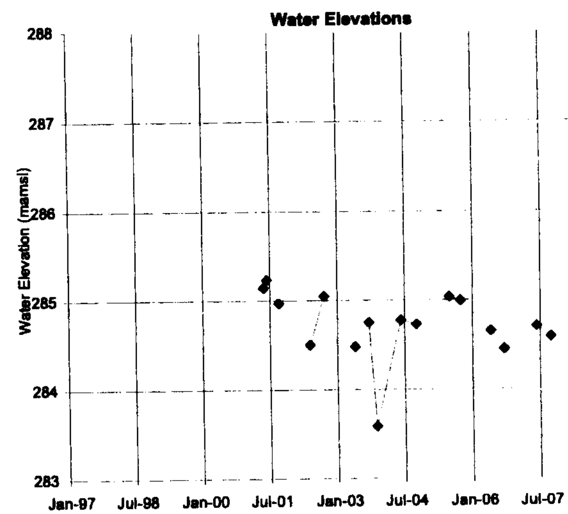
Aurora – Groundwater Monitoring Wells

OWS0134-05

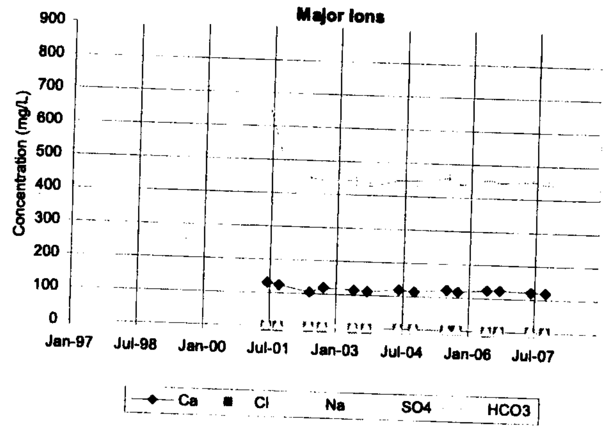


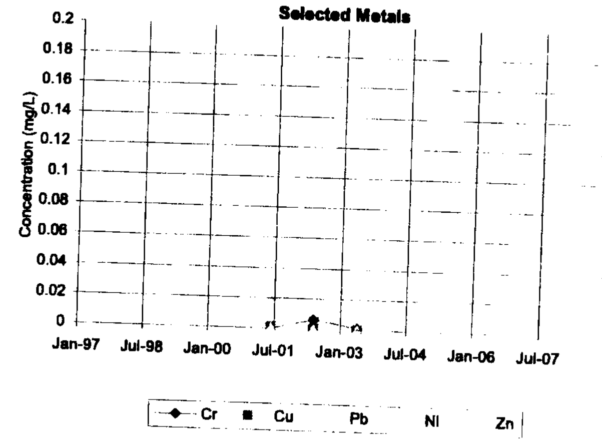


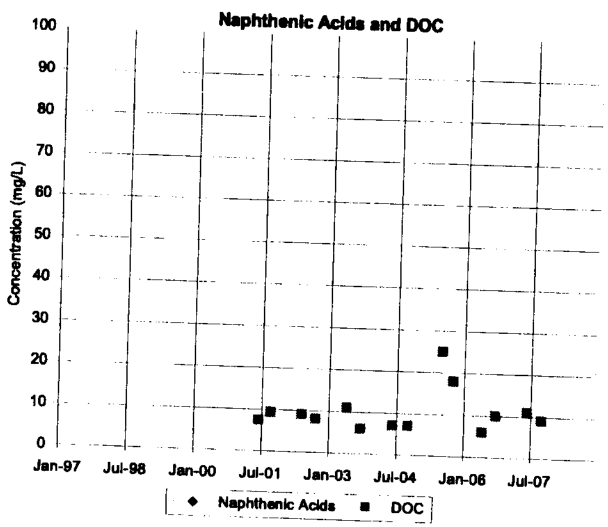


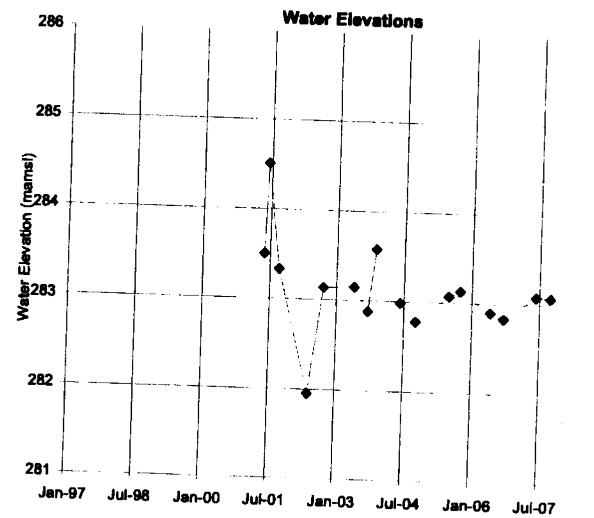


OWS0134-06

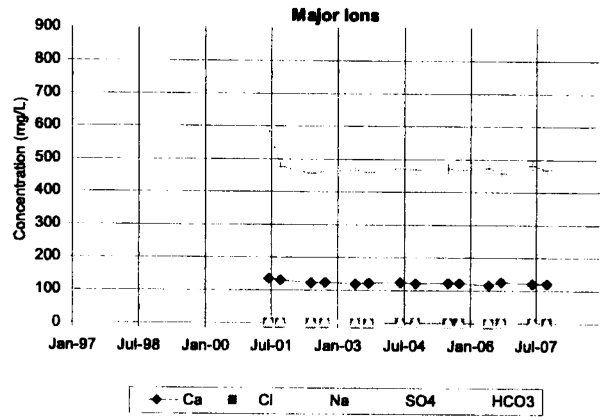

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

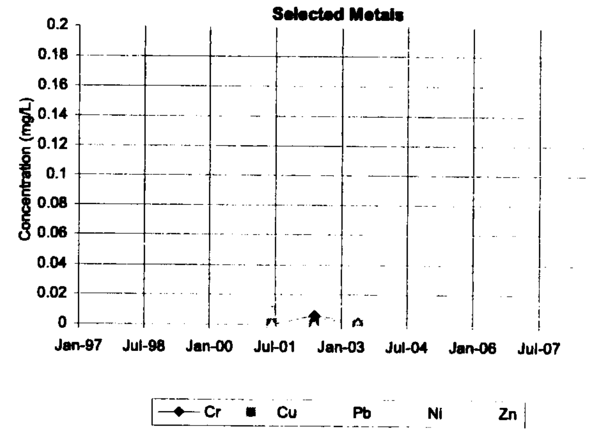

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

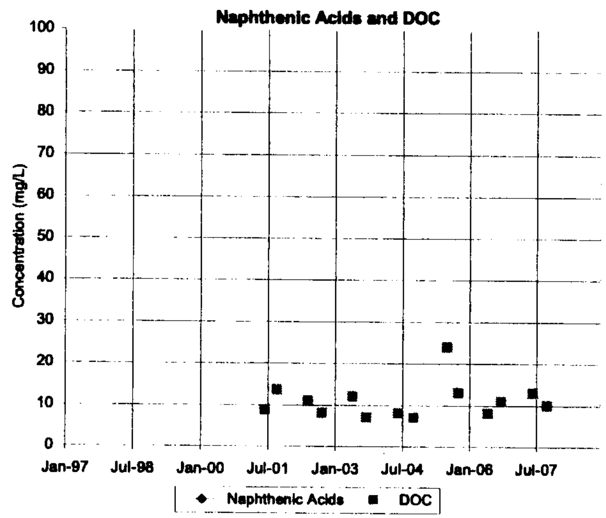

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

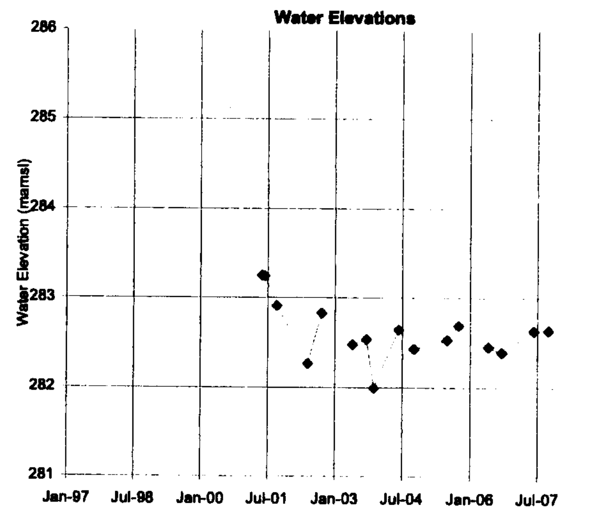

Water Elevations
Water Elevation (mamsl)
286
285
284
283
282
281
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0134-07

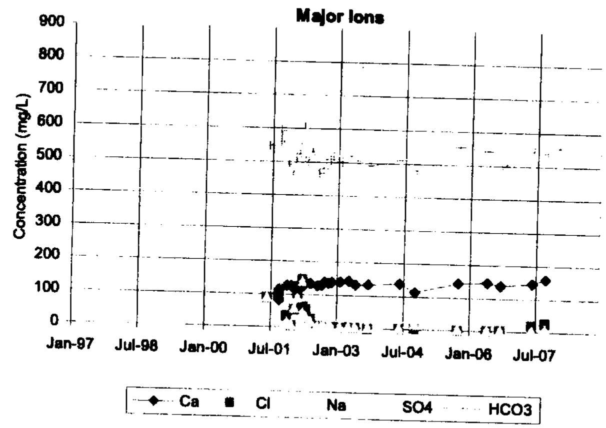

Major Ions
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

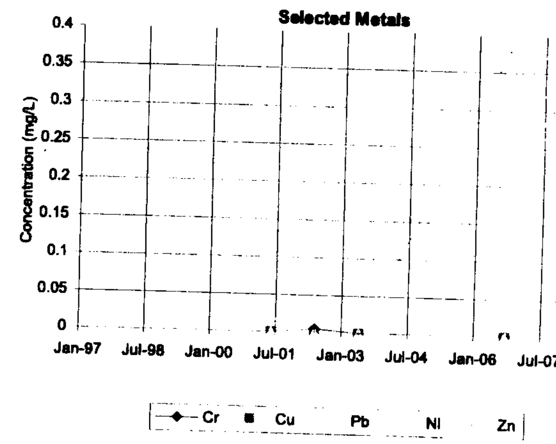

Selected Metals
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

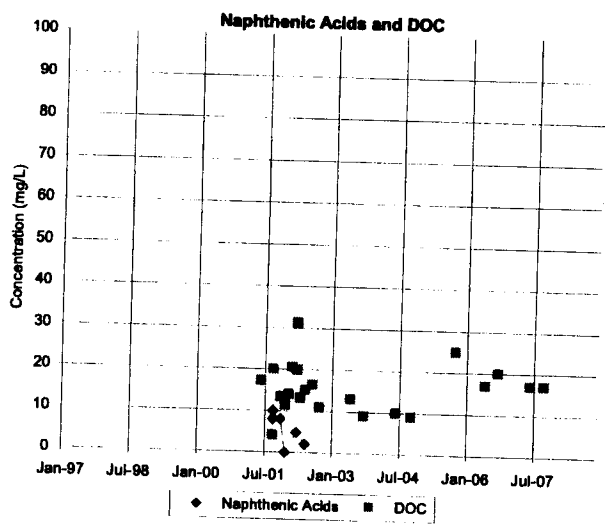

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

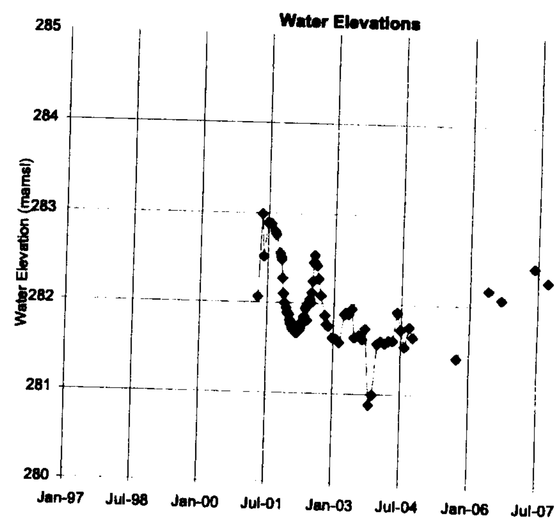

Water Elevations
286
285
284
283
282
281
Water Elevation (mamsl)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0134-08

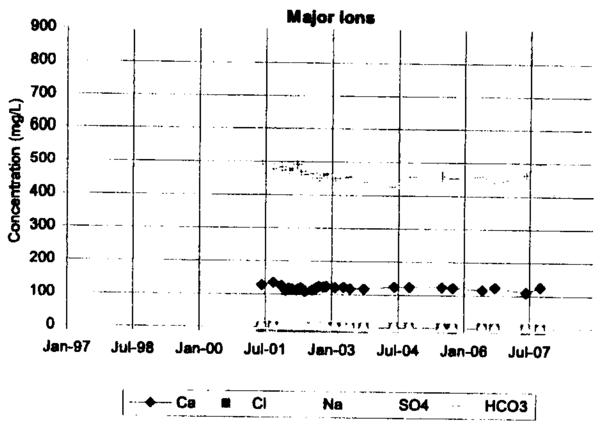

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

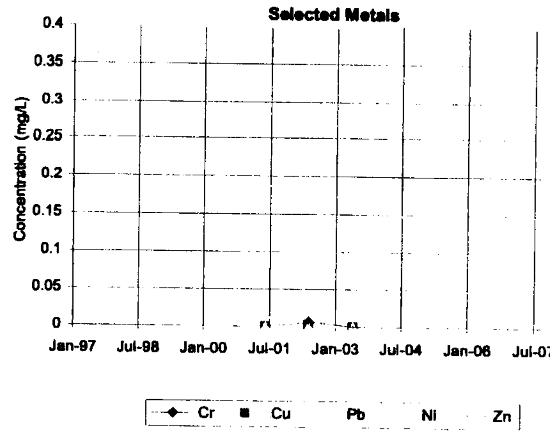

Selected Metals
Concentration (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

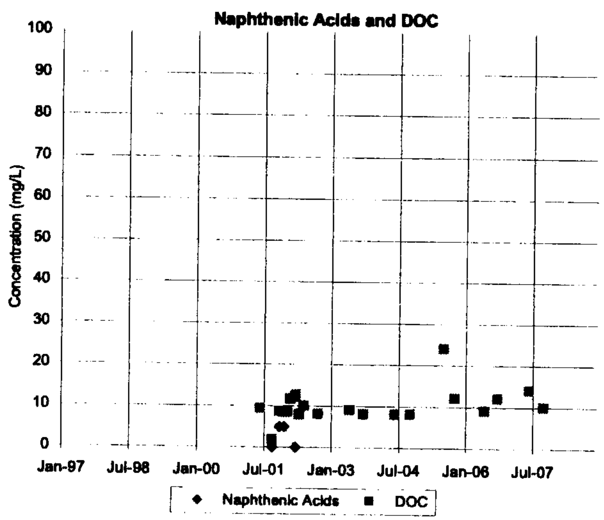

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

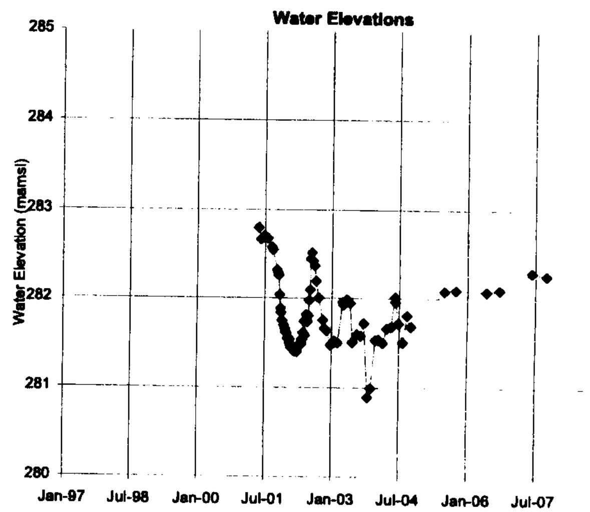

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0134-09

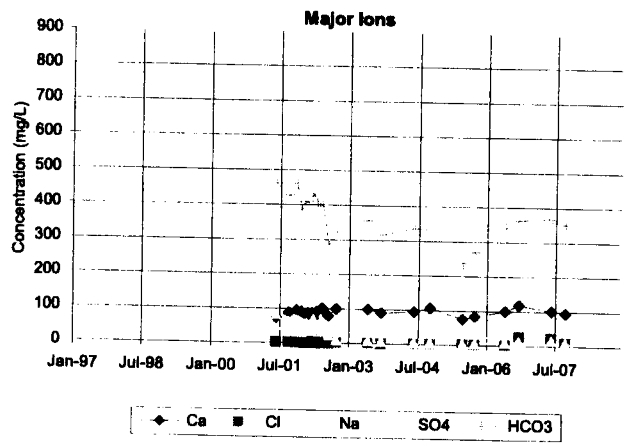

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

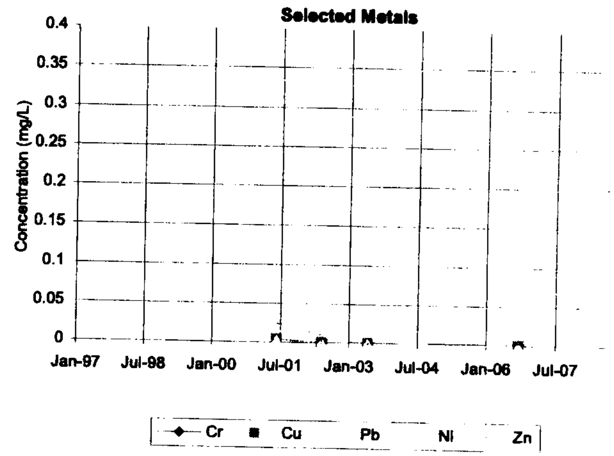

Selected Metals
Concentration (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

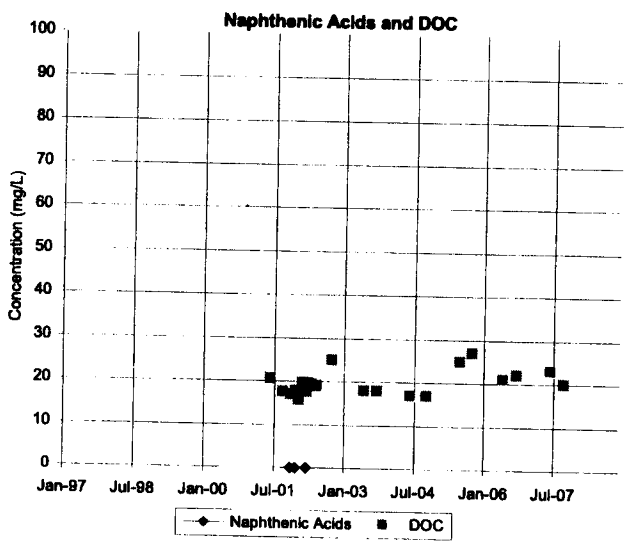

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

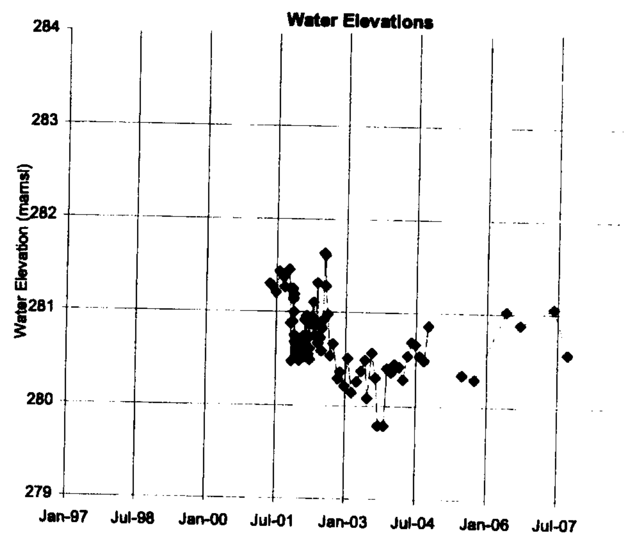

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0134-10

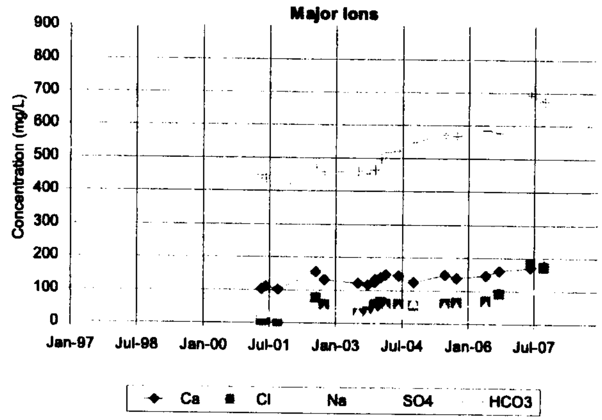

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

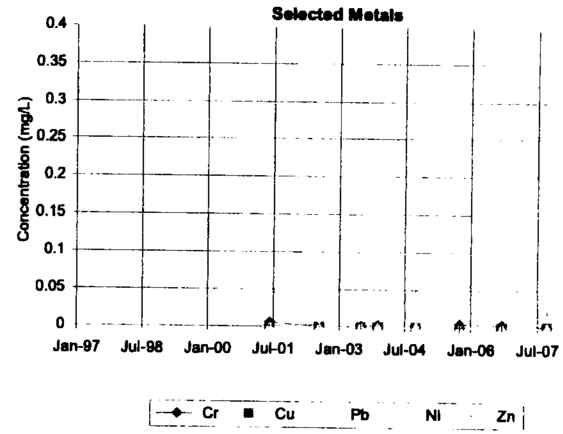

Selected Metals
Concentration (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

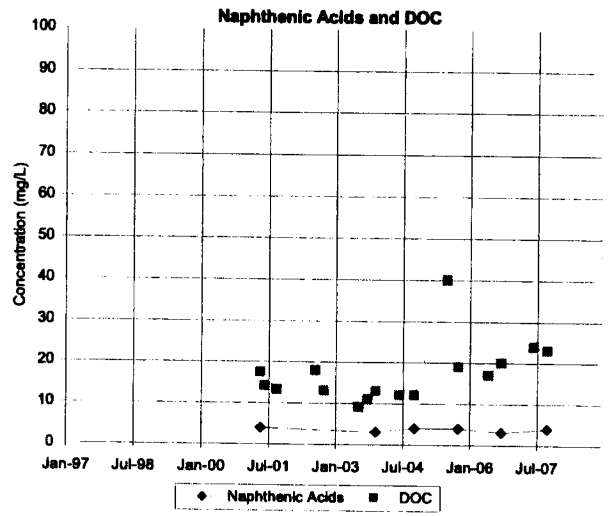

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

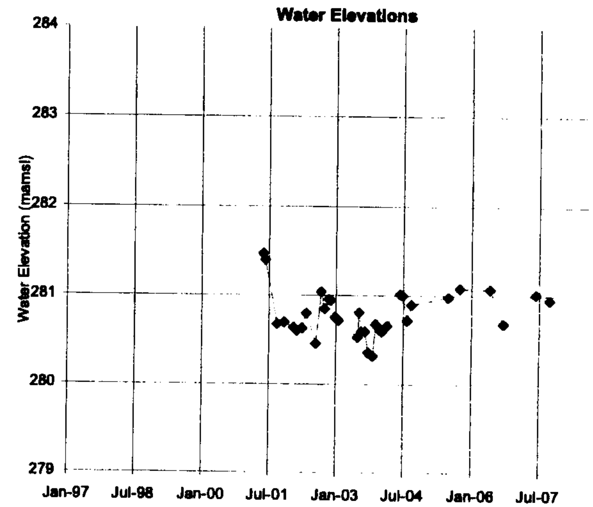

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0134-11

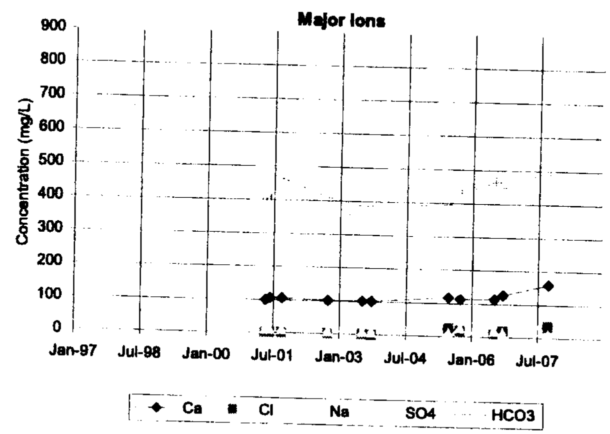

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

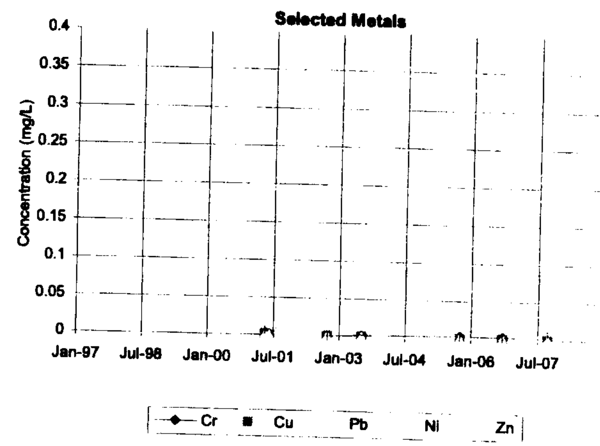

Selected Metals
Concentration (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

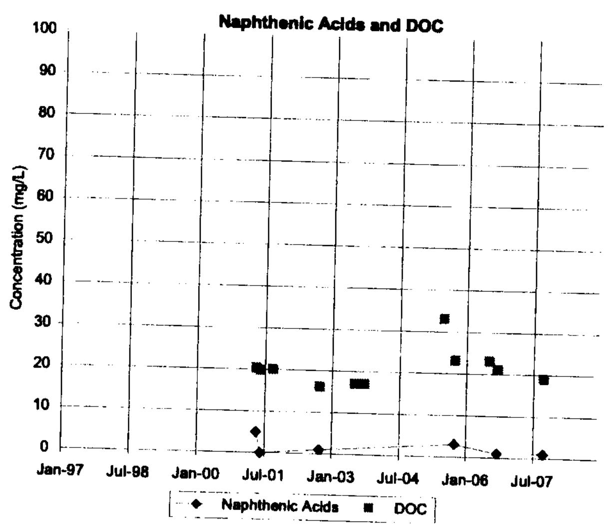

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

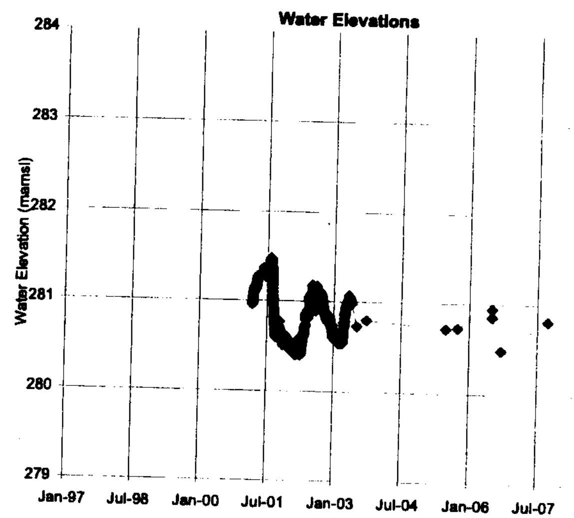

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0134-12

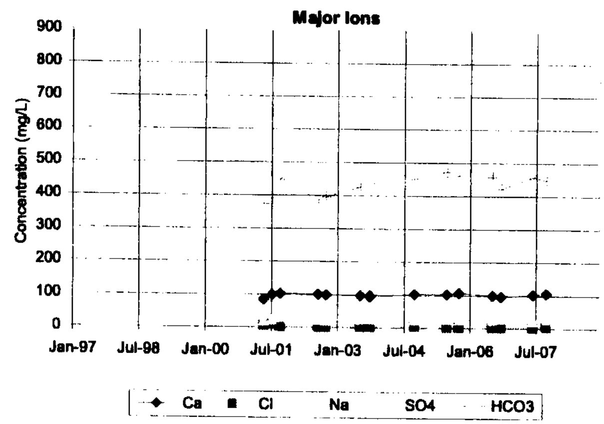

Major Ions
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

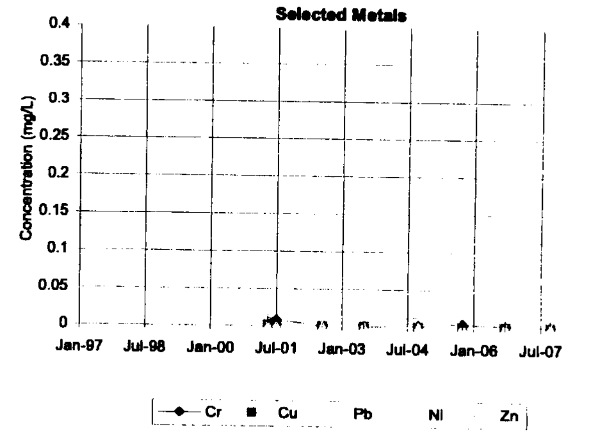

Selected Metals
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

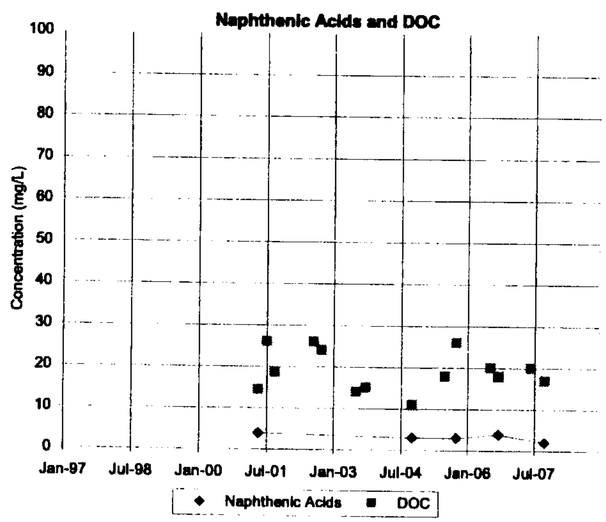

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

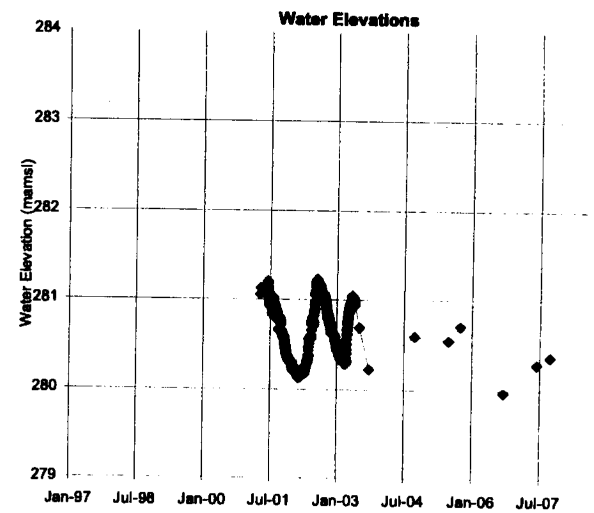

Water Elevations
284
283
282
281
280
279
Water Elevation (mamsl)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0134-13

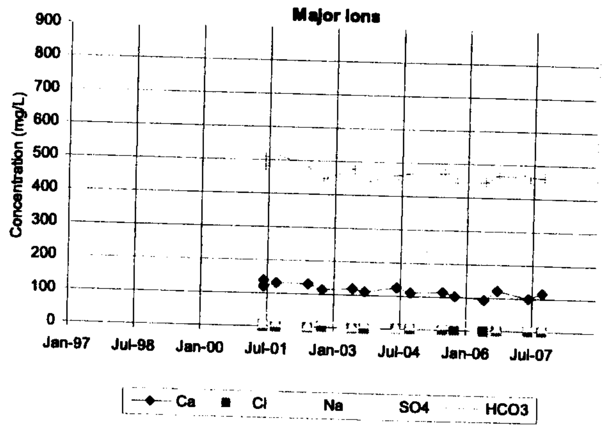

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

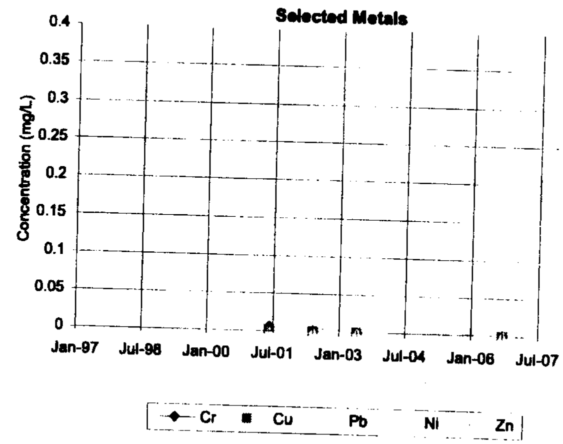

Selected Metals
Concentration (mg/L)
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

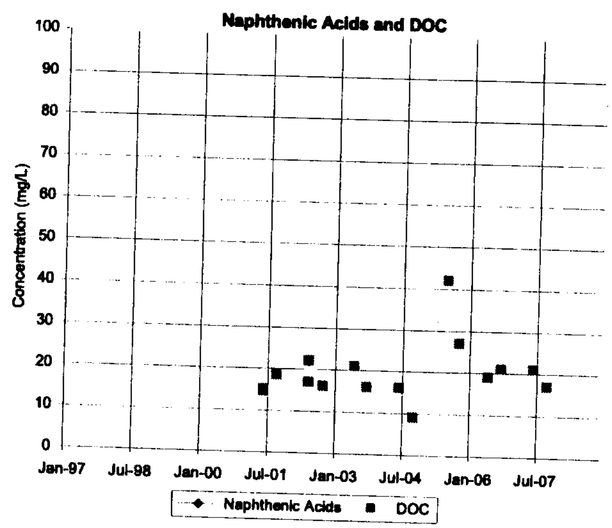

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

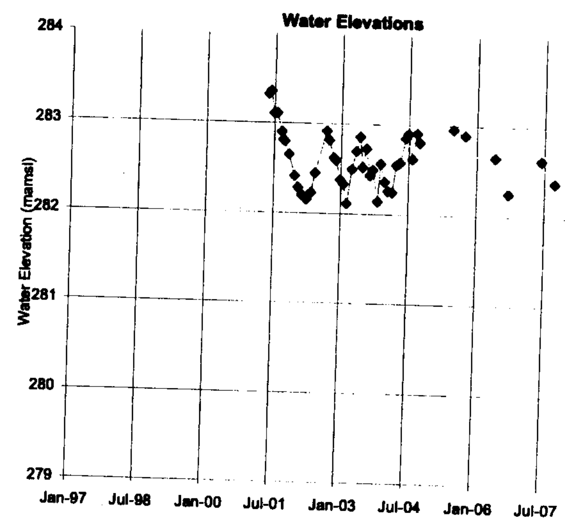

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0134-14

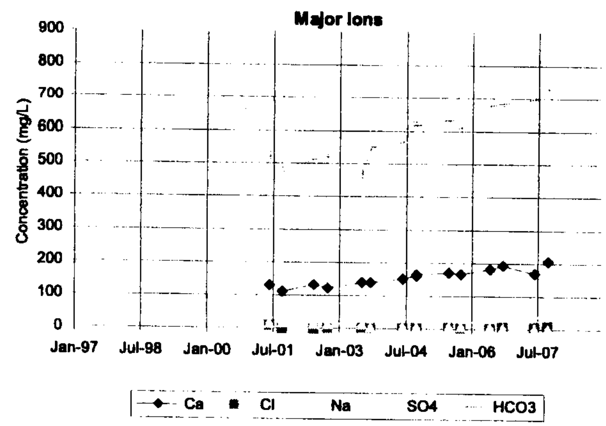

Major Ions
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca
Cl
Na
SO4
HCO3

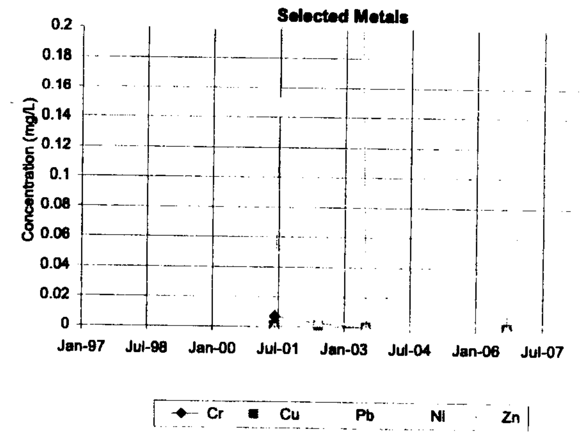

Selected Metals
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr
Cu
Pb
Ni
Zn

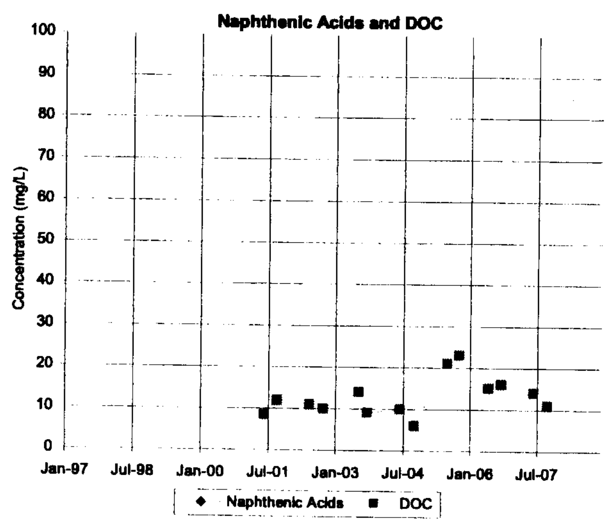

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids
DOC

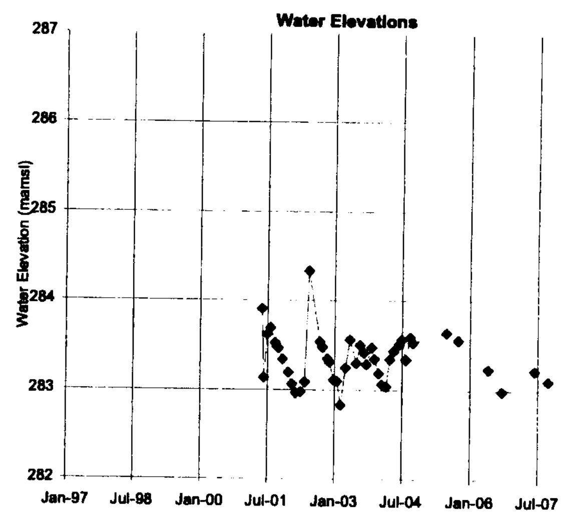

Water Elevations
284
283
282
281
280
279
Water Elevation (mamsl)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0134-15

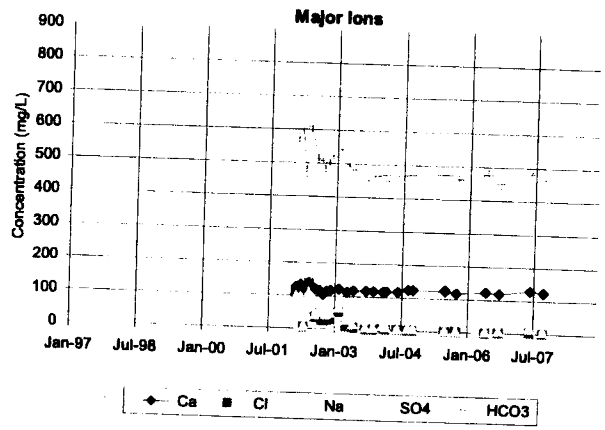

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

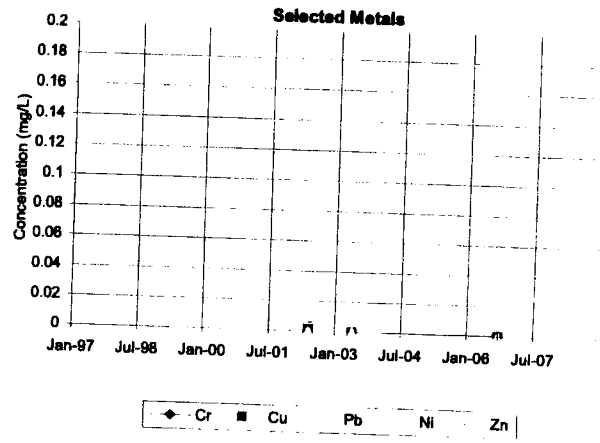

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

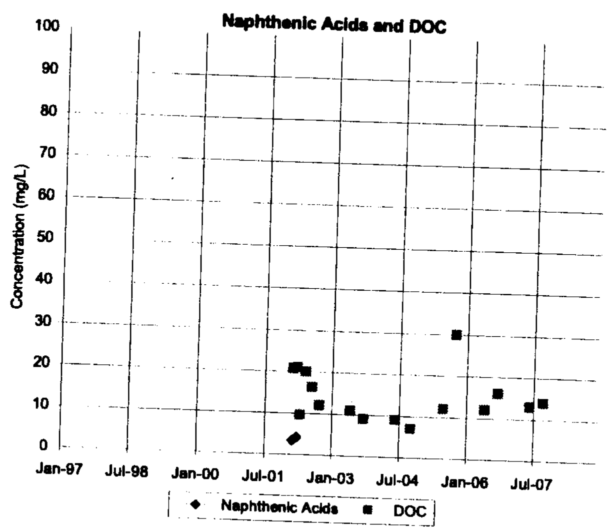

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

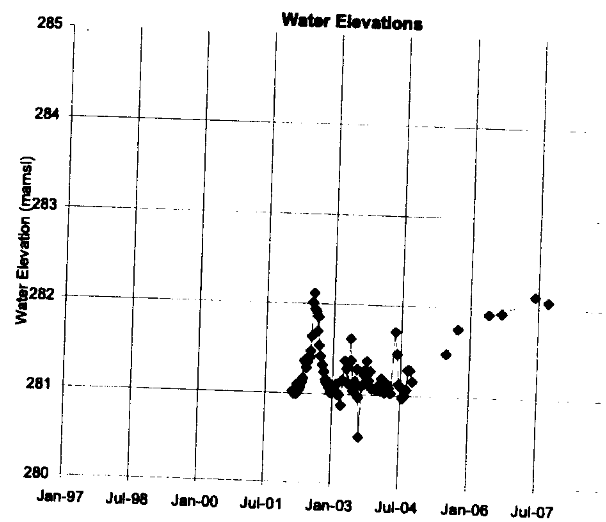

Water Elevations
Water Elevation (mamsl)
287
286
285
284
283
282
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-01

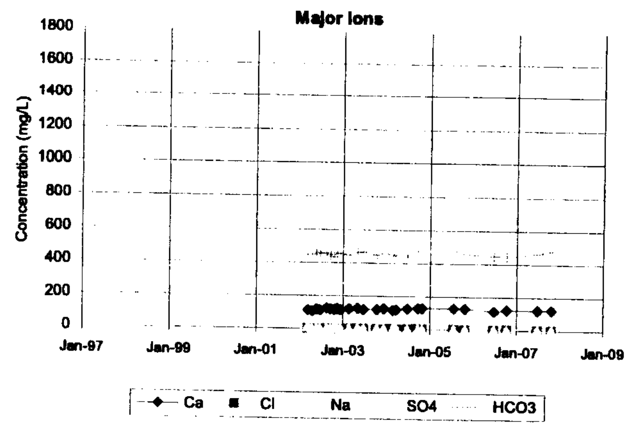

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

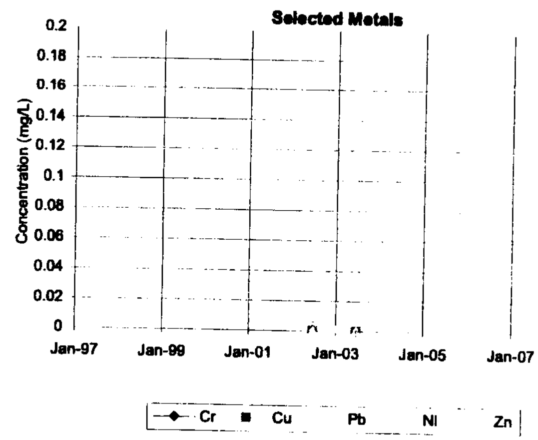

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

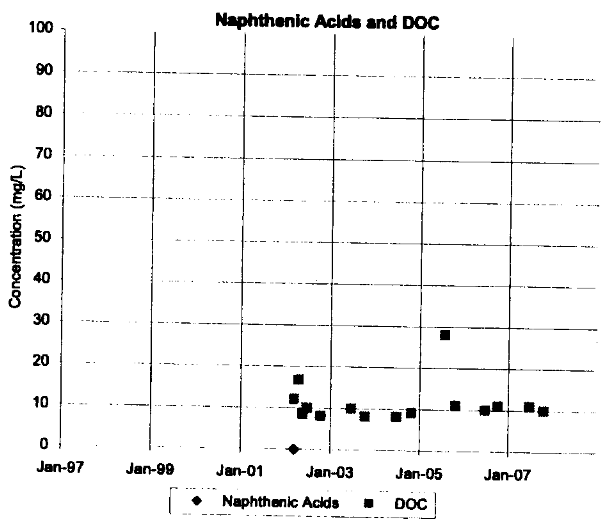

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

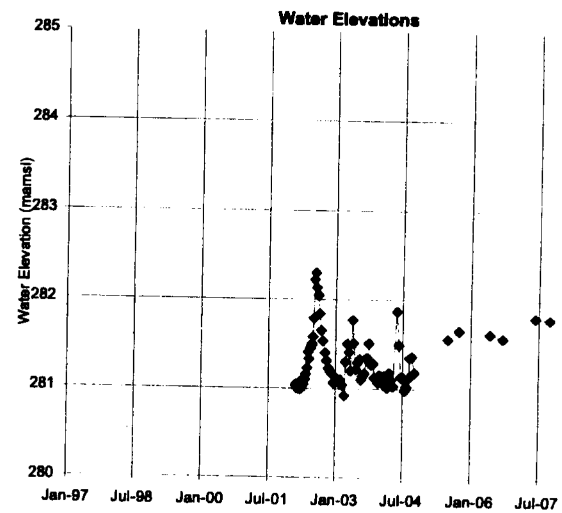

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0234-02A

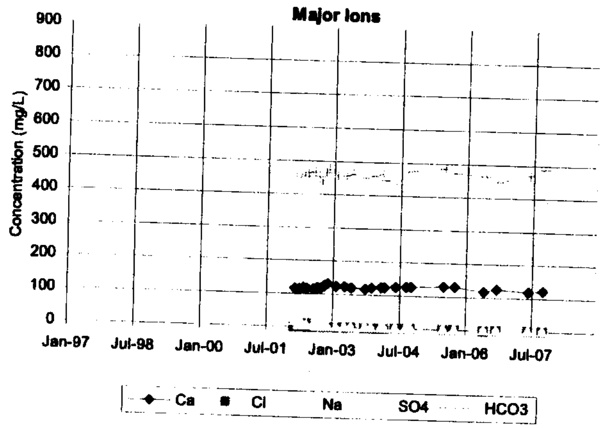

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Jan-09
Ca
Cl
Na
SO4
HCO3

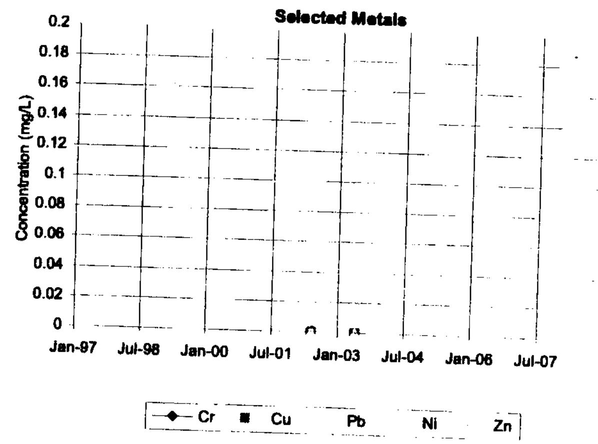

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Cr
Cu
Pb
Ni
Zn

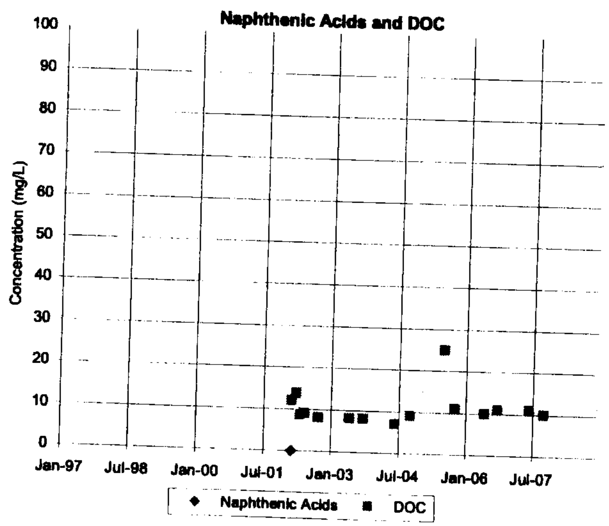

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jan-99
Jan-01
Jan-03
Jan-05
Jan-07
Naphthenic Acids
DOC

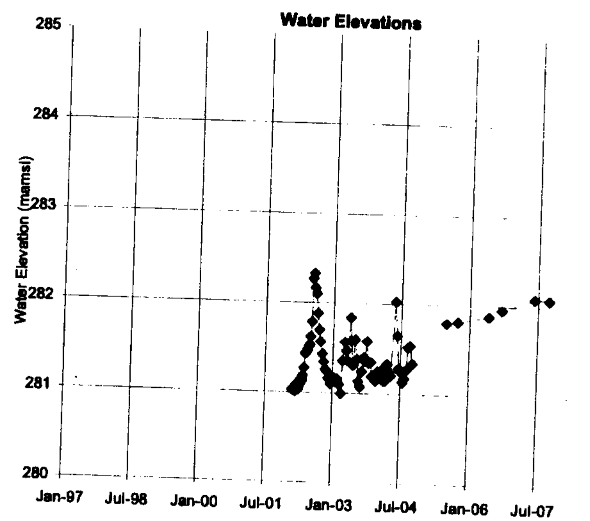

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0234-02B

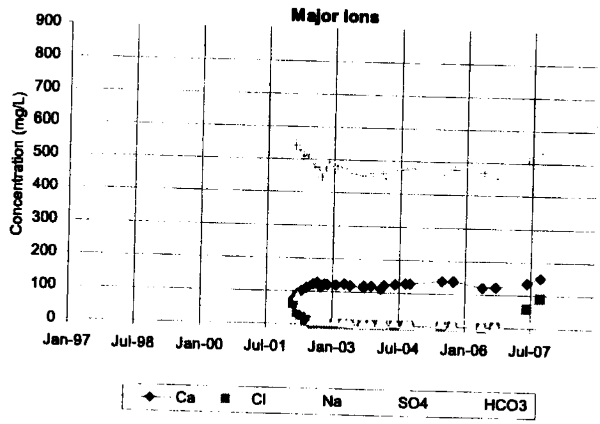

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

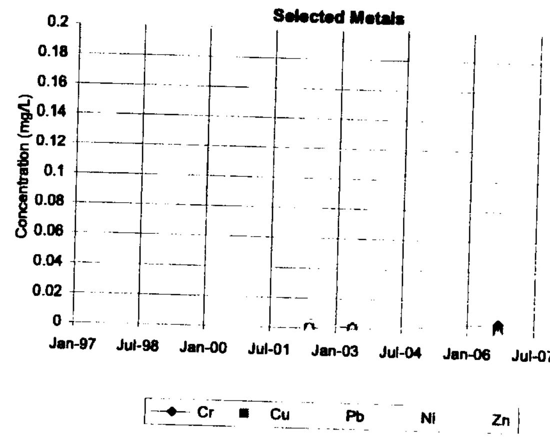

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

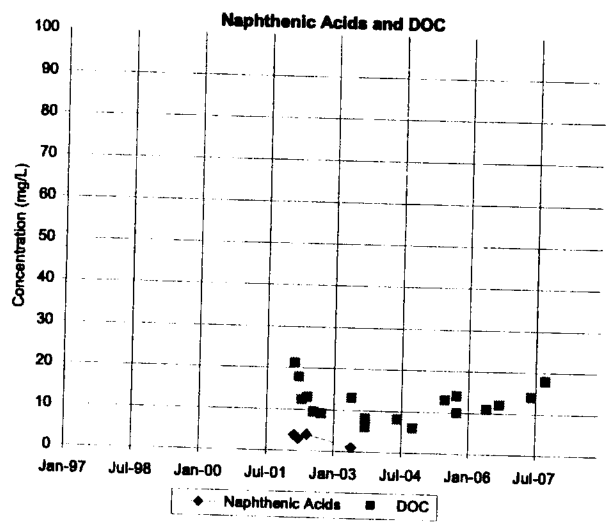

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

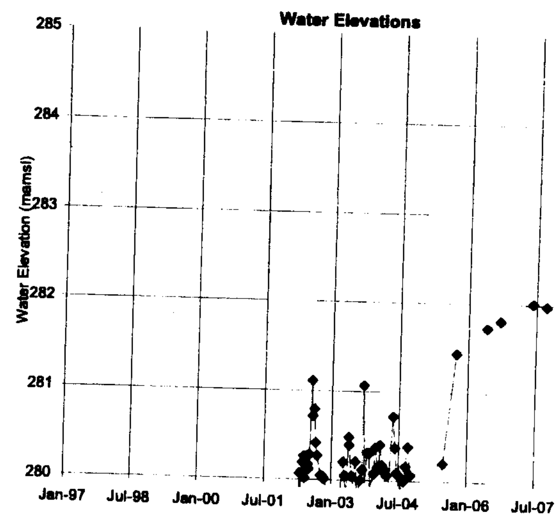

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-03

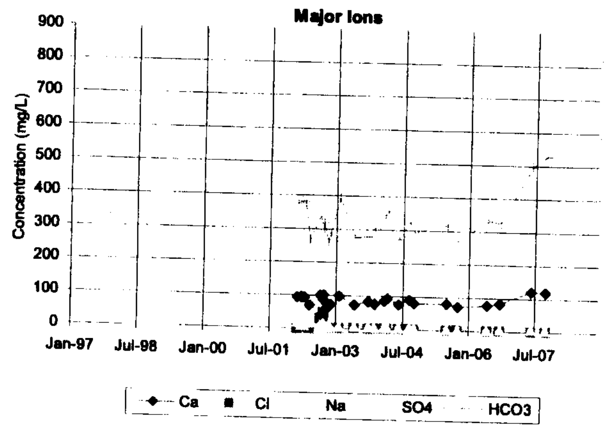

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

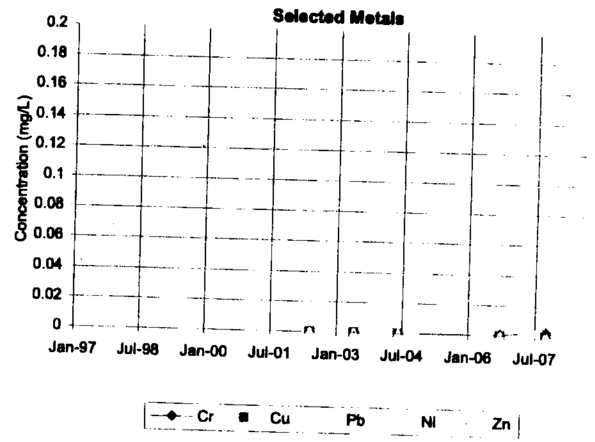

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

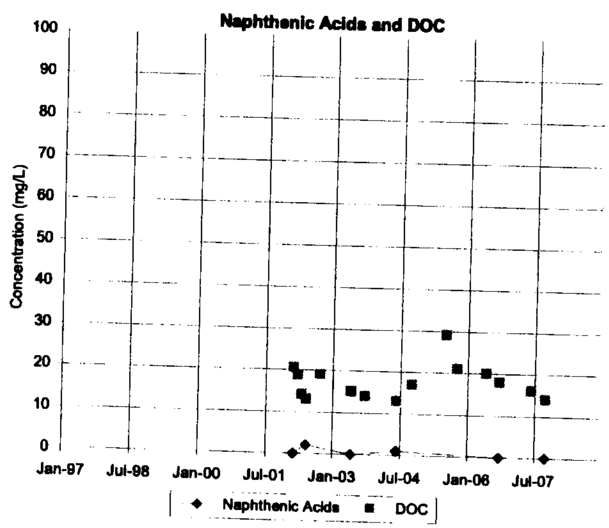

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

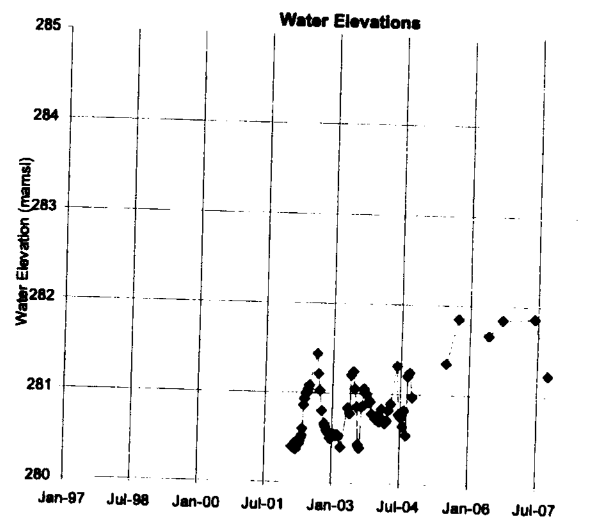

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0234-04

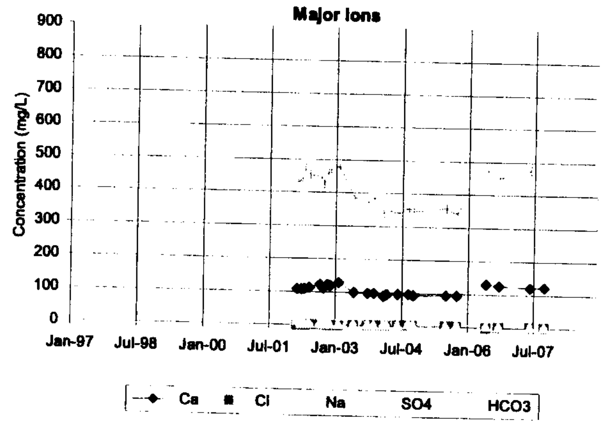

Major Ions
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

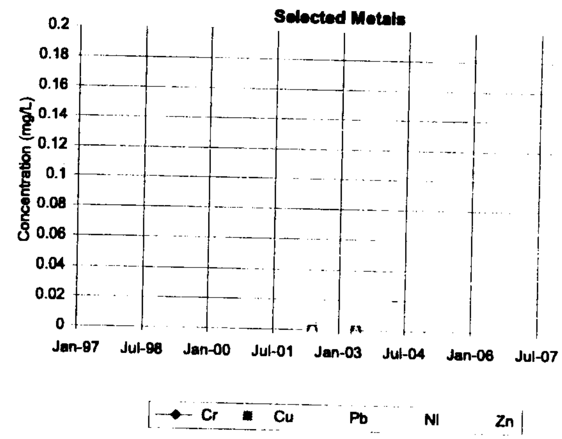

Selected Metals
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Concentration (mg/L)
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

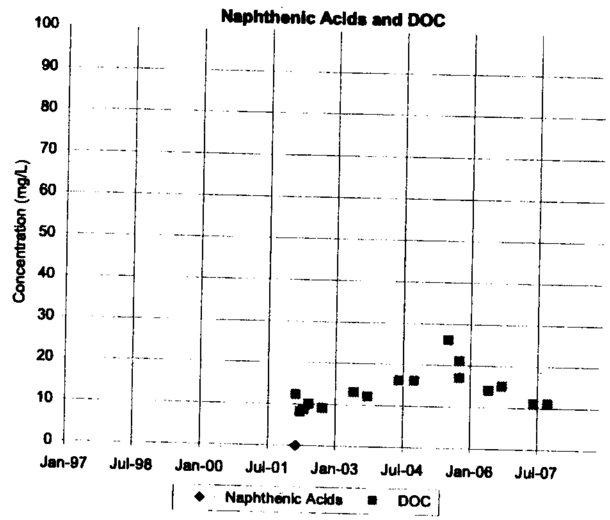

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

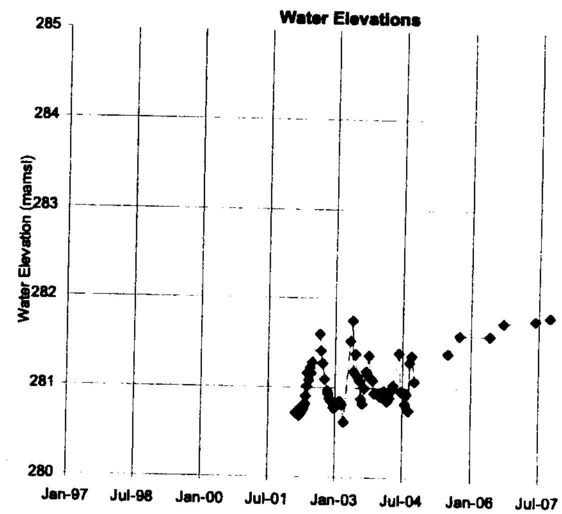

Water Elevations
285
284
283
282
281
280
Water Elevation (mamsl)
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0234-05

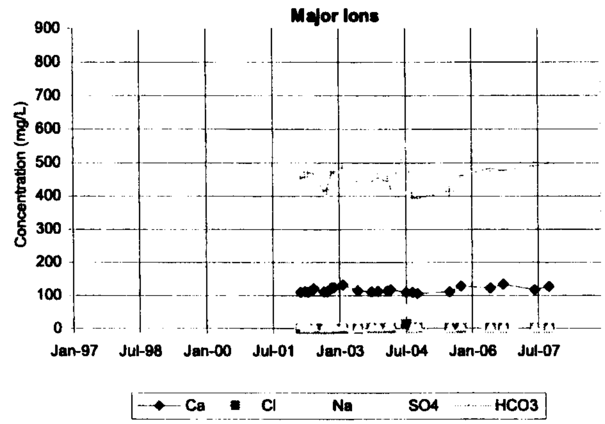

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

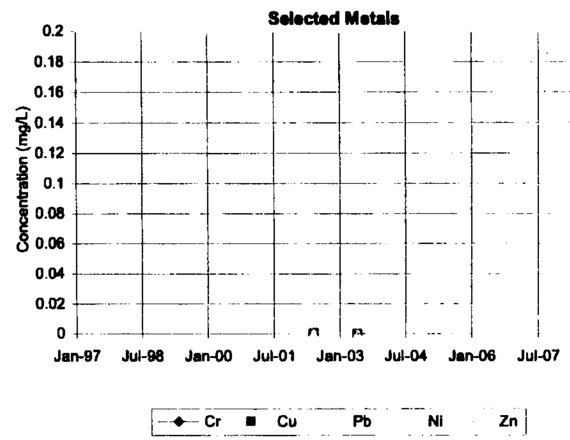

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

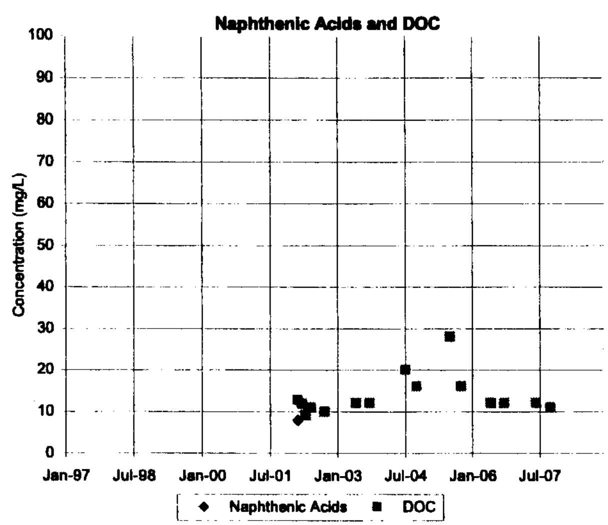

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

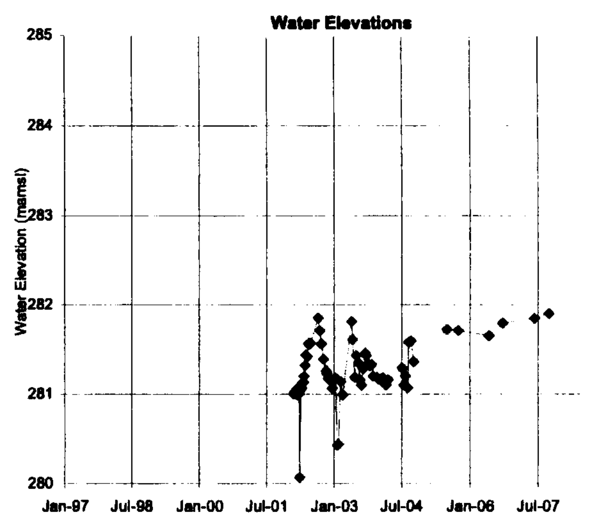

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-06

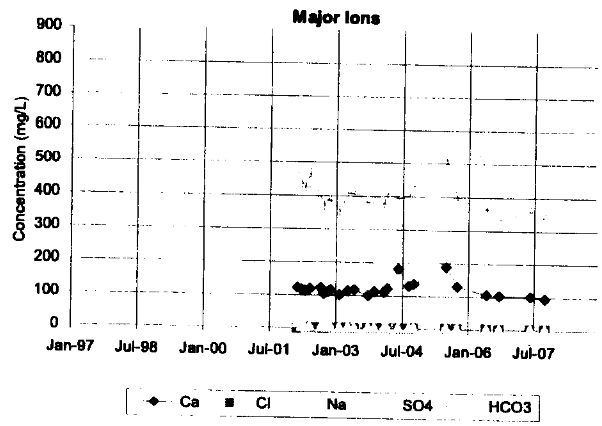

Major Ions
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

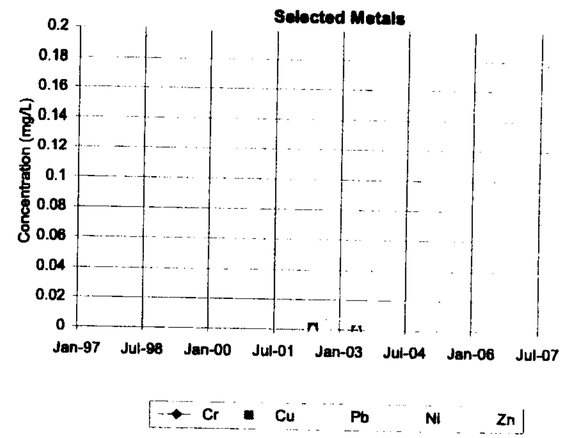

Selected Metals
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

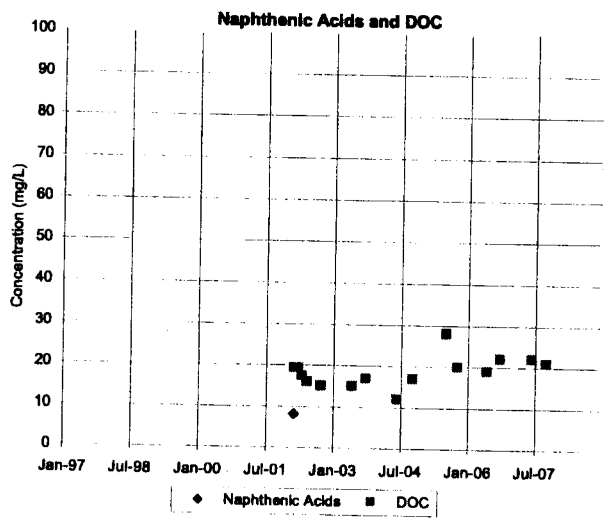

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

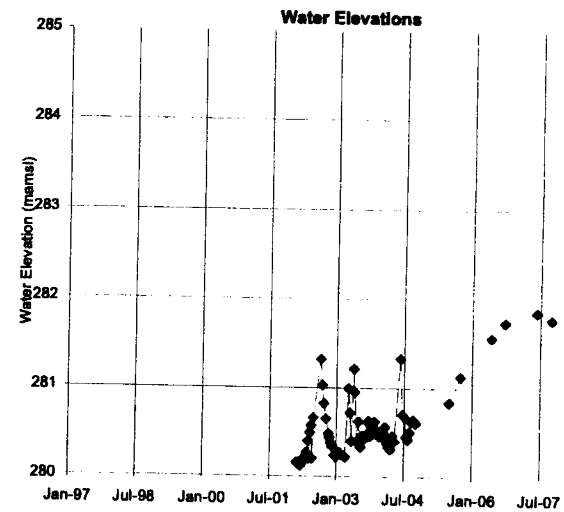

Water Elevations
285
284
283
282
281
280
Water Elevation (mamsl)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-07

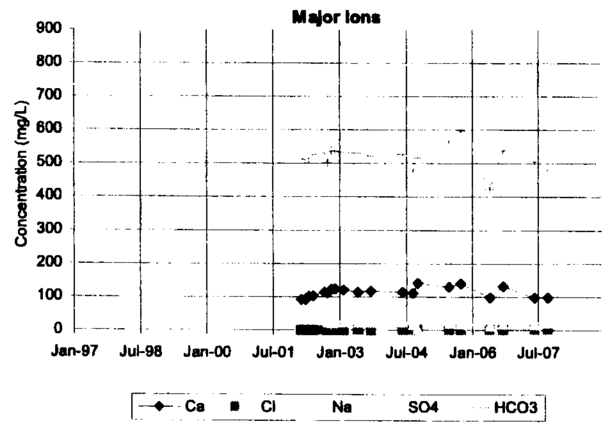

Major Ions
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

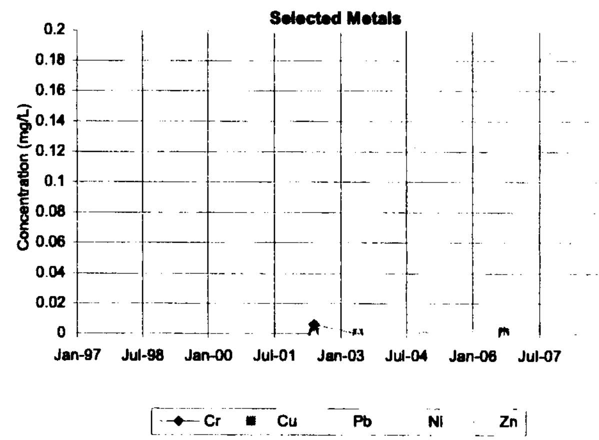

Selected Metals
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

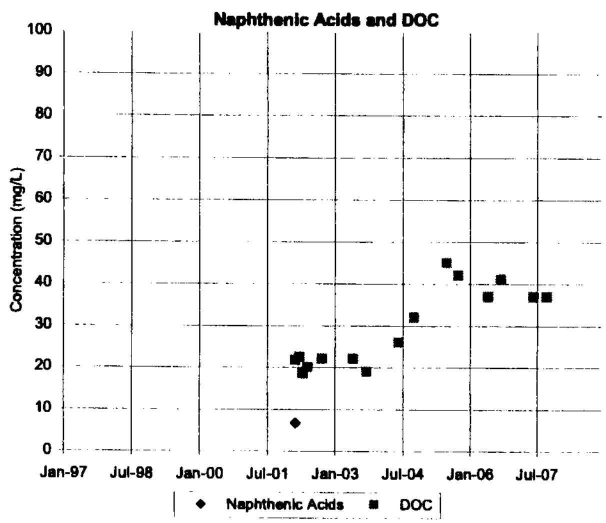

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

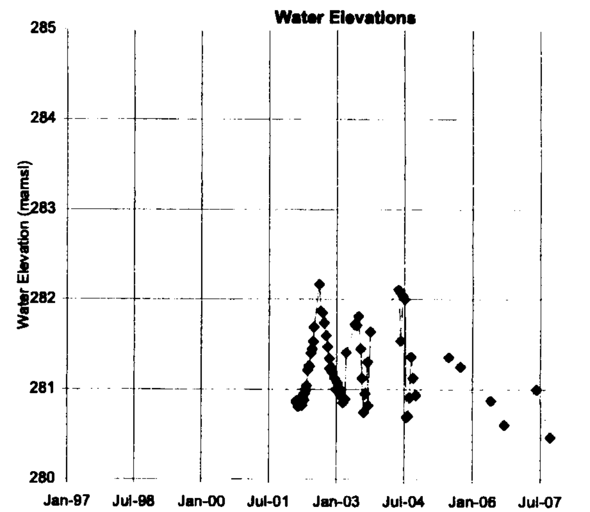

Water Elevations
285
284
283
282
281
280
Water Elevation (mamsl)
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-08

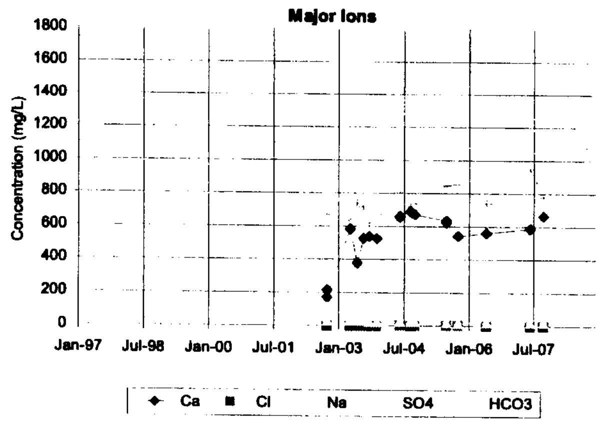

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

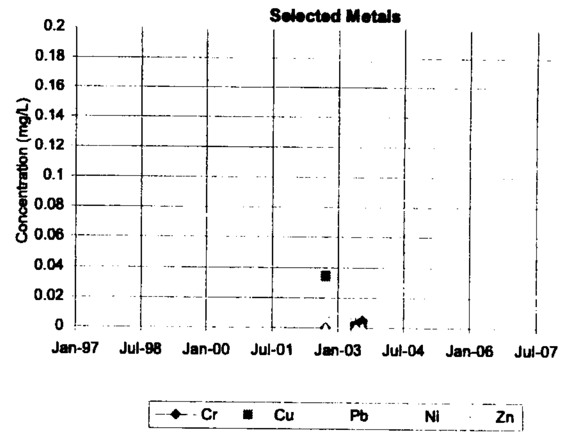

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

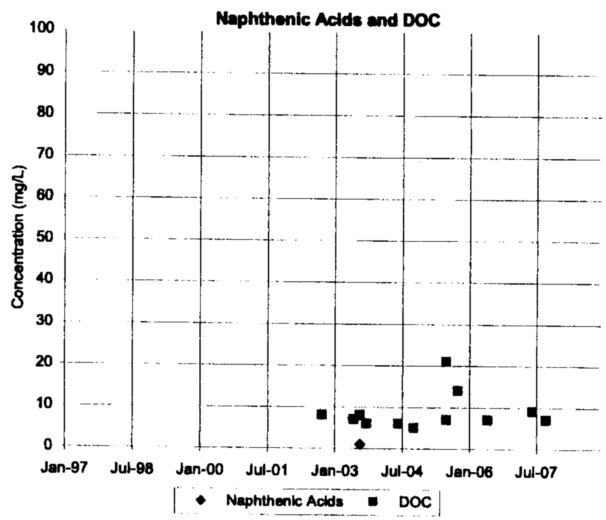

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

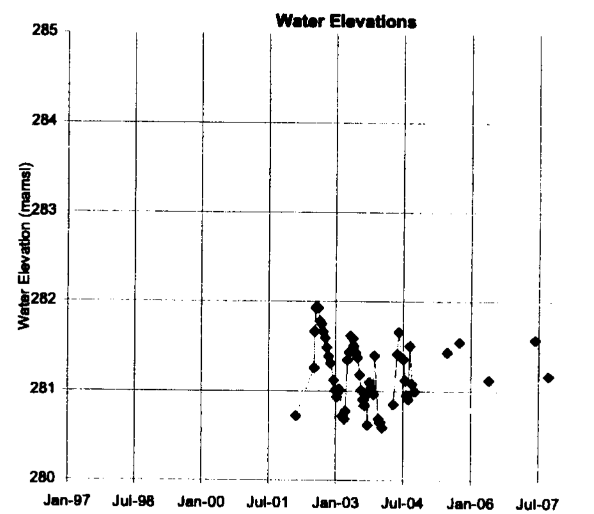

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0234-09

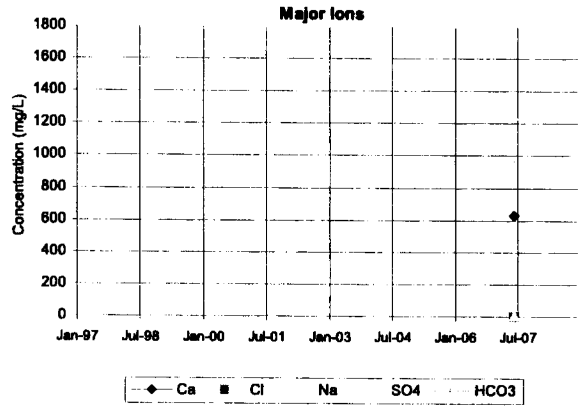

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

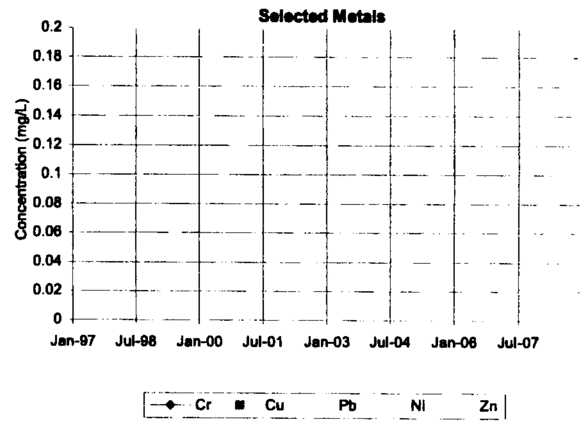

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

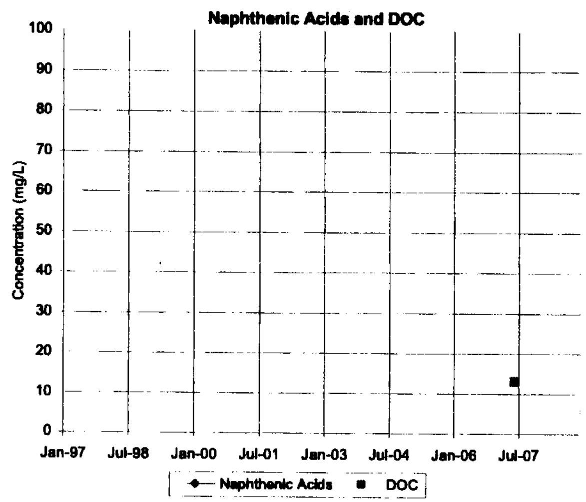

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

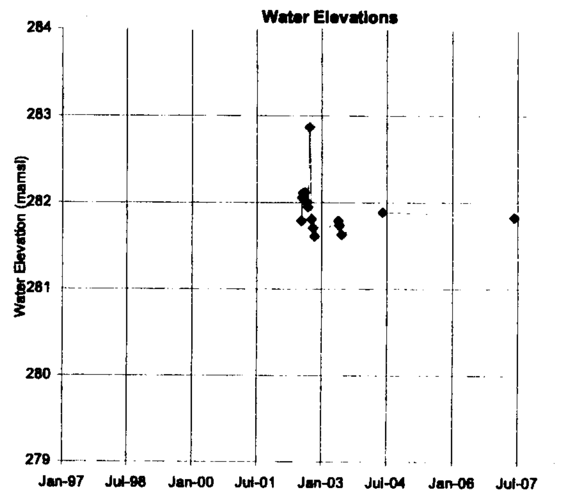

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-10

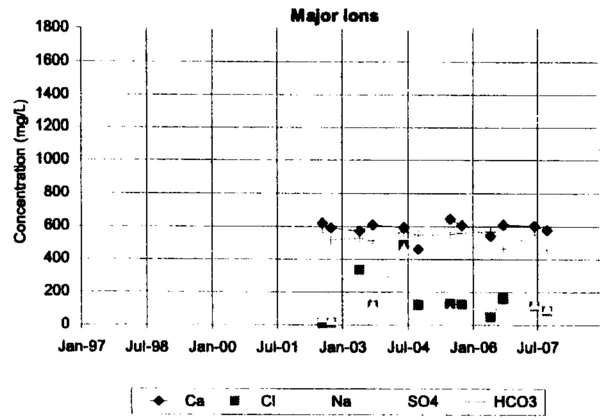

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

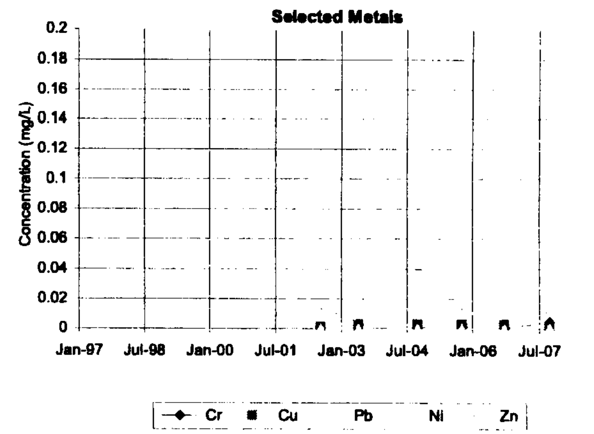

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

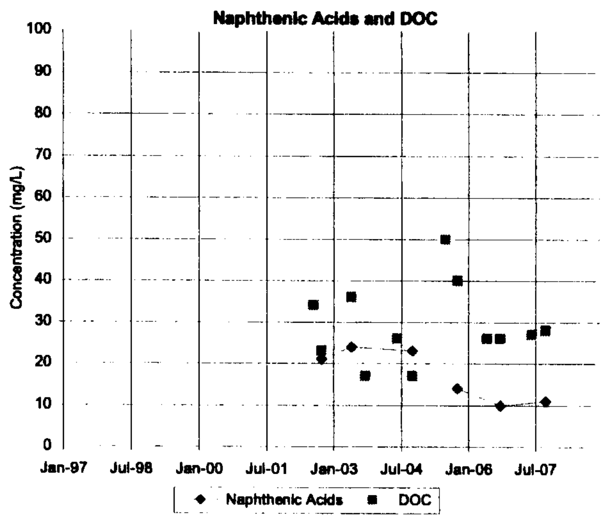

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

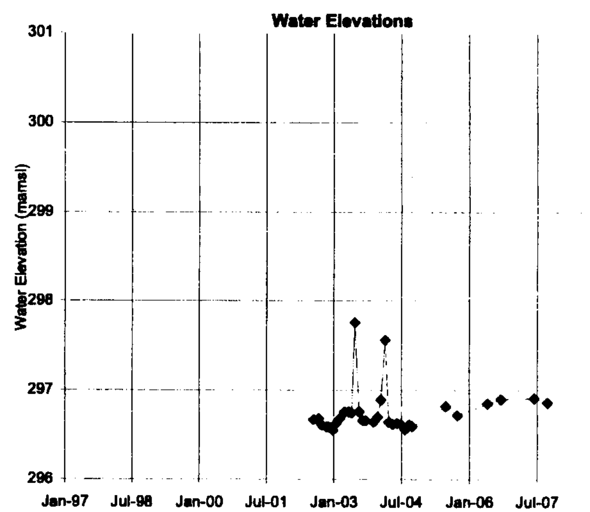

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-14

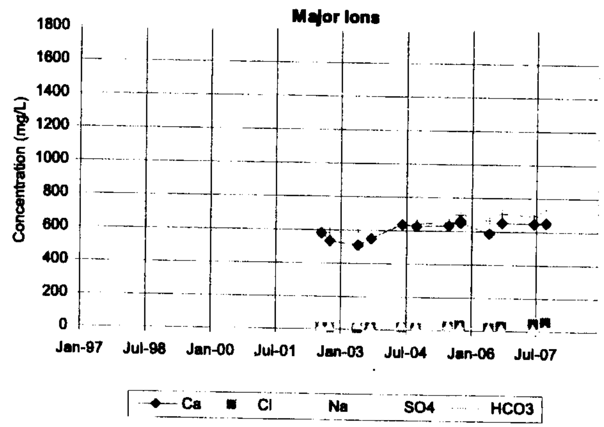

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

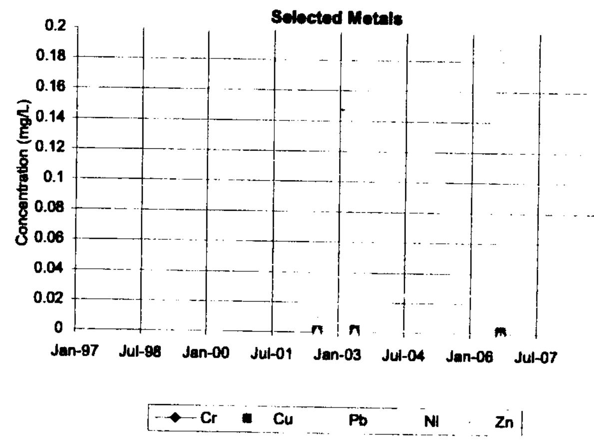

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

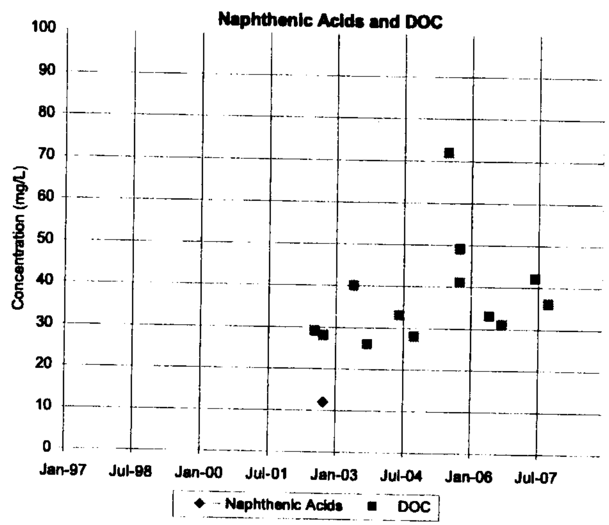

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

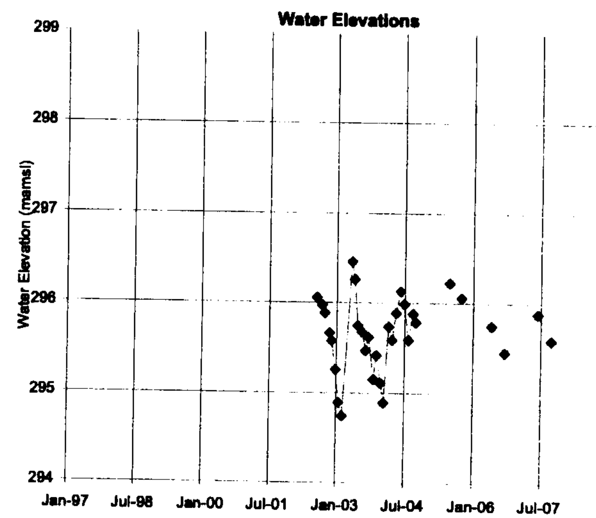

Water Elevations
Water Elevation (mamsl)
301
300
299
298
297
296
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0234-15

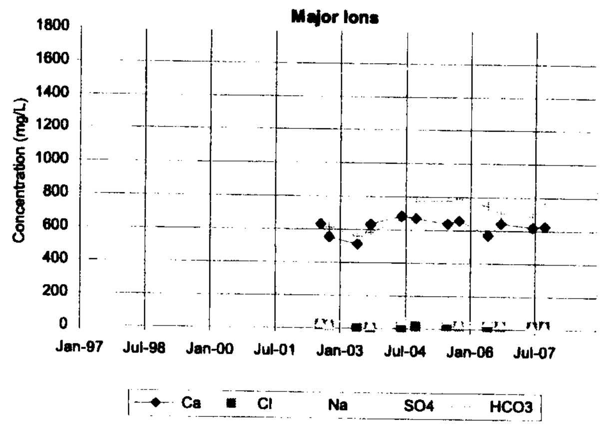

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

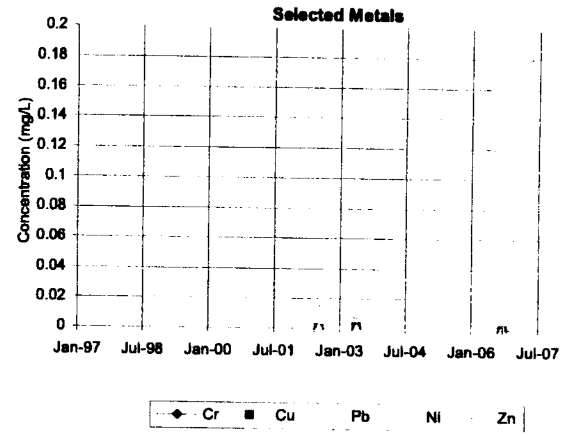

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

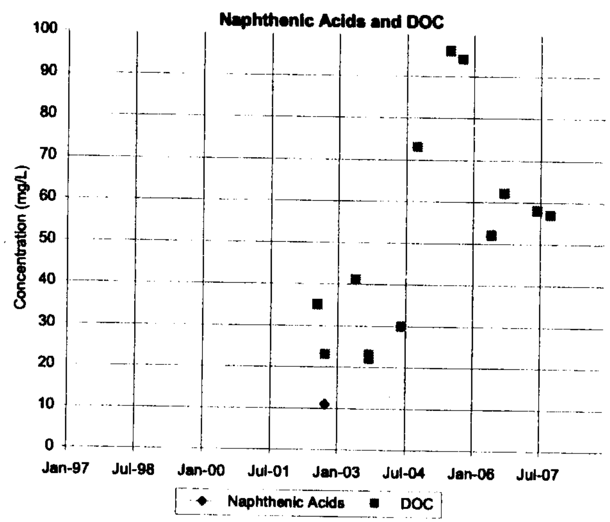

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

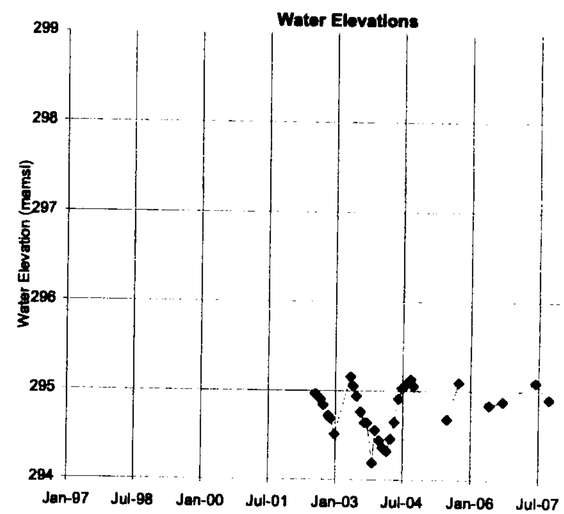

Water Elevations
Water Elevation (mamsl)
299
298
297
296
295
294
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0234-16

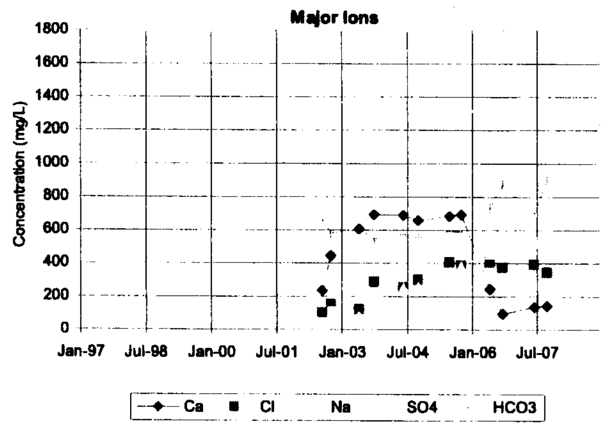

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

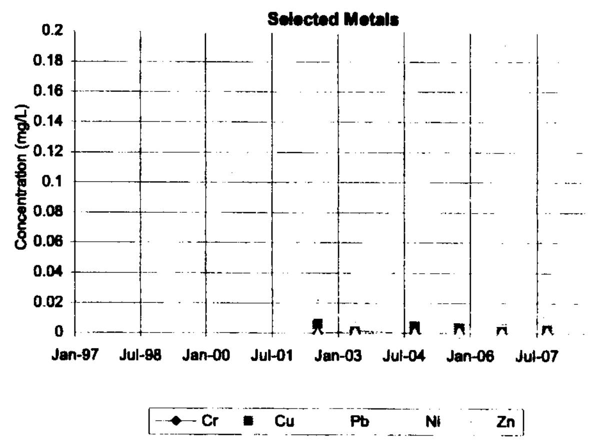

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

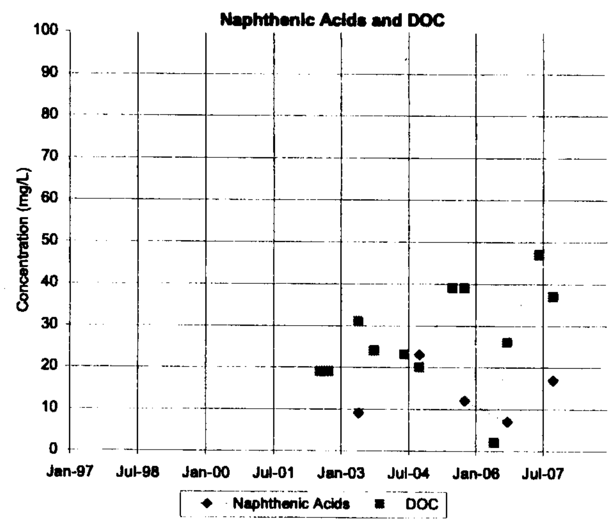

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

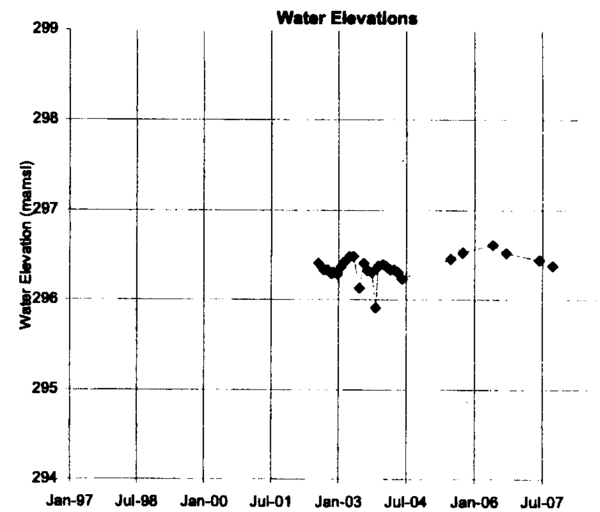

Water Elevations
Water Elevation (mamsl)
299
298
297
296
295
294
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0234-17

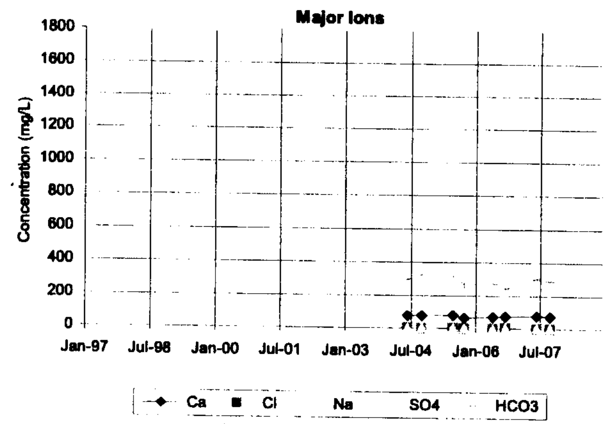

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

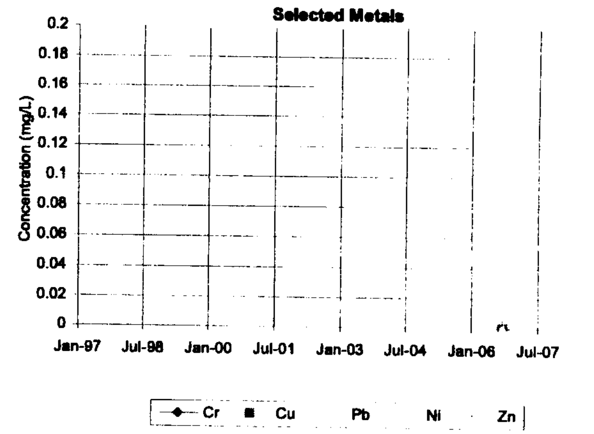

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

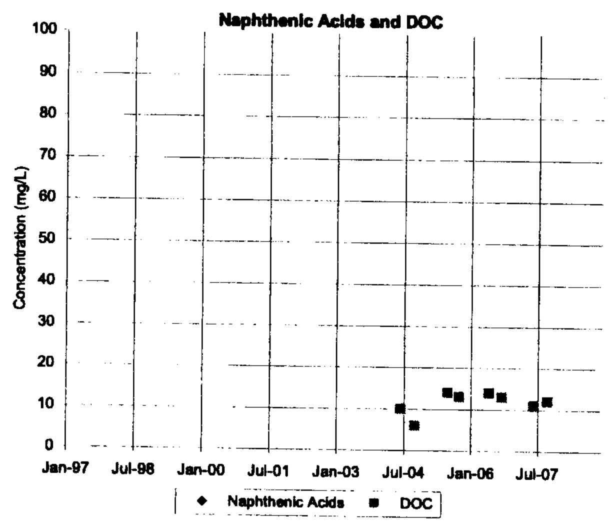

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

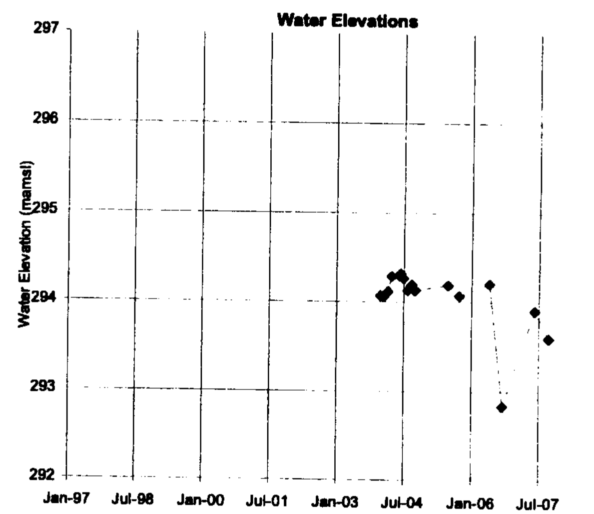

Water Elevations
Water Elevation (mamsl)
299
298
297
296
295
294
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0310-04

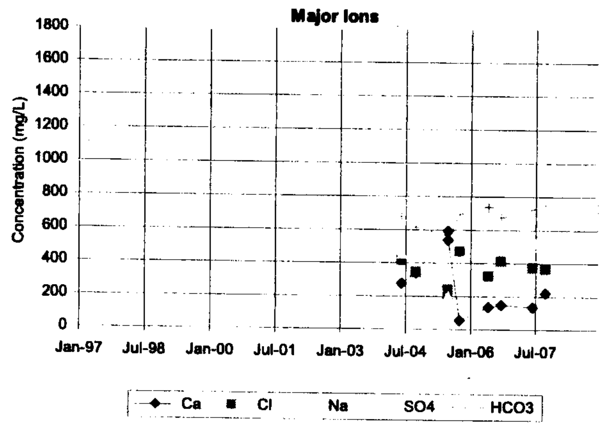

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

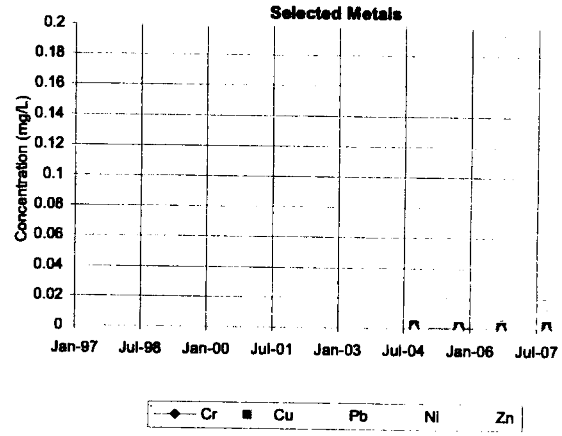

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

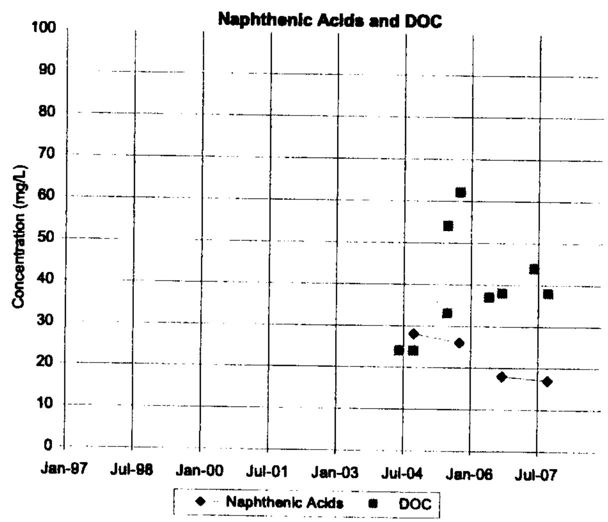

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

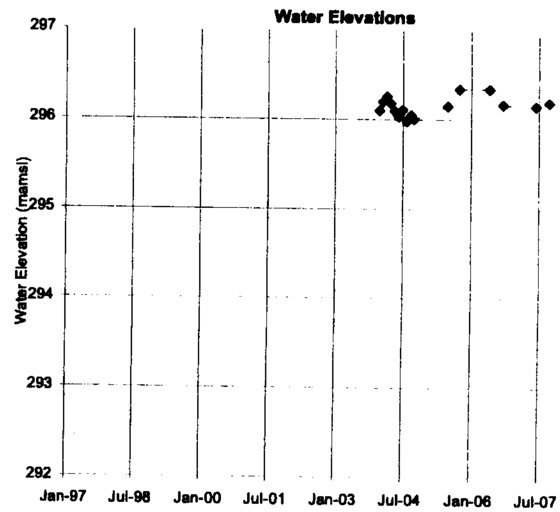

Water Elevations
Water Elevation (mamsl)
297
296
295
294
293
292
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0334-06

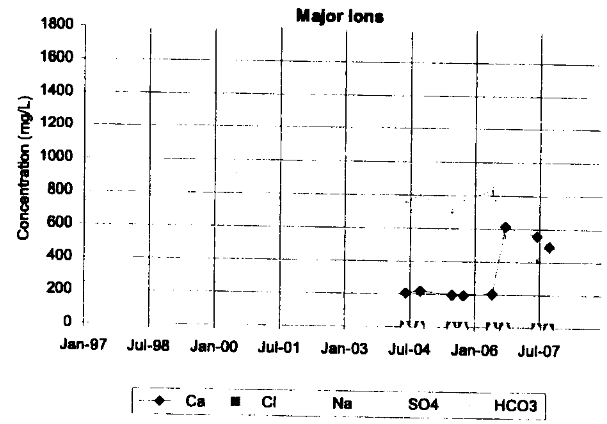

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

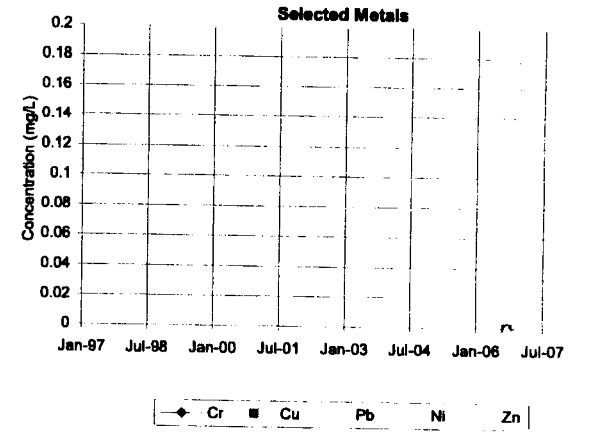

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

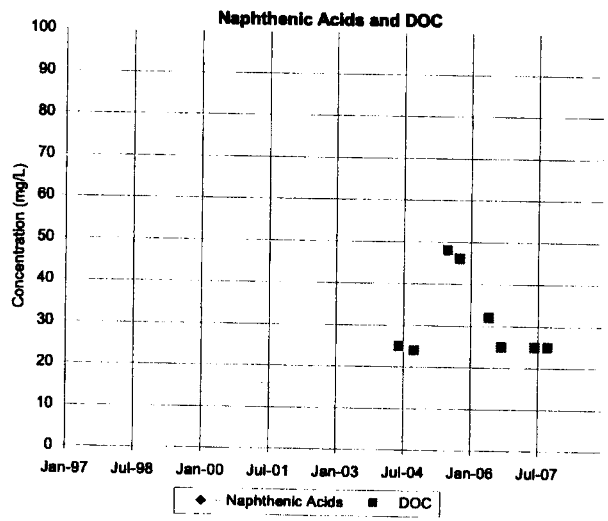

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

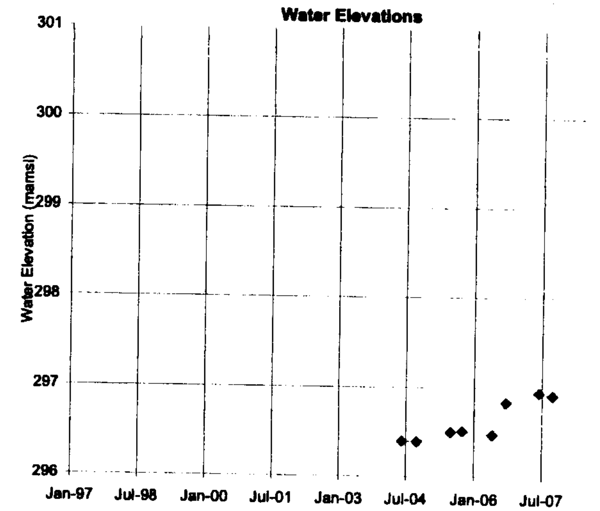

Water Elevations
Water Elevation (mamsl)
297
296
295
294
293
292
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0334-07

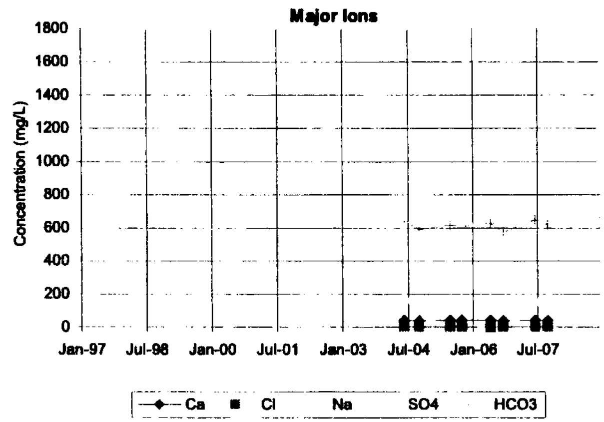

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

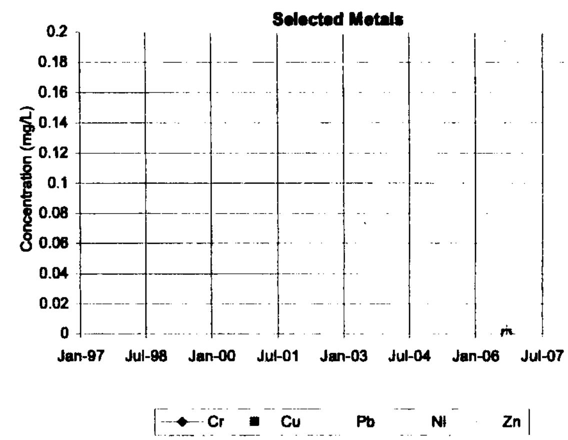

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

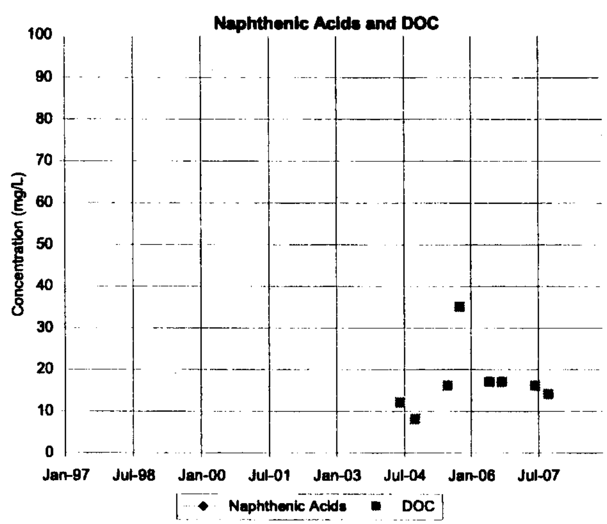

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

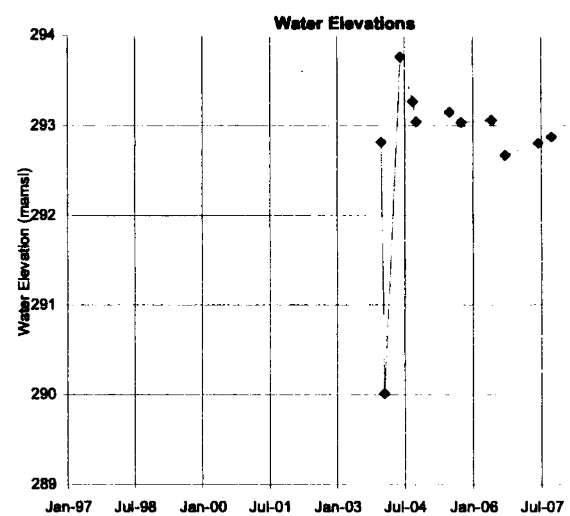

Water Elevations
Water Elevation (mamsl)
301
300
299
298
297
296
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0334-09

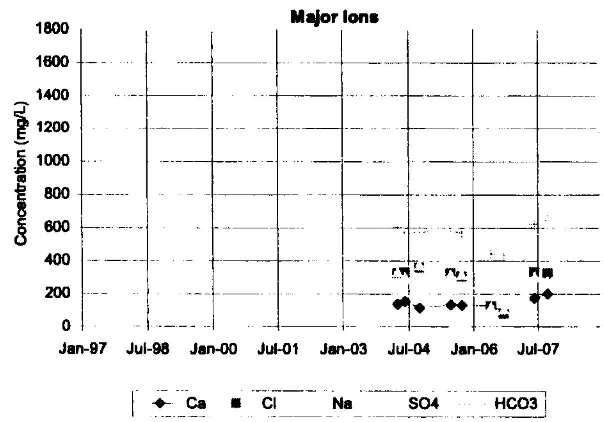

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

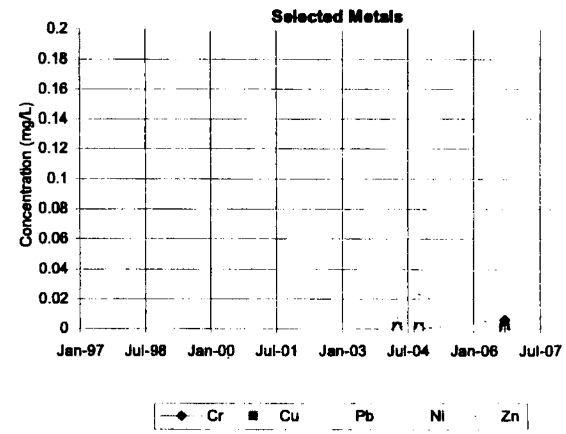

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

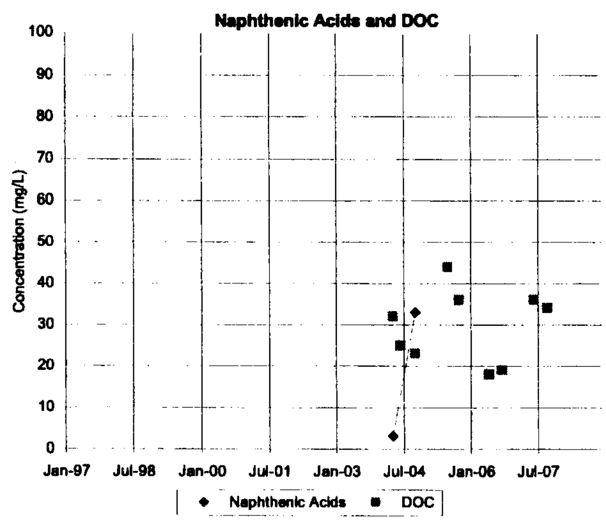

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

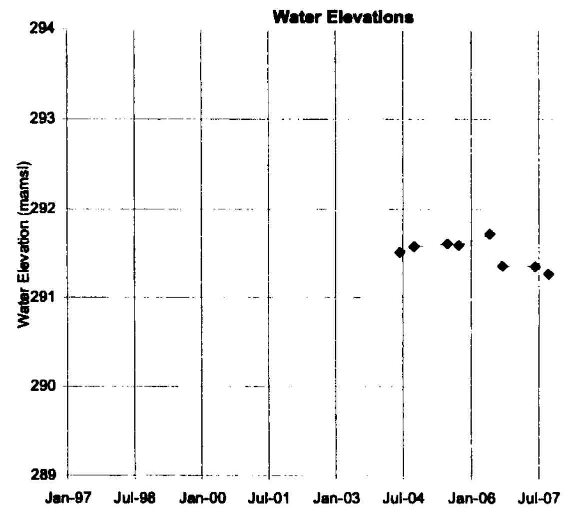

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0410-01

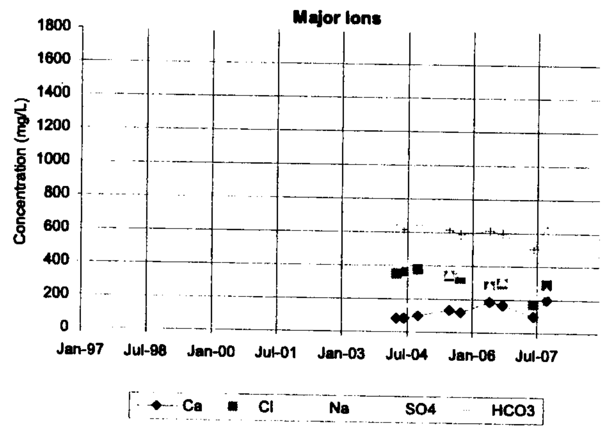

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca
Cl
Na
SO4
HCO3

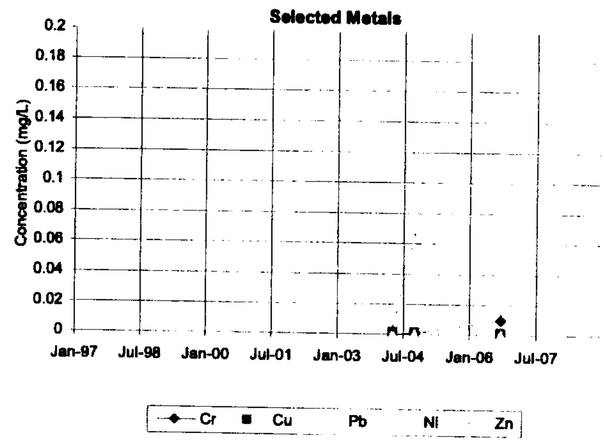

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr
Cu
Pb
Ni
Zn

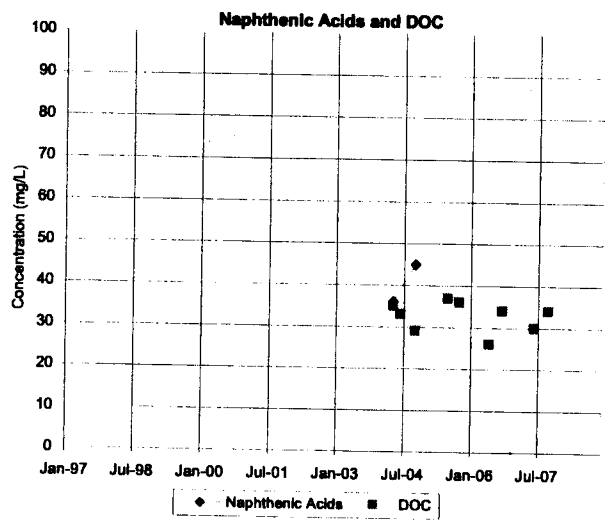

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids
DOC

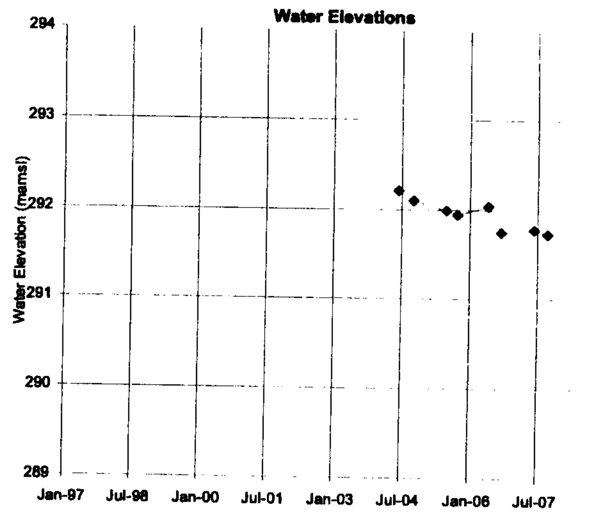

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0410-02

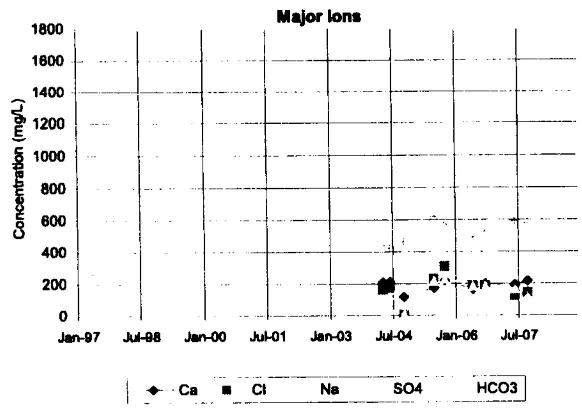

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

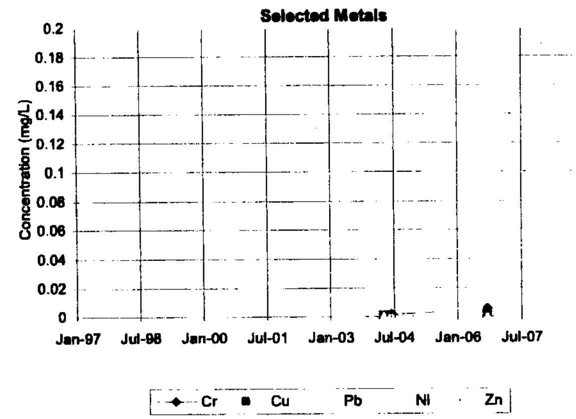

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

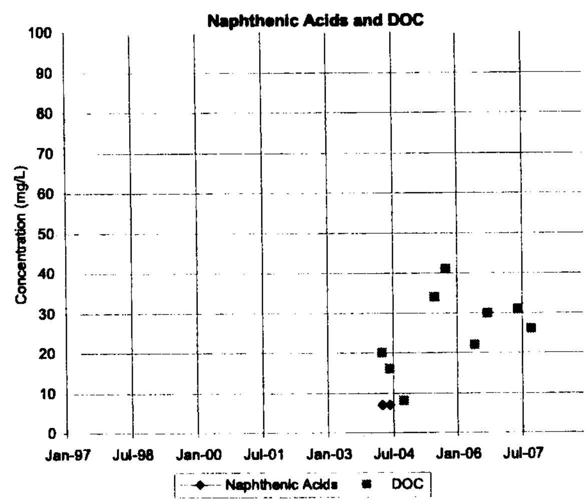

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

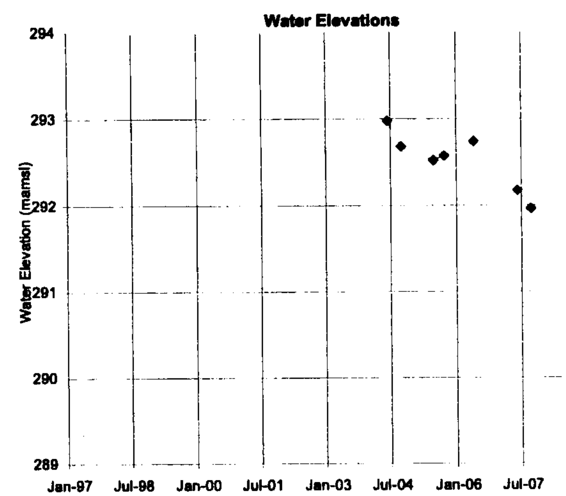

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS041003A

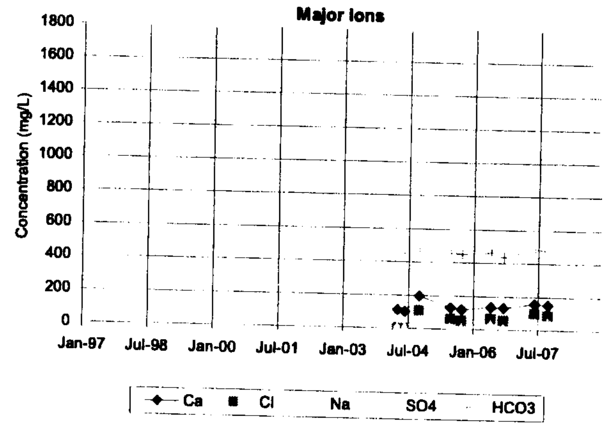

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

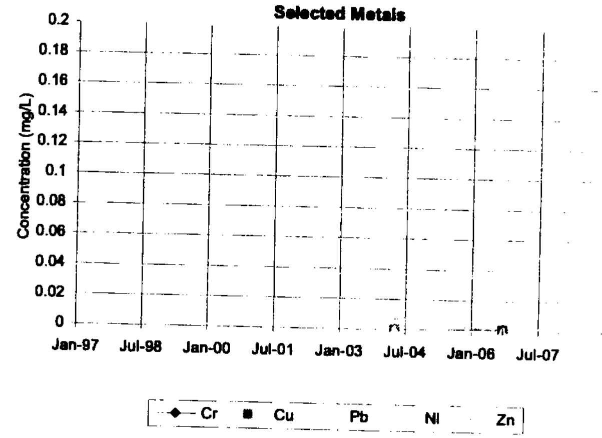

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

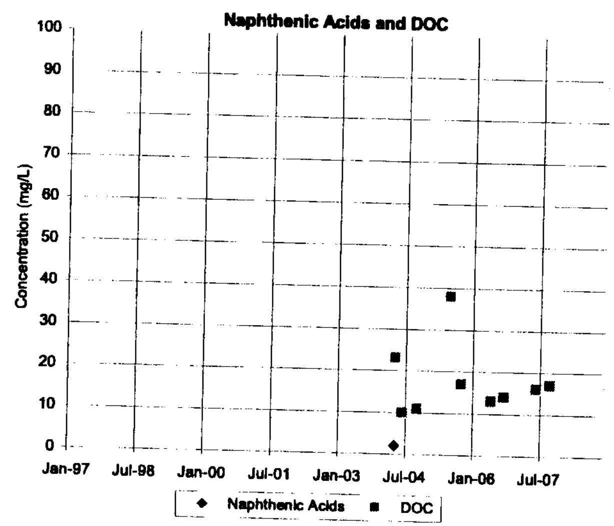

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

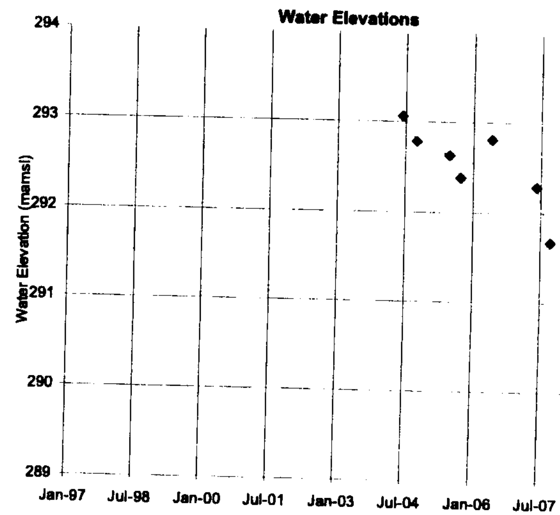

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS041003B

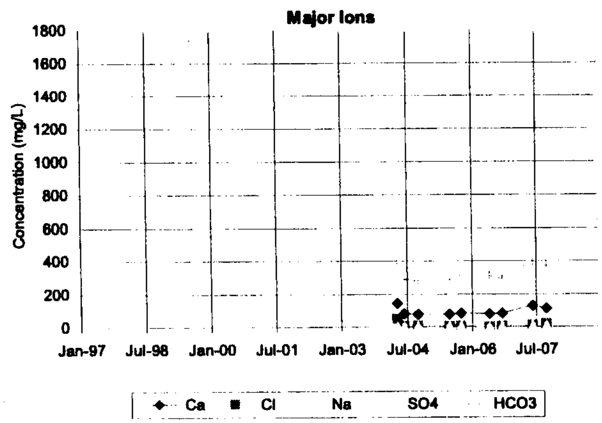

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

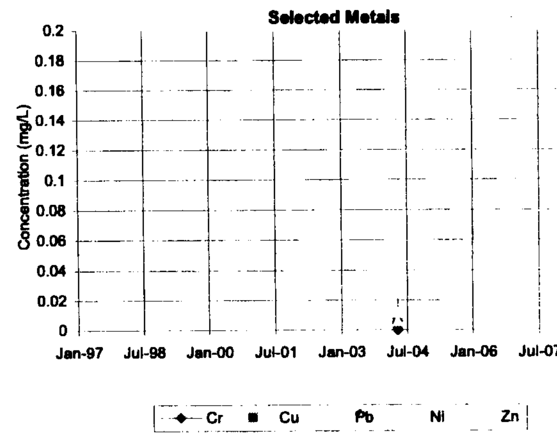

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

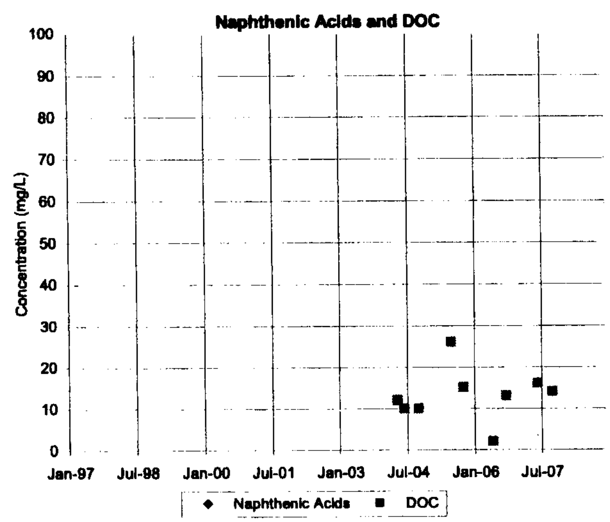

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

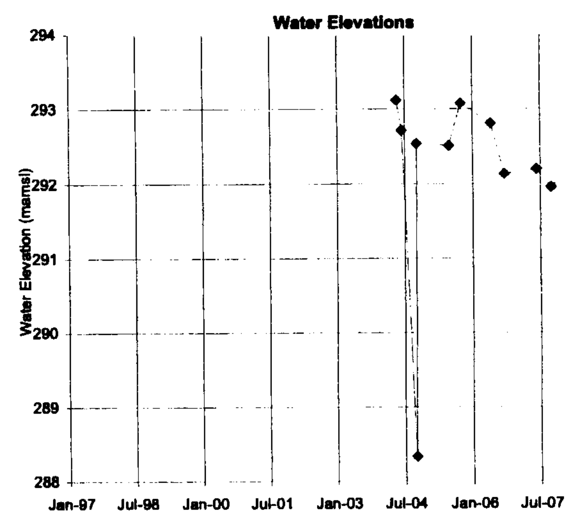

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0410-04

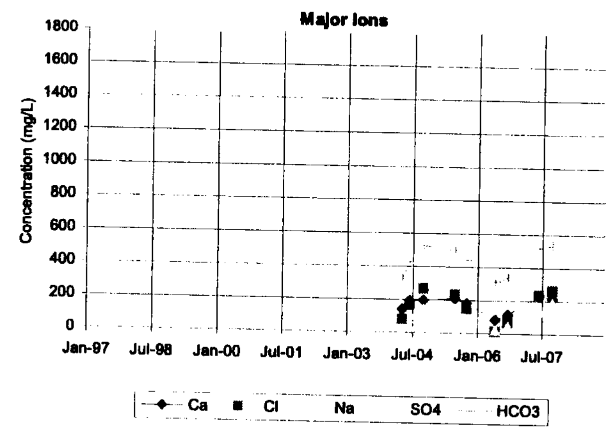

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca
Cl
Na
SO4
HCO3

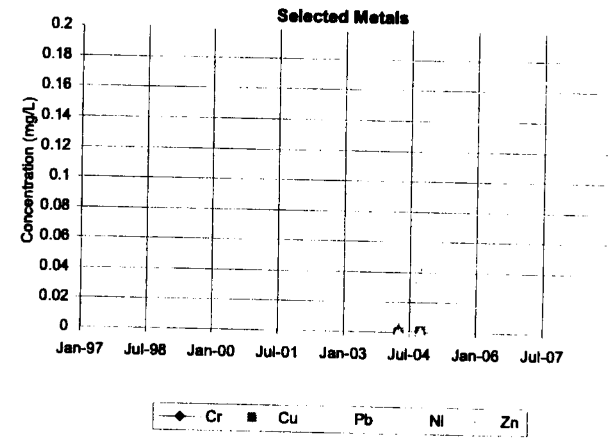

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr
Cu
Pb
Ni
Zn

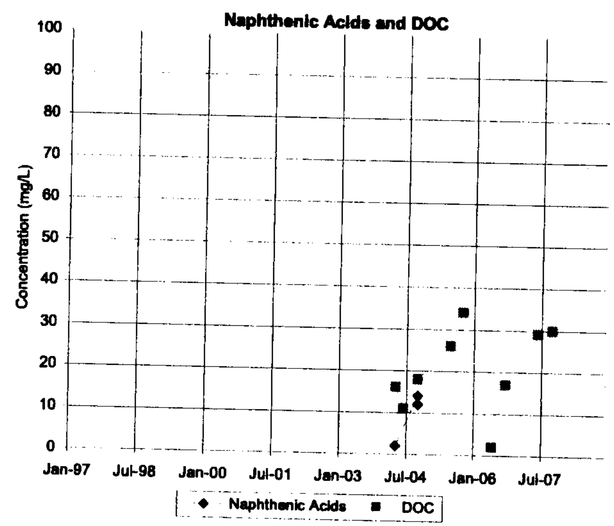

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids
DOC

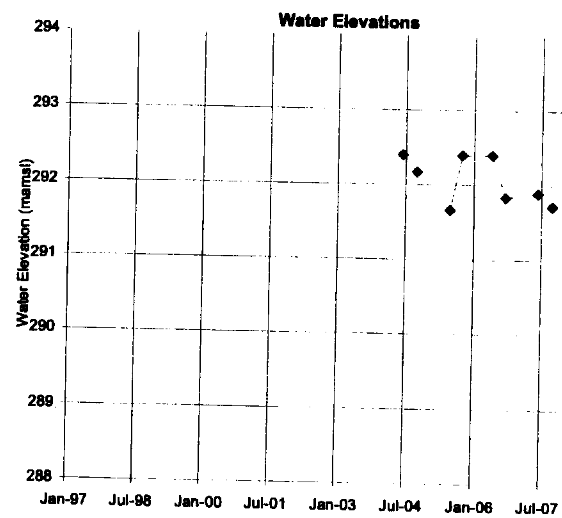

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
288
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0410-05

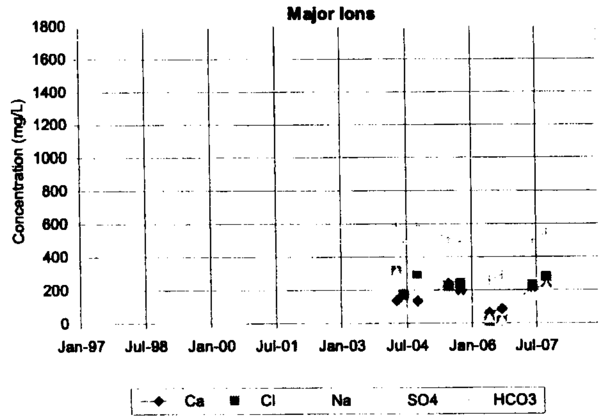

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

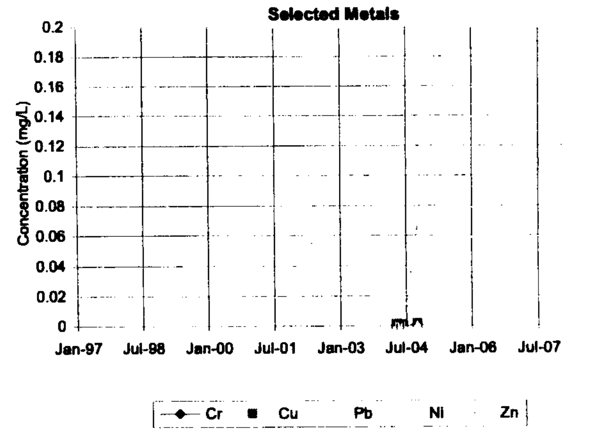

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

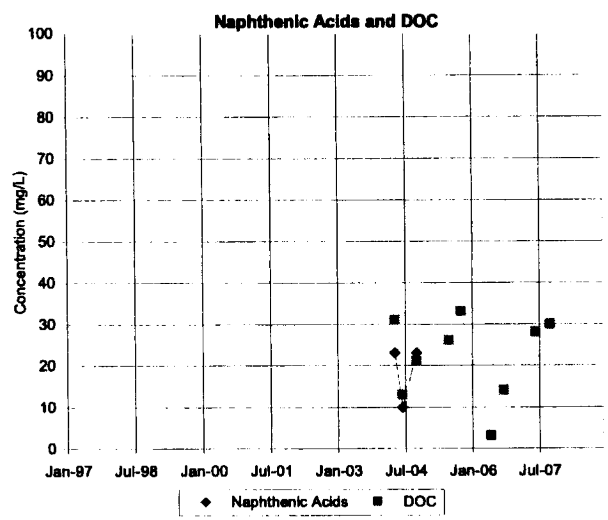

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

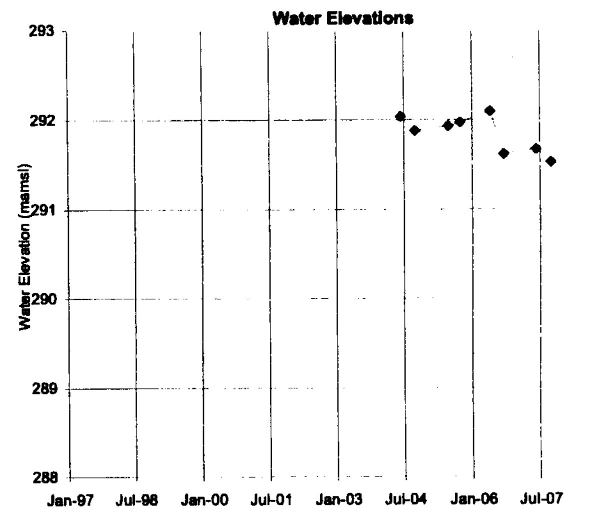

Water Elevations
Water Elevation (mamsl)
294
293
292
291
290
289
288
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0410-06

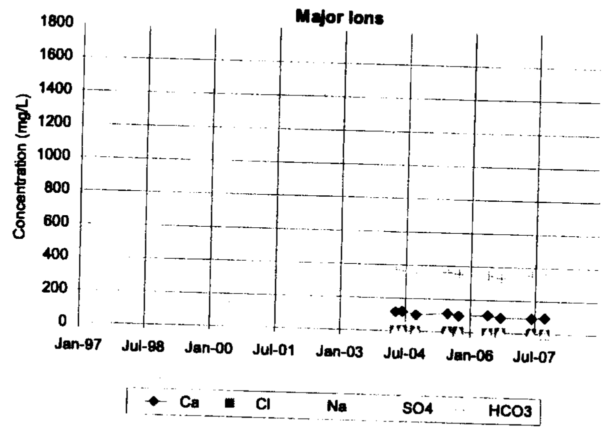

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

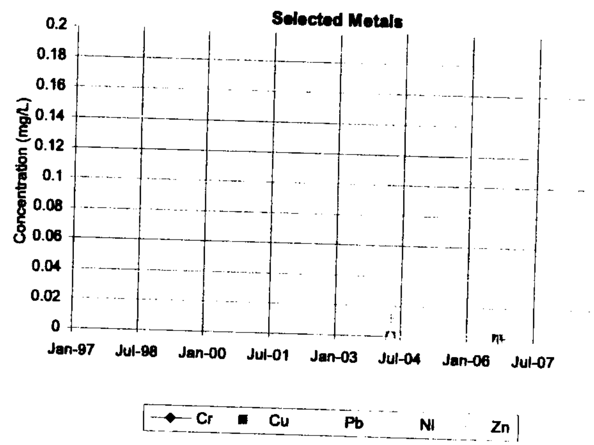

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

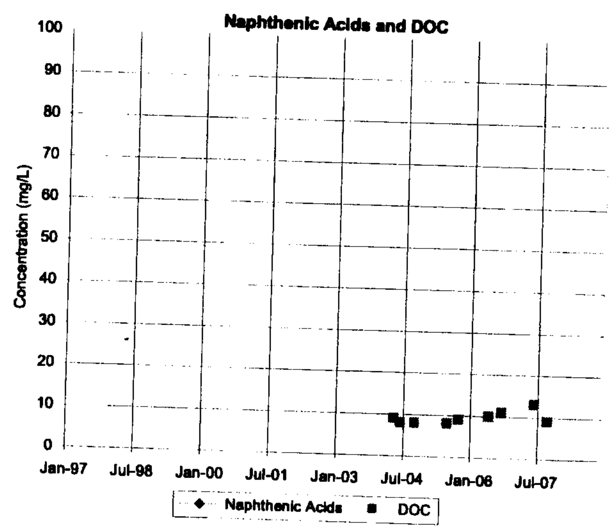

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

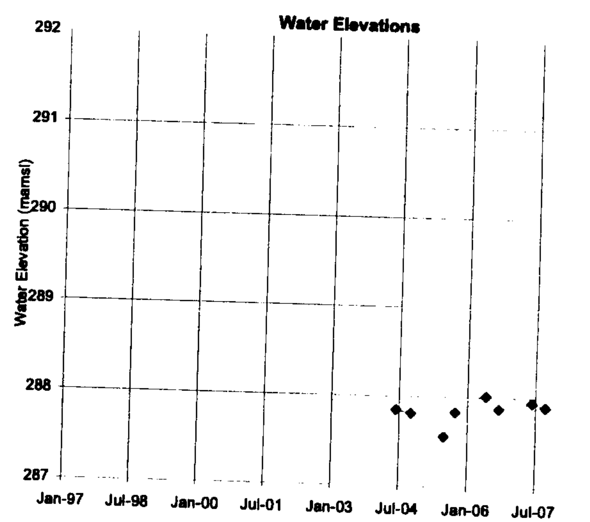

Water Elevations
Water Elevation (mamsl)
293
292
291
290
289
288
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0410-17

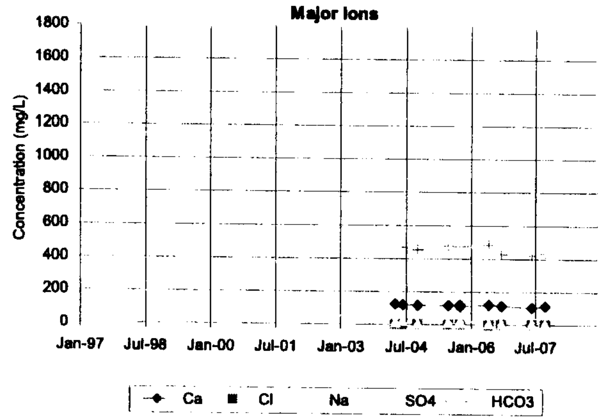

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Ca Cl Na SO4 HCO3

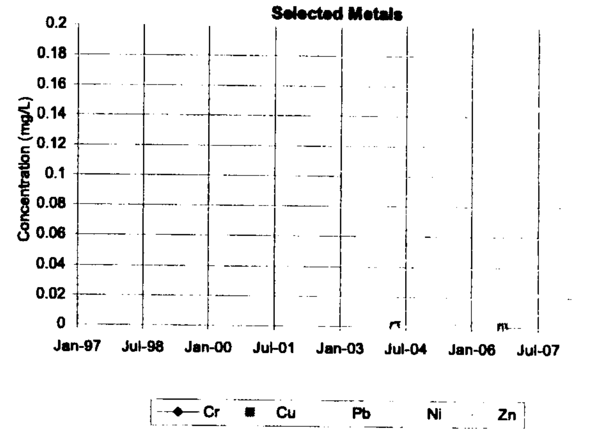

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Cr Cu Pb Ni Zn

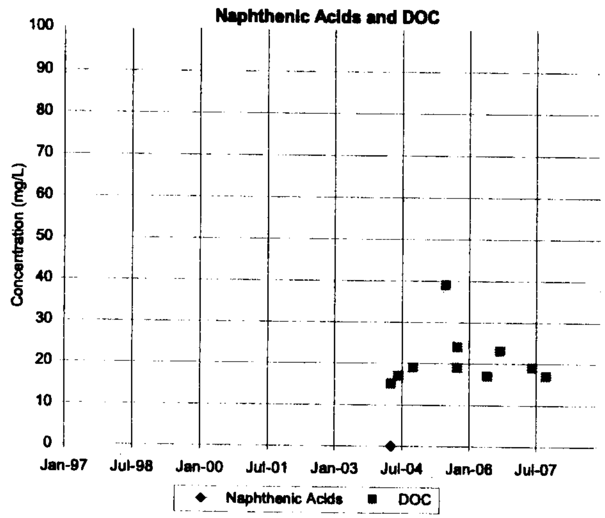

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07
Naphthenic Acids DOC

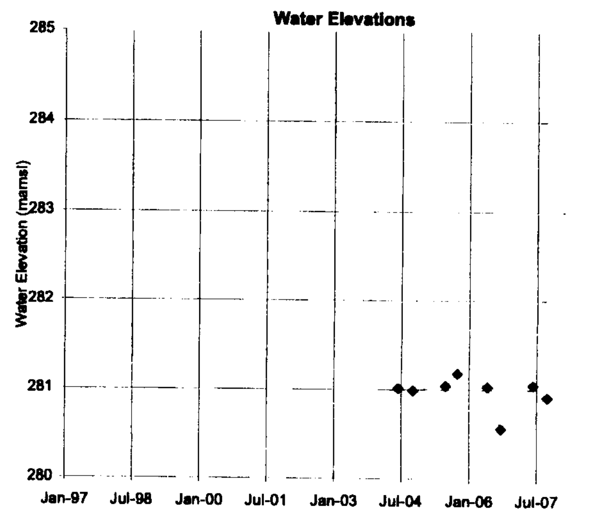

Water Elevations
Water Elevation (mamsl)
292
291
290
289
288
287
Jan-97 Jul-98 Jan-00 Jul-01 Jan-03 Jul-04 Jan-06 Jul-07

OWS0434-15

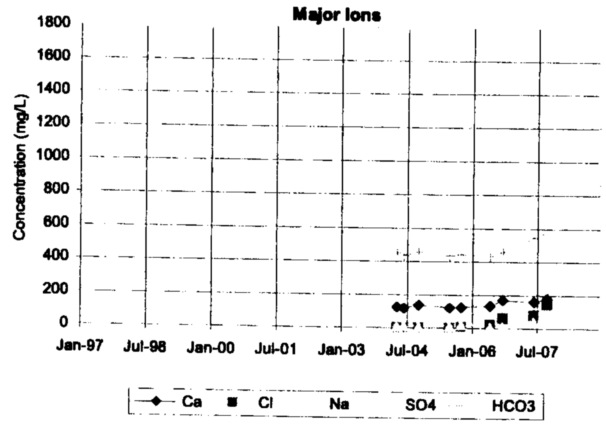

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

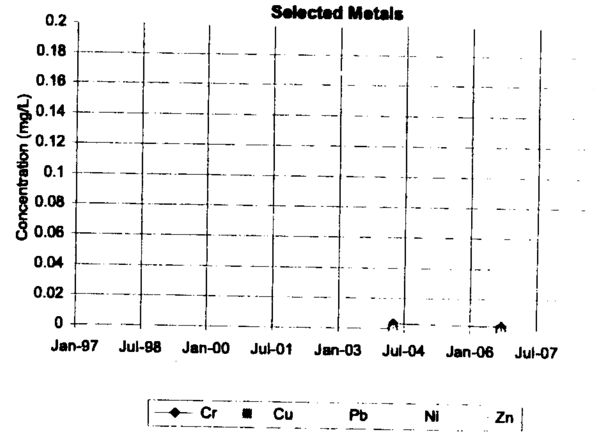

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

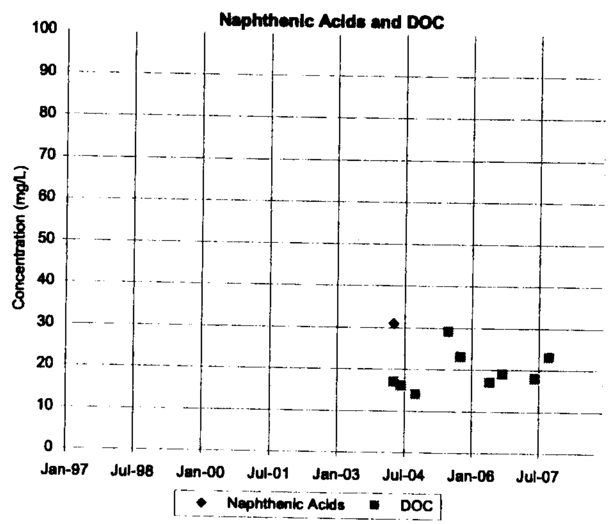

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

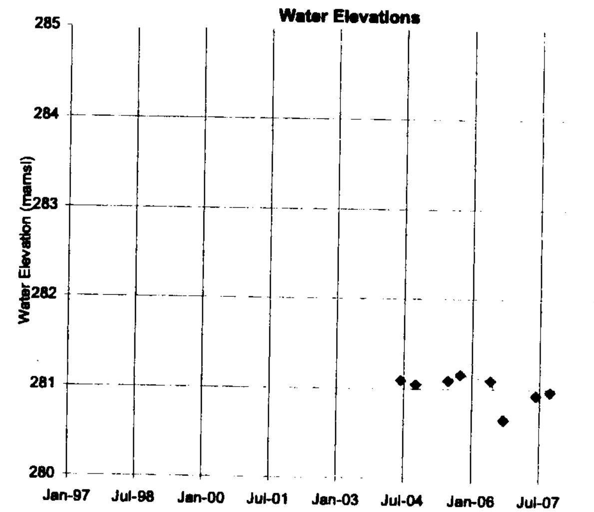

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0434-16

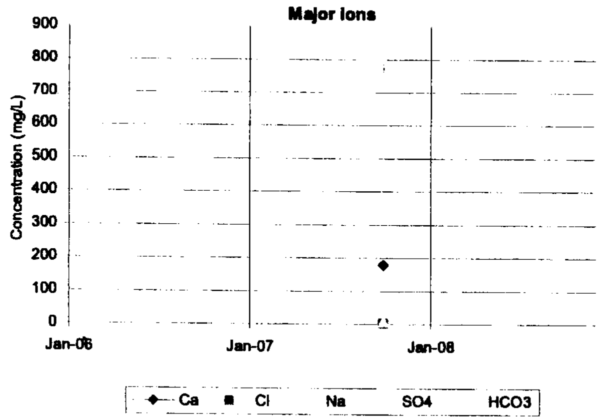

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Ca
Cl
Na
SO4
HCO3

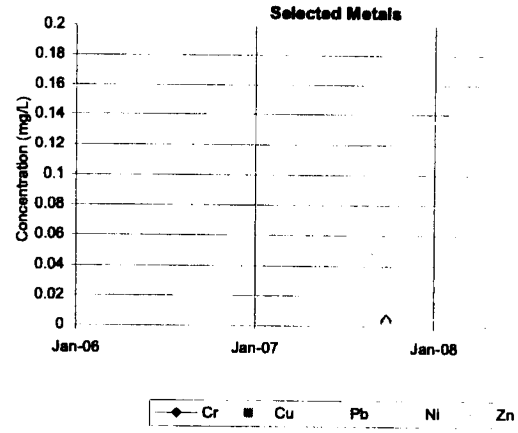

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Cr
Cu
Pb
Ni
Zn

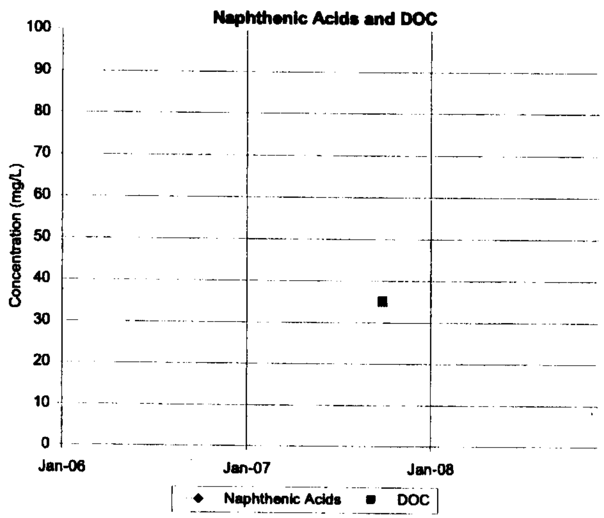

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07
Naphthenic Acids
DOC

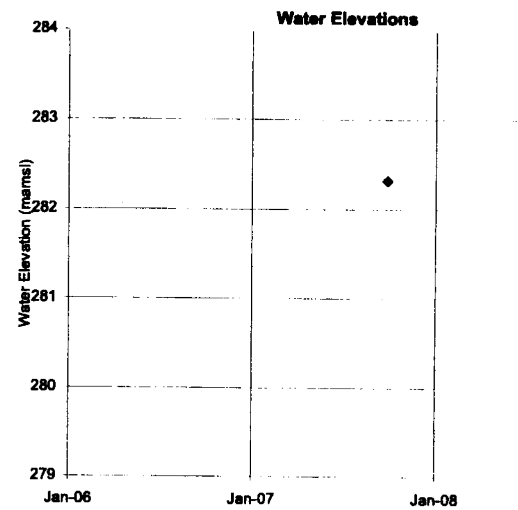

Water Elevations
Water Elevation (mamsl)
285
284
283
282
281
280
Jan-97
Jul-98
Jan-00
Jul-01
Jan-03
Jul-04
Jan-06
Jul-07

OWS0734400

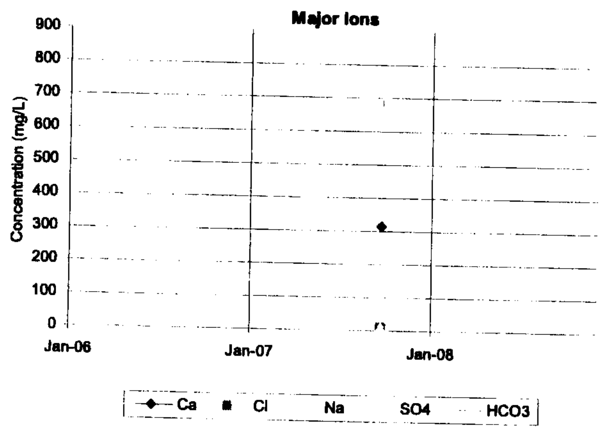

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

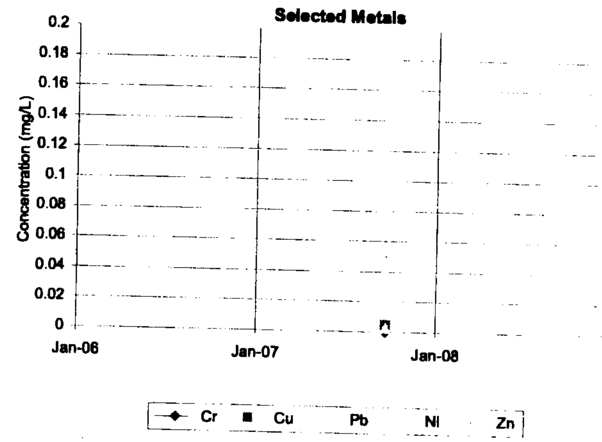

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

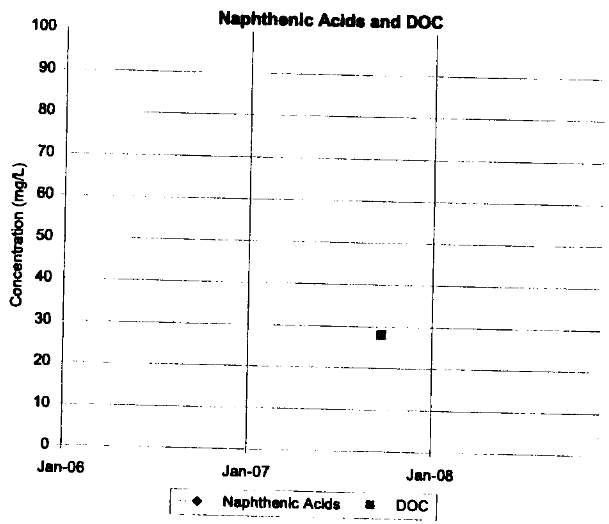

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

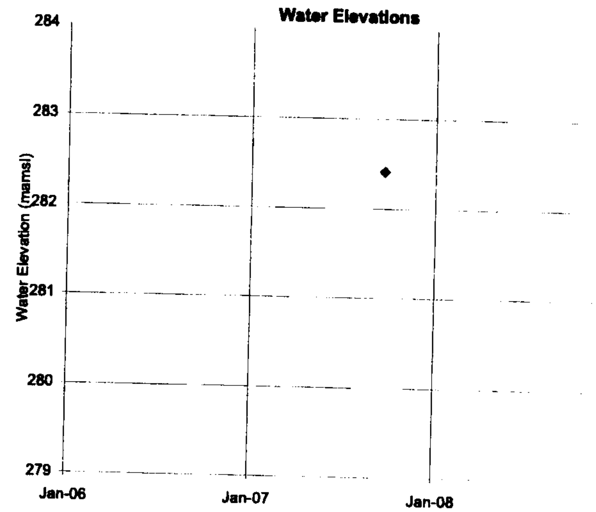

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734405

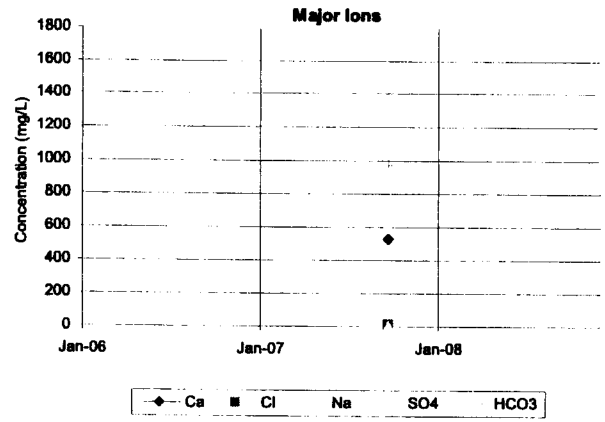

Major Ions
900
800
700
600
500
400
300
200
100
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

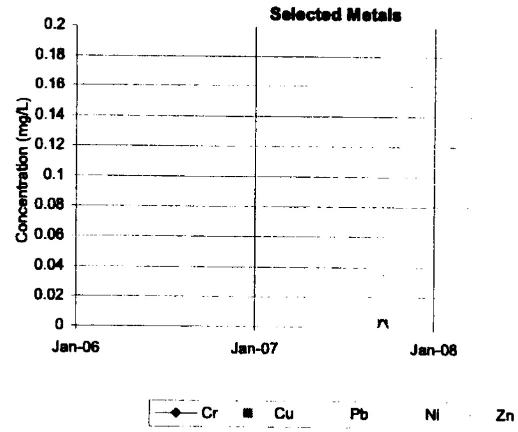

Selected Metals
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

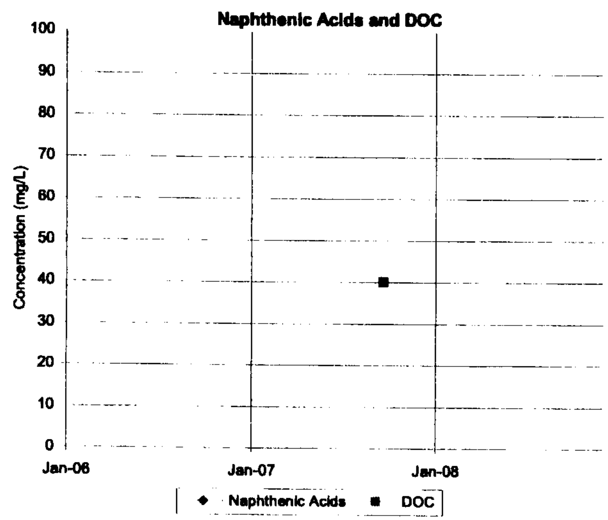

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

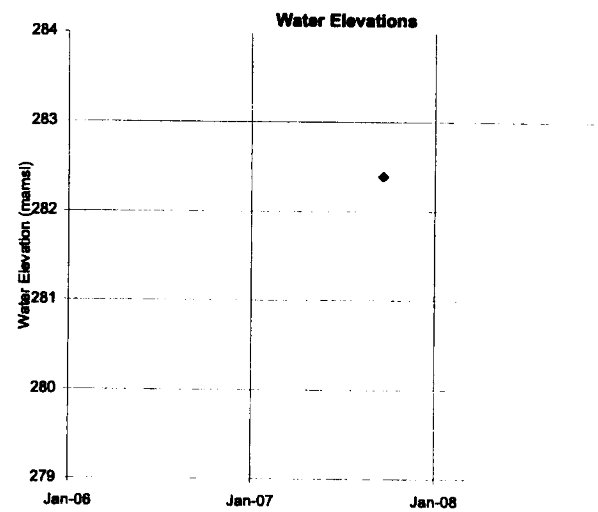

Water Elevations
284
283
282
281
280
279
Water Elevation (mamsl)
Jan-06
Jan-07
Jan-08

OWS0734406

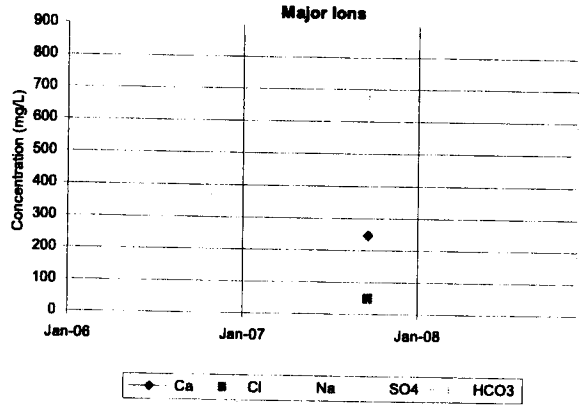

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

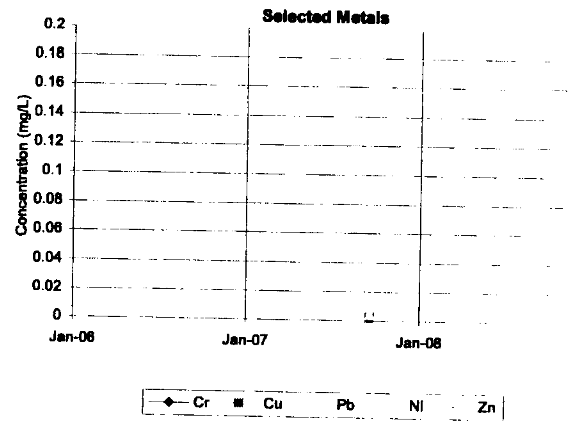

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

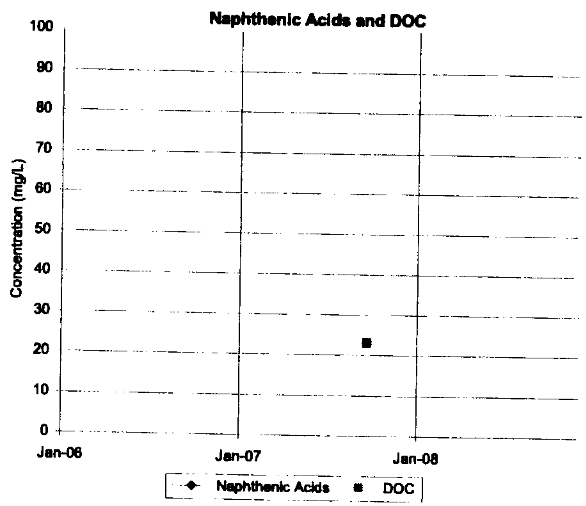

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

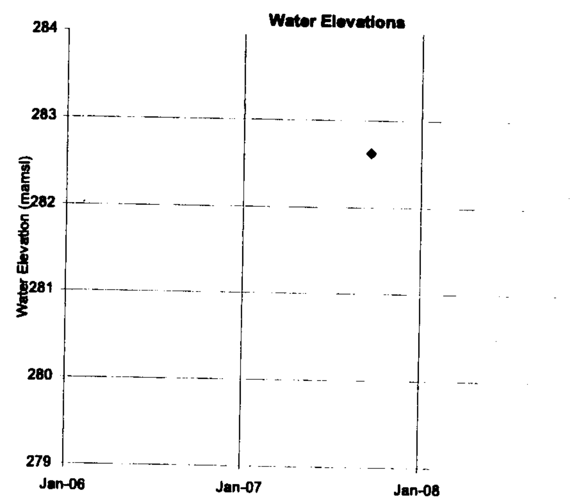

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734407

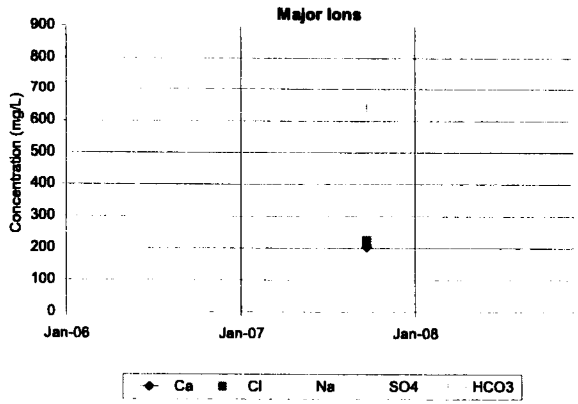

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

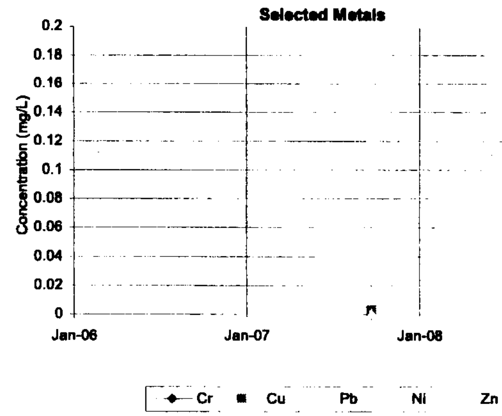

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

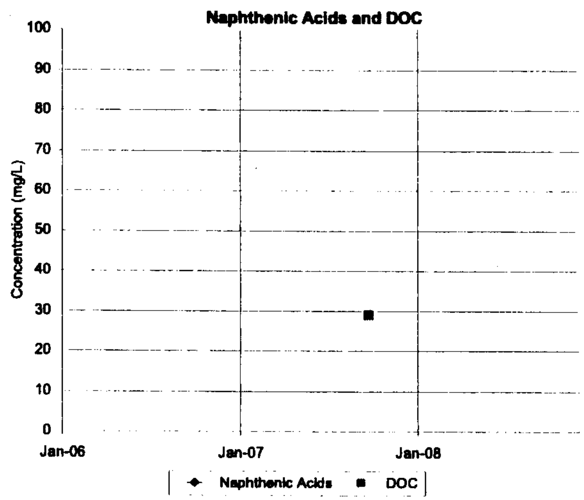

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

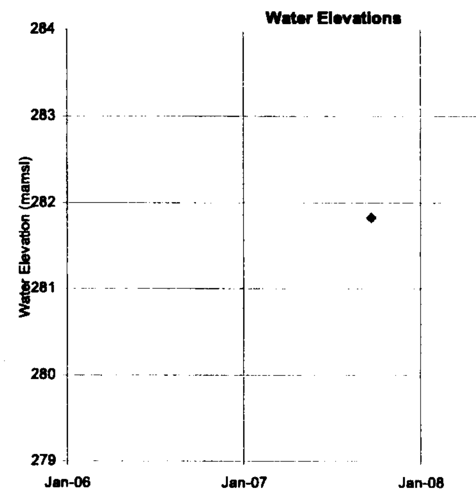

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734408

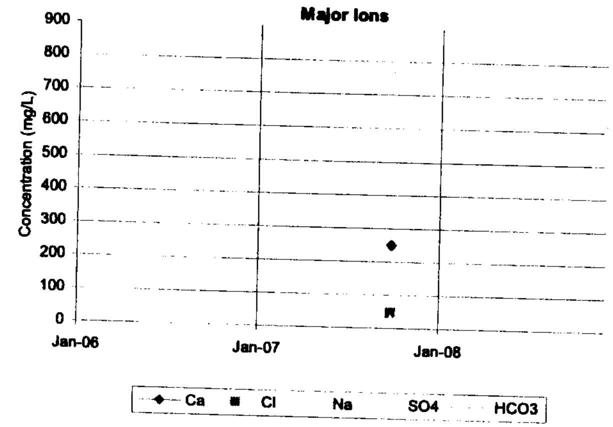

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

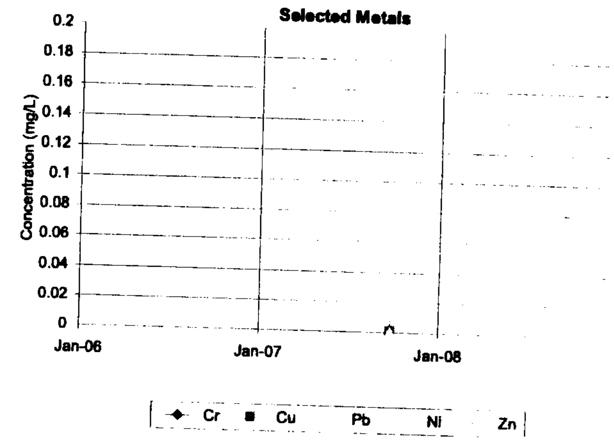

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

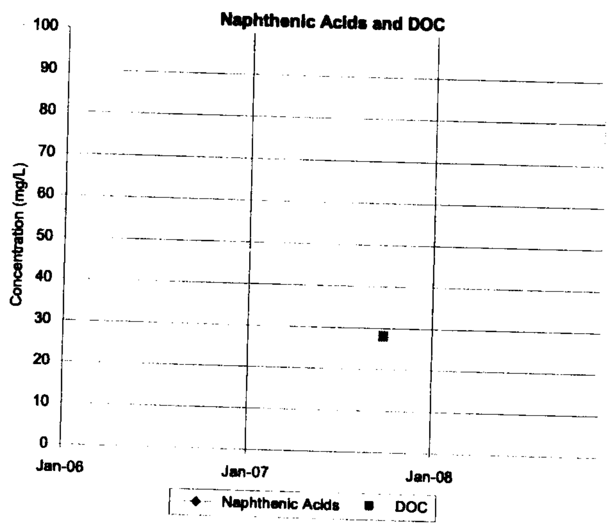

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

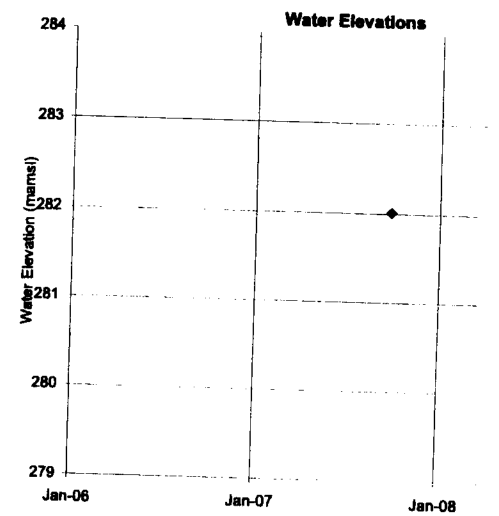

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734409

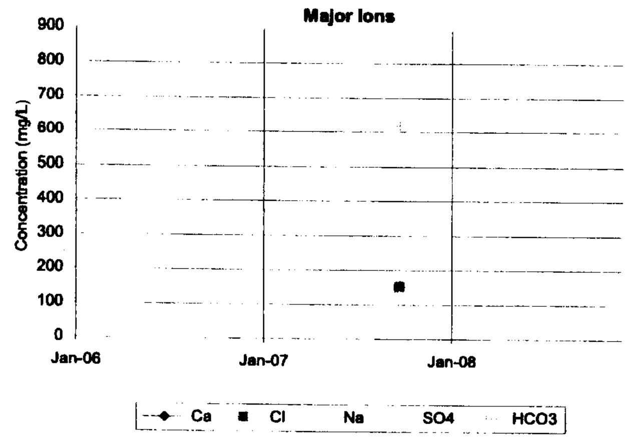

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

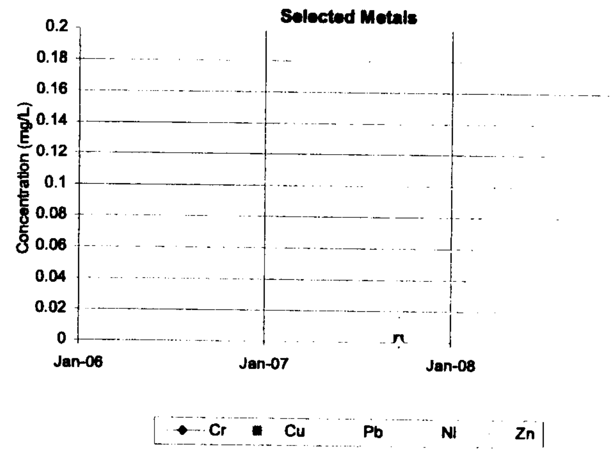

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

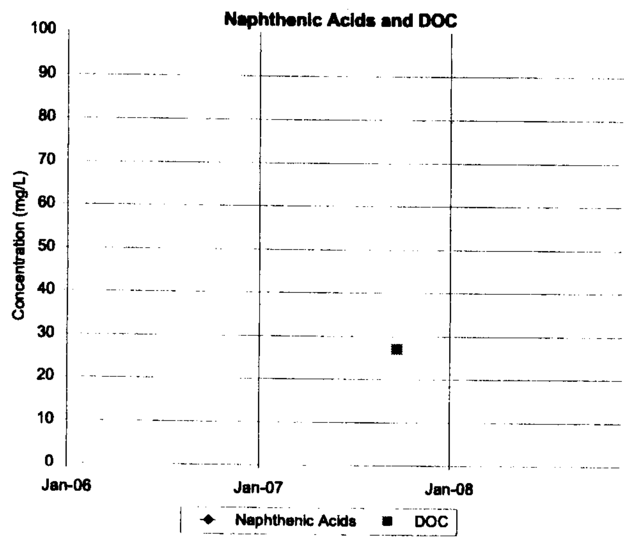

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

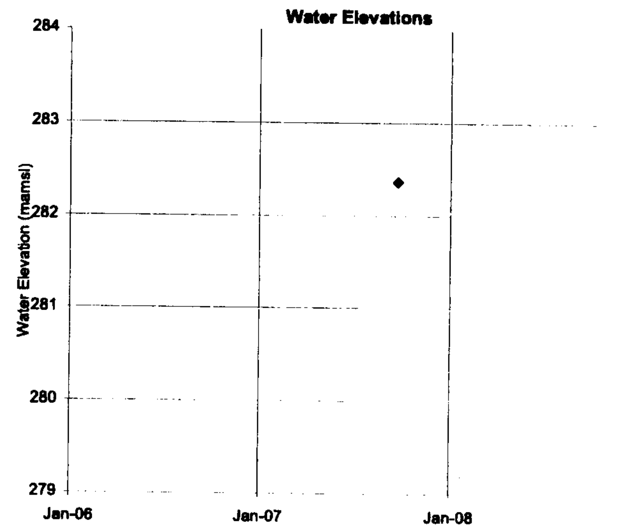

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734410

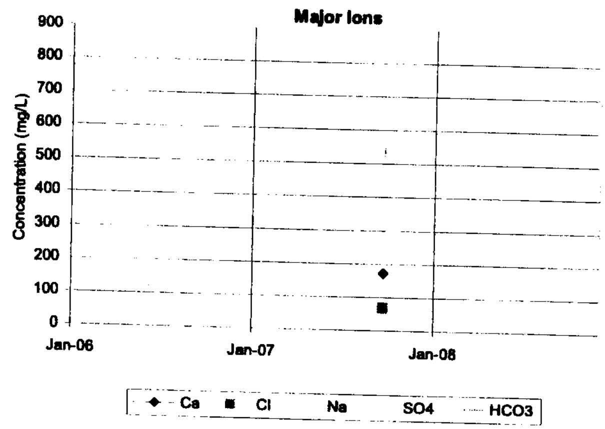

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

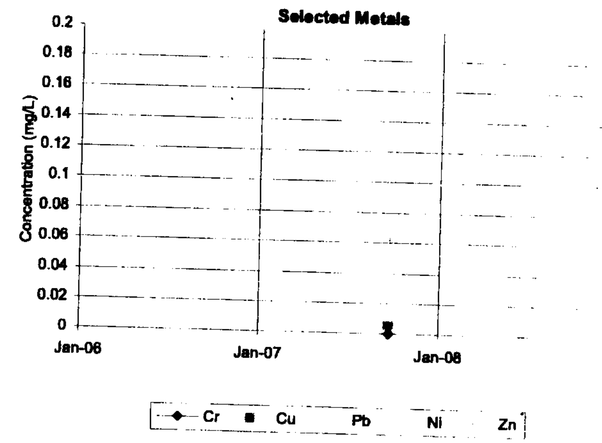

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

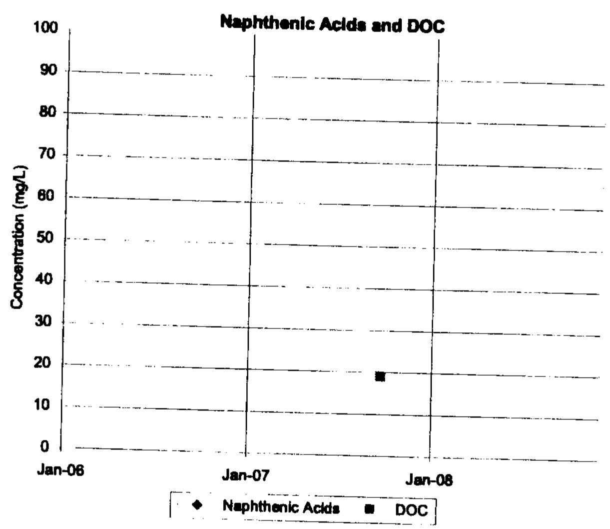

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

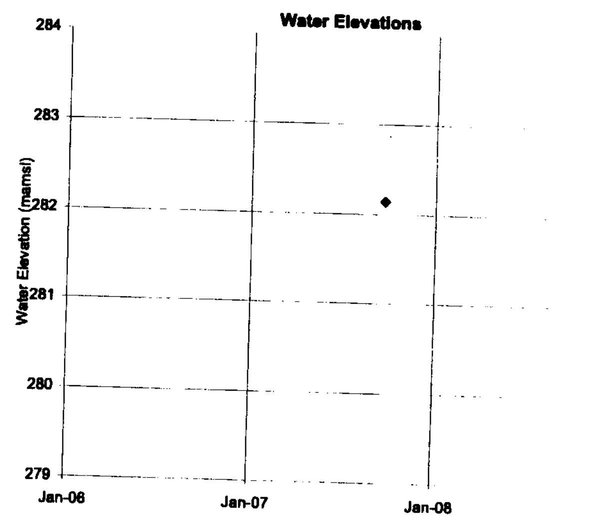

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734411

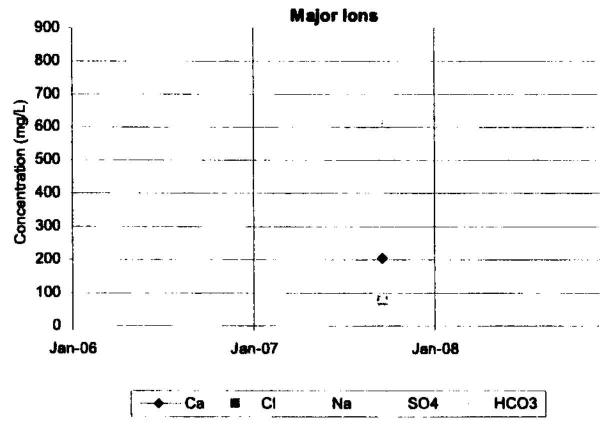

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

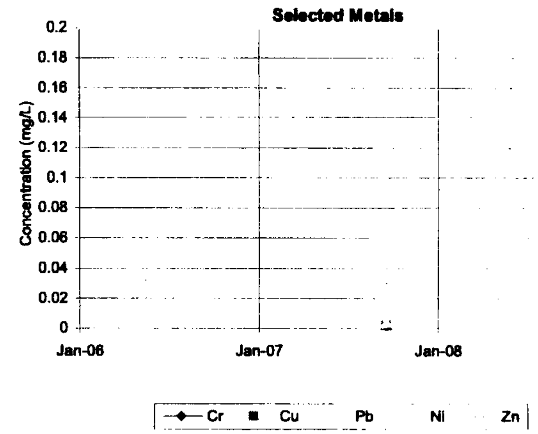

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

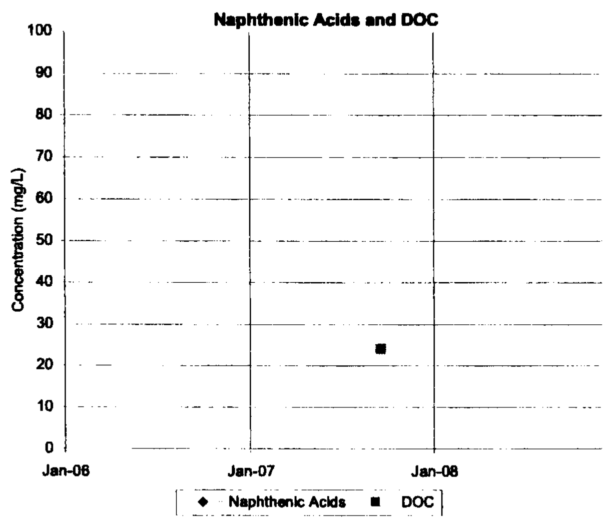

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

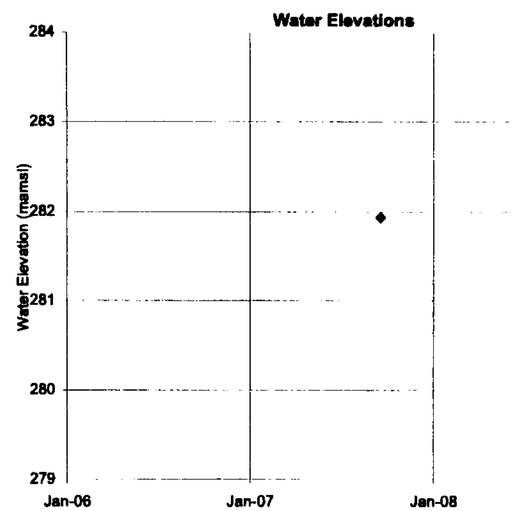

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734412

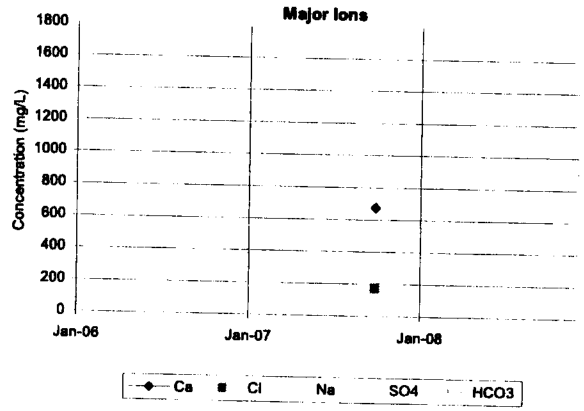

Major Ions
Concentration (mg/L)
900
800
700
600
500
400
300
200
100
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

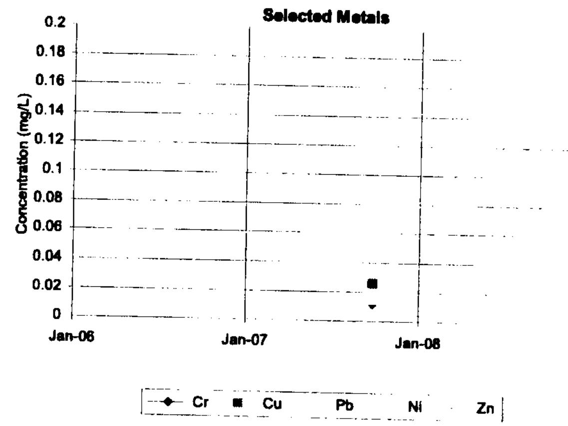

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

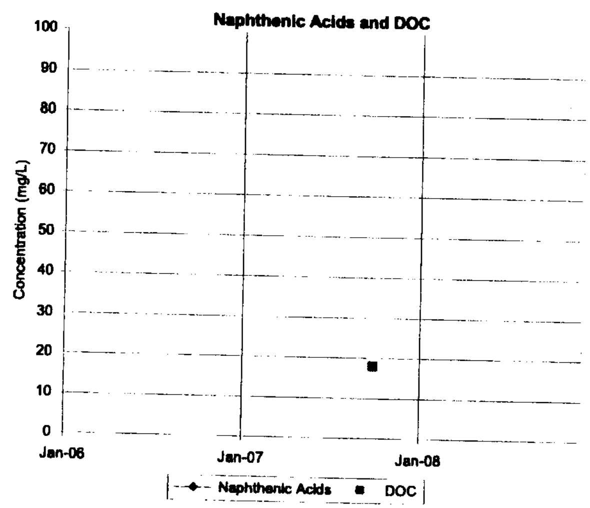

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

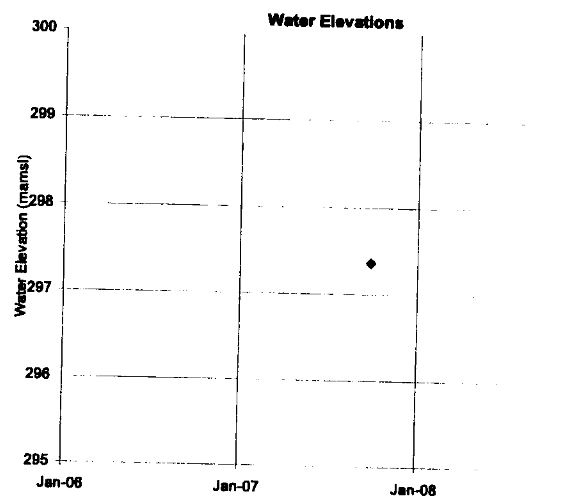

Water Elevations
Water Elevation (mamsl)
284
283
282
281
280
279
Jan-06
Jan-07
Jan-08

OWS0734413

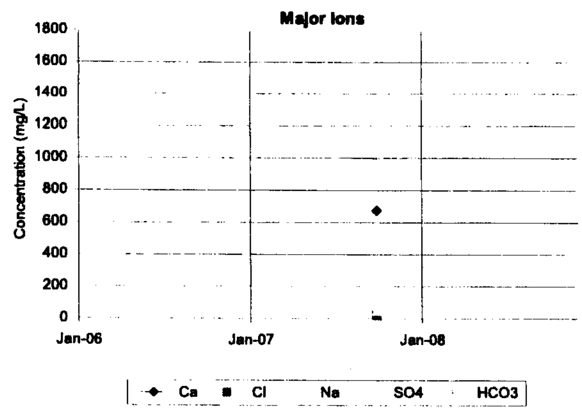

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

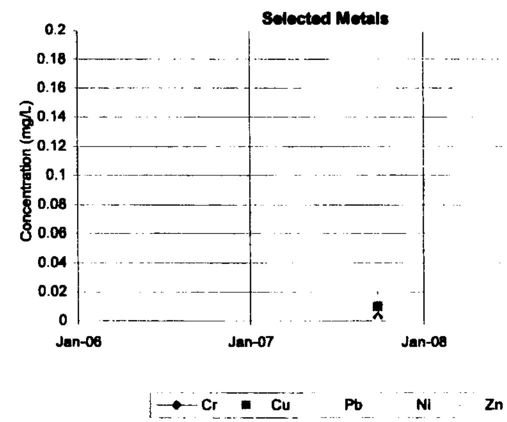

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

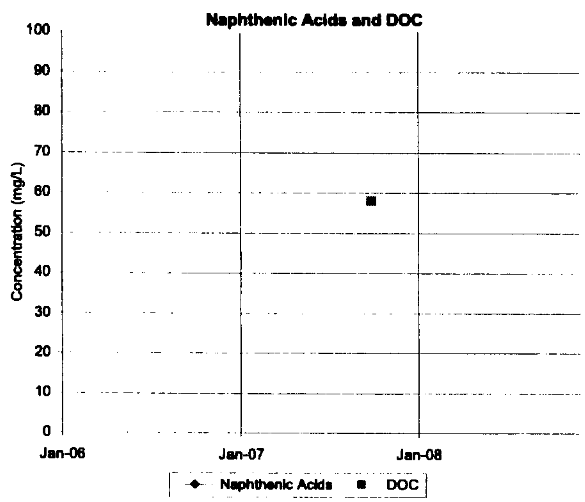

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

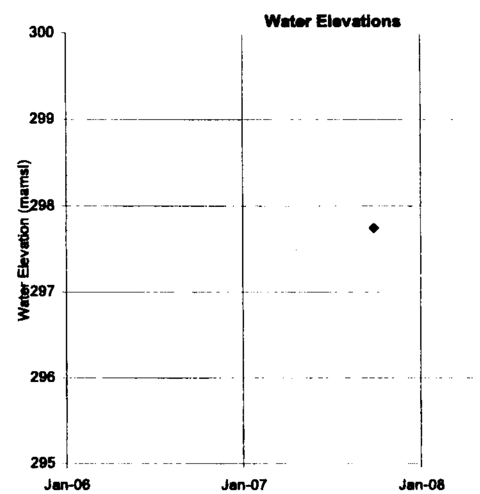

Water Elevations
Water Elevation (mamsl)
300
299
298
297
296
295
Jan-06
Jan-07
Jan-08

OWS0734414

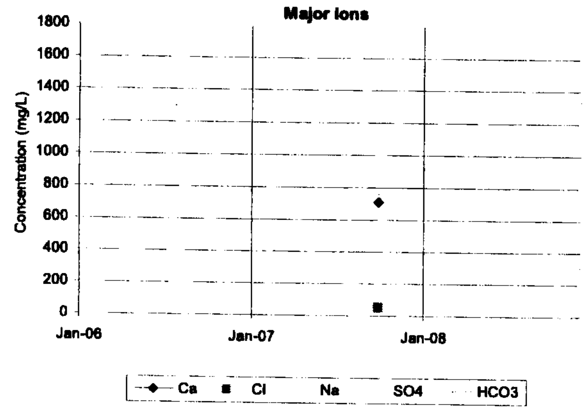

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

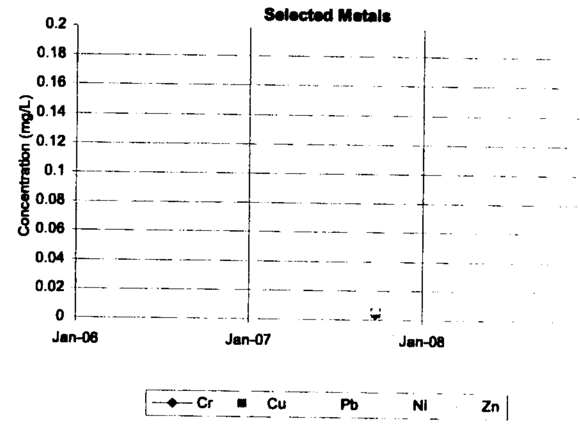

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

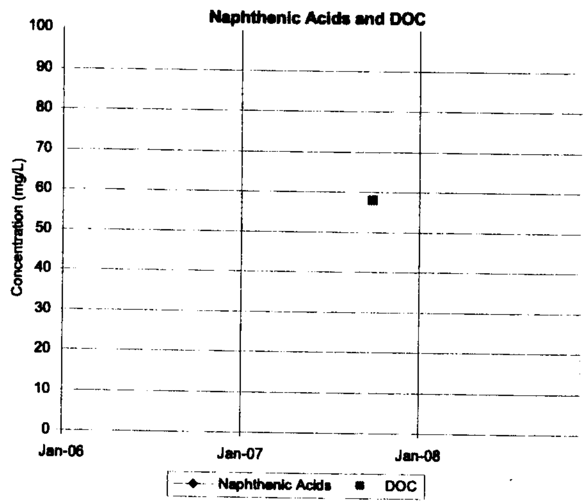

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

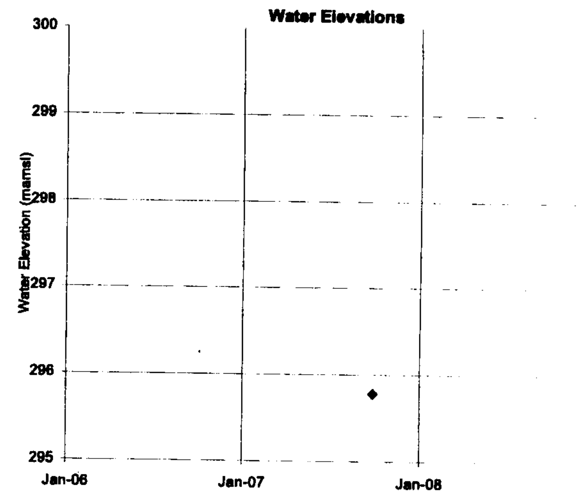

Water Elevations
Water Elevation (mamsl)
300
299
298
297
296
295
Jan-06
Jan-07
Jan-08

OWS0734416

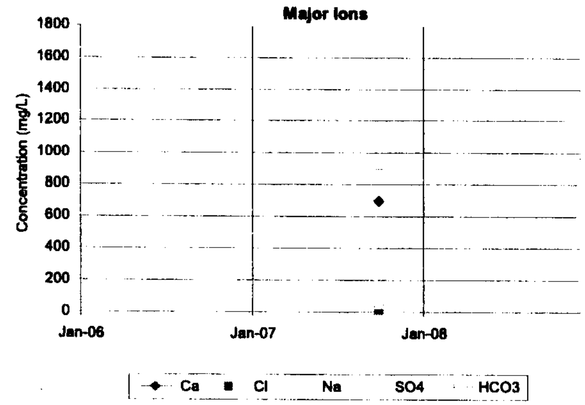

Major Ions
Concentration (mg/L)
1800
1600
1400
1200
1000
800
600
400
200
0
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

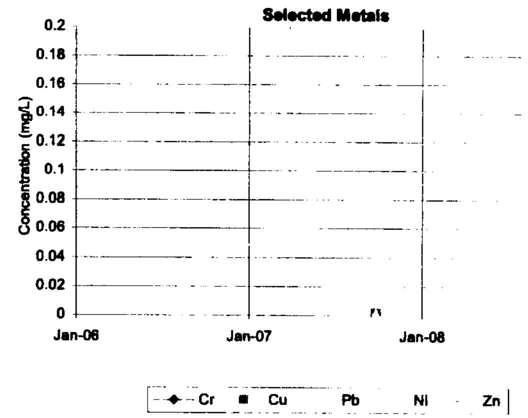

Selected Metals
Concentration (mg/L)
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

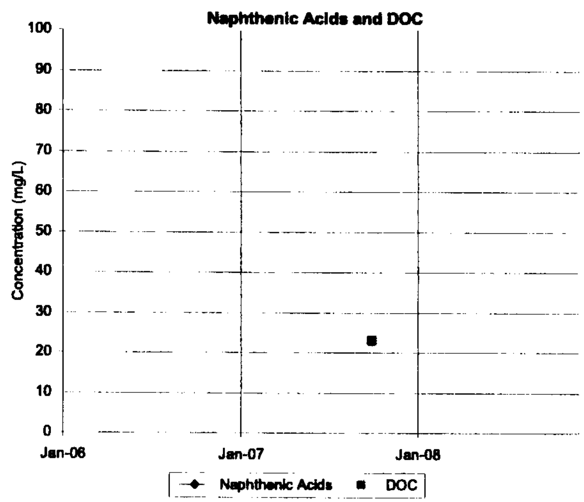

Naphthenic Acids and DOC
Concentration (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

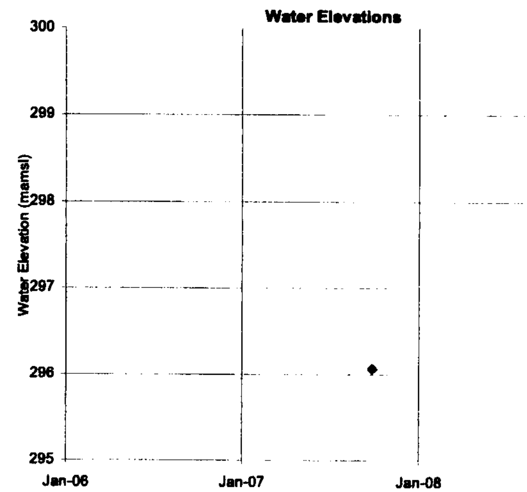

Water Elevations
Water Elevation (mamsl)
300
299
298
297
296
295
Jan-06
Jan-07
Jan-08

OWS0734417

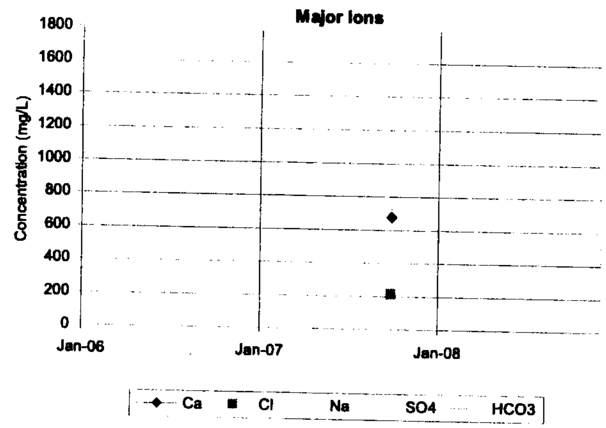

Major Ions
1800
1600
1400
1200
1000
800
600
400
200
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3

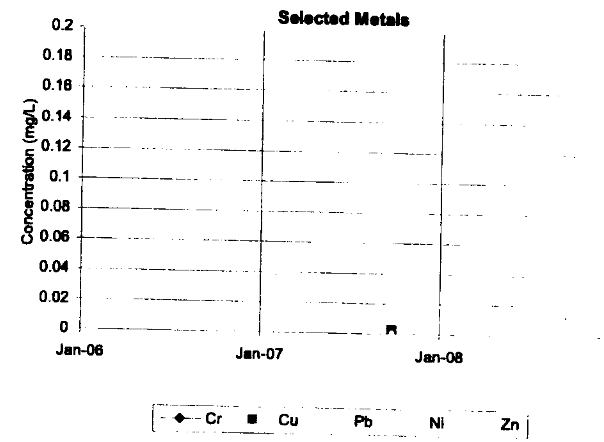

Selected Metals
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn

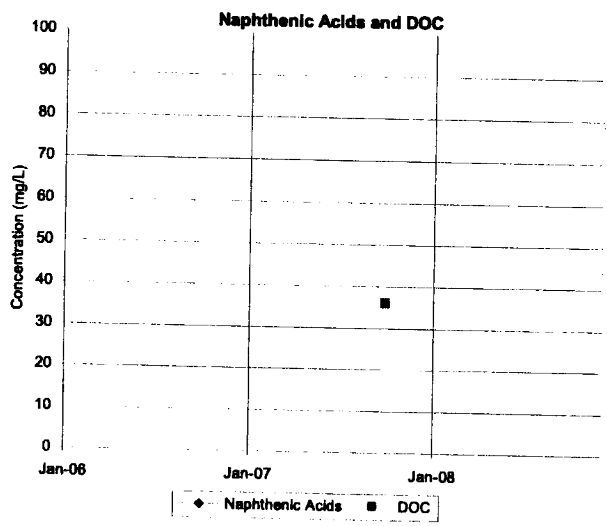

Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC

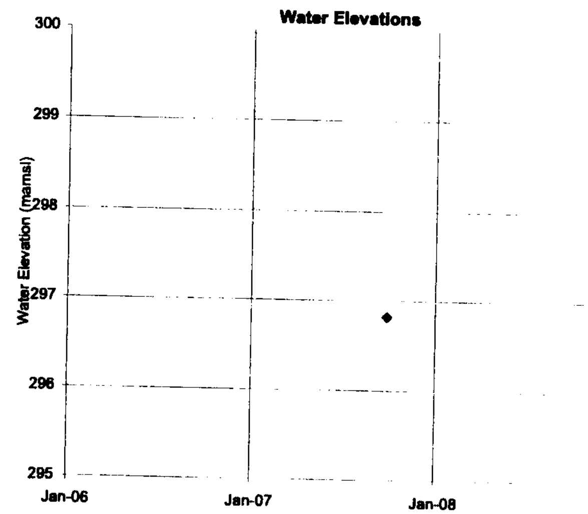

Water Elevations
300
299
298
297
296
295
Water Elevation (mamsl)
Jan-06
Jan-07
Jan-08

OWS0734418


Major Ions
1800
1600
1400
1200
1000
800
600
400
200
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Ca
Cl
Na
SO4
HCO3


Selected Metals
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Cr
Cu
Pb
Ni
Zn


Naphthenic Acids and DOC
100
90
80
70
60
50
40
30
20
10
0
Concentration (mg/L)
Jan-06
Jan-07
Jan-08
Naphthenic Acids
DOC


Water Elevations
300
299
298
297
296
295
Water Elevation (mamsl)
Jan-06
Jan-07
Jan-08

APPENDIX C

ADDITIONAL ANALYTICAL DATA FOR LOCATION ATP BY SYNCRUDE RESEARCH

Table : Properties of Surface and MFT Pore Waters from Syncrude's Aurora Settling Pond: July 27, 2007
Station 1. Surface Elevation 320.3m (AMSL)

	Water Zone	FINE TAILS ZONE				
Depth	**2m**	**10m**	**11m**	**13m**	**15m**	**20m**
General						
Elevation (AMSL) (m)	318	310	309	307	305	300
pH (units)	8.35	8.17	7.86	7.9	7.79	7.78
Conductivity (uS/cm)	2980	3050	3010	2880	2760	2750
Temperature (C)	23.6	12.8	12.2	12.5	12.7	13
Dissolved Solids (% by wt)**	0.175	0.178	0.178	0.164	0.166	0.164
Solids Content (g/100g)	0.04	17.6	26.62	33.46	37.33	35.11
Methylene Blue (mls 6mN/100g)						
Alkalinity (mg.L^{-1})**	566	589	601	679	723	725
Chem. Oxygen Demand (mg.L^{-1})**	194	174		140	138	188
Biol. Oxygen Demand (mg.L^{-1})	2.2					
Dissolved Oxygen (mg.L^{-1})						
Redox Potential (mV)	140	134		128	92	62
Phenols (mg.L^{-1})**	0.01	0.012		0.012	0.011	0.026
Cyanide (mg.L^{-1})**	0.003	0.002		0.002	0.002	0.003
Sulphides (mg.L^{-1})	<0.01	<0.01		<0.01	<0.01	<0.01
Total Pet. Hydrocarbon (mg.L^{-1})	11.6					
Bitumen Content (% by wt)		0.29	0.42	4.94	1.54	4.54
Naphtha Content (% by wt)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dis. Organic Carbon (mgC.L^{-1})**	45	44		35	34	57
Naphthenic Acids (mg.L^{-1})	79.6	79.9		58.8	49.3	63.3
Tannin&Lignin (mg.L^{-1})**	1	1.4		1.3	1.4	3.5
Surfactants (MBAS) (mg.L^{-1})**	1	1		1	1	1
Hardness (as $CaCO_3$)**	107	118	142	119	184	191
Acute Toxicity						
IC_{50} (% by vol)						
IC_{20} (% by vol)						
Nutrients						
o-Phosphate (mgP.L^{-1})	0.016	0.012		0.011	0.011	0.063
Total Phosphorous (mgP.L^{-1})	0.06	0.06		0.06	0.06	0.08
Ammonia (mgN.L^{-1})	4.21	3.92	3.38	2.71	3.15	3.21
Nitrate + Nitrite (mgN.L^{-1})	0.072	0.01		0.003	0.003	
Total Nitrogen (mgN.L^{-1})	4.15	4.84		3.5	3.28	3.81
Major Ions (mg. L^{-1})						
I) Cations						
Na^+	613	611	590	543	522	529
K^+	18	23	31	15	16	17
Mg^{++}	13	15	19	16	22	17
Ca^{++}	21	22	25	21	37	43
II) Anions						
F^-	BDL	BDL	BDL	BDL	BDL	BDL
Cl^-	380	380	370	390	400	410
$SO_4^=$	337	324	292	101	27.1	13.3
$CO_3^=$	0	17.7	16.8	7.8	0	0
HCO_3^-	691	683	699	812	882	884

* Samples from Station1 in Aurora TP, July 27, 2007: 6352700N, 474400E (UTM). Surface elevation: 320.5m (AMSL). ** Fine Tails Pore Water (centrifuged at 30 000g and 0.45u filter-passing)

Table : Properties of Surface Zone Waters from Syncrude's Aurora Settling Basin: 2002-2007

VARIABLES	Surface Zone Waters of ATP					
	2007	2006	2005	2004	2003	2002
General						
Surface Elevation (AMSL) (m)	318	315	310	305	301	
pH (units)	8.35	8.14	8.26	7.97	8.15	8.18
Conductivity (uS/cm)	2980	2750	2500	2330	2330	2290
Temperature ©	23.6					
Dissolved Solids (% wt)**	0.175	0.172	0.162	0.15	0.153	0.153
Solids Content (g/100g)	0.04	<0.01	<0.01	0.03	0.155	0.163
Alkalinity ($mg.L^{-1}$)**	566	529	492	525		
COD ($mg.L^{-1}$)**	194	186	152	146		
BOD ($mg.L^{-1}$)	2.2	0.5	0.5	1.4		
DO ($mg.L^{-1}$)				-		
Eh (mV)	140	71		249		
Phenols ($mg.L^{-1}$)**	0.01	0.007	0.002	<0.01		
Cyanide ($mg.L^{-1}$)**	0.003	0.002	0.002	0.003		
Sulphides ($mg.L^{-1}$)	<0.01			<0.01		
TPH ($mg.L^{-1}$)	11.6	2	14	2		
Bitumen Content (% by wt.)						
Naphtha Content (% by wt)	<0.01					
DOC ($mgC.L^{-1}$)**	45	36	34.9	36.2		
Naphthenic Acids (mg/L)	79.6	62.5	54	46.5	34	35
Tannin&Lignin ($mg.L^{-1}$)**	1	1	<0.5	0.5		
Surfactants (MBAS) ($mg.L^{-1}$)**	1	1	1	<0.7		
Hardness (as $CaCO_3$)**	107	147	165	219	237	205
IC_{50} (% by vol)			-	>100	100	100
IC_{20} (% by vol)			-	82	51	25
o-Phosphate ($mgP.L^{-1}$)	0.016	0.012	0.008	0.019	BDL	BDL
Tot. Phosphorous ($mgP.L^{-1}$)	0.06	0.02	0	0.09	BDL	BDL
Ammonia ($mgN.L^{-1}$)	4.21	2.45	1.24	1.5	1.64	0.01
Nitrate + Nitrite ($mgN.L^{-1}$)	0.072	1.3	0.19	0.284		
Tot. Nitrogen ($mgN.L^{-1}$)	4.15	1.3	1.8	2.68		
Major Ions (mg/L)						
i) Cations						
Sodium (Na^+)	613	576	542	495	483	459
Potassium (K^+)	18	22.8	19.3	17.5	15.8	14.4
Magnesium (Mg^{++})	13	18.6	18.6	21.6	21.9	19.7
Calcium (Ca^{++})	21	27.9	34.8	51.6	58.4	49
ii) Anions						
Fluoride (F^-)	BDL	<0.01	<0.01	<0.01	<0.01	<0.01
Chloride (Cl^-)	380	380	365	370	350	385
Sulphate ($SO_4^=$)	337	273	243	201	174	145
Carbonate ($CO_3^=$)	0	16.5	0	0	0	0
Bicarbonate (HCO_3^-)	691	612	600	640	594	633

Table : Trace and Major Elements in Aurora Settling Pond Waters: 2007

		Surface Zone ("Free" Water) **	Fine Tails Zone (Pore Water)**				
Depth	units	**2m**	**10m**	**11m**	**13m**	**15m**	**20m**
Trace							
Aluminum (Al)	mg/L	0.2	0		0.6	0	0
Antimony (Sb)	mg/L	0.008	0.003		0.002	0.001	0
Arsenic (As)	mg/L	<0.001	<0.001		0.006	0.006	<0.001
Barium (Ba)	mg/L	0.25	0.22		0.17	0.79	0.83
Beryllium (Be)	mg/L	<0.001	<0.001		<0.001	<0.001	<0.001
Boron (B)	mg/L	1.4	2.3		2.7	2.7	2.1
Cadmium (Cd)	mg/L	<0.001	<0.001		<0.001	<0.001	<0.001
Calcium (Ca)	mg/L	21	22	25	21	37	43
Chromium (Cr)	mg/L	<0.001	<0.001		<0.001	<0.001	<0.001
Cobalt (Co)	mg/L	0.008	0.007		<0.001	<0.001	<0.001
Copper (Cu)	mg/L	0.006	0.008		<0.001	0.002	<0.001
Iron (Fe)	mg/L	<0.001	<0.001		0.003	0.004	0.003
Lead (Pb)	mg/L	<0.001	<0.001		<0.001	0.6	0.7
Lithium (Li)	mg/L	0.2	0.2		<0.001	<0.001	<0.001
Magnesium (Mg)	mg/L	13	15	19	16	22	20
Manganese (Mn)	mg/L	0.07	0.12		0.02	0.09	0.25
Mercury (Hg)	mg/L	<0.05	<0.05		<0.05	<0.05	<0.05
Molybdenum (Mo)	mg/L	0.11	0.105		0.052	0.018	0.006
Nickel (Ni)	mg/L	0.013	0.016		0.009	0.008	0.008
Potassium (K)	mg/L	18	23	31	15	16	17
Selenium (Se)	mg/L	<0.005	<0.005		<0.005	<0.005	<0.005
Silicon (Si)	mg/L	2.1	2.8		4	4.7	5.6
Silver (Ag)	mg/L	<0.0005	<0.0005		<0.0005	<0.0005	<0.0005
Sodium (Na)	mg/L	613	611	590	543	522	529
Strontium (Sr)	mg/L	0.7	0.8		0.8	1.1	0.9
Sulphur (S)	mg/L	80	87	81	22	12	6
Thallium (Tl)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Tin (Sn)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Titanium (Ti)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Uranium (U)	mg/L	0.009	0.008	0.008	0.009	0.003	0.006
Vanadium (V)	mg/L	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Zinc (Zn)	mg/L	0.15	0.15	0.13	0.11	0.09	0.07
Zirconium (Zr)	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

*Dissolved: 0.45u filter-passing. Analyzed using ICP/MS (except As, Se, Sb by Hydride AA and Hg by Cold Vapour AA) by Maxxam Analytical. All values expressed in mg/L.

** Samples from Station1 in Aurora TP, July 27, 2007: 6352700N, 474400E (UTM). Surface elevation: 320.5m (AMSL). Fine Tails Pore Water (centrifuged at 30 000g and 0.45u filter-passing)

Table : PAH Concentrations in Surface and Fine Tails Zones of Aurora TP: 2007 **APPENDIX C**

	Mol wt	PAH Concentrations (mg/kg)				
		Surface	Fine Tails Zone			
Depth		2m	10m	13m	15m	20m
Solids Content (wt%)**		<0.02		23.6	36.4	39.4
Hydrocarbon (wt%)**		<0.01		0.86	2.49	5.43
Naphtha (wt%)**		<0.01		<0.01	,0.07	
Naphthalene*	128	<0.0001	0.36	0.07	<0.5	<0.5
Methyl naphthalene	142	<0.0001	0.59	0.11	<0.5	<0.5
C2-Subst'd Naphthalene	156	<0.0001	0.65	0.14	<0.5	<0.5
C3-Subst'd Naphthalene	170	<0.0001	0.42	0.19	4.0	4.3
C4-Subst'd Naphthalene	184	<0.0001	0.28	0.70	9.8	8.4
Benzo(b)thiophene	134	<0.002	<0.2	<0.2	<0.2	<0.2
Methyl Benzo(b)thiophene	148	<0.002	<0.2	<0.2	<0.2	<0.2
C2 sub'd Benzo(b)thiophene	162	<0.004	<0.4	<0.4	<0.4	<0.4
C3 sub'd Benzo(b)thiophene	176	<0.004	<0.4	<0.4	<0.4	<0.4
C4 sub'd Benzo(b)thiophene	190	<0.004	<0.4	<0.4	<0.4	<0.4
Acenaphthylene*	152	<0.0001	<0.05	<0.05	<0.5	<0.5
Acenaphthene*	154	<0.0001	<0.05	<0.05	<0.5	<0.5
Methyl Acenaphthene	168	<0.0001	<0.05	<0.05	0.6	0.5
Fluorene*	166	<0.0001	<0.05	<0.05	<0.5	<0.5
Methyl Fluorene	180	<0.0001	0.09	0.30	3.1	3.3
C2-Subst'd Fluorene	194	<0.0001	0.21	0.92	9.5	9.8
C3-Subst'd Fluorene	208	<0.0001	0.36	1.4	13	13
Biphenyl	154	<0.0001	0.09	<0.05	<0.5	<0.5
Methyl Biphenyl	168	<0.0001	<0.05	<0.05	<0.5	<0.5
C2-Subst'd Biphenyl	182	<0.0001	<0.05	<0.05	<0.5	<0.5
Phenanthrene*	178	<0.0001	0.09	<0.05	1.8	1.9
Anthracene*	178	<0.0001	<0.05	<0.05	<0.5	<0.5
Methyl Phenan/Anthracene	192	<0.0001	0.26	0.66	17	17
C2-Subst'd Phenan/Anthracene	206	<0.0001	0.76	3.0	30	30
C3-Subst'd Phenan/Anthracene	220	<0.0001	0.88	3.0	27	26
C4-Subst'd Phenan/Anthracene	234	<0.0001	1.5	4.0	38	33
Retene (1-Methyl-7-Isopropyl-Phenanthrene)	219	<0.0001	<0.05	0.16	0.8	0.7
Dibenzothiophene*	184	<0.0001	<0.05	0.07	<0.5	<0.5
Methyl Dibenzothiophene	198	<0.0001	0.15	0.63	5.8	5.8
C2-Subst'd Dibenzothiophene	212	<0.0001	0.51	2.3	22	23
C3-Subst'd Dibenzothiophene	226	0.0002	0.86	3.3	27	26
C4-Subst'd Dibenzothiophene	240	<0.0001	0.80	2.4	21	20
Fluoranthene*	202	<0.0001	<0.05	<0.05	<0.5	<0.5
Benzo(j)fluoranthene	252	<0.0001	<0.05	<0.05	<0.5	<0.5
Pyrene*	202	<0.0001	0.07	0.13	1.0	1.0
Methyl Pyrene/Fluoranthene	216	<0.0001	0.22	0.46	3.6	3.9
C2 sub'd fluoranthene/pyrene	230	0.0001	0.29	0.73	5.6	5.9
C3 sub'd fluoranthene/pyrene	244	<0.0001	0.30	0.89	7.3	7.9
Benzo(a)Anthracene/ Chrysene *	228	<0.0001	0.12	0.35	3.2	3.4
Chrysene	228	<0.0001				
Methyl Chrysene/Benz(a)Anthrac.	242	<0.0001	0.20	0.56	4.7	5.0
C2-Subst'd Chrysene/Benz(a)Anthrac.	256	<0.0001	0.25	0.66	5.2	5.8
Benzo[b&k]Fluoranthene*	252	<0.0001	<0.05	<0.05	<0.5	<0.5
Benzo[a]Pyrene*	252	<0.0001	<0.05	<0.05	<0.5	<0.5
Methyl Benzo[a] Pyrene /Benzo[b&k]Fluoranthene	266	<0.0001	0.11	0.23	2.7	2.9
C2-Subst'd Benzo[a] Pyrene /Benzo[b&k]Fluoranthene	280	<0.0001	<0.05	0.28	2.0	1.9
Indeno[c,d-1,2,3]Pyrene*	276	<0.0001	<0.05	<0.05	<0.5	<0.5
Dibenzo[a,h]Anthracene*	278	<0.0001	<0.05	<0.05	<0.5	<0.5
Benzo[g,h,i]Perylene*	276	0.0004	<0.05	<0.05	<0.5	<0.5

Priority PAH's as defined in the US EPA Protocol (Method 625) plus alkyl derivatives.

GC/MS analyses performed by Enviro-Test Laboratories, Edmonton, Alberta.

* Samples from Station 1 in Aurora TP, July 27, 2007: 6352700N, 474400E (UTM). Surface elevation: 320.5m (AMSL)

APPENDIX C

Table : Fractionation of extractable organics in Aurora TP: 2007

A) Extractable Organics: Gravimetric Analysis

SAMPLE	FRACTIONS OF EXTRACTABLE ORGANIC MATERIAL				
	ACID EXTRACT*	BASE/NEUTRAL EXTRACT**			
		Total	Alumina Column Fractions		
			Fraction 1	Fraction 2	Fraction 3
a. "Free Water" Zone (ug/L) [a]					
1. Total Sample (2m)	55000	<8000	<8000	<8000	<8000
2. Dissolved Fraction (2m)					
b. Fine Tails Zone **(mg/kg of dry weight)** [b]					
2. Fine Tails (includes SPM and Bitumen) (mg/kg of dry weight)					
Depth: 10m	6200	2600	<1000	<1000	<1000
Depth: 13m	2500	11000	4900	1300	<500
Depth: 15m	9700	100000	41000	20000	1500
Depth: 20m	5400	110000	43000	17000	1100
Depth: 20m(duplicate)	4100	94000	36000	18000	2000

* acid (pH=2) partition of the dichloromethane soxhlet extraction of sample (see following Table for Elution Profile).

** base/neutral partition of dichloromethane extract of sample. B/N extract separated into three fractions on an alumina column based on polarity. NB. Volatile components less than C7 not included. Quantitation by gravimetric analysis of each fraction.

a) Detection Limit: 8000ug/L b) Detection Limit: 500 or 1000mg/kg

Samples from Station 1 in Aurora TP, July 27, 2007: 6352700N, 474400E (UTM). Surface elevation: 320.5m (AMSL)

**** Elution Profile of Alumina Adsorbent for Base/Neutral Extract**

FRACTION	ELUTION SOLVENT	CHEMICAL CLASS REPRESENTED (based on polar character)
1	Pentane	Saturates/Olefins and MonoAromatics
2	Benzene	PAH's and Polycyclic Aromatic Sulphur Hydrocarbons
3	Chloroform	PAHN's Heterocyclics

B.) Extractable Organics: GC/FID Analysis

SAMPLE	FRACTIONS OF EXTRACTABLE ORGANIC MATERIAL				
	ACID EXTRACT*	BASE/NEUTRAL EXTRACT**			
		Total	Alumina Column Fractions		
			Fraction 1	Fraction 2	Fraction 3
a. "Free Water" Zone (ug/L) [a]					
1. Total Sample (2m)	38000	5200	1700	720	650
2. Dissolved Fraction (2m)					
b. Fine Tails Zone **(mg/kg of dry weight)** [b]					
2. Fine Tails (includes SPM and Bitumen) (mg/kg of dry weight)					
Depth: 10m	170	2500	1500	380	20
Depth: 13m	760	8000	5500	1200	120
Depth: 15m	4700	61000	40000	11000	900
Depth: 20m	3900	59000	39000	9000	780
Depth: 20m(duplicate)	2500	56000	35000	9600	780

* acid (pH=2) partition of the dichloromethane soxhlet extraction of sample (see following Table for Elution Profile).

** base/neutral partition of dichloromethane extract of sample. B/N extract separated into three fractions on an alumina column based on polarity. NB. Volatile components less than C7 not included. Quantitation by GC/FID of each fraction.

a) Detection Limit: 50ug/L b) Detection Limit: 20mg/kg

Samples from Station 1 in Aurora TP, July 27, 2007: 6352700N, 474400E (UTM). Surface elevation: 320.5m (AMSL)

**** Elution Profile of Alumina Adsorbent for Base/Neutral Extract**

FRACTION	ELUTION SOLVENT	CHEMICAL CLASS REPRESENTED (based on polar character)
1	Pentane	Saturates/Olefins and MonoAromatics
2	Benzene	PAH's and Polycyclic Aromatic Sulphur Hydrocarbons
3	Chloroform	PAHN's Heterocyclics

Table : Concentrations of BTEX VOCs in Aurora TP: 2007

COMPOUND	SOURCE OF SAMPLE				
	SURFACE ZONE WATERS	*FINE TAILS (ug/g)*			
	2m	*10m*	*13m*	*15m*	*20m*
VOLATILE ORGANIC					
Benzene*		<0.03	<0.01	<0.01	<0.01
Toluene*		<0.05	<0.02	<0.02	<0.02
Ethylbenzene*		<0.05	<0.02	<0.02	<0.02
Xylenes*		<0.1	<0.04	<0.04	0.04
Solids and Hydrocarbon Content (g/100g)**					
Solids (g/100g)	<0.04	17.6	33.5	37.3	35.1
Bitumen (g/100g)	<0.01	0.29	4.94	1.54	4.54
Naphtha (g/100g)	<0.01	<0.01	<0.01	<0.01	<0.01

*BTEX analysis (EPA SW-846). BTEX analysis by Enviro-Test Laboratories, Edmonton, AB

** OWS and Naphtha analysis performed at Syncrude Research, Edmonton.

Samples from Station 1 in Aurora TP, July 27, 2007: 6352700N, 474400E (UTM). Surface elevation: 320.5m (AMSL)

APPENDIX D: Well Completion Data

APPENDIX D

	OWS9710011	OWS9710026	OWS9710027	OWS9710028	OWS9734001	OWS9734002	OWS9734003	OWS9734004	OWS9734005	OWS9734006	OWS9734007
Northing	6354223.21	6353480.57	6354324.91	6354489.36	6351223.43	6352628.24	6352436.69	6352826.55	6352597.16	6352597.16	6352040.53
Easting	472142.1	475929.05	474928.72	473836.87	469143.99	469543.66	469947.07	470743.13	470965.69	470965.69	471328.03
Ground Elevation	297.64	286.68	293.13	296.16	301.58	299.2	299.72	299.16	299.58	299.58	297.63
Depth of Hole	8.23	2.54	6.86	6.3	8.07	6.22	7.62	8.23	3.79	7.32	5.49
Well Stickup	0.9	0.86	0.91	0.91	0.77	1.19	1.27	0.99	1	1.65	0.76
Well Elevation	298.54	287.54	294.04	297.07	302.35	300.39	300.99	300.15	300.58	301.23	298.39
Top of Bentonite	1.83	0.61	0	0	2.4	1.16	1.52	3.05	0.61	3.05	1.83
Top of Sand	3.47	1.22	1.83	1.98	3.93	2.38	3.05	4.57	1.04	3.96	2.74
Top of Screen	5.18	1.78	4.32	3.91	5.15	3.3	4.57	5.18	1.65	4.27	3.35
Bottom of Screen	6.71	2.69	5.79	5.38	6.61	4.76	6.1	6.71	3.18	5.79	4.88
Bottom of Well	8.23	2.69	6.86	6.3	8.07	6.22	7.62	8.23	3.78	7.32	5.49
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	1/29/1997	3/19/1997	3/22/1997	3/22/1997	1/21/1997	1/21/1997	1/21/1997	1/20/1997	4/2/1997	1/18/1997	1/25/1997

	OWS9734008	OWS9734009	OWS9734010	OWS9734012	OWS9734014	OWS9734015	OWS9734017	OWS9734018	OWS9734020	OWS9734021	OWS9734022
Northing	6351716.3	6351222.97	6350827.58	6353382.27	6351807.89	6350950.45	6350825.99	6350156.73	6350566.25	6350981.76	6350981.76
Easting	471151.21	470340.43	469541.41	472506.46	471943.62	471435.79	471143.52	471586.11	475095.2	475582.08	475582.08
Ground Elevation	297.41	298.05	299.49	299.01	295.57	293.9	293.77	293.22	282.22	282.33	282.33
Depth of Hole	5.18	3.96	4.13	8.23	4.42	4.27	5.49	4.57	2.59	3.96	3.05
Well Stickup	0.77	0.76	0.55	0.75	1.02	0.53	1.12	0.86	0.91	0.79	0.46
Well Elevation	298.18	298.81	300.04	299.76	296.59	294.43	294.89	294.08	283.13	283.12	282.79
Top of Bentonite	1.22	0.91	1.45	0.91	0.91	0.91	1.52	0.3	0.61	1.52	1.07
Top of Sand	2.74	1.83	2.06	2.59	2	1.83	3.05	2.13	1.07	3.05	1.22
Top of Screen	3.05	1.96	2.36	3.5	2.96	2.43	3.66	2.43	1.6	3.35	2.74
Bottom of Screen	4.57	3.48	3.82	6.4	4.42	3.96	5.18	3.96	2.59	3.96	3.05
Bottom of Well	5.18	3.96	4.13	7.92	4.42	4.26	5.49	4.57	2.59	3.96	3.05
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	1/25/1997	1/24/1997	1/24/1997	1/30/1997	3/7/1997	1/27/1997	1/27/1997	1/27/1997	3/22/1997	1/28/1997	1/28/1997

APPENDIX D

	OWS9734023	OWS9734024	OWS9734025	OWS973416A	OWS973416B	OWS9834755	OWS9934761	OWS9934762	OWS0010765	OWS0010766	OWS0110-01
Northing	6351425.91	6352926.73	6352609.53	6352442.7	6352442.7	6350230.06	6351952.1	6350908.8	6353802.9	6353941.3	6354227.59
Easting	475847.49	473388	473745.14	475947.81	475947.81	468889.75	475838.1	475501.2	475431.5	475054.5	474207.82
Ground Elevation	282.52	294.68	292.51	283.49	283.49	299.08	282.56	282.03	290.99	293.5	293.802
Depth of Hole	2.44	4.57	4.88	5.59	8.23	6.1	5.79	4.57	6.1	6.1	7
Well Stickup	0.69	0.36	0.97	0.86	0.91	1	0.91	0.91	0.91	0.76	1.1
Well Elevation	283.21	295.04	293.48	284.35	284.4	300.08	283.47	282.94	291.9	294.26	294.902
Top of Bentonite	0.3	0.91	1.22	1.22	0.91	0	0	0	0	0	0
Top of Sand	1.07	2.44	2.74	2.44	1.98	0.9	3.35	3.13	3.96	3.66	2.74
Top of Screen	1.22	2.74	3.35	4.06	7.01	1.6	4.1	3.2	4.57	4.57	3.96
Bottom of Screen	2.13	4.27	4.57	5.59	8.23	2.5	5.64	4.42	6.1	6.1	5.49
Bottom of Well	2.44	4.57	4.87	5.59	8.23	2.5	5.64	4.42	6.1	6.1	5.49
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	1/28/1997	1/29/1997	1/29/1997	3/20/1997	3/19/1997	12/10/1998	3/11/1999	3/11/1999	8/16/2000	8/16/2000	2/27/2001

	OWS0110-02	OWS0110-03	OWS0110-04	OWS0134-05	OWS0134-06	OWS0134-07	OWS0134-08	OWS0134-09	OWS0134-10	OWS0134-11	OWS0134-12
Northing	6354225.86	6354057.59	6353358.55	6353123.52	6352987.08	6352965.05	6352610.75	6352605.14	6351425.55	6350429.28	6350317.45
Easting	474671.81	474673.51	475542.82	475850.38	476096.24	476367.93	475754.99	475950.87	475733.69	474871.54	474765.17
Ground Elevation	292.985	292.95	287.514	285.383	284.652	284.012	283.749	283.387	282.177	281.661	281.777
Depth of Hole	7	7.6	4.3	3.7	8.8	5.2	5.8	7	3.2	4	2.7
Well Stickup	1	1	0.75	0.65	1	0.9	0.95	1	0.85	0.9	0.9
Well Elevation	293.985	293.95	288.264	286.033	285.652	284.912	284.699	284.387	283.027	282.561	282.677
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	2.74	3.66	3.35	1.83	7.01	4.27	3.81	5.79	1.22	3.05	1.83
Top of Screen	3.05	3.96	3.66	2.13	7.32	4.57	4.27	6.35	1.68	3.35	2.13
Bottom of Screen	3.81	5.49	4.27	3.66	8.84	5.18	5.79	6.96	3.2	3.96	2.74
Bottom of Well	3.81	5.49	4.27	3.66	8.84	5.18	5.79	6.96	3.2	3.96	2.74
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	2/27/2001	2/24/2001	2/22/2001	2/22/2001	2/22/2001	2/23/2001	2/28/2001	2/28/2001	3/2/2001	3/2/2001	3/2/2001

APPENDIX D

	OWS0134-13	OWS0134-14	OWS0134-15	OWS0134-16	OWS0134-17	OWS0210-11	OWS021012A	OWS021012B	OWS0210-13	OWS0234-01	OWS023402A
Northing	6350232.12	6350154.22	6350150.59	6350152.03	6350237.36	6355128.28	6354969.34	6354970.28	6354791.53	6352450.51	6352448.62
Easting	474849.77	473975.58	473573.08	473221.81	470015.2	475045.35	474665.56	474667.48	474294.07	475811.82	475947.5
Ground Elevation	281.491	284.012	284.694	289.505	294.742	293.03	293.56	293.55	294.17	283.21	282.92
Depth of Hole	2.7	4	4.3	1.2	2.1	15.24	13.72	13.72	13.72	9.14	9.14
Well Stickup	0.9	0.9	1	1	0.9	0.91	0.94	0.99	0.91	0.89	1.12
Well Elevation	282.391	284.912	285.694	290.505	295.642	293.94	294.5	294.54	295.08	284.1	284.04
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	1.52	3.2	2.59	0.3	1.22	3.05	2.74	3.96	3.05	4.19	3.51
Top of Screen	1.83	3.35	2.74	0.46	1.52	6.83	3.06	7.19	4.47	4.5	3.87
Bottom of Screen	2.74	3.96	4.27	1.22	2.13	8.36	4.58	8.71	5.99	6.02	5.4
Bottom of Well	2.74	3.96	4.27	1.22	2.13	8.36	4.58	8.71	5.99	6.02	5.4
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	4/18/2001	3/1/2001	3/1/2001	3/1/2001	3/3/2001	4/8/2002	4/9/2002	4/9/2002	4/9/2002	2/26/2002	2/27/2002

	OWS023402B	OWS0234-03	OWS0234-04	OWS0234-05	OWS0234-06	OWS0234-07	OWS0234-08	OWS0234-09	OWS0234-10	OWS0234-14	OWS0234-15
Northing	6352448.59	6352200.05	6352119.4	6352279.79	6352372.2	6351983.79	6351797.41	6351747.01	6351846.87	6350540.73	6350260
Easting	475951.06	475841.98	476009.7	476010.58	476099.23	476008.84	476010.64	475833.21	475835.69	469363.18	469669.72
Ground Elevation	282.92	282.54	282.05	282.36	282.28	282.48	282.09	283.6	285.98	299.03	297.33
Depth of Hole	9.14	9.14	6.1	6.1	7.62	4.57	3.05	4.57	6.1	6.096	4.572
Well Stickup	1.04	0.94	0.94	1.02	0.99	0.97	0.93	0.86	1.14	0.89	0.84
Well Elevation	283.96	283.48	282.99	283.38	283.27	283.45	283.02	284.46	287.12	299.92	298.17
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	6.4	3.81	3.2	4.12	3.96	1.78	1.52	1.83	2.59	1.22	1.32
Top of Screen	6.63	4.09	3.56	4.42	4.28	2.07	1.7	2.13	2.92	1.38	1.47
Bottom of Screen	7.39	5.61	5.08	5.94	5.8	2.98	2.31	3.05	4.45	2.91	3
Bottom of Well	7.39	5.61	5.08	5.94	5.8	2.98	2.31	3.05	4.45	2.91	3
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	2/26/2002	2/27/2002	2/27/2002	2/27/2002	2/28/2002	2/28/2002	3/1/2002	2/28/2002	3/1/2002	6/11/2002	6/12/2002

APPENDIX D

	OWS0234-16	OWS0234-17	OWS0310-01	OWS0310-02	OWS0310-03	OWS0310-04	OWS0334-06	OWS0334-07	OWS0334-09	OWS0410-01	OWS0410-02
Northing	6350259.38	6350859.3	6354061.28	6354129.09	6354209.9	6354412.33	6350958.77	6350235.45	6350154.85	6354088.28	6354072.88
Easting	469863.29	469504.59	472896.23	472966.5	472987.68	473598.4	469514.47	468998.91	470006.66	474530.79	474327.01
Ground Elevation	296.57	300.12	299.482	296.845	296.306	295.48	300.11	298.62	294.1	293.03	293.7
Depth of Hole	4.572	7.62	13.72	12.19	13.72	13.72	7.62	6.1	3.05	12.192	12.192
Well Stickup	0.89	0.91	0.91	0.79	0.53	0.89	0.91	0.89	0.89	1.09	0.94
Well Elevation	297.46	301.03	300.392	297.635	296.836	296.37	301.02	299.51	294.99	294.12	294.64
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	0.91	2.44	5.59	6.4	4.95	6.1	3.56	1.7	2.54	2	3.6
Top of Screen	1.02	3.05	6.02	7.06	5.61	6.6	3.68	1.32	2.54	4.57	5.03
Bottom of Screen	2.54	4.57	7.54	8.59	6.83	8.13	5.21	2.84	3.02	7.62	8.08
Bottom of Well	2.54	4.57	7.54	8.59	6.83	8.13	5.21	2.84	3.02	9.14	9.6
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	6/12/2002	7/30/2002	9/29/2003	9/29/2003	9/29/2003	11/24/2003	11/25/2003	11/21/2003	11/25/2003	3/27/2004	3/29/2004

	OWS041003A	OWS041003B	OWS0410-04	OWS0410-05	OWS0410-06	OWS0410-07	OWS0410-08	OWS0410-09	OWS0410-10	OWS0410-11	OWS0410-12
Northing	6354343.12	6354345.58	6354477.26	6354337.67	6354238.7	6354999.91	6355033.47	6354669.07	6355415.37	6355750.87	6355724.81
Easting	474061.18	474059.73	474234.41	474317.52	474439.13	473200.02	473930.04	475497.24	472991.79	473721.76	475018.43
Ground Elevation	294.31	294.33	294.25	293.79	293.67	296.34	294.68	297.09	296.99	297.89	293.64
Depth of Hole	15.24	15.24	15.24	15.24	13.716	13.716	15.24	21.336	18.288	18.288	16.764
Well Stickup	0.95	1.01	0.94	0.86	1.02	0.89	0.86	0.3	0.97	0.94	0.81
Well Elevation	295.26	295.34	295.19	294.65	294.69	297.23	295.54	297.39	297.96	298.83	294.45
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	1.22	4.57	3.05	4.33	3.96	6.22	2.13	11.89	5.18	4.06	3.1
Top of Screen	3.05	8.53	7.47	5.03	4.57	6.4	3.45	12.67	7.54	7.16	3.68
Bottom of Screen	4.57	11.58	8.99	8.08	7.62	7.92	4.98	15.7	10.64	10.26	6.78
Bottom of Well	6.1	14.63	8.99	9.6	9.14	7.92	4.98	15.7	10.67	10.29	6.81
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	3/30/2004	3/30/2004	3/27/2004	3/29/2004	3/30/2004	3/27/2004	3/27/2004	3/31/2004	3/30/2004	3/30/2004	3/29/2004

APPENDIX D

	OWS0410-13	OWS0410-14	OWS0410-17	OWS0410-19	OWS0410-20	OWS0410-21	OWS0410-22	OWS0410-23	OWS0410-24	OWS0410-25	OWS0410-26
Northing	6355486.24	6356212.74	6353692.45	6354320.43	6354147.04	6354087.97	6354036.41	6354090.07	6354135.16	6354113.36	6354143.12
Easting	476391.64	476063.18	475316.83	472891.86	472844.25	472715.3	472549.36	472961.56	471855.54	472139.38	472353.5
Ground Elevation	292.73	290.69	291.53	297.19	296.97	296.4	296.4	298.59	297.12	296.62	297.04
Depth of Hole	15.24	16.764	9.144	13.716	12.192	11.887	12.192	15.24	12.19	12.19	12.19
Well Stickup	0.84	0.76	0.84	1	0.72	0.72	0.84	1.07	0.86	0.86	0.89
Well Elevation	293.57	291.45	292.37	298.19	297.69	297.12	297.24	299.66	297.98	297.48	297.93
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	3.05	2.44	2.18	6.71	4.27	4.27	3.35		6.1	6.55	5.18
Top of Screen	9.91	6.27	4.57	7.01	6.1	4.88	3.66	6.86	6.1	6.73	5.18
Bottom of Screen	11.43	7.8	7.62	8.53	9.14	7.92	6.71	9.91	7.62	8.26	6.68
Bottom of Well	11.45	7.8	9.14	11.58	7.62	9.45	9.75	12.95	7.67	8.31	6.73
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	3/26/2004	3/26/2004	3/27/2004	3/23/2004	3/20/2004	3/26/2004	3/24/2004	3/22/2004	5/18/2004	5/18/2004	5/18/2004

	OWS0410-27	OWS0410-28	OWS0410-29	OWS0410-30	OWS041031A	OWS041031B	OWS0410-32	OWS0410-33	OWS0410-34	OWS0410-35	OWS0410-36
Northing	6353921.25	6353825.05	6353827.32	6353716.72	6353714.11	6353717.16	6353412.3	6353964.7	6353879.13	6353423.55	6354410.62
Easting	472069.38	471856.6	472465.57	472245.75	472460.45	472462.15	472461.58	472831.53	472764.04	475475.41	473463.92
Ground Elevation	296.61	297.04	299.77	299.28	301.53	300.55	298.75	300.12	300.44	288.45	296.12
Depth of Hole	12.19	12.19	13.72	13.72	13.72	13.72	12.19	15.24	15.24	7.62	13.72
Well Stickup	0.84	0.84	0.84	0.84	0.81	0.81	0.84	0.84	0.84	0.91	0.91
Well Elevation	297.45	297.88	300.61	300.12	302.34	301.36	299.59	300.96	301.28	289.36	297.03
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	7.01	4.27	7.16	5.64	3.28	8.84	4.52	8.53	5.79	4.39	8.13
Top of Screen	7.62	6.68	7.42	5.87	4.5	8.89	4.47	8.86	6.2	4.57	8.66
Bottom of Screen	9.14	8.2	8.94	7.39	6.02	10.41	5.99	10.39	7.72	6.1	10.19
Bottom of Well	9.19	8.28	8.99	7.44	6.07	10.41	6.05	10.44	7.77	6.1	10.19
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	5/17/2004	5/17/2004	5/27/2004	5/27/2004	5/20/2004	5/20/2004	5/27/2004	5/19/2004	5/19/2004	11/4/2004	11/5/2004

APPENDIX D

	OWS0434-15	OWS0434-16	OWS0510-01	OWS0510-02	OWS0510-03	OWS0510-04	OWS0510-05	OWS0510-06	OWS0534-07	OWS0534-08	OWS0534-09
Northing	6350376.15	6350168.86	6355026.8	6354925.24	6354725.58	6355323.27	6355449.03	6355624.8	6352435.23	6352115.61	6352108.85
Easting	474907.27	474631.53	471646.93	471651.21	471649.87	471653.27	471638.41	471647.46	475777.28	475888.33	475865.22
Ground Elevation	281.46	281.42	298.35	298.13	298.03	300.64	306.9	311.9	284.51	282.91	282.62
Depth of Hole	4.572	3.048	15.24	10.06	5.33	18.29	23.77	28.96	13.72	7.62	6.1
Well Stickup	0.86	0.91	0.79	0.71	0.92	0.86	0.77	0.79	0.92	0.9	0.97
Well Elevation	282.32	282.33	299.14	298.84	298.95	301.5	307.67	312.69	285.43	283.81	283.59
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	0.76	0.91	2.45	6	1.5	6.04	7.13	20.5	5.79	3.81	3.2
Top of Screen	1.22	0.85	2.75	6.12	2.03	6.35	8.13	21.25	6.1	3.96	3.29
Bottom of Screen	1.52	2.68	8.85	9.18	3.55	9.4	18.8	24.3	7.62	5.49	4.78
Bottom of Well	1.52	2.68	11.8	10	5.3	12.58	23.7	26.2	7.62	5.49	4.78
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	4/2/2004	4/2/2004	4/6/2005	4/5/2005	4/5/2005	4/7/2005	4/9/2005	4/12/2005	6/9/2005	6/10/2005	6/9/2005

	OWS0534-10	OWS0534-11	OWS0734400	OWS0734405	OWS0734406	OWS0734407	OWS0734408	OWS0734409	OWS0734410	OWS0734411	OWS0734412
Northing	6351784.27	6351785.71	6350204.991	6350628.861	6350727.659	6350827.54	6351165.726	6351263.802	6351351.513	6351526.268	6351611.35
Easting	475747.08	475738.9	474426.222	475025.251	475139.647	475272.818	475676.025	475687.867	475696.04	475714.15	475721.293
Ground Elevation	283.79	283.75	282.86	282.65	284.49	284.74	282.83	282.7	282.57	283.04	301.29
Depth of Hole	13.72	9.14	5.41	4.21	5.63	7.36	5.33	5.56	5.49	5.33	5.06
Well Stickup	0.9	0.91	1.2	1.08	1.06	1.09	1.09	0.75	1.23	1.06	1.1
Well Elevation	284.69	284.66	284.06	283.72	285.55	285.83	283.92	283.45	283.8	284.1	284.17
Top of Bentonite	0	0	0	0	0	0	0	0	0	0	0
Top of Sand	2.95	4.11	1.83	1.22	2.44	3.66	1.83	1.83	1.22	1.22	1.52
Top of Screen	3.2	4.81	2.59	1.52	2.9	4.57	2.67	2.74	2.44	2.13	2.29
Bottom of Screen	4.72	6.3	4.12	3.05	4.42	6.1	4.19	4.27	3.96	3.66	3.81
Bottom of Well	4.72	6.3	5.41	4.21	5.63	7.36	5.33	5.56	5.49	5.33	5.06
Well Diameter	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drill Date	6/7/2005	6/9/2005	10/12/2007	10/11/2007	10/11/2007	10/10/2007	10/2/2007	10/2/2007	10/3/2007	10/3/2007	10/3/2007

APPENDIX D

	OWS0734413	OWS0734414	OWS0734416	OWS0734417	OWS0734418
Northing	6350992.594	6350341.652	6350380.209	6350599.709	6350910.743
Easting	469148.972	469316.066	470128.208	470035.359	469766.247
Ground Elevation	297.42	298.76	295.62	296.72	297.93
Depth of Hole	7.16	4.05	5.58	4.22	4.36
Well Stickup	0.95	0.84	0.94	1.02	0.87
Well Elevation	302.24	300.51	298.81	298.65	299.72
Top of Bentonite	0	0	0	0	0
Top of Sand	3.87	0.91	2.26	0.91	0.91
Top of Screen	4.11	1.22	2.74	1.37	1.52
Bottom of Screen	5.64	2.74	4.27	2.9	3.05
Bottom of Well	7.16	4.05	5.58	4.22	4.36
Well Diameter	0.05	0.05	0.05	0.05	0.05
Drill Date	9/29/2007	9/29/2007	10/1/2007	10/1/2007	9/29/2007

APPENDIX E: Groundwater Sampling Procedures

PROCEDURES FOR GROUNDWATER SAMPLING AND SURFACE WATER AT THE SYNCRUDE AURORA

This technical procedure was prepared specifically for the groundwater and surface water sampling programs at the Syncrude Aurora Mine.

APPENDIX E

A) GROUNDWATER SAMPLING PROCEDURES

1. Plan and Prepare for Groundwater Sampling

If wells need to be developed, Develop the well before proceeding

2. Measure Water Level

3. Purge the Well

4. Collect the Groundwater Samples

5. Record Water Quality Parameters

6. Decontaminate the Equipment

Repeat Steps 2 to 6 for the Next Well

7. Complete Sample Chain-of-Custody Form, Store and Submit Sample to Lab

1) Plan and Prepare for Groundwater Sampling

Off-site Preparation

- Calibrate water quality meter daily, either the night before or that morning. Record calibration information in meter calibration log book.
- Prepare sampling bottles for wells to be purged and sampled. Label with the well number and type of analysis required.
- Ensure that the number of wells is achievable in a day so that samples can be shipped the same day as sampled. Sampling conducted Sunday through Thursday in most cases. Occasionally, sampling can be done on Friday, but the laboratory must be notified to expect Saturday morning samples.
- To maximize efficient use of time, wells within close proximity to each other should be selected each day.
- Organize groundwater sampling equipment (i.e., water level tape, water quality meter, spare Waterra tubing and foot valves) and datasheets.

On-site Preparation

- Put on appropriate personal protective equipment (hard hat, safety glasses, steel toed boots, Nomex coveralls where applicable (e.g., sulphur block area).
- Put on disposable Nitrile gloves at each individual well prior to sample collection and change between wells.
- Unlock monitoring well and note the well condition (i.e., missing lock, damage). Confirm the well number written on the well.

2) Measure Water Level

- Total well depths are provided by Syncrude.
- Measure water level with a water level tape.
- Move Waterra tubing (if folded) to allow water level tape to enter the well with little restriction.
- Read static water level at the top of casing (TOC). In most cases the casing has been previously marked with permanent marker on one side (always the high side if casing was cut uneven). Read and record water level at this mark.
- Subtract the static water level from the total well depth. Then multiply the well water level by 2.032 L/m for a 2 inch casing, 1.13 L/m for 1.5 inch casing or 4.51 L/m for 3 inch casing to determine one well volume. Then multiply by 3 to determine 3 well volumes. Round well volume to the nearest whole number (i.e., 16.7 L would be rounded to 18 L).

3) Purge the Well

- Pull Waterra tubing up off the bottom (1 to 3 m) before purging.
- Purge water by hand into a graduated pail until 3 well volumes are achieved.
- For a few shallow wells that typically have poor recovery, an attempt should be made to purge the well with a peristaltic pump.
- If 3 well volumes are achieved, proceed to collect the required samples.
- If 3 well volumes are not achieved (i.e., well bails dry), then allow well to recover prior to collecting samples.

4) Collect the Groundwater Samples

- Label bottles with the date of collection.
- If water remains turbid after 3 wells volumes have been purged, allow well to sit for an hour or two to allow the suspended solids to settle out prior to sampling. This method is very common at the Aurora site on the newer 03 and 04 wells.
- Put on disposable Nitrile gloves and discard after use.
- Wells that recover well and do not bail dry should be sampled immediately after purging. For wells that do not recover well, sampling should be done as soon as possible and not more than 24 hours after purging.
- Keep Waterra tubing 1 to 3 m off the bottom of the well to minimize total suspended solids in water sample.
- For wells with high suspended solids, minimize agitation by slower pumping action.
- Allow water to pass onto the ground until sample is clear in colour or visually clear of suspended solids before sampling.
- Ensure correct number and type of bottles to be filled from the table provided by Syncrude.
- Fill bottles by hand directly from end of Waterra tubing.
- For a few shallow wells that typically have poor recovery or for wells with high suspended solids, use a peristaltic pump to collect the sample.
- If a dissolved metals sample is required, filter the samples using a 45 micron (single use filter supplied by Syncrude) directly attached to the Waterra tubing. Also filter the dissolved organic carbon (DOC) sample. Allow water to pass through the filter for a few seconds prior to collection of the sample.
- As per Syncrude request, if a dissolved metals sample is not required, do not field filter the DOC sample. This will be done at the laboratory.

- Add preservatives to filled bottles as appropriate and shake to ensure thorough mixing of preservative and water sample.

- For samples where no headspace is required (i.e., volatiles), fill bottles so that the water mounds at the rim to ensure no air bubbles are trapped.

- If a well is dry or frozen, record time it was visited and comments (i.e., frozen, dry, etc.). Revisit it later in the field program and attempt to sample it again.

- Record time of sample collection on datasheet when last bottle is filled.

5) Record Water Quality Parameters

- Collect field water quality parameters after groundwater samples have been collected.

- Field water quality was measured using a Y.S.I. 556 Multiprobe meter.

- Collect water into a plastic 500 mL container that has been rinsed with de-ionized water and ambient water.

- Allow temperature, pH and EC to stabilize prior to recording parameters. Stir the water sample lightly during readings to ensure water is uniform in all parameters.

- Record temperature, pH, EC and specific conductance (conductivity corrected to 25°C).

- Record colour and odour if any as well as other visual observations (i.e., hydrocarbon sheen).

6) Decontaminate the Equipment

- Decontaminate water level tape after use at each well by spraying with a phosphate-free decontamination soap (Liqui-Nox™) and rinse with tap water. Use a clean paper towel to wipe the probe. Spray the probe with methanol to remove any solvent-soluble residues that may remain and allow to evaporate. Rinse probe with de-ionized water (from Syncrude laboratory).
- Rinse container used for field water quality parameters and water quality meter probe with de-ionized water after use.

7) Complete Sample Chain-of-Custody Form, Store and Submit Sample to Lab

- Keep samples in coolers with ice packs during the day.

- Ensure samples are shipped to the laboratory on the same day, as they are collected.

- Complete chain of custody forms and send with samples.

- Pack samples with newspaper to minimize bottle movement and breakage.

8) Quality Assurance/Quality Control Procedures

- Collect one trip blank and one field blank during the field program and analyze for trace parameters.
- Collect one duplicate sample for approximately every 10 samples collected for metals, naphthenic acids and phenols and one duplicate sample for approximately every 20 samples collected for routine parameters.
- Fill both the initial sample bottle and the duplicate sample bottle at the same time (i.e., 1/4 into first bottle, 1/4 into second bottle, etc.), so that they are as similar as possible.
- Use a random approach for determining which sites should be sampled in duplicate. Choose wells that produce enough water to fill two complete sets of sample bottles.
- Give duplicate sample bottles a unique sample number and fictitious sampling time on chain of custody forms in order to submit it to the laboratory as a "blind" duplicate. Write the duplicate sample identification on the datasheet indicating, which sample it, is a duplicate of.

B) SURFACE WATER SAMPLING PROCEDURES

1) Plan and Prepare for Surface Water Sampling

Off-site Preparation

- Calibrate water quality meter daily, either the night before or that morning. Record calibration information in meter calibration log book.
- Prepare sampling bottles for surface water sites to be sampled. Label with the surface site number and type of analysis required.
- Ensure that the number of surface water sites is achievable in a day so that samples can be shipped the same day as sampled. Sampling conducted Sunday through Thursday in most cases. Occasionally, sampling can be done on Friday, but the laboratory must be notified to expect Saturday morning samples.
- To maximize efficient use of time, sites within close proximity to each other should be selected each day.
- Organize surface water sampling equipment (i.e., sampling pole, 1L plastic collection bottle, water quality meter) and datasheets.

On-site Preparation

- Put on appropriate personal protective equipment (hard hat, safety glasses, steel toed boots, Nomex coveralls where applicable (e.g., sulphur block area).
- Put on disposable Nitrile gloves at each individual surface water site prior to sample collection and change between sites.

2) Collect the Surface Water Sample

- Put on disposable Nitrile gloves and discard after use
- Rinse the decontaminated collection bottle with ambient water three times prior to sample collection.
- Where possible, such as finger drainpipes, fill bottles directly from end of pipe.
- In ponds and non-flowing water, fill bottles at 25 cm below the surface, reaching out from shore with the sample pole at stations marked "sample point".
- In shallow surface water sites, care should be taken to not disturb bottom sediment while filling bottles.
- In flowing water, collect the water sample with the mouth of the sample bottle pointing upstream 25 cm below the surface.
- Label bottles with the date of collection.

- Ensure correct number and type of bottles to be filled from the table provided by Syncrude.

- Add preservatives to filled bottles as appropriate and shake to ensure thorough mixing of preservative and water sample.

- No field filtering is required unless suspended solids are high.

- For samples where no headspace is required (i.e., volatiles), fill bottles so that the water mounds at the rim to ensure no air bubbles are trapped.

- If a surface site is dry, record time it was visited and comments (i.e., dry, etc.). Revisit it later in the field program (especially after rainfall events) and attempt to sample it again.

- Record time of sample collection on datasheet when last bottle is filled.

3) Record Water Quality Parameters

- Collect field water quality parameters after surface water samples have been collected.

- Field water quality was measured using a Y.S.I. 556 Multiprobe meter.

- Collect water into a plastic 500 mL container that has been rinsed with de-ionized water and ambient water.

- Allow temperature, pH and EC to stabilize prior to recording parameters. Stir the water sample lightly during readings to ensure water is uniform in all parameters.

- Record temperature, pH, EC and specific conductance (conductivity corrected to 25°C).

- Record colour and odour if any as well as other visual observations (i.e., hydrocarbon sheen).

4) Decontaminate the Equipment

- Decontaminate collection bottle after use at each site. Spray with a phosphate-free decontamination soap (Liqui-Nox™). Then, rinse with tap water. Spray bottle with methanol to remove any solvent-soluble residues that may remain and allow to evaporate. Then, rinse bottle with de-ionized water (from Syncrude laboratory).

- Use a new collection bottle whenever necessary, especially if the previous surface water site left an oily residue on the collection bottle or if a hydrocarbon sheen was observed at the site.

- Rinse container used for field water quality parameters and water quality meter probe with de-ionized water after use.

5) Complete Sample Chain-of-Custody Form, Store and Submit Sample to Lab

- Keep samples in coolers with ice packs during the day.

- Ensure samples are shipped to the laboratory on the same day, as they are collected.

- Complete chain of custody forms and send with samples.
- Pack samples with newspaper to minimize bottle movement and breakage.

6) Quality Assurance/Quality Control Procedures

- Collect one trip blank and one field blank during the field program and analyze for trace parameters.
- Collect one duplicate sample for approximately every 10 samples collected for metals, naphthenic acids and phenols and one duplicate sample for approximately every 20 samples collected for routine parameters.
- Fill both the initial sample bottle and the duplicate sample bottle at the same time (i.e., 1/4 into first bottle, 1/4 into second bottle, etc.), so that they are as similar as possible.
- Use a random approach for determining which sites should be sampled in duplicate. Choose sites that have enough water to fill two complete sets of sample bottles.

C) GROUNDWATER WELL DEVELOPMENT PROCEDURES

1) Selection of Wells to be Developed

- Syncrude identifies the wells that need to be developed each season. These include monitoring wells with a history of high sediment loads as well as newly installed wells.

2) Well Development

- If necessary, install Waterra tubing and foot valve.
- Develop wells using a power Waterra pump (if the well is deep) or by hand (if the well is shallow).
- Keep Waterra tubing just off the bottom of the well.
- If using the power pump, move the tubing up as necessary to reduce wear on the casing/foot valve interface if well development goes on for hours.
- Record start and finish times for well development.
- Collect water purged from each well in a graduated bucket and determine total volume purged as well as visual water clarity throughout the development process.
- Continue purging water from the well until the water is visually clear or until 4 hours have passed. As per Syncrude request, no more than 4 hours should be spent developing a well.
- Record water level, purge volume and recovery rate. Also record visual water turbidity (e.g., turbid, clearing up, cloudy, very clear) as it changes during well development.
- Release purged water well away from the well casing to reduce the risk of purge water entering the water table near the well.
- If a well bails dry before well development is complete, allow it to recover and revisit the well for further development to a maximum of 4 hours.

3) Collect Groundwater Sample

- Collect groundwater samples from developed wells immediately after development.
- If water is still not clear after 4 hours of development, allow water to settle for a couple hours prior to collecting the groundwater sample.

Follow groundwater sampling procedures in Section A.

Appendix XXI:

Richard Frank et al., “Profiling Oil Sands Mixtures from Industrial Developments and Natural Groundwaters for Source Identification,” in (2014) 48 Environmental Science and Technology 5, pp 2660–2670

Environmental Science & Technology

Article

pubs.acs.org/est

Profiling Oil Sands Mixtures from Industrial Developments and Natural Groundwaters for Source Identification

Richard A. Frank,[†] James W. Roy,[†] Greg Bickerton,[†] Steve J. Rowland,[‡] John V. Headley,[§] Alan G. Scarlett,[‡] Charles E. West,[‡] Kerry M. Peru,[§] Joanne L. Parrott,[†] F. Malcolm Conly,[§] and L. Mark Hewitt*,[†]

[†]Water Science and Technology Directorate, Environment Canada, 867 Lakeshore Road, Burlington, Ontario, Canada L7R 4A6

[‡]Petroleum and Environmental Geochemistry Group, Biogeochemistry Research Centre, University of Plymouth, Drake Circus, 5 Plymouth PL4 8AA, U.K.

[§]Water Science and Technology Directorate, Environment Canada, 11 Innovation Boulevard, Saskatoon, Saskatchewan, Canada, S7N3H5

Supporting Information

ABSTRACT: The objective of this study was to identify chemical components that could distinguish chemical mixtures in oil sands process-affected water (OSPW) that had potentially migrated to groundwater in the oil sands development area of northern Alberta, Canada. In the first part of the study, OSPW samples from two different tailings ponds and a broad range of natural groundwater samples were assessed with historically employed techniques as Level-1 analyses, including geochemistry, total concentrations of naphthenic acids (NAs) and synchronous fluorescence spectroscopy (SFS). While these analyses did not allow for reliable source differentiation, they did identify samples containing significant concentrations of oil sands acid-extractable organics (AEOs). In applying Level-2 profiling analyses using electrospray ionization high resolution mass spectrometry (ESI-HRMS) and comprehensive multidimensional gas chromatography time-of-flight mass spectrometry (GC × GC-TOF/MS) to samples containing appreciable AEO concentrations, differentiation of natural from OSPW sources was apparent through measurements of O_2:O_4 ion class ratios (ESI-HRMS) and diagnostic ions for two families of suspected monoaromatic acids (GC × GC-TOF/MS). The resemblance between the AEO profiles from OSPW and from 6 groundwater samples adjacent to two tailings ponds implies a common source, supporting the use of these complimentary analyses for source identification. These samples included two of upward flowing groundwater collected <1 m beneath the Athabasca River, suggesting OSPW-affected groundwater is reaching the river system.

1. INTRODUCTION

The Canadian oil sands region contains an estimated 168.6 billion barrels of recoverable bitumen,[1] accounting for 97% of Canada's petroleum reserves and ranking Canada third globally in terms of domestic oil reserves.[2] Recent studies investigating the loading of inorganic and neutral organic compounds have identified significant aerial depositions of priority pollutants[3,4] associated with mining activities. These results, combined with recent calls for a greater understanding of the potential environmental impacts resulting from industrial development of the oil sands,[5−7] have catalyzed the implementation of a new Canada−Alberta Joint Oil Sands Monitoring Program (JOSMP[8]).

One of the objectives of the JOSMP is to evaluate the nature and extent of the possible migration of contaminants associated with mining developments to regional aquatic ecosystems.[5,7] The proximity of several large containment structures (e.g., tailings ponds) containing oil sands process-affected water (OSPW) to the Athabasca River and its tributaries provides an obvious focus for this investigation. Process-affected waters contain complex mixtures of neutral and polar organic compounds, in addition to dissolved metals and major ions (e.g. Na, Cl, SO_4, HCO_3).[9] Of significance are the acid-extractable organics (AEOs), which include naphthenic acids (NAs). These are attractive from a monitoring perspective because they have demonstrated acute[10,11] and sublethal[12] toxicity.[13] Furthermore, their enhanced water solubility makes them prime candidates for possible migration beyond containment structures via groundwater, which is important given the zero-discharge policy for surface water releases within mining lease licenses. Advancements in analytical techniques including electrospray ionization high resolution mass spectrometry (ESI-HRMS) and comprehensive multidimensional

Received: January 10, 2014
Accepted: January 21, 2014

gas chromatography time-of-flight mass spectrometry (GC × GC-TOF/MS) have shown that mixtures of oil sands-derived AEOs include compounds containing aromatic rings,[14−16] other multiple oxygenated acid species, and sulfur- and nitrogen-heteroatoms.[17−22]

Several studies have shown or suggested leakage of OSPW into groundwater and migration of OSPW-affected groundwater away from impoundments.[23−27] Numerical modeling[23,24] estimated leakage from the base of one impoundment and dyke at <75 L s^{-1} (about 0.1% of the lowest daily Athabasca River flow recorded, 75 m^3 s^{-1}).[28] A plume of OSPW-impacted groundwater has also been mapped to extend approximately 500 m away from another nearby impoundment.[25,26] In these studies, a variety of geochemical and organic signatures have been employed[24,26,29] in attempts to track potential leakage, including: bicarbonate,[24,30] sodium,[30] the sodium to chloride ratio, the water type as indicated by its position on a Piper plot, boron, ammonium,[25,26] and various measures of AEOs (including by Fourier transform infrared spectroscopy (FTIR), ESI-MS, synchronous fluorescence spectroscopy (SFS[16,31])). Although advanced analytical and chromatographic techniques such as ESI-HRMS,[19,32] APPI-HRMS[33,34] and GC × GC-TOF/MS[31,35−37] have provided breakthroughs in the identification of classes within OSPW-derived AEO mixtures, there has been minimal progress differentiating the similar, but less-studied, AEO mixtures present in the natural background waters within the McMurray Formation.[19] Given the large areas requiring monitoring under the JOSMP, it is important to establish whether a unique chemical profile of OSPW exists that could be employed to identify and track OSPW-affected groundwater and surface waters.

Recent attempts to profile industrial and natural waters from the oil sands region have begun to indicate potential chemical markers for successful differentiation. For example, a 2011 pilot study[38] at one tailings impoundment used ESI-HRMS and ^{13}C isotopic signatures of the carboxylic acid functional groups in NAs for profiling. This study, and a related study[39] that compared ^{13}C isotopic signatures between OSPW, monitoring wells, unprocessed oil sand and Athabasca River water, illustrates the potential of these techniques for differentiation. To date, the most complete study used liquid-chromatography (LC)-ESI-TOF/MS to profile oil sands AEOs in lakes, the Athabasca River and some of its tributaries, and pore water (e.g., potentially discharging groundwater) collected from the Athabasca River.[27] Although this investigation indicated that similarities in surface water compositions of two tributaries and OSPW were suggestive of seepage, the clustering of OSPW and pore water sites following principal components analysis made differentiation difficult. Consequently, the application of more specific analytical techniques was recommended. Furthermore, it is important to note that a systematic investigation, beyond proof-of-concept, examining the range of naturally occurring bitumen-derived AEO, lacking any possible OSPW influence, has yet to be conducted.

The objective of the present study was to identify chemical components that could distinguish OSPW-affected groundwater from natural groundwater containing bitumen-derived AEOs within the McMurray Formation. The first part of the study involved application of Level-1 analyses consisting of assessing geochemistry (major ions, Na, B, NH_4), total AEO concentrations, and the presence/absence of maxima in a SFS profile characteristic of oil sands mono- and diaromatic NAs, to two different OSPW containments and a broad variety of natural groundwater samples. Level-2 analyses, consisting of advanced separation and ESI-HRMS techniques, were then applied to differentiate bitumen-derived AEO mixtures originating from OSPW from those naturally present in groundwater in the oil sands region. In the second part of the study, both Level-1 and 2 analyses were applied to groundwater samples collected adjacent to two tailings ponds to determine whether their chemical profiles resembled those of natural or OSPW sources.

2. MATERIALS AND METHODS

2.1. Sample Collection. For the first part of the study, duplicate samples of OSPW were collected from each of two tailings ponds from different oil sands developments between September 20 and 25, 2009 (OSPW 1, 2; Figure 1). Far-field groundwater samples (15−20 mL) were collected from 20 sites. One groundwater seep sample collected in the Joslyn Creek catchment was obtained on October 19, 2010, directly from groundwater discharging to the surface at the seepage face. The remaining 19 were collected using a stainless steel drive-point system[40] at depths of 30−120 cm below the streambed of the Athabasca River and associated tributaries (Ells River, Steepbank River) between May and October 2010. Far-field was defined in this study as >1 km upstream or downstream from any tailings pond, given the likely dominance of groundwater flow perpendicular to the Athabasca River. Level-1 analyses of these samples included the assessment of geochemical parameters (defined below), total AEO concentrations (referred to in the Results as [NA] and determined by low resolution ESI-MS), and expected maxima in an SFS profile associated with suspected mono- and diaromatic acids.[31] Far-field samples containing appreciable amounts of NAs (>5 mg L^{-1}) and both OSPW samples were selected for detailed profiling by ESI-HRMS and GC × GC-TOF/MS. For the second part of this investigation, a total of seven near-field samples (<200 m from an OSPW containment) were collected near two tailings ponds. Two samples were collected from Site A: an interceptor well and a monitoring well. In addition, five samples were collected from Site B: an interceptor well, a monitoring well, and three drive-point groundwater samples along the western shore of the Athabasca River. On-development interceptor and monitoring wells (4.8−39.0 m depths) were sampled June 22−23, 2010, while drive point samples were collected as noted above. All near-field samples underwent Level-2 analyses for comparison with OSPW and far-field samples with appreciable NAs, in addition to Level-1 analyses. Locations of the near- and far-field samples selected for AEO profiling are presented in Figure 1.

2.2. Geochemical Analysis. Measured geochemical parameters comprised anions (including chloride, sulfate, and nitrate) analyzed by ion chromatography, major cations (including sodium and calcium) analyzed by direct aspiration using an inductively coupled argon plasma system,[40] and ammonium analyzed by spectrophotometry using a phenolhypochlorite reagent (absorbance measured at 640 nm). Samples were also analyzed for a suite of trace metals (including boron) at Environment Canada's National Laboratory for Environmental Testing (NLET) (Burlington, ON) using Inductively Coupled Plasma-Sector Field Mass Spectrometry.[41] Samples were categorized into different water types according to the relative balances of major ions as depicted on a Piper plot, which is a graphical technique commonly applied in groundwater studies.[24,27]

2.3. Synchronous Fluorescence Spectroscopy (SFS). Analysis by SFS was performed using a Perkin-Elmer Luminescence spectrometer LS50B and data collection was controlled

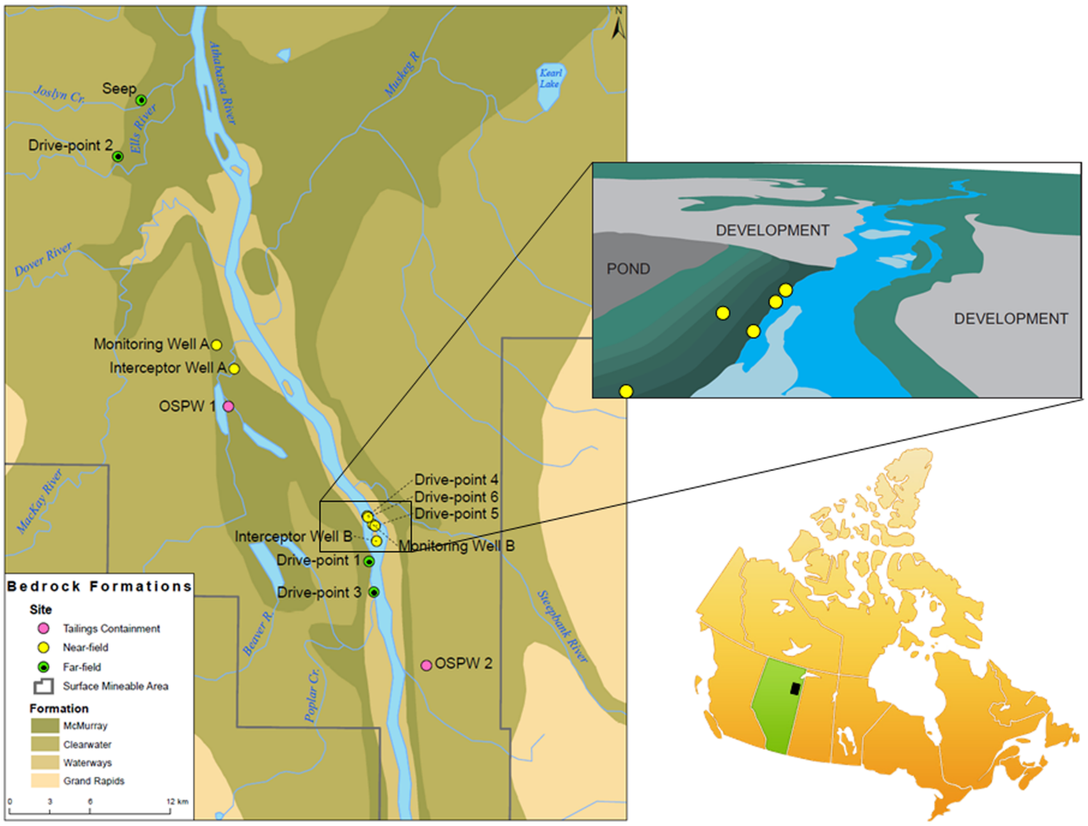


Figure 1. Map depicting sampling locations of OSPW, Near-field and Far-field locations prioritized for Level-2 profiling. Inset depicts close-up of area illustrating locations of Site B Near-field drive-points, interceptor and monitoring wells.

by FL Winlab 3 software (Perkin-Elmer, Norwalk, CT) as previously described.[16] The expected maxima for an SFS oil sands NA profile are at 282, 320, and 333 nm.[16,31] In this investigation, samples that exhibited maxima at 282 and 320 nm above a signal intensity of 100 were identified as positive for this profile.

2.4. Sample Preparation for Detailed Profiling. Prior to analysis by ESI-HRMS and GC × GC-TOF/MS, all samples were extracted by solid phase extraction (SPE) to remove residual salts and to concentrate polar organics. For each 15-mL sample, a 200 mg styrene divinylbenzene, Isolute ENV+ SPE cartridge (Biotage, Charlotte, NC) was conditioned with 10 mL of acetonitrile followed by 10 mL of milli-Q water at a flow rate of approximately 5 mL min^{-1}. Each sample was acidified to pH 2 using 12 M HCl, and drawn through the SPE cartridge at a flow rate of approximately 1 mL min^{-1}. The adsorbed AEOs were eluted into 12-mL glass scintillation vials using 7 mL of acetonitrile at 1 mL min^{-1}. Each extract was subsequently evaporated to dryness under a stream of N_2, assessed by constant weight, and reconstituted in 3.0 mL of acetonitrile. This 3.0 mL extract volume was partitioned into 1-mL aliquots and a single aliquot was examined by ESI-HRMS and, after conversion to the methyl esters, a second aliquot by GC × GC-TOF/MS.

2.5. Infusion-Electrospray Ionization Mass Spectrometry. Low resolution ESI-MS analyses[32] for NAs were conducted with a Quattro Ultima (Waters Corp., Milford, MA) triple quadrupole mass spectrometer equipped with an ESI interface operating in negative-ion mode. The MS conditions were set as follows: source temperature 90 °C; desolvation temperature 220 °C; cone voltage setting 62 V; capillary voltage setting 2.63 kV; cone gas (N_2) flow rate 158 L h^{-1}; desolvation gas (N_2) flow rate 489 L h^{-1}. The multiplier was set at 650 V and full scan mass spectra were acquired in the m/z range 50−550. Samples (5 μL) were loop injected by use of a Waters 2695 separations module with 50:50 acetonitrile/water containing 0.1% ammonium hydroxide as the eluent at 200 μL min^{-1}.

Level-2 AEO profiling of sample extracts using ESI-HRMS was performed on a LTQ Orbitrap Velos mass spectrometer (Thermo Fisher Scientific, San Jose, CA) using electrospray ionization in negative ion mode. ESI source conditions were as follows: heater temperature was set to 50 °C, sheath gas flow rate was set to 25 (arbitrary units), auxiliary gas flow rate was set to 5 (arbitrary units), spray voltage set to 2.90 kV, capillary temperature was set to 275 °C and the S lens RF level was set to 67%. Samples were analyzed in full scan with an m/z range of 100−600, at a resolution set to 100 000 using the lockmass of m/z 212.07507 $[M-H]^-$ of n-butyl benzenesulfonamide. Resulting NA concentrations were determined by comparison to a predefined 5-point regression ($R^2 > 0.989$) of OSPW-derived NAs at known concentrations (initially quantified by FTIR). Xcalibur version 2.1 software (Thermo Fisher Scientific San Jose, CA) was used for data acquisition, instrument operation, and quantitative data analysis. Class distributions were determined using acquired accurate mass data and Composer version 1.0.2 (Sierra Analytics, Inc. Modesto, CA) with an average mass error for all classes of approximately 1 ppm, with an O_2 mass error of 0.065 ppm.

2.6. GC × GC-TOF/MS. Extracts selected for Level-2 AEO profiling by GC × GC-TOF/MS were evaporated to dryness under a stream of N_2, methylated by refluxing for 90 min at 70 °C with boron trifluoride-methanol (2 mL; Aldrich, Poole, UK), back-extracted into hexane (2 × 1 mL) and concentrated under a stream of N_2 to 50 μL. Conditions for analysis were essentially as described previously.[36] Briefly, analyses were conducted using

Table 1. Level-1 Analyses for OSPW and Natural (Far-field) Groundwater Samples, Collected from the Shore of Rivers in the Oil Sands Area of the Athabasca River Watershed[a]

Associated surface water body	Sample type	Water type	Na:Cl (molar)	[Na] (mg L^{-1})	[B] (μg L^{-1})	[NH_4] (mg L^{-1})	[NA] (mg L^{-1})	SFS OSPW profile?
	OSPW 1	saline	2.5	636	2275	28.40	54	Y
	OSPW 2	saline	1.0	287	3164	1.30	60	Y
Athabasca R.	Drive-point 1	saline	1.7	1577	4040	0.84	48	Y
Ells R.	Drive-point 2	n/a	n/a	n/a	n/a	0.91	27	Y
Athabasca R.	Drive-point 3	fresh	1.4	1.8	68.7	0.18	<DL	N
Joslyn Cr.	Seep	fresh	22.6	6	15	n/a	4	N
Athabasca R.	Drive-point 7	sulfate	1.84	182	577	<DL	26	Y
Athabasca R.	Drive-point 8	fresh	1.80	52.6	126	16.2	20	N
Athabasca R.	Drive-point 9	saline	1.13	713	1620	0.57	33	Y
Athabasca R.	Drive-point 10	fresh	<DL	<DL	90.6	1.03	7	Y
Athabasca R.	Drive-point 11	fresh	0.76	4.3	66	0.17	4	Y
Athabasca R.	Drive-point 12	fresh	2.05	4.9	77.5	3.00	4	N
Ells R.	Drive-point 13	fresh	10.28	119	384	0.41	4	N
Ells R.	Drive-point 14	fresh-alkaline	11.91	135	435	0.03	5	N
Ells R.	Drive-point 15	sulfate	11.84	594	695	0.03	4	N
Ells R.	Drive-point 16	alkaline	2.40	680	1340	1.44	10	Y
Steepbank R.	Drive-point 17	fresh	6.62	3.4	126	0.17	5	n/a
Steepbank R.	Drive-point 18	fresh	0.00	<DL	67.2	0.09	5	n/a
Steepbank R.	Drive-point 19	fresh	0.00	<DL	77.7	0.07	4	n/a
Steepbank R.	Drive-point 20	fresh	2.96	4.8	217	0.04	n/a	n/a
Steepbank R.	Drive-point 21	fresh	0.00	<DL	125	<DL	6	n/a
Steepbank R.	Drive-point 22	fresh	0.00	<DL	204	0.03	n/a	n/a

[a]Y, observed. N, not observed. n/a, bitumen in sample prevented analysis for Drive-point 2; SFS not conducted for Drive-points 17–22; insufficient sample for NAs for Drive-points 20, 22. <DL, values less than method detection limit of 0.01 mg L^{-1} for Na; 3 mg L^{-1} for NAs; 0.02 mg L^{-1} for NH_4.

an Agilent 7890A gas chromatograph (Agilent Technologies, Wilmington, DE) equipped with a Zoex ZX2 GC × GC cryogenic modulator (Houston, TX) interfaced with an Almsco BenchToFdx time-of-flight mass spectrometer (Almsco International, Llantrisant, UK) operated in positive ion electron ionization mode and calibrated with perfluorotributylamine. The scan speed was 50 Hz, the first-dimension column was 50 m × 0.25 mm ×0.40 mm VF1-MS (Varian, Palo Alto, CA), and the second-dimension column was 2.5 m × 0.15 mm ×0.15 mm VF-17MS (Varian). Three μL of sample were injected in a splitless mode at 300 °C. The initial temperature of the oven (40 °C) was held for 1 min and then increased at 2 °C min^{-1} to 325 °C and held for 10 min. The modulation period was 4 s, the transfer line temperature was 280 °C, and the ion source temperature was 300 °C. Helium was used as the carrier gas at a constant flow rate of 0.8 mL min^{-1}. Subsequent data processing was conducted using GCImage v2.1 (Zoex).

3. RESULTS AND DISCUSSION

3.1. Profiling OSPW versus Natural Groundwaters. Differentiation between the 2 OSPW and the 20 natural groundwater (far-field) samples was first attempted in the Level-1 analyses that included geochemical data, total NAs, and the presence/absence of the SFS NA profile (Table 1). The SFS profiles of OSPW from the two mining operations studied (Figure 2) were consistent with those obtained in previous analyses.[16,31] Concentrations of total NAs in the OSPW samples were 54 and 60 mg L^{-1}, consistent with values previously reported for OSPW.[42] In previous studies,[24,29] 30 mg L^{-1} and 40 mg L^{-1} were used as the lower NA concentration limit to identify OSPW-affected water. However, one study[43] identified OSPW with NA concentrations below 10 mg L^{-1}.

Of the 14 far-field samples analyzed by SFS, 7 had spectral profiles similar to those of OSPW, although Drive-points 7 and 11 differed in that they exhibited lower signal intensities at 282 nm and elevated signal intensities at 320 and 345 nm (SI Figure S1). While the majority of the far-field samples in the current study had lower NA concentrations than OSPW (<10 mg L^{-1}), Drive-point 2, on the Ells River, contained 27 mg L^{-1} and 4 samples from an area along the Athabasca River where the McMurray Formation outcrops at the river edge (near Drive-point 1; Figure 1) ranged from 20 to 48 mg L^{-1}. Generally, appreciable NA concentrations corresponded with the presence of the SFS profile for OSPW, and vice versa, but there were a few exceptions which are currently under investigation: Drive-point 11 had a positive SFS profile and NA concentration of 4 mg L^{-1}, and Drive-point 8 had a negative SFS profile and a NA concentration of 20 mg L^{-1} (Table 1). The occurrence of an SFS profile similar to that observed for OSPW in many far-field samples with appreciable NA concentrations illustrates that these parameters are effective at identifying the presence of bitumen-derived AEOs, however they alone cannot be used to indicate whether these AEOs are originating from natural or OSPW sources.

A full description of the geochemical comparisons between far-field groundwater and OSPW is provided in SI Geochemistry. Briefly, analysis of the geochemical data showed that the ranges of most parameters (Na, B, and NH_4 concentrations, Na:Cl ratio) from the 20 far-field samples encompassed those for OSPW in this study (Table 1). When plotted on a Piper Plot (Figure 3A), the far-field samples plotted across all water types (alkaline, saline, sulfate, fresh), whereas the OSPW samples in general were commonly of alkaline or saline water type.[24,25,29,43] These results are consistent with previous conclusions that geochemical parameters alone cannot broadly distinguish OSPW

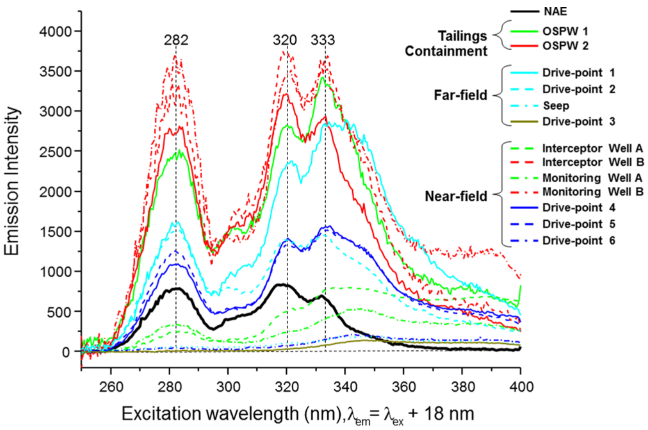


Figure 2. Spectra from synchronous fluorescence spectroscopy (SFS) for Near-field, and Far-field samples, as well as for a naphthenic acid extract (NAE) isolated from "fresh" OSPW.

from bitumen-influenced natural groundwaters in the oil sands region.

Due to the qualitative nature of the data obtained from the SFS analysis, a rigorous principal component analysis could not be performed to assess the ability of the entire Level-1 analyses to distinguish OSPW from natural groundwaters. However, it is clear (Table 1; SI Geochemistry & SI Figure 1) that OSPW tends to be elevated in concentrations of Na, B, NH_4, and NA, as well as the characteristic SFS spectra for suspected oil sands aromatic organic acids). Several of the far-field samples (Drive-points 1, 9, and 16) have a similar composition, especially when considering dilution effects on OSPW-affected groundwater. Thus, while a combination of the Level-1 parameters does not provide a universal indicator for OSPW migration, they have been found to be useful as site-specific tracers (i.e., tracking known plumes)[26] where information on local groundwater chemistry and flow systems is available.[43]

The Level-1 analyses did, however, reveal multiple significant sources of naturally occurring bitumen-derived AEOs (Table 1). The Level-2 analyses then focused on profiling the complex AEO mixtures present in OSPW and natural sources by utilizing these new sources of natural AEOs from different hydrogeological settings. Drive-points 1 and 2 exhibited two of the highest NA concentrations and signal intensities of the SFS profile (Figure 2). The Drive-point 1 sample was collected from the top of the limestone layer in an area where bitumen-containing sands were exposed at the bank of the Athabasca River, and also had elevated levels of B and Na, as well as a saline-alkaline water type. The sample from Drive-point 2 was collected along the Ells River near an area designated for future oil sands mining development, but where no activities existed at the time of sampling. The extracted groundwater contained bituminous globules (note: filters clogged immediately preventing the collection of samples for major ion determinations). In this same general area, but on the smaller tributary of Joslyn Creek, a natural groundwater seep sample (Seep) was collected that also contained bituminous globules, but did not exhibit the SFS NA profile (Figure 2) and had low Na, B, and NA concentrations (fresh water type). Finally, the Drive-point 3 sample was collected off of the McMurray Formation and had low Na, B, and NA concentrations (fresh water type), and no SFS signature.

Level-2 analysis by ESI-HRMS of the AEO containing far-field samples provided relative contributions of various ion classes via heteroatom histograms (Figure 4), including those assigned to

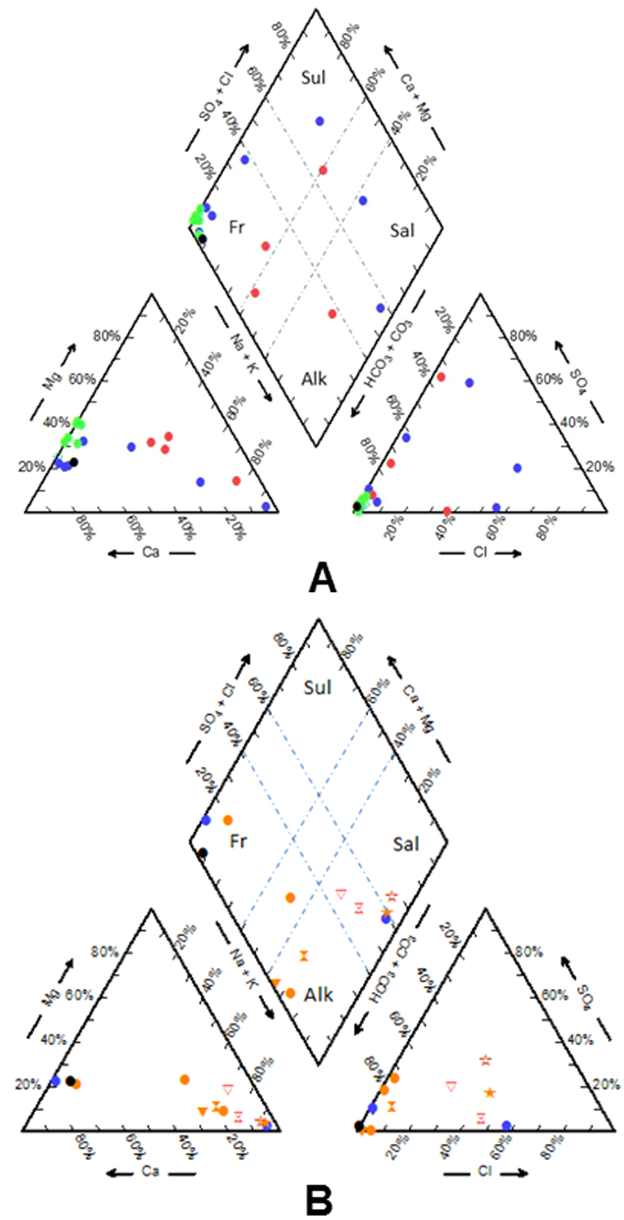


Figure 3. (A) Piper plot of major ions for natural far-field groundwater samples (>1 km from a tailings pond) collected along the Athabasca River (blue), Steepbank River (green), Ells River (red) and Joslyn Creek (black; seep) in the oil sands area. (B) Piper plot of major ions from the samples selected for Level 2 analyses, except for Drivepoint 2, separated by symbol type: OSPW (stars), interceptor wells (hourglass), on-development monitoring wells (triangle), and off-development drive-point or seep samples (circles); and by site/location: Site A samples in red outline; Site B samples in orange; background groundwater along Athabasca in blue; Joslyn Creek in black. Diamonds are divided (by dotted lines) into water type sections: Fr, fresh; Sul, sulfate; Sal, saline; Alk, alkaline (Hunter, 2001).

O_x, O_xS_y, N_xO_y, and $N_xO_yS_z$ species. For comparison purposes, the responses for all species were assumed to be the same in Figure 4, understanding that this assumption is not valid as ion-suppression and matrix effects are known to be prevalent for ESI-MS analyses of such complex mixtures. Furthermore, as authentic standards were not available for the thousands of components revealed by HRMS, these data are considered semi-quantitative. The O_x species in particular are of much interest as this group contains the classical NAs (O_2 components)

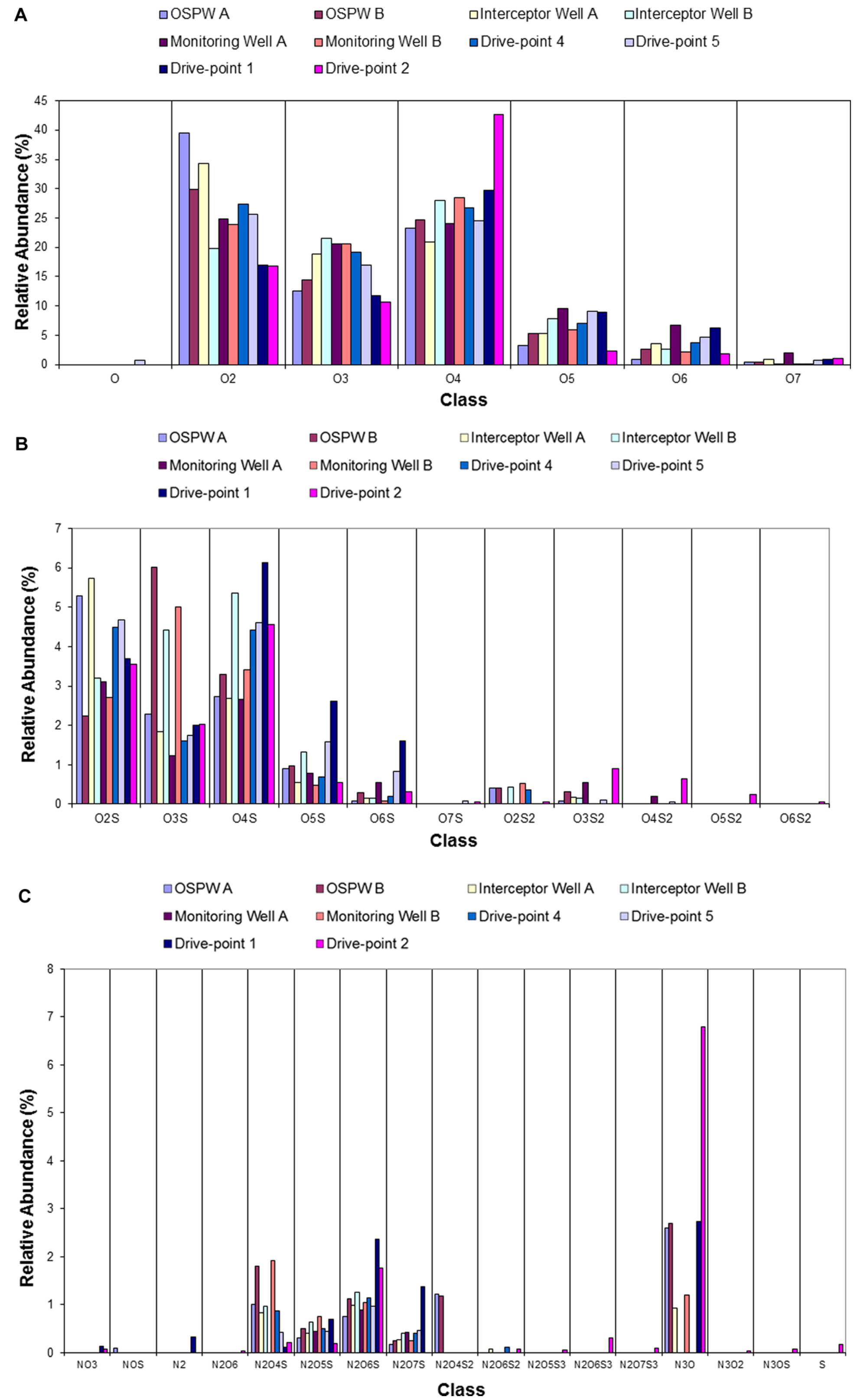


Figure 4. Level-2 HRMS speciation profiles for samples representative of On-development, Near-field, and Far-field samples.

along with higher oxidized hydroxyl acids (O_3 species), dicarboxylic acids (O_4), and possibly humic, fulvic, or weathered acids (O_{5-7}).

All far-field samples with detectable concentrations of NAs (Drive-points 1 and 2) were dominated by O_x heteroatoms, with notable observations concerning ratios of O_2:O_4 containing ion classes (Table 2; Figure 4a). OSPW samples 1 and 2 had O_2:O_4 ratios of 1.69 and 1.21, respectively, however, Drive-points 1 and 2 differed whereby the O_2:O_4 ratios were the lowest observed at 0.57 and 0.40, respectively (Table 2).

Table 2. Summary of Level-1 and Level-2 data for all OSPW, Near-field and Select Far-field Samples[a]

		Level-1						Level-2		
		Water type	Na:Cl (molar)	[Na] (mg L^{-1})	[B] (μg L^{-1})	[NA] (mg L^{-1})	SFS OSPW Profile?	HRMS O_2:O_4	GC × GC-TOF/MS Monoaromatic acids? Family A	Family B
Tailings containment	OSPW 1	saline	2.5	636	2275	54	Y	1.69	7/7	Y+
	OSPW 2	saline	1.0	287	3164	60	Y	1.21	7/7	Y+
Far-field	Drive-point 1	saline	1.7	1577	4040	48	Y	0.57	1/7; peak #5	Y
	Drive-point 2	n/a	n/a	n/a	n/a	27	Y	0.40	2/7; peaks #1,5	Y
	Drive-point 3	fresh	1.3	2	69	<DL	N		0/7	N
	Seep	fresh	22.6	6	15	4	Y		0/7	N
Near-field Site A	Interceptor Well	saline	1.7	631	1230	60	Y	1.65	4/7; peaks #1,3−5	Y+
	Monitoring Well	alkaline	2.7	549	743	30	Y	1.04	5/7; peaks #1−5	Y+
Near-field Site B	Interceptor Well	alkaline	7.8	272	1469	39	Y	0.71	4/7; peaks #1−4	Y
	Monitoring Well	alkaline	33.0	359	1640	43	Y	0.84	5/7; peaks #1−5	N
	Drive-point 4	alkaline	14.0	300	1620	50		1.02	7/7	Y+
	Drive-point 5	alkaline	18.0	61	1380	55	Y	1.04	5/7;peaks #1−5	Y+
	Drive-point 6	fresh	5.8	16	170	5	N	0.92	0/7	N

[a]Y, Observed for SFS, both Family B monoaromatic acids by GC × GC-TOF/MS at correct m/z and GC retention times. Y+ indicates enriched signal for Family B acids. N, Not observed for SFS or Family B monoaromatic acids at correct m/z and GC retention times. n/a, bitumen in sample prevented analysis. <DL values less than method detection limit of 0.01 mg L^{-1} for Na; 3 mg L^{-1} for NAs. O_2:O_4 ratios cannot be reported for NA <5 mg L^{-1}.

Ratios of O_xS ion classes, among others, have previously been proposed as useful diagnostic markers for OSPW in surface waters using Fourier transfer ion cyclotron resonance mass spectrometry (FTICR-MS).[19] In the current investigation, the increased prevalence of O_2 over O_4 species in OSPW samples and the reversal in the natural far-field samples appeared to be similarly reflected in the O_2S:O_4S ratios at these sites (Figure 4B), however the trend was less consistent. Although the sample set in this investigation only included two samples each of the anthropogenic and natural sources that contained appreciable concentrations of NAs, the diagnostic potential observed for the O_2:O_4 ratio is nevertheless consistent with suggestions from previous work using ESI-HRMS[19,33,38] and supports use of this ratio in tracking OSPW.

Qualitative analysis by GC × GC-TOF/MS focused on two groups of well-resolved acids previously suggested to be monoaromatic steroidal-type acids,[31] using base peak or characteristic ions (Family A m/z 145; Family B m/z 237, 310). Analysis of the two OSPW samples revealed strong signal intensities for both families, consistent with previous analyses of NAs extracted from OSPW by GC × GC-TOF/MS.[31] Seven distinct Family A members were identified by retention times (R1 ± 0.1 min, R2 ± 0.2 s) that were used in profiling (Peak 1: R1−113.2 min, R2−2.8 s; Peak 2: R1−114.2 min, R2−2.6 s; Peak 3: R1−117.0 min, R2−3.0 s; Peak 4: R1−118.7 min, R2−3.0 s; Peak 5: R1−120.3 min, R2−3.1 s; Peak 6: R1−122.9 min, R2−2.4 s; Peak 7: R1−123.5 min, R2−2.4 s) and two distinct Family B compounds were similarly identified (m/z 237: R1−106.2 min, R2−1.4 s; m/z 310: R1−106.5 min, R2−1.5 s) (Figure 5). In contrast, Drive-points 1 and 2, the far-field samples with appreciable NA concentrations and SFS signal intensities approximating OSPW (Figure 2; Table 2), exhibited only 1 or 2 of the 7 Family A isomers, and comparably minimal signals for Family B. The remaining two far-field samples (Drive-point 3 and Seep) lacked any signal for both families under the conditions used (Table 2). Acids with structures similar to those of Families A and B are suspected as contributors to the 282 nm maximum in the SFS profile,[31] however, the present results indicate that different monoaromatic acids are contributing to the SFS profiles within the far-field samples. While lack of authentic reference compounds and limited sample volumes in the present study precluded definitive identifications of these acids, their potential as tracers of OSPW migration is certainly indicated. Work is underway to better characterize the structures of these compounds and to establish their relevance for monitoring migration of OSPW.

3.2. Profiling Groundwaters near Tailings Ponds. The Level-2 profiling analyses were then applied to a series of groundwater samples collected near two previously studied tailings ponds, to determine if their profiles more closely resembled OSPW or natural bitumen-derived AEOs. Samples were collected from near-field on-development interceptor and monitoring wells near tailings ponds A and B, as well as from shallow drive-points along the bank of the Athabasca River, within 200 m of tailings containment B (Figure 1). Although it cannot be assumed that any of these samples contain OSPW, they were collected in areas where previous studies have suggested OSPW impacts on local groundwater (Site A;[26] Site B [24]) as determined by Level-1 analyses similar to those employed in this study.

Analysis by ESI-HRMS of the two Site A samples revealed O_2:O_4 ratios of 1.65 and 1.04 for Interceptor well A and Monitoring well A, respectively, closely resembling the 1.29 and 1.61 ratios measured for OSPW (Table 2; Figure 4A). The somewhat lower ratio for the Monitoring well, as well as a lower NA concentration (Interceptor well A: 59.8 mg L^{-1}; Monitoring well A: 29.7 mg L^{-1}) indicates that the sample may have contained a mixture of OSPW and natural groundwater-derived NAs. Moreover, all Site A samples fell within a similar zone on a Piper plot (intermediate between alkaline and saline; Figure 3B).

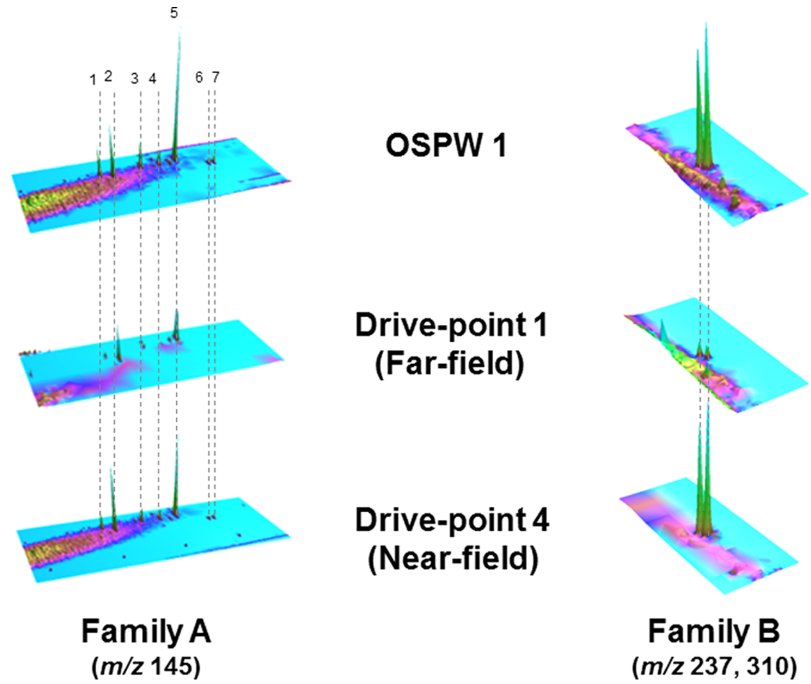


Figure 5. GC × GC-TOF/MS ion chromatograms for selected samples from OSPW, Far-field (Drive point 1) and Near-field (Drive-point 4) sites. Shown are the monoaromatic *m/z* 145 (Family A) and *m/z* 237 and 310 (Family B) ions; refer to Experimental for exact retention times.

Analysis by GC × GC-TOF/MS of the interceptor and monitoring well samples from Site A revealed 4 and 5 of the 7 diagnostic *m/z* 145 isomers (Family A), respectively, and enriched signal intensities for the *m/z* 237 and 310 ions (Family B) for both samples (Table 2). Qualitatively, both on-development samples were identical, with the exception of peak 2, which was absent from Interceptor well A. This, together with the enriched intensities of Family B ions, is consistent with both of the OSPW samples and contrasts with all of the far-field samples. Collectively, the Level-1 and Level-2 analyses all demonstrate a close similarity between these two Site A samples and OSPW, as opposed to the natural far-field groundwater. Consequently, both samples likely contain differing proportions of OSPW, with greater dilution from other water sources in Monitoring well A.

Consistent with both OSPW samples (and near-field Site A samples), GC × GC-TOF/MS analysis revealed that most of the Site B near-field samples exhibited enriched Family B aromatic acid signal intensities. With the exception of Drive-point 6, all Site B near-field samples consistently contained at least 4 out of the 7 Family A isomers, with peaks 6 and 7 being absent from all but one sample. It is worth noting that Drive-point 4 was the only non-OSPW sample of this study where all 7 Family A isomers were detected. There were no detectable signals for either ion Family for Drive-point 6 (Figure 5), suggesting it was not affected by OSPW. Furthermore, Level-1 analyses for this sample showed very low Na, B, and NA concentrations, no SFS signal, and a fresh water type (Table 2), in contrast to OSPW, supporting this contention. Monitoring well B was an exception where Family B ions were not detected, and while Interceptor well B exhibited these ions, they were at much lower intensities than both OSPW and near-field samples containing appreciable concentrations of NAs.

Level-2 profiling by ESI-HRMS of Site B near-field samples was also consistent with OSPW. Drive-points 4 and 5 had appreciable NA concentrations and O_2:O_4 ratios near 1.0, compared to 1.2 for Site B OSPW. The Interceptor and Monitoring well samples for Site B exhibited O_2:O_4 ratios of 0.71 and 0.84, respectively (Table 2; Figure 4A). These values, although lower than other near-field and OSPW samples, were greater than the two far-field samples with appreciable NA concentrations. It is important to understand that water collected in interceptor wells may emanate from a variety of sources (e.g., OSPW seepage, natural groundwater, surface runoff, etc.) that are mixed in unknown proportions with temporal fluctuations. It is therefore expected that interceptor systems will have a broad range of values that should lie between the range described by OSPW and the natural far-field samples.

When comparing the HRMS data for all Level-2 analyses, several trends are evident. First, the AEO profiles for O_2 and O_4 species are skewed to the left (OSPW influence) and right (natural bitumen-derived) respectively, whereas the profiles for the O_3, O_5, O_6, and O_7 components are bell shaped (Figure 4A). Although the rationale for these differences is not established, the relative abundances of the species may be linked to differences in the primary sources of these component classes. The relative abundances of the higher O_x species ($x > 4$; Figure 4A) were generally lower (<10%) compared to the levels of the O_2 and O_4 species (15−40%), and are likely indicative of the presence of weathered NAs and natural humic and fulvic acids. A complementary trend to that observed for the O_x species is also apparent for the O_xS_y species (Figure 4B), in which the profiles for the O_2S and O_3S species are skewed to the left (OSPW influence) whereas the O_4S, O_5S, O_6S, and O_4S_2 species are skewed to the right (natural bitumen-derived). These O_xS_y species are believed to contain natural surfactants, and possibly industrial additives, and warrant further investigation for their diagnostic utility as previously suggested.[19] While the profiles for the N-containing heteratomic species (Figure 4C) illustrate that some species classes are enriched (i.e., N_2O_4S, N_2O_6S, and N_3O), their application for source differentiation is unclear at present. Finally, although the O_2:O_4 ratio for the Drive-point 6 sample of 0.92 is suggestive of the influence of OSPW, the low NA concentration

(4.8 mg L^{-1}), coupled with the lack of detectable Family A and B acids and a fresh water type strongly indicates this is not the case and illustrates the importance of utilizing the Level-1 and 2 techniques in complement.

The results from the Level-2 analyses of the Site B groundwater samples containing appreciable concentrations of NAs (all samples except Drive-point 6, as noted above) are generally supported by the Level-1 analysis. All had elevated concentrations of B (1400−1600 μg L^{-1}) and NAs (39−55 mg L^{-1}) in a range similar to OSPW (Table 2), as well as exhibited the SFS signal characteristic of NAs. All were of similar water type (alkaline or alkaline-fresh), and Na concentrations were elevated, with the exception of the sample from Drive-point 5. Note that complete support for all of the Level-1 analyses was not expected, given the results on geochemical variation in background groundwater samples from this study, as previously discussed.

The chemical profiles of the Drive-point 4 and 5 samples more closely resembled those of OSPW than any of the far-field samples, particularly in the presence and distributions of the Family A and B acids. Previous work has relied on less definitive tracers, such as total NA concentrations and major ions,[24−26] or attributed differences in the chemical profiles of surface waters to groundwater inputs when the groundwater samples themselves did not exhibit an OSPW influence.[27] The fact that the sample from Drive-point 6 (not resembling OSPW) was collected within ∼100 m of Drive-point 4 (strongly resembling OSPW), illustrates the inherent variability in groundwater geochemistry that can be expected given the convergence of local and regional flow systems along this river valley, where groundwaters with varying geochemical evolutions and characteristics may be encountered and combined with the potential localized effects of tailings structures and oil sands development. As such, future monitoring activities should give careful consideration to spatial replication of sampling in areas that may have highly variable and heterogeneous flow paths.

To investigate the potential for false-negatives, three samples (Far-field: Drive-point 3 and Seep; Near-field: Drive-point 6) were selected for detailed profiling. Rationale for their selection included that they exhibited lower concentrations of bitumen-derived AEOs ([NA] ≤ 5 mg L^{-1}), an absence of the characteristic SFS spectra for oil sands organic acids, and a "fresh" water type, in addition to the following: Drive-point 3 is located off of the McMurray Formation; the Seep sample contained bituminous globules, similar to Drive-point 2; and the proximity of Drive-point 6 to Drive-points 4 and 5 that exhibited bitumen-derived AEOs. Level-2 profiling confirmed that these three samples do not contain bitumen-derived AEOs, validating the absence of false negatives. Subsequent attempts to apply multivariate statistics to the differences reported in Table 2 were precluded by the qualitative data provided by the SFS and GC × GC-TOF/MS analyses.

3.3. Study Implications. The present investigation demonstrates that SFS, ESI-MS, and several geochemical analyses (Level-1 analyses) should not be used in isolation or in combination as a universal indicator of OSPW-affected groundwater, as these were unable to reliably differentiate OSPW from natural groundwaters containing bitumen-derived AEOs. However, data from ESI-HRMS and GC × GC-TOF/MS profiles (Level-2 analyses) for both sources appeared consistent within each source type, and different between them. Given the relatively small sample volumes utilized here for the Level-2 analyses (15−20 mL), these methodologies on their own likely would not enable conclusive differentiation of OSPW from all natural groundwater sources. However, the profiles provided by these methods, used in complement with the Level-1 analyses, collectively indicated that differentiation of sources was possible. This was highlighted by the Level-2 profiles of Drive-points 4 and 5 more closely resembling those of OSPW than any of the far-field samples, particularly in the presence and distributions of the Family A and B acids. The resemblance between the AEO profiles from OSPW and from 6 groundwater samples adjacent to two tailings ponds implies a common source, supporting the use of these complimentary analyses for source identification. These samples included two of upward flowing groundwater collected <1 m beneath the Athabasca River, suggesting OSPW-affected groundwater is reaching the river system. While profiling AEO mixtures from the Athabasca River was outside the groundwater focus of this study, the tools developed herein should provide this capability. Ongoing work with larger sample volumes is aimed at confirming and improving the diagnostic utility of the compound classes identified in this study.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Figure S1 includes synchronous fluorescence spectra of all far-field samples. Geochemical criteria have been developed from past studies for differentiating OSPW from natural groundwater, these are briefly discussed and applied to the samples collected in this study. This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Author

*Phone: (905)319-6924; fax: (905)336-6430; e-mail: mark.hewitt@ec.gc.ca.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

We thank William Govenlock, Jody Klassen, Ryan Levitt, Jason Miller, and Kirsten Nickel (Environment Canada-Edmonton); Jim Syrgiannis (Environment Canada-Regina); Andrew Basha and Bill Streeton (Environment Canada-Calgary); and Ruth Vanderveen, Katherine French, André Talbot, Amanda Malenica, Charles Talbot and John Voralek (Environment Canada-Burlington), for providing field, technical, and logistical support. We thank Susan Brown, Pamela Collins, and Jerry Rajkumar (Environment Canada-Burlington) for inorganic analyses. Access to the Athabasca River was graciously provided by Northland Forest Products (Fort McMurray, Alberta). A special appreciation is extended to the Fort McMurray offices of Alberta Environment and Sustainable Resource Development and the Water Survey of Canada for logistical support. A portion of the funding for the GC × GC-TOF/MS instrumentation was kindly provided by the European Research Council (project OUTREACH, Grant number: 228149 to SJR). Disclaimer: The views in this paper are only held by the authors and are not representative of the official policy of the authors' individual affiliations.

■ REFERENCES

(1) *ST98-2012 Alberta's Energy Reserves 2011 and Supply/Demand Outlook 2012−2021*; Energy Resources Conservation Board, 2012; p 290.

(2) *Upstream Dialogue—The Facts on Oil Sands*; Canadian Association of Petroleum Producers, 2012; p 64.

(3) Kelly, E. N.; Schindler, D. W.; Hodson, P. V.; Short, J. W.; Radmanovich, R.; Nielsen, C. C. Oil sands development contributes elements toxic at low concentrations to the Athabasca River and its tributaries. *Proc. Natl. Acad. Sci.* **2010**, *107* (37), 16178−16183.

(4) Kelly, E. N.; Short, J. W.; Schindler, D. W.; Hodson, P. V.; Ma, M.; Kwan, A. K.; Fortin, B. L. Oil sands development contributes polycyclic aromatic compounds to the Athabasca River and its tributaries. *Proc. Natl. Acad. Sci.* **2009**, *106* (52), 22346−22351.

(5) Dillon, P.; Dixon, D. G.; Driscoll, C.; Giesy, J. P.; Hurlbert, S.; Nriagu, J. *Evaluation of Four Reports on Contamination of the Athabasca River System by Oil Sands Operations*; Water Monitoring Data Review Committee—Prepared for Government of Alberta, 2011; p 55.

(6) Kindzierski, W.; Jin, J.; Gamal El-Din, M. *Review of Health Effects of Naphthenic Acids: Data Gaps and Implications for Understanding*, Oil Sands Research and Information Network, OSRIN Report No. TR-20; University of Alberta, School of Energy and the Environment: Edmonton, Alberta, 2012; p 43.

(7) *Environmental and Health Impacts of Canada's Oil Sands Industry*; Royal Society of Canada Expert Panel, 2010.

(8) *Joint Canada/Alberta Implementation Plan for Oil Sands Monitoring*; Environment Canada and Alberta Environment, 2012; p 27.

(9) Allen, E. W. Process water treatment in Canada's oil sands industry: I. Target pollutants and treatment objectives. *J. Environ. Eng. Sci.* **2008**, *7*, 123−138.

(10) Frank, R. A.; Kavanagh, R.; Burnison, B. K.; Arsenault, G.; Headley, J. V.; Peru, K. M.; Solomon, K. R. Toxicity assessment of generated fractions from an extracted naphthenic acid mixture. *Chemosphere* **2008**, *72*, 1309−1314.

(11) Scarlett, A. G.; Reinardy, H. C.; Henry, T. B.; West, C. E.; Frank, R. A.; Hewitt, L. M.; Rowland, S. J., Acute toxicity of aromatic and non-aromatic fractions of naphthenic acids extracted from oil sands process-affected water to larval zebrafish. *Chemosphere* **2013**, *93*, 415−420.

(12) Reinardy, H. C.; Scarlett, A. G.; Henry, T. B.; West, C. E.; Hewitt, L. M.; Frank, R. A.; Rowland, S. J., Aromatic naphthenic acids in oil sands process-affected water, resolved by GC × GC-MS, only weakly induce the gene for vitellogenin production in zebrafish (*Danio rerio*) larvae. *Environ. Sci. Technol.* **2013**, *47*, 6614−6620.

(13) FTFC. Clark hot water extraction fine tailings. In *Advances in Oil Sands Tailings Research*; FTFC (Fine Tailings Fundamentals Consortium): Alberta Department of Energy, Oil Sands and Research Division; Edmonton, AB, Canada, 1995; Vol.*I*.

(14) Frank, R. A.; Fischer, K.; Kavanagh, R.; Burnison, B. K.; Arsenault, G.; Headley, J. V.; Peru, K. M.; Van Der Kraak, G.; Solomon, K. R. Effect of carboxylic acid content on the acute toxicity of oil sands naphthenic acids. *Environ. Sci. Technol.* **2009**, *43* (2), 266−271.

(15) Jones, D.; West, C. E.; Scarlett, A. G.; Frank, R. A.; Rowland, S. J. Isolation and estimation of the 'aromatic' naphthenic acid content of an oil sands process-affected water extract. *J. Chromatogr., A* **2012**, *1247*, 171−175.

(16) Kavanagh, R.; Burnison, B. K.; Frank, R. A.; Solomon, K. R.; Van Der Kraak, G. Detecting oil sands process-affected waters in the Alberta oil sands region using synchronous fluorescence spectroscopy. *Chemosphere* **2009**, *76*, 120−126.

(17) Barrow, M. P.; Headley, J. V.; Peru, K. M.; Derrick, P. J. Data visualization for the characterization of naphthenic acids within petroleum samples. *Energy Fuels* **2009**, *23*, 2592−2599.

(18) Bataineh, M.; Scott, A. C.; Fedorak, P. M.; Martin, J. W. Capillary HPLC/QTOF-MS for characterizing complex naphthenic acid mixtures and their microbial transformation. *Anal. Chem.* **2006**, *78*, 8354−8361.

(19) Headley, J. V.; Barrow, M. P.; Peru, K. M.; Fahlman, B.; Frank, R. A.; Bickerton, G.; McMaster, M. E.; Parrott, J.; Hewitt, L. M. Preliminary fingerprinting of Athabasca oil sands polar organics in environmental samples using electrospray ionization Fourier transform ion cyclotron resonance mass spectrometry. *Rapid Commun. Mass Spectrom.* **2011**, *25*, 1899−1909.

(20) Headley, J. V.; Peru, K. M.; Fahlman, B.; Colodey, A.; McMartin, D. W. Selective solvent extraction and characterization of the acid extractable fraction of Athabasca oil sands process waters by Orbitrap mass spectrometry. *Int. J. Mass Spectrom.* **2013**, *345*−*347*, 104−108.

(21) Headley, J. V.; Peru, K. M.; Mohamed, M. H.; Frank, R. A.; Martin, J. W.; Hazewinkle, R. R. O.; Humphries, D.; Gurprasad, N. P.; Hewitt, L. M.; Muir, D. C. G.; Lindeman, D.; Strub, R.; Young, R. F.; Grewer, D. M.; Whittal, R. M.; Fedorak, P. M.; Birkholz, D. A.; Hindle, R.; Reisdorph, R.; Wang, X.; Kasperski, K. L.; Hamilton, C.; Woudneh, M.; Wang, G.; Loescher, B.; Farwell, A.; Dixon, D. G.; Ross, M. S.; Dos Santos Pereira, A.; King, E.; Barrow, M. P.; Fahlman, B.; Bailey, J.; McMartin, D. W.; Borchers, C. H.; Ryan, C. H.; Toor, N. S.; Gillis, H. M.; Zuin, L.; Bickerton, G.; McMaster, M. E.; Sverko, E.; Shang, D.; Wilson, L. D.; Wrona, F. J., Chemical fingerprinting of oil sands naphthenic acids in environmental samples—A review of analytical methods. *J. Environ. Sci. Health, Part A: Toxic/Hazard. Subst. Environ. Eng.* **2013**, *48*, 1145−1163.

(22) Smith, D. F.; Schaub, T. M.; Kim, S.; Rodgers, R. P.; Rahimi, P.; Teclemariam, A.; Marshall, A. G. Characterization of acidic species in Athabasca bitumen and bitumen heavy vacuum gas oil by negative-ion ESI FT-ICR MS with and without acid-ion exchange resin prefractionation. *Energy Fuels* **2008**, *22*, 2372−2378.

(23) Ferguson, G. P.; Rudolph, D. L.; Barker, J. F. Hydrodynamics of a large oil sand tailings impoundment and related environmental implications. *Can. Geotechnol. J.* **2009**, *46*, 1446−1460.

(24) Hunter, G. P. Investigation of groundwater flow within an oil sands tailings impoundment and environmental implications. University of Waterloo, 2001.

(25) MacKinnon, M. D.; Kampala, G.; Marsh, B.; Fedorak, P. M.; Guigard, S., Indicators for assessing transport of oil sands process-affected waters. In *Bringing Groundwater Quality Research to the Watershed (Proceedings of GQ2004 International Conference of Groundwater Quality)*, Thomson, N. R., Ed.; IAHS Press, 2005; Vol. *297*, pp 71−80.

(26) Oiffer, A. A. L.; Barker, J. F.; Gervais, F. M.; Mayer, K. U.; Ptacek, C. J.; Rudolph, D. L. A detailed field-based evaluation of naphthenic acid mobility in groundwater. *J. Contam. Hydrol.* **2009**, *108*, 89−106.

(27) Ross, M. S.; dos Santos Pereira, A.; Fennell, J.; Davies, M.; Johnson, J.; Sliva, L.; Martin, J. W. Quantitative and qualitative analysis of naphthenic acids in natural waters surrounding the Canadian oil sands industry. *Environ. Sci. Technol.* **2012**, *46*, 12796−12805.

(28) Athabasca River below McMurray. In *Environment Canada Water Level and Stream Flow Statistics*, Water Survey of Canada Station 07DA001; January 1957 to December 2011, 2013.

(29) Baker, K. M. Identification of process water in a surficial aquifer at Syncrude's Mildred Lake Site; University of Waterloo, 1999.

(30) Kasperski, K. L. A review of properties and treatment of oil sands tailings. *AOSTRA J. Res.*, **1992**, *8*, 11−53.

(31) Rowland, S. J.; West, C. E.; Jones, D.; Scarlett, A. G.; Frank, R. A.; Hewitt, L. M. Steroidal aromatic "naphthenic acids" in oil sands process-affected water: Structural comparisons with environmental estrogens. *Environ. Sci. Technol.* **2011**, *45*, 9806−9815.

(32) Headley, J. V.; Peru, K. M.; Armstrong, S. A.; Han, X.; Martin, J. W.; Mapolelo, M. M.; Smith, D. F.; Rogers, R. P.; Marshall, A. G. Aquatic plant-derived changes in oil sands naphthenic acid signatures determined by low-, high-, and ultrahigh-resolution mass spectrometry. *Rapid Commun. Mass Spectrom.* **2009**, *23* (4), 515−522.

(33) Barrow, M. P.; Peru, K. M.; Fahlman, B.; Hewitt, L. M.; Frank, R. A.; Headley, J. V. Beyond naphthenic acids: Environmental fingerprinting of water from natural sources and the Athabasca oil sands industry using atmospheric pressure photoionization Fourier transform ion cyclotron mass spectrometry. *Environ. Sci. Technol.* **2014**, *(currently in review)*.

(34) Barrow, M. P.; Witt, M.; Headley, J. V.; Peru, K. M. Athabasca oil sands process water: Characterization by atmospheric pressure photoionization and electrospray ionization Fourier transform ion cyclotron resonance mass spectrometry. *Anal. Chem.* **2010**, *82*, 3727−3735.

(35) Rowland, S. J.; Scarlett, A. G.; Jones, D.; West, C. E.; Frank, R. A. Diamonds in the rough: Identification of individual naphthenic acids in oil sands process water. *Environ. Sci. Technol.* **2011**, *45*, 3154−3159.

(36) Rowland, S. J.; West, C. E.; Scarlett, A. G.; Ho, C.; Jones, D. Differentiation of two industrial oil sands process-affected waters by

two-dimensional gas chromatography/mass spectrometry of diamondoid acid profiles. *Rapid Commun. Mass Spectrom.* **2012**, *26*, 572−576.
(37) Rowland, S. J.; West, C. E.; Scarlett, A. G.; Jones, D.; Frank, R. A. Identification of individual tetra- and pentacyclic naphthenic acids in oil sands process water by comprehensive two-dimensional gas chromatography-mass spectrometry. *Rapid Commun. Mass Spectrom.* **2011**, *25*, 1198−1204.
(38) Ahad, J. M. E.; Pakdel, H.; Savard, M. M.; Calderhead, A. I.; Gammon, P. R.; Rivera, A.; Peru, K. M.; Headley, J. V., Characterization and quantification of mining-related naphthenic acids' in groundwater near a major oil sands tailings pond. *Environ. Sci. Technol.* **2013**, *47*, 5023−5030.
(39) Ahad, J. M. E.; Pakdel, H.; Savard, M. M.; Simard, M.-C.; Smirnoff, A. Extraction, separation, and intramolecular carbon isotope characterization of Athabasca oil sands acids in environmental samples. *Anal. Chem.* **2012**, *84*, 10419−10425.
(40) Roy, J. W.; Bickerton, G. A proactive screening approach for detecting groundwater contaminants along urban streams at the reach-scale. *Environ. Sci. Technol.* **2010**, *44*, 6088−6094.
(41) *SOP 2003 - Standard Operating Procedure for the Analysis of Dissolved, Extractable and Total Trace Metals in Water by "Direct Aspiration" or "In Bottle Digestion" Inductively Coupled Plasma-Sector Field Mass Spectrometry (ICP-SFMS)*; NLET2008.
(42) Clemente, J. S.; Fedorak, P. M. A review of the occurrence, analyses, toxicity, and biodegradation of naphthenic acids. *Chemosphere* **2005**, *60*, 585−600.
(43) Gibson, J. J.; Birks, S. J.; Moncur, M.; Yi, Y.; Tattrie, K.; Jasechko, S.; Richardson, K.; Eby, P. *Isotopic and Geochemical Tracers for Fingerprinting Process-Affected Waters in the Oil Sands Industry: A Pilot Study*; Oil Sands Research and Information Network, University of Alberta, School of Energy and the Environment, Edmonton, AB, OSRIN Report No. TR-12: 2011; p 109.

Appendix XXII:

Letter from Environmental Defence to federal Environment Minister (27 May 2015)

environmental
defence
INSPIRING CHANGE

May 27th, 2015

Minister Leona Aglukkaq
House of Commons
Ottawa, Ontario

Dear Minister,

I am writing on behalf of Environmental Defence Canada to seek action from your department regarding the enforcement of s. 36(3) of the *Fisheries Act* with regard to toxic leakage from tar sands tailings ponds.

On July 29th, 2014, the Commission for Environmental Cooperation (CEC) 2014 notified the Government of Canada that "central questions remain open" regarding Environmental Defence and our co-submitters' assertions "that Canada is failing to enforce" the *Fisheries Act*. As such, the CEC recommended that it undertake a factual record to more deeply investigate this issue.

The three Parties to NAFTA voted against this recommendation. Nonetheless, the issues remain. There is strong evidence that toxic chemicals are leaking from tar sands tailings ponds into nearby rivers. Most recently, a study undertaken with the participation of Environment Canada scientists (Profiling oil sands mixtures from industrial developments and natural groundwaters for source identification, published in *Environmental Science and Technology*) showed that chemicals found in groundwater and migrating into the Athabasca River had the chemical fingerprint of tailings pond wastewater. There remain open questions about Environment Canada's enforcement of the *Fisheries Act* with respect to these leakages.

I am therefore writing to you, on behalf of Environmental Defence, to request that you exercise your authority as Canada's Environment Minister and instruct Environment Canada's enforcement branch to effectively enforce s. 36(3) of the *Fisheries Act* in order to end the practice of allowing widespread leakage of toxic water from tar sands tailings ponds.

Sincerely,

Dale Marshall
National Program Manager, Environmental Defence

cc. Gordon Owen, Chief Enforcement officer, Environment Canada

180 Metcalfe Avenue, Suite 300, Ottawa Ontario K2P 1P5
Tel: 613-868-9917
Fax: 416-323-9301 email: dmarshall@environmentaldefence.ca
www.environmentaldefence.ca