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REPORT ON

AQUATIC RESOURCES BASELINE STUDY FOR THE MUSKEG RIVER MINE PROJECT

Submitted to:

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Project 972-2237

ACKNOWLEDGEMENTS

This aquatic baseline report was prepared for Shell Canada Ltd. (Shell) by Golder Associates Ltd. (Golder) as part of the Muskeg River Mine Environmental Impact Assessment. Ian Mackenzie was the Project Manager and John Gulley was the Oil Sands Director. Marie Lagimodiere was the Aquatics component leader.

Celine Larose and Tony Calverley lead the field work and were assisted by Ken Allen, Chris Stoesz, Tanis Dirks and Janice Cursons. Tanis Dirks was the report coordinator and Dave Fernet was the senior technical advisor. The report was prepared by Celine Larose, Tanis Dirks, Zsolt Kovats and J.P. Bechtold. Dave Fernet, Serge Metikosh and Marie Lagimodiere reviewed the report. Carole Collins formatted the report.

EXECUTIVE SUMMARY

Shell Canada Limited (Shell) is proposing the Muskeg River Mine Project on the west side of Lease 13, which is located within the Muskeg River watershed east of the Athabasca River and north of Fort McMurray, Alberta. As part of the Environmental Impact Assessment (EIA) for the Muskeg River Mine oil sands development, Shell initiated an aquatic environmental baseline program. This program was conducted in 1997 to: 1) describe the current conditions with respect to surface water, porewater and sediment quality, benthic invertebrate communities, fish habitat and fish communities; and 2) provide a baseline for comparing future conditions. This study is an addition to previous studies conducted within the watershed, including the Aurora Mine aquatic baseline study for Syncrude Canada, the Other Six Leases Operations (OSLO) studies, the Alsands studies and the Alberta Oil Sands Environmental Research Program (AOSERP) studies.

Major findings of the 1997 study include:

- naturally occurring hydrocarbons can be found in river sediments and porewater; however, there is no discernible impact of these hydrocarbons on surface water quality;
- benthic invertebrate surveys carried out during the last decade have documented similar benthic communities along the lower Athabasca River and moderate year-to-year variation in community structure in the Muskeg River basin;
- fish habitat in the Athabasca River within the study area is relatively poor because of the homogeneous habitat and shifting sand bottom. High quality habitat exists in the Muskeg River and its tributaries; and
- there are diverse fish communities in the Athabasca and Muskeg rivers.

Study Area

The local study area (LSA) includes the Muskeg River watershed, Isadore's Lake watershed and the Athabasca River from the mouth of the Muskeg River to the northern Lease 13 boundary. However, the aquatic baseline study focuses on the Muskeg River Mine Project development area which includes Jackpine Creek, the central portion of the Muskeg River, Isadore's Lake and Mills Creek. The man-made Alsands Drain system and a few unnamed ponds are also within the development area.

Methods

As part of the Muskeg River Mine aquatic baseline program, Golder Associates Ltd. was retained to conduct seasonal field sampling to supplement existing information. Data collected during the 1997 Regional

Aquatics Monitoring Program (RAMP) were also included where applicable.

The 1997 field program consisted of water sampling in the Athabasca River, Muskeg River, Jackpine Creek, Muskeg Creek, Shelley Creek, Isadore's Lake, Mills Creek and the Alsands Drain. Fish inventories were conducted in the Muskeg River, Jackpine Creek and the Alsands Drain and fish habitat was mapped in the Muskeg River. Bottom sediment was sampled at a number of locations in the Athabasca River and its major tributaries as part of RAMP. Historical information was summarized for benthic invertebrates and porewater quality from previous studies completed in the Athabasca River and the Muskeg River basin.

Surface Water

River water in the Athabasca River and the Muskeg River basin is characterized by a pH range of 7 to 8 and low to moderate levels of dissolved salts (total dissolved solids).

The Athabasca River is characterized by high levels of suspended sediment during spring and summer resulting in elevated concentrations of nutrients (e.g., total phosphorus) and a number of metals (e.g., aluminum, iron, manganese). Nutrient levels are indicative of moderate enrichment from natural sources and, potentially, from upstream point sources (pulp mills and municipal sewage treatment plants). Levels of dissolved metals and naturally occurring hydrocarbons are generally low. Detectable, but low, levels of organic compounds are present. There is no evidence of toxicity in Athabasca River water.

The Muskeg River and its tributaries are characterized by clear water in all seasons. Nutrient levels are low to moderate and vary seasonally. Dissolved organic carbon is elevated in all streams, reflecting natural muskeg drainage inputs. Concentrations of total metals are generally low with the exception of iron, manganese, silicon and strontium. Naturally occurring hydrocarbons and naphthenic acids are occasionally detectable, but at very low levels. Trace organic compounds (PAHs) were not detected at the sites sampled and none of the streams were toxic to bacteria (Microtox ®).

The water quality of Isadore's Lake and Mills Creek is generally similar to other waterbodies in the Muskeg River basin. Differences include higher dissolved salts in Mills Creek in the fall and slightly lower dissolved organic carbon and nutrient levels in both Isadore's Lake and Mills Creek.

Water quality of the Alsands Drain differs slightly from those of natural tributaries of the Muskeg River. Concentrations of dissolved salts and total Kjeldahl nitrogen, total alkalinity and hardness were higher and phosphorus level was lower in the Alsands Drain than in other streams. Levels of metals were similar to those in natural streams.

There are minor water quality guideline exceedances for aquatic life in the Athabasca River, the Muskeg River and its tributaries, Isadore's Lake and the Alsands Drain. In the Athabasca River, certain metals and total phosphorus exceed water quality guidelines due to high suspended sediment load. In the Muskeg River, its tributaries and Isadore's Lake, concentrations of total phosphorus, total phenolics and a number of metals exceeded chronic water quality guidelines. Overall, water quality is good in all waterbodies sampled within the study area and occasional guideline exceedances appear to have no impact on aquatic life.

Sediment Quality

Bottom sediments have not been extensively sampled in the aquatics local study area. In the Athabasca River, recent studies found elevated levels of naturally occurring hydrocarbons above and adjacent to existing oil sands operations. Exceedances of Threshold Effect Levels (TELs) for cadmium and nickel were found near Tar Island Dyke and at Fort Creek. The limited data available do not reveal spatial trends consistent with input of PAHs from oil sands operations, but suggest there is an increase in natural input of PAHs near the upstream limit of the oil sands area.

Bottom sediment samples from the Muskeg River and Jackpine Creek showed concentrations of metals and PAHs were below those in the Athabasca River. Potential exceedances of the TEL values for benz(a)anthracene and chrysene occurred at the sites sampled in the Muskeg River basin; however, since concentrations of these compounds were reported together, exceedances cannot be identified with certainty.

Porewater Quality

The limited porewater data from the oil sands area suggest that the chemical composition of porewaters can vary greatly, depending on the amount of oil sands in the substratum. The concentrations of dissolved salts varied widely in porewater samples collected in 1995 from the Athabasca and Muskeg rivers and Jackpine Creek. Naphthenic acids concentrations were variable but low at all sites. Naturally occurring PAHs were detectable in the Athabasca River but not in the Muskeg River or Jackpine Creek. None of the samples were toxic to bacteria.

Benthic Invertebrates

The Athabasca River provides relatively low quality, largely depositional habitat for benthic invertebrates. The shifting sand bottom typical of this reach supports benthic communities of low density and taxonomic richness (number of taxa), consisting largely of chironomid midge larvae, oligochaete worms and nematodes. A number of studies documented localized, minor biological effects of water releases from oil sands operations in the Athabasca River. Reductions in invertebrate density and taxonomic richness below Tar Island Dyke and the refinery wastewater and sewage outfalls were reported in historical studies.

The benthic communities in the Muskeg River basin are more diverse, reflecting a variety of benthic habitats. Depositional sites typically supported invertebrate communities with moderate density and low taxonomic richness, consisting almost exclusively of oligochaete worms, nematode worms and chironomid midge larvae. Density was lower at the erosional sites; however, a greater variety of invertebrates was found. Erosional benthic communities consisted of all taxa found at the depositional sites and included aquatic insects of various orders. Qualitative examination of a subset of the available data for stream sites in the Muskeg River basin revealed that, although invertebrate density may vary considerably among years, taxonomic composition of the resident benthic communities has remained relatively similar during the last decade.

Fish Habitat

The Athabasca River has turbid cool-water habitat with dynamic shifting-sand channels. Single channels are the major channel type but near islands and sand bars, multiple channels are present. Major habitat features include backwaters and snyes associated with islands and sandbars. The substrate is almost entirely sand although there are a few areas where bedrock is predominant. Instream cover is minimal except for that provided by depth and turbidity.

Fish habitat is highly variable in the Muskeg River. Habitat above Lease 13, in the upper portion of Reach 4, Reach 5 and Reach 6 is characterized by slow, deep meandering runs that flow through muskeg. The river substrate is dominated by silt, and there are large amounts of instream debris. Beaver activity is common in the upper reaches and may limit fish passage.

Fish habitat of the Muskeg River within and below Lease 13, in Reaches 1 to 3 and the lower portion of Reach 4, is characterized by fast-moving runs and riffles that flow through well-drained upland areas. Deep runs and pools (> 2.0 m) are also common in these reaches of the river. The substrate is dominated by cobble and gravel. Overhanging bank vegetation and instream debris is present, providing suitable instream cover for fish.

Jackpine Creek has 5 distinct reaches that differ mainly in gradient. The lowermost and uppermost reaches have low gradients with slow meandering runs. Reaches 2 and 4 have a slightly higher gradient with more habitat diversity and fewer meanders than Reaches 1 and 5. Reach 3 has a high gradient and cobble/gravel substrate is common, with riffle/run/pool sequences predominant. Beaver activity is common in Reaches 1 and 2.

Standing waters in the Muskeg River watershed and Mills Creek watershed consist of shallow muskeg ponds north and south of the Muskeg River and a few upland lakes (13 m to 22 m deep) south of the Muskeg River. The shallow ponds have no inflow or outflow channels and their substrate is dominated by organic muck or sand. One of the lakes has a permanent outflow and two intermittent streams connect three of the lakes. Submergent and emergent vegetation is present in all the waterbodies.

The Alsands Drain is the drainage system developed for the Alsands Project. There is no previously documented spawning, nursery or rearing fish habitat in the drainage system. The Alsands Drain is uniform in its physical characteristics with slow deep runs in the northern end and shallower, faster runs in the southern end. Beaver activity is present along the length of the drainage system. Submergent and emergent vegetation is also present.

Isadore's Lake is a former part of the Athabasca River that has developed into an oxbow lake. Isadore's Lake is productive, clear and relatively shallow, with a few deep pools. The substrate is organic muck and maximum depth measured is 4.25 m. The lake is bordered by emergent vegetation. Substrate, submergent vegetation and depth documented in recent studies was similar to the findings of previous studies except the open water area of Isadore's Lake was larger. Beaver activity was evident throughout the lake.

Mills Creek is a small stream that drains into Isadore's Lake. It is characterized by low quality runs, occasionally interspersed with riffles. The substrate is predominantly sand, with small areas of boulder and cobble. Moderate instream cover and overhead cover from woody debris and aquatic vegetation is present.

Fish Communities

Historically, twenty-seven species of fish have been reported from the Athabasca River in the area of the Muskeg River Mine Project. Recent and historical studies indicate that goldeye, walleye, white sucker, longnose sucker and lake whitefish are the most abundant sport and commercial fish species in the Athabasca River near the Muskeg River Mine Project local study area. Arctic grayling, burbot, northern pike, bull trout, mountain whitefish, yellow perch and a variety of forage fish species have also been documented to reside in the Athabasca River at some point in their life cycle. Species abundance and distribution patterns in 1997 are similar to those reported by previous studies.

Eleven fish species were captured in the Muskeg River watershed during the 1997 fish inventories. Species found in the Muskeg River included Arctic grayling, northern pike, white and longnose sucker and some forage fish species.

Arctic grayling migrate up the Muskeg River and its tributaries to spawn and remain there during the summer months to feed. Recent observations suggest that the young-of-the-year may also overwinter in this area, however, overwintering habitat for adult arctic grayling is minimal. Northern pike, white sucker and longnose sucker spawn in these tributaries as well, and move back to the Athabasca River at the end of the summer.

Forage fish are the only fish species present in the shallow muskeg ponds, the deep upland lakes within the Muskeg River watershed and the Alsands Drain. No fish have been captured in Mills Creek. Northern pike have been documented to reside and spawn in Isadore's Lake when they can access the lake during high Athabasca River flows.

TABLE OF CONTENTS

SECTION **PAGE**

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1. INTRODUCTION

1.1 OBJECTIVES

aquatic baseline study

Shell Canada Limited (Shell) is proposing the Muskeg River Mine Project on the west side of Lease 13, about 75 km northeast of Fort McMurray. Lease 13 is located on the east side of the Athabasca River within the Muskeg River watershed (Figure 1.1-1). As part of the Environmental Impact Assessment (EIA) for the Muskeg River Mine Project oil sands development, Shell initiated an aquatic environmental baseline program. This program builds on previous studies within the watershed, namely the aquatic baseline study for Syncrude Canada Limited's (Syncrude) Aurora Mine (Golder 1996a, Golder 1996b), the OSLO studies from the late 1980s (Beak 1986, R.L.& L. 1989) and the Alsands Studies from the early 1980s (Webb 1981).

field surveys for the aquatic baseline study

As part of the aquatic baseline program, Golder Associates Ltd. was retained to conduct seasonal field sampling. The first sampling survey was in February 1997. The purpose of winter sampling was to determine winter water quality and to evaluate the potential for fish to overwinter in the Muskeg River watershed. Winter sampling results are summarized in Section 3.1 of this report and detailed in Golder (1997a). Spring, summer and fall sampling was also undertaken to supplement existing information on seasonal water quality and fish utilization, and to evaluate fish habitats in the Muskeg River watershed. These data were compared with historical data for the study area (Webb 1981, Bond and Machniak 1979, O'Neil et al. 1982, Beak 1986, R.L.& L. 1989). The 1997 field program consisted of sampling in the Muskeg River and its tributaries on the west side of Lease 13, as well as in Isadore's Lake and Mills Creek (a small tributary of Isadore's Lake).

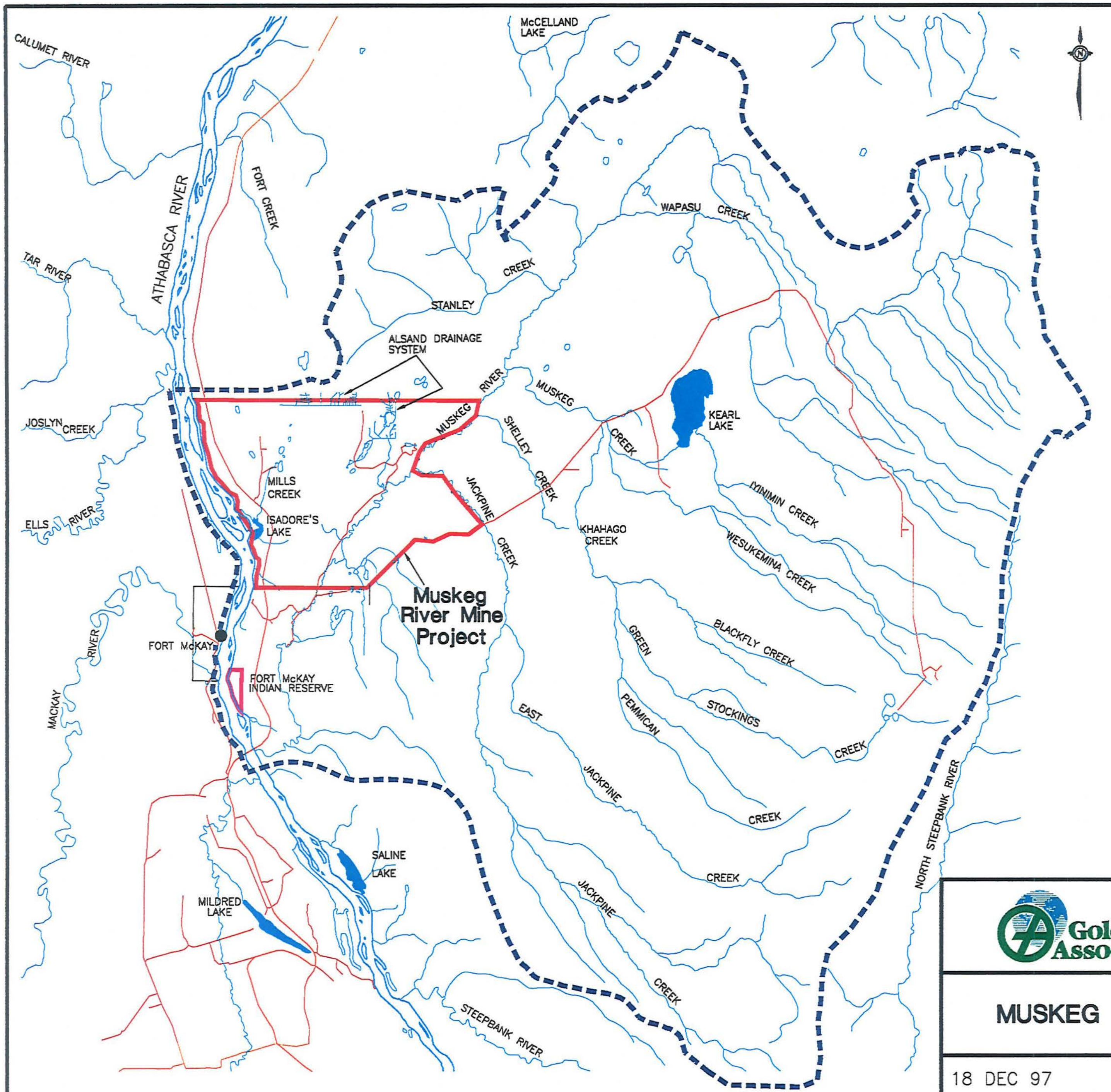
RAMP

The reach of the Athabasca River from the mouth of the Muskeg River to Fort Creek, which is north of the Lease 13 boundary, was surveyed as part of the Regional Aquatics Monitoring Program (RAMP) in the spring, summer and fall seasons of 1997. Results from these inventories will be compiled in Golder 1998. Available data are summarized in the appropriate sections of this report.

1.2 STUDY AREA

local study area description

The proposed Muskeg River Mine Project is located in the centre of the Muskeg River watershed. A section of Jackpine Creek, a tributary of the Muskeg River, the central portion of the Muskeg River, Isadore's Lake and Mills Creek are located within the development area (Figure 1.1-1). Muskeg River tributaries within the local study area (LSA) include Shelley, J:\1997\2237\6050\BASELINE\STUD13.dwg



LEGEND

LOCAL STUDY AREA FOR AQUATICS (SURFACE WATER HYDROLOGY, WATER QUALITY, AND AQUATIC RESOURCES)

MUSKEG RIVER MINE PROJECT

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I 84A AND 84H FROM RESOURCE DATA DIVISION ALBERTA ENVIRONMENTAL PROTECTION, 1997.

0 5 10 15km

SCALE 1:300,000

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MUSKEG RIVER MINE PROJECT AREA

18 DEC 97	Figure 1.1-1	DRAWN BY: RFM/DC

Jackpine and Muskeg creeks. However, the proposed mine development project will be located in the western portion of Lease 13.

watercourses in development area

The development area includes the Muskeg River from the northern lease boundary to the mouth, the portion of Jackpine Creek from the Canterra Road to the mouth, and the Athabasca River from the mouth of the Muskeg River to the northern Lease 13 boundary. As well, the development area includes Mills Creek and Isadore's Lake, which is connected to the Athabasca River through an outlet at the west end of the lake.

significant fish habitat

Jackpine Creek and the Muskeg River represent significant fish habitat in this region since they provide spawning habitat for Arctic grayling and northern pike (R.L.&L. 1989, Golder 1996a). Isadore's Lake is also significant since northern pike have been reported to reside and spawn in the lake (Webb 1981, Golder 1997b).

2. METHODS

2.1 HISTORICAL DATA SOURCES

background information

Information pertaining to aquatic biological resources (fisheries, water quality, benthic invertebrates) and aquatic habitats in the oil sands of northeastern Alberta was reviewed before developing the current studies.

historical information for Athabasca River

Aquatic studies associated with the Athabasca River area date back to the late 1970s, early 1980s, during the height of the Alberta Oil Sands Environmental Research Program (AOSERP) research activities (Tripp and McCart 1979, Barton and Wallace 1980, Bond 1980, Tripp and Tsui 1980). A few other studies were conducted during this period (Noton 1979, Webb 1980). Different studies were done under the Other Six Leases Operation (OSLO) joint venture in the 1980s (Beak 1986, R.L.& L. 1989). More recently, the Northern River Basins Study (NRBS) has added additional data for the area, from surveys done during 1992 to 1994 (R.L.& L. 1994). Studies from 1995 to 1996 include the Steepbank and Aurora mines aquatic baseline studies (Golder 1996a) in 1995 and additional fisheries surveys done for Syncrude in 1996 (Golder 1996b) (Table 2.1-1).

historical information for Muskeg River basin

The Muskeg River and its tributaries were surveyed in a number of aquatic studies (Bond and Machniak 1979, Webb 1980, O'Neil et al. 1982, Beak 1986, R.L. & L. 1989) (Table 2.1-1). The most recent aquatic studies of the Muskeg River basin and Isadore's Lake were done for the Aurora Mine EIA (Golder 1996a, 1996b and 1997b).

Table 2.1-1 Historical Data Sources

Project	Year	River/ Creek	Description	Information	Reference
AOSERP	1978	Athabasca River	Investigations of the spring spawning fish populations	F	Tripp and McCart (1979)
AOSERP	1976-1978	Muskeg River, Jackpine Creek	An intensive study of the fish fauna	F	Bond and Machniak (1979)
AOSERP	1976-1977	Athabasca and Muskeg rivers	Benthic habitat and communities	B	Barton and Wallace (1980)
AOSERP	1976-1977	Athabasca River	Fisheries resources downstream of Fort McMurray	F	Bond (1980)
Syncrude Baseline	1975	Athabasca River	Baseline studies of aquatic environments	W, F, B	McCart et al. (1977)
AEP monitoring	1977-1983	Athabasca River	AEP long-term monitoring of benthic invertebrate communities	B	Anderson (1991)
GCOS (now Suncor) Monitoring	1978	Athabasca River	Study of benthic invertebrates and sediment chemistry	W, B, S	Noton (1979)

Project	Year	River/ Creek	Description	Information	Reference
AOSERP	1978	Athabasca River	Fisheries and habitat investigations of tributary streams	F	Tripp and Tsui (1980)
Alsands	1979	Unnamed lakes and ponds	Survey of lakes and ponds	W, F, P	Webb (1980)
Suncor Monitoring	1981	Athabasca River	Survey of water quality and benthic invertebrates	W, B	Noton and Anderson (1982)
SandAlta	1981	Jackpine Creek and Muskeg River	Aquatic investigations in the Hartley (Jackpine) Creek area	F, B	O'Neil et al. (1982)
Suncor Monitoring	1982	Athabasca River	Study of benthic invertebrates	B	Boerger (1983)
AEP monitoring	1970-1985	Athabasca River	Water quality surveys	W	Hamilton et al. (1985)
OSLO	1985	Athabasca and Muskeg rivers and Jackpine Creek	Aquatic baseline survey for the OSLO Oil sands Project	W, F, B	Beak (1986)
OSLO	1988	Athabasca and Muskeg rivers and Jackpine Creek	OSLO Project: Water quality and fisheries resources baseline studies	W, F, B	R.L. & L. (1989)
AEP monitoring	1988-1989	Athabasca River	Winter water quality surveys	W	Noton and Shaw (1989)
AEP monitoring	1990-1993	Athabasca River	Water quality surveys	W	Noton and Saffran (1995)
NRBS	1992	Athabasca River	A general fish and riverine habitat inventory	F	R.L. & L. (1994)
Suncor monitoring	1994	Athabasca River	Study of effects of TID seepage on benthic invertebrates	B	Golder (1994)
Aurora/ Steepbank mines baseline	1995	Athabasca, Muskeg and Steepbank rivers and Jackpine Creek	Aquatic baseline studies	W, F, B, S	Golder (1996a)
Aurora/ Steepbank mines baseline	1996	Athabasca River	1996 fisheries investigations: addendum to Golder (1996a)	F	Golder (1996b)

NOTE: W = surface water, S = sediments, P = plants, B = benthic invertebrates, F = fisheries.

2.2 SURFACE WATER, SEDIMENT AND POREWATER QUALITY

2.2.1 Water Quality Approach

surveys done to supplement existing data

Data generated by a number of surveys were summarized to describe existing water, sediment and porewater quality in the Muskeg River basin, Isadore's Lake and the Athabasca River within the oil sands area. Historical data were summarized by reach and season for the Athabasca and Muskeg rivers and for streams with adequate (multisite, multiyear) data.

2.2.2 Surface Water Quality

1997 Surveys

Site Locations and Sampling Dates

seasonal sampling

Seasonal water quality data were collected from a number of locations within and outside Lease 13 during the 1997 baseline program (Figure 2.2-1). Water quality sampling was carried out in each season of 1997: spring (May 21 to 26); summer (July 19 to 26); and fall (September 15 to 22 and October 19). Winter sampling was done in March and reported in Golder (1997a).

sample locations

Water quality site locations are listed in Table 2.2-1. Three tributaries were sampled in the Muskeg River watershed. Water was collected from the mouth of Jackpine Creek and at the Canterra road crossings of Shelley and Muskeg creeks (Figure 2.2-1). Water was also collected from Isadore's Lake and Mills Creek. As well, composite samples were collected above the mouth of the Muskeg River in the Athabasca River.

timing of sampling

Samples were collected during all seasons of 1997 at the mouth of Jackpine Creek and above the mouth of the Muskeg River on the Athabasca River. Surface water sampling at Shelley Creek and at Muskeg Creek was carried out in the winter, spring and summer (Table 2.2-2). No fall samples were collected from this station, because refinement of the project area resulted in the exclusion of the eastern portion of Lease 13. Mills Creek was sampled in the spring and fall. Water was collected from Isadore's Lake in the winter, summer and fall. Since access to Isadore's Lake was impeded by high water levels in the spring, water was collected from the inlet to this lake (Mills Creek).

RAMP

Additional data were collected in 1997 as part of the RAMP, a program which was initiated by Suncor, Syncrude and Shell, to monitor the effects of oil sands developments on aquatic resources in an efficient and coordinated manner.

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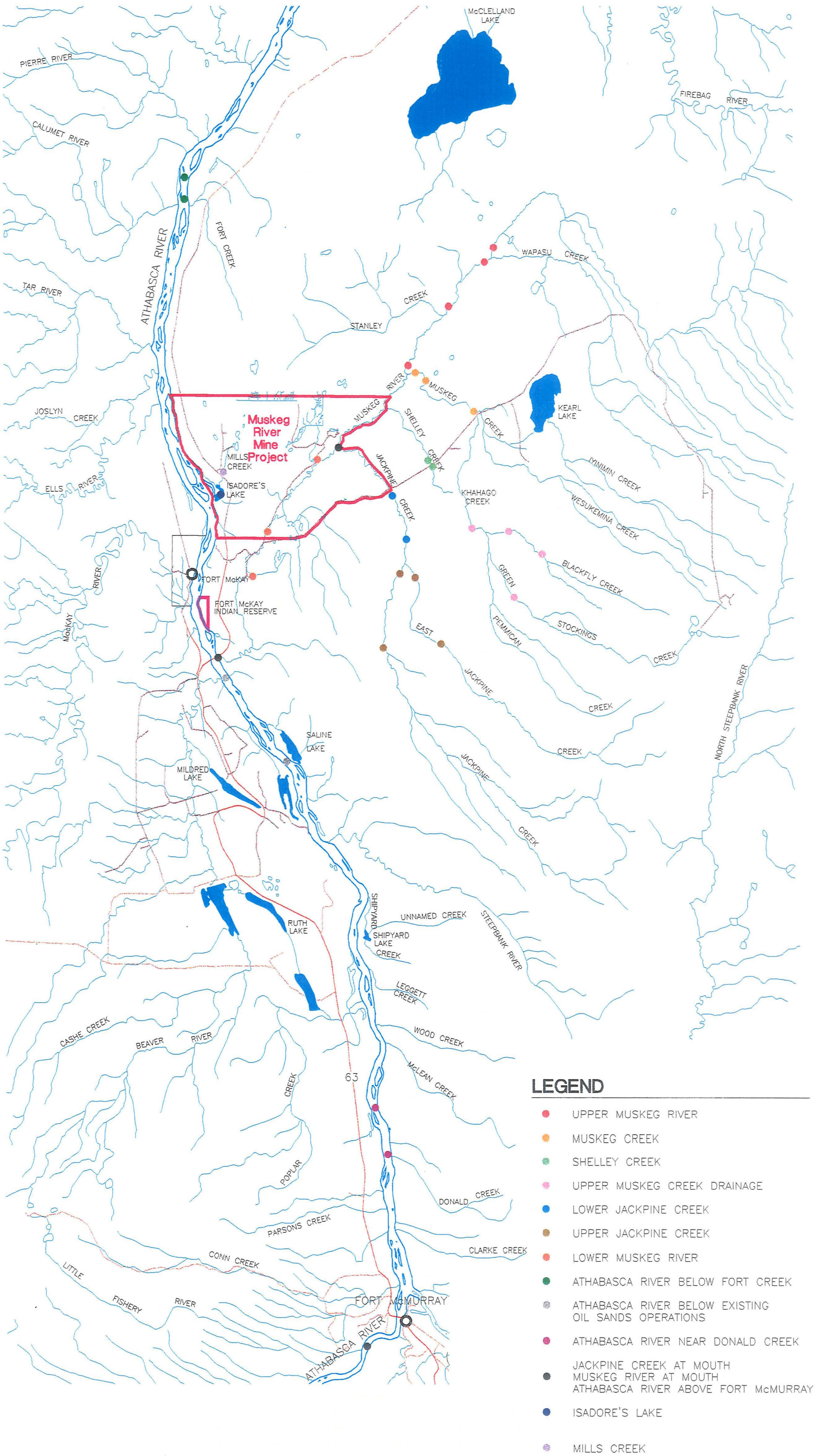

SCALE
0 5 10 15 20km

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I
84A AND 84H FROM RESOURCE DATA DIVISION
ALBERTA ENVIRONMENTAL PROTECTION, 1997.

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WATER QUALITY SAMPLING STATIONS

07 JAN 98	Figure 2.2-1	DRAWN BY: CG

Table 2.2-1 Water Quality Site Locations

Site Description	Data Source	Reference
Athabasca River above Fort McMurray	NAQUADAT Site 00AL07CC0500 NAQUADAT Site 00AL07CC0600	NAQUADAT NAQUADAT
Athabasca River near Donald Creek	RAMP monitoring site A3 Aquatic Baseline site AW004	Golder (1998) Golder (1996a)
Athabasca River below existing Oilsands operations	Aquatic Baseline site AW009 Muskeg River Mine Project baseline site	Golder (1996a) Golder 1997 (current study)
Athabasca River below Fort Creek	NAQUADAT Site 00AL07DA4200 NAQUADAT Site 00AL07DA4250 NAQUADAT Site 00AL07DA4300 RAMP monitoring site A15	NAQUADAT NAQUADAT NAQUADAT Golder (1998)
Muskeg River at mouth	NAQUADAT Site 00AL07DA2600 NAQUADAT Site 00AL07DA2650 RAMP monitoring site Aquatic Baseline site 30	NAQUADAT NAQUADAT Golder (1998) Golder (1996a)
Lower Muskeg River	NAQUADAT Site 00AL07DA2550 Muskeg River Mine Project baseline site Aquatics baseline site 18 R.L.& L. site 18	NAQUADAT Golder 1997 (current study) Golder (1996a) R.L.& L. (1989)
Upper Muskeg River	Muskeg River Mine Project baseline site R.L.& L. site 1 R.L.& L. site 2 R.L.& L. site 3	Golder 1997 (current study) R.L.& L. (1989) R.L.& L. (1989) R.L.& L. (1989)
Jackpine Creek at mouth	NAQUADAT Site 00AL07DA2500 RAMP monitoring site Muskeg River Mine Project baseline site Aquatics baseline site 17 R.L.& L. site 17	NAQUADAT Golder (1998) Golder 1997 (current study) Golder (1996a) R.L.& L. (1989)
Lower Jackpine Creek	R.L.& L. site L4 R.L.& L. site 17	O'Neil et al. (1982) O'Neil et al. (1982)
Upper Jackpine Creek	NAQUADAT Site 00AL07DA2300 NAQUADAT Site 00AL07DA2400 R.L.& L. site 15 R.L.& L. site 16 R.L.& L. site L6 R.L.& L. site L7	NAQUADAT NAQUADAT R.L.& L. (1989) R.L.& L. (1989) O'Neil et al. (1982) O'Neil et al. (1982)
Muskeg Creek	NAQUADAT Site 00AL07DA2000 NAQUADAT Site 00AL07DA2150 Muskeg River Mine Project baseline site Aquatic baseline site 50 R.L.& L. site 10 R.L.& L. site 11	NAQUADAT NAQUADAT Golder 1997 (current study) Golder (1996a) R.L.& L. (1989) R.L.& L. (1989)
Shelley Creek	NAQUADAT Site 00AL07DA2200 Muskeg River Mine Project baseline site	NAQUADAT Golder 1997 (current study)
Upper Muskeg Creek drainage	Aquatic baseline site 55 R.L.& L. site 12 R.L.& L. site 13 R.L.& L. site 14	Golder (1996a) R.L.& L. (1989) R.L.& L. (1989) R.L.& L. (1989)
Isadore's Lake	Muskeg River Mine Project baseline site	Golder 1997 (current study)
Mills Creek	Muskeg River Mine Project baseline site	Golder 1997 (current study)

three RAMP sampling campaigns in Athabasca River

Three Athabasca River sampling sites were selected: one site upstream of the oil sands development area, above the mouth of Donald Creek and one site downstream of all oil sands developments, below the mouth of Fort Creek (Table 2.2-2). An additional sampling location was selected at the mouth of the Muskeg River. Water samples were collected at these sites in three different sampling campaigns: spring (May 6 to 13), summer (July 24 to 30) and fall (October 2 to 12). All water quality data collected during the RAMP will be compiled in Golder 1998. Relevant spring and summer data are summarized in this report.

Water Quality Sampling

parameters measured: Muskeg River

At all surface water quality stations, basic field parameters, such as pH, conductivity, dissolved oxygen and water temperature were measured following Golder Technical Procedure 8.3-1 (Appendix I). Field parameters were measured using Horiba (pH) and Yellow Springs Instruments (YSI) meters. Samples collected from the Muskeg River basin, Isadore's Lake and Mills Creek were analyzed for conventional water quality parameters, such as total organic carbon, major ions and total suspended solids (Table 2.2-2). These samples were also analyzed for nutrients, recoverable hydrocarbons, naphthenic acids, biochemical oxygen demand (BOD), general toxicity (Microtox® test) and total metals. Dissolved metals were also analyzed in the winter, summer and fall samples. Water collected from the Athabasca River above the mouth of the Muskeg River was analyzed for organic compounds including polycyclic aromatic hydrocarbons (PAHs) (Table 2.2-2).

parameters measured: RAMP

Samples collected under the RAMP were analyzed for the same parameters as the Muskeg River basin samples: conventional parameters, total organic carbon, major ions, total suspended solids, nutrients, recoverable hydrocarbons, naphthenic acids, BOD, general toxicity, metals and dissolved metals (Table 2.2-2).

QA/QC procedures

As part of the Quality Assurance/Quality Control (QA/QC) procedures, triplicate samples and a field blank were collected from one randomly selected station for each field survey trip under the Muskeg River Mine Project and RAMP sampling programs. Water quality samples were collected, stored and shipped to laboratories following procedures set out in Golder Technical Procedures 8.3-1 (Appendix I).

Water Quality Parameters

conventional parameters

Characterization of water quality was intended to provide information on conventional water quality parameters (e.g., acidity, alkalinity, major ions, nutrients, metals) that are typically measured in surface waters and compounds associated with natural deposits of oil sands (recoverable hydrocarbons, PAHs) and oil sands operations (naphthenic acids). In addition to chemical concentrations, the bacterial luminescence (Microtox®) test was used as an indicator of toxicity to aquatic organisms. Oil sands-related parameters are briefly described below.

Table 2.2-2

Water Quality Parameters Sampled in Muskeg River Mine Project, 1997

Parameter	Sites Sampled								
	Athabasca River above mouth of Muskeg River	Isadore's Lake	Mills Creek	Shelley Creek	Muskeg Creek	Jackpine Creek	Athabasca River below Fort Creek*	Athabasca River above Donald Creek*	Muskeg River at the Mouth*
Field measured									
pH	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Specific Conductance	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Temperature	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Dissolved Oxygen	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Group 1 - Conventional									
pH		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Specific Conductance		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Colour		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Total Alkalinity		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Total Hardness		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Bicarbonate		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Carbonate		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Total Suspended Solids		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Total Dissolved Solids		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Total Organic Carbon		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Dissolved Organic Carbon		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Group 2 - Major Ions									
Calcium		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Magnesium		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Potassium		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Sodium		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Chloride		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Sulphate		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Sulphide		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Group 3 - Nutrients									
Nitrogen - Total Ammonia		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Nitrogen - Total Kjel-Nitro.		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Nitrate + Nitrite		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Total Phosphorus		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Dissolved Phosphorus		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Chlorophyll "a"		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Group 4 - BOD									
Biochemical Oxygen Demand		W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Group 5 - Other									

Table 2.2-2

Water Quality Parameters Sampled in Muskeg River Mine Project, 1997

Parameter	Sites Sampled								
	Athabasca River above mouth of Muskeg River	Isadore's Lake	Mills Creek	Shelley Creek	Muskeg Creek	Jackpine Creek	Athabasca River below Fort Creek*	Athabasca River above Donald Creek*	Muskeg River at the Mouth*
Recoverable Hydrocarbons	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Naphthenic Acids	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Microtox IC50 and IC20	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Total Phenolics	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Group 6 - Total Metals									
Aluminum - zinc	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Antimony (Sb)	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Arsenic (As)	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Mercury (Hg)	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Selenium (Se)	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	P, U, F	P, U, F	P, U, F
Group 7 - Dissolved metals									
Aluminum - zinc	W, P, U, F	W, U, F	W, F	U	U	W, U, F	P, U, F	P, U, F	P, U, F
Antimony (Sb)	W, P, U, F	W, U, F	W, F	U	U	W, U, F	P, U, F	P, U, F	P, U, F
Arsenic (As)	W, P, U, F	W, U, F	W, F	U	U	W, U, F	P, U, F	P, U, F	P, U, F
Mercury (Hg)	W, P, U, F	W, U, F	W, F	U	U	W, U, F	P, U, F	P, U, F	P, U, F
Selenium (Se)	W, P, U, F	W, U, F	W, F	U	U	W, U, F	P, U, F	P, U, F	P, U, F
Group 8 - PAHs									
Target PAHs (Naphthalene...)	W, P, U, F								
Alkylated PAHs (Methyl naphthalenes)	W, P, U, F								
Group 9 - General Toxicity									
Microtox	W, P, U, F	W, U, F	W, P, F	W, P, U	W, P, U	W, P, U, F	W, U, F		

KEY SEASON
U = Summer
P = Spring
F = Fall
W = Winter

* Stations Sampled under the 1997 RAMP Program

oil sands parameters

Recoverable hydrocarbons (mineral oil) include hydrocarbons derived from natural oil sands deposits. During laboratory analysis, naturally occurring, polar hydrocarbons are removed from the sample. This parameter is a useful indicator of the amount of oil sands-related hydrocarbons in surface waters and sediments. In the oil sands area, recoverable hydrocarbon levels tend to be low or below the detection limit in surface waters, but elevated levels have been measured in sediments containing bitumen.

PAHs

Polycyclic aromatic hydrocarbons are complex organic compounds that may have adverse effects on aquatic organisms at elevated concentrations, or may cause tainting of fish flesh. These compounds may originate from the combustion of fossil fuels and organic matter (i.e., forest fires), petroleum products and natural deposits of oil sands. In the oil sands area, levels of PAHs are usually correlated with those of recoverable hydrocarbons.

naphthenic acids

Naphthenic acids are a complex group of naturally occurring, organic acids that are leached from oil sands during the hot water extraction process currently used to extract bitumen from oil sands. They have been shown to cause acute toxicity in aquatic organisms at elevated concentrations. In the oil sands area, naphthenic acids are usually below the detection limit in surface waters, but may be present at low levels in sediments containing bitumen. Since these compounds are liberated during the course of oil sands extraction, "process-affected" waters usually contain elevated levels. For this reason, naphthenic acids can be used as an indicator of waters discharged from oil sands industries.

Laboratory Analysis

Water samples were analyzed by Enviro-Test Laboratories (ETL) of Edmonton for conventional parameters, nutrients, BOD, total phenolics, recoverable hydrocarbons and total and dissolved metals. Microtox® tests were carried out by HydroQual Laboratories in Calgary. See Appendix II for general descriptions of analytical methods used for laboratory analyses.

Historical Data

Before 1997, surface water samples were collected in the oil sands area under the following programs:

- routine monitoring by Alberta Environmental Protection (AEP);
- Alberta Oil Sands Environmental Research Program (AOSERP);
- Other Six Leases Operations (OSLO) Project (R.L. & L. 1989);
- Ecotoxicological studies of the lower Athabasca River, as part of Environment Canada's Program on Energy Research and Development (PERD);
- Northern River Basins Study (NRBS); and

- baseline studies in support of Suncor's Steepbank Mine and Syncrude's Aurora Mine (Golder 1996a).

existing water quality data compiled

To describe existing water quality in the study area, only relatively recent data were used (1972 to 1997). Data collected by AEP and NRBS were obtained from the NAQUADAT database. Data collected during the OSLO Project in the Muskeg River basin and baseline data collected for Suncor and Syncrude in 1995 were obtained from the relevant reports. Water quality data generated by PERD were not included in the data summary. Relatively few water samples were collected during PERD and analyses were oriented toward specific parameters to provide supporting data for toxicity studies.

Data Summary Methods

surface water quality data summarized

Surface water quality data were summarized by river reach and season. Sites used to represent reaches are shown on Figure 2.2-1. Seasons were defined as follows:

Winter:	November, December, January, February, March
Spring:	April, May
Summer:	June, July, August
Fall:	September, October

The raw data are shown in the data tables for reaches or parameters with a single sample per season. If there were two samples per season, both measurements are shown as a range (minimum and maximum). For seasons with three or more samples per season, the median, range and number of samples are shown. For efficient presentation of results, only selected parameters are shown in the data tables. All parameters are listed in Appendices V-1 to V-7.

2.2.3 Sediment Quality

sediment sampling

Bottom sediment chemistry of the Athabasca River within the oil sands area has been described in a number of studies in the 1970s (Noton 1979, IEC Beak 1983 and Beak 1988). However, none of the studies sampled intensively. More recently, Golder (1994, 1995, 1996a) conducted additional small-scale sampling as part of bioaccumulation studies examining the effects of seepage from Suncor's Tar Island Dyke (TID) and during baseline studies carried out to support Suncor's Steepbank Mine EIA. Small-scale sediment sampling for specific contaminants was also completed as part of PERD (Brownlee 1990, Brownlee et al. 1993) and NRBS (Crosley 1996, Brownlee at al. 1997). Additional samples were collected in 1997 from a number of locations in the Athabasca River and its major tributaries as part of RAMP (Golder 1998). All sediment quality parameters are listed in Appendix V-8.

2.2.4 Porewater Quality

limited porewater quality data

Porewater is the water occupying the void spaces between sediment particles. Porewater quality data are limited in the oil sands area. The available data consist of analytical results for a few samples collected in 1994 and 1995 by Golder (1994, 1995, 1996a). These results were obtained from reference sites in the Athabasca River (upstream and across from Suncor), the Steepbank River (three relatively widely spaced sites) and from single sites at the mouth of the Muskeg River and the mouth of Jackpine Creek (Golder 1996a).

2.2.5 Comparisons with Water Quality Guidelines

To provide an indication of the "level" of water quality in the waterbodies discussed, concentrations of individual chemicals (parameters) were compared with water and sediment quality guidelines for the protection of aquatic life. Winter water chemistry data were used for these comparisons, because concentrations of the majority of chemicals are usually at their annual maximum in surface waters in this season. This is due to the lowest annual dilution capacity in rivers during the winter low-flow period. Sediment chemistry does not vary greatly by season. Therefore, all available sediment data were compared with guidelines.

Guidelines developed by regulatory agencies based on toxicity data were used for these comparisons (Table 2.2-3), as recommended by Alberta Environmental Protection (1996). Compliance with acute guidelines in surface waters protects aquatic organisms from short-term, lethal effects; meeting chronic guidelines provides protection from longer-term, lethal or sublethal effects (e.g., reduced growth or reproduction). Sediment chemistry was compared with values of the threshold effect level (TEL) and the probable effect level (PEL), using the interim freshwater Canadian sediment quality guidelines (Smith et al. 1996).

Table 2.2-3 Water and Sediment Quality Guidelines for the Protection of Aquatic Life

Parameter	Units	Water Quality Guidelines		
		Acute	Chronic	Reference
Surface Water				
Chloride	mg/L	860	230	USEPA
Nitrate	mg/L	-	10	CCME
Nitrite	mg/L	-	0.06	CCME
Total Suspended Solids	mg/L	-	10	ASWQG
Total Phenolics	mg/L	-	0.005	ASWQG
Total Ammonia (low winter flow)	mg/L	16	2.1	USEPA
Total Ammonia (open water flow)	mg/L	10	1.9	USEPA
Total Phosphorus	mg/L	-	0.05	ASWQG
Aluminum (Al)	mg/L	-	0.1	CCME
Arsenic (As)	mg/L	0.36	0.01	USEPA, ASWQG
Barium (Ba)	mg/L	-	1	ASWQG
Beryllium (Be)	mg/L	0.13	0.0053	USEPA
Boron (B)	mg/L	-	0.5	ASWQG
Cadmium (Cd)	mg/L	0.0074*	0.0018*	USEPA
Chromium (Cr)	mg/L	0.016	0.011	USEPA
Cobalt (Co)	mg/L	-	0.05	CCME
Copper (Cu)	mg/L	0.027*	0.007*	ASWQG
Iron (Fe)	mg/L	-	0.3	ASWQG
Lead (Pb)	mg/L	0.17*	0.007*	USEPA
Lithium (Li)	mg/L	-	2.5	CCME
Manganese (Mn)	mg/L	-	0.05	ASWQG
Mercury (Hg)	mg/L	0.0024	0.000012	USEPA
Molybdenum (Mo)	mg/L	-	1	BCMOE
Nickel (Ni)	mg/L	2.3*	0.25*	USEPA
Selenium (Se)	mg/L	-	0.01	ASWQG
Silver (Ag)	mg/L	0.01*	0.05	USEPA, ASWQG
Uranium (U)	mg/L	-	0.01	CCME
Vanadium (V)	mg/L	-	10	BCMOE
Zinc (Zn)	mg/L	0.19*	0.17*	USEPA
Sediment		TEL	PEL	
Arsenic	μg/g	5.9	17	Smith et al. 1996
Cadmium	μg/g	0.596	3.53	Smith et al. 1996
Chromium	μg/g	37.3	90	Smith et al. 1996
Copper	μg/g	35.7	197	Smith et al. 1996
Lead	μg/g	35	91.3	Smith et al. 1996
Mercury	μg/g	0.174	0.486	Smith et al. 1996
Nickel	μg/g	18	35.9	Smith et al. 1996
Zinc	μg/g	123	315	Smith et al. 1996
Phenanthrene	μg/g	0.0419	0.515	Smith et al. 1996
Benz(a)anthracene	μg/g	0.0317	0.385	Smith et al. 1996
Benzo(a)pyrene	μg/g	0.0319	0.782	Smith et al. 1996
Chrysene	μg/g	0.0571	0.862	Smith et al. 1996
Fluoranthene	μg/g	0.111	2.355	Smith et al. 1996
Pyrene	μg/g	0.053	0.875	Smith et al. 1996

NOTES: - = no guideline; * guideline specified for hardness of 175 mg/L $CaCO_3$

ASWQG = Alberta Surface Water Quality Guidelines

BCMOE = British Columbia Ministry of the Environment

CCME = Canadian Council of Ministers of the Environment

USEPA = United States Environmental Protection Agency

TEL = Threshold effect level

PEL = Probable effect level

2.3 BENTHIC INVERTEBRATES

2.3.1 Approach

numerous benthic invertebrate surveys reviewed

Benthic invertebrate surveys carried out in the oil sands area have included baseline studies for EIAs, effluent or dyke seepage monitoring, long-term monitoring, bioaccumulation studies and secondary production studies. Historical information was summarized from a number of large-scale studies completed in the lower Athabasca River and the Muskeg River basin in the past 20 years (Table 2.1-1).

The aim of the baseline data summary was: (1) to provide a general description of the benthic fauna of the study area; (2) to explore spatial and year-to-year variation in benthic community structure; and (3) to summarize effects of existing oil sands operations on resident benthic communities (in the Athabasca River only).

The Athabasca River data were described in qualitative terms, based on the large amount of available information, which was recently summarized by Golder (1996a). Descriptions of benthic habitats and associated fauna in the Muskeg River basin were obtained from three studies completed from 1985 to 1995 (Beak 1986, R.L. & L. 1989, Golder 1996a). Several sites sampled by all three studies were selected for graphical analysis, to allow assessment of differences between streams and year-to-year variability. Kearl Lake was also included in this analysis, since other lakes in the study area may be expected to have a similar benthic fauna and show similar degree of year-to-year variation. Total invertebrate density and order-level taxonomic composition were summarized by year for each selected site.

2.4 FISH HABITAT

2.4.1 Fish Habitat Sampling Approach

sampling to verify existing data

Sampling areas for fish habitat were determined from the results of previous studies in the local study area. Surveys were developed to expand on the work done for the Aurora project and to also verify historical habitat information. Particular attention was given to the reaches of the Muskeg River within the study area that were only briefly surveyed in previous studies.

habitat maps updated

Habitat maps for the Athabasca River, from below the mouth of the Muskeg River to just above the Lease 13 southern boundary, were updated during the summer and fall 1997 sampling seasons under the RAMP (Golder 1998). Reaches in the Athabasca River, within the Muskeg River Mine Project study area, were mapped in 1995 (Golder 1996a) and 1996 (Golder 1996b).

2.4.2 Fish Habitat Sampling Locations

Muskeg River habitat mapping

Habitat mapping for representative sections of the Muskeg River was done in fall 1997. Efforts were concentrated in the area from the mouth of Jackpine Creek to the existing Alsands Drain, and above and below the bridge at the Canterra Road crossing.

previous habitat mapping

Information collected in 1997 builds on the habitat mapping done in 1995 and 1996 (Golder 1996a,b).

2.4.3 Habitat Evaluation Methods

stream habitat classification

Habitat mapping followed the procedures set out in Golder Technical Procedure 8.5-1 (Appendix III). The Athabasca River was mapped according to the Large River Habitat Classification System, which is used to map large rivers that show a limited amount of instream heterogeneity. This system consists of three components: channel form, bank habitat types and special habitat features.

GPS records

The Muskeg River was mapped according to the Stream Habitat Classification and Rating System. The stream mapping system is based on individual channel units (i.e., riffle/pool/run) in combination with depth, velocity and substrate characteristics that provide a subjective quality rating for each unit, in relation to the habitat requirements of the various fish life stages (i.e., spawning, rearing, feeding, overwintering). Sampling locations, and significant habitat areas, such as spawning sites and locations of significant fish concentrations, were recorded using a Trimble GeoExplorer Geographic Positioning System (GPS).

habitat mapping

During habitat mapping, the location and extent of each habitat mapping unit, as defined by the relevant mapping system (Appendix III), was delineated on copies of 1:10,000 air photos of the Muskeg River study area and 1:50,000 topographic maps of the Athabasca River. Transect stations were established at selected locations on the Muskeg River to provide measurements of the physical habitat conditions for representative habitat types. Measurements at the habitat transects on the Muskeg River included channel width, wetted width, water depth, velocity, substrate composition, cover availability, bank stability and bank vegetation. Due to high flows in fall 1997, only depths and habitat types were recorded.

2.4.4 Habitat Data Analysis

Habitat data were summarized according to Golder Technical Procedure 8.5-1 (Appendix III).

2.5 FISH COMMUNITIES

2.5.1 Fish Inventory Approach

fish population parameters have been studied

Fish population parameters, such as size, age distributions, age and growth and general species composition, have been documented for Jackpine Creek and the Muskeg River (Beak 1986, Bond 1980, Bond and Machniak 1979, O'Neil 1982, R.L. & L. 1989, Golder 1996a) and the Athabasca River (R.L.& L. 1994, Golder 1996a, 1996b).

recent surveys to fill data gaps

Recent fisheries surveys of the Muskeg River system were limited primarily to one season (spring or summer) and to spot checks of representative areas within watercourses. A fish fence operated by Golder Associates in spring and fall 1996 indicated that Arctic grayling and northern pike, white sucker and longnose sucker use the Muskeg River system for spawning (Golder 1996a). However, data gaps existed on the spatial extent and seasonal use of the Muskeg River and Jackpine Creek by sport fish such as Arctic grayling.

The fish inventory surveys were developed to:

- confirm the results of existing studies of the area;
- document species presence and abundance in the study area; and
- fill the data gaps with respect to fish population parameters, such as size, age and growth and species composition in the Muskeg River system.

2.5.2 Fish Inventory Sampling Areas

The Athabasca River reaches within the LSA were sampled in the RAMP. Data from the seasonal surveys are summarized in this report.

determination of sampling areas

Available habitat and fish inventory information from previous studies was used to select sampling locations in the Muskeg River and Jackpine Creek. For sport and commercial/domestic fish species, sampling areas were selected that were representative of the habitats available within the study area. Sampling areas included: backwater areas, side channel habitat and potential spawning, rearing, feeding and overwintering habitats. Sampling areas for forage species were restricted to areas that provided potential habitat for this species assemblage. These included channel edge areas and backwaters that exhibit shallow depths and slow velocities.

seasonal sampling

Sampling reaches and methods used in each section are listed in Table 2.5-1. Location of each sampling section is shown on Figure 2.5-1. Sampling was done on a seasonal basis during the open-water season and included the following periods: spring (May 21 to 26); summer (July 19 to 26); and fall (September 15 to 22 and October 19). Potential overwintering habitats were evaluated during the winter field survey trip and reported in Golder (1997a).

Table 2.5-1 Summary of Fish Inventory from the Muskeg River Mine Project Study Area, 1997

Station ID	Watercourse	Station Type	Station UTMs	Description	Season Sampled	Sampling Method
MUR-F-1	MUSKEG RIVER	REACH	471555E/6346395N - 470915E/6345685N	Muskeg River below Jackpine Creek (section between mouth of Jackpine Creek and Alsands Drain)	P, U, F	PEF
MUR-F-2	MUSKEG RIVER	REACH	469933.8E/6345126.4N - 469549.5E/6344696.8N	1st reach above bridge crossing at Canterra Road	P, U	PEF
MUR-F-3	MUSKEG RIVER	REACH	469565.8E/6344408.5N - 469239.6E/6344046.3N	2nd reach above bridge crossing at Canterra Road	P, U	PEF
MUR-F-4	MUSKEG RIVER	REACH	468364.0E/6343076.2N - 468043.3E/6342058.1N	3rd reach above bridge crossing at Canterra Road	P	PEF
MUR-F-5	MUSKEG RIVER	REACH	466625E/6340275N - 466450E/6339450N	Muskeg River D/S of Canterra Road Bridge	P, U, F	PEF
MUR-F-6	MUSKEG RIVER	REACH	471777.4E/6346926.4N - 474671.4E/6346387.1N	Muskeg River above mouth of Jackpine Creek	P, U	PEF
MUR-F-7	MUSKEG RIVER	REACH	471661.2E/6346291.5N - 471326.6E/6345822.5N	Muskeg River above mouth of Jackpine Creek	P	PEF
MUR-F-8	MUSKEG RIVER	REACH	470914.0E/6345753.3N - 470027.5E/6345410.0N	Muskeg River above Jackpine Creek to Alsands Drain	P, U	PEF
MUR-F-9	MUSKEG RIVER	REACH		Muskeg River	F	PEF
MUR-F-10	MUSKEG RIVER	REACH	472310E/6347525N - 471770E/6346860N	Muskeg River	U	PEF
MUR-F-11	MUSKEG RIVER	REACH	474475E/6348630N - 472310E/6347540N	Muskeg River near Jackpine headwater	F	PEF
MUR-F-GN1	MUSKEG RIVER	POINT	466621.2E/6340029.7N	Muskeg River 600m D/S of Canterra Road Bridge	F	GN
MUR-F-GN2	MUSKEG RIVER	POINT	465559.7E/6338708.6N	Muskeg River 75m D/S of where fish fence was set up in 1995	F	GN
MUR-F-MT1	MUSKEG RIVER	POINT	417661.2E/6346291.5N	Muskeg River below mouth of Jackpine Creek	P	MT
MUR-F-MT1	MUSKEG RIVER	POINT	466600.7E/6340289.9N	Muskeg River 200m D/S of Canterra Road	F	MT
MUR-F-MT2	MUSKEG RIVER	POINT	465658.8E/6339240.5N	Muskeg River Reach #9	F	MT
JAC-F-1	JACKPINE CREEK	REACH	471900E/6346150N - 471700E/6346350N	Jackpine Creek 200 m upstream of the mouth	P, U	EF, BP
JAC-F-2	JACKPINE CREEK	REACH	474775E/6344175N - 475200E/6343500N	Jackpine Creek	P, U	BP
JAC-F-3	JACKPINE CREEK	REACH	474475E/6348630N - 472310E/6347540N	Jackpine Creek	F	EF
JAC-F-GN1	JACKPINE CREEK	POINT	47505E/6343775N	Jackpine Creek upstream of the bridge	U	GN
JAC-F-GN2	JACKPINE CREEK	POINT	475000E/6343800N	Jackpine Creek backwater below first riffle above bridge	U	GN
JAC-F-MT1	JACKPINE CREEK	POINT	471661.2E/6346291.5N	Jackpine Creek at mouth	P	MT
JAC-F-MT2	JACKPINE CREEK	POINT	475000E/6343800N	Jackpine Creek backwater 15 m upstream of bridge below a riffle	U	MT
MIC-F-MT1	MILLS CREEK	POINT	463825.8E/6344780.3N	Mills Creek 25 m upstream of road culvert	F	MT
MIC-F-MT2	MILLS CREEK	POINT	463825.8E/6344780.3N	Mills Creek 35m upstream of road culvert	F	MT
ATR-F-10A*	ATHABASCA RIVER	REACH	463824.6/6330627.3 - 462505.6/633429.9	LDB from Beaver Creek confluence to LDB to opposite D/S end of Alexander Island	P, U	EF
ATR-F-10B*	ATHABASCA RIVER	REACH	464286.2/6330931.5	RDB opposite Beaver Creek confluence to RDB behind D/S end of Alexander Island	P, U	EF
ATR-F-11A*	ATHABASCA RIVER	REACH	462505.6/6334329.9 - 462259.8/6338084.8	LDB opposite Alexander Island to LDB at top of Height Island	P, U	EF
ATR-F-11B*	ATHABASCA RIVER	REACH	462736E/6334191N - 462343E/6337893N	From D/S end of Alexander Island to D/S of island opposite Fort McKay	P, U	EF
ATR-F-12A*	ATHABASCA RIVER	REACH	462067.6W/6338226.8N	End of Reach 11A	U	EF
ATR-F-12B*	ATHABASCA RIVER	REACH	462444E/6337985N - 463447E/6341398N	From D/S of island opposite Fort McKay to D/S of Height Island	P, U	EF

* Sampling Performed Under the 1997 RAMP Program

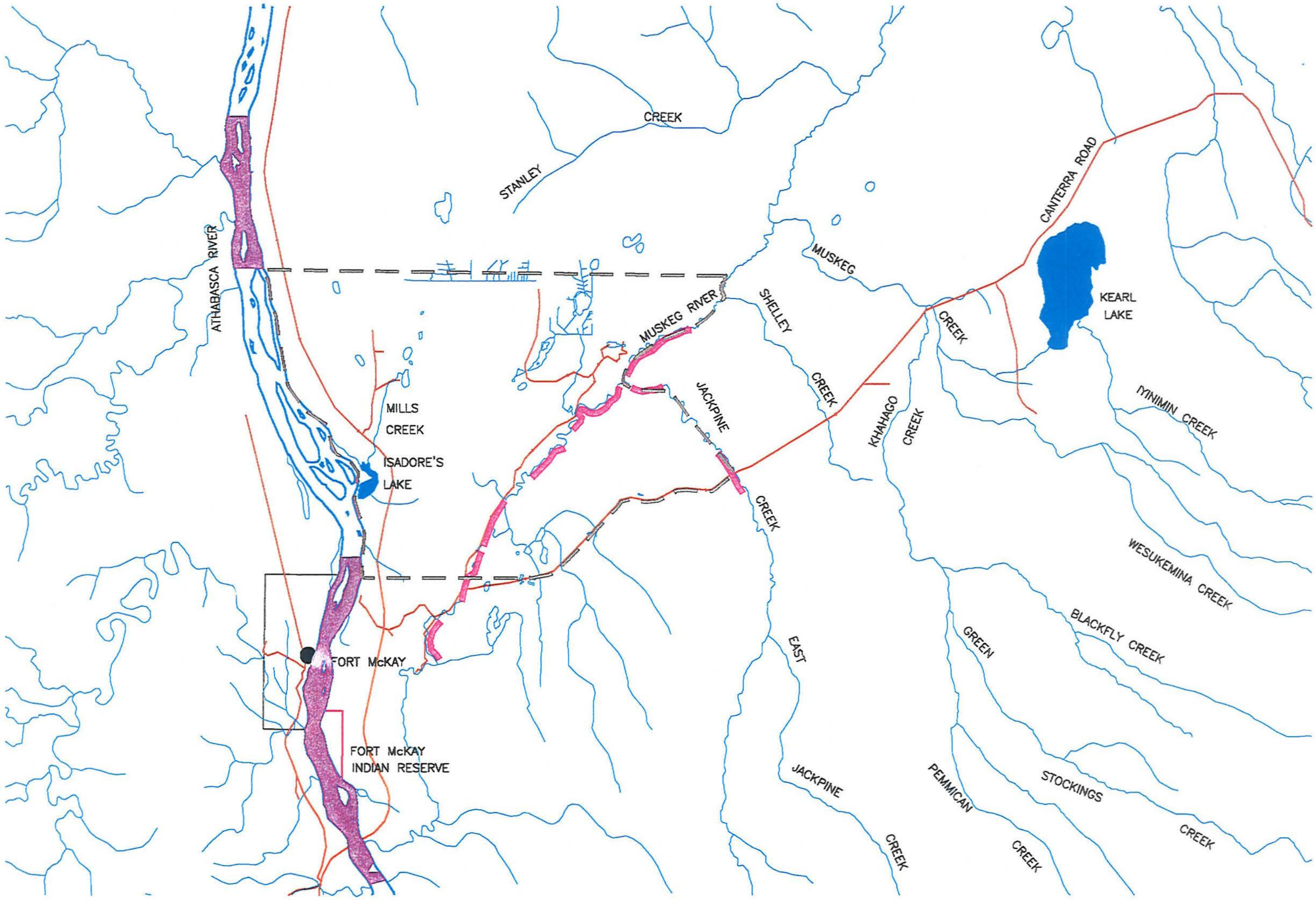
KEY

SEASON
P = Spring
U = Summer
F = Fall

FISH INVENTORY METHODS
BP = Backpack Electrofisher
EF = Boat Electrofisher
PEF = Portable Boat Electrofisher
GN = Gill Net
KS = Kick Sampling
MT = Minnow Trap
PE = Post-Emergent Fry Drift Trap
SN = Beach Seine
SL = Set Line

ABBREVIATIONS
U/S = Upstream
D/S = Downstream
RDB = Right downstream bank
LDB = Left downstream bank

J:\1997\2237\6050\FISHINV.DWG



LEGEND

MUSKEG RIVER MINE PROJECT DEVELOPMENT AREA

FISH INVENTORY REACHES

FISH INVENTORY REACHES FOR 1997 RAMP

0 2000 4000 6000 8000 10000(m)

SCALE 1:200,000

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I
84A AND 84H FROM RESOURCE DATA DIVISION
ALBERTA ENVIRONMENTAL PROTECTION, 1997.

Golder Associates

SHELL CANADA LIMITED

MUSKEG RIVER MINE PROJECT
FISH INVENTORY SAMPLING REACHES

17 NOV 1997	FIGURE 2.5-1	DRAWN BY: DC/VS

2.5.3 Fish Inventory Methods

Fish inventory sampling was done following Golder Technical Procedure 8.1-3 (Appendix IV) during the spring, summer and fall surveys. Table 2.5-1 presents a complete list of fish inventory sampling reaches, methods used in each section and the season sampled.

All 1997 RAMP inventory surveys were done using a Smith-Root model SR18 electrofishing boat. Sampling for large fish species in the Muskeg River was primarily done with an inflatable boat equipped with a model 5.0 GPP electrofishing unit.

sampling techniques

Minnow traps were used to survey smaller forage fish species in the Muskeg River. Gills nets were used in deep pools and wherever the water was too deep for effective electrofishing. A Smith-Root Type VII backpack electrofishing unit was used to sample sections of Jackpine Creek.

CPUE calculated

For all sampling techniques, catch-per-unit-effort (CPUE) (number of fish/unit of sampling effort) was calculated to determine the relative abundance of fish species captured.

fish coding system

All captured fish were enumerated and identified to species following the coding system recommended by McKay et al. (1990). Fork length and weight were measured for large fish species. They were also examined for external pathology according to Golder Technical Procedure 8.1-3 (Appendix IV). Non-lethal ageing structures were taken according to the recommendations in McKay et al. (1990). In addition, if discernible by external examination, sex and state of maturity of individual fish were recorded.

2.5.4 Methods for Fish Population Data Summary

fish data in Excel

All fish data collected during each survey were entered in Microsoft Excel spreadsheets. Statistical analyses and frequencies were done using Microsoft Excel software.

CPUE values used for relative abundances

CPUE values for each capture method (boat electrofishing, backpack electrofishing, gill netting and minnow trapping) were calculated for each species, from each section or reach, to determine relative abundances and enable comparisons of 1997 catch results with previous studies.

fisheries data QA/QC

Data files were checked and verified against original field data. RAMP data were entered into files by Syncrude personnel. A subgroup (10% of the data) was verified by Golder Associates personnel.

3. RESULTS

3.1 SURFACE WATER, SEDIMENT AND POREWATER QUALITY

3.1.1 Surface Water Quality

surface water quality unique in oil sands area

Surface water quality of the oil sands area is unique in Alberta. Rivers and streams are frequently underlain by oil sands, which contribute varying amounts of naturally occurring hydrocarbons to surface waters. Small streams are largely fed by muskeg drainage water, which is reflected in their water chemistry. These influences are much less pronounced in the Athabasca River, which derives most of its flow from upstream sources.

water quality compared with appropriate guidelines

In the sections that follow, water, sediment and porewater quality are described in the lower Athabasca River and smaller waterbodies within the aquatics LSA. Existing exceedances of water and sediment quality guidelines are identified by comparisons with regulatory guidelines listed in Table 2.2-3.

Athabasca River

Point Source Inputs

wastewater point sources upstream of oil sands area

Major point sources of wastewaters discharged to the Athabasca River upstream of the oil sands area include effluents from five pulp mills and sewage from five communities. Previous surveys documenting the effects of such inputs concluded that they are most pronounced during the winter low-flow period when the river's dilution capacity is the lowest. The type and severity of these effects were described in detail by Hamilton et al. (1985), Noton and Shaw (1989) and Noton and Saffran (1995). In general, the effects of upstream point sources were not found to extend into the oil sands reach of the Athabasca River, because of the high dilution capacity of the river.

localized effects near Suncor plant

Within the oil sands area, the Athabasca River receives mine drainage, refinery wastewater and treated sewage from Suncor and mine runoff waters (through Poplar Creek) and treated sewage from Syncrude. The effects of these discharges on water quality were not discernible during any of the above three large-scale investigations of water quality, or subsequent baseline studies. Smaller-scale surveys by Syncrude and Suncor documented localized effects in the immediate vicinity of the Suncor plant, shown as increases in the concentrations of dissolved solids, total organic carbon, oil and grease, total phenolics, ammonia and odour (McCart et al. 1977, Noton and Anderson 1982). These increases were minor in most cases and were restricted to single sites, or were inconsistent among sampling times. Only odour was consistently elevated for some distance downstream.

Summary of the Existing Information

data sources for lower Athabasca River

Water quality of the lower Athabasca River has been monitored extensively by AEP since the 1970s. Data were summarized in three AEP reports (Hamilton et al. 1985, Noton and Shaw 1989, Noton and Saffran 1995) and are available from NAQUADAT. Recent surveys during baseline studies for the Steepbank and Aurora Mine EIAs (Golder Associates 1996a), RAMP (Golder 1998) and 1997 baseline studies for the Muskeg River Mine Project (Golder 1997a and more recent field programs) generated additional information. To provide an overview of water quality in the lower Athabasca River, the data gathered from these sources were summarized for the following four areas (Figure 2.2-1):

- upstream of Fort McMurray, near the southern limit of the oil sands area;
- near the mouth of Donald Creek, between Fort McMurray and existing oil sands operations;
- near Saline Lake and just upstream of the Muskeg River, below existing oil sands operations; and
- downstream from Fort Creek, below all existing and proposed oil sands operations.

water quality of lower Athabasca River

Water quality of the lower Athabasca River has not changed measurably over the last two decades. It is characterized by a typical pH range of 7 to 8 and moderate levels of dissolved salts (total dissolved solids), hardness and alkalinity (Table 3.1-1). Spring and summer high flows usually cause a large increase in suspended sediment load, which is reflected in elevated concentrations of nutrients (e.g., total phosphorus) and a number of metals measured as totals (e.g. aluminum, iron, manganese) during these seasons. Total alkalinity, total dissolved solids and total hardness are typically highest in the winter, reflecting seasonal changes in hydrology. Nutrient levels are indicative of moderate enrichment from natural sources and, potentially, from upstream point sources (pulp mills and sewage treatment plants). Levels of dissolved metals, PAHs and naturally occurring hydrocarbons are generally low. Microtox® tests have not provided evidence of toxicity in river water.

Recent toxicity studies conducted under PERD also documented detectable but low levels of trace organic compounds (PAHs and chlorophenolic compounds) in Athabasca River water and found low or no acute or chronic toxicity to a variety of test organisms (Brownlee 1990, Dutka et al. 1990, 1991, McInnis et al. 1992, 1994, Xu et al. 1992, Brownlee et al. 1993, Golder 1996a).

Table 3.1-1 Water Quality of the Lower Athabasca River (1976-1997)

Parameter	Units	Upstream Fort McMurray				Near Donald Creek			Below Existing Oil Sands Operations			Below Fort Creek			
		Winter	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Conventional Parameters and Nutrients															
pH	-	7.88	8.01	7.98	7.90	7.81 - 8.10	7.63	7.82-8.00	7.94	7.63 - 8.00	-	7.92	8.20	7.95	8.30
Total Alkalinity	mg/L	169	102	98	110	76 - 97	88	92-95	104	90 - 94	-	144	99	90	104
Total Dissolved Solids	mg/L	243	159	144	158	140 - 141	120	146-200	146 - 240	123 - 158	-	-	46	182	140-160
Total Suspended Solids	mg/L	2	82	127	19	19 - 181	624	4-57	30 - 190	624 - 676	-	3	215	266	36
Total Hardness	mg/L	190	114	105	124	111	114	100-104	121	101 - 118	-	158	103	92	105.7
Dissolved Organic Carbon	mg/L	8.0	10.0	8.0	8.0	7.1 - 11.0	16.7	9.0-9.2	7.6	13.0 - 16.1	-	6.8	11.0	12.7	8.8
Total Kjeldahl Nitrogen	mg/L	0.54	0.87	0.81	0.62	1.20	-	-	-	0.20	-	0.33	1.20	1.01	0.50
Total Ammonia	mg/L	0.03	0.02	0.01	0.01	<0.01 - <0.05	0.04	<0.01-<0.05	<0.01	0.04 - <0.05	-	0.06	0.05	0.03	<0.05
Total Phosphorus	mg/L	0.022	0.110	0.128	0.033	0.140 - 0.144	0.390	0.084-0.087	0.120	0.298 - 0.440	0.080	0.029	0.082	0.290	0.058
Dissolved Phosphorus	mg/L	0.012	0.013	0.013	0.007	0.020	-	0.022	-	0.019	0.010	0.020	0.015	0.018	0.013
Metals (Total)															
Aluminum (Al)	mg/L	0.055	0.844	0.908	0.23	0.17 - 5.18	8.64	0.11-2.23	0.15 - 4.05	10.1 - 14.1	3.89	0.0155	3.66	6.13	2.38
Arsenic (As)	mg/L	0.0004	0.0012	0.0012	0.001	0.0006 - 0.002	0.007	0.0005-0.0013	0.0008 - 0.0017	0.0057 - 0.007	0.0015	0.0004	0.0011	0.0045	0.0008
Cadmium (Cd)	mg/L	0.001	0.001	<0.001	<0.001	<0.0002 - <0.003	<0.003	<0.002-<0.003	<0.0002 - <0.003	0.0002 - <0.003	<0.0002	0.001	<0.001	0.001	0.001
Chromium (Cr)	mg/L	0.003	0.0045	0.004	0.0025	<0.002 - 0.0051	0.003	<0.002-0.0026	<0.002 - 0.0051	<0.002 - 0.0197	0.0043	0.0025	0.005	0.00995	0.003
Copper (Cu)	mg/L	0.001	0.004	0.005	0.0015	<0.001 - 0.007	-	0.049	0.004 - 0.0061	0.0181	0.0041	0.0015	0.002	0.008	0.002
Iron (Fe)	mg/L	0.17	3.21	3.12	0.35	0.43 - 5.24	17.90	0.91-2.19	0.43 - 3.76	17.60 - 19.40	2.98	0.46	5.04	16.10	2.41
Mercury (Hg)	mg/L	0.0001	0.0001	<0.0001	<0.0001	<0.0002 - <0.05	<0.05	<0.0001-<0.05	<0.0002 - <0.05	<0.0001 - <0.05	<0.0001	0.0001	<0.0001	<0.0001	<0.0001
Vanadium (V)	mg/L	<0.002	0.002	0.005	-	<0.002 - 0.013	0.009	<0.0001	0.004 - 0.011	0.015 - 0.038	0.010	<0.002	0.009	0.023	0.006
Zinc (Zn)	mg/L	0.007	0.015	0.013	0.007	-	-	0.014	-	-	0.034	-	-	-	0.005
Metals (Dissolved)															
Aluminum (Al)	mg/L	0.01	0.0675	<0.002-0.02	0.02	0.241	0.0159	0.0443	0.0572	0.0499	0.0729	-	0.415	0.026	0.036
Arsenic (As)	mg/L	0.0005	0.0009	0.0009	0.0006	0.001	<0.0004	0.0005	0.0006	0.0006	0.0006	-	0.0012	0.0005	0.0005
Cadmium (Cd)	mg/L	<0.001	<0.001-0.006	<0.001	-	<0.0001	0.0028	0.0001	<0.0001	0.0002	0.0001	-	0.0001	0.0002	0.0001
Chromium (Cr)	mg/L	0.003	0.003	0.003	0.003	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	<0.0004	-	0.0007	<0.0004	<0.0004
Copper (Cu)	mg/L	<0.001	<0.001-0.003	0.002	-	0.0043	0.0022	0.0022	0.0024	0.006	0.0042	-	0.0049	0.003	0.002
Iron (Fe)	mg/L	0.11	0.1	0.07	0.12	1.14	0.1	0.14	0.32	0.08	<0.01	-	1.93	0.43	0.14
Mercury (Hg)	mg/L	-	-	-	-	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	-	<0.0002	<0.0002	<0.0002
Vanadium (V)	mg/L	<0.001	0.001-<0.00	<0.001	-	0.0012	<0.0001	<0.0001	0.0002	<0.0001	0.0002	-	0.002	0.0001	<0.0001
Zinc (Zn)	mg/L	0.002	<0.001	<0.001	-	-	0.038	0.014	0.006	0.027	0.023	-	0.015	0.016	0.019
Organics															
Naphthenic Acids	mg/L	-	-	-	-	<1 - 2	<1	<1	<1	<1	ND	-	1	-	-
Recoverable Hydrocarbons	mg/L	-	-	-	-	<0.5 - <1	1	<1	<0.5 - <1	<0.5 - <1	-	-	<0.5	-	-
PAHs and Alkylated PAHs	µg/L	-	-	-	-	ND	ND	ND	ND - 0.03	ND	-	-	-	-	-
Target PANHs	µg/L	-	-	-	-	ND	ND	ND	ND	ND	-	-	-	-	-
Phenolics	µg/L	-	-	-	-	ND	ND	-	ND	ND	-	-	-	-	-
Volatile organics	µg/L	-	-	-	-	ND	-	-	ND	-	-	-	-	-	-
Toxicity															
Microtox IC50	%	-	-	-	-	100	100	>100	91 - 100	100	-	-	-	-	-
Microtox IC25	%	-	-	-	-	100	100	>100	91 - 100	100	-	-	-	-	-

NOTES: - = No data; ND = Not detected; PAH = Polycyclic aromatic hydrocarbon; PANH = Polycyclic aromatic nitrogen heterocycle
Median concentrations (n>2), ranges (n=2), or measured concentrations (n=1) are presented

water quality guideline exceedances

Comparisons with water quality guidelines (Table 2.2-1) were made using fall medians near Donald Creek and upstream from the Muskeg River due to lack of winter data for these reaches; winter medians were used for the other two reaches. Exceedances of the guidelines were found for a number of metals and total phosphorus (Table 3.1-2). These exceedances were typically minor and were largely by metals that tend to be elevated due to increased suspended sediment levels (e.g., aluminum, iron, manganese). Overall, the guideline exceedances found under baseline conditions are of no concern regarding potential adverse effects on aquatic organisms.

no spatial trends in water quality in lower Athabasca River

In general terms, water quality of the Athabasca River is good, though periods of high suspended sediments may cause stress to aquatic organisms. The available data do not provide evidence of spatial trends in water quality along the lower Athabasca River.

Muskeg River

water quality of Muskeg River

The Muskeg River is characterized by clear water in all seasons (i.e., low total suspended solids levels), low to moderate dissolved salt concentrations, moderate nutrient levels and pH ranging between 7 and 8 (Table 3.1-3). This river drains areas with substantial muskeg cover, which is reflected in elevated dissolved organic carbon levels. Concentrations of total metals are near the detection limits with the exception of iron, manganese, silicon and strontium. Naturally occurring hydrocarbons and naphthenic acids are occasionally detectable, but at very low levels. Trace organic compounds were not detected at the mouth of the river in 1995 and river water was not toxic to bacteria (Microtox® test). Seasonal variation in water quality is limited, with only minor increases in levels of certain ions in winter and lower dissolved organic carbon concentration during spring snowmelt. Longitudinal trends are not apparent in the available data set.

water quality guideline exceedances

Concentrations of total phosphorus, total phenolics and a number of metals occasionally exceed chronic water quality guidelines in the Muskeg River (Table 3.1-2). Overall, water quality of the Muskeg River can be classified as good and occasional guideline exceedances are of no concern to aquatic life.

Tributaries of the Muskeg River

water quality of tributaries similar to Muskeg River

Water quality is similar in tributaries of the Muskeg River and resembles that of the Muskeg River (Tables 3.1-4 and 3.1-5). The concentration of dissolved salts is low to moderate and all streams run clear in all seasons. pH is usually between 7 and 8. Dissolved organic carbon is elevated in all streams, reflecting inputs of muskeg drainage water and nutrient levels are low to moderate. Levels of metals are generally low with the exception of iron, manganese and silicon. Naturally occurring hydrocarbons were

Table 3.1-2 Summary of Water and Sediment Quality Guideline Exceedances

Parameter	Athabasca R. upstream Fort McMurray (Winter)	Athabasca R. near Donald Creek (Fall)	Athabasca R. upstream Muskeg River (Fall)	Athabasca R. below Fort Creek (Water in Winter, Sediment in Fall)	Athabasca River above TID, West Bank (sediment)	Athabasca River at TID, East Bank, 1994 (sediment)	Athabasca River at TID, East Bank, 1995 (sediment)	Athabasca River at TID, West Bank, 1994 (sediment)	Mouth of Muskeg River (Water in Winter, Sediment in Fall)	Lower Muskeg River (Winter)	Muskeg River upstream Jackpine Creek (sediment)	Upper Muskeg River (Winter)	Mouth of Jackpine Creek (Water in Winter, Sediment in Fall)	Lower Jackpine Creek (Fall)	Upper Jackpine Creek (Winter)	Shelley Creek (Winter)	Muskeg Creek (Winter)	Upper Muskeg Cr. Drainage (Winter)	Isadore's Lake (Winter)	Alsands Drain (Fall)	Muskeg Drainage Water
Water Quality Guideline Exceedances																					
Total Phosphorus		C	C									C	C			C		C	C		
Total Aluminum		C	C																C		C
Total Copper		A,C												ND							
Total Iron		C	C	C					C	C		C	C	ND	C	C	C	C	C	C	C
Total Manganese	ND	C	C	ND					C	C		C		ND	C	C	C	C	C	C	C
Total Mercury	C			C					C	C		C		C	C		C				ND
Total Phenolics									C	ND		ND		ND	ND	ND	ND	ND	ND	C	
Sediment Quality Guideline Exceedances																					
Cadmium							TEL														
Nickel				TEL		TEL		TEL													
Benz(a)anthracene					TEL*				TEL*		TEL*		TEL*								
Chrysene					TEL*				TEL*		TEL*		TEL*								
Fluoranthene					TEL																
Pyrene					TEL																

NOTES:

C = chronic guideline exceeded

A = acute guideline exceeded

ND = no data

TEL = threshold effect level exceeded

TID = Tar Island Dyke

*concentrations of benz(a)anthracene and chrysene were reported as one number, which exceeded the TEL for both of these compounds

Table 3.1-3 Water Quality of the Muskeg River (1972-1997)

Parameter	Units	At Mouth				Lower Muskeg River				Upper Muskeg River			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Conventional Parameters and Nutrients													
pH	-	7.50	7.70	8.01	8.00-9.20	7.40	7.50	7.80	7.72	7.43	7.50	7.62	7.65
Total Alkalinity	mg/L	257	113	148	153	259	101	170	136	301	128	196	171
Total Dissolved Solids	mg/L	331	143	202	184	303	138	195	162	327	135	211	23
Total Suspended Solids	mg/L	4	1	3	6	6	5	3	3	10	3	4	-
Total Hardness	mg/L	253	111	153	148	253	74	156	141	291	125	177	168
Dissolved Organic Carbon	mg/L	21.4	15.8	24.0	24.0	20.0	17.3	22.5	25.3	21.5	16.8	24.5	24.5
Total Kjeldahl Nitrogen	mg/L	1.11	0.60-0.76	1.05	0.70	1.30	0.86	1.04	0.90	1.50	0.81	1.04	0.85
Total Ammonia	mg/L	0.23	<0.03	0.04	0.05	0.59-1.63	<0.05	-	-	0.82	0.05	0.14	0.07
Total Phosphorus	mg/L	0.027	0.034	0.029	0.045	0.038	0.031	0.025	0.028	0.099	0.031	0.055	0.037
Dissolved Phosphorus	mg/L	0.008	<0.02	0.015	0.014	<0.02	0.60	-	-	-	-	-	-
Metals (Total)													
Aluminum (Al)	mg/L	0.01	0.01	0.05	0.06	0.04	0.07	0.05	0.04	0.03	0.03	0.04	0.02
Arsenic (As)	mg/L	0.0002	0.0003	<0.0004	0.001	<0.0004	<0.0004	<0.005	0.001-<0.005	0.0004	0.0004	0.0002	0.0005
Cadmium (Cd)	mg/L	0.001	<0.002	<0.001	0.003	<0.0002-0.001	<0.0002	-	-	<0.001	<0.001	<0.001	<0.001
Chromium (Cr)	mg/L	0.003	0.002	0.002	0.006	<0.0004-0.01	<0.0004	-	-	<0.001	0.001	0.001	0.001
Copper (Cu)	mg/L	0.001	0.001	0.004	0.001	0.002	0.0008	-	-	<0.001	<0.001	<0.001	<0.001
Iron (Fe)	mg/L	1.37	0.56	0.84	1.14	2.42	0.79	-	-	6.2	1.06	2.71	1.17
Mercury (Hg)	mg/L	0.0001	<0.0002	<0.0002	<0.05	0.0001	0.0001	<0.0001	0.0001	0.0001	0.0001	<0.0001	0.0001
Vanadium (V)	mg/L	<0.002	0.0015	0.002	0.002	0.0005	0.0004	-	-	<0.001	0.001	<0.001	0.001
Zinc (Zn)	mg/L	0.003	0.0065	0.015	0.0205	0.013-0.03	0.011	-	-	0.0055	0.0015	0.001	0.011
Metals (Dissolved)													
Aluminum (Al)	mg/L	-	0.0315	0.0094	0.0269	-	0.0315	-	-	-	-	-	-
Arsenic (As)	mg/L	<0.00075	<0.0004	<0.0004-<0.0005	<0.001	0.0004	0.0005	0.00035	0.0004	0.0005	0.0005	0.00025	<0.0002-0.0003
Cadmium (Cd)	mg/L	<0.001	<0.0001	0.0001-<0.001	<0.0001	-	<0.0001	-	-	-	-	-	-
Chromium (Cr)	mg/L	0.004	<0.0004	<0.003	0.003	0.003	0.003	0.003	0.003	0.003	0.005	0.003	<0.003
Copper (Cu)	mg/L	0.001	0.0013	0.0009-<0.001	0.0011	-	0.0013	-	-	-	-	-	-
Iron (Fe)	mg/L	0.48	1.03	0.12-0.41	0.25	-	1.03	-	-	-	-	-	-
Mercury (Hg)	mg/L	-	<0.0002	<0.0002	0.0002	-	<0.0002	-	-	-	-	-	-
Vanadium (V)	mg/L	<0.001	0.0001	<0.0001-<0.001	-	-	0.0001	-	-	-	-	-	-
Zinc (Zn)	mg/L	<0.001	0.008	0.001-0.017	-	-	0.008	-	-	-	-	-	-
Organics													
Naphthenic Acids	mg/L	-	1	<1	<1	<1	4	-	-	-	<1	<1	-
Recoverable Hydrocarbons	mg/L	-	0.5	<0.75	<1	2	<0.5	-	-	0.4	<0.1	0.15	0.25
PAHs and Alkylated PAHs	µg/L	-	-	ND	ND	ND	-	-	-	-	-	-	-
Target PANHs	µg/L	-	ND	ND	ND	ND	-	-	-	-	-	-	-
Phenolics	µg/L	-	ND	ND	ND	ND	-	-	-	-	-	-	-
Toxicity													
Microtox IC50	%	-	>100	>100	100	>99	>91	-	-	-	>100	>100	-
Microtox IC25	%	-	>100	100	100	-	>91	-	-	-	>100	>100	-

NOTES: - = No data; ND = Not detected; PAH = Polycyclic aromatic hydrocarbon; PANH = Polycyclic aromatic nitrogen heterocycle

Median concentrations (n>2), ranges (n=2), or measured concentrations (n=1) are presented

Table 3.1-4 Water Quality of Jackpine Creek (1976-1997)

Parameter	Units	At Mouth				Lower Jackpine Creek				Upper Jackpine Creek			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer	Fall
Conventional Parameters and Nutrients													
pH	-	7.10	7.60	7.58	7.80	7.50-8.00	7.30-8.30	7.70	7.50	7.75	7.62	7.70	7.58
Total Alkalinity	mg/L	134	74	126	101	141-303	56-99	136	182	273	79	128	110
Total Dissolved Solids	mg/L	136	84	142	124	147-385	74-117	168	202	330	108	145	125
Total Suspended Solids	mg/L	13	5	2	3	12	2	3	7	6	5	3	4
Total Hardness	mg/L	121	57	99	85	130-276	51-75	110	171	259	58	104	102
Dissolved Organic Carbon	mg/L	28.0	17.0	22.5	19.0	13.0-34.0	12.0-28.0	11.5-27.0	12.5-27.0	23.0	14.3	24.3	25.6
Total Kjeldahl Nitrogen	mg/L	0.45	0.82	1.29	0.80	0.50-1.23	0.86-1.02	0.91	0.64	0.86	0.80	1.04	0.82
Total Ammonia	mg/L	-	0.03	0.065	<0.05	-	-	0.12-0.22	-	1.60	0.05	<0.05	0.01-0.03
Total Phosphorus	mg/L	0.140	0.020	0.025	0.020	0.071	0.030	0.026	0.030	0.044	0.022	0.030	0.024
Dissolved Phosphorus	mg/L	-	-	-	0.013-0.014	-	-	-	-	<0.02	<0.02	-	-
Metals (Total)													
Aluminum (Al)	mg/L	0.07	0.09	0.05	0.04	0.03-0.07	0.08-0.34	<0.01	0.06	0.0475	0.07	0.055	0.04
Arsenic (As)	mg/L	-	0.0004	0.0050	0.0004	-	-	0.0080	0.0080-0.0200	<0.0004	0.0004	0.0004	0.0006
Cadmium (Cd)	mg/L	-	<0.001	<0.0055	<0.001	-	-	<0.01	-	<0.001	<0.0002	<0.001	<0.001-0.004
Chromium (Cr)	mg/L	-	<0.001	0.008	<0.0016	-	-	<0.01	-	<0.01	<0.0004	<0.001-0.004	<0.001-0.012
Copper (Cu)	mg/L	-	<0.001	0.003	0.0024	-	-	<0.005	-	0.0009	0.001	<0.001	<0.001
Iron (Fe)	mg/L	-	0.26-0.47	0.96	1.12	-	-	0.51-0.52	-	2.25-2.40	0.47	0.87-0.93	0.57-0.58
Mercury (Hg)	mg/L	<0.0001	<0.0001	<0.0001	<0.00005	<0.0001-0.0003	<0.0001	<0.0001	0.0002	0.0001	<0.0002	<0.0001	<0.0001
Vanadium (V)	mg/L	-	<0.001	<0.006	0.0014	-	-	<0.1	-	0.0004	0.0002	0.002-0.005	<0.002
Zinc (Zn)	mg/L	-	0.001-0.003	0.020	0.027	-	-	0.030-0.100	-	0.011-0.025	0.008	0.001-0.433	0.002-0.186
Metals (Dissolved)													
Aluminum (Al)	mg/L	-	-	-	0.058-0.092	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	0.0010	0.0007	0.0004	0.0010	<0.0001-0.0200	0.0011	0.0014-0.0040	< 0.0010	0.0003	0.001	0.0005	0.0003
Cadmium (Cd)	mg/L	-	-	-	<0.001	-	-	-	-	-	-	-	-
Chromium (Cr)	mg/L	0.003	<0.003	<0.003	<0.003	<0.003	<0.003	<0.003	0.003	0.003	0.003	0.003	0.003
Copper (Cu)	mg/L	-	-	-	0.0022-0.0027	-	-	-	-	-	-	-	-
Iron (Pb)	mg/L	-	-	-	0.32-0.34	-	-	-	-	-	-	-	-
Mercury (Hg)	mg/L	-	-	-	<0.0002	-	-	-	-	-	-	-	-
Vanadium (V)	mg/L	-	-	-	0.0002-0.0003	-	-	-	-	-	-	-	-
Zinc (Zn)	mg/L	-	-	-	0.016-0.02	-	-	-	-	-	-	-	-
Organics													
Naphthenic Acids	mg/L	-	-	-	1	-	-	-	-	<1	<1	<1	<1
Recoverable Hydrocarbons	mg/L	-	<0.1	0.3	0.5	-	-	0.6-1.5	-	<1	<0.5	<0.5	<1
PAHs and Alkylated PAHs	μg/L	-	-	-	-	-	-	-	-	-	ND	ND	ND
PANHs	μg/L	-	-	-	-	-	-	-	-	-	ND	ND	ND
Phenolics	μg/L	-	-	-	-	-	-	-	-	-	ND	ND	ND
Volatile Organics	μg/L	-	-	-	-	-	-	-	-	-	ND	-	-
Toxicity													
Microtox IC50	%	-	-	-	-	-	-	-	-	>99	>91	100	>100
Microtox IC25	%	-	-	-	-	-	-	-	-	-	>100	>100	>100

NOTES: - = No data; ND = Not detected; PAH = Polycyclic aromatic hydrocarbon; PANH = Polycyclic aromatic nitrogen heterocycle
Median concentrations (n>2), ranges (n=2), or measured concentrations (n=1) are presented

Table 3.1-5 Water Quality of Other Muskeg River Tributaries (1976-1997)

Parameter	Units	Muskeg Creek				Shelley Creek			Upper Muskeg Creek Drainage			
		Winter	Spring	Summer	Fall	Winter	Spring	Summer	Winter	Spring	Summer	Fall
Conventional Parameters and Nutrients												
pH	-	7.20	7.17	7.70	7.43	7.20	7.30	7.75	7.80	7.80	7.69	7.61
Total Alkalinity	mg/L	168	79	115	109	284	60	106	233	84	140	112
Total Dissolved Solids	mg/L	196	87	123	125	290	70	129	260	93	146	125
Total Suspended Solids	mg/L	5	5	4	1	14	3	2	11	1	3	3
Total Hardness	mg/L	146	60	95	83	243	45	89	188	65	114	87
Dissolved Organic Carbon	mg/L	33.5	16.5	28.0	26.5	32.0	14.0	24.8	-	-	33.2	29.6
Total Kjeldahl Nitrogen	mg/L	1.71	1.13	1.22	0.82	2.33	0.92	0.20	1.48	0.67	0.84	0.87
Total Ammonia	mg/L	0.46	0.05	0.05	0.04	0.51	0.05	0.05	1.04	0.04	0.08	0.03
Total Phosphorus	mg/L	0.052	0.030	0.034	0.033	0.200	0.020	0.025	0.135	0.019	0.032	0.019
Dissolved Phosphorus	mg/L	< 0.02	< 0.02	< 0.02	-	< 0.02	< 0.02	< 0.02	-	-	-	-
Metals (Total)												
Aluminum (Al)	mg/L	0.04	0.07	0.03	0.02	0.05	0.04	0.038-0.043	0.04	0.02	0.06	0.02
Arsenic (As)	mg/L	0.0004	0.0003	<0.0005	0.0003	0.0011	0.0004	<0.0004	0.0011	0.0004	0.0009	0.0004
Cadmium (Cd)	mg/L	<0.001	<0.001	<0.001	<0.001	<0.0002	<0.0002	0.0002	<0.001	<0.001	<0.002	0.001
Chromium (Cr)	mg/L	<0.001	0.001	0.002	0.001	<0.0004	<0.0004	<0.0004-0.0018	<0.001	<0.001	< 0.0055	0.001
Copper (Cu)	mg/L	<0.001	<0.001	0.001	<0.001	0.0012	0.0012	0.0009-0.001	<0.001	0.001	<0.001	<0.001
Iron (Fe)	mg/L	1.15	0.47	0.61	0.39	7.92	0.09	0.39-0.61	3.30	0.43	0.64	0.46
Mercury (Hg)	mg/L	0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.0001	0.0001	<0.0001	<0.00005	0.00005	<0.000075
Vanadium (V)	mg/L	<0.001	<0.001	>0.002	<0.001	0.001	<0.0002	<0.0002-0.0007	<0.001	<0.001	<0.005	0.001
Zinc (Zn)	mg/L	0.0045	0.0065	0.0105	0.004	0.027	0.005	0.028-0.103	0.006	0.002	0.020	0.003
Metals (Dissolved)												
Arsenic (As)	mg/L	0.001	<0.0005	0.0004	0.0002	0.001	0.0005	0.0002-0.0005	-	-	-	-
Chromium (Cr)	mg/L	0.003	0.003	<0.003	<0.003	<0.003	0.003	-	-	-	-	-
Organics												
Naphthenic Acids	mg/L	1	<1	<1	<1	1	<1	<1	-	-	<1	<1
Recoverable Hydrocarbons	mg/L	1.1	<0.3	<0.3	0.4	<1	<0.5	<0.5	0.6	<0.1	0.7	<0.4
Toxicity												
Microtox IC50	%	>99	91-100	>100	<100	>99	>91	-	-	-	>100	>100
Microtox IC25	%	-	>100	>100	<100	-	-	-	-	-	>100	>100

NOTES: - = No data; ND = Not detected; median concentrations (n>2), ranges (n=2), or measured concentrations (n=1) are presented occasionally detected during previous studies, at levels slightly above the detection limit. Trace organic compounds have not been detected in Jackpine Creek and none of the streams sampled were toxic to bacteria. Naphthenic acids were measured occasionally at the detection limit in Jackpine, Muskeg and Shelley creeks. As in the Muskeg River, concentrations of dissolved ions, nutrients and dissolved organic carbon vary seasonally.

water quality guideline exceedances

Comparisons with guidelines were made using fall medians for the lower Jackpine Creek and winter medians for all other tributary sites. Concentrations of total phosphorus and a number of metals occasionally exceed chronic water quality guidelines in theses streams (Table 3.1-2). However, occasional guideline exceedances are of no concern to aquatic life and water quality of the tributaries of the Muskeg River can be classified as good.

Isadore's Lake and Mills Creek

water quality of Isadore's Lake and Mills Creek

Water quality of Isadore's Lake and Mills Creek was assessed during the Muskeg River Mine Project baseline surveys in 1997. The data suggest that, in terms of water quality, these waterbodies are generally similar to others in the Muskeg River basin (Table 3.1-6). Differences from other surface waters in the basin include higher dissolved salts in Mills Creek in the fall and slightly lower dissolved organic carbon and nutrient levels in both Isadore's Lake and Mills Creek. However, these differences may simply represent the limited data available at present for Isadore's Lake and Mills Creek.

water quality guideline exceedances

Concentrations of total phosphorus and a number of metals exceeded chronic water quality guidelines in Isadore's Lake; no exceedances were documented in Mills Creek (Table 3.1-2). Overall, water quality of Isadore's Lake and Mills Creek can be classified as good and the guideline exceedances noted are of no concern to aquatic life.

Alsands Drain

water quality of Alsands Drain

Water quality of the Alsands Drain differed slightly from those of natural tributaries of the Muskeg River. Concentrations of dissolved salts and total Kjeldahl nitrogen, total alkalinity and hardness were higher and phosphorus level was lower in the Alsands Drain than in other streams (Table 3.1-7). Levels of metals were similar to those in natural streams. Total phenolics concentration was elevated and exceeded the applicable water quality guideline. As in most other streams in the basin, concentrations of iron and manganese exceeded water quality guidelines (Table 3.1-2).

Table 3.1-6 Water Quality of Isadore's Lake and Mills Creek in 1997

Parameter	Units	Isadore's Lake			Mills Creek	
		Winter	Summer	Fall	Spring	Fall
Conventional Parameters and Nutrients						
pH	-	7.20	8.40	8.00	8.00	8.00
Total Alkalinity	mg/L	287	129	136	237	237
Dissolved Organic Carbon	mg/L	15.0	11.0	9.0	5.0	7.0
Total Dissolved Solids	mg/L	290	236	220	390	894
Total Suspended Solids	mg/L	24	2	6	7	<2
Total Hardness	mg/L	277	154	164	345	319
Total Kjeldahl Nitrogen	mg/L	0.8	0.4	0.4	<0.2	<0.2
Total Ammonia	mg/L	0.51	<0.05	0.11	<0.05	<0.05
Total Phosphorus	mg/L	0.140	0.016	0.012	0.042	<0.002
Dissolved Phosphorus	mg/L	<0.02	0.008	0.012	0.050	<0.002
Metals (Total)						
Aluminum (Al)	mg/L	0.368	0.018	0.062	0.055	0.031
Arsenic (As)	mg/L	0.0011	<0.0004	0.0018	<0.0004	<0.0004
Cadmium (Cd)	mg/L	<0.0002	<0.0002	0.0003	<0.0002	<0.0002
Chromium (Cr)	mg/L	<0.0004	0.0014	<0.0004	<0.0004	<0.0004
Copper (Cu)	mg/L	0.0012	0.0009	0.0066	0.0008	0.0008
Iron (Fe)	mg/L	7.92	0.21	<0.01	0.82	0.05
Mercury (Hg)	mg/L	<0.0002	0.0001	<0.0001	<0.0002	<0.0001
Vanadium (V)	mg/L	0.0009	0.0004	<0.0002	<0.0002	<0.0001
Zinc (Zn)	mg/L	0.027	0.013	0.012	0.009	0.008
Metals (Dissolved)						
Aluminum (Al)	mg/L	-	-	0.0346	-	0.023
Arsenic (As)	mg/L	-	-	0.0016	-	<0.0004
Cadmium (Cd)	mg/L	-	-	0.0003	-	<0.0001
Chromium (Cr)	mg/L	-	-	<0.0004	-	<0.0004
Copper (Cu)	mg/L	-	-	0.0015	-	0.0013
Iron (Fe)	mg/L	-	-	0.02	-	0.03
Mercury (Hg)	mg/L	-	-	<0.0002	-	<0.0002
Vanadium (V)	mg/L	-	-	0.0001	-	<0.0001
Zinc (Zn)	mg/L	-	-	0.017	-	0.01
Organics						
Naphthenic Acids	mg/L	1	<1	1	<1	<1
Recoverable Hydrocarbons	mg/L	<1	<0.5	<0.5	<0.5	<0.5
Phenolics	mg/L	-	<0.001	<0.001	<0.001	<0.001
Toxicity						
Microtox IC50	%	>99	-	-	>91	-
Microtox IC25	%	-	-	-	>91	-

NOTES: - = no data; measured values (n = 1) are presented

Table 3.1-7 Water Quality of the Alsands Drain in Fall 1997

Parameter	Units	Alsands Drain
Conventional Parameters and Nutrients		
pH	-	7.40-7.50
Total Alkalinity	mg/L	245-247
Dissolved Organic Carbon	mg/L	15.0-17.5
Total Dissolved Solids	mg/L	328-440
Total Suspended Solids	mg/L	2-4
Total Hardness	mg/L	254-335
Total Kjeldahl Nitrogen	mg/L	0.90-1.25
Total Ammonia	mg/L	0.05-0.30
Total Phosphorus	mg/L	0.009-0.017
Dissolved Phosphorus	mg/L	0.005-0.008
Metals (Total)		
Aluminum (Al)	mg/L	0.032-0.035
Arsenic (As)	mg/L	0.0004
Cadmium (Cd)	mg/L	<0.0002
Chromium (Cr)	mg/L	<0.0004
Copper (Cu)	mg/L	0.002-0.003
Iron (Fe)	mg/L	0.68-0.70
Mercury (Hg)	mg/L	<0.0001
Vanadium (V)	mg/L	0.0002
Zinc (Zn)	mg/L	0.009-0.010
Organics		
Naphthenic Acids	mg/L	1
Recoverable Hydrocarbons	mg/L	<0.05
Total Phenolics	mg/L	0.03-0.04

NOTES: Ranges (n = 2) are presented

Dissolved Versus Total Metal Concentrations in Surface Waters

limited data available on dissolved metals

Available data were examined to see if there are general relationships between total and dissolved metal concentrations on a seasonal basis. In rivers with seasonally varying levels of suspended sediments, total metal levels also tend to fluctuate seasonally. However, because only a small fraction of the total metals is in the dissolved form, total metal measurements reveal little about the potential for biological effects during periods of high suspended sediment levels. Therefore, seasonal estimates of the proportions of dissolved and particulate forms of metals may advance our understanding of the potential effects of elevated levels of metals on aquatic biota.

Only limited data are available at present regarding dissolved metal concentrations in the study area. However, some patterns are beginning to emerge (Table 3.1-8). In all rivers sampled, dissolved aluminum, cobalt, titanium and vanadium tend to form a small percentage of total metals. In contrast, antimony, calcium, sodium and strontium were mostly in the dissolved form. Other metals were either in the intermediate range (e.g., molybdenum), or the percentage of the dissolved form varied widely by season (e.g., iron).

proportion of dissolved metals usually lower in Athabasca River

Percentages of dissolved metals were typically lower in the Athabasca River than in the Muskeg River basin, which reflects the generally higher suspended sediment levels in the Athabasca River. As well, seasonal variation in the percentage of dissolved metals was greater in the Athabasca River, as may be expected, since this river carries a seasonally varying sediment load, whereas suspended sediment level is relatively constant in the Muskeg River basin.

Muskeg Drainage Water

muskeg drainage water quality not characterized in detail

Muskeg water refers to standing water in areas covered with muskeg and the water that saturates muskeg. Large volumes of muskeg drainage water are expected to enter surface waters during muskeg dewatering, which is the initial phase of oil sands mine development. Since concerns have been raised about the potential influence of muskeg drainage water on receiving stream water quality, the available data on muskeg water were summarized to provide background information.

The quality of muskeg drainage waters has not been characterized in detail, with the exception of major ion concentrations (Schwartz 1980). Schwartz (1980) also examined the relative contributions of muskeg drainage water, groundwater and precipitation to stream flow in the Muskeg River basin. A few samples of muskeg drainage water were also collected by Syncrude in the Aurora Mine area (during muskeg dewatering) and were analyzed for a wider variety of parameters.

Table 3.1-8 Dissolved Metals Expressed as the Percentage of Total Metals

Metal	Athabasca River			Muskeg River Basin		
	Spring (n=3)	Summer (n=1)	Fall (n=1)	Spring (n=1)	Summer (n=1)	Fall (n=3)
Aluminum (Al)	6	<1	2	14	13	7
Antimony (Sb)	-	83	100	-	100	-
Arsenic (As)	52	11	40	-	-	-
Barium (Ba)	59	22	52	75	87	68
Boron (B)	70	55	79	87	100	99
Cadmium (Cd)	-	100	-	-	-	-
Calcium (Ca)	89	54	92	-	89	-
Chromium (Cr)	19	-	-	-	-	-
Cobalt (Co)	42	3	25	-	-	15
Copper (Cu)	57	33	100	100	12	50
Iron (Fe)	23	<1	-	100	59	24
Lead (Pb)	40	9	92	93	-	46
Lithium (Li)	66	28	64	83	91	88
Manganese (Mn)	57	2	14	92	49	49
Molybdenum (Mo)	49	50	83	65	45	16
Nickel (Ni)	70	22	32	-	50	28
Potassium (K)	59	80	53	-	84	-
Silicon (Si)	24	8	-	62	87	94
Sodium (Na)	100	100	93	-	87	-
Strontium (Sr)	84	68	91	89	89	89
Titanium (Ti)	4	1	1	22	29	4
Uranium (U)	58	34	73	-	-	-
Vanadium (V)	11	-	2	25	-	11
Zinc (Zn)	28	42	68	73	100	73

NOTES:

Data from 1997 RAMP field program

\- = no data

muskeg drainage water accounts for most of the flow in Muskeg River and Jackpine Creek during open water season

In the Muskeg River and Jackpine Creek, the proportions of total flow contributed by muskeg drainage water, groundwater and precipitation vary considerably by season under natural conditions (Schwartz 1980). Baseflow in winter is contributed almost exclusively by groundwater. The makeup of spring flows is highly variable, and includes precipitation (snowmelt), groundwater and muskeg water in rapidly changing proportions. From late spring to freeze-up, muskeg drainage contributes an average of 80% of stream flow in Jackpine Creek and about 60% of the flow in the Muskeg River.

muskeg water quality

In samples collected by Schwartz (1980), most pH measurements were between 6 and 8, but the full range of measurements was wide (1.98 to 9.15). Calcium was the dominant cation in muskeg waters, with lower concentrations of sodium and magnesium, while bicarbonate dominated the anions (Table 3.1-9). Concentrations of most ions varied seasonally, but within a relatively narrow range. Bicarbonate, calcium, magnesium, iron, sodium, potassium and specific conductance increased from a minimum in May to a maximum in mid-August. Chloride and sulphate levels varied without a discernible seasonal trend.

The ion chemistry of muskeg water documented by Schwartz (1980) was compared with the surface water data for streams that likely receive a large proportion of their flow from muskeg drainage during the summer and fall (Table 3.1-9). Based on this qualitative comparison, stream water chemistry during the spring is most similar to muskeg water chemistry, which is inconsistent with expectations based on the estimated seasonal contribution of muskeg water to stream flow described above.

Muskeg drainage water samples collected by Syncrude were different from Schwartz's (1980) samples (Table 3.1-9). All major ions were more concentrated in the Syncrude samples. Comparison of these data with seasonal medians for streams in the Muskeg River basin indicated that muskeg drainage waters are most similar to surface waters sampled during the winter. Major ion composition of muskeg water was very similar to that in stream samples collected in the winter, but levels of nitrogen compounds were generally lower in muskeg water. Levels of metals in muskeg water were similar to those in surface waters, or in some cases higher, but total metal measurements likely reflect the elevated suspended sediment levels in the Syncrude samples.

Concentrations of total aluminum, iron and manganese exceeded chronic water quality guidelines in muskeg water samples collected by Syncrude (Table 3.1-2). These exceedances were likely caused by the elevated suspended sediment level noted above.

muskeg water quality similar to local surface waters

In summary, the limited data available regarding the quality of muskeg drainage waters are inconsistent, but suggest that these waters are not substantially different from stream water in the Muskeg River basin. This is not surprising, since a large proportion of the water in streams in the region originates from muskeg drainage.

Table 3.1-9 Water Quality of Muskeg Drainage Waters Compared with Stream Water in the Muskeg River Basin

Parameter	Units	Muskeg Drainage Water[1]	Muskeg Drainage Water[2]	Muskeg River, Jackpine Creek, Shelley Creek and Muskeg Creek (Seasonal Median Values)			
				Winter	Spring	Summer	Fall
Conventional Parameters and Major Ions							
pH	-	7.13	-	7.45	7.60	7.80	7.60
Conductance	μS/cm	481	137	480	167	255	226
Total Dissolved Solids	mg/L	263	-	300	111	174	156
Total Suspended Solids	mg/L	29	-	6	5	3	3
Calcium	mg/L	85.0	17.0	69.0	20.0	33.1	30.0
Magnesium	mg/L	11.8	4.9	17.1	6.0	9.0	8.5
Potassium	mg/L	0.9	0.6	1.5	1.3	0.5	0.8
Sodium	mg/L	4.4	4.1	15.1	8.2	11.8	12.3
Bicarbonate	mg/L	317	81	349	100	171	183
Chloride	mg/L	<0.05-<0.5	2.4	4.8	1.7	2.1	2.0
Sulphate	mg/L	<0.1-3.1	5.9	5.1	4.1	4.5	3.3
Total Hardness	mg/L	261	-	242	72	116	111
Total Alkalinity	mg/L	260	-	256	85	141	119
Total Organic Carbon	mg/L	10.2	-	25.0	18.0	25.5	25.5
Dissolved Organic Carbon	mg/L	9.8	-	23.0	15.8	24.0	24.0
Biochemical Oxygen Demand	mg/L	6.4	-	1.5	1.0	0.8	1.7
Total Phenolics	mg/L	<0.001	-	0.007	0.009	<0.001	0.002
Nutrients							
Nitrate + Nitrite	mg/L	<0.03-0.016	-	0.100	<0.003	<0.1	<0.05
Total Ammonia	mg/L	0.17	-	0.53	<0.05	<0.05	0.04
Total Kjeldahl Nitrogen	mg/L	0.34	-	1.30	0.83	<0.20	0.82
Total Phosphorus	mg/L	<0.1	-	0.052	0.030	<0.005	0.031
Metals (Totals)							
Aluminum (Al)	mg/L	0.33	-	0.04	<0.01	<0.005	<0.01
Cadmium (Cd)	mg/L	<0.0002	-	<0.001	<0.001	<0.001	<0.001
Chromium (Cr)	mg/L	0.011	-	<0.001	<0.001	<0.001	<0.001
Copper (Cu)	mg/L	0.0035	-	<0.001	<0.001	<0.001	<0.001
Iron (Fe)	mg/L	4.44	-	1.41	0.56	0.84	0.925
Lead (Pb)	mg/L	<0.0003	-	0.002	<0.02	<0.02	<0.002
Manganese (Mn)	mg/L	0.357	-	0.487	0.024	0.041	0.053
Vanadium (V)	mg/L	<0.002-0.005	-	<0.001	<0.001	<0.001	<0.001
Zinc (Zn)	mg/L	0.020	-	0.008	0.006	<0.001	0.016

NOTES: - = no data

[1]Median values or range (n=4); data from Syncrude, Aurora Mine, February and March, 1997.

[2]Means for 144 samples of standing water in muskeg (Schwartz 1980).

3.1.2 Sediment Quality

Athabasca River

generally low PAH levels in bottom sediments

Bottom sediments of the Athabasca, Peace, Smoky and Wapiti rivers were collected during the Northern River Basins Study (NRBS) for assessment of PAHs, PCBs and pulp mill-related organic compounds (Crosley 1996, Brownlee et al. 1997). Brownlee et al. (1997) reported low levels of individual PAHs (<22 µg/g) at a number of sites along the Athabasca River, including three sites in the lower reaches (above Horse River, above Firebag River and at the mouth). None of the reported concentrations exceeded the applicable Threshold Effect Level (TEL) guidelines. Levels of PAHs were similar at all sites in the Athabasca River and were generally lower than in Peace and Wapiti River sediments.

Crosley (1996) reported an increase in total PAHs in the clay-silt fraction of bottom sediments from approximately 1 µg/g in the upper and mid-reaches of the Athabasca River to >2 µg/g above Fort McMurray. This abrupt increase was followed by a minor decline near Fort McKay. Crosley (1996) suggested that the increase in the lower reaches of the river was most likely due to natural sources, and speculated that the decline in sediment PAH levels between Fort McMurray and Fort McKay suggests that oil sands industries are not contributing significant PAHs to river sediments.

bottom sediment quality usually within guidelines

Bottom sediment quality of three closely-spaced sites near Suncor's TID was assessed in 1994 and 1995 by Golder Associates (1994, 1996a). The presence of varying amounts of oil sands was indicated by detectable but low levels of PAHs in both years and relatively high hydrocarbon content at all three sites in 1995 (Table 3.1-10). Levels of certain PAHs exceeded the TEL guidelines at one site, located just upstream from existing oil sands operations (Table 3.1-2). Levels of metals were typical of the bottom sediments of large rivers in Alberta (e.g., Shaw et al. 1994). Cadmium concentration was equal to the TEL in one sample (at TID, Right Bank) and the TEL guideline for nickel was exceeded at two sites (both banks at TID). Microtox® tests of sediment extracts in 1994 did not detect toxicity to bacteria at any of the sites sampled.

Bottom sediments of the Athabasca River were most recently sampled in 1997, during the fall field program of the RAMP (Golder 1998). The sample collected below the oil sands area contained higher levels of hydrocarbons and PAHs than the sample from upstream of the oil sands area (Table 3.1-10), which conflicts with findings of Crosley (1996). Levels of metals were similar to those reported in previous samples from this river. Nickel levels exceeded the TEL below Fort Creek (Table 3.1-2).

available data does not suggest PAH accumulation in oil sand area

The limited data available do not reveal consistent spatial trends indicating input of PAHs from oil sands operations, but suggest there is an increase in natural input of PAHs in the oil sands area relative to the upper reaches of the river.

Table 3.1-10 Sediment Quality of the Athabasca River in 1994, 1995 and 1997

Parameter	Units	1994[1]			1995[2]			1997[3]	
		1 km Above TID West Bank	At TID East Bank	At TID West Bank	1 km Above TID West Bank	At TID East Bank	At TID West Bank	At Donald Creek	At Fort Creek
Total Organic Carbon	Weight %	1.07	1.31	0.49-1.61	1.39	0.49	1.02	0.67	2.32
Recoverable Hydrocarbons	µg/g	-	-	-	2160	450	703	423	1190
Metals									
Aluminum	µg/g	6420	7670	4250-7740	3910	3730	4890	10700	7790
Arsenic	µg/g	1.7	2.1	1.3-2.0	0.6	0.9	1.0	5.6	5.1
Cadmium	µg/g	<0.3	<0.3	<0.3	<0.3	0.6	0.5	<0.5	<0.5
Chromium	µg/g	15.3	17.3	13.4-17.2	13.9	11.1	12.4	19.0	20.2
Copper	µg/g	5.1	7.9	3.6-8.6	4.6	3.6	6.5	15	15
Iron	µg/g	13600	16400	10200-14800	11000	9820	13100	15000	15500
Lead	µg/g	3	6	6-8	4	5	5	9	8
Mercury	µg/g	0.023	0.03	<0.02-0.03	0.03	0.04	0.03	0.05	0.06
Nickel	µg/g	15.0	18.0	14.0-19.0	13.8	11.8	15.6	16.0	19.0
Molybdenum	µg/g	1.0	1.2	0.9-1.4	<0.3	0.4	0.5	<1	<1
Vanadium	µg/g	18.8	19.4	14-19.8	14.7	12.8	14.5	28.0	18.5
Zinc	µg/g	35.6	43.6	26.3-46.1	29.9	27.6	39.6	53.0	57.4
PAHs									
Phenanthrene	µg/g	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	0.01	0.01
Benz(a)anthracene/Chrysene	µg/g	2.1	<0.01	<0.01-0.02	0.03	<0.01	0.01	0.02	0.025
Benzo(a)pyrene	µg/g	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.006
Fluoranthene	µg/g	0.4	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.006
Pyrene	µg/g	1.5	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Total PAHs	µg/g	4.30	-	0.50	0.66	0.07	0.13	0.48	1.203
Toxicity									
Microtox Screen	% Control	73-99	118	91-120	-	-	-	-	-

NOTES:

[1]Golder (1994)

[2]Golder (1996a)

[3]Samples collected in fall 1997 for RAMP

PAH = Polycyclic aromatic hydrocarbon

TID = Tar Island Dyke

\- = no data or not applicable

Muskeg River and Jackpine Creek

generally low levels of metals and PAHs in sediments

Bottom sediment samples were collected in fall 1997 from Muskeg River and Jackpine Creek as part of the RAMP for the oil sands area (Golder 1998). Levels of metals were typically lower than in the Athabasca River (Table 3.1-11) or the North Saskatchewan River (Shaw et al. 1994), and no guideline exceedances were found. Concentrations of PAHs were below those in the Athabasca River. Potential exceedances of the TEL value for benz(a)anthracene and chrysene occurred at all three sites sampled in the Muskeg River basin (Table 3.1-2); however, since concentrations of these compounds were reported together, exceedances cannot be identified with certainty.

3.1.3 Porewater Quality

characteristics of porewater in oil sands area

The limited porewater data from the oil sands area suggest that the chemical composition of porewaters can vary greatly, depending on the amount of oil sands in the substratum. The concentrations of dissolved salts varied widely in porewater samples collected in 1995 from the Athabasca, Steepbank and Muskeg rivers and Jackpine Creek (Table 3.1-12; Golder 1996a). Dissolved salt levels were lowest in the Muskeg River and Jackpine Creek and highest in the Steepbank River, most likely reflecting the relative amounts of oil sands at the sampling sites. Ammonia level varied moderately among sites, with a high value at one site in the Steepbank River. Naphthenic acids concentrations were variable but low at all sites. Naturally occurring PAHs were detectable at one site in the Athabasca River and all three sites in the Steepbank River, but not in the Muskeg River or Jackpine Creek. One sample from the Steepbank River (15 km from the mouth) contained PAHs at levels higher than previously found in process-affected porewaters adjacent to TID (Golder 1994, 1995). None of the samples were toxic to bacteria in the Microtox® test.

Table 3.1-11 Sediment Quality in the Muskeg River and Jackpine Creek in 1997

Parameter	Units	Muskeg River at Mouth	Muskeg River upstream Jackpine Creek	Jackpine Creek at Mouth
Total Organic Carbon	%	3.0	4.5	2.0
Recoverable Hydrocarbons	µg/g	3440	3690	5660
Metals				
Aluminum (Al)	µg/g	2970	5820	3060
Arsenic (As)	µg/g	1.0	2.4	1.2
Cadmium (Cd)	µg/g	<0.5	<0.5	<0.5
Chromium (Cr)	µg/g	6.9	12.3	7.8
Copper (Cu)	µg/g	7	10	7
Iron (Fe)	µg/g	11200	23000	5430
Lead (Pb)	µg/g	<5	<5	<5
Mercury (Hg)	µg/g	0.04	0.04	0.03
Molybdenum (Mo)	µg/g	<1	<1	<1
Nickel (Ni)	µg/g	6	9	6
Vanadium (V)	µg/g	9	16	11
Zinc (Zn)	µg/g	26.4	37.9	22.2
PAHs				
Phenanthrene	µg/g	0.007	0.009	<0.003
Fluoranthene	µg/g	0.003	0.006	0.004
Pyrene	µg/g	0.012	0.015	0.006
Benz(a)anthracene/Chrysene	µg/g	0.035	0.057	0.034
Benzo(a)pyrene	µg/g	0.013	0.016	0.015
Total PAHs	µg/g	1.712	3.888	2.027

NOTES: PAH = Polycyclic aromatic hydrocarbon

Table 3.1-12 Porewater Chemistry and Toxicity in the Athabasca, Steepbank and Muskeg Rivers and Jackpine Creek in 1994 and 1995

Site	Sodium (mg/L)	Total Dissolved Solids (mg/L)	Naphthenic Acids (mg/L)	Total Ammonia (mg/L)	Total PAHs (μg/L)	Microtox IC50 (%)
Athabasca R. 1 km above TID, West Bank	1210	3220	17	0.78	0.04	>100
Athabasca River at TID, West Bank	12.8	259	<1	0.58	ND	>100
Athabasca River at TID, East Bank	423	1730	<1	0.59	ND	>100
Steepbank River at the mouth	12.6-26.5	240-374	2-4	0.47-0.62	ND-0.84	>100
Steepbank River, 15 km from the mouth	380-5120	1370-14500	3-16	0.50-3.01	1.21-33.75	>100
Steepbank River, 25 km from the mouth	11.5-26.1	125-228	<1-5	0.03-0.06	ND-0.03	>100
Muskeg River at the mouth	11.0	130	<1	<0.01	ND	>100
Jackpine Creek at the mouth	10.5	168	<1	0.01	ND	>100

NOTES:
TID = Tar Island Dyke
ND = Not detected
PAH = Polycyclic aromatic hydrocarbon
Data from Golder (1996a)

3.2 BENTHIC INVERTEBRATES

3.2.1 Athabasca River

generally low quality benthic habitat

In the oil sands area, the Athabasca is a large river with a considerable silt load during the summer months. It provides relatively low quality, largely depositional habitat for benthic invertebrates. The shifting sand bottom typical of this reach supports benthic communities of low density and taxonomic richness (number of taxa), consisting largely of chironomid midge larvae, oligochaete worms and nematodes. During long-term monitoring by AEP, Anderson (1991) found no major differences in benthic community structure on natural substrates between a site located upstream of the Horse River (just upstream of Fort McMurray) and one at Embarras (near the mouth). Other studies also found relatively homogeneous fauna in the reach adjacent to oil sands operations (McCart et al. 1977, Noton 1979, Noton and Anderson 1982, Boerger 1983, Golder 1996a). This suggests that benthic communities are similar throughout the lower Athabasca River.

more diverse fauna on artificial substrates

A more diverse fauna colonized artificial substrates used for monitoring oil sands-related discharges, with representatives of a number of pollution-sensitive invertebrate groups (Ephemeroptera, Plecoptera, Trichoptera; McCart et al. 1977, Noton 1979, Noton and Anderson 1982, Golder 1996a). These studies were typically of shorter reaches of the river and concentrated on individual oil sands operations.

oil sands may influence benthic fauna

Results of McCart et al. (1977) and Barton and Wallace (1980) suggest that the presence of oil sands in bottom sediments may influence the resident benthic fauna. McCart et al. (1977) found that bituminous substrates (sediment containing oil sands) tended to support higher proportions of oligochaetes and chironomids. Barton and Wallace (1980) reported that the variety and density of invertebrates on oil sands were significantly lower than on rubble substrates.

possible localized discharge-related effects

A number of studies documented localized, minor biological effects of water releases from Suncor's oil sands operation in the Athabasca River. Reductions in invertebrate density and taxonomic richness below TID and the refinery wastewater and sewage outfalls were reported by Noton (1979), Noton and Anderson (1982) and Boerger (1983). Results of recent benthic surveys suggest that biological effects are absent below Suncor's discharges (Golder 1994, 1996a). However, these studies did not sample immediately below outfalls and, thus, localized discharge-related effects cannot be ruled out.

3.2.2 Muskeg River Basin

three major benthic invertebrate studies

Benthic communities in the Muskeg River, several of its tributaries and Kearl Lake were characterized at 19 sites in spring, summer and fall 1988, during the OSLO Project (R.L. & L. 1989). The results of benthic invertebrate studies carried out in 1985 at a subset of the OSLO sites by Beak (1986) were also summarized by R.L. & L. 1989. More recently, Golder Associates (1996a) sampled nine sites in this area in fall 1995.

composition of benthic communities in 1985 and 1988

In 1985 and 1988, stream sites were classified as pool, riffle or run habitat. Pool sites supported slightly fewer taxa and lower numbers of invertebrates than other habitats. All sites were dominated by chironomid midges and other dipterans, followed by non-insect taxa and the aquatic insect groups Ephemeroptera, Trichoptera and Plecoptera. The percentage of insects was slightly higher at riffle sites than at pool or run sites, and the benthic invertebrate community was dominated by detritivores at all sites. Kearl Lake supported a relatively unproductive benthic community, which was also dominated by detritivores.

composition of benthic communities in 1995

In 1995, benthic communities in these waterbodies also reflected the habitat types sampled. Stream sampling sites were classified as depositional or erosional habitat. Depositional sites typically supported invertebrate communities with moderate density and low taxonomic richness, consisting almost exclusively of oligochaete worms, nematode worms and chironomid midge larvae. The benthic community of Kearl Lake was similar to those of depositional sites, but supported a less abundant fauna. Density was lower at the erosional sites; however, a greater variety of invertebrates was found. Erosional benthic communities consisted of all taxa found at the depositional sites and included aquatic insects of various orders.

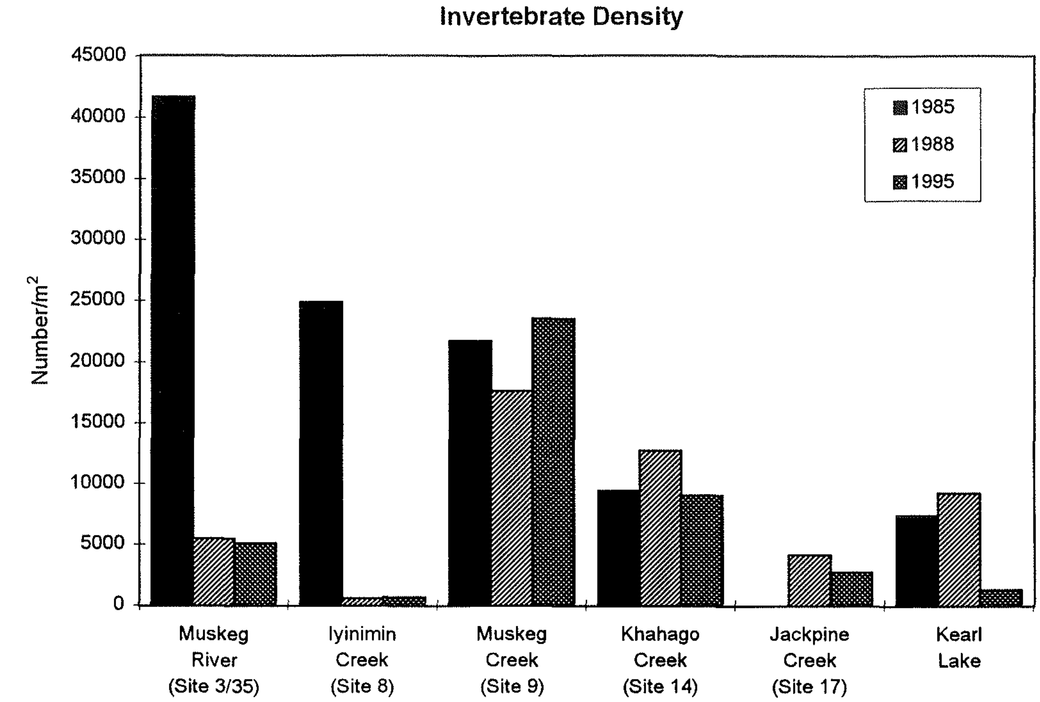
The structure of benthic communities, in terms of relative proportions of functional feeding groups, was also consistent with habitat type in 1995. Depositional sites (pools) supported largely collector-gatherer taxa. The fauna of erosional sites (riffles and runs) comprised a large proportion of collector-gatherers, but other groups such as scrapers and predators were also abundant.

three surveys compared

Results of the three benthic invertebrate surveys were compared at a subset of common sites to examine year-to-year variation in invertebrate density and community composition. The fall data sets were used for these comparisons, since all three studies sampled during this season.

density variable, lowest taxonomic richness in Kearl Lake

Benthic invertebrate density varied considerably among years in the Muskeg River, Iyinimin Creek and Kearl Lake, but remained similar at the other three stream sites selected for this summary (Figure 3.2-1). Taxonomic richness was low and variable in fall samples in all three years,



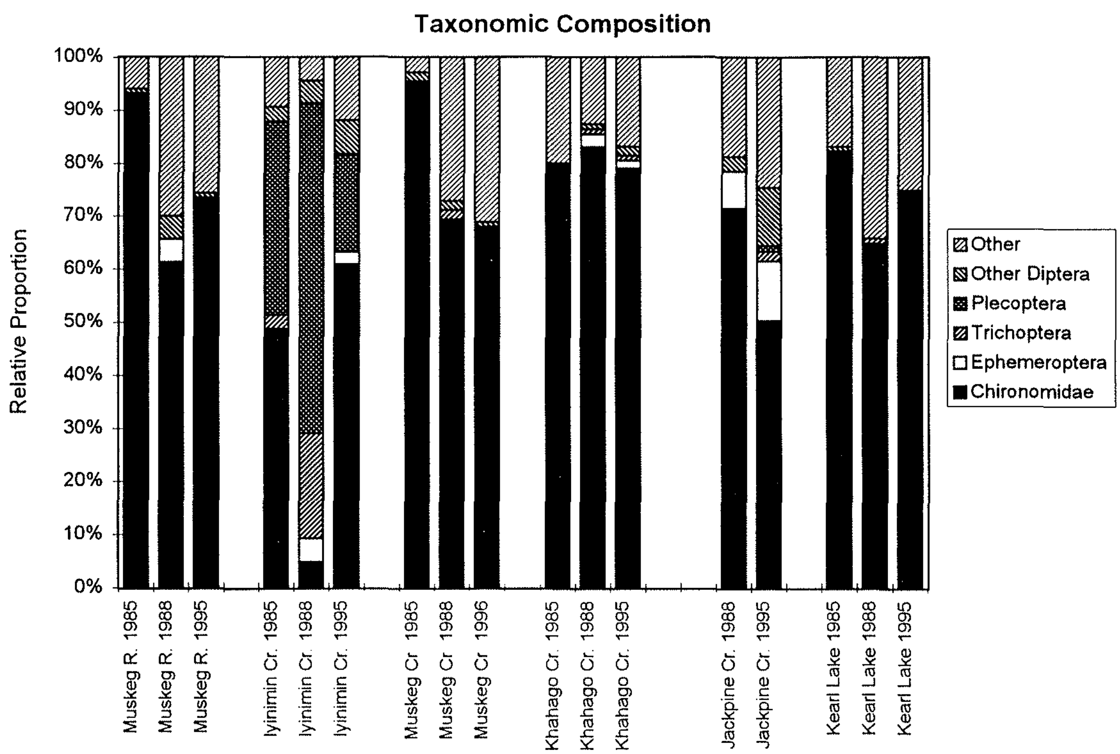


Figure 3.2-1 Comparison of benthic invertebrate density and taxonomic composition among sites sampled in the Muskeg River basin during the fall of 1985, 1988 and 1995.

with a typical range of 19 to 30. Lowest taxonomic richness usually occurred in Kearl Lake. This variable cannot be compared between 1985 and the other two years, because of differences among years in the lowest taxonomic levels the samples were identified to.

taxonomic composition similar in all three years

Taxonomic composition was less variable among years than total density or taxonomic richness. All stream sites, with the exception of Iyinimin Creek, were numerically dominated by chironomid midges and non-insect taxa ("Other" category in Figure 3.2-1). This type of community is typical of most streams in the Muskeg River basin, since the predominant lotic habitat type is depositional, characterized by slow current velocity and large amounts of organic material in the sediments. The Iyinimin Creek site supported a relatively large proportion of stonefly nymphs (Plecoptera), which is consistent with the erosional habitat reported at this site in all three surveys. The fauna of the Jackpine Creek site was unique, since it included the largest proportion of mayfly nymphs (Ephemeroptera), which were nearly absent from other stream sites selected for this comparison. Kearl Lake supported the simplest community, which consisted almost exclusively of chironomid midges and oligochaete worms.

This qualitative examination of a subset of the available data for stream sites in the Muskeg River basin and Kearl Lake revealed that, although invertebrate density may vary considerably among years, taxonomic composition of the resident benthic communities has remained relatively similar during the last decade.

3.3 FISH HABITAT

3.3.1 Athabasca River

Historical Information

baseline fish/fish habitat inventory

In spring 1992, for the Northern River Basins Study, R.L.&L. Environmental Services Ltd. (1994) conducted a baseline fish/fish habitat inventory of the Athabasca River and lower reaches of its major tributaries. Field studies on habitat characteristics were conducted at 10 representative reaches between Jasper Lake, Jasper National Park and Lake Athabasca.

intensive habitat surveys

Within the 10 reaches studied, intensive surveys were done at sites chosen to be representative of the river reach in which it was located. Existing habitat conditions were documented in detail at each site including depth, velocity, substrate and instream cover. Observations of species habitat selection with regard to water temperature and turbidity were noted. Habitat was also identified based on a classification system developed for use on the Peace River by R.L.&L. (Hildebrand 1990) for the Peace River and adapted for the Athabasca River (R.L.&L. 1994). This system consists of three components: channel form, bank habitat types and special features (e.g., snyes, backwaters). The major channel and bank habitat categories of this mapping system are described in Appendix III.

channel and bank habitat categories

Reach nine was approximately 125 km and extended from Fort McMurray to the Firebag River (R.L.&L. 1994) (Figure 3.3-1). This reach was generally characterized as a Type M channel (multiple channel) (Appendix III). Type U (unobstructed channel) was the second most abundant channel type, followed by Type S (singular island). Erosional bank habitat types were dominant; depositional habitats and limited amounts of armoured/stable bank habitats were also noted. Shoals were the special habitat features recorded (R.L.&L. 1994).

habitat mapping: Athabasca River

In 1995, Golder Associates (Golder 1996a) habitat-mapped the Athabasca River upstream of Lease 13 as part of the aquatics baseline study for the Steepbank Mine (Figure 3.3-1). The Large River Habitat Classification System defined by R.L.&L. (1994) was used to habitat-map selected areas in 1995, 1996 and 1997 (Golder 1996a, 1996b, 1998) (Appendix III).

In 1996, Golder Associates (1996b) habitat-mapped an area on the Athabasca River from Saline Lake to Sutherland Island. This area included the reach of the Athabasca River adjacent to Lease 13 (Figure 3.3-1). Data collected were compiled in an addendum to the aquatic baseline report for Syncrude's Aurora Mine Environmental Impact Assessment (Golder 1996b). Effort was concentrated in the area 10 km downstream of the Peter Loughheed Bridge.

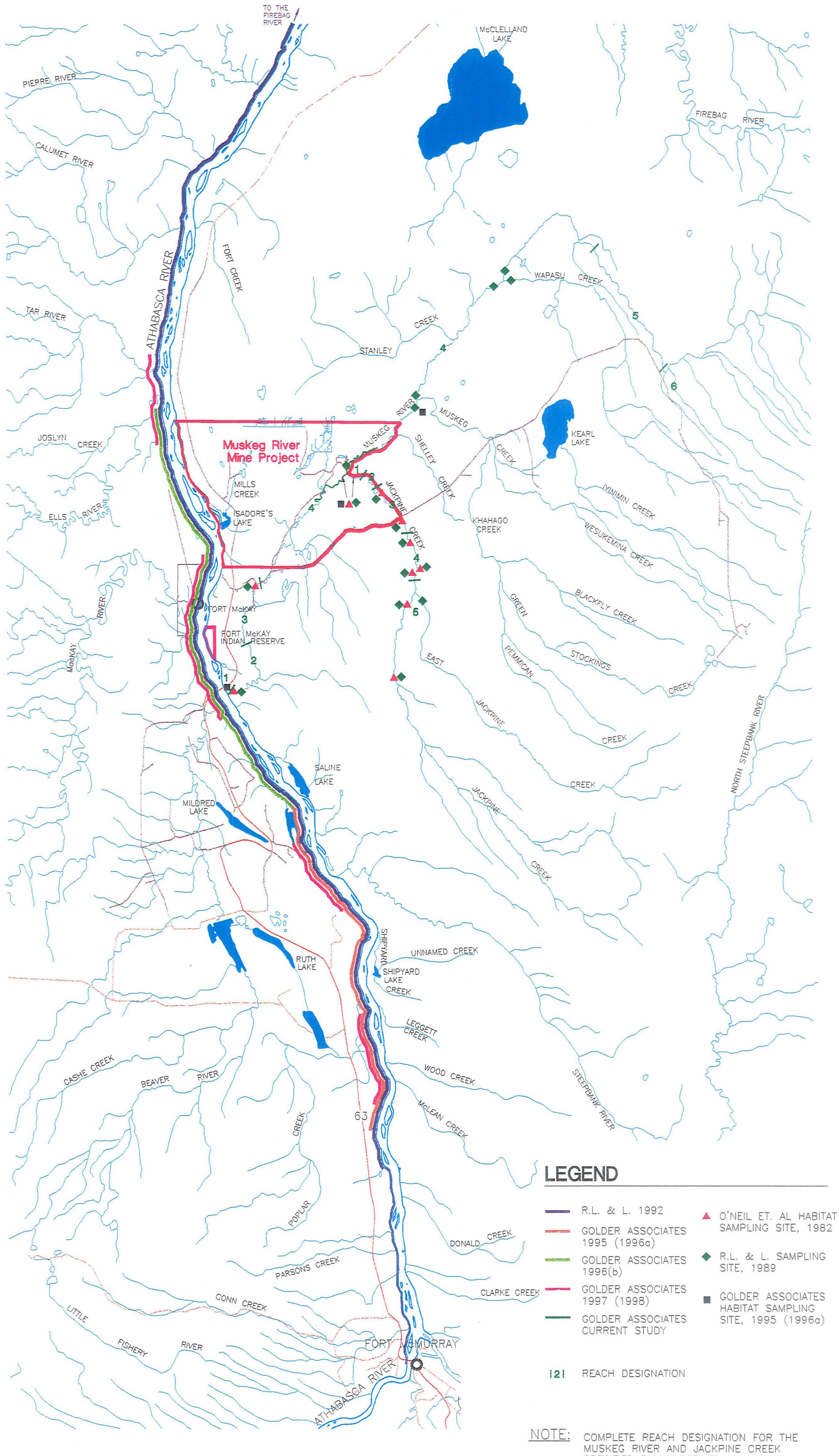
turbid cool-water habitat

Results of the habitat mapping indicates that the Athabasca River has turbid cool-water habitat with dynamic shifting-sand channels. Single channels are the major channel type but near islands and sand bars, multiple channels are present. Major habitat features include backwaters and snyes associated with islands and sandbars. The substrate is almost entirely sand although there are a few areas where bedrock substrate is predominant. Instream cover is minimal except for that provided by depth and turbidity.

1997

RAMP habitat maps

In 1997, fish habitat maps for three reaches of the Athabasca River near Lease 13 were updated as part of RAMP (Figure 3.3-1). These habitat maps are presented in the RAMP report (Golder 1998).



REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I
84A AND 84H FROM RESOURCE DATA DIVISION
ALBERTA ENVIRONMENTAL PROTECTION, 1997.

Golder Associates

SHELL CANADA LIMITED

HABITAT MAPPING OF THE ATHABASCA RIVER, MUSKEG RIVER AND JACKPINE CREEK

07 JAN 98	FIG. No. 3.3-1	DRAWN BY: TM/VS

3.3.2 Muskeg River and Jackpine Creek

Historical Information

habitat studies: Muskeg River and Jackpine Creek

Griffiths (1973) completed one of the first fisheries and fish habitat surveys on the lower Muskeg River. Habitat descriptions were general and the Muskeg River tributaries were not included. A more detailed habitat study of the Muskeg River and Jackpine Creek was completed by Bond and Machniak (1979). The Muskeg River and Jackpine Creek were both divided into five reaches on the basis of stream gradient, flow characteristics, substrate and channel form (e.g., straight, irregular, meander). Point samples were taken to provide site-specific biophysical data (e.g., channel characteristics, substrate, flow, obstructions), and a general description of each reach sampled was provided.

Muskeg River headwaters studied

Walder et al. (1980) extended the area of interest to include a sixth reach that covers the extreme headwater portions of the Muskeg River. Point sample habitat assessments were also made at selected sites and included channel widths, overhead cover and bank characteristics. A general description of each reach was also provided.

detailed habitat mapping

Detailed habitat mapping of the lower Muskeg River and Jackpine Creek was first carried out by O'Neil et al. (1982) as part of the SandAlta Project. Sample sites were selected to provide an accurate characterization of conditions within the reach. At each of the habitat sampling locations, 200 m of stream was delineated for detailed examination (Figure 3.3-1). The stream habitat classification system used was based on the system currently used by R.L.&L. Environmental Services Ltd. (Appendix III). This system was used in subsequent habitat studies of the Muskeg River and Jackpine Creek. This habitat classification system includes delineation of channel characteristics, maximum and average depth of pools, runs and riffles, pool:run:riffle ratios, flow characteristics, substrate, bank form and stability, riparian vegetation and aquatic macrophyte growth.

More detailed habitat mapping of the Muskeg River and Jackpine Creek was done by Beak (1986) and R.L.&L. (1989) as part of the OSLO study (Figure 3.3-1). The five reaches of Muskeg River and Jackpine Creek delineated in previous studies were analyzed and habitat assessments were done on 50 m of stream at specific sampling locations.

video survey: Muskeg River

Golder Associates (1996a) assessed the applicability of this historical information to current conditions by conducting habitat assessments on a representative set of the original sites reported by R.L.&L. (1989) (Figure 3.3-1). Golder Associates concluded that the historical information was valid (Golder 1996a). As well, the entire length of the Muskeg River was videotaped from a helicopter to document current habitat conditions. Information from the video was transferred to a habitat map and compared to the same reach of river mapped in 1997 (Figure 3.3-2).

1997

habitat mapping: Reach 4 of Muskeg River

In fall 1997, Golder Associates mapped habitats in a portion of Reach 4 of the Muskeg River within the Shell Lease 13 boundary (Figure 3.3-1 and Figure 3.3-3). Due to high flows, the entire area was mapped as run habitat, and backwaters and instream vegetation were noted. No habitat transects were surveyed, although depths were recorded at regular intervals (Figure 3.3-3).

Muskeg River

Muskeg River drainage

The Muskeg River flows southwest to the Athabasca River. It receives discharge from several smaller drainages: Wapasu, Muskeg, Shelley and Jackpine creeks that flow from the south; Stanley Creek drains from the north; and a number of smaller unnamed tributaries. The aquatic habitat of the Muskeg River varies throughout its length and is described in the following paragraphs.

Reaches 1 and 2

Reach 1, in the area of the river mouth, is a fairly straight reach that extends for 0.5 km (O'Neil et al. 1982, R.L.&L. 1989, Golder 1996a) (Figure 3.3-1). The next 8.5 km comprise Reach 2, which has irregular meanders. Both reaches have a high gradient and are characterized by runs, riffles and pools. Shallow, fast runs are predominant at the mouth, with the occasional riffle and pool. Farther upstream in Reach 2, pools are more common. Substrate composition in these reaches is mainly gravel and cobble with very little evidence of sedimentation. Near the mouth, banks are less than a few metres high, while farther upstream in Reach 2, the banks consist of 10 to 20 m cliffs.

Reach 3

Characteristics of Reach 3 are intermediate between Reaches 2 and 4. It has a lower gradient than Reach 2, but still has gravel substrate and runs interspersed with riffles and pools (R.L.&L. 1989). The runs are deep and slow, which is a characteristic representative of Reach 4.

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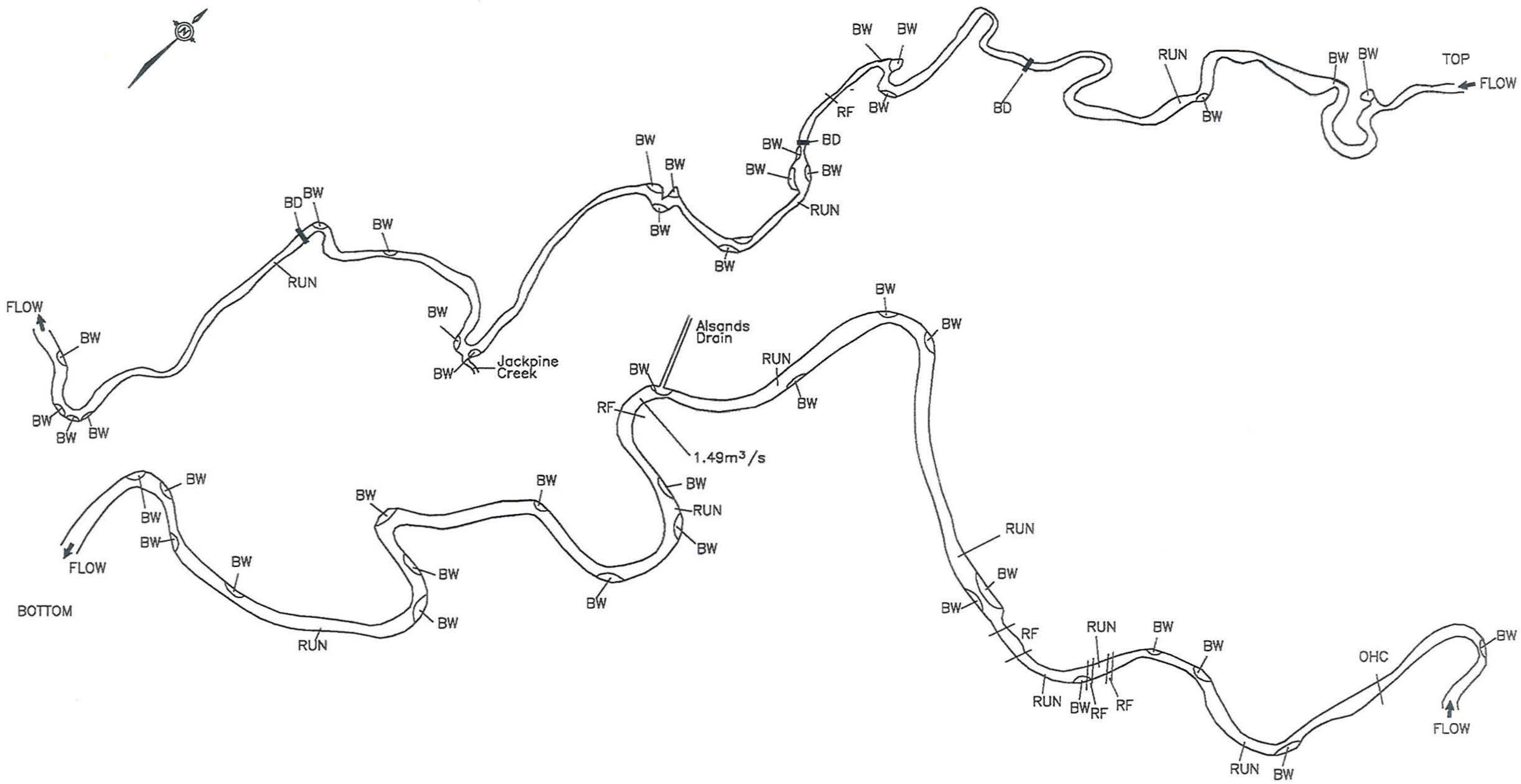

LEGEND

RF – Riffle
BW – Backwater
BD – Beaver dam
OHC – Overhead cover

NOTE

SEE FIGURE 3.3–1 FOR REACH LOCATION

0 100 200 300 400 500m
SCALE 1:10,000

Golder Associates | SHELL CANADA LIMITED

HABITAT MAP OF THE MUSKEG RIVER, SPRING 1995

07 JAN 98 | Figure 3.3–2 | DRAWN BY: VS/TM

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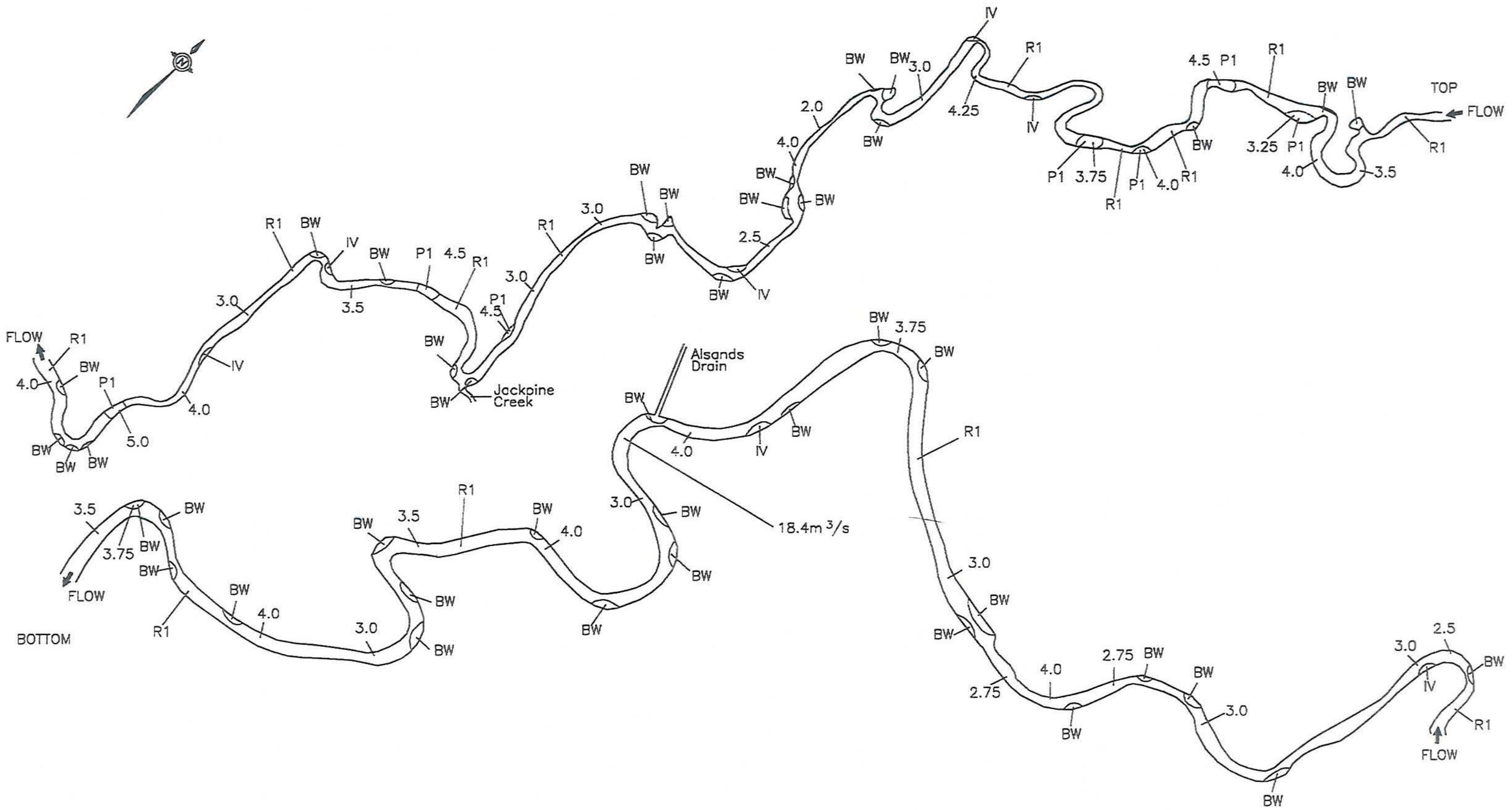


LEGEND

R1 – Run
BW – Backwater
IV – Inundated vegetation
4.0 – Depth in metres

NOTE

SEE FIGURE 3.3–1 FOR REACH LOCATION

0 100 200 300 400 500m
SCALE 1:10,000

Golder Associates

SHELL CANADA LIMITED

HABITAT MAP OF THE MUSKEG RIVER, FALL 1997

07 JAN 98	Figure 3.3–3	DRAWN BY: VS/TM

Reach 4

Reach 4 is very long (over 60 km) and represents the most common type of habitat in the Muskeg River. Here the river has slow, deep meandering runs. Substrate in the runs consists mainly of organic debris and silt with a few large boulders. Riffles are uncommon but there are a few associated with cobble substrate. Beaver activity is common and there are many dams causing ponding.

Reaches 5 and 6

Reaches 5 and 6 encompass the headwaters of the Muskeg River and although exhibiting a relatively high gradient, contain large numbers of beaver impoundments, debris, pools and fine/silted substrates.

Jackpine Creek

Jackpine Creek has 5 distinct reaches that differ mainly in gradient. Reach 1 (3.4 km) has a low gradient that results primarily in slow runs and tortuous meanders (R.L.&L. 1989, Golder 1996a) (Figure 3.3-1). Beaver activity is common within this reach. Reach 2 (3.4 km to 7.4 km) has a slightly higher gradient, more habitat diversity and fewer meanders than Reach 1. Beaver dams are also common in this stretch of river, resulting in flat flow characteristics interspersed with run-riffle-pool sequences. In Reach 3 the stream gradient is higher and cobble/gravel substrate is common. Riffle/run/pool sequences are predominant. Reach 4 (9.4 km to 14.9 km) has a moderate gradient and similar flow and meander pattern to Reach 2. Reach 5 of Jackpine Creek is similar to Reach 1.

3.3.3 Waterbodies in the Muskeg River Mine Project Area

Historical Information

previous studies on lakes and ponds in the area

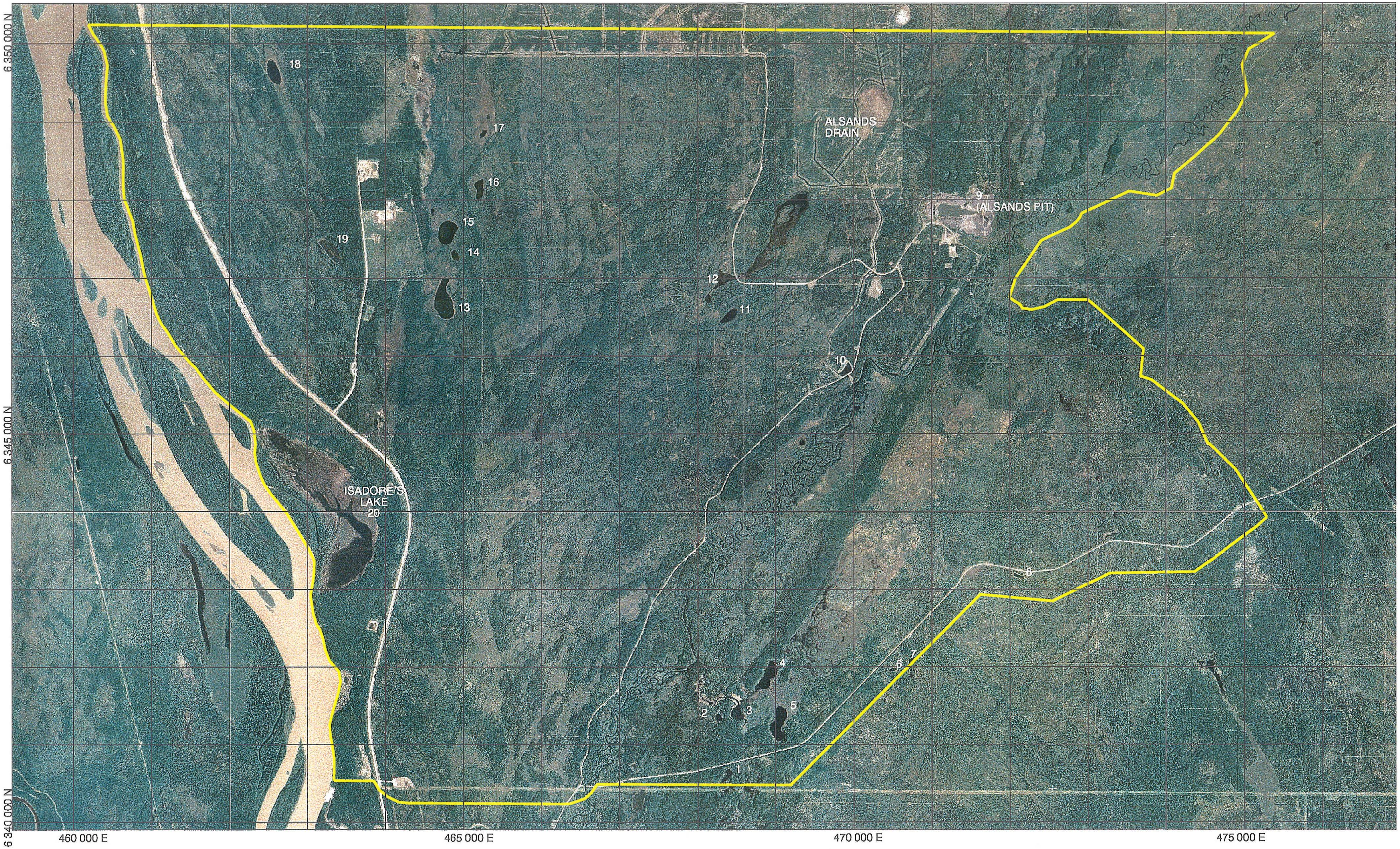
Lakes and ponds in the Muskeg River Mine Project development area have been examined as part of the following studies:

- Alsands Project (Webb 1980)
- Addendum to Syncrude Aurora Mine Environmental Baseline Program (Golder 1997b)
- Muskeg River Mine Project (current study)

The Alsands Project (Webb 1980) included water quality, bathymetry and fisheries surveys of 23 lakes and ponds over 1 ha in size within the Muskeg River Mine Project development area. Substrate characteristics, depth, surface area and presence of inlet or outlet streams of these lakes and ponds were also noted.

orthophoto survey

Golder Associates (1997b) conducted fish surveys and habitat assessments of Isadore's Lake, Mills Creek and Pond 13 (Figure 3.3-4). In the summer of 1997, fish surveys and basic habitat characteristics were also done on the



LEGEND

Muskeg River Mine Project Area

NOTE: UTM Grid in NAD 27
SOURCE: The Orthoshop
Date of Photography: 97/06/11

1:50,000

500 0 500 1000 1500 2000 2500 3000

Metres

MAP PROJECTION: Universal Transverse Mercator Zone 12 **DATUM:** NAD 83

Golder Associates

SHELL CANADA LIMITED

WATERBODIES WITHIN MUSKEG RIVER MINE PROJECT

18 Dec. 1997	FIGURE NO. 3.3-4	PRODUCED BY: J. Shaw REVIEWED BY:

/data8/oilsands/972-2237/9700/9750/working/arcview/ortho11x17.apr

Alsands Drain and Pond 12. In addition, an orthophoto of the Muskeg River Mine development area was taken in June 1997. It was used to identify existing waterbodies in the area and for comparison with historical data.

Waterbodies in the Muskeg River Watershed

Ponds and Lakes

characteristics of ponds and lakes: Muskeg River watershed

Webb (1980) sampled eight shallow muskeg ponds (<1.5 m) north of the Muskeg River and four upland lakes (13.4 m to 22.3 m) south of the Muskeg River. Shallow pond size ranged from 2.6 ha to 31.0 ha and lake size ranged from 1.6 ha to 6.7 ha (Webb 1980). The shallow ponds had no inlets or outlets and their substrate was organic muck or sand. One of the lakes had a permanent outflow and two intermittent streams connected three of the lakes. Lake substrate was predominantly organic muck with local areas of sand, boulders, rubble or mud. Submergent vegetation in these waterbodies included pondweed (*Potamogeton spp.*), Canada waterweed (*Elodea longivaginata)*, common bladderwort (*Utricularia vulgaris*), yellow water lily (*Nuphar variegatum*), Northern water milfoil (*Myriophyllum exalbescens*), water smartweed (*Polygonum natans*) and coontail (*Ceratophyllum demersum*)(Webb 1980).

orthophoto update of waterbodies

An orthophoto of the area taken by Golder Associates (June 1997) indicates that only two of the shallow muskeg ponds (Ponds 11 and 12) previously sampled by Webb (1980) remain (Figure 3.3-4). The areas of these ponds were calculated from the orthophoto using a Geographic Information System (GIS). Ponds 11 and 12 show a reduction in area (Table 3.3-1). The Alsands Drain, the Alsands pit (Pond 9) and a small waterbody connected to the Alsands drainage system currently exist (Pond 10).

The orthophoto also indicates that the four upland lakes previously sampled by Webb (1980) remain (Figure 3.3-4). The areas of lakes numbered 2 to 5 range from 0.7 ha to 6.0 ha (Table 3.3-1). In addition, four small ponds (Ponds 1,6,7,8) are noted south of the Muskeg River (Figure 3.3-4).

A draining activity was undertaken by Syncrude in 1997. This activity, designed to begin dewatering of the Aurora north site, resulted in drainage of significant portions of Alsands Drain area and connecting ponds.

Table 3.3-1 Areas and Depths of Ponds Sampled in the Muskeg River Mine Project Area

Pond/Lake Number	Golder (1997) Area (ha)	Webb (1980) Area (ha)	Webb (1980) Maximum Depth (m)
1	1.2	-	-
2	0.7	1.6	17.7
3	4.7	4.2	22.3
4	5.2	5.5	20.7
5	6.0	6.6	13.4
6	0.4	-	-
7	0.9	-	-
8	0.5	-	-
9	5.8	-	-
10	1.5	-	-
11	2.1	2.9	1.5
12	25.5	31.0	1.2
13	8.7	10.6	1.8
14	0.8	2.2	1.5
15	5.5	7.1	1.2
16	2.0	2.9	1.2
17	0.5	1.1	1.1
18	4.0	4.9	1.5
19	3.7	5.1	1.1
20	46.1	33.9	4.0

Alsands Drain

characteristics of Alsands Drain

The Alsands Drain is a drainage system developed for the Alsands Project. Water from the drain enters the Muskeg River. There is no previously documented spawning, nursery or rearing fish habitat in the area of the drainage system (Webb 1981). The drainage system is fairly uniform in its physical characteristics with slow, deeper runs (2.0 m to 3.0 m) in the northern end and shallower, faster runs (0.5 m) in the southern end. Beaver dams are present along the length of the drainage system. Submergent and emergent aquatic macrophytes occur in many areas.

Waterbodies in the Mills Creek Watershed

Ponds

pond characteristics

Webb (1980) sampled 11 shallow muskeg ponds (>2.0 m) in the Mills Creek subwatershed. The size of these ponds ranged from 0.7 ha to 24.4 ha (Webb 1980). Webb found these ponds had no inlet or outlet and the substrate was organic muck and sand. Submergent vegetation consisted of coontail, pondweed and bladderwort.

orthophoto update

The Golder Associates orthophoto indicates that seven of these ponds remain (Figure 3.3-4). The areas of Ponds 13 to 19 range from 0.5 ha to 8.7 ha (Table 3.3-1).

Pond 13, which forms the headwaters of Mills Creek, was sampled during fall 1996 (Golder 1997b). This pond is shallow and eutrophic with approximately 0.20 m of organics and algae present on the bottom. Maximum depth of the pond in fall 1996 was 1.4 m.

Isadore's Lake

characteristics of Isadore's Lake

Isadore's Lake (also called Cree Burn Lake) is a former part of the Athabasca River that has developed into an oxbow lake. Water enters through local runoff, extreme Athabasca River flood events and Mills Creek, which drains from the east. Isadore's Lake is drained by a wetlands area and a small stream at the northern end. The lowland areas around the lake are dominated by black spruce (*Picea mariana*) and the upland areas are dominated by aspen (*Populus tremuloides*) and white spruce (*Picea glauca*).

Isadore's Lake was sampled as part of the Alsands Project (Webb 1980). At that time the lake area was 33.9 ha. Its substrate was organic muck and maximum depth was 4 m. The lake did not stratify during the survey period. Isadore's Lake was surrounded by a sedge-covered flat that varies from very narrow in the south to extensive in the north. Large beds of pond lily were present in the lake. Submergents included coontail, pondweed, waterweed and bladderwort. A large beaver dam was present at Mills Creek.

orthophoto update

Golder Associates sampled Isadore's Lake in 1996. This lake is approximately 1.2 km long and 0.5 km wide, and its open-water area calculated from the orthophoto is 46.1 ha. (Table 3.3-1). The lake is shallow, productive and clear with a few deep pools. The edges of the lake are 0.5 m deep bordered by emergent vegetation such as common cattail (*Typha latifolia*) and sedge (*Carex spp.*). Measured depths ranged from 2.1 m to 4.25 m in fall 1996 (Golder 1997b). Substrate, submergent vegetation and depth were similar to the findings of Webb (1980). Three beaver lodges were present and beaver activity was evident throughout the lake (Golder 1997b).

Mills Creek

characteristics

Habitat mapping was done for Mills Creek in fall 1996 in the area where it crosses Highway 963 (Golder 1997b). Mills Creek is a small stream that drains into Isadore's Lake. Mills Creek has a well-defined meandering channel where it intersects Highway 963. It becomes interspersed with flooded areas a few hundred metres above and below Highway 963 (Golder 1997b). The average channel width in the area near the road was 3.3 m and the average wetted width was 2.4 m. The habitat was primarily low quality runs, although shallow riffles were found occasionally. The substrate was primarily sand, with small areas dominated by boulder and cobble. Moderate instream cover and overhead cover from woody debris and aquatic vegetation was found throughout the mapped segment.

3.4 FISH COMMUNITIES

historical/current fish population data

Surveys to gather information on fish populations in the study area were done in spring, summer and fall 1997. Winter data were reported in detail in Golder Associates (1997a) and are briefly summarized in this section. In addition, historical data where available, are presented to place current data into context. The seasonal distribution and abundance of all fish species is presented in relation to habitat use and availability.

overviews of each area under study

For each area under study (the Athabasca River reaches within the LSA, the Muskeg River watershed and Isadore's Lake and Mills Creek watershed) a description of historical data, an overview of data collected in the Aurora Mine studies and additional information gathered in 1997 to complement existing data are included. Brief summaries of the life histories of major fish species are presented in each section.

3.4.1 Athabasca River

RAMP surveys most recent

Several fisheries surveys of the Athabasca River have been done in the vicinity of Lease 13. The AOSERP studies of the late 1970s were among the first to characterize the fish fauna of the Athabasca River (McCart et al. 1977, Bond 1980, Tripp and McCart 1979, Tripp and Tsui 1980) (Figure 3.4-1). The most recent surveys were done in spring, summer and fall 1997 as part of the RAMP. As well, Syncrude conducted fisheries inventories in 1996 and from 1989 to 1991 for the portion of the Athabasca River downstream of the Muskeg River to Fort Creek (Golder 1998, Syncrude unpublished data). The Northern River Basins Study (NRBS) fish inventories in 1994 also included the area adjacent to and downstream of the Muskeg River Mine Project area (R.L.&L. 1994).

Historical Studies

Twenty-seven species of fishes have been reported historically from the Athabasca River in the Muskeg River Mine Project area (Bond 1980) (see Table 3.4-1 for fish species common and scientific names). The most abundant large fish reported in the vicinity of development area were: longnose sucker, goldeye, lake whitefish and walleye (Bond 1980).

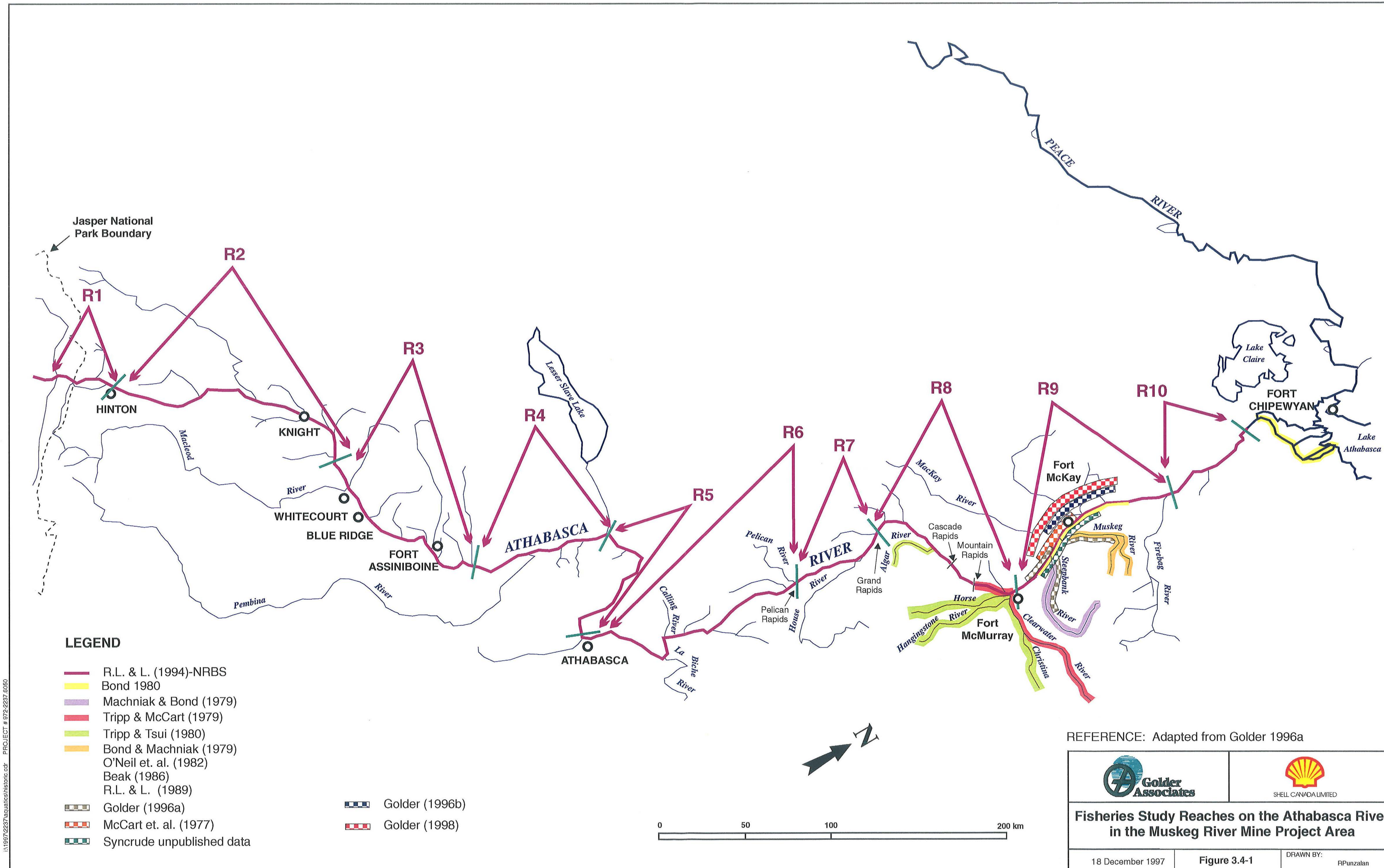


Figure 3.4-1 Fisheries Study Reaches on the Athabasca River in the Muskeg River Mine Project Area

Table 3.4-1 Fish Species Names and Codes

Species Common Name	Scientific Name	Code
Arctic Grayling	*Thymallus arcticus*	ARGR
Brook Stickleback	*Culaea inconstans*	BRST
Bull Trout	*Salvelinus confluentus*	BLTR
Burbot	*Lota lota*	BURB
Cisco	*Coregonus artedi*	CISC
Emerald Shiner	*Notropis atherinoides*	EMSH
Fathead Minnow	*Pimephales promelas*	FTMN
Finescale Dace	*Phoxinus neogaeus*	FNDC
Flathead Chub	*Platygobio gracilis*	FLCH
Goldeye	*Hiodon alosoides*	GOLD
Iowa Darter	*Etheostoma exile*	IWDR
Lake Chub	*Couesius plumbeus*	LKCH
Lake Whitefish	*Coregonus clupeaformis*	LKWH
Longnose Dace	*Rhinichthys cataractae*	LNDC
Longnose Sucker	*Catostomus catostomus*	LNSC
Mountain Whitefish	*Prosopium williamsoni*	MNWH
Ninespine Stickleback	*Pungitius pungitius*	NNST
Northern Pike	*Esox lucius*	NRPK
Northern Redbelly Dace	*Phoxinus eos*	NRDC
Pearl Dace	*Semotilus margarita*	PRDC
River Shiner	*Notropis blennius*	RVSH
Shiner Species	*Notropis* sp.	SH Sp.
Slimy Sculpin	*Cottus cognatus*	SLSC
Spoonhead Sculpin	*Cottus ricei*	SPSC
Spottail Shiner	*Notropis hudsonius*	SPSH
Sucker (Unidentified)	*Catostomus* sp.	Su. Sp.
Trout-Perch	*Percopsis omiscomaycus*	TRPR
Walleye	*Stizostedion vitreum*	WALL
White Sucker	*Catostomus commersoni*	WHSC
Yellow Perch	*Perca flavescens*	YLPR
Unidentified		UNID

Other fish species captured in the Athabasca River, historically, include lake whitefish, mountain whitefish, burbot, northern pike, Arctic grayling and yellow perch. Fish species occurrence and seasonal use of the Athabasca River is presented in Table 3.4-2.

Aurora Studies

Species composition in the 1996 Aurora Mine studies was similar to the historical studies (Golder 1996a). Eighteen species were caught in the spring, summer and fall inventories (Table 3.4-2). A similar species composition was also found in 1995 during the Steepbank Mine baseline studies (Golder 1996b).

1997 RAMP Studies

In 1997, fisheries inventories were done under the RAMP to monitor fish communities in the Athabasca River. Reaches within the oil sands region were selected for the RAMP from areas previously surveyed for the Steepbank and Aurora Mine projects, for Syncrude's 1989 to 1991 surveys and in areas of potential concern (Golder 1996a, 1996b, 1998).

Fourteen species were captured in the reach of river from the mouth of the Muskeg River to the lower half of Lease 13 (Table 3.4-2). The most abundant species captured in the study area were walleye, goldeye, white sucker, longnose sucker and lake whitefish (fall season only) (Table 3.4-3). For a more detailed description of the RAMP data, refer to Golder Associates (1998).

Species abundance and distribution patterns were similar to those reported by the AOSERP studies of the late 1970s (McCart et al. 1977, Bond 1980, Tripp and McCart 1979, Tripp and Tsui 1980), the recent NRBS fish inventories (R.L.&L. 1994) and the Steepbank and Aurora Studies (Golder 1996a, 1996b, Syncrude unpublished data).

Life History Summaries

large species are migratory

Fish species that use the Athabasca River near the Muskeg River Mine Project area fall into two categories: migratory and resident. Most of the large fish species are migratory (Table 3.4-2). Fish use of the Athabasca River near the study area is shown on Figure 3.4-2.

sport and commercial species

Recent and historical studies indicate that goldeye, walleye, white sucker, longnose sucker and lake whitefish are the most abundant sport and commercial fish species in the Athabasca River near the Muskeg River Mine Project local study area (Bond 1980, Golder 1996b, 1998).

Table 3.4-2 Fish Species Use of the Athabasca River Near the Muskeg River Mine Project

Species	1997 Study[1]	1996 Study[2]	Past Studies	Spawning	Rearing	Feeding	Overwintering	Migrating
*Arctic Grayling			●			✓	✓	✓
*Burbot	●	●	●	✓	✓	✓		✓
*Emerald Shiner	●	●	●	✓	✓	✓	✓?	✓
*Flathead Chub	●	●	●	✓	✓	✓	✓?	
*Goldeye	●	●	●	✓?	✓	✓		✓
*Lake Chub	●	●	●	✓	✓	✓	✓	
*Lake Whitefish	●	●	●			✓		✓
*Longnose Sucker	●	●	●		✓	✓		✓
*Northern Pike	●	●	●			✓	✓	
*Spottail Shiner	●	●	●	✓	✓	✓	✓	
*Trout Perch	●	●	●		✓	✓	✓	
*Walleye	●	●	●		✓	✓		✓
*White Sucker	●	●	●		✓	✓		✓
Brassy Minnow			●			✓		
Brook Stickleback			●			✓		
Bull Trout			●			✓		
Fathead Minnow			●			✓		
Finescale Dace			●			✓		
Iowa Darter			●			✓		
Longnose Dace			●			✓		
Mountain Whitefish	●	●	●			✓		
Ninespine Stickleback			●			✓		
Northern Redbelly Dace			●			✓		
Pearl Dace			●			✓		
River Shiner	●							
Slimy Sculpin			●	✓	✓	✓	✓	
Spoonhead Sculpin			●			✓		
Yellow Perch		●	●			✓		

* Common, widespread species in the Athabasca River. Note that Arctic grayling are mainly found in the tributaries during the open-water season.

[1] Golder 1998.

[2] Golder 1996b.

[3] Data from Bond 1980, McCart et al. 1977, Tripp and McCart 1979, Tripp and Tsui, 1980, R.L. & L. 1994. Syncrude's unpublished fish inventories 1989-91. Golder 1996a, 1996b and 1998.

● present in study area

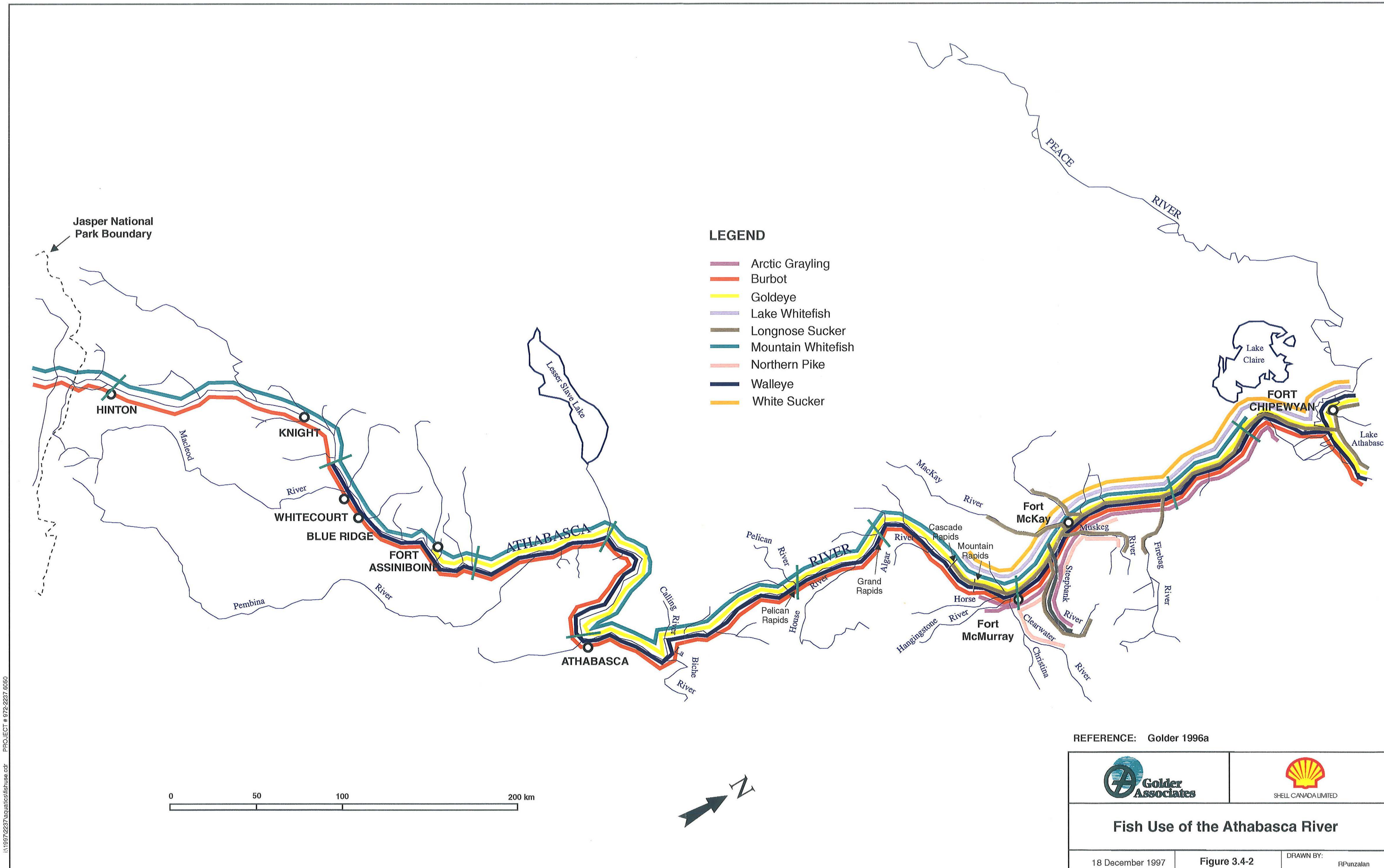
✓kind of habitat use

? may use habitat but use not confirmed

Table 3.4-3 Total Number of Each Species Observed and Captured from the Athabasca River in the Muskeg River Mine Project, 1997

Species	Spring	Summer	Fall	Total	Percent
Burbot	1	4		5	0.28
Emerald Shiner		1		1	0.06
Fathead Minnow					
Finescale Dace					
Flathead Chub	129	50		179	10.19
Goldeye	302	24		326	18.56
Lake Chub	10	36		46	2.62
Lake Whitefish	3	23		26	1.48
Longnose Dace					
Longnose Sucker	170	16		186	10.59
Mountain Whitefish	1	1		2	0.11
Northern Pike	24	33		57	3.25
Pearl Dace					
River Shiner	3			3	0.17
Slimy Sculpin					
Spoonhead Sculpin					
Spottail Shiner	1	1		2	0.11
Sucker Sp.	271			271	15.43
Trout-Perch	15	20		35	1.99
Walleye	180	160		340	19.36
White Sucker	258	17		275	15.66
Yellow Perch	2			2	0.11
Unidentified					
TOTAL	**1368**	**386**		**1756**	

NOTE: Fall data not available at the time of this report. Will be available in Golder 1998.



Fish Use of the Athabasca River

18 December 1997 | Figure 3.4-2 | DRAWN BY: RPunzalan

i:\1997\2237\aquatics\fishuse.cdr PROJECT # 972-2237.6050 *key indicator resources*

Life history summaries are included for species that will be used as key indicator resources in the impact assessment. See Golder Associates (1996a) for details on these and other Athabasca River fish species.

Walleye

evenly distributed throughout LSA

Walleye were found in the Athabasca River during spring, summer and fall of 1997. Adult and juvenile walleye were very common in the spring and many young-of-the-year (YOY) were captured in the summer near the mouth of tributaries, such as the Muskeg and McKay rivers (Golder 1998). Adult walleye did not congregate in specific areas in the spring or summer but were found evenly distributed throughout the LSA.

abundant at mouths and backwaters

In 1995, adult and juvenile walleye were very common in the spring. Patterns of abundance were similar to those observed by Bond (1980) with peak catches in the spring but continued presence of walleye throughout the open-water season (Golder 1996a). In 1995, adult and juvenile walleye were most commonly found at the mouths of tributaries and in backwaters. Walleye captured in backwaters were found along armoured bank types. This type of habitat association was also found by R.L. & L. (1994). The same type of habitat association was observed during the 1997 surveys (Golder 1998).

spawning locations uncertain

Most of the adults found in 1995 and 1997 were caught in the spring season and were ripe or spent males (Golder 1996a, 1998, in prep). Few females were caught in spawning condition. Similar results were obtained in previous studies with the percentage of ripe or spent males ranging from 63 to 97% and no females in spawning condition (Tripp and McCart 1979, Golder 1996a). Young-of-the-year walleye were found in the 1997 and 1995 inventory surveys at a number of sites in the LSA, indicating that they use this area for rearing and summer feeding. Walleye spawning locations have not been located with certainty but there is evidence they spawn at the rapids upstream of Fort McMurray (Tripp and McCart 1979). A radiotelemetry study of walleye included in RAMP may enhance understanding of walleye life history within the Athabasca River system.

Population parameters, such as size, age distributions and age and growth were analyzed in past studies and found to be fairly consistent from one study to the next (McCart et al. 1977, Tripp and McCart 1979, Syncrude unpublished data).

Goldeye

Historical studies report that immature goldeye migrate from Lake Athabasca to feed in the lower reaches of the Athabasca River in the spring. While previous studies have not documented goldeye spawning in the vicinity of the Muskeg River Mine Project, some goldeye were found in spawning condition in 1995, 1996 and 1997 (Golder 1996a, 1996b, 1998, in prep).

spring abundance

Abundance data indicate that goldeye enter the LSA in April and May and largely migrate out of the study area by the end of October (Golder 1996a). Tripp and McCart (1979) and Bond (1980) found the highest abundance of goldeye in May, as was observed in 1996 (Golder 1996b) and 1997 (Golder 1998). Surveys in 1995 for the Steepbank Mine found goldeye were abundant in the spring but were most abundant in the summer (Golder 1996a). Syncrude (unpublished data from 1989 to 1991) also found this species to be common throughout the open-water season with numbers decreasing in the fall as goldeye presumably move downstream to overwinter in Lake Athabasca (Golder 1996a).

highest concentration in LSA

The highest concentration of goldeye captured and observed in the 1997 surveys was in the Athabasca River reaches of the Muskeg River Mine Project study area (i.e. from the mouth of the Muskeg River to the lower half of the lease boundary) (Golder 1998).

Population parameters such as size, age distributions and age and growth were analyzed in past studies (Tripp and McCart 1979, Golder 1996a). Results were similar from one study to the next. A length-at-age distribution for goldeye captured in 1995 showed these fish to be larger for a given size compared with results from previous studies (Golder 1996a).

White Sucker

wide use of Athabasca River

White sucker make wide use of the Athabasca River during their life cycle (Figure 3.4-2). This species spawns in the tributaries, namely the Muskeg, Steepbank and McKay rivers. They feed in these watercourses for a short time and then move back into the Athabasca River.

spawning not documented in Athabasca River

White sucker have not been documented to spawn in the Athabasca River in past studies (Tripp and McCart 1979, Golder 1996a). These fish are thought to overwinter in Lake Athabasca, the delta and in the lower part of the Athabasca River (Tripp and Tsui 1980).

Longnose Sucker

spawn in upstream tributaries

Like white sucker, longnose sucker migrate upstream in the spring and move into the tributaries to spawn. They feed during the summer in the tributaries and in the mainstem Athabasca River and are believed to return to the delta and Lake Athabasca in the fall to overwinter (Tripp and McCart, McCart et al. 1977, Golder 1996a).

stay in tributaries in summer

The 1995 surveys by Golder Associates (1996a) indicated that most longnose sucker captured in the Athabasca River were adults. However, in late spring 1995, fry were captured below the Muskeg River. In the 1997 RAMP study the majority (42%) of the adults captured in the Athabasca River were from reaches within the Muskeg River Mine LSA. Most fish were captured in the spring, indicating they remain in the tributaries in the summer. Only a few juveniles were captured in the different seasonal surveys; however, high water levels precluded using survey techniques efficient for sampling juvenile fish (i.e., seining, backpack electrofishing) (Golder 1998).

population parameters

Population parameters, such as length-frequency distributions and length-at-age relationships, are presented in Golder (1996a) and compared with results from previous studies. Longnose sucker captured in 1995 were faster growing than fish from previous studies on the Athabasca River and its tributaries. Population parameters for longnose sucker from the 1997 RAMP inventories are similar to the 1995 results (Golder 1996a, Golder 1998). Further details can be found in Golder Associates (1998).

Lake Whitefish

project area important feeding/resting area

Lake whitefish are residents of Lake Athabasca and the delta, where they overwinter and spend the summer feeding. Most lake whitefish spawn in lakes, but some populations such as those in the Peace-Athabasca Delta migrate upstream to spawn in the Athabasca River and some of its tributaries (McCart et al. 1977). Past studies indicate that lake whitefish spawn at the rapids upstream of Fort McMurray in the fall (Golder 1996a). The Athabasca River near the Muskeg River Mine Project (especially the mouths of tributaries) is an important feeding and resting area for lake whitefish moving upstream to spawn (Bond 1980, Golder 1996a).

Similar seasonal patterns of abundance and habitat use were found in subsequent studies. In 1995, lake whitefish were captured in all seasons, although most individuals were captured in the fall (Golder 1996a). In the summer, adult lake whitefish were observed congregating at the mouth of the Steepbank River but were uncommon elsewhere in the study area. Large numbers of lake whitefish were caught in the fall of 1996 in the study area (Golder 1996b). The 1997 inventories yielded comparable data to past studies (Golder 1998).

Other Fish Species

mountain whitefish dominant sport fish species

Mountain whitefish also migrate within the Athabasca River system. They are found in low abundance in the Athabasca River near the Muskeg River Mine Project area. Farther upstream on the Athabasca River (NRBS Reaches 1 to 5), mountain whitefish are the dominant sports fish species (Figure 3.4-1). Feeding migrations of mountain whitefish often occur in the tributaries but spawning and overwintering locations are unknown (Bond 1980). In the 1997 inventories only a few mountain whitefish were captured in the study area (Table 3.4-3). These numbers are comparable to the studies done in 1996 in the same area (Golder 1996b).

northern pike overwinter in the Athabasca River

Northern pike use different parts of the Athabasca River system for various aspects of their life history. They spawn in the tributaries and in a few areas of the Athabasca River that have flooded vegetation (R.L.&L. 1994). Northern pike are thought to overwinter in the Athabasca River. The summer inventories in 1995 indicated that northern pike tend to remain in the tributaries or in the Athabasca River near the mouths of the tributaries (Golder 1996a). Northern pike were also consistently present in the 1996 inventories but in fairly low numbers (Golder 1996b). This pattern of abundance was also demonstrated in the summer of 1997 (Golder 1998).

all-season habitats for northern pike

Juvenile northern pike were uncommon but still present at most sites surveyed in the 1995, 1996 and 1997 inventories. Adults were more common than juveniles and were most abundant at the mouths of tributaries or close to them (Golder 1996a, 1996b and 1998). The presence of northern pike throughout the study area and through all seasons indicates that habitats in this area provide summer feeding and rearing areas for this species.

Arctic grayling spawn and summer tributaries

Arctic grayling migrate up tributaries in spring to spawn and remain there until late fall (Bond and Machniak, Golder 1996a). No Arctic grayling were captured on the Athabasca River in 1995 or 1996 (Golder 1996a and 1996b). However, they are occasionally found in the mainstem Athabasca in late fall, when they leave the tributaries (Syncrude unpublished data). A few Arctic grayling were captured in the 1997 RAMP season (Golder 1998).

burbot spawn in Athabasca River

Burbot are found in the mainstem Athabasca River throughout the open-water season, although in the summer some burbot are thought to migrate back to Lake Athabasca to avoid warm water temperatures (Bond 1980). Burbot spend part of the winter in Lake Athabasca but migrate into the river to spawn during late winter (January or February). Burbot spawning has been documented in the Athabasca River near Suncor (Bond 1980). Burbot are found in low numbers in the LSA (Golder 1998).

yellow perch uncommon

Yellow perch are uncommon in the Athabasca River, but reside in some of the tributaries. No perch were captured in the LSA in 1996 but two perch were captured in spring 1997 during the RAMP inventory (Golder 1996b, 1998).

major small fish species: Athabasca River

The major small fish species in the Athabasca River near the Muskeg River Mine Project were flathead chub, spottail shiner, lake chub, trout-perch, slimy sculpin and emerald shiner. Most of these species are found in the Athabasca River year-round except for emerald shiner, which are thought to overwinter in the Peace-Athabasca Delta and then migrate into the Athabasca River to spawn (Bond 1980). Flathead chub is one of the most common small fish species found in the Athabasca River (McCart et al. 1977). They are generally confined to the mainstem and rarely enter the tributaries. Spottail shiner also reside primarily in the mainstem Athabasca River. In contrast, lake chub are common in both the mainstem Athabasca River and in the tributaries. They likely spawn in the lower reaches of the tributaries and overwinter in both the tributaries and the Athabasca River. Trout-perch also spawn in the tributaries but feed and overwinter in the

Athabasca River near Suncor (McCart et al. 1977). Slimy sculpin are found in both the tributaries and the Athabasca River.

3.4.2 Muskeg River Basin

Muskeg River, Jackpine Creek and Tributaries

previous studies

Several fisheries surveys were done in the Muskeg River and Jackpine Creek. Some of the first studies were done for the AOSERP program (Machniak and Bond 1979) and the Alsands Project (Webb 1981). Studies in the 1980s, O'Neil et al. (1982) and R.L. & L. (1989), further defined the Muskeg River fisheries resource. Recent inventories were also conducted for the Aurora Mine Project (Golder 1996a).

1997 surveys

The 1997 Muskeg River Mine Project fisheries surveys were done in the winter, spring, summer and fall.

Table 3.4-4 summarizes species occurrence in the Muskeg River and Jackpine Creek for earlier studies (1980s), the Aurora Mine baseline study (1995) and the current study.

1997 Results

majority of fish captured in summer

Eleven species were captured in the Muskeg River watershed during the 1997 fish inventories (Table 3.4-5). The majority of fish were captured during the summer season. Species found in the Muskeg River included Arctic grayling, northern pike, white and longnose sucker and some smaller forage fish species.

Table 3.4-4 Fish Species Use of the Muskeg River and Tributaries

Species	Muskeg River below Jackpine Creek	Muskeg River above Jackpine Creek	Jackpine Creek
Arctic Grayling	■ ● ○	○	■ ○
Northern Pike	■ ● ○	■ ● ○	■
Mountain Whitefish	■		■ ○
Walleye	■ ●	○	
Lake Whitefish	■		
Burbot	■ ●		
Longnose Sucker	■ ● ○	■ ○	■ ● ○
White Sucker	■ ● ○	■ ○	■ ●
Lake Chub	■ ● ○	■ ○	■ ○
Pearl Dace	■ ●	■ ○	■ ●
Slimy Sculpin	■ ●		■ ●
Trout-perch	■ ●		
Longnose Dace	■ ●		■ ○
Fathead Minnow	■ ●		■ ●
Brook Stickleback	■ ○	■	■ ● ○
Spoonhead Sucker			○
Northern Red Belly Dace			■

Data obtained from O'Neil et al. 1982, Beak 1986, Bond and Machniak 1979, R.L & L. 1989, Golder 1996a.

■ - occurrence of species documented in historical studies only.

● - occurrence of species documented in 1995 (Golder 1996a)

○ - occurrence of species documented in 1997 (Muskeg River Mine Project Aquatic Baseline Study)

Only a few fish were captured in the spring and fall inventories in both the Muskeg River and Jackpine Creek (Table 3.4-4). The low abundance during spring and fall was likely the result of high water levels in both seasons, which greatly diminished efficiency of traditional inventory techniques.

The same sampling problem was encountered by O'Neil et al. (1982) when they surveyed Jackpine Creek by electrofishing. However, when they used different techniques such as a fish fence and underwater surveillance, they observed more fish. For example, they captured only a few Arctic grayling by electrofishing, but over 900 passed through a fish fence installed in Jackpine Creek. Fish traps were used to monitor upstream movements of fish in Jackpine Creek, and underwater surveillance was used as an inventory technique in high water flows.

Total abundance of fish species captured by backpack and portable electrofishing at selected reaches on the Muskeg River and Jackpine Creek are shown in Table 3.4-6. Results are fairly similar from one study to the next. However, abundance for selected reaches in Jackpine Creek was slightly lower than previous years. Reach 5 on the Muskeg River was added to the reaches inventoried in 1995 and 1988 so there are no comparable historical data. Additional reaches were surveyed in 1997 on the Muskeg River. All reaches inventoried are showed on Figure 3.4-4.

Table 3.4-5 Total Number of Fish Captured from the Muskeg River and Jackpine Creek, 1997

Species	Muskeg River			Jackpine Creek		
	Spring	Summer	Fall	Spring	Summer	Fall
Arctic Grayling	1	12	5		1	
Brook Stickleback	1		2	1	2	
Emerald Shiner						
Fathead Minnow				1		
Finescale Dace						
Flathead Chub				1		
Lake Chub		27	10		25	
Lake Whitefish						
Longnose Dace					2	
Longnose Sucker	3	9			2	
Mountain Whitefish					1	
Northern Pike		5	1			
Pearl Dace		1	7			
Slimy Sculpin						
Spoonhead Sculpin					22	
Spottail Shiner						
Trout Perch						
Walleye		2				
White Sucker		97	3			
Unidentified					1	
TOTAL	**5**	**153**	**28**	**3**	**55**	**0**
GRAND TOTALS	**Muskeg River**		**186**	**Jackpine Creek**		**58**

Table 3.4-6 Relative Abundance by Backpack and Portable Electrofishing for Fish Caught at Selected Sites on the Muskeg River and Jackpine Creek

Site	Year*	Species and Number														
		ARGR	BRST	BURB	FTMN	LKCH	LNDC	LNSC	NRPK	PRDC	SLSC	SPSC	TRPR	WALL	WHSC	Total
Jackpine Creek																
17	1997	-	-	-	-	2	1	-	-	-	-	2	-	-	-	5
	1995	-	-	-	3	-	-	2	-	-	1	-	-	-	-	6
	1988	-	7	-	-	-	-	-	-	3	-	-	-	-	1	11
S3	1997	-	1	-	-	23	1	-	-	-	-	20	-	-	-	45
	1995 Spring	-	-	-	41	-	4	-	-	-	34	-	-	-	-	79
	1995 Fall	-	4	-	25	-	9	-	-	-	44	-	-	-	-	82
	1988	-	-	-	-	-	1	-	-	46	5	-	-	-	6	58
Muskeg River																
4	1995d	-	-	-	-	-	-	-	1[c]	-	-	-	-	-	-	-
	1988	-	3	-	-	-	-	-	1	1	-	-	-	-	-	5
	1985	-	-	-	-	-	-	-	6[b]	-	-	-	-	-	-	6
5	1997	-	-	-	-	6	-	2	1	1	-	-	-	1	11	6
	1995	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	1988	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
18	1997	-	-	-	-	8	-	4	-	-	-	-	-	-	1	13
	1995	1	-	-	-	-	-	6	-	-	-	-	-	-	11	18
	1988	-	-	-	-	-	-	8	-	16	16	-	-	-	3	43

[b] fish caught by gill net

[c] fish observed from shore but not captured

[d] not electrofished in 1995 due to water conditions

* 1988 (R.L.&L. 1989), 1985 (Beak 1986), 1995 (Golder 1996a)

Species Codes:

ARGR	Arctic Grayling	NRPK	Northern Pike
BRST	Brook Stickleback	PRDC	Pearl Dace
BURB	Burbot	SLSC	Slimy Sculpin
FTMN	Fathead Minnow	SPSC	Spoonhead Sculpin
LKCH	Lake Chub	TRPR	Trout Perch
LNDC	Longnose Dace	WALL	Walleye
LNSC	Longnose Sucker	WHSC	White Sucker

juveniles captured or observed in summer

The largest number of juveniles were captured or observed in the summer for the Muskeg River and Jackpine Creek. Juveniles from the Muskeg River were mainly longnose and white sucker and were captured near the mouth of Jackpine Creek or in Reach 10 upstream of the mouth of this watercourse. No young-of-the-year were captured in the Muskeg River watershed in the 1997 inventories.

The type of data gathered gives an inaccurate picture of relative abundance since electrofishing efficiency was so low during spring and fall. However, the results from the 1997 studies indicate a continued presence and use of different sections of the Muskeg River and Jackpine Creek by the same species observed in historical studies (O'Neil et al. 1982, R.L.& L. 1989, Golder 1996a).

The type of data gathered from the operation of a fish fence in the spring and fall of 1995 gives a better indication of the size and composition of the fish community. A total of 748 fish passed through the upstream trap in the spring. Longnose (41%) and white sucker (40%) were the most common species, followed by northern pike (17%) and Arctic grayling (2%) and a single walleye (<1%) (Golder 1996a). A total of 551 fish passed through the downstream trap in the fall. Lake chub was the most abundant species (45%) followed by northern pike (21%), white sucker (16%), Arctic grayling (14%) and longnose sucker (4%) (Golder 1996a).

Life History Summaries

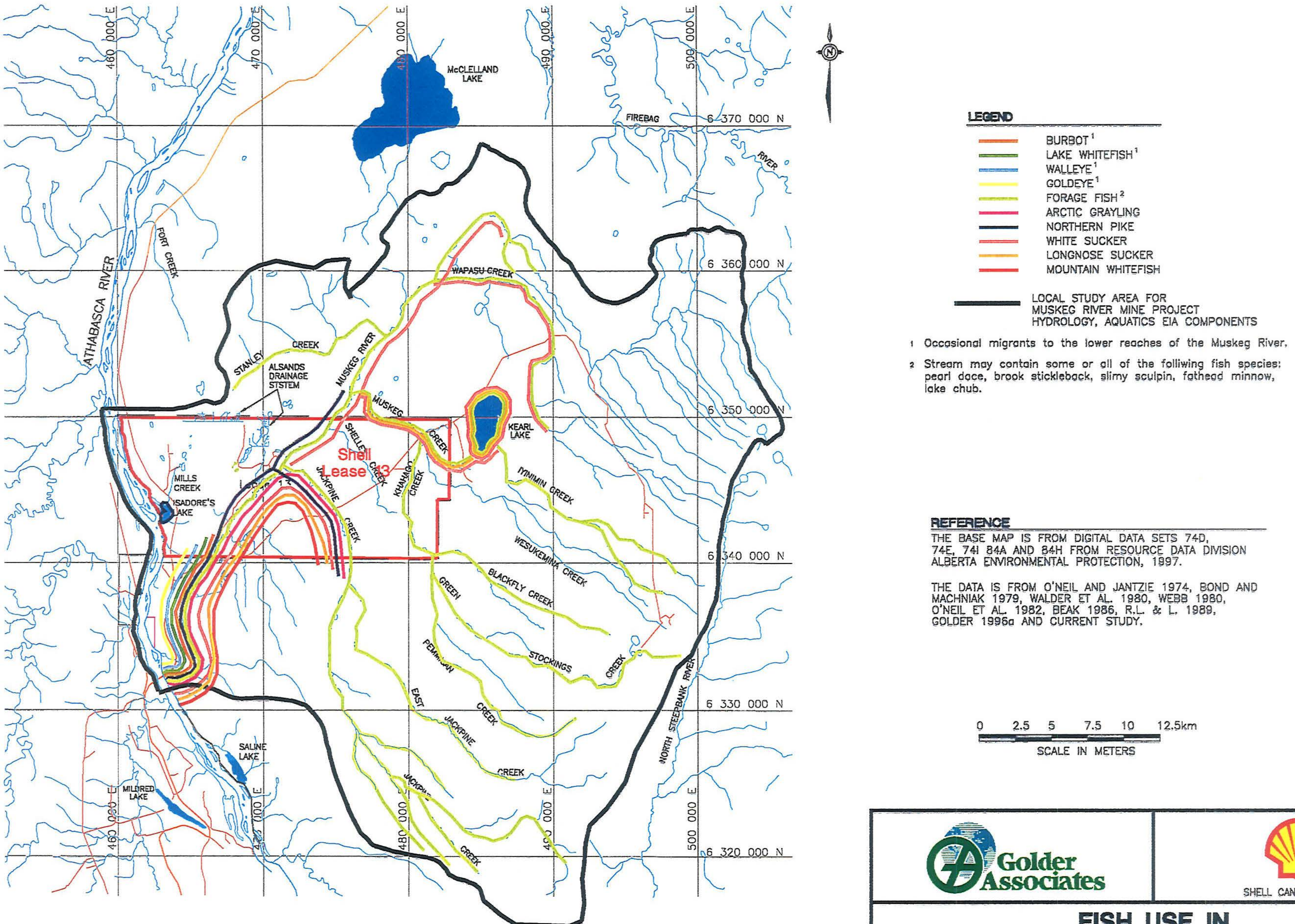
Life history summaries are presented for the following species: Arctic grayling, longnose sucker, northern pike and forage fish species. Where available, current data are compared with historical data. The degree of detail presented is based on the amount of information available from the current study.

Arctic Grayling

early spring spawning movements

Arctic grayling typically migrate up tributaries in the spring to spawn (Figure 3.4-3). Spawning movements occur early in the spring, sometimes even under the ice. In the Steepbank River in 1977, Arctic grayling migration was completed by the end of April (Machniak and Bond 1979). On the Muskeg River in 1995, Arctic grayling migration was under way by the time the fish fence was installed in early May and appeared to be completed near the end of May.

J:\1997\2237\6050\FISHUSE2.DWG



REFERENCE

THE BASE MAP IS FROM DIGITAL DATA SETS 74D, 74E, 74I 84A AND 84H FROM RESOURCE DATA DIVISION ALBERTA ENVIRONMENTAL PROTECTION, 1997.

THE DATA IS FROM O'NEIL AND JANTZIE 1974, BOND AND MACHNIAK 1979, WALDER ET AL. 1980, WEBB 1980, O'NEIL ET AL. 1982, BEAK 1986, R.L. & L. 1989, GOLDER 1996a AND CURRENT STUDY.

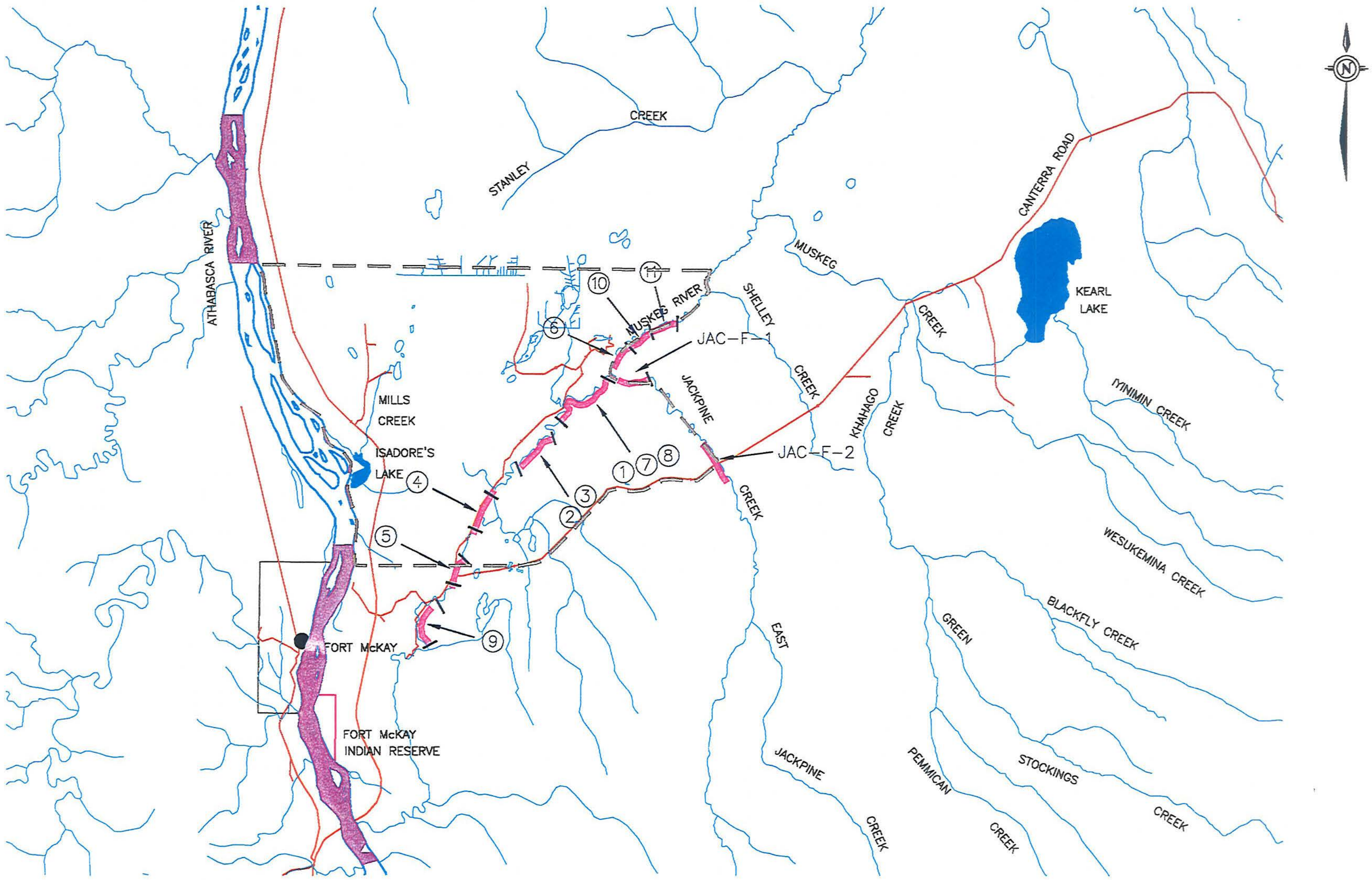
Golder Associates

SHELL CANADA LIMITED

FISH USE IN THE MUSKEG RIVER SYSTEM

19 DEC 1997	Figure 3.4–3	DRAWN BY: TM

J:\1997\2237\6050\FISHRCH.DWG



LEGEND

MUSKEG RIVER MINE PROJECT DEVELOPMENT AREA

FISH INVENTORY REACHES

FISH INVENTORY REACHES FOR RAMP PROGRAM

0 2000 4000 6000 8000 10000(m)

SCALE 1:200,000

REFERENCE

DIGITAL DATA SETS 74D, 74E, 74I 84A AND 84H FROM RESOURCE DATA DIVISION ALBERTA ENVIRONMENTAL PROTECTION, 1997.

Golder Associates

SHELL CANADA LIMITED

MUSKEG RIVER MINE PROJECT FISH INVENTORY REACHES

17 NOV 1997	FIGURE 3.4-4	DRAWN BY: VS/TM

remain in tributaries over summer

Unlike other species that spawn in the tributaries (i.e., longnose and white sucker) most Arctic grayling remain in the tributaries throughout the summer months to feed. Data collected from the fall fish fence in 1995 indicate that adult Arctic grayling leave the tributaries in the fall, likely due to the scarcity of overwintering habitat (Golder 1996a). However, young-of-the-year are thought to overwinter in the Muskeg River (Machniak and Bond 1979, O'Neil et al. 1982).

spawning migration Muskeg River

Only 14 adult Arctic grayling were captured in the spring upstream fence in 1995. However, the migration was already underway when the fish fence was installed and hence, a number of Arctic grayling could have entered the Muskeg River before the installation in early May (Golder 1996a).

spawning migration into Jackpine Creek

In 1995, only one Arctic grayling was captured upstream of the fish fence, near the mouth of Jackpine Creek. No Arctic grayling were found in Jackpine Creek in that year, despite the presence of suitable spawning, rearing and summer feeding habitat (Golder 1996a). There was an unsubstantiated claim (local angler) of a 30 cm Arctic grayling caught in June downstream of the bridge on Jackpine Creek (identified as reach JAC-F-J2 on Figure 3.4-4). The spawning migration of this species into Jackpine Creek was documented by O'Neil et al (1982). In the spring of 1982, over 900 Arctic grayling passed through their fish fence on Jackpine Creek in May.

Jackpine Creek used for summer feeding

O'Neil et al. (1982) documented spawning in the higher gradient portions of Jackpine Creek (between 7.4 and 14.9 km from the mouth) as well as summer feeding and rearing. This area was not sampled in 1997. Only one Arctic grayling (female) was captured in a gill net in summer of 1997 near the bridge at the Canterra road crossing (Figure 3.4-4), indicating this species still uses Jackpine Creek for summer feeding and possibly for spawning.

decrease in Arctic grayling population

Inventories in 1995 and 1997 have not yielded similar results to the O'Neil et al. (1982) surveys, which suggests the abundance of this species might be decreasing. This apparent decrease since 1981 may be due to exploitation (i.e., angling) or to some other environmental stress on the fish community. A similar decrease in abundance of Arctic grayling in the Hangingstone River (a tributary to the Clearwater River) was attributed to angling pressure (Tripp and Tsui 1980).

Eighteen Arctic grayling were captured during the 1997 fisheries inventories in the Muskeg River (Table 3.4-7). Fish were caught in three main areas: above the mouth of Jackpine Creek, near the mouth of Jackpine Creek and in the vicinity of the Alsands Drain.

Table 3.4-7 Total Number of Each Species Captured by Reach from the Muskeg River, 1997

Station	Season	ARGR	BRST	LKCH	LNDC	LNSC	NRPK	PRDC	SPSC	UNID	WALL	WHSC	Total
MUR-F-1	Spring												
MUR-F-1	Summer	4		7		3						19	33
MUR-F-1	Fall											1	1
MUR-F-1	Fall	1											
MUR-F-2	Spring												
MUR-F-2	Summer			3		2						17	22
MUR-F-3	Spring					2							2
MUR-F-3	Summer	1		1								11	13
MUR-F-4	Spring												
MUR-F-5	Spring												
MUR-F-5	Summer			1								18	19
MUR-F-5	Fall			1								1	2
MUR-F-6	Spring					1							1
MUR-F-6	Summer			6		1	1	1			1	11	21
MUR-F-6	Fall												
MUR-F-7	Spring												
MUR-F-8	Spring	1											1
MUR-F-8	Summer	3					3					8	14
MUR-F-8	Fall	4	2	7			2	7					22
MUR-F-9	Fall			2								1	3
MUR-F-10	Summer	4		9		3	1				1	13	31
MUR-F-10	Fall												
MUR-F-11	Fall											1	1
		18	2	37		12	7	8	0	0	2	101	186

Species Codes:

ARGR	Arctic Grayling	NRPK	Northern Pike
BRST	Brook Stickleback	PRDC	Pearl Dace
BURB	Burbot	SLSC	Slimy Sculpin
FTMN	Fathead Minnow	SPSC	Spoonhead Sculpin
LKCH	Lake Chub	TRPR	Trout Perch
LNDC	Longnose Dace	WALL	Walleye
LNSC	Longnose Sucker	WHSC	White Sucker

minimal overwintering habitat in Muskeg River system

In the fall of 1995, 76 adult Arctic grayling were captured at the downstream fish fence. This out-migration from the Muskeg River system occurred from September to October. However, most fish (85%) exited the Muskeg River over a seven-day period in October (Golder 1996a). Overwintering habitat in the Muskeg River was evaluated in winter 1997 and was found to be minimal for large adult fish due to low flows and the likelihood of some portions of the river freezing completely to the bottom (Golder 1997a). However, young-of-the-year and small juveniles could potentially use certain sections of this river as overwintering habitat (Golder 1997a).

Northern Pike

Northern pike use different parts of the Athabasca River system for various aspects of their life history. Significant spawning migrations from the Athabasca River into the Muskeg River were documented in historical studies (Tripp and McCart 1979).

spring and fall captures on the Muskeg River

In 1995, northern pike were captured in both the spring and fall fish fences on the Muskeg River. An upstream migration of 123 northern pike occurred in May. In the fall, 117 northern pike moved through the downstream fish trap: 83 were adults and 34 were juveniles (Golder 1996a).

no pike in lower reaches of Jackpine Creek

In the past, northern pike have been documented to spawn in the lower reaches of Jackpine Creek (O'Neil 1982); however, no northern pike were recorded in this watercourse in 1995 (Golder 1996a) or in 1997.

northern pike likely extensive throughout project area

Northern pike have also been found in the upper reaches of the Muskeg River in both present and past studies (R.L.& L. 1989, Golder 1996a). In the spring of 1995, one northern pike was observed at Site 4 in the upper reaches of the Muskeg River (Table 3.4-6). This reach was not sampled in 1997. However, one northern pike was captured and one was observed in the area above Jackpine Creek during the 1997 summer inventory (Table 3.4-7). R.L.&L. (1989) speculated that there is an isolated population in this area due to the large number of beaver dams downstream of the area where northern pike were caught. High water flows in 1997 were sufficient to allow access to the upper reaches of the Muskeg River by northern pike, as field crews were able to boat upstream of Jackpine Creek to Shelley Creek. Northern pike can therefore likely use these reaches for spawning and summer feeding and move downstream in the fall. Suitable habitat for spawning and rearing was observed throughout the Muskeg River Mine Project area, indicating possible use over an extensive area.

Longnose Sucker

Jackpine Creek and Muskeg River are important spawning and rearing areas

Evidence from fish fences on Jackpine Creek (Bond and Machniak 1979) and the Muskeg River (Golder 1996a) indicates these watercourses are important spawning and rearing areas for longnose sucker. In spring 1995, between May 8 and 13, over 300 longnose sucker moved through the fish fence on the Muskeg River to spawn (Golder 1996a). Data showed that adult longnose sucker likely migrate out of the Muskeg River system sometime in the summer.

electrofishing inventories indicated presence of longnose sucker

Electrofishing inventories of the Muskeg River and Jackpine Creek during spring 1997 indicated the presence of longnose sucker in Jackpine Creek and downstream of Jackpine Creek (Golder 1996a). Relative abundance was similar to 1997 catches although no longnose sucker were captured in the upper sections of the Muskeg River in 1997.

In 1997, 14 longnose sucker were captured in both the Muskeg River and Jackpine Creek. They were found above and below the mouth of Jackpine Creek. Use of the Muskeg River watershed by longnose sucker is shown on Figure 3.4-3.

Jackpine Creek provides spawning and rearing habitat

Spawning habitat (i.e., gravel substrate) is available in Jackpine Creek and previous studies have shown that longnose sucker spawn in the high gradient area between 5.5 and 14.2 km from the mouth (O'Neil et al. 1982). In spring 1995, adult longnose sucker were observed in pools near the mouth of the creek (Site 17; Table 3.4-6) but only juvenile longnose sucker were captured upstream (Site S3; Table 3.4-6) near the bridge at the Canterra Road crossing, and no adult fish spawning sites were observed in this area (Golder 1996a). Comparable results were found in the 1997 inventories. During summer 1997, two juvenile longnose sucker were captured by minnow traps in this section of the creek. Only one adult was observed in the spring in the same reach.

Documentation of juvenile longnose sucker in the Muskeg River and Jackpine Creek in the spring, and the fact that a number of juveniles passed through the downstream fish trap in 1995 (Golder 1996a), indicate that these watercourses provide rearing habitat for juvenile longnose sucker.

Forage Fish

A number of other forage fish in addition to longnose sucker are found in the Muskeg River and Jackpine Creek. White sucker, pearl dace, brook stickleback and lake chub are the most abundant forage fish species found in these watercourse.

White Sucker

seasonal abundance and distribution similar to longnose sucker

Seasonal abundance and distribution of white sucker is similar to that of longnose sucker. White sucker spawn in Muskeg River tributaries, and feed there in the summer. They leave the Muskeg River watershed in the fall to overwinter in Lake Athabasca, the Delta and in the lower Athabasca River (Tripp and Tsui 1980).

large number of white sucker reported

White sucker have been reported in large numbers in past studies (O'Neil et al. 1982, R.L.& L. 1989). In spring 1995, several hundred white sucker migrated upstream to spawn in the Muskeg River. Size and age distribution as well as age and growth were determined and found to be similar to past studies (Golder 1996a).

The largest number of fish captured in the Muskeg River in summer 1997 was white sucker (n=97) (Table 3.4-5). The majority of these fish were adults, although a few juveniles (n=5) were also captured. Only three white sucker were caught in the fall, indicating these fish had likely left the Muskeg River system. No white sucker were found in Jackpine Creek in 1997.

Pearl Dace

Pearl dace is a common species in the Muskeg River and the Muskeg River tributaries (Machniak and Bond 1979). In 1995 and 1997, only a few pearl dace were captured in this river system (Table 3.4-5).

Brook Stickleback

brook stickleback widespread

This species is widespread throughout the upper reaches of the Muskeg River drainage (R.L.& L. 1989, Golder 1996a). A total of 140 brook stickleback were collected from the Muskeg River drainage in 1995 (Golder 1996a). Only a few brook stickleback were captured in 1997 (Table 3.4-5). High water levels in both spring and fall, coupled with higher water velocities, made the sampling less effective and hence might account for the low numbers of stickleback caught in 1997.

Lake Chub

lake chub common

Lake chub is common in both the mainstem Athabasca River and in the tributaries. In 1995, this species was documented at the fish fence on the Muskeg River (Golder 1996a). Overwintering is thought to occur in the tributaries and in the mainstem Athabasca River (Bond 1980). Numbers of lake chub captured in the Muskeg River and Jackpine Creek in 1997 are shown in Table 3.4-5.

Ponds and Lakes in the Muskeg River Watershed

no sport fish

Two upland lakes south of the Muskeg River two shallow muskeg ponds north of the Muskeg River contain forage fish (Ponds 3, 5, 11 and 12 in Figure 3.3-4). Webb (1980) reported the presence of brook stickleback and pearl dace in these waterbodies. No studies were conducted in 1997 for these waterbodies. No sport fish species have been reported from these ponds and lakes.

Alsands Drainage System

No fish were captured or observed while using a portable electrofisher to survey one of the drainage ditches along the southwest end of the Alsands drainage system. Electrofishing effort was 839 s. A minnow trap set in the same area also caught no fish (effort: 20 h).

Similarly, no fish were captured in a gill net set overnight in the downstream end of the drainage system just upstream of a large beaver dam (effort: 30 ft. net, 2 in. mesh, 22 h). Forage fish were captured in a minnow trap set near the gill net. Northern redbelly dace (n = 21), lake chub (n = 5) and brook stickleback (n = 60) were captured (effort: 19.3 h).

only forage fish captured in drainage system

In summary, only forage fish were captured in the Alsands drainage system. Access to the drainage system is likely through the drainage channel where it enters the Muskeg River. In periods when water levels are high it is likely that fish can access the drainage system throughout this channel. Beaver activity also likely prevents extensive movement of fish through the drainage system. Habitat in the drainage system is relatively homogeneous except for a few areas of aquatic vegetation that could provide suitable habitat for northern pike and forage fish.

3.4.3 Isadore's Lake and Mills Creek Watersheds

Mills Creek Watershed

In the fall 1996 fisheries surveys no fish were captured or observed in Mills Creek (Golder 1997b). The presence of shallow, low quality habitat is likely the reason for the absence of fish in Mills Creek.

Mills Creek watershed low quality habitat

No fish were captured or observed in headwater pond of Mills Creek during fisheries surveys in fall 1996 or in 1997 when minnow traps were set at this site. It is likely that the pond does not support fish because it is a shallow, eutrophic system that would likely result in anoxic conditions during the winter, leading to winterkill. If this were the case, downstream barriers to migration would prevent the lake from being colonized again in the summer.

Isadore's Lake

northern pike spawn in Isadore's Lake

A fisheries survey of Isadore's Lake was done as part of the Alsands studies in the 1980s. Webb (1981) captured 19 adult northern pike from the lake. As well, several young-of-the-year were observed, indicating that northern pike spawned in the lake. One northern pike was captured by gill net in Isadore's Lake in autumn 1996 (Golder 1997b). At that time, the outlet to the Athabasca River was impassable to fish due to low water levels and beaver dam blockages. It is not clear if the northern pike captured in Isadore's Lake was a resident fish, or if it originated from the Athabasca River before 1996.

pike spawning habitat limited in Athabasca River

It is likely that northern pike from the Athabasca River use Isadore's Lake for spawning when flow and passage conditions in the outlet allow them access to the lake. Spawning habitat for northern pike is limited in the mainstem Athabasca River, and northern pike would be expected to use any suitable and accessible waterbodies, tributaries or side channels in the Athabasca River flood plain for spawning.

4. CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details please contact the undersigned.

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6. GLOSSARY OF TERMS

Acute	Acute refers to a stimulus severe enough to rapidly induce an effect; in aquatic toxicity tests, an effect observed in 96 hours or less is typically considered acute. When referring to aquatic toxicology or human health, an acute effect is not always measured in terms of lethality.
Ambient	The conditions surrounding an organism or area, excluding any effects of human activities.
AEP	Alberta Environmental Protection
AOSERP	Alberta Oil sands Environmental Research Program.
ASWQO	Alberta Surface Water Quality Objectives. Numerical concentrations or narrative statements which have been established to support and protect the designated uses of water. These are minimum levels of quality, developed for Alberta watersheds, below which no waterbody is permitted to deteriorate. These objectives were established as minimum levels which would allow for the most sensitive use. These concentrations represent a goal which should be achieved or surpassed.
Backwater	Discrete, localized area exhibiting reverse flow direction and, generally, lower stream velocity than main current; substrate similar to adjacent channel with more fines.
Baseline	A surveyed condition which serves as a reference point to which later surveys are compared.
Benthic Invertebrates	Invertebrate organisms living on the bottom of lakes, ponds and streams. Examples of benthic invertebrates include the aquatic insects such as caddisfly larvae, which spend at least part of their life on or in bottom sediments. Many benthic invertebrates are major food sources for fish.
Bitumen	Bitumen is a component of oilsand. It is a highly viscous, tarry, black hydrocarbon material having an API gravity of about 9° (specific gravity about 1.0). It is a complex mixture of organic compounds. Carbon accounts for 80 to 85% of the elemental composition of bitumen, hydrogen -10%, sulphur ~ 5%. Nitrogen, oxygen, and trace elements make up the remainder.
BOD	Biochemical Oxygen Demand.

Bottom Sediments	Material which lie on the bottom of a body of water. Examples include soft mud, silt, sand, gravel, rock and organic litter.
Bottom-feeding Fish	Fish that feed on the sediment and/or organisms (i.e., benthic invertebrates) associated with the bottom of a waterbody.
Chronic	Defines a stimulus that lingers or continues for a relatively long period of time, often one-tenth of the life span or more. Chronic should be considered a relative term depending on the life span of the organism. The measurement of a chronic effect can be reduced growth, reduce reproduction, etc., in addition to lethality.
Community	Plant or animal species living in close association in a defined location (e.g., fish community of a lake).
Concentration	Quantifiable amount of a chemical in environmental medium, expressed as mass of a substance per unit volume (e.g., mg/L), or per unit sample mass (e.g., mg/g).
Conductivity	A measure of a water's capacity to conduct an electrical current. It is the reciprocal of resistance. This measurement provides an estimate of the total concentration of dissolved ions in the water.
CPUE	Catch per unit of effort.
Detection Limit (DL)	the lowest concentration at which individual measurement results for a specific analyte are statistically different from a blank (that may be zero) with a specified confidence level for a given method and representative matrix.
Discharge	In a stream or river, the volume of water that flows past a given point in a unit of time (i.e., m^3/s).
Diversity	The variety, distribution and abundance of different plant and animal communities and species within an area.
Drainage Basin	The total area that contributes water to a stream. Also known as the watershed.
Effluent	Stream of water discharging from a source.
Environmental Impact Assessment (EIA)	A review of the effects that a proposed development will have on the local and regional environment.

Fauna	A term referring to an association of animals living in a particular place or at a particular time.
Forage Area	The area used by an organism for hunting or gathering food.
GIS	Geographical Information System. Pertains to a type of computer software that is designed to develop, manage, analyze and display spatially referenced data.
GPS	Global Positioning System. This system is based on a constellation of satellites which orbit the earth every 24 hours. GPS provides exact position in standard geographic grid (e.g., UTM).
Lethal	Causing death by direct action.
m^3/s	Cubic metres per second. The standard measure of water flow in rivers; i.e., the volume of water in cubic metres that passes a given point in one second.
Oil sands	A sand deposit containing a heavy hydrocarbon (bitumen) in the intergranular pore space of sands and fine grained particles. Typical oil sands comprise approximately 10 wt% bitumen, 85% coarse sand (>44μm) and a fines (<44μm) fraction, consisting of silts and clays.
Organics	Chemical compounds, naturally occurring or otherwise, which contain carbon, with the exception of carbon dioxide (CO_2) and carbonates (e.g., $CaCo_3$).
Orthophoto	Photograph copy prepared from airphotos in which the displacements of an image due to distortions have been removed.
Overwintering Habitat	Habitat used during the winter as a refuge and for feeding.
PAH	Polycyclic Aromatic Hydrocarbon. A chemical by-product of petroleum-related industry and combustion of organic materials. PAHs are composed of at least two fused benzene rings. Toxicity increases with molecular size and degree of alkylation.
PANH	Polycyclic Aromatic Nitrogen Heterocycle.
PEL	Probable Effect Level. Concentration of a chemical in sediment above which adverse effects on an aquatic organism are likely.

Porewater	Water that is present between the grains of a soil or rock.
QA/QC	Quality Assurance/Quality Control refers to a set of practices that ensure the quality of a product or a result. For example, "Good Laboratory Practice" is part of QA/QC in analytical laboratories and involves proper instrument calibration, meticulous glassware cleaning and an accurate sample information system.
Reach	A comparatively short length of river, stream channel or shore. The length of the reach is defined by the purpose of the study.
Rearing Habitat	Habitat used by young fish for feeding or as a refuge from predators.
Relative Abundance	The proportional representation of a species in a sample or a community.
Riffle Habitat	Shallow rapids where the water flows swiftly over completely or partially submerged materials to produce surface agitation.
Run Habitat	Areas of swiftly flowing water, without surface waves, that approximates uniform flow and in which the slope of water surface is roughly parallel to the overall gradient of the stream reach.
Snye	Discrete section on non-flowing water connected to a flowing channel only at its downstream end, generally formed in a side channel or behind a peninsula (bar).
Spawning Habitat	A particular type of area where a fish species chooses to reproduce. Preferred habitat (substrate, water flow, temperature) varies from species to species.
Species	A group of organisms that actually or potentially interbreed and are reproductively isolated from all other such groups; a taxonomic grouping of genetically and morphologically similar individuals; the category below genus.
Sport/Game Fish	Large fish that are caught for food or sport (e.g., northern pike, trout).
TEL	Threshold Effect Level. Concentration of a chemical in sediment or water below which adverse effects are expected to occur rarely.

Transect	A line drawn perpendicular to the flow in a channel along which measurements are taken.
Toxic	A substance, dose, or concentration that is harmful to a living organism.
Toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism.
Watershed	See drainage basin.
Wetlands	Term for a broad group of wet habitats. Wetlands are transitional between terrestrial and aquatic systems, where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands include features that are permanently wet, or intermittently water-covered such as swamps, marshes, bogs, muskeg, potholes, swales, glades, slashes and overflow land of river valleys.
YOY	Young of the year. Fish from age 0 to the end of the first year after hatching.

APPENDIX I

SURFACE WATER SAMPLING METHODS

1. PURPOSE

This document describes the sampling protocols used by Golder Associates to collect surface water samples. It contains sampling instructions and information concerning appropriate containers, preservation and handling of water quality samples.

2. APPLICABILITY

This technical procedure is applicable to any persons involved in the collection of surface water samples. It is applicable to all geographic areas.

3. DEFINITIONS

3.1 Analytical Request Form

Standard form provided by analytical laboratories. This form is filled out by the person collecting samples and is used to indicate how each sample is to be analyzed. This form is often combined with the Chain-of-Custody Form in a single document.

3.2 Chain-of-Custody Form

Standard form used to track the movement of sample containers from the time they leave the field until they arrive at the specified laboratory. The Chain-of-Custody form provides a clear record of sample transport and handling, thereby reducing the risk of sample loss during transport. This form may be combined with the Analytical Request Form in a single document.

3.3 Chemical Analysis

Analytical procedure used to measure the *amount* of a certain compound, or group of compounds, present in a sample.

3.4 Preservatives

Preservatives are used to maintain sample integrity from the time a sample is collected until it is analyzed. Sample preservation may involve adding acid or other fixatives to collected waters or simply keeping them refrigerated. Sample-specific requirements are outlined in this document (Table 1); preservatives, when required, are provided by the analytical laboratory.

3.5 Quality Assurance/Quality Control (QA/QC)

Quality Assurance refers to a detailed protocol used to produce high quality products, while Quality Control refers to the process by which this protocol is tested to ensure that final products are of the specified quality. With reference to water sampling, QA protocol includes the use trained personnel, proper sampling methods, clean containers and equipment, proper sample preservation and transportation and detailed documentation of the entire process; field, travel and other assorted test blanks are used for Quality Control testing.

3.6 Sample Types

3.6.1 Grab Samples

Sample containing water collected during a single sampling event (i.e., water taken from a given place at a given time).

3.6.2 Composite Samples

Sample containing a mixture of water collected from multiple locations or from different times at the same location.

3.6.3 Equipment Blanks

Equipment blanks are used to detect contamination from sampling equipment. They are prepared by rinsing precleaned equipment with deionized water and collecting the rinsate into an appropriate container.

3.6.4 Field Blanks

Field blanks are used to detect contamination during sample collection and transport. They are prepared during a sampling event by filling the appropriate container with deionized water. Field blanks are usually used in situations where there is reason to suspect that contamination will occur during sample collection and transport.

3.6.5 Travel Blanks

Travel blanks detect sample contamination during transport. Travel blanks consist of pre-filled bottles provided by the analytical lab. They accompany empty sample bottles to the field site, where they are left intact and unopened inside the shipping cooler. The unopened travel blanks are then returned to the analytical lab to be analyzed along with collected samples.

3.6.6 Field Spikes

Field spikes are used to measure the performance of the complete analytical system, including sample handling, preservation and storage, as well as interference from the sample matrix. To generate a field spike, field personnel fill the usual sampling container with sample, leaving a small amount of space at the top. They then add a specified amount of the chemical or compound of interest to the bottle and submit it with the rest of the samples. In general, field spikes are not recommended due to the logistical difficulties of transporting concentrated solutions in the field. If there is reason to doubt the performance of the sampling system, then a separate study involving field spikes should be carried out.

3.6.7 Standard Reference Samples

Standard reference samples, or blind QA samples, are samples of known concentration that are submitted to the analytical lab as a normal sample. The lab is not informed about the identity of the sample until after all analyses are complete.

3.6.8 Replicate Samples

Replicate samples are used to evaluate within-site variation. Replicate samples are collected by filling multiple containers at a single site. They are labelled and preserved individually and are submitted separately to the analytical laboratory. Check the SWI for the number of replicate samples required per sampling site.

3.6.9 Split Samples

Split samples are used to check analytical variation. A single sample (e.g. grab) is collected and is split into two sample containers. These are labelled and preserved individually and are submitted separately to the analytical laboratory.

3.7 Specific Work Instructions (SWI)

Detailed instructions in a standardized format provided to field personnel. The SWI describe all aspects of the work to be conducted, including personnel allocation, procedures to be used, time allocation and any additional information deemed necessary by the project or task manager.

3.8 Toxicity Analysis

Analytical procedure specifically designed to examine how the health of living organisms may be affected by exposure to a given substance or sample. Toxicity tests can be based on either: acute exposures (short-term exposures lasting only a small portion of the animals life cycle, e.g. 96 hours for rainbow trout); or, chronic exposures (longer-term exposures meant to represent a significant portion of the animal's life cycle, or a particularly sensitive portion of the animal's life cycle, e.g. 28 days for *Daphnia magna*). Responses measured in toxicity tests can be lethal (e.g. mortality), or sublethal (e.g., reduced growth or reproduction). Unlike other procedures, toxicity testing evaluates the sample as a whole, rather than describing its chemical make-up.

4. REFERENCES AND SUGGESTED READING

4.1 Sampling Methodology

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4.2 Laboratory Capabilities and Pricing

- Chemex Labs (Alberta) Inc. 1995. Service Description and Price List
- Enviro-Test Labs. 1996. Service Description and Price List
- HydroQual Laboratories Ltd. 1996. Statement of Qualifications

5. DISCUSSION

5.1 General Safety

Refer to Golder Associates Ltd. Health and Safety Manual.

5.2 Sampling Procedures

Samples are collected as representative pieces of a larger puzzle. Ideally, they should describe all of the characteristics of the larger body from which they originate, which, by its very definition, is too large to analyze directly. As a result, it is very important to follow a well-organized sampling plan and to preserve sample integrity throughout the collection and transportation process.

5.2.1 General Practices

Usually, analytical laboratories will provide pre-cleaned sample containers, shipping containers, required forms for sample submission and specific sample shipping instructions. It is important to check with the lab that these arrangements have been made. Similarly, field crews should familiarize themselves with the SWI before initiating a sampling program. By reviewing the instructions, personnel can ensure that they have all of the equipment they require to fulfill the objectives of the sampling program. Field crews will also then be aware of the types of samples they are being asked to collect, be they grab samples, composite samples or QA/QC test blanks. Finally, sample crews should organize themselves such that samples will be collected and shipped during the early part of the work week (Monday to Wednesday) to help avoid delays caused by weekend shipping.

Sampling Locations

General sampling locations are described in SWI. However, field crews will have a certain degree of freedom in choosing the exact locations from which to take the samples. When selecting these sites, personnel should consider the layout of the local environment, project objectives and personal safety. They should then choose areas that are both easily accessible and representative of the target waterbody or waterbodies.

Once sampling sites have been identified, they must be accurately described relative to permanent landmarks, such as groundwater wells, outfalls or distinctive landscape features; measuring the distance from permanent landmarks to each site with an appropriate compass heading is recommended. Ideally, one should try to use the Global Positioning System (GPS), but locations can also be recorded as the perpendicular distance from the shoreline and the distance upstream or downstream of a permanent landmark.

Sample Collection

- Start sampling at the least contaminated site (i.e., the reference site) and move from there to the more contaminated areas.
- If sampling equipment must be used, then it must be cleaned before and after use. This may involve rinsing with ambient water, cleaning with soap and water, acid washing, rinsing with organic solvents or pure water, or a combination of these. Refer to the SWI for details.

- Each sample bottle must be labelled at the time of collection with either waterproof, permanent marker or using pre-printed waterproof labels. See section 5.3.2 for details of label format.

- When sampling, it is important to rinse sample containers 3 times before actually taking a sample. Rinse each bottle by partially filling it with ambient water, loosely attaching the cap and shaking the bottle; drain the water and repeat the process. As a general rule, rinse plastic bottles unless instructed otherwise by the analytical laboratory. Bottles that already contain the appropriate preservatives and containers for the following analyses should *not* be rinsed prior to taking the sample:
  - volatile organic compounds (VOCs), including total volatile hydrocarbons (TVH), total extractable hydrocarbons (TEH), BTEX (benzene, toluene, ethylbenzene and xylene) and total petroleum hydrocarbons (TPH; includes TVH, TEH and BTEX); and
  - bacteriological testing (e.g., fecal coliforms).

- Carefully fill sample containers, without splashing, leaving only enough space for preservatives (if required - see Table 1). Be sure to keep hands and fingers downstream of bottle opening and sample upstream of bridges, boats and yourself to prevent sample contamination. If no preservatives need to be added, completely fill the bottles and cap tightly. There should be as little air in the containers as possible, as it can affect sample integrity.

- Whenever possible, fill sample containers directly from the source, without using an intermediate container to transfer the sample. This avoids potential sample contamination due to carry-over from one sample to the next. Also, take care to avoid contaminating sample waters through contact with rubber, oil, gasoline and other machinery fluids, metal-based paints, cigarette ash, paper tissues and other such material.

- Sample bottles should then be stored appropriately (Table 1). In most cases, this will involve keeping the sample cool (4°C) and dark. Samples should never be allowed to freeze and should be shipped as soon as possible to the appropriate analytical lab, in coolers with reusable ice packs. If possible, avoid using bags of ice purchased from convenience stores; the water that leaks out of these bags as the ice melts may ruin sample labels.

- Chain-of-Custody and Analytical Request forms must accompany all samples (one set of forms per sample shipment). Prior to shipping, the person submitting the sample should inform the analytical lab by telephone or fax that the samples will be arriving. As well, he or she should check back later to confirm arrival of the samples and to explain analysis requests if needed.

5.2.2 Sampling for Metals

When collecting samples for a metals analysis, it is important that sample waters do not come into contact with any metal products. Samples for metals analysis also have other stringent collection and preservation requirements (Table 1). For example, waters collected for dissolved metal analysis have to be field-filtered using a 0.45 µm polycarbonate or cellulose acetate filter and then preserved with acid. Field crews need to be aware of these restrictions to ensure that samples are taken correctly and that they maintain their integrity until they can be analyzed. Special sampling and preservation instructions should be included in the SWI.

5.2.3 Sampling for Organic Chemicals

In addition to the general principles outlined above, there are specific protocols associated with sampling for organic measurements. As described above, sample bottles should *not* be rinsed prior to taking samples for certain organics analyses. It is also very important to completely fill each bottle, as certain organics will volatilize into the overlying air space and will be lost after opening the bottle. Finally, proper containers must be used when sampling for organics, since some bottles will release or absorb organic compounds when filled with water. Generally, glass containers are used, but certain tests may require other materials; be sure to obtain the appropriate sample bottles from the analytical laboratory and refer to the SWI.

5.3 Sample Documentation

The importance of proper sample documentation cannot be overemphasized. Lack of careful documentation can lead to misunderstandings and questionable test results. Components of proper documentation of field activities are described below.

5.3.1 Field Notebooks

Field notebooks must be kept, describing all field activities. Format of field notes and information to be recorded should follow Golder Associates' specific guidelines. During the field survey, field notes must be maintained in a permanent, safe location at the field site where samples are collected. If possible, new entries in the field note book should be photocopied at the end of each field day and copies should be stored in a safe place.

5.3.2 Sample Labels

Sample labels must contain the following information:

- Sample identifier (name of site or sample code);
- Date (written as day/month/year; month abbreviated as three letters) and time (24 hour clock) of collection;
- Initials of collector; and
- Analysis requested (this is usually done by the analytical laboratory in the form of a code on the sample bottle).

Fill out labels at the time of collection using waterproof ink and affix a label to each sample container. Plastic bottles may be labelled by writing directly on the bottle using a waterproof marker; however, this approach is not recommended if samples are transported over long distances (friction may rub label off) or if bags of ice are used to keep the samples cool (water may damage label information).

5.3.3 Custody Seals

If required for a project, numbered seals should be used to detect unauthorized tampering with samples in transit. Attach the seal in a way that it is necessary to break it to open the cooler containing the samples. The number on the custody seal should be recorded in the field note book and on the Chain-of-Custody and Analytical Request forms

5.3.4 Chain-of-Custody Forms and Analytical Request Forms

Chain-of-Custody and Analytical Request forms must accompany all samples submitted for analysis. These forms are usually combined as a single document. An example of Golder Associates' combined Chain-of-Custody and Analytical Request Form is provided in Appendix 1.

The combined form must be filled out completely and the white and yellow copies should be sent along with the samples being submitted. Field personnel should retain the pink copy after it is signed by the shipper. Depending on the shipping container, these forms can either be enclosed inside the sealed container or attached firmly to the outside of the container. In either case, it is advisable to enclose the forms within a waterproof plastic bag to guard against damage. It is important that each person having custody or control of the samples identify themselves on this form. This means that the person collecting the sample, any intermediate persons involved in packaging, storing or transporting the sample and the person accepting the sample on behalf of the analytical lab must all be identified.

5.4 Sample QA/QC

The main goal of sample QA/QC is to monitor for various sources of contamination during sample collection, transport and analysis. This process will involve the use of field, travel and other test blanks. QA/QC programs are designed on a project-specific basis. Details of individual QA/QC programs are described in the SWI.

6. EQUIPMENT AND MATERIALS

6.1 Sampling

The following is a list of sampling equipment generally recommended for surface water sampling:

- Pre-cleaned sample bottles and required preservatives (usually supplied by the analytical laboratory)
- Coolers and reusable ice packs
- Waterproof labels and permanent markers
- Sampling equipment (e.g. Kemmerer or Van Dorn bottles)

6.2 Site Location and Sample Documentation

For proper sample site identification and sample documentation, field crews may need:

- Bound, water-proof field logbooks
- Maps
- Air photos
- Indelible ink pens and pencils
- Long tape measure
- Survey flagging tape
- Compass
- GPS unit
- Combined Analytical Request and Chain-of-Custody forms

6.3 Health and Safety

The following health and safety equipment is recommended for surface water sampling:

- Waders and waterproof gloves
- Heavy socks, warm pants, rain gear and other articles of clothing suitable for prolonged water work
- Extra set of clothes
- First aid kit
- Approved personal floatation device for deep water or boat work

TABLE 1

SUMMARY OF SAMPLE COLLECTION, PRESERVATION AND STORAGE REQUIREMENTS

PARAMETER	BOTTLE TYPE	ETL[1] LABEL	SAMPLE PRESERVATION	PRESERVATIVE CODE (ETL)[1]	HOLDING TIME	COMMENTS
Conventional Chemistry						
pH to TDS + DOC	500 mL plastic	"routine"	in the dark at 4°C	-	**48 hrs.**	Note short holding time
TOC	100 mL amber glass	unlabelled	1 mL H_2SO_4	Fluorescent Red	5 days	Do not triple rinse
Major Ions						
Calcium to Sulphate	in "routine" bottle	n/a	-	-	-	
Sulphide	100 mL plastic	"Sulphide"	1 mL NaOH+ 2 mL zinc acetate	Orange	5 days	
Nutrients						
Ammonia, TKN & Total P	500 mL plastic	"nutrients"	2 mL H_2SO_4	Purple	10 days	Indicate on label that sample is preserved
Nitrate + Nitrite & Dissolved P	in "routine" bottle	n/a	-			
Bacterial						
Biochemical Oxygen Demand	1 L plastic	unlabelled	in the dark at 4°C		**48 hrs.**	Note short holding time
Coliforms	300 mL sterilized glass	unlabelled	in the dark at 4°C	-	**48 hrs.**	Note short holding time
Toxicity						
Daphnia magna 48 h. Static Acute	1 L clear glass / plastic	unlabelled	in the dark at 4°C	-	5 days	
Rainbow trout 24 and 96h Static Acute	20 L collapsible carboy	unlabelled	in the dark at 4°C	-	5 days	
Algal Growth 72h Inhibition/Stimulation	1 L clear glass / plastic	unlabelled	in the dark at 4°C	-	3 days	
Ceriodaphnia dubia 7d Growth and Reproduction	20 L collapsible carboy	unlabelled	in the dark at 4°C	-	3 days	
Fathead Minnow 7d Survival/Growth	20 L collapsible carboy	unlabelled	in the dark at 4°C	-	3 days	
Bacterial Luminescence (Microtox IC50 and IC20)	1 L clear glass	unlabelled	in the dark at 4°C	-	48 hrs.	Note short holding time
Other						
Total Recoverable Hydrocarbons	1 L amber glass	"oil & grease"	2 mL H_2SO_4	Purple	5 days	Do not triple rinse
Naphthenic acids	1 L amber glass	unlabelled	0.5g ascorbic acid + 2 NaOH pellets		10 days	Do not triple rinse; preservative in bottle
Total Phenolics	100 mL amber glass	unlabelled	1 mL H_2SO_4	Fluorescent Red	**24 hrs.**	Note short holding time Do not triple rinse
Chlorophyll *a*	500 mL plastic	"nutrient"	in the dark at 4°C	-	**48 hrs.**	Note short holding time Indicate on label that sample is unpreserved
Total Metals						
Aluminum to Zinc + Sb, As & Se	500 mL plastic	"metals"	2 mL NO_3	Blue	6 months	
Mercury (Hg)	250 mL plastic	"mercury"	2 mL NO_3 + dichromate	Yellow	30 days	
Dissolved metals						
Aluminum to Zinc + Sb, As & Se	500 mL plastic	"metals"	filter, 2 mL NO_3	Blue	6 months	See dissolved metals sampling protocol
Mercury (Hg)	250 mL plastic	"mercury"	filter, 2 mL NO3 + dichromate	Yellow	30 days	See dissolved metals sampling protocol
PAHs						
Naphthalene....	2 L clear glass	unlabelled	in the dark at 4°C	-	14 days	Bottle may be 4 L Do not triple rinse
Phenolics						
Phenol....	in PAH bottle	unlabelled	-	-	-	
Volatile Organics						
Acetone...	40 mL amber glass	unlabelled	Na2S2O3, 2 crystals, dark, 4°C	-	14 days	Do not triple rinse; preservative in bottle

NOTE: 1ETL = Enviro-Test Laboratories

APPENDIX II

LABORATORY ANALYTICAL METHODS

APPENDIX II
LABORATORY ANALYTICAL METHODS
(G = glass, P = plastic)

PARAMETER	ETL CODE	METHOD	DETECTION LIMIT	UNITS	REQUIRED VOLUME	CONTAINER TYPE	SAMPLE PRESERVATION	HOLDING TIME	COMMENTS
Field measured									
pH	-	Meter			-	-	-	-	
Specific Conductance	-	Meter		uS/cm	-	-	-	-	
Temperature	-	Meter		°C	-	-	-	-	
Dissolved Oxygen	-	Meter		mg/L	-	-	-	-	
WATER QUALITY PARAMETERS									
Group 1 - Conventional									
pH	PHW1W1	Meter	0.01		500 ml	"Routine" P	in the dark at 4 °C	48 hrs.	
Specific Conductance	ECW1W1	Meter	0.2	uS/cm					
Colour	CLO2W1	Colour disk	3	T.C.U.					
Total Alkalinity	TAL2W1	Titration	5	mg/L					
Total Hardness	HARD	Calculated	1	mg/L					
Bicarbonate	BIC1W1	Calculated	5	mg/L					
Carbonate	CO31W1	Calculated	5	mg/L					
Total Suspended Solids	TSS1W1	Gravimetric	2	mg/L				7 days	
Total Dissolved Solids	DSW1W1	Calculated	10	mg/L				7 days	
Total Organic Carbon	TOC1W1	n Infrared TO	1	mg/L	100 ml	"TOC" glass	1 ml H_2SO_4	5 days	
Dissolved Organic Carbon	DOC1W1	TOC Analyzer	1	mg/L	in TOC bottle			5 days	filter at lab
Group 2 - Major Ions									
Calcium	ICPCAR	ICP	0.05	mg/L	500 ml	"Routine" P	in the dark at 4 °C	5 days	
Magnesium	ICPMGR	ICP	0.1	mg/L				5 days	
Potassium	ICPKR	ICP	0.1	mg/L				5 days	
Sodium	ICPNAR	ICP	1	mg/L				5 days	
Chloride	CHL1W1	Colorimetry	0.5	mg/L				14 days	
Sulphate	ICPSO4	Colorimetry	0.5	mg/L				5 days	
Sulphide	CUL2W1	Titration	0.002	mg/L	100 ml	"Sulphide" P	2 ml Zn acetate + 1 ml NaOH	5 days	
Group 3 - Nutrients									
Nitrogen - Ammonia	NH41W1	Colorimetry	0.05	mg/L	100 ml	"nutrients" P	2 ml H_2SO_4	10 days	
Nitrogen - Kjeldahl	TKN1W1	Colorimetry	0.2	mg/L	100 ml	"nutrients" P	2 ml H_2SO_4	5 days	
Nitrate + Nitrite	NO231W1	Colorimetry	0.05	mg/L	100 ml	"Routine" P	in the dark at 4 °C	48 hours	
Total Phosphorus	TPW1W1	Colorimetry	0.02	mg/L	50 ml	"nutrients" P	2 ml H_2SO_4	10 days	
Dissolved Phosphorus	TDP1W1	Colorimetry	0.02	mg/L	50 ml	"Routine" P	in the dark at 4 °C	5 days	filter and preserve at lab
Group 4 - BOD									
Biochemical Oxygen Demand	BOD1W1	Winkler	2	mg/L	1 L	"BOD" P	in the dark at 4 °C	48 hours	
Group 5 - Other									
Total Recoverable Hydrocarbons	HOG2W1	APHA 5520F	0.5	mg/L				5 days	
Naphthenic acids	NAP1W8	FTIR	1	mg/L	1 L	"Naph." G	0.5g asorbic acid + 2 NaOH pellets	10 days	
Microtox IC50 and IC20				%	1 L	"Micro." G	in the dark at 4 °C	5 days	done by Hydroqual
Total Phenolics	PHE1W1	EPA 420.2	0.001	mg/L	100 ml	"Phen." G	H_2SO_4 < pH 2	24 hrs.	
Chlorophyll "a"	CHP1W	Colorimetry							done by Hydroqual

LABORATORY ANALYTICAL METHODS

(G = glass, P = plastic)

PARAMETER	ETL CODE	METHOD	DETECTION LIMIT	UNITS	REQUIRED VOLUME	CONTAINER TYPE	SAMPLE PRESERVATION	HOLDING TIME	COMMENTS
Group 6 - Total Metals									
Aluminum (Al)	PMSALT	ICP	0.005	mg/L	500 ml	P	NO_3 < pH 2	28 days	
Antimony (Sb)	PMSSBT	AA	0.0004	mg/L					
Arsenic (As)	PMSAST	AA	0.0004	mg/L					
Barium (Ba)	PMSBAT	ICP	0.0002	mg/L					
Beryllium (Be)	PMSBET	ICP	0.001	mg/L					
Boron (B)	PMSBT	ICP	0.002	mg/L					
Cadmium (Cd)	PMSCDT	ICP	0.0002	mg/L					
Calcium (Ca)	PMSCAT	ICP	0.05	mg/L					
Chromium (Cr)	PMSCRT	ICP	0.0004	mg/L					
Cobalt (Co)	PMSCOT	ICP	0.0005	mg/L					
Copper (Cu)	PMSCUT	ICP	0.0004	mg/L					
Iron (Fe)	PMSFET	ICP	0.01	mg/L					
Lead (Pb)	PMSPBT	ICP	0.0001	mg/L					
Lithium (Li)	PMSLIT	ICP	0.003	mg/L					
Magnesium (Mg)	PMSMGT	ICP	0.01	mg/L					
Manganese (Mn)	PMSMNT	ICP	0.0001	mg/L					
Mercury (Hg)	PMSHGT	CVAA	0.0002	mg/L	250 ml	P	2 ml NO_3 + dichromate	30 days	
Molybdenum (Mo)	PMSMOT	ICP	0.0001	mg/L	500 ml	P	NO_3 < pH 2	28 days	
Nickel (Ni)	PMSNIT	ICP	0.0004	mg/L					
Phosphorus (P)		ICP		mg/L					
Potassium (K)	PMSKT	ICP	0.01	mg/L					
Selenium (Se)	PMSSET	AA	0.0004	mg/L					
Silicon (Si)	PMSSIT	ICP	0.007	mg/L					
Silver (Ag)	PMSAGT	ICP	0.001	mg/L					
Sodium (Na)	PMSNAT	ICP	0.1	mg/L					
Strontium (Sr)	PMSSTR	ICP	0.0001	mg/L					
Sulphur (S)	ICPST	ICP	0.5	mg/L					
Titanium (Ti)	PMSTIT	ICP	0.0004	mg/L					
Uranium (U)	PMSUT	ICP	0.0001	mg/L					
Vanadium (V)	PMSVT	ICP	0.0002	mg/L					
Zinc (Zn)	PMSZNT	ICP	0.002	mg/L					
Group 7 - Dissolved metals									
Aluminum (Al)		ICP	0.005	mg/L	500 ml	P	filter, NO_3 < pH 2	28 days	
Antimony (Sb)		AA	0.0004	mg/L					
Arsenic (As)		AA	0.0004	mg/L					
Barium (Ba)		ICP	0.0002	mg/L					
Beryllium (Be)		ICP	0.001	mg/L					
Boron (B)		ICP	0.002	mg/L					
Cadmium (Cd)		ICP	0.0002	mg/L					
Calcium (Ca)		ICP	0.05	mg/L					
Chromium (Cr)		ICP	0.0004	mg/L					
Cobalt (Co)		ICP	0.0005	mg/L					
Copper (Cu)		ICP	0.0004	mg/L					
Iron (Fe)		ICP	0.01	mg/L					
Lead (Pb)		ICP	0.0001	mg/L					
Lithium (Li)		ICP	0.003	mg/L					

LABORATORY ANALYTICAL METHODS
(G = glass, P = plastic)

PARAMETER	ETL CODE	METHOD	DETECTION LIMIT	UNITS	REQUIRED VOLUME	CONTAINER TYPE	SAMPLE PRESERVATION	HOLDING TIME	COMMENTS
Magnesium (Mg)		ICP	0.01	mg/L					
Manganese (Mn)		ICP	0.0001	mg/L					
Mercury (Hg)		CVAA	0.0002	mg/L	250 ml	P	filter, 2 ml NO_3 + dichromate	30 days	
Molybdenum (Mo)		ICP	0.0001	mg/L	500 ml	P	filter, NO_3 < pH 2	28 days	
Nickel (Ni)		ICP	0.0004	mg/L					
Phosphorus (P)		ICP		mg/L					
Potassium (K)		ICP	0.01	mg/L					
Selenium (Se)		AA	0.0004	mg/L					
Silicon (Si)		ICP	0.007	mg/L					
Silver (Ag)		ICP	0.001	mg/L					
Sodium (Na)		ICP	0.1	mg/L					
Strontium (Sr)		ICP	0.0001	mg/L					
Titanium (Ti)		ICP	0.0004	mg/L					
Uranium (U)		ICP	0.0001	mg/L					
Vanadium (V)		ICP	0.0002	mg/L					
Zinc (Zn)		ICP	0.002	mg/L					
Group 8a - Target PAHs									
Naphthalene		GC/MS	0.02	ppb	4 L	G - amber	in the dark at 4 °C	7days	
Acenaphthylene		GC/MS	0.02	ppb					
Acenaphthene		GC/MS	0.02	ppb					
Fluorene		GC/MS	0.02	ppb					
Dibenzothiophene		GC/MS	0.02	ppb					
Phenanthrene		GC/MS	0.02	ppb					
Anthracene		GC/MS	0.02	ppb					
Fluoranthene		GC/MS	0.02	ppb					
Pyrene		GC/MS	0.02	ppb					
Benzo(a)Anthracene/Chrysene		GC/MS	0.02	ppb					
Benzo(b&k)fluoranthene		GC/MS	0.02	ppb					
Benzo(a)pyrene		GC/MS	0.02	ppb					
Indeno(c,d-123)pyrene		GC/MS	0.02	ppb					
Dibenzo(a,h)anthracene		GC/MS	0.02	ppb					
Benzo(g,h,i)perylene		GC/MS	0.02	ppb					
Group 8b - Alkylated PAHs									
Methyl naphthalenes		GC/MS	0.02	ppb	contained in above sample				
C2 Substituted naphthalenes		GC/MS	0.04	ppb					
C3 Subst'd naphthalenes		GC/MS	0.04	ppb					
C4 Subst'd naphthalenes		GC/MS	0.04	ppb					
Biphenyl		GC/MS	0.04	ppb					
Methyl biphenyl		GC/MS	0.04	ppb					
C2 Substituted biphenyl		GC/MS	0.04	ppb					
Methyl acenaphthene		GC/MS	0.04	ppb					
Methyl fluorene		GC/MS	0.04	ppb					
C2 Substituted fluorene		GC/MS	0.04	ppb					
Methyl phenanthrene/anthracene		GC/MS	0.04	ppb					
C2 Subst'd phenanthrene/anthracene		GC/MS	0.04	ppb					
C3 Subst'd phenanthrene/anthracene		GC/MS	0.04	ppb					
C4 Subst'd phenanthrene/anthracene		GC/MS	0.04	ppb					

LABORATORY ANALYTICAL METHODS

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PARAMETER	ETL CODE	METHOD	DETECTION LIMIT	UNITS	REQUIRED VOLUME	CONTAINER TYPE	SAMPLE PRESERVATION	HOLDING TIME	COMMENTS
1-Methyl-7-isopropyl-phenanthrene (Retene)		GC/MS	0.04	ppb					
Methyl dibenzothiophene		GC/MS	0.04	ppb					
C2 Substituted dibenzothiophene		GC/MS	0.04	ppb					
C3 Subst'd dibenzothiophene		GC/MS	0.04	ppb					
C4 Subst'd dibenzothiophene		GC/MS	0.04	ppb					
Methyl fluoranthene/pyrene		GC/MS	0.04	ppb					
Methyl benzo(a)anthracene/chrysene		GC/MS	0.04	ppb					
C2 Subst'd benzo(a)anthracene/chrysene		GC/MS	0.04	ppb					
Methyl benzo(b or k) fluoranthene/methyl benzo(a		GC/MS	0.04	ppb					
C2 Subst'd benzo(b or k) fluoranthene/benzo(a)py		GC/MS	0.04	ppb					
SEDIMENT QUALITY PARAMETERS									
Total Metals									
Aluminum (Al)	PMSALT	ICP/MS	0.005	mg/L	500 ml	G	NO_3 < pH 2	6 months	
Antimony (Sb)	PMSSBT	AA	0.0004	mg/L					
Arsenic (As)	PMSAST	AA	0.0004	mg/L					
Barium (Ba)	PMSBAT	ICP/MS	0.0002	mg/L					
Beryllium (Be)	PMSBET	ICP/MS	0.001	mg/L					
Boron (B)	PMSBT	ICP/MS	0.002	mg/L					
Cadmium (Cd)	PMSCDT	ICP/MS	0.0002	mg/L					
Calcium (Ca)	PMSCAT	ICP/MS	0.05	mg/L					
Chromium (Cr)	PMSCRT	ICP/MS	0.0004	mg/L					
Cobalt (Co)	PMSCOT	ICP/MS	0.0005	mg/L					
Copper (Cu)	PMSCUT	ICP/MS	0.0004	mg/L					
Iron (Fe)	PMSFET	ICP/MS	0.01	mg/L					
Lead (Pb)	PMSPBT	ICP/MS	0.0001	mg/L					
Lithium (Li)	PMSLIT	ICP/MS	0.003	mg/L					
Magnesium (Mg)	PMSMGT	ICP/MS	0.01	mg/L					
Manganese (Mn)	PMSMNT	ICP/MS	0.0001	mg/L					
Mercury (Hg)	PMSHGT	AA	0.0002	mg/L	125 ml	G	2 ml NO_3	30 days	
Molybdenum (Mo)	PMSMOT	ICP/MS	0.0001	mg/L	500 ml	G	NO_3 < pH 2	6months	
Nickel (Ni)	PMSNIT	ICP/MS	0.0004	mg/L					
Phosphorus (P)		ICP/MS		mg/L					
Potassium (K)	PMSKT	ICP/MS	0.01	mg/L					
Selenium (Se)	PMSSET	AA	0.0004	mg/L					
Silicon (Si)	PMSSIT	ICP/MS	0.007	mg/L					
Silver (Ag)	PMSAGT	ICP/MS	0.001	mg/L					
Sodium (Na)	PMSNAT	ICP/MS	0.1	mg/L					
Strontium (Sr)	PMSSTR	ICP/MS	0.0001	mg/L					
Sulphur (S)	ICPST	ICP	0.5	mg/L					
Titanium (Ti)	PMSTIT	ICP/MS	0.0004	mg/L					
Uranium (U)	PMSUT	ICP/MS	0.0001	mg/L					
Vanadium (V)	PMSVT	ICP/MS	0.0002	mg/L					
Zinc (Zn)	PMSZNT	ICP/MS	0.002	mg/L					
Target PAHs									

LABORATORY ANALYTICAL METHODS
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PARAMETER	ETL CODE	METHOD	DETECTION LIMIT	UNITS	REQUIRED VOLUME	CONTAINER TYPE	SAMPLE PRESERVATION	HOLDING TIME	COMMENTS
Naphthalene	PAH7S	GC/MS	0.01	ppm	125 ml	G	in the dark at 4 °C	14 days	
Acenaphthylene	PAH7S	GC/MS	0.01	ppm					
Acenaphthene	PAH7S	GC/MS	0.01	ppm					
Fluorene	PAH7S	GC/MS	0.01	ppm					
Dibenzothiophene	PAH7S	GC/MS	0.01	ppm					
Phenanthrene	PAH7S	GC/MS	0.01	ppm					
Anthracene	PAH7S	GC/MS	0.01	ppm					
Fluoranthene	PAH7S	GC/MS	0.01	ppm					
Pyrene	PAH7S	GC/MS	0.01	ppm					
Benzo(a)Anthracene/Chrysene	PAH7S	GC/MS	0.01	ppm					
Benzo(b&k)fluoranthene	PAH7S	GC/MS	0.01	ppm					
Benzo(a)pyrene	PAH7S	GC/MS	0.01	ppm					
Indeno(c,d-123)pyrene	PAH7S	GC/MS	0.01	ppm					
Dibenzo(a,h)anthracene	PAH7S	GC/MS	0.01	ppm					
Benzo(g,h,i)perylene	PAH7S	GC/MS	0.01	ppm					
Alkylated PAHs									
Methyl naphthalenes	PAH7S	GC/MS	0.01	ppm			contained in above sample		
C2 Substituted naphthalenes	PAH7S	GC/MS	0.02	ppm					
C3 Subst'd naphthalenes	PAH7S	GC/MS	0.02	ppm					
C4 Subst'd naphthalenes	PAH7S	GC/MS	0.02	ppm					
Biphenyl	PAH7S	GC/MS	0.02	ppm					
Methyl biphenyl	PAH7S	GC/MS	0.02	ppm					
C2 Substituted biphenyl	PAH7S	GC/MS	0.02	ppm					
Methyl acenaphthene	PAH7S	GC/MS	0.02	ppm					
Methyl fluorene	PAH7S	GC/MS	0.02	ppm					
C2 Substituted fluorene	PAH7S	GC/MS	0.02	ppm					
Methyl phenanthrene/anthracene	PAH7S	GC/MS	0.02	ppm					
C2 Subst'd phenanthrene/anthracen	PAH7S	GC/MS	0.02	ppm					
C3 Subst'd phenanthrene/anthracen	PAH7S	GC/MS	0.02	ppm					
C4 Subst'd phenanthrene/anthracen	PAH7S	GC/MS	0.02	ppm					
Methyl dibenzothiophene	PAH7S	GC/MS	0.02	ppm					
C2 Substituted dibenzothiophene	PAH7S	GC/MS	0.02	ppm					
C3 Subst'd dibenzothiophene	PAH7S	GC/MS	0.02	ppm					
C4 Subst'd dibenzothiophene	PAH7S	GC/MS	0.02	ppm					
Methyl fluoranthene/pyrene	PAH7S	GC/MS	0.02	ppm					
Methyl benzo(a)anthracene/chrysen	PAH7S	GC/MS	0.02	ppm					
C2 Subst'd benzo(a)anthracene/chry	PAH7S	GC/MS	0.02	ppm					
Methyl benzo(b or k) fluoranthene/m	PAH7S	GC/MS	0.02	ppm					
C2 Subst'd benzo(b or k) fluoranthen	PAH7S	GC/MS	0.02	ppm					
Others									
Recoverable Hydrocarbons	HOG1S	Gravimetric	100	ppm	125 ml	G			
Volatile Organics	VOC 1S1	GC/MS	*		125 ml	G		14 days	
Texture	PSA1S	Hydrometer			125 ml	bag			

LABORATORY ANALYTICAL METHODS

(G = glass, P = plastic)

PARAMETER	ETL CODE	METHOD	DETECTION LIMIT	UNITS	REQUIRED VOLUME	CONTAINER TYPE	SAMPLE PRESERVATION	HOLDING TIME	COMMENTS
Total Organic Carbon	COM1S	Dichromate	0.10%		125 ml	G			
*Varies from 10 ppb to 2000 ppb, depending on compound									

APHA -American Public Health Association
FTIR - Fourier Transformed Infrared Spectrometer
EPA - Environmental Protection Agency
ICP - Inductively Coupled Plasma
AA - Atomic Absorption
CVAA - Cold Vapour Atomic Absorption
GC/MS - Gas Chromatography/Mass Spectroscopy

APPENDIX III

WATERCOURSE HABITAT MAPPING SYSTEMS

1. PURPOSE

This technical procedure details the classification system and map coding system to be used for habitat mapping a watercourse and provides instructions on habitat mapping procedures and standards. The habitat mapping system consists of two components: 1) The **Large River Habitat Classification System** - a general system for mapping large mainstem rivers; and, 2) The **Stream Habitat Classification and Rating System** - a more detailed system for mapping discrete channels units which is primarily used for intermediate rivers and smaller streams.

2. APPLICABILITY

This technical procedure is applicable to all personnel involved in habitat mapping of all sizes of watercourses in Alberta. The technique was developed primarily in Alberta in consultation with Alberta Fish and Wildlife. With respect to describing aquatic habitats it is applicable to some areas outside of Alberta but may be superseded by local criteria (e.g., B.C. MOE guidelines). This procedure may not be applicable to low gradient streams in the plains areas east of Alberta without some modification. Portions of the stream classification system were developed in relation to salmonid species and would require interpretation in order to be suitable for evaluating habitat conditions for other fish species.

3. DEFINITIONS

Each of the habitat mapping system components includes a set of habitat types or categories, the definitions of which are included in the two different classification systems in Tables 1 and 2. Some more general definitions are presented here.

3.1 Bank

Banks are components of a watercourse. Banks comprise the borders of the stream channel and form the typical boundaries of the channel. The banks are only in contact with the water during high flow or flood events. They typically have rooted vegetation to distinguish them from the normally active channel. Certain bank features can influence the quality of instream fish habitat, particularly with respect to cover for fish.

3.2 Bank Stability

The stability or erodability of the banks is based on factors such as bank slope, bank material, evidence of seepages, undercutting, erosion and slumping. Unstable banks are banks which shed material (bank material or vegetation) into the watercourse. The input of fine sediments into rivers and streams can result in detrimental sedimentation of instream habitats. Alternatively, vegetation and other bank materials which fall in the channel may be beneficial by providing cover for fish or may be detrimental by causing blockages.

3.3 Channel

The channel is the main component of a watercourse. It is the area of the watercourse that typically has flowing water, on at least a seasonal basis, and is usually defined by the area of the stream substrate. The channel is distinguishable from the banks since it has contact with flowing water for at least a portion of each season which usually prevents establishment of permanent vegetation.

3.4 Channel Form

Channel form refers to the cross-sectional shape of the channel as defined by the width:depth ratio of the channel. Channel form will range from deeply incised (low width:depth) to broad (high width:depth).

3.5 Channel Unit (sometimes referred to as habitat type)

Channel units are the hydraulic and morphological features of a stream channel. A channel unit is a section of channel which is homogeneous with respect to water depth, velocity and cover and is separated from other channel units by gradients in these parameters. Channel units are sometimes referred to as habitat types. The most common channel units are **pool**, **riffle** and **run**, although a total of 12 channel units have been defined (Table 2).

The pressure or absence of channel units in a watercourse is the determining factor when choosing which component of the habitat mapping system to employ when working on large rivers. If a river does not show any channel unit differentiation, the *Large River Habitat Classification System* is used. If channel units are present, then the *Stream Habitat Classification and Rating System* is used.

3.6 Channel Width

The horizontal distance along a transect line from stream bank to stream bank (rooted vegetation to rooted vegetation) at the normal high water marks measured at right angles to the direction of flow.

3.7 Cover

Cover is defined as aspects of the physical environment which provide resting places or protection from predators for fish. Cover consists of two categories: 1) **Instream Cover** - any feature which provides a velocity shelter (e.g., large substrate particles, submerged debris, etc.); 2) **Overhead Cover** - any feature which provides visual isolation for the fish (e.g., overhanging vegetation, undercut bank, turbulence, water depth, etc.).

When habitat mapping a watercourse, available cover for fish is evaluated for each section of the channel as it is assigned a classification. For the *Large River Habitat Classification System*, near-shore cover is a part of assigning shoreline habitat types. For the *Stream Habitat Classification and Rating System*, cover is evaluated when assigning a channel unit rating for pool and run channel units.

Cover is assessed by the visual examination and estimation of the quality and quantity of the available features with respect to instream and overhead cover for different fish life stages. Smaller life stages such as fry require smaller cover compared to adult fish. Areas of high quality cover would provide cover for a number of individuals of all life stages. Areas of moderate cover would provide little or no cover for adults but some cover for juveniles and fry. Areas of poor cover would not provide cover for adults and only limited cover for juveniles and fry.

3.8 Discharge

A measurement of the volume of surface water flowing in the stream channel, measured as the volume flowing past a specific point over a given time (i.e., m^3/s). Stream discharge has significant effect on water level and depth in the various habitat types. In order to reduce the effects of variable discharge levels on habitat mapping, it is recommended that habitat mapping be conducted during the late summer low flow period.

3.9 Habitat Associations

Habitat associations are the relationships between habitat categories and fish presence, abundance and use. If the habitat mapping activities are conducted in conjunction with fisheries inventory sampling, the species, numbers and life stages of fish captured should be assessed by habitat type. That is, for each habitat type (either shoreline habitat type or channel unit type and class) the types of fish captured should be recorded. This not done for each individual habitat area but for each general type (e.g., fish captured in all Class 1 Pool channel units, versus Class 2 Pools or each class of run habitat or in riffle channel units).

3.10 Habitat Map

A habitat map is a map of a section of watercourse showing the location and extent (i.e., boundaries) of each habitat type. What constitutes a habitat type depends on which of the two mapping systems is employed. With the *Large River Habitat Classification System*, habitat types are the bank habitat features as described in Table 1. With the *Stream Habitat Classification and Rating System*, the habitat types are the channel units described in Table 2.

3.11 Stream Confinement

Stream confinement refers to the confinement of the watercourse within the boundaries of the floodplain. It is the degree to which the lateral movement of the stream channel is limited by terraces or valley walls.

3.12 Stream Habitat

The physical stream environment which provides a place for aquatic biota (fish, invertebrates, plants, etc.) to live, grow and reproduce. Several types of fish habitat should be considered when habitat mapping and include **spawning habitat**, **fry nursery habitat**, **juvenile rearing habitat**, **adult feeding habitat** and **overwintering habitat**.

3.13 Stream Gradient

The slope of the streambed over which the stream runs. Some channel characteristics are directly related to the gradient. Examples include average velocity, substrate coarseness, and presence and extent of various channel units. Gradient classification: low <2%; medium 2-5%; high >5%.

3.14 Stream Pattern

Channel pattern describes the sinuosity of the channel or the degree to which the channel deviates from straightness. Sinuosity is the channels meander pattern which can range from straight to tortuously meandering.

3.15 Substrate

Stream substrate is the material found on the bottom of the channel portion of the watercourse. It refers to the surficial deposits that can be seen when viewing the streambed. As part of the habitat evaluation process, the substrate is evaluated with respect to particle size composition. Particle size composition refers to the proportions of the substrate particles within each category from a series of size categories. The size categories employed are presented on Table 4. These range from fine sediments (fines are particles <2 mm in size and include clay, silt and sand) through gravels, cobbles, boulders and bedrock. A substrate evaluation is conducted by visual observation. The observer estimates the percentage of the substrate particles, by surface area, in each of the size categories.

3.16 Undercut Bank

An undercut bank has been eroded at the base by flowing water, allowing water to be present underneath a portion of the bank. Although undercutting usually adds to bank instability, it may also provide cover for fish. If the overhanging portion of the bank provides and effective with >9 cm over water with a depth of >0.15 m, it provides a cover feature.

3.17 Watercourse

A natural or artificial waterway which periodically or continuously contains moving water. It has a definite channel, banks which normally confine water and displays evidence of fluvial processes.

3.18 Wetted Width

The width of the water surface measured at right angles to the direction of flow. Multiple channel widths are summed to obtain total wetted width.

4. REFERENCES AND SUGGESTED READING

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5. DISCUSSION

The habitat mapping and classification system is used to provide an ecologically relevant inventory of stream habitats within a designated study area. The mapping procedure is meant to describe the habitats available within the stream and to detail the location and extent of each habitat type/class. The habitat classification system is intended to be ecologically meaningful with respect to describing and cataloguing physical habitats in relation to the requirements of fish species and their various life stages (spawning, incubation, nursery, rearing, summer feeding, holding, overwintering, migration); and also to a lesser extent the relationship between physical habitat and benthic invertebrate productivity, at least with respect to fish food production. Researchers have determined that fish distinguish between the habitat types and sub-classes of habitat types that have been used to map streams. It is intended that this classification system will provide an ecological association of habitat characteristics and fish use/abundance.

Streams are habitat mapped to provide an inventory of the available habitats and to show the locations of habitats that are of importance to fish such as migration routes, spawning habitats and rearing habitats. Habitat maps are used in several applications. A habitat map can be used to show the habitat types that may be impacted by a proposed point disturbance such as a pipeline crossing or bridge construction. A habitat map of a length of stream can also be used to evaluate alternate locations of disturbances in order to minimize the impacts. Habitat maps may be applied to document changes to a stream environment over time, from disturbances or due to habitat rehabilitation or improvement programs. A primary use of the habitat mapping procedure is to provide an inventory of the habitats present in a stream that is subject to a proposed impact in order to ensure compliance with the Federal Regulations stating that "No Net Loss" of productive fish habitat is to occur as a result of a proposed disturbance or alteration of the stream.

The habitat mapping and classification system is composed of two components. The first is a general system called the **"Large River Habitat Classification System"** which is used to map large mainstem rivers such as the Peace or Athabasca rivers where habitat heterogeneity is less than for smaller streams, and use of a more detailed system is not appropriate. The second component is a the more detailed **"Stream Habitat Classification and Rating System"**, which is used for watercourses with a greater degree of channel complexity and which display different types of channel units. Whether the Large River Habitat Classification System (Table 1) is used or the Stream Habitat Classification and Rating System (Table 2) is used will depend on the size of the watercourse and the types of available habitats.

5.1 How to Draw a Habitat Map

It is best to have a **base map** prepared on which to record the habitat map. This is much preferred to drawing a free-hand schematic diagram of the watercourse while in the field. Base maps must usually be prepared in the office before heading out for the field. Air photos provide a good template to prepare basemaps. Air photos can be borrowed from the University Photo Library and photocopied to avoid having to purchase the photos. Topographical maps may also be used to prepare a base map but usually need to be enlarged on a photocopier to provide a map. For small streams which appear on the map as only a single line, it is still best to make an enlargement and then to draw in a second line parallel to the line on the map, approximating the channel. Base maps should be sufficiently large to allow for sufficient detail to be recorded.

Once a map or air photo has been obtained and the enlargement has been made, the watercourse can be traced onto a mylar overlay then traced onto waterproof paper to provide a base map for use in the field. Do not photocopy the mylar tracing onto waterproof paper as you will not be able to erase the lines. You may need to do to redraw portions of the channel if changes have occurred since the photo or map was made. It may be possible to reduce the number of steps here if you can use a light table to trace the map or photo directly to waterproof paper. While producing the base map, be sure to record the scale of the map, particularly if the original map was enlarged to make the base map. If the map used to produce the base map has a scale drawn on it, enlarge this scale along with the map to provide the scale for the base map.

Base maps are very important to provide an accurate representation of the watercourse, to aid in drawing in the boundaries between habitat types, the location of each habitat type and the area and length of each habitat type. This type of accuracy is very difficult with free-hand drawings made onto blank paper. If base maps are not available and this type of accuracy is required, a tape measure or hip chain can be used to measure the lengths for each habitat type. This will help ensure the free-hand drawing is accurate and to scale. Simple free-hand schematic drawings are acceptable if this type of accuracy is not required of a large number of streams are to be mapped making the preparation of a base map for each stream impractical.

The habitat map is produced by **delineating on the base map the location and extent of each of the habitat features**. To do this, the channel is divided into a continuous series of habitat types by drawing on the base map the boundaries of each habitat type and attaching a label to identify the habitat type. The habitat types to be drawn on the map depend on which of the two habitat mapping systems is being employed. For the *Large River Habitat Classification System*, bank habitat types are delineated. For the *Stream Habitat Classification and Rating System*, channel units are delineated. The habitat types to be included, the definitions of these features, and the abbreviations (map symbols) used to label each feature on the habitat map are detailed in Tables 1 and 2. It is important to draw on the map the boundary of each habitat type so that the length of each habitat type can be measured during the data analysis and interpretation process.

Also to be recorded during on the habitat map are the following: **Project Number/Title, Watercourse Name** or some type of identifier if the stream is unnamed, **Location** of the stream or section of stream being mapped, **Date**, and **Personnel (Crew)**. If more than one page is required to complete the habitat map for a given watercourse, record the **page number** on each page (i.e. Page 1 of 2, Page 2 of 2, etc.). If possible, the discharge or relative water level at the time of mapping should be recorded since the water level greatly affects the depths, and potentially the classification of the habitat types. For this reason, **it is preferable to conduct all habitat mapping procedures under late summer base flow conditions.**

Other information to be recorded on the habitat map in order to standardize the maps between projects and observers. The map must show a **North arrow**, an arrow showing the **direction of flow** in the channel, a **scale** or the words 'schematic diagram-not to scale, and a **legend** explaining the abbreviations and symbols used on the map. Before turning the map into drafting for preparation for inclusion in a report, add a **Figure Name** and **Number**.

In addition to habitat types, qualitative descriptions of substrate conditions can be recorded on to the habitat maps the general substrate conditions. Typically, this process would be applied during use of the *Stream Habitat Classification and Rating System* to describe the substrate conditions for specific areas, such as potential spawning habitats, or to describe the substrate type within each individual channel unit. Substrate composition is presented as the percent occurrence (visual estimation) of each substrate size category. Substrate particle sizes are presented on Table 4.

5.2 Large River Habitat Classification System

This is a general system based on gross morphology and habitat types along the river banks and shoreline. It consists of two primary components: 1) "major habitat type", which defines the type of channel present; and, 2) "bank habitat type", which details the structure of the bank and near shore habitats. "Special habitat features" considered significant to fish distribution/use in these large rivers are also to be included on the map. Table 1 presents the details of the large river habitat classification system.

The Large River Habitat Classification System is to be used on large rivers which do not show any differentiation of channel units; distinct pool, riffle and run habitats are absent. In most large rivers, such as the Peace or Athabasca Rivers, the lower segments of the river are wide with relatively low gradients and large flow volumes. Channels do not contain physical or hydraulic features which create riffle/pool sequences. There is little or no differentiation of habitat types in the channel. It should be realized, however, that at any given point, depths across the width of the channel may vary. Habitat features that fish might use are generally associated with shoreline areas, areas of instream islands and tributary confluences. These features should be identified on the habitat map.

Shoreline habitats change as the structure of the banks change, providing one of the few characteristics that can be mapped. Elements of the bank structure which affect fish habitat include: water depth along the shoreline, substrate type and cover features to substrate, fallen debris/vegetation, and protrusions from the bank which create low velocity related habitats. Therefore, bank features are the basis of the Large River Habitat Classification System.

To draw a habitat map using the large river system, begin by **dividing the length of the watercourse in the study area into *Major Habitat Types***, depending on the number of permanent/vegetated islands present. This can often be done from the base map or air photo which will normally show all permanent islands. Any islands not on the original base map should be drawn onto the habitat map. Next, the **shorelines should be divided into *Bank Habitat Types*** according to the criteria in Table 1. This should be done for both shorelines as well as the shorelines around all permanent islands. Remember to show the boundaries of each Bank Habitat Type. This is usually done by demarcating the boundaries with a short line drawn at the shoreline, perpendicular to the shoreline, and labeling the area inside the boundaries with the appropriate Bank Habitat Type (e.g. A1, E5, etc.). Bank Habitat Types should be a continuous series along the shorelines without any blank, unlabelled sections. For any tributaries which enter the river within the study area, examine the tributary mouth and **label the tributary confluence according to the categories in Table 1.** To complete the map, **draw in the location and extent, again showing the boundaries, of all *Special Habitat Features***, as defined in Table 1.

5.3 Stream Habitat Classification and Rating System

This is a detailed mapping system based on individual channel units. These units are defined as sections of stream of homogenous with respect to depth, velocity and cover. The extent of each channel unit should be delineated on the map, as should the class rating for each unit (where appropriate). Some of the channel units also have modifiers (types) which should also be recorded. Table 2 presents the details of the stream habitat classification and rating system. This system is employed for mapping all watercourses which have distinct channel units such as pool, riffle and run habitats.

To draw a habitat map using the stream mapping system, the **length of stream in the study area is divided into a continuous series of channel units.** Table 2 presents the definitions for each of the 12 types of channel unit. Lines drawn across the channel are used to delineate the location and extent of each channel unit. The appropriate channel unit symbol (abbreviation) is used to label the channel unit. In addition to the channel unit type, three types of channel units have different sub-classes. **Run, pool and impoundment channel unit types should be further divided into Class 1, Class 2 or Class 3, depending on water depth and available cover for fish**, as described in Table 2. The classification should be included in the label on the habitat map (e.g. a riffle would simply be labeled RF on the map but a pool would be labeled as P1, P2 or P3, depending on the Class). Make sure the entire length of the channel in the study area has been divided into channel units on the map, including boundary lines, and that each unit has a complete label. In order to better define the available habitats in the study area, **record the maximum water depth in each channel unit and include it in the channel unit label** (e.g. a Class 1 pool that has a maximum depth of 4.0m should be labeled P1-4.0m).

Dividing the run, pool and impoundment units into subclasses is based on water depth and the quality of available cover for fish. Some general water depth guidelines are included in Table 2 to assist in classifying these channel units. However, these depths are not the only criteria. The classification of each channel unit is also based on its potential use by different life stages of fish (Table 1). For example, if a run channel unit is slightly shallower than the minimum depth for a Class 1 (Table 3), but high quality cover for adult fish is present, it would be classified as Class 1. Conversely, a run channel unit that is deeper than the minimum depth for a Class 1 run but with very poor cover would be classified as a Class 2 run.

The use of the channel unit and class categories are meant to relate instream habitats to the potential utilization by fish species and life stages. Much of the criteria used to establish the classifications are based on the habitat requirements of salmonid species. In Alberta, this includes non-anadromous trout and whitefish. Table 5 provides the fish utilization expected for each of the habitat types. The overall goal of the Stream Habitat Classification and Rating System is to provide habitat classifications that relate to fish utilization. Therefore, the associations within Table 5 should be kept in mind when assigning classifications.

TABLE 5

CHANNEL UNIT CLASSIFICATION AND HABITAT ASSOCIATIONS FOR SALMONIDS

Spawning		Nursery/Rearing	Adult Feeding	Overwintering
Trout (gravel sub.)	Whitefish (cobble sub.)			
RF	R2	RF	R1	P1
RF/BG	R2/BG	RF/BG	R2	R1
R3	RF	R1	R2/BG	R2
R3/BG		R2	P1	R2/BG
		R2/BG		
		R3/BG		

From Table 5 it can be seen that the potential utilization of some channel units, particularly those suitable for spawning, depends on substrate particle size. Therefore, a quick assessment of substrate size should be made for each channel unit. **For each channel unit record the dominant and co-dominant substrate size classes** and include this information with the channel unit label. For some projects, substrate particle sizes should be recorded in full detail as presented on Table 4. However, for most projects general substrate sizes could be used such as fines, gravel, cobble and boulder, without further dividing the substrate particles. For example, a Class 2 run channel unit with a maximum depth of 0.8 m and a cobble dominant and gravel co-dominant substrate would be labeled *R2-0.8m, cobble/gravel.*

Table 3 presents additional habitat features along with their symbols and abbreviations. These features include structures that would occur at specific points rather than for sections of the channel such as beaver dams or ledges. Other relevant features in Table 4 include aspects of cover such as areas of undercut or unstable banks, overhanging vegetation, inundated vegetation, debris piles or root wads. **Draw the appropriate symbol on the map to show the location of these features.**

5.4 Habitat Map Interpretation

Once the habitat map is completed, it is analyzed to determine the relative proportion of each habitat type in the study area. Measure the overall length of watercourse in the study area (i.e. section of watercourse habitat mapped) and the length of each habitat type; either bank habitat type (if using the large river system) or channel unit type (stream system). Sum the lengths of stream in each habitat type and calculate the percent composition, by length, of each habitat type for the study area as a whole. For the large river mapping system, the results will be presented as the percent composition of each bank type: e.g. 60% E5, 30% A1, and 10% D1. For the stream mapping system, the results are presented for each type and class of channel unit; e.g. 40% RF, 5% R1, 10% R2, 20% R3, 5% P1, 15% P2 and 5% P3.

If a coincidental fisheries inventory was conducted during the classification of fish habitat associations, observed fish use for each habitat type along with the proportion of each type should be included for a more accurate assessment of fish use in the study area. Otherwise, Table 5 can be compared to the habitat composition of the stream to evaluate the potential fish use in the study area.

TABLE 1: LARGE RIVER HABITAT CLASSIFICATION SYSTEM

MAJOR HABITAT TYPES

Type	Symbol	Description
Unobstructed channel	U	single main channel, no permanent islands, side bars occasionally present, limited development of exposed mid-channel bars at low flow
Singular island	S	two channels around single, permanent island, side and mid-channel bars often present at low flow
Multiple island	M	more than two channels and permanent islands, generally extensive side and mid-channel bars at low flow

BANK HABITAT TYPES

Type	Symbol	Description
Armoured/Stable	A1	largely stable and at repose; cobble/s.boulder/gravel predominant; uniform shoreline configuration; bank velocities low-moderate; instream/overhead cover limited to substrate and turbidity
	A2	cobble/s.-l.boulder predominant; irregular shoreline due to cob/boulder outcrops producing BW habitats; bank velocity low (BW)-mod; instream/overhead cover from depth, substrate and turbidity
	A3	similar to A2 with more l.boulder/bedrock; very irregular shoreline; bank velocities mod-high with low velocity BW/eddy pools providing instream cover; overhead cover from depth/turbidity
	A4	artificial rip-rap substrates consisting of angular boulder sized fill; often associated with high velocity areas; shoreline usually regular; instream cover from substrate; overhead cover from depth/turbulence
Canyon	C1	banks formed by valley walls; l.cobble/boulder bedrock; stable at bank-water interface; typically deep/high velocity water offshore; abundant velocity cover from substrate/bank irregularities
	C2	steep, stable bedrock banks; regular shoreline; mod-deep/mod-fast water offshore; occasional velocity cover from bedrock fractures
	C3	banks formed by valley walls, primarily fines with some gravel/cobble at base; moderately eroded at bank-water interface; mod-high velocities; no instream cover
Depositional	D1	low relief, gently sloping bank; shallow/slow offshore; primarily fines; instream cover absent or consisting of shallow depressions or embedded cobble/boulder; generally associated with bars
	D2	similar to D1 with gravel/cobble substrate; some areas of higher velocities producing riffles; instream/overhead cover provided by substrate/turbulence; often associated with bars/shoals
	D3	similar to D2 with coarser substrates (cobble/boulder); boulders often imbedded; mod-high velocities offshore; instream cover abundant from substrate; overhead cover from turbulence
Erosional	E1	high, steep eroded banks with terraced profile; unstable; fines; mod-high offshore velocity; deep immediately offshore; instream/overhead cover from submerged bank materials/vegetation/depth
	E2	similar to E1 without the large amount of instream vegetative debris; offshore depths shallower
	E3	high, steep eroding banks; loose till deposits (gravel/cobble/sand); mod-high velocities and depths; instream cover limited to substrate roughness; overhead cover provided by turbidity
	E4	steep, eroding/slumping highwall bank; primarily fines; mod-high depths/velocities; instream cover limited to occasional BW formed by bank irregularities; overhead cover from depth/turbidity
	E5	low, steep banks, often terraced; fines; low velocity; shallow-moderate; no instream cover; overhead cover from turbidity
	E6	low slumping/eroding bank; substrate either cobble/gravel or silt with cobble/gravel patches; moderate depths; mod- high velocities; instream cover from abundant debris/boulder; overhead cover from depth/turbidity/overhanging vegetation

SPECIAL HABITAT FEATURES

Type	Symbol	Description
Tributary confluences	TC	confluence area of tributary entering mainstem
[sub-classified according	TC1	intermittent flow, ephemeral stream
to tributary flow and	TC2	flowing, width <5m
wetted width at mouth at	TC3	flowing, width 5-15m
the time of the survey]	TC4	flowing, width 16-30m
	TC5	flowing, width 31-60m
	TC6	flowing, width >60m
Shoal	SH	shallow (<1m deep), submerged areas in mid-channel or associated with depositional areas around islands/side bars
	SHC	submerged area of coarse substrates
	SHF	submerged area of fine substrates
Backwater	BW	discrete, localized area exhibiting reverse flow direction and, generally, lower velocity than main current; substrate similar to adjacent channel with more fines
Rapid	RA	area with turbulent flow, broken surface (standing waves, chutes etc.), high velocity (>1 m/s), armoured substrate (large boulder/bedrock) with low fines
Snye	SN	discrete section of non-flowing water connected to a flowing channel only at its downstream end, generally formed in a side channel or behind a peninsula (bar)
Slough	SL	non-flowing water body isolated from flowing waters except during flood events; oxbows
Log Jam	LJ	accumulation of woody debris; generally located on island tips, heads of sidechannels, stream meanders; provide excellent instream cover

TABLE 2: STREAM HABITAT CLASSIFICATION AND RATING SYSTEM

(Adapted from R.L.&L. 1992 & Hawkins et. al 1993)

Channel Unit	Type	Class	Map Symbol	Description
Falls			FA	Highest water velocity; involves water falling over a vertical drop; impassable to fish
Cascade			CA	Extremely high gradient and velocity; extremely turbulent with entire water surface broken; may have short vertical sections, but overall is passable to fish; armoured substrate; may be assoc. with chute (RA/CH)
Chute			CH	Area of channel constriction, usually due to bedrock intrusions; associated with channel deepening and increased velocity
Rapids			RA	Extremely high velocity; deeper than riffle; substrate extremely coarse (Lcobble/boulder); instream cover in pocket eddies and associated with substrate
Riffle			RF	High velocity/gradient relative to run habitat; surface broken due to submerged or exposed bed material; shallow relative to other channel units; coarse substrate; usually limited instream or overhead cover for juvenile or adult fish (generally ≤0.5m deep)
Run (glide)			R	Moderate to high velocity; surface largely unbroken; usually deeper than RF; substrate size dependent on hydraulics
	Depth/Velocity Type			Run habitat can be differentiated into one of 4 types: deep/slow, deep/fast shallow/slow, or shallow/fast
		Class 1	R1	Highest quality/deepest run habitat; generally deep/slow type; coarse substrate; high instream cover from substrate and/or depth (generally >1.0 m deep)
		Class 2	R2	Moderate quality/depth; high-mod instream cover except at low flow; generally deep/fast or moderately deep/slow type (generally 0.75-1.0m deep)
		Class 3	R3	Lowest quality/depth; generally shallow/slow or shallow/fast type; low instream cover in all but high flows (generally 0.5-0.75m deep)
Flat			FL	Area characterized by low velocity and near-laminar flow; differentiated from pool habitat by high channel uniformity; more depositional than R3 habitat
Pool			P	Discrete portion of channel featuring increased depth and reduced velocity relative to riffle/run habitats; formed by channel scour
		Class 1	P1	Highest quality pool habitat based on size and depth; high instream cover due to instream features and depth; suitable holding water for adults and for overwintering (generally >1.5m deep)
		Class 2	P2	Moderate quality; shallower than P1 with high-mod instream cover except during low flow conditions, not suitable for overwintering
		Class 3	P3	Low quality pool habitat; shallow and/or small; low instream cover at all but high flow events
Impoundment		Class 1-3	IP (1-3)	Includes pools which are formed behind dams; tend to accumulate sediment/organic debris more than scour pools; may have cover associated with damming structure; identify as Class 1, 2 or 3 as for scour pools
	Dam Type			Three types of impoundments have been identified based on dam type; debris, beaver and landslide
Backwater			BW	Discrete, localized area of variable size exhibiting reverse flow direction; generally produced by bank irregularities; velocities variable but generally lower than main flow; substrate similar to adjacent channel with higher percentage of fines
Snye			SN	Discrete section of non-flowing water connected to a flowing channel only at its downstream end; generally formed in a side-channel or behind a peninsula
Boulder Garden			BG	Significant occurrence of large boulders providing significant instream cover; always in association with an overall channel unit such as a riffle (RF/BG) or run (e.g. R1/BG)

TABLE 3

ADDITIONAL HABITAT MAPPING SYMBOLS

Feature	Abbr.	Symbol	Description
Ledge	LE		Area of bedrock intrusion into the channel; often associated with chute or plunge pool habitat, may have a vertical drop affecting fish passage
Overhead Cover	OHC		Area of extensive or high quality overhead cover
Instream Cover	ISC		Area of high quality instream cover (velocity shelter) for all life stages
Undercut Bank	UCB		Area of extensive/high quality undercut bank providing overhead cover
Unstable Bank	USB		Area of unstable bank with potential to collapse instream, affecting instream habitat or producing sedimentation
Overhanging Veg.	OHV		Area of high quality overhanging vegetation providing overhead cover and stream shading
Inundated Veg.	INV		Area of inundated vegetation; either submergent macrophytes or flooded terrestrial
Debris Pile	DP		Debris pile (e.g. log jam) which influences instream habitat; include effect on cover
Root Wad	RW		Fallen terrestrial vegetation large enough to provide cover for fish
Beaver Dam	BD	XX	Include effect on fish passage

Considerations

Overhead cover includes overhanging vegetation, undercut bank or debris which has an effective width >9 cm over water with a depth > 0.15 m.

Instream cover is provided by aquatic vegetation or by substrate particles as large or larger than small cobbles when associated with water depths >0.15 m.

Deep water may provide cover if depth is >0.5 m.

Vertical drops >0.8 m are potentially impassable for resident trout species.

Generally, suitable spawning sites for trout occur in pool tail-outs, riffles and the transition areas from runs to riffles where the dominant substrate sizes range from small gravel to small cobble, fines (particles <2 mm) comprise <30% of the substrate, minimum water depths exceed 0.15 m, and velocities range from 0.3 to 1.0 m/s. Individual patches of gravel must be 1-2 m^2 to be considered as spawning habitat.

TABLE 4

SUBSTRATE CRITERIA

SUBSTRATE DEFINITIONS, CODES AND SIZE-RANGE CATEGORIES

CLASS NAME	SIZE RANGE	
	MM	INCHES
Clay/Silt	<0.06	<0.0024
Sand	0.06-2.0	0.0024-0.08
Small Gravel	2-8	0.08-0.3
Medium Gravel	8-32	0.3-1.3
Large Gravel	32-64	1.3-2.5
Small Cobble	64-128	2.5-5
Large Cobble	128-256	5-10
Small Boulder	256-762	10-30
Large Boulder	>762	>30
Bedrock	-	-

APPENDIX IV

FISH INVENTORY METHODS

1. PURPOSE

This technical procedure presents the techniques and methodologies used for standard fisheries sampling during fish inventory studies for the purposes of determining species presence, distribution, relative abundance, basic population characteristics and for conducting population estimates. Decisions regarding the type of sampling gear to use, the specific techniques to be employed and the timing of sampling will be determined prior to the commencement of the field study by the project team or project manager. However, due to the nature of fisheries work, some decisions regarding sampling specifics will depend upon conditions in the field. The methods for general fisheries inventory work are covered in this technical procedure. Other technical procedures are required in addition to this one in order to conduct fish sampling for specific tasks such as biomarking/fish health studies. This technical procedure does not detail the Quality Assurance/Quality Control requirements for components of field programs, such as note taking/data recording, as they are included in other documents.

2. APPLICABILITY

This technical procedure is applicable to all personnel involved in fisheries surveys for lakes and streams, including all sizes and orders of streams. It covers sampling equipment and techniques currently owned/used by Golder. Additional techniques are available which may be the most suitable method for specific circumstances or project requirements. If this is the case, the project manager must authorize the use of any new technique or the purchase of additional equipment.

3. DEFINITIONS AND METHODS

3.1 Abundance, Relative

The proportional representation of a species in a sample or a community. In fisheries inventories, relative abundance is typically used to describe the relative number of fish captured for each different species at a sampling site. Relative abundance can also be determined for the same species at different sites or in different seasons. It can also be determined for different life stages of the same species.

In some limited cases, the number of fish captured can be used to describe relative abundance. This is suitable for a single effort in a single sampling area where relative abundance is simply the relative number of fish captured. For example, if 20 fish of one species and 10 fish of another species were captured in 100 seconds of electrofishing at a site, species one is determined to have a relative abundance twice that of species two.

For any sampling situation which is more complicated, Catch-Per-Unit-Effort (CPUE) values must be calculated to determine relative abundance. CPUE values take into account the sampling effort required to catch the fish as well as the number of fish captured. For example, if 20 fish of one species were captured in 100 seconds of electrofishing at one site, and 20 fish of the same species were captured in 200 seconds of electrofishing at a second site, CPUE data shows that this species has a relative abundance at the first site which is twice that of the second site. In this example, twice the effort was required to capture the same number of fish at site two. This example also shows why it would be unsuitable to derive conclusions about relative abundance based solely on the numbers of fish captured.

In order to be able to determine relative abundance, you must record all sampling efforts in a manner suitable for calculating CPUE data.

3.2 Ageing Structures

Ageing structures are bony parts of the fish which are taken for ageing analyses. In fish from temperate zones, these structures contain annual bands (annuli) which delineate seasonal variation in growth which can be counted to determine the fishes' age. Primary examples of these structures are scales, fin rays, saggital otoliths, cleithra and opercula. The appropriate ageing structures to collect vary according to fish species and life stage and include lethal and non-lethal sampling measures. Consult the table of "**Recommended Fish Ageing Structures**" (available in the aquatics reference file) for the appropriate structure and collection method for each species. With respect to fish ageing, all procedures used by Golder (i.e., the ageing structures which are collected and the methods used to determine age) conform to the manual of Fish Ageing Methods for Alberta (Mackay et al. 1990).

Following removal from the fish, ageing structures should then be placed in a "scale envelope", which consists of a small envelope which has been stamped with fields for recording the following information:

- date
- fish number
- species
- fork length
- weight
- life history stage
- sex
- state-of-maturity
- sampling gear
- sampling location
- ageing structure collected
- project number

Blank envelopes are ordered in batches of 1000 and must be stamped prior to use. If your project includes the collection of ageing structures, it may be necessary to order the required envelopes and stamp them before heading out into the field.

The scale envelopes should be allowed to dry overnight before being stored. Upon returning from the field, the envelopes should be stored frozen in a one of Golder's freezers.

3.3 Anaesthetic

An anaesthetic is used in situations requiring live fish to be removed from the water and handled for extended periods, such as during surgery to implant radio transmitters, or to quiet fish for measurements. The anaesthetic commonly used by Golder is MS-222, known as tricaine methanesulfonate. The concentration of anaesthetic to be used depends on the required level of sedation. For surgery, which requires the fish to remain sedated for a period of 5-10 minutes, a concentration of 100 mg/L is used (i.e. 4 g of MS-222 in 40 L of water). The fish is placed in the anaesthetic bath for 2-4 minutes until the desired level of sedation is reached. Care must be taken as overdoses lead to direct mortality. When monitoring the fish in the anaesthetic solution, watch for loss of coordination (when the fish no longer keeps itself upright) and respiration rate. Towards the end of the anaesthetization period, the fish will begin to "Cough".

Use of anaesthetic for quieting fish for measurements is not typically recommended unless the fish is difficult to handle or may injure itself. Fish anaesthetized with MS-222 are not recommended for consumption by anglers for a period of 2-4 weeks following exposure to the anaesthetic. Therefore, use only on fish which will not be captured and consumed or with permission of Alberta Fisheries Management Division.

3.4 Biomass

Biomass is the total mass (weight) of fish, or of fish of a given species, within a study area. It is a component of population estimates, as an estimate of the total number of fish in the study area is required to calculate biomass. Using either total removal data or a mark/recapture population estimate for the study site, the total biomass is calculated by multiplying the total population of fish by the average weight of the fish captured. Results can be expressed as units of weight over study area dimensions (e.g. kg/m of stream, kg/m^2 of lake).

3.5 Capture/Sampling Techniques

The following sampling techniques are used to capture fish. Some techniques are very specific to one life stage while others are more general. All sampling techniques have some degree of sampling bias associated with them with respect to fish size selectivity and sampling efficiencies based on environmental parameters such as water depth, conductivity, stream size etc. It is important to understand these biases when designing or implementing a study plan and when interpreting the data and drawing conclusions from the results.

3.5.1 Airlifting

Airlift sampling is used to collect fish eggs from the substrate for species which are broadcast spawners (i.e. do not bury their eggs). It can be used simply to determine if incubating eggs are present or to determine the relative density of eggs at each spawning site. The airlift sampler consists of a gas powered generator and compressor unit, a length of hose, an airlift head and couplers to connect the hose to the compressor and airlift head. The airlift head is attached to a long pole and consists of a 4" or 6" diameter hollow tube with a 90° bend at the upper end. The lower end of the airlift head has an internal tube which runs around the internal circumference and which is perforated. With the lower end of the airlift head held against the substrate, air is pumped from the compressor through a hose and into the perforated tube. Air rising inside the airlift head creates a vacuum effect which lifts loose particles up from the substrate. A removable collection bag placed over the upper end of the airlift head collects the particles. The sample is dumped into a sampling tray and examined for the presence of eggs.

This technique is employed when sampling water too deep to kick sample or when a quantitative sample is required. Since the area (cm^2) of the airlift head is known, simply count the number of times the head is touched to the substrate for each sample in order to determine the number of eggs/cm^2 in the sample. Quantitative sampling can be used to determine the relative use of the spawning areas sampled, as determined by egg density. Remember to record the size of the airlift head used.

3.5.2 Angling

Angling refers to the use of angling gear, such as rod and reel, to sample for fish. Angling is an active technique using lures, bait or flies. Leaving a static, baited line in one place is referred to as a Set Line and is not an angling technique. On the other hand, jigging with a baited line would be an angling technique.

Sampling effort should be recorded as both the number of hours angled and the number of angling tools used. It would be recorded as angler-hours, or as rod-hours or some equivalent if more than one piece of angling gear is used per angler. The types of hooks, size of hooks, and number of hooks should also be recorded. In addition, notes on the types of habitats fished and the length of shore line covered if trolling is conducted should be recorded.

3.5.3 Drift Net

Drift net is a passive sampling technique for use in flowing water for the capture of life stages which are moving or drifting downstream. A drift net consists of a long, tapering net with an open mouth at the upstream end and a detachable sample bottle at the downstream end. Drift nets are anchored in place in the stream and filter the water passing through them, collecting materials from the water column. They can be placed to sample the bottom, middle or top of the water column or can be stacked to sample the entire water column. At regular intervals, the nets are removed and cleaned by dumping the collection jars into a sampling tray and examining the sample for the presence of fish. Typically the drift nets are checked and cleaned twice per day, once first thing in the morning and once again in the evening. Record the catch separately for each period in order to be able to determine diurnal patterns.

Sampling effort is usually recorded as the number of hours between net cleanings to determine catch/hour. If more detail is required, it is also possible to estimate the volume of water sampled by the net during the period between net cleanings to determine the catch/m^3. To do this, measure the velocity of the water at the sampling site before setting the drift net and again after lifting the net for cleaning to determine the average water velocity through the net. Multiply the average velocity (m/s) by the area of the net mouth (m^2) to get the volume sampled per unit time (m^3/s) (remember to record the size of the drift net mouth). Multiply this value by the time the net was in place to calculate the total volume sampled. For this calculation, the drift net mouth must be completed submerged.

3.5.4 Electrofishing

Electrofishing refers to the use of electricity to stun and capture fish. An electrical current is passed between electrodes placed in the water and the resulting electrical field attracts passing fish (galvanotaxis) toward the positive electrode (anode). As fish pass close to the anode they encounter an increasingly stronger current gradient which acts as a narcotic and stuns the fish (galvanonarcosis), allowing them to be easily dip-netted from the water. Once captured, the fish may be identified, weighed, measured, tagged and then returned to the water. Fish taken by electrofishing revive quickly when returned to the water. Effort is automatically recorded by the electrofishing unit as the number of seconds of active electrofishing (i.e. the time current is applied to the water). **Record the effort (seconds) immediately after completion of sampling and reset the timer to zero.** Electrofishing techniques require experienced operators in order to reduce injury to the fish and to eliminate potential injury to the personnel involved. Safety training or working with experienced personnel is required for operating electrofishing equipment.

Backpack Electrofishing

Backpack electrofishing is a sampling technique for small, wadable streams. A backpack electrofisher consists of a portable electrofishing unit and a power source (12v battery or mini generator) attached to a pack frame. It is equipped with a hand held, button-operated anode pole and a cathode plate which is left trailing in the water. The operator wears the pack unit and uses the button switch to activate the anode in order to stun fish while wading instream. One or more assistants wading next to the operator use dip nets to capture the stunned fish. The assistant also adjusts the electrofisher settings for the operator and monitors the electrical output. Sampling is normally conducted while moving upstream so that fish are not disturbed, prior to being sampled, by disturbances to the stream bed and material moving downstream with the flow.

Boat Electrofishing

Boat electrofishing is an extremely effective sampling technique for moderately shallow water and is used for intermediate streams, large rivers and shallow littoral areas in lakes. Two types of boat electrofisher are available, both of which consist of an electrofishing control box which is powered by a 5,000 watt generator. The ***portable boat electrofisher*** has a free control box and generator which can be loaded into an inflatable boat (Zodiac) and is ideal for small or intermediate sized rivers which cannot be waded and which cannot be effectively sampled by the low current outputs provided by a backpack electrofisher. Two anode configurations are possible, depending on stream size, and include either a hand-held, button operated anode pole or a foot-switch operated portable boom system. In both cases, a floating cathode plate is employed. The boat can be drifted downstream or an outboard jet can be used to provide increased mobility. In comparison, an ***electrofishing boat*** consist of an 18' aluminum river boat with an integral electrofisher control box and generator. It is also equipped with a work platform and flow-through live well for holding fish. It has a foot-switch operated anode boom system and uses the boat hull as the cathode. Boat electrofishers are designed for any intermediate or large river which is deep enough to allow a boat of this size to float and which has a site with a suitable boat launch. This unit has the largest anode/cathode surface area and is capable of generating the largest electrical field and the highest current outputs. Boat electrofishing sampling for both types of units is usually conducted while floating downstream, as this makes fish easier to dipnet and puts less stress on the dipnets and anodes.

3.5.5 Emergent Trap

An emergent trap is a passive sampling technique specifically designed to capture fry as they emerge from the substrate following hatching. A typical emergent trap consists of a square metal frame (0.3m x 0.3m) covered with a small mesh net and collection bottle. The mouth of the trap is placed on top of the substrate at a known or suspected spawning area where incubating eggs are known or thought to be present. It is left in place through the incubation period. Once the fry have hatched and absorbed their yolk sacs they emerge from the substrate. The fry from the eggs which were located under the trap mouth will be captured by the trap.

Emergent traps can be used to verify a suspected spawning area or to check for hatching success at a know spawning site.

3.5.6 Fry Traps

A fry trap is a passive sampling technique used to capture fry which are drifting downstream in flowing water. It is suitable for capturing fry which are larger than post-emergent size but which are not yet strong swimmers. The fry trap is anchored to the stream bed using 2 rebar posts and consists of a large metal frame open at the upstream end and otherwise covered with small mesh metal screening. "Wings" lead from the trap mouth into a low velocity area at the downstream end of the trap where the fry accumulate. The trap is designed so that it will pivot at the anchor point on the stream bed. To check the trap, simply tilt it forward and hold a collection bucket in front of the "top" of the low velocity holding cell. Water and fry from the holding cell will pour into the bucket as the trap is tilted. Typically the traps are checked and cleaned twice per day, once first thing in the morning and once again in the evening. Record the catch separately for each period in order to be able to determine diurnal patterns.

Sampling effort is usually recorded as the number of hours between trap cleanings to determine catch/hour. If more detail is required, it is also possible to estimate the volume of water sampled by the trap during the period between trap cleanings to determine the catch/m^3. To do this, measure the depth and velocity of the water at the sampling site before setting the trap and again after checking the trap to determine the average water depth and velocity through the trap during the sampling period. Multiply the average depth (m) by the average velocity (m/s), then by the width of the trap mouth (m) to get the volume sampled per unit time (m^3/s) (remember to record the width of the trap mouth). Multiply this value by the time the trap was in place to calculate the total volume sampled.

3.5.7 Gill Netting

A method of capturing fish that involves the setting of nets of various mesh sizes anchored in place in a river or lake. A gill net consists of netting suspended between a weighted "lead" line and buoyant "float" line which, when set, forms a vertical wall of netting. The lead line is attached at both ends to heavy weights to hold it in place and keep the net taught. The float line is attached at either end to floats. In Alberta, the floats must each consist of a pole which stands upright at the water surface and extends above the water surface for a minimum of 1.0 m. The top of the poles must have a blaze red or orange flag measuring at least 20 cm x 20 cm and marked with the Fish Collection Licence Number in 20 mm high letters. Typically, we use sandbags filled with rocks or sand from the gill net site for lead line weights. This way, all we have to carry with us to the site is a few empty sandbags. New gill nets need to have a length of sideline attached to either end which extends from the float line to the lead line to take the tension when the net is lifted to ensure that the mesh does not rip.

Gill nets are designed to function by catching on the gill covers of fish as they attempt to swim through. Fish of a size for which the gill net mesh size is designed swim into the net but can only pass partway through the mesh. When the fish struggles the twine slips behind the gill covers (opercula) and the fish becomes "gilled". Therefore, the mesh size of the gill net is important when selecting a net or nets for your sampling activity as gill netting can be a very size selective technique.

Gill net mesh size can be measured as either the stretch measure or square measure of the openings in the mesh. At Golder, we always use the stretch measure to identify our gill nets and when reporting results. The stretch measure is the distance between two opposite corners of the square mesh opening, when the square is stretched flat. Gill net mesh sizes typically range from 1.9 to 14.0 cm (3/4"-5.5"). As most gill nets are sold using imperial units of measure, the following table will help you convert mesh sizes to metric units.

Stretch Mesh Sizes:

Imperial (inches)	3/4	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Metric (cm)	1.9	2.5	3.8	5.1	6.3	7.6	8.9	10.2	11.4	12.7	14.0

Gill net meshes are constructed either of monofilament or nylon. Monofilament is sturdier and longer lasting but gill nets made from this material do not compress and take up a much larger volume than a nylon net of the same dimensions. For longer nets, the volume of a monofilament net becomes significant.

Gill nets can be simple or multi-mesh. Simple nets consist of one mesh size only, although different nets may have different lengths and depths. Multi-mesh nets are also called "gang" nets and consist of more than one mesh size. Each mesh size occurs in a discreet section of the net which is called a panel. Gang nets typically have from two to five different mesh sizes or panels. Usually, each panel has the same length, although this is not always the case. An important component of recording sampling effort is to record the dimensions of all gill nets that are set. Record the depth of each net as well as the total length. Also record the number of panels, the mesh size of each panel and the length of each panel. Effort should also be recorded as the number of hours the net is set and CPUE is expressed as either duration (hrs), panel-hours, or meter-hours, depending on the type and variety of nets set.

Since the size of the mesh will have a major role in determining the size of fish (i.e. species or life stages) that will be captured, it is extremely important to record the mesh sizes of any gill net used. It is also important to record the catch for each individual panel or mesh size. The field form used to record the catch has a space for recording the mesh size for each fish captured. When removing fish from the gill net, the fish must be separated by mesh size.

Selecting a gill net or nets to be used for a project will vary depending on your sampling goals. Long gang nets with several different mesh sizes, from small to large mesh, are best for general inventory sampling and have the smallest level of sampling bias. For single mesh nets or nets with few panels, it is generally true that the larger the mesh size used the larger the fish that will be captured. The small 1.9 cm mesh nets will capture fish as small as the larger minnow species and juvenile life stages of larger fish. Mesh sizes in the range of 5.1-7.6 cm are typically used for salmonid species while larger mesh sizes will be employed to capture adult northern pike and burbot. Most gill nets will capture a larger size range of fish than mesh size would dictate as some species will be captured without necessarily being "gilled". For example, suckers may be entangled by their large lips and northern pike often bite and roll in the mesh, becoming entangled in mesh sizes too small to capture them by gilling. Bullheads on the other hand are often captured in mesh sizes too large to gill them when their pectoral and dorsal spines become entangled in the mesh.

Nets selected for sampling in rivers are generally different from those used in lakes. River gill nets typically have large floats attached to the float line for added buoyancy. Shorter nets are used as they must be set in low velocity pockets such as backwaters or pools and heavy weights are used to anchor the net so that it will remain in position in flowing water. Caution should be taken when setting nets in a river at high stage if floating debris is moving downstream which could damage or move the net. In lakes, much longer nets can be used if required and, since lakes typically have greater depths than rivers, nets can be set at a variety of depths. Lake nets can be set so that they float near the surface, are set along the lake bed or are positioned in mid column. For floating sets, nets with large floats attached to the float line can be used and long leads are tied to the weights to allow the net to remain at the surface. For sinking sets, nets without additional floats or with small floats are used. For bottom sets, the weights are tied tight to the lead line and long leads are tied to the floats so that the net will sit on the bottom and the floats will remain at the surface. For mid column sets, leads are attached to both the weights and floats so the net will be positioned between the bottom and the surface.

Gill netting is a sampling technique that can be used in the winter as nets can be set under the ice. In lakes where there is no current a jigger is used to run a length of sideline under the ice. A large hole is opened in the ice and the jigger is placed under the ice. The sideline is tied to the jigger and the lever arm is manipulated to send the jigger moving away from the hole. Once the jigger has moved far enough it must be relocated, either by sight if the ice is clear or by sound as the jigger is equipped with a "clicker" device. A hole is drilled at the location of the jigger and a hook is used to pull the sideline up the hole. In rivers or in the case of thick lake ice a Murphy stick is used to set the net. A Murphy stick consists of two sections of aluminum pipe hinged together which extends as an under-ice probe. The far end of the probe has an eye-hook at the end and a float a short distance back. A length of sideline a little longer than the gill net is tied to the eye-hook and the far end of the probe is pushed down through one hole in the ice and maneuvered towards a second hole where the attached sideline is hooked and pulled up through the hole. The process is repeated several times to extend the rope as far as desired. Once the sideline has been placed under the ice it is then attached to one end of the gill net and used to pull the net under the ice.

As a sampling technique, gill nets can have a high mortality rate if the fish are left in the net for a prolonged period or if water temperatures are high. If fish mortality is a concern, the nets should be cleaned of fish on a regular basis (e.g. every two hours). If mortality is desirable (i.e. fish are to be sacrificed) or not a concern, nets should be set overnight in order to sample day and night periods of fish movements and to allow capture of fish which may avoid the net if it is visible during daylight hours in low turbidity water.

3.5.8 Hoop Net (Fyke Net)

A hoop net is cylindrical net distended by a series of hoops or frames with one or more internal funnel-shaped throats whose tapered ends are directed inward from the mouth to prevent fish from escaping once they enter the net. A fyke net is a hoop net with two wings or leads of webbing attached to the mouth to guide fish into the enclosure. Our hoop nets have large square hoops at the front of the net and taper to a smaller diameter with smaller ring hoops at the back end. Webbing extends inwards and backwards between the sides of the first square hoop to form a "V" slot at the net mouth and a funnel is attached to the back of the second square hoop. The chamber between the funnel and the rear of the net is termed the "pot". The net is tapered at the rear end and held closed with a draw string which can be opened to permit removal of the trapped fish from the pot, although trapped fish may also be present between the "V" slot and the funnel. The funnel also has a draw string which allows removal of fish from this chamber. If it is desirable to have a fyke net, use two lengths of webbing tied to the sides of the hoop net mouth to convert the hoop net to a fyke net.

Fyke nets are typically set at a time and location where fish will be moving through the area in a direction that will lead them into the net mouth. They are very effective when set in small tributaries to lakes or larger rivers during a spawning run but can also be used in shallow areas of lakes and larger rivers. The net and wings are anchored in place by tying them to rebar posts embedded in the substrate. The wings of the net should be set at a 45° to the axis of the hoop net.

As the holding chambers in the fyke nets are small, they should be checked and cleaned of fish on a regular basis, particularly during an active spawning run. Try to set the net so that fish in the holding chamber will not be subjected to high water velocities. Sampling effort is usually recorded as the number of hours between net cleanings. Record fyke net dimensions such as mesh size, mouth size, wing lengths and, when used in streams, whether full or partial channel blockage was achieved and whether the net mouth was oriented upstream or downstream.

3.5.9 Kick Sampling

Kick sampling is used to collect fish eggs from the substrate in spawning areas, both for species which are broadcast spawners and for those which bury their eggs (i.e. from trout redds). It can be used to determine if incubating eggs are present but it is generally considered a qualitative (i.e. non-quantitative) sampling technique and, unlike airlifting, is not suitable for determining the relative density of eggs. The kick sampler is attached to a pole and consists of a tapered net attached to a metal frame which forms the mouth of the net. It is generally used in flowing water. To use, grasp the pole and place the kick net against the substrate. Stand upstream of the net mouth and use your feet to disturb the substrate, letting the disturbed materials float into the net. Remove the net from the water and examine the contents of the net for eggs.

Kick sampling can only be conducted in water shallow enough or which is flowing slow enough to allow instream wading. This technique is simpler to use than the airlift sampler and requires considerably less equipment. It is a very efficient and fast technique for identifying spawning areas in wadable streams, particularly over long lengths of stream.

3.5.10 Minnow Trap

Minnow trapping is a passive sampling technique used to sample for the presence of minnow species and small life stages (i.e. fry) of larger species which can be difficult to capture using other techniques such as electrofishing or gill netting. The traps we use are Gee Minnow Traps which consist of two pieces which are clipped together to form a small cylinder slightly tapered at either end. Each end has a funnel which leads into the centre of the trap which allows fish to enter but prevents them from escaping. The traps are generally placed on the substrate in the shallow shoreline areas of lakes and streams with the long axis of the trap parallel to the shoreline. A length of sideline is used to tie the trap to a stake or anchor on shore to keep it in place. The anchor site is usually flagged so that the site can be easily found when returning to check the trap. The traps can be baited or unbaited, depending on if the intent is to trap fish moving through the area or attract fish to the trap.

Sampling effort is recorded as the number of hours that the trap is set.

3.5.11 Observation

Underwater observation involves the use of either snorkeling or SCUBA techniques to observe, count or record the activities of fish. Scuba diving is generally restricted to lake habitats but may also be employed in deeper rivers. It is a fairly intrusive technique and is considered to be more disruptive than snorkeling and requires that the observer have a valid scuba certificate. Snorkeling is commonly employed by Golder to conduct fish observations in stream habitats which have low turbidities. It is less disruptive than SCUBA and logistically simpler. Equipment used for snorkeling includes a diving mask, snorkel, dry suit, diving gloves and an underwater writing slate. A wet suit can be used in place of a dry suit in warm water but a dry suit is preferable as it increases observation time. To date, snorkeling has been used by Golder to study the habitat preferences of some fish species but the technique can also be used to determine fish abundance and distribution.

3.5.12 Post-Emergent Trap

Post-emergent traps are a passive sampling technique for use in flowing water to sample for the presence of post-emergent fry. Unlike emergent traps which capture the fry as they emerge from the substrate, post-emergent traps capture the fry as they drift downstream following emergence. Unlike emergent traps, it is not required that they be set at a spawning site overtop of incubating eggs, there only needs to be a spawning area somewhere upstream of the set location. Post-emergent traps are essentially extremely large drift nets. Each trap consist of a tapered, small-mesh net attached to a metal frame which forms the trap mouth. The trap mouths are 0.9 x 0.9 m in size. Each net is equipped with a removable sample bottle attached at the downstream end of the net. A post-emergent trap is set by anchoring two rebar poles into the substrate and looping the four hoops attached to the trap over the poles and sliding the trap down until the bottom of the trap sits on top of the substrate with the mouth facing upstream.

Post-emergent traps should be checked at a minimum of twice per day, once in the morning and once in the evening. Definite diurnal/nocturnal patterns have been observed using these traps, so be sure to record the catch separately for each sampling period. To check the catch, remove the trap from the stream and wash all materials from the netting into the sample bottle. Dump the contents of the bottle into a sampling tray to look for the fry. Post-emergent fry are extremely small and almost transparent. They are best seen by looking for the large, dark eyes which will be their most obvious feature. They may also be seen to be swimming around in the sampling tray. It is also prudent to check the mesh of the trap for additional fry as they are so small that some become "gilled" on the mesh and do not wash down into the collection bottle. If more than one species may be hatching at the time and location of your study and you are not sure of the identification of fry in the sample, the sample should be preserved in 5% buffered formalin for laboratory identification.

Sampling effort is recorded as either catch/hr or catch/m^3, as described for fry traps (section 3.5.6). Post-emergent traps are used to check for the presence of post-emergent fry in the study area, either as proof of spawning activity in upstream areas or simply to tell if this life stage or a certain species is present. They are also used in entrainment studies, which are conducted to determine if fish are entering man-made structures such as diversion canals or water intakes. In addition, they may be used to determine the timing of hatching periods and the relationship between hatching and environmental parameters such as discharge or water temperature.

3.5.13 Seine Netting

Seine netting refers to the use of a specifically designed net to catch fish by dragging it through the water. Seine nets consist of netting suspended between a float line and a lead line. The netting is constructed of thicker net material than gill nets so that fish do not become gilled in the mesh. Mesh sizes vary but most nets are constructed of minnow netting which has a small mesh size and is suitable for catching forage fish and small life stages of larger fish species. Larger mesh seine nets are also available for sampling for large fish and are much easier to drag through the water. Two types of seining operations are possible, beach seining and boat seining.

Beach seining is accomplished by two people dragging the net through the water while wading and is used in shallow water areas in lakes and streams. To beach seine, each person grabs one end of the net by placing one foot in the loop at the end of the lead line and holding the loop at the end of the float line in their hands. One person walks out from shore to a suitable depth. Both people then walk parallel to shore dragging the net between them. The lead line is kept in contact with the substrate to prevent fish from escaping under the net by dragging the foot looped to the lead line along the bottom. As they walk through the water, fish are herded in front of the net. The person near shore moves slower than the person further out. When the further person has passed the near shore person they curve back to shore, meeting the near shore person at the waters edge and bringing the two ends of the net together forming a pen holding the captured fish. Both people then drop the float lines and pick up the lead lines and standing side-by-side pull the net up on shore, ensuring that the lead line remains in contact with the substrate at all times. The trapped fish will congregate in the end of the looped net and will be dragged up onto shore.

Boat seining is a specialized technique used in water too deep to wade. It usually involves the use of long, large mesh seine nets for the capture of large fish. It is particularly useful in areas where fish congregate such as spawning areas of lakes or snye areas in rivers. The principle is similar to beach seining except that a boat is used to move the offshore end of the net through the water. A pole is attached to both the lead and float lines, at the boat end of the net, and is used to keep the lead line on the bottom.

Seine netting is a suitable technique only where the bottom is fairly smooth. If large substrate particles, debris, or aquatic vegetation is present which will cause the lead line to lift off the bottom as it passes, the technique will not be very efficient and most or all fish will escape. Seine netting is typically used to sample for the presence and abundance of small fish and life stages which are not effectively sampled for using other inventory techniques.

Sampling effort is recorded as the number of seine hauls made and either the distance (m) or the area (m^2) seined for each haul. Record the dimensions of the seine net used (length/depth/mesh size) and the shoreline distance of each seine haul. If area is required, multiply the length of the seine haul by the length of the seine net used.

3.5.14 Set (Trot) Line

A set line is a series of leaders and baited hooks strung from one central line which is anchored to shore. Set lines are used to catch predatory fish and are usually set out overnight. Golder set lines are 30 m in length, which includes a 10 m lead with no hooks and 20 m of line with a total of 10 leaders/hooks set at 2 m intervals. A large lead weight is attached to the end of the line to keep it in place once it is set. The 10 m lead is used to set the baited hooks well out from shore or can be tied short to keep the hooks near shore, as desired.

Sampling effort is recorded as the number of hours the line is set or the number of hook-hours if set lines of different lengths and number of hooks are used. Record the size of the hooks that are used (e.g. #8 hooks).

3.5.15 Trap/Counting Fence

Fish traps or counting fences are a passive sampling technique used to capture fish as they move past a specific location. They consist of one or more trap boxes with fences (wings) which stretch out in front of the entrances of the boxes to lead fish into the trap. The trap boxes are large holding pens enclosed on four sides as well as on the bottom with metal or plastic mesh. The front of each box has an opening equipped with a funnel which leads into the interior of the trap box. The boxes are also equipped with locking plywood lids to protect the fish as they congregate in the traps. The fences consist of angular aluminum frames with a series of holes into which are fitted round aluminum rods to form a barrier to fish passage. The counting fence is installed by attaching the components to rebar posts driven into the stream bed and by placing sandbags on cradles included in the fence design. The fences or wings are set as close as possible on a 45° angle to the trap box entrance.

Two types of counting fence set-up are possible, the **one-way fence** and the **two-way fence**. The one-way fence has only one trap box and one set of wings and is used to capture fish moving in one direction. The two way fence has two trap boxes facing in opposite directions, each with its own set of wings, to capture fish moving in both directions. Counting fences can be used to sample portions of the shoreline in lakes or large rivers but are typically used in small or medium sized streams to close off the entire channel and capture all fish moving past the trap location. In this case, the box which captures fish moving upstream is called the upstream trap and the box catching fish moving downstream is called the downstream trap. In streams, the trap boxes should be set in a location where the water velocity is not too high so that the fish caught in the trap can rest. If no such site is available, a piece of plywood placed upstream of the trap will provide a velocity shelter

The counting fence should be checked a minimum of twice a day, once first thing in the morning and once again in the evening and the fish removed from the traps using a dipnet. The fence should also be cleaned of debris to keep the water flowing freely through it and to reduce the build up of pressure on the fence. Record the day, time and catch each time the fence is checked. During an active spawning run, the fence may need to be checked more frequently so that the number of fish holding in the trap boxes does not become too large. Record the catch separately for each sampling period. After removing the fish from the trap boxes they should be released in the direction that they were traveling so that they can continue in that direction (i.e. fish from the upstream trap should be released upstream of the counting fence while fish from the downstream trap should be released downstream of the fence).

Counting fences are used to determine the species, relative abundances and timing of movements of fish past the sampling site. They are typically used to capture fish during their spawning runs in the spring or fall or to quantify the movements of fish into and/or out of tributary streams.

3.6 Catch-Per-Unit-Effort (CPUE)

Catch-Per-Unit-Effort is a measure which relates the catch of fish, with a particular type of gear, to the sampling effort expended; it is expressed as: ***number of fish captured/unit of effort***. Results can be given for a particular species or the entire catch. CPUE is used to define species relative abundance and to compare abundances between sites and/or seasons. Effort can be expressed a number of ways depending on the sampling equipment. If CPUE data is required, sampling effort must be recorded. Following are common CPUE calculations for traditional sampling gear:

• electrofishing (boat and backpack)	No. of fish/100 seconds (of active electrofishing)
• gill net	No. of fish/net-hour, or /panel-hour, or/100m of net-hour
• set line (trot line)	No. of fish/hour, or /hook-hour
• angling	No. of fish/hour, or /angler-hour, or /rod-hour
• minnow trap	No. of fish/hour, or /trap-hour
• seining	No. of fish/area seined (m^2), or /length of shoreline seined (m)
• counting fence (fish trap)	No. of fish/hour
• drift net/post-emergent trap	No. of fish/hour, or /volume of water (m^3)

It is important to recognize the components of the effort inherent in the sampling technique being employed so that effort will be recorded properly. Most field forms will have fields specifically designed to record the pertinent information. Record all aspects of your sampling effort (e.g., number of set lines used and number of hooks per line) so that CPUE can be calculated. CPUE values will be used in our own studies to establish relative abundance. Our data may also be used in a more historical context to compare the abundances we record with past or future research, using both similar and different sampling gear, and CPUE values may need to be recalculated to conform to other studies. The more detailed used when recording sampling effort, the easier it will be to accommodate these needs.

3.7 Coldwater Fish

When dealing with the general suitabilities of freshwater habitats for game fish species, temperature regime is often used to describe the habitat potential and the species assemblage which could possibly be present. Although the terms are not definitive or precise, the designations of habitats as "coldwater" or "coolwater" habitats and the associated fish fauna as "coldwater" or "coolwater" species are often used.

Coldwater fish are those which have a preference for summer water temperatures ranging from about 10-18 °C. In Alberta, this encompasses all of the salmonid species including the trouts, whitefishes and Arctic Grayling. Within this group the species will have differing temperature preferences and tolerances (see section 3.50 - Temperature Criteria).

3.8 Condition Factor (Ponderal Index)

Condition factors are used to describe the plumpness and, by inference, the well-being of individual fish. Formulas are used to calculate condition factors using the fish's length and weight and are based on the principle that the weight of a fish will vary with the cube of its length. Any variation in the shape or plumpness will be measured using the formula. Golder primarily uses the coefficient of condition *K*, also called the Fulton condition factor. The formula (**using metric length and weight data**) is as follows:

$$K = [\text{weight (g)} \times 10^5] / \text{fork length}^3 \text{ (mm)}$$

Condition factor is believed to reflect the nutritional state or well-being of an individual fish. The *K* value will be 1.0 for fish whose weight is equal to the cube of its length. Fish which have a *K* value >1.0 are more plump and are thought to have a higher degree of well-being or better nutritional state-of-health, whereas fish with a value <1.0 are considered to be less robust.

Condition factors vary with season, sex, sexual maturity, age and various other factors. Therefore, if sufficient data is available, average condition factors for a species should be calculated separately for each sex and should exclude young-of-the-year fish. Condition factors also vary by species, particularly if they have different shapes, and should not be used to compare well-being between fish species. They can, however, be used to determine differences in the condition of fish of the same species in different years or at different sites. Fulton's condition factor is also limited for comparisons between fish populations in different lakes because of differences in growth parameters. Other formulas for condition factor calculations are available and would be designated by the project manager if they are required.

3.9 Coolwater Fish

Coolwater fish are those which generally prefer summer water temperatures ranging from about 18-26°C. Alberta species generally considered to belong to this group include northern pike, walleye, sauger, yellow perch, goldeye, mooneye and lake sturgeon (see also Section 3.7 - Coldwater Fish).

3.10 Creel Census

The term "creel" refers to the basket a fisherman uses to hold the fish which have been angled and a creel census refers to a survey in which recreational fisherman are censused in order to determine aspects of the recreational fishery. Important survey goals typically include determining angler effort and success (i.e. fishing pressure and harvest) and may include examining the fisherman's catch for tagged fish or to collect ageing structures.

3.11 Dissolved Oxygen Criteria

The dissolved oxygen concentration in the water is an important habitat component. Different fish species have different dissolved oxygen requirements and have different tolerances to low dissolved oxygen levels. Dissolved oxygen criteria provide minimum dissolved oxygen levels that are necessary to protect various life stages and have been developed for selected game fish species. Golder has prepared a document which list the criteria for selected Alberta species (Taylor and Barton 1992).

3.12 Fecundity

The most common measure of reproductive potential in fish. Female reproductive potential is the total number of eggs (ova) in both ovaries of a gravid female fish. Fecundity normally increases with the size of the female within a given species. For most studies conducted by Golder, fecundity is determined for female fish only. Fecundity is determined by recording the total weight (g) of both ovaries and removing a small sub-sample of known weight from the middle of the ovaries (usually a 1.0 g sample). Count the number of eggs in the sub-sample to determine the number of eggs/g of ovary. Multiply this value by the total ovary weight to calculate the total number of eggs.

3.13 Field Forms

Golder uses a number of specially designed field forms to aid in recording field data. They are not meant to replace the use of a field book or the recording of detailed field notes. They are intended to provide a template showing the type of supporting data that must be recorded for each sampling technique and provide an organized method of recording the sampling results. For each specific or general type of sampling technique there is a ***Catch Record Form*** (e.g. Gill Net Catch Record Form) for recording sampling information such as location, technique, effort and is used to summarize the results. The main form for recording the catch results is the ***Fish Sample Record Form*** which has fields for recording length and weight data and other particulars for each individual fish. On the back of this form you will find a list of all abbreviations to be used when recording data.

A copy of each field form is kept in the aquatics reference file located at Carole Collins desk (Aquatic Ecology Group Secretary). Copy the forms you will require onto waterproof paper and return the originals to the file.

3.14 Fish Collection Licence

Fish collection licences or permits are granted by provincial governments or by DFO and are required for all fisheries sampling activities. Obtaining a license varies from province to province. In Alberta, a Fish Collection Licence is granted to Golder by Alberta Environmental Protection, Fisheries Management Division. Each Licence is specific to the waterbody(s) being sampled and is valid for a specified time period. To obtain a Licence you must forward a letter of request to the F & W District office for the region in which you wish to sample. Include in the letter the reason for sampling, the location(s) to be sampled, the period the permit should be valid for, the capture techniques to be employed, the fate of the fish captured (i.e. will any be sacrificed), and the personnel to conduct the sampling. They will then send a Licence granting permission to carried out the proposed activities. They may impose specific restrictions on the licence (i.e., restricted number of fish allowed to be sacrificed, designation of a certain landfill for fish disposal, or specific reporting requirements) and the permits should be read carefully to ensure all restrictions will be followed. The original permit or licence should be immediately placed in the project file and a copy of the document given to the field personnel. You must be prepared to produce a copy of the permit while conducting any field sampling.

The Fish Collection Licence will also specify a date by which a permit return is to be submitted to the issuer. In Alberta, the permit return is a form which accompanies the Licence. The form requests information regarding the sampling conducted under authority of the Licence, such as sampling locations and results. Fill out the form and send it to the office which issued the Collection Permit following completion of sampling activities and prior to the date specified on the Licence.

3.15 Forage Fish

A general term applied to smaller species of fish that "forage" on small invertebrate animals or plant materials. This includes minnow species and other small fish such as sculpins, stickleback, trout-perch and darters.

3.16 Game (Sport) Fish

Fish used by anglers for recreational fishing or sought after by the commercial fishing industry, e.g., northern pike, walleye, trout, etc.

3.17 Geographical Position

All sampling sites, whether they are point locations (such as a minnow trap site) or sections (such as a section of river that was electrofished), should be recorded on a map of the study area. The standard is to use a 1:50,000 NTS topographical map but other maps or airphotos can be used if they provide greater detail. The geographical position of sampling sites can also be recorded using Universal Transverse Mercator (UTM) grid coordinates or by degrees of latitude/longitude. UTM coordinates are particularly useful in case the map is lost as they can be used to pinpoint the sampling site on a new map.

UTM and latitude/longitude are two different systems of grid coordinates used to establish geographical location. Both systems appear in the margins of 1:50,000 scale National Topographical Service maps. A calibrated ruler is used to calculate coordinates of any point on the mapsheet. Golder always uses UTM coordinates rather than lat/long, unless otherwise specified by the client.

The most accurate way to record the position of the sampling site is to use Geographical Position System (GPS) technology. If possible, use a GPS rover unit to record a position file at the sampling site that can be stored for differential correction. You should also use the GPS unit to record a "real-time" waypoint in the event that the stored file is lost or accidentally deleted. If you do not have a GPS unit capable of differential correction, a simpler unit will allow you to record a waypoint, which will be less accurate.

3.18 Gradient

Gradient refers to the vertical drop in elevation along a watercourse over a horizontal distance. It is recorded as the percent gradient. To determine the gradient over a length of stream, measurements are taken off of a 1:50,000 scale NTS map of the watercourse. Locate a point upstream and downstream of the study area on the map where contour lines cross the stream and determine the difference in elevation

(m) between these two points. Measure the distance (m), following the channel, between the same two points using a map wheel. The gradient is calculated as follows:

gradient (%) = [difference in elevation (m)/distance (m)] x 100

In very flat terrain determining gradient from a map may not be possible. In these situations, gradient may also be measured in the field using a clinometer. With this method one person with a clinometer stands at the upstream end of the section to be measured, a second person moves as far downstream as possible while still visible to the upstream person. Both individuals stand at the very edge of the stream with their feet at the water surface. The upstream person uses the clinometer to measure the angle from his or her eyes to the eyes of the other person. If your clinometer measures in % then this value should be recorded. If the clinometer measures in degrees, then percent can be calculated by taking the tangent of that number and multiplying by 100. This technique may need to be repeated several times and averaged to determine the gradient of a large section of stream.

3.19 Growth

Fish show indeterminate growth in that they continue to grow throughout their lives rather than stop growing once they reach an "adult size". However, growth rate is asymptotic, meaning the growth rate decreases with increasing age approaching some maximum value for the individual or population. As growth rate is a function of time, true growth rates can only be determined when fish length and age is known. Two parameters related to growth rate are: 1) the maximum size which is possible for fish in a given population, and; 2) the rate at which maximum size is achieved. The maximum size value indicates whether the population is "stunted" (i.e. does not have the potential to reach the normal maximum size for the species) and differentiates between populations that are stunted and those which do not achieve their potential maximum due to a short life span. If the maximum size for the population is at the lower end of the normal range for the species, than the population is slow growing rather than stunted. See Mackay et al. (1990) for methods of calculating maximum size and rate.

3.20 Gonads

Organs which are responsible for producing haploid reproductive cells in multicellular animals. In the male, these are the testes and in the female, the ovaries. In fish they are located in the peritoneal cavity, extending between the diaphragm and the cloaca, and running along the dorsal side of the cavity along both sides of the spine. When the fish is gravid, the gonads will fill much of the peritoneal cavity.

3.21 GSI (Gonadal:Somatic Index)

Gonad-Somatic Index is the proportion of reproductive tissue in the body of a fish to total body weight. It is calculated by dividing the total weight (g) of the gonads by the total body weight (before gonad removal) and multiplying the result by 100. It is used as an index of the proportion of growth allocated to reproductive tissues in relation to somatic growth. It is believed to be an indicator of fish health in that a fish with a comparatively low GSI for its species is considered to not have sufficient energy available for proper gonad growth. Fish are seasonal spawners and the size of the gonads changes dramatically as they pass through the various stages of gamete maturation. It is preferable to conduct GSI measurements for fish just prior to the spawning season when the gonads are fully developed (i.e. gravid).

3.22 Habitat

Fish habitat refers to aspects of the physical environment which provide the requirements of a fish community, species or life stage. Habitat evaluations conducted for fisheries studies generally involve measurements or evaluations of macro- and/or micro-habitat conditions in order to determine the types of fish or life stages an area might support, the quality of available habitats or habitat limitations.

Macro-habitat

Macro-habitat refers to habitat components which are attributable to a general region or section of the study area. They are general conditions related to geographical location, climate, stream order, lake type, etc. For macro-habitat evaluations, we typically measure general water quality parameters (dissolved oxygen, temperature regime, pH, conductivity, turbidity, visibility (secchi depth), stream gradient), as they relate to describing coldwater and coolwater habitats and the types of fish species which may be present. Different fish species have different tolerances for macro-habitat conditions which affect their abundances and distribution.

Micro-habitat

Micro-habitat conditions are the physical conditions at a specific location. For micro-habitat assessments we measure or evaluate water depth, velocity, substrate particle size and condition, and the availability of cover for fish. Cover includes instream cover (i.e. any objects which provide velocity shelters) and overhead cover (i.e. anything which provides visual isolation). Each fish species has a range of micro-habitat conditions which are suitable, ranging from barely useable to optimal. In addition, each species has a series of life stages which may also have different habitat requirements. These life stages include spawning, incubation/embryo, nursery, rearing, feeding (adult summer) and overwintering.

Knowledge of the suitable and preferred habitat conditions for different species and life stages is very useful when conducting fisheries inventories, habitat evaluations and impact assessments. Information concerning these habitat requirements is available in the form of Habitat Suitability Index (HSI) models and Habitat Preference Criteria (HPC). HSI models were developed by the U.S. Fish and Wildlife Service and are species-specific models, with each model containing information for all life stages of one fish species. The models include all the habitat variables (macro- and micro-habitat) that accumulated research has determined to be significant to each species with respect to population abundance. Each habitat variable is provided along with the range of suitable and optimal conditions. HPC are species-specific curves showing suitable and preferred conditions for micro-habitat variables (depth, velocity, substrate and cover). HPC curves are available for a limited number of game fish species and were developed from snorkeling observations of the different species and life stages (developed for the most part by Golder from streams in Alberta).

Measurements of macro- and micro-habitat conditions in lakes and streams are useful in combination with inventory data and existing information to establish habitat potential for a study area. Habitat based assessments are being used more frequently to provide a complete picture of habitat potential, with respect to use by different fish species and life stages, rather than relying on fish inventory data from a specific point in time.

3.23 Length

Refers to the whole body length of a fish. There are three types of length measurements: standard length, fork length, and total length. The measurement most commonly used in Canada and ***required for use by Golder*** is the ***Fork Length*** and is ***always recorded in millimetres (mm)***. Fork length is the distance from the most anterior point on the head to the tip of the median caudal fin rays. The fork length of captured fish is measured on a fork length board, which is a trough or flat board with a ruler attached to the surface and a vertical block at the anterior (zero mm) end. Place the fish on the board with its head flush with the block and spread the caudal fin to show the mm mark under the anterior point of the fork.

Some fish species such as burbot, sculpins and darters do not have a fork in their caudal fins. For these species, the standard measurement is Total Length, which is the distance from the most anterior part of the head to the distal tip of the longest caudal fin ray.

The fish which must be measured for length and weight may vary between projects. You will always be measuring game species but will not necessarily have to measure rough or forage fish. The project manager will be able to tell you what is required. For instances where large numbers of individuals are being captured and the time required to measure length and weight is excessive, it may be possible to measure length only for some fish. A large number of lengths are required to produce a complete length-frequency distribution (see section 3.25) while a lesser number of weight measurements are required to provide an accurate length-weight analysis (see section 3.26). If fish are being preserved, always measure length and weight before preserving.

3.24 Length-at-Age

Length-at-age analysis is used to determine the average length of fish in each age class in the population. This analysis can only be conducted for individuals for which age is known. For each age class (i.e 1 year old fish, 2 year old fish, etc.) calculate the range of lengths, mean length and the standard deviation of the mean. Plot this data graphically showing the range, mean and standard error (error bars) (see section 3.47 standard error and standard deviation) with age as the X-axis.

3.25 Length-Frequency Analysis

Length and weight data provide the statistics that are the cornerstone of fisheries research and management. Rate of change of length in individuals and length-frequency distributions are key attributes of fish populations. Length-frequency analyses provide an important description of population structure and are used to provide information for the interpretation of age and growth, especially for young fish. Length-frequency distributions reflect the interaction of rates of reproduction, growth and mortality of the population. However, when interpreting length-frequency data it is important to evaluate sampling biases for the capture technique that was used, particularly with respect to size selectivity. The length-frequency distribution of a population is shown graphically by plotting the number of fish in each size class using a histogram chart. Typically, size classes include every 50 mm fork length interval (i.e. 0-50 mm, 51-100 mm, 101-150 mm..... etc.) but may be more frequent if you have a large sample size. When plotting the length-frequency distribution using Microsoft Excel, label the size classes on the X-axis of the graph using the complete label (i.e. 0-50 mm, not 50 mm).

Using the length-frequency analysis to determine fish age and growth rates is called the Peterson method. The plot of the length-frequency analysis is examined for peaks which are believed to represent each of the year classes in the population. The peak closest to the Y-axis would represent zero aged fish (young-of-the-year) and each peak after that should represent another year class. Great care must be exercised when conducting age analysis with this technique. Typically, distinct peaks are only evident for the first few year-classes. Individual fish exhibit different growth rates and as they get older, the overlap in size ranges for each age class becomes too great and the peaks in the length-frequency distribution are lost. In addition, this method requires measurement of a large number of fish which represent an unbiased sample of the population. The size intervals (fork length classes) chosen for plotting these data are particularly important, as size intervals which are too large or too small will obscure the peaks. Other problems with this method include dominant year-classes which may obscure the peaks of weaker year-classes and divergent growth rates of male and female fish complicates the analysis as does the small incremental changes in length which occur in older fish. However, the Peterson method is quite suitable for some forage fish populations where the life-span is short. It is the recommended ageing method for some minnow species which may have life-spans as short as three years.

3.26 Length-Weight Relationships

Length-weight relationships can be used in order to assess the state of well-being of a fish population. These relationships can be used to compare the condition or "fatness" of fish in a population to other populations, or to that in previous years. As a fish population size increases and/or food resources decline, individual fish become thinner and the ratio of weight to length decreases.

The relationship between fish length and body weight is curvilinear, and can normally be represented by the following function:

$$W = aL^b$$

where W = weight, L = length, and 'a' and 'b' are constants which are characteristic of the population being examined. The constant 'b' reflects the rotundness of the fish or the rate at which weight increases for a given increase in length. In general, a value of 'b' less than 3.0 represents fish becoming less rotund as length increases, and 'b' greater than 3.0 indicates a population where fish become more rotund as length increases. If 'b' is equal to 3.0, growth is isometric, meaning shape does not change as fish grow.

The length-weight relationship that we typically use is called length-weight regression analysis. The length-weight relationship can be changed from curvilinear to linear (straight line) using a $\log_{10}$ transformation of both length and weight. The relationship between length and weight becomes:

$$\log W = \log a + b \log L$$

where log a is the 'Y' intercept of the regression line and b is the slope of the line. A regression analysis can be conducted from length and weight measurements of a sub-sample of the fish population. Be sure to measure fish which are representative of the size range in the population, that is an even number of fish should be measured from all size groups in the population, from the smallest to the largest fish. A general rule is that at least 30 fish should be measured to provide a large enough sample size to calculate an accurate regression. The regression analysis plots the log weight versus log length for all the fish measured and then produces the "best fit" straight line that approximates the mathematical relationship between length and weight. The regression analysis can be conducted by entering the length-weight data on a computer spread sheet (Microsoft Excel) and having the program conduct the log transformation of the data. The computer program will provide the regression equation, including the values for 'a' and 'b'. When conducting a regression analysis, you should also record the 'R' value (coefficient of determination) that the computer calculates as this value represents properties of the linear relationship. The higher the 'R' value, the more closely the data conforms to a straight line and the better the regression equations represents the data.

Differences often exist in the body weight to length relationship for males and females in the same population. If possible, length-weight regressions should be calculated separately for the two sexes. The relationship also changes throughout the annual growing-season, particularly for females, as gonad size and weight increases, so care should be taken when comparing various sets of data. Prior to conducting a length-weight regression analysis, the length-weight data should be plotted on a scatter diagram in order to spot 'outlying' data points. Points which are well outside the range represented by the other data points should be checked for accuracy to make sure both length and weight were recorded properly.

3.27 Lesion

Lesions are the result of a pathological change in body tissue. External hemorrhagic lesions (bloody sores) may be observed on the body surface of the fish and should be recorded on the Fish Sample Record form. Reddened areas and lesions on the body surface are evidence of systemic (widespread, internal) infections of bacteria or superficial bacterial infections. Skin lesions in wild fish are seen most often in the early spring when rising water temperatures encourage bacterial growth at a time when fish are least resistant to it. An increased prevalence of skin lesions also has been associated with fish from water with a high organic load and bacterial community, such as below a sewage outfall.

3.28 LSI (Liver:Somatic Index)

Liver-Somatic Index is also known as hepato:somatic index. It is the ratio of liver weight (g) versus total body weight, expressed as a percentage of total body weight. The LSI is used as an indicator of fish health. Energy is stored in the liver in the form of glycogen and the relative size of the liver is believed to correlate with nutritional state.

3.29 Marking/Tagging

Identification of individual fish or simply identification of fish which have been captured is required for some projects. Different marking techniques are available, depending on the goals of the study.

3.29.1 Anchor (Floy) Tagging

A practical and inexpensive method of permanently marking individual fish. The tag, shaped like an inverted "T", is most commonly inserted through the fishes' back at the base of the rear portion of the dorsal fin and anchored between the epipleural bones of the dorsal fin using a special tag-gun. The tip of the gun is a hollow needle which is inserted through the skin and muscle. As the handle of the tag-gun is depressed, an injector rod pushes the anchor portion of the tag out the end of the gun through the needle. The tag-gun needle will not pass through fish scales. In order to insert the needle, use the tip of the needle to lift the posterior edge of a scale and slip it in under the scale. Fully insert the needle through the skin by inserting it to the base of the needle and depress the handle. Once the tag-gun handle has been fully depressed, hold it in the depressed position while giving the gun a quarter turn to free the tag from the needle. Still with the handle depressed, remove the tag-gun needle from the fish and the tag will remain anchored in place.

The posterior portion of the Floy tag remains outside the fishes' body and is usually brightly coloured and carries a numeric identification code. This tagging method is used when conducting mark-recapture population estimates and basic fish movement studies. It is also the preferred marking technique when seeking angler return data to aid in establishing fish movements. Tags marked with the researchers address and the phrase "$2 reward" are often used to ensure angler response.

When sampling, always record the recapture of marked fish, even if the tag is not one that was inserted during your present study. It is common to catch fish carrying old Floy tags inserted by other agencies who will provide the date and location the fish was tagged; information which will provide movement data for all of the researchers involved. Older tags will usually have a build up of algae and will need to be scraped clean with a knife in order to read the tag number and other information.

Floy tags will usually carry the name and address of the client/agency that Golder is working for and, therefore, the tags are usually provided by the client. If this is not the case, Floy tags will need to be ordered and discussion with the client may be necessary to decide what writing the tags will carry.

3.29.2 Visual Implant (VI) Tagging

A "micro-tag" method using tags which are inserted under the skin. VI tags are suitable for use when a tagging method is required which has minimal effects on the swimming and feeding efficiency of the fish. Good for tagging smaller fish than is possible with the anchor tag method, such as small fish species or juvenile fish. Each tag consists of a small metal strip with an individual alpha-numeric code (typically three digits) which is inserted using an injector into a clear tissue somewhere on the fishes body (e.g., post-ocular tissue for salmonids). If working with non-salmonids, it will be necessary to determine a suitable implant location for the fish species you are working with. The implant location should have a sufficiently thick layer of clear tissue so that there will be room to insert the flat injector needle and the tag can be read through the tissue. Record in the field notes the location (including left or right side) of tag insertion for each fish species that you are tagging. To tag a fish, insert the injector needle into the selected tissue, depress the injector and hold it down while removing the needle from the fish.

3.29.3 Batch Marking

A marking method which does not distinguish between individual fish. Common methods are fin clipping or dye marking. Batch marking can be used to distinguish fish from specific sites by varying the location on the fishes' body which is dye marked, the colour of the dye or varying which fin is clipped by sampling site. This method is suitable for simple movement studies and for simple mark-recapture population estimates. This method is also used when extremely large numbers of fish need to be marked, as it is simple and more economical than anchor or VI tagging.

Dye marking is accomplished by injecting a small amount of a coloured dye or liquid plastic sub-cutaneously. It can be used for marking very small fish, such as minnows and other forage fish, since a very small hypodermic needle can be used as the injector. One disadvantage of dye marking forage fish is that it is difficult to avoid using a colour which is readily visible to the researcher without increasing the probability of predation of the marked individuals.

Fin clipping includes removing or distinctively altering a fin in a recognizable manor. Fin removal is usually only conducted for non-essential fins such as the adipose fin on salmonids. For other fins such as the pectoral or pelvic fins, the first two fin rays may be removed. For larger fish, a hole punch can be used to make a distinctive mark on a fin. When clipping a fin, it is important to make straight, regular cuts to distinguish the mark from naturally frayed or eroded fins. Record the fin which is marked for each sampling site.

3.29.4 Radio Tagging

Attachment of a battery powered radio transmitter to a fish in order to follow its movements using a radio telemetry receiver. The transmitter is affixed externally or surgically implanted in the body cavity. To avoid adverse effects on swimming ability, the transmitter should be <2% of the fishes' body weight. Ground, boat or aerial surveys are conducted with the telemetry receiver in order to follow the fishes movements.

3.30 Maturity (State-of-Maturity)

Maturity refers to the state of gonad maturation of an individual fish at the time it is examined. It does not refer to whether or not the fish is "mature" (i.e adult); classification of a fish as juvenile or adult is referred to as life-history stage (see Section 3.46).

For adult fish, the gonads will typically progress through a series of conditions or phases of maturation each year during the seasonal development cycle. Although juvenile fish have only one possible state-of-maturity, adult fish can be one of several maturities. The state-of-maturity is used to determine the current reproductive status of the individual. For fish populations, state-of-maturity data can be used to determine the size or age at first spawning, the proportion of the stock that is reproductively active, or to illustrate the nature of the reproductive cycle.

Golder uses a system that includes **9 maturity categories**. The 9 categories, their definitions and abbreviation codes are presented on the back of the Fish Sample Record forms used to record the data.

More detailed definitions and descriptions of each maturity category, for both males and females, are provided in Appendix I. Maturity is best determined by conducting an internal examination of the gonads, which requires sacrificing the fish. Maturity can sometimes be determined by external examination of the fish based on fish size and by knowing the typical spawning period for the fish in relation to the capture date or, for some species, by external secondary sexual characteristics which become pronounced during the spawning season (see Section 3.41). The classification system includes an "unknown" category for fish which are examined externally and for which maturity cannot be determined.

For many studies, most or all fish will be released live and only external examinations will be conducted. For other studies, a sub-sample of fish captured will be sacrificed for definitive state-of-maturity data. The following are some hints for establishing state-of maturity from external examination. *Pre-spawning* fish will be found immediately prior to the species spawning season. Fish of a size large enough to be adult or displaying secondary sexual characteristics at this time and with a strongly distended body cavity may be *Pre-spawning*. During the spawning season, gametes (milt or roe) can be extruded from the fish with gentle pressure on the abdomen and it will be obvious that the fish is *Ripe*. *Spent* female fish can be identified by a flaccid, concave abdomen resulting from shedding of the large egg mass and abdominal abrasions obtained during spawning activity. They may extrude a small number of residual eggs in response to pressure on the abdomen. *Spent* males may also have abdominal abrasions and will probably still extrude milt with abdominal pressure, but the milt may appear "watery". Other maturity classifications are very difficult to determine from external examination.

3.31 Milt

Milt is a milky white fluid extruded by male fish during spawning activity and contains the sperm. During spawning season, ripe male fish will extrude milt in response to pressure on the abdomen.

3.32 Necrosis

The death of a tissue due to injury or disease.

3.33 Parasites

Fish are subject to several types of internal and external parasites. A complete parisitological examination requires sacrificing of the subject and microscopic examination of some tissues. For general fisheries inventories, the occurrence of macro-parasites which can be readily observed by the an-aided eye should be recorded on the Fish Sample Record Form. A basic external examination is conducted while measurements of length and weight are conducted. An internal examination is conducted for fish which have been sacrificed. Common external parasites include body lice, gill lice, leeches and lamprey. Common internal parasites include tapeworms, nematodes and flukes associated with the gastro-intestinal tract and other internal organs.

3.34 Pathology

For fisheries inventory studies, pathology refers to the field examination of captured fish for indications of parasites, disease and abnormalities, without the use of special procedures (e.g. tissue collection) or tools (e.g. microscope). This can include either external pathology or external and internal pathology.

External Pathology

Examination of the body surface , fins, eyes, gills and gill chamber for signs of parasites, disease or abnormalities (deformations). Components of the external examination include body form, body surface, lips and jaws, snout, barbels, opercles, isthmus, eyes, fins, gills, pseudobranch, branchial cavity, anus, and the urogenital opening. A basic external examination can be conducted for most fish while measurements of length and weight are being conducted and the results recorded on the Fish Sample Record Form.

Internal Pathology

Examination of the body cavity and internal organs for signs of parasites, disease and abnormalities. Components of the internal examination include body cavity, mesenteric fat, liver, gall bladder, hind gut, stomach, pyloric caeca, intestines, spleen, gas bladder, kidney, gonads, and muscle. A basic internal examination can be conducted for fish which have been sacrificed.

3.35 Population Estimates

Population estimates are used to determine or approximate the total number of fish, for one species or a number of species, within a study area. Population estimates may be calculated for a portion of a waterbody (e.g. a section of stream - #fish/km) or an entire waterbody (e.g. a lake - #fish/ha). Two basic types of population estimates are used; Removal and Mark-Recapture.

Removal (Reference - Armour et al. 1983)

Removal population estimates involve the isolation of the study area using a physical barrier to block fish movements followed by the removal of fish from the area to provide a population estimate. This technique is restricted to study areas which can be isolated and is typically used in small streams. Small-mesh blocking nets are placed at the upstream and downstream boundaries of the study area to prevent immigration or emigration of fish from the study area. Long minnow seine nets are used as blocking nets and are held in place using rebar posts embedded in the substrate. Care must be taken to ensure the bottom of the net remains in contact with the stream substrate to form an effective barrier.

Electrofishing is used as the capture technique, typically backpack or portable boat electrofishing, depending on stream size and water depth. It is vital that the capture technique be very efficient. If the stream is too deep or wide for effective sampling by backpack electrofishing, the portable boat electrofisher should be used or use two backpack units working simultaneously. Multiple electrofishing passes are conducted within the study area and the catch (species and length) and sampling effort are recorded for each pass. Captured fish are retained in a holding pen or are released outside the study area. The catch will decline with each pass as the number of fish in the study area is reduced. Ideally, the catch on the final pass will be zero as total removal is achieved, however, total removal is not required. What is required is that the capture efficiency must be high enough that the probability of capture for each individual is high. When this requirement is met, most of the fish in the study area will be captured on the first pass. After two electrofishing passes, the capture probability is calculated (Armour et al. 1983). If the capture probability is 0.8 or greater, the capture efficiency is high enough to provide an accurate population estimate and a sufficient number of passes has been conducted. In practice, capture probabilities as high as 0.8 are uncommon and additional passes must be conducted. Typically, 3 or 4 passes must be conducted to get a good estimate of capture efficiency and to get enough data to calculate a population estimate. If after 4 passes the number of fish being captured has not declined to near zero, the sampling technique is not sufficiently effective and the population estimate will have poor accuracy. A population estimate can be calculated from such data, but the confidence intervals will be very large.

It is very important that the diminishing catch on subsequent passes be due to the reduced number of fish in the study area and not to a reduced amount of sampling effort. It is vital that a similar effort be expended on all passes. The number of seconds of electrofishing and the search pattern in the study area should be similar for all passes. Monitor the electrofishing seconds throughout each pass in order to ensure this requirement is met.

If total removal is achieved, the population estimate for each species is equal to the total number of individuals captured. If total removal is not achieved, formulas are used to calculate the population estimate. Two formulas are available; the first is a simple formula for computations for two removal passes and the second is more complex for computations for more than two removal passes (Armour et al. 1983). Both of these formulas are presented on a Microsoft Excel spreadsheet in the G:\Aquatics directory. Simply type in your data for each species (ie. number of fish captured on each pass) and the spreadsheet will calculate capture probability, population estimate, standard error and the 95% confidence interval. The lower limit for the 95% confidence interval is sometime lower than the number of fish that was captured. If this is the case, the lower limit should be changed to equal the number of fish captured as this number represents the minimum population size.

Mark-Recapture

Mark-recapture population estimates are used in situations where isolation of the study area is not possible or for situations where removal of a significant portion of the population is not practical. Using this technique, a sub-population of fish is captured, marked and released. These fish are then allowed to mix with the larger unmarked population. A sub-sample of fish is then captured and the number of marked and unmarked fish is used to determine the proportion of the total population represented by the marked sub-population. As the size of the marked sub-population is known, the size of the total population can be calculated. This technique is useful in large and intermediate sized streams and in lakes. Any sampling technique with good sampling efficiency can be used but is typically limited to electrofishing, particularly in flowing waters. The mark-recapture technique assumes a closed population (no immigration/emigration) which is not usually true in many situations. Study design should include aspects to reduce the effects of immigration/emigration of fish. For size selective sampling techniques such as electrofishing, population estimates should be conducted separately for different size classes.

For most mark-recapture population estimates, it is recommended that multiple sampling passes be conducted to capture and mark fish. This is followed by a few days without sampling to allow mixing of marked fish in the general population. A sampling pass (census) is then conducted to determine the portion of marked to unmarked fish in the census sample. Batch marking (see section 3.29) can be used for this technique. The population estimate is calculated using the Chapman modification of the Peterson method (Ricker 1975) as follows:

$$N = (M+1)\,(C+1)\,/\,R+1$$

where N = population estimate, M = number of marked fish, C = sample taken for census, and R = number of marked fish in the census sample.

At Golder we generally use the ***CAPTURE*** program (Otis et al. 1978) for mark-recapture population estimates. For this method, the fish marking technique must be Floy or VI tagging (see section 3.29) as each individual fish must be identifiable. Multiple sampling events are conducted in order to tag fish and to keep daily counts of the number of tagged and untagged fish that are captured. The results are then arranged in a matrix which has one line for each individual fish that was captured, along with the day or days it was captured/tagged and recaptured. This matrix is used by the CAPTURE software to provide the population estimate. The CAPTURE program is located in the G:\Aquatics directory. The CAPTURE software tracks the capture/recapture history for each individual fish over each pass and calculates the population estimate based on these results. This technique is believed to provide a more accurate result than the single census-pass estimate presented above. This technique does not require a rest period between the marking passes and a census pass and is more suitable for use in open populations where fish movements in or out of the study area may occur.

3.36 Riparian

With respect to fisheries habitat evaluations, riparian areas are terrestrial habitats bordering water bodies (lakes and streams). Riparian areas are not included within the boundaries of the waterbody but are significant in providing habitat features such as overhanging vegetation, inputs of large-woody-debris, sediment stabilization, shading, moderation of surface water run-off, nutrient inputs, etc. Riparian conditions, including species of bank vegetation and floodplain vegetation when possible, are an important part of habitat evaluations.

3.37 Roe

Fully developed, unfertilized eggs produced in the ovaries of adult female fish. During spawning season, ripe female fish will extrude roe in response to pressure on the abdomen.

3.38 Rough Fish

Large fish species (i.e. non-forage fish) which are not included as game fish. Primarily sucker species.

3.39 Sacrifice

Fish which are killed in order to allow internal examination or collection of ageing structures are referred to as sacrificed. For each fish captured, information on whether or not the fish was sacrificed is recorded on the Fish Sample Record Form (i.e. capture code), which helps to identify fish which have been examined internally versus those which were only examined externally. Fish which are sampling mortalities (accidentally killed as a result of capture) are also recorded as sacrificed. Even if intentionally sacrificing fish is not a part of the study design, dead fish should be examined internally for definitive sex and state-of-maturity data, as well as stomach contents and internal pathology when time allows.

3.40 Sampling Bias

Sample inaccuracy caused by bias or imprecision in sampling; e.g., bias towards large fish because of the type of sampling gear. In statistics, a sampling bias may be represented as skewedness or as variance.

3.41 Sex

Sex refers to the sex of the individual fish, usually recorded as either male or female. However, since determination of sex may be difficult from external examination or from internal examination of juvenile fish, sex may also be recorded as unknown.

Sex Determination (Lethal)

To determine the sex of a fish, an incision should be made on the ventral surface of the body from a point immediately anterior of the anus toward the head to a point immediately posterior to the pelvic fins exposing the gonads. If necessary, a second incision may be made on the left side of the fish from the initial point of the first incision toward the dorsal fin. To observe the gonads, fold back the tissue. Ovaries appear whitish to greenish to orange and have a granular texture. The eggs will be readily apparent in developed ovaries. Testes appear creamy white and have a smooth texture.

Sex Determination (Non-Lethal)

Determination of sex from external examination of the fish is generally more difficult. For some species, sex may be determined from external secondary sexual characteristics, observable either during the spawning season or, for some species, at any time of year. For most fish species, sex of adult fish can be determined during the spawning season by forcing extrusion of the sexual product (milt/roe).

Secondary sexual characteristics are external physical characteristics displayed by fish which distinguish sex. Some species do not display secondary sexual characteristics. Other species show secondary sexual characteristics during the spawning season and these characteristics are only useful for distinguishing sex for adult fish during the spawning season. Still other species have morphological differences which allow determination of sex from external examination at any time.

Mountain whitefish develop small tubercles (raised bumps) on the lateral scales prior to spawning. These tubercles are generally more pronounced in males than in females but, alone, tubercles may not be a reliable indicator of sex. Trout may show differences in jaw morphology with females having a rounded jaw and male developing a kype (extended, upwardly hooked lower jaw). This characteristic is not reliable in that the male may not develop a kype, particularly in smaller adults. Males for most sucker species develop obvious tubercles which show as hard nodules in the pelvic, lower caudal and, particularly, the anal fin during the spawning season and which are very reliable for determining sex in adult fish. Many species, such as minnows, suckers and some trout develop distinct body coloration or markings during the spawning season which may aid in separating the sexes. Two species, goldeye and mooneye, show a difference in anal fin structure between mature male and female fish which is a reliable external indication to distinguish sex at any time. In the female, the longest rays of the anal fin are the first four and all of the anal fin rays are slender. The overall shape of the fin is "smoothly concave". The first half of the anal fin of the male has long rays followed by much shorter rays at the back, giving the fin a "lobed" appearance. In the male, the anterior rays are thick near the base. This characteristic is not reliable for juvenile fish.

3.42 Spawning Surveys

Spawning surveys refer to the visual observation of spawning activity or sampling for the presence of incubating eggs and are used to determine if a site has been used as a spawning area, to determine the distribution of spawning sites within a study area, or to collect micro-habitat data (Habitat Preference Criteria) at known spawning areas. Spawning occurs when eggs (roe) and milt (sperm) are extruded by the fish so as to mix and produce fertilized ovum. This is accomplished in a number of ways by different species. Most game fish species for which spawning surveys are typically conducted are either spring or fall spawning species. There are two basic types of spawning surveys (***egg surveys or redd surveys***) depending on the spawning strategy of the species involved.

Egg Surveys

Some species, such as mountain whitefish, lake whitefish, lake trout, walleye and sauger are ***broadcast spawners*** which distribute their eggs over the substrate in areas of suitable depth, velocity and substrate type. The eggs fall into the interstitial spaces (crevices) in the substrate to incubate, although some species will spawn over hard sand if rocky substrates are not available. Spawning surveys for broadcast spawners are conducted using kick sampling and/or airlift sampling techniques (see sections 3.5.1 and 3.5.9). If the study area is small, systematic sampling can be used to examine the entire area for eggs. In large study areas where this type of sampling is impractical, sampling is conducted by examining areas of suitable spawning habitat for the target species. Habitat preference information (see section 3.22) is used to determine the habitat types that should be examined. The section of the stream or portion of lake that is examined during the survey and the location of all spawning sites where incubating eggs are recovered should be identified on maps of the study area. The standard is to use 1:50,000 scale topographical maps but other maps or air photos may be used if they provide greater accuracy. The number of eggs recovered is also recorded for each spawning site and, depending on the sampling technique, sampling effort may also be recorded at each site.

If incubating eggs are found in a study area where more than one species may be spawning, measure egg diameter for the recovered eggs and use egg size, colour and features such as the presence or absence of oil globules to identify the eggs. Egg diameter can be measured using an egg measuring trough. Place 10 eggs in the trough and measure the total amount of the ruler covered, divide this distance by 10 to get an average egg diameter. Scott and Crossman (1973) provide egg descriptions for most species. If egg identification is still doubtful, collect a sample of eggs, measure the egg diameter, and preserve the sample in 5% buffered formalin.

Some fish species use spawning strategies which are part-way between broadcast spawners and species which construct spawning nests. These species include Arctic grayling and several sucker species such as longnose and white sucker. No actual nest or redd is prepared but spawning occurs close over the substrate while the fish are vigorously vibrating and the fertilized eggs become somewhat covered by the substrate material stirred up during this vibration. In some cases, such as spawning areas used by a large number of suckers, disturbances of the substrate can be visually observed but it is not possible to enumerate the number of spawning acts or the number of fish involved. For species such as Arctic grayling, these disturbances are indistinct. Spawning surveys for these species are conducted using egg surveys, as for broadcast spawners.

Still other species, such as northern pike and yellow perch, attach their incubating eggs to submerged vegetation (aquatic macrophytes or flooded terrestrial vegetation). Spawning surveys for these species are conducted by searching for eggs in areas of submerged vegetation. A kick sampling net or other small mesh net is swept through the vegetation and the net contents are examined for eggs.

Redd Surveys

Most trout species (including brook, brown, bull, cutthroat and rainbow trout) construct excavations in the substrate into which the fertilized eggs are deposited. A similar excavation immediately upstream of the depression is dug and the materials from this excavation are used to cover the incubating eggs. These excavations or spawning "nests" are termed ***redds*** and are typically constructed in flowing water, although areas of ground-water upwellings in lakes may also be used. As the algae and silt covered rocks are turned over during redd construction, the redds can usually be readily observed due to their "clean" nature and distinctive shape (i.e. distinct depression upstream of a mound). Redd surveys are conducted by one or more observers walking or floating through a study area, enumerating the redds observed, and recording the locations of the redds on a 1:50,00 map of the study area. The study area (section of stream or portion of lake) examined should also be recorded on the map. Not all excavations are redds which contain incubating eggs and it may sometimes be difficult to determine if a disturbance of the streambed is truly a redd. Therefore, redds should be enumerated and classified into the following categories: 1) Class A redd - large or distinct, well formed or spawning fish present; 2) Class B redd - less distinct, most likely an active redd; 3) Class C redd - small or indistinct, possible redd but not definite.

If more than one trout species may be spawning in the study area, enumeration of the redds by species may be difficult. If this is the case, species identification for each redd is best facilitated by conducting the redd survey during the active spawning period so that it is likely that the fish will be present at the redds to aid in identification. Knowing the species and size of the fish in the study area will also help, as some species build larger redds than others. If only one species is expected to be spawning in the study area, the redd survey is usually conducted towards the end of the spawning season when the maximum number of redds will be present.

Repeated redd surveys in the same study area can be used to define the spawning season if required. Surveys are conducted at regular intervals from the start of the spawning season and the number and location of redds on each successive survey is used to determine the length and peak of spawning activity.

3.43 Species Code

Standard abbreviation of fish species names is based on the following rules (MacKay et al. 1990):

a) use a four letter abbreviation
b) for a one word name - use the first four letters
   e.g., GOLD for goldeye
c) two word names - use the first letter in each word plus the next consonant in each word
   e.g., ARGR for Arctic grayling,
   LKWH for lake whitefish, and,
   WHSC for white sucker
   (exception - due to duplication, use BRTR for brook trout and BNTR for brown trout)
d) three word names - use the first letter in the first two words and the first letter and next consonant in the last word
   e.g., NRDC for northern redbelly dace

The species codes for all Alberta species are presented on the back of the Fish Sample Record Form.

3.44 Species Composition

A term that refers to the species found in the sampling area.

3.45 Species Distribution

Where the various species in an ecosystem are found at any given time. Species distribution varies with season and life history stage.

3.46 Stage (Life History Stage)

Stage refers to the life history stage (or life stage) of the individual fish. Three stage categories are used to describe free swimming fish: ***fry, juvenile or adult***. The incubating egg is also a life stage and is referred to as the embryo stage.

Fry are also called young-of-the-year (YOY) and are fish from their hatching date until the first anniversary of their hatching date. Juvenile fish are fish from one year old until reaching sexual maturity. Adult fish are fish which are sexually mature.

Definitive life history stage is determined for an individual by internal examination of the gonads. Fry and juvenile fish would have undeveloped gonads and would be classified as immature with respect to state-of-maturity. Fry can usually be separated from juvenile fish by their small size (i.e. smallest fish in the population) and, for some species, by secondary characteristics such as parr marks. Adult fish are sexually mature fish which have spawned in the past or will spawn in the upcoming spawning season. Their state-of-maturity can be one of several categories, from maturing to spent.

Determination of stage from external examination is not always possible. Identification of fry is based on their small size. However, it is not always possible to tell large juvenile fish from small adult fish, in which case an ***unknown*** category is provided in addition to the three main categories. Evidence of sexual maturity, such as secondary sexual characteristics or extrusion of milt or roe during the spawning season can be used to identify adult fish.

3.47 Standard Error and Standard Deviation

Standard error (SE) and standard deviation (SD) both express the variability of results 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 population.

Standard error is calculated as: $SE=SD \div \sqrt{n}$; where n=sample size. Microsoft Excel will calculate SD automatically. In order to calculate SE the formula in Excel would be "=StDev(cells with data)/(sample size)^0.5". The "^.05" denotes square root (by asking excel to calculate to the power of 0.5).

Standard error is 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.

3.48 Stomach Content/Gut Analysis

Stomach content analysis is used to determine the diet and food preferences of fish. The stomach is removed from the sacrificed individual and opened to allow examination of its contents. Record stomach fullness as the percentage of fullness, from 0 to 100%. Record the contents of the stomach as percentage of the material in the stomach, not as percentage of the total stomach volume (e.g. a stomach that was half full, with all the contents being mayflies would be recorded as follows: 50% full, 100% mayfly).

For invertebrates in the stomach contents, record the contents to the lowest taxonomic level possible. Family level is usually required, but Genus should be recorded if known. Unidentifiable, overdigested invertebrates should be recorded as IR (invertebrate remains) and unidentifiable fish remains should be recorded as FR (fish remains).

3.49 Study Site/Sampling Location

A study site or sampling location is the portion of a study area at which sampling is conducted. The site may be a ***point location*** (such as a gill net or set line location) a ***transect*** (cross section of a stream channel or lake) or a ***section*** (such as a section of stream electrofished or an area of a lake which is seined). In any event, the location of the sampling site must be recorded in the field notes. For large studies or studies with multiple sampling locations on the same waterbody, you may wish to number each sampling site. For a single waterbody, sample site may be numbered sequentially (i.e #1, #2, etc.). For multiple waterbodies, you may wish to combine the number with an abbreviation for the waterbody (e.g. BR1 = Bow River Site #1). You may also wish to identify the type of sampling conducted (e.g. GN1 = gill net set #1). All study site abbreviations must be clearly identified in the field notes. At a minimum, all study sites should be recorded on a 1:50,000 scale topographical map. Other maps or air photos may also be used if they provide greater detail than the 1:50,000 map. See section 3.17 for additional methods of recording location.

Study areas on flowing watercourses are often divided into homogeneous sections called reaches. A ***reach*** is a relatively homogenous section of stream having a uniform set of characteristics and habitat types. A reach is relatively uniform with respect to channel morphology, flow volume, gradient and habitat types and is separated from other reaches by changes in these characteristics. Conventionally, reach numbers are assigned in an upstream ascending order starting from the mouth of the stream. Typically, reach lengths are too long to sample in their entirety, in which case representative study sections will be selected in each reach for determining species distribution and abundances.

3.50 Temperature Criteria

Water temperature is a very important habitat component. Different fish species have different temperature requirements and have different tolerances to high water temperatures. Temperature regime in lakes and rivers can affect the presence, distribution and abundance of fish species (see sections 3.7 and 3.9). Temperature criteria provide maximum temperature levels that are tolerable by various life stages and have been developed for selected game fish species. Golder has prepared a document which list the criteria for selected Alberta species (Taylor and Barton 1992).

3.51 Underwater Video

Underwater video equipment includes a remote control underwater camera, light and above surface monitor and video recorder. Underwater video is used to determine fish presence, general abundance and activity. It is not generally useful for recording fish numbers. It is a sampling technique that is effective in both the open water season and for winter sampling under the ice.

3.52 Water Quality

Water quality is a basic aspect of fisheries habitat and can influence fish survival, distribution, abundance and reproductive success. Basic water quality parameters that are measured for fisheries studies include; temperature, dissolved oxygen, pH, conductivity, visibility (secchi depth), turbidity, total suspended solids (TSS) and total dissolved solids (TDS).

3.53 Weight

Weight refers to the total body weight (wet weight) of fish. It is measured for live fish before they are released or for sacrificed fish immediately after they have been killed. Along with length, weight is one of the most basic parameters measured evaluate the key attributes of fish populations.

Weight should be measured **in grams (g)** using a properly calibrated dial scale or electronic scale, depending on fish size. Golder uses dial scales fitted with fork length troughs for measurements of intermediate and large fish. Two types of dial scale are used; small scales which are rated for 0-4 kg in weight are used for most fish species, large scales rated for 0-25 kg are used for large fish species. For forage fish species and fry life stages of large fish species, more sensitive digital electronic scales are used.

3.54 Weight-at-Age

Weight-at-age analysis is used to determine the average weight of fish in each age class in the population. This analysis can only be conducted for individuals for which age is known. For each age class (i.e 1 year old fish, 2 year old fish, etc.) calculate the range of weights, mean weight and the standard deviation of the mean. Plot this data graphically with age as the X-axis, showing the range, mean and standard deviation (error bars). Weight -at-age is usually plotted on the same graph as length-at-age data.

4. REFERENCES AND SUGGESTED READING

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5. DISCUSSION

All basic aspects of each fisheries sampling program should be clear before commencement of field work. The field supervisor and field crew should be appraised by the project manager of all study design details. This will include study objectives, delineation of the study area, sampling techniques, data requirements and budgeting. Conditions at the field site may require alteration of the study design. The field crew should act in coordination with the project manager regarding changes to sampling protocols.

APPENDIX I

MATURITY CODES AND DEFINITIONS

UNKNOWN (UN): This category is used when state-of-maturity cannot be determined. This will most often occur for fish which have only been examined externally, where no examination of the gonads has been conducted. It may also be used following internal examination of the gonads when the observer cannot definitely determine the maturity of the fish. The gonads have been examined but the observer is unsure which maturity category to use, or the conditions of the gonads do not appear to match any of the maturity categories. If this is the case, record a complete description of the gonads and, if possible, collect a sample for microscopic examination.

IMMATURE (IM): This category is for immature fish (fry or juvenile life stages); defined as fish which have never spawned before and will not spawn in the coming spawning season. The gonads will be undeveloped and will be small and largely transparent. They will be string-like organs situated on the dorsal surface of the body cavity (dorsal to other internal organs) and will lie close under the vertebral column. In very young or small fish, determination of sex from examination of the immature gonads may be difficult or impossible.

Male: The testes will typically be smooth in texture and yellow, pink or white in colour. In suckers and percids, immature male testes can be identified by the position of the testicular artery. The artery is usually totally or partially imbedded in the organ.

Female: The ovaries will typically have a granular texture and will be yellow or pink in colour. In suckers and percids, immature female ovaries can be identified by the position of the ovarian artery. The artery is usually completely outside the organ, resting on top of the surface tissue and attached with connective tissue.

MATURING (MA): A maturing fish is a fish which has not spawned before but will spawn in the coming spawning season. This category refers to a fish whose gonads are developing for the first time. Fish in the maturing category are, for the first time, considered adult fish as they are hormonally similar to sexually mature individuals. Since the gonads are developing for the first time, development may not be complete at the time the fish is examined. The gonads may be developed (enlarged and showing sperm or egg development) primarily at the anterior end. The posterior end of the gonad may still be undeveloped and appear thinner (similar to an immature gonad). This category can be difficult to interpret in the field, being difficult to tell from the *Green* category, and examination of the gonads by microscope may be required. In general, the gonads of a maturing fish will be smaller than those for a *Green* fish.

Male: In the field, maturing testes will be smaller and paler than those of fully developed males but considerably larger than immature testes. If unsure, take a sample for histological analysis and designate the fish as *Green* (GN).

Female: In the field, maturing ovaries will be smaller and paler than those of fully developed females but considerably larger than immature ovaries. If unsure, take a sample for histological analysis and designate the fish as *Green* (GN).

SEASONAL DEVELOPMENT (SD): Fish in this category are sexually mature adults which have spawned in one or more previous spawning seasons and will spawn in the coming spawning season. The gonads are undergoing their seasonal development following the last spawning season. This is the longest of the sexually mature stages as it extends from just after the post-spawning period until the next pre-spawning period, as the fish utilizes its resources to produce new gametes. For spring spawning fish (e.g. walleye, northern pike, longnose sucker, rainbow trout, etc.), this category would last from late May to early April of the next year. For fall spawning fish (e.g. lake whitefish, mountain whitefish, bull trout, brook trout, etc.) this category would last from the end of the fall spawning season one year (September to November) through to the fall of the next year. However, for most fish, gonadal development occurs primarily during the growing season with only limited gonadal development during the winter months.

Male: The testes will vary greatly in size and colour within this category depending on the time of year the fish is examined. Early in development (i.e. after the post-spawning period), the testes will be small and yellow to light orange in colour. By early fall (i.e. after the primary gonad development period in the summer), they will have grown to nearly mature size and be white in colour. At this point, the testes will be large and distinct. Note: Suckers have a black coloured testicular membrane which may mask the white colour of the testes.

Female: The ovaries will vary greatly in size and colour within this category depending on the time of year they are sampled. Early in development (i.e. after the post-spawning period), the ovaries will be small and yellow to light orange in colour. Developing oocytes will be small and dark orange in colour and will give the ovary a granular appearance. By early fall (i.e. after the primary gonad development period in the summer), the ovaries will have grown considerably to nearly mature size and be bright yellow to orange in colour. The individual eggs will be readily apparent.

PRE-SPAWNING (PR): Fish in this category are sexually mature adults which have spawned in one or more previous spawning seasons and will spawn in the coming spawning season. The *Pre-spawning* category follows right after the *Seasonal Development* category, with respect to both time and stage of gonadal development, and occurs when the gonads have completed their seasonal development prior to the spawning season. This is a short term condition which extends from time the gonads are fully developed until the start of spawning activity.

Male: Externally the abdomen will be slightly distended. Semen can sometimes be extruded with pressure to the abdomen. If this is the case, small amounts of loose semen will be extruded followed by more viscous semen if pressure is re-applied. Internally, the testes will be large and white and will fill much of the body cavity. Pre-spawning condition can also be inferred by the capture location of the male. Males will usually only enter spawning condition once they are on the spawning grounds and around mature females. Thus a male caught away from the spawning grounds as the spawning season approaches is most likely still in pre-spawning condition, even if some sexual products can be extruded. Note: Semen can be extruded from sexually mature males as early as February in spring spawning species.

Female: Externally the abdomen will be noticeably distended. Sometimes a few eggs can be extruded with strong pressure to the abdomen. Care must be taken when applying pressure as the eggs are difficult to extrude and injury to the female can occur. The abdomen will feel tight and hard. Internally, the ovaries will be large and bright yellow to bright orange in colour. The size can be up to 25% of the total body weight and the gonads will fill much of the body cavity. Individual eggs will be large, round and obvious, some eggs will be translucent. Pre-spawning condition can also be inferred by capture location. Females will usually only enter spawning condition once they are on the spawning grounds and around mature males. Thus a female caught away from the spawning grounds as the spawning season approaches is most likely still in pre-spawning condition, even if some sexual products can be extruded.

RIPE (RP): Fish in this category are sexually mature adults. *Ripe* is the term for the spawning condition. The *Ripe* category follows right after the *Pre-spawning* category, with respect to both time and stage of gonadal development, and occurs when the gametes (semen and eggs) have become loose in the gonads. This is a short term condition which extends from start to the end of spawning activity. Externally the fish will appear as they do during the *Pre-spawning* stage but extrusion of the gametes will occur in response to slight pressure on the abdomen.

Male: Externally the abdomen will be slightly distended. Semen can be extruded with light pressure to the abdomen. Large amounts of loose semen will be produced if pressure is applied. Internally, the testes will be large and white.

Female: Externally the abdomen will be greatly distended. Eggs immersed in ovarian fluid can be extruded with light pressure to the abdomen. Large amounts of loose eggs will be produced if pressure is applied. Internally, the ovaries will be large and yellow or orange. The eggs will be large and translucent and some will appear to be loose as the ovarian tissue is weak (i.e. the ovarian sac will be transparent and thin). Eggs will be loose inside the sac and they will be immersed in clear ovarian fluid.

SPENT (SP): Fish in this category are sexually mature adults. *Spent* is the term for the post-spawning condition. The *Spent* category follows right after the *Ripe* category, with respect to both time and stage of gonadal development, and occurs following spawning activity when the gametes (semen and eggs) have been largely extruded during spawning. This length of time a fish will spend in this category depends on how long it takes for the fish to begin the next cycle of seasonal gonadal development, at which time the fish will again be classified as *Green*.

Male: Externally, the abdomen will be slightly flaccid, especially ventrally. Some semen can still be extruded with pressure to the abdomen but it will most likely be watery (i.e. not as intense a white colour as in spawning males). Internally, the testes will be reduced in size and gray to creamy-white in colour. Hemorrhaging and distended blood vessels on the surface of the organ are common. Post-spawning males are known to stay on the spawning grounds for some time (up to 2 weeks) so capture location is not always a reliable indication of whether the fish has finished spawning.

Female: Externally, the abdomen will be noticeably flaccid, especially ventrally. The surface of the abdomen may be red or roughened with abrasions and the urogenital opening may be extended or swollen. Some eggs can still be extruded with pressure but will be few in number and they will be associated with watery ovarian fluid. Internally, the ovaries will be greatly reduced in size and dark orange to brown in colour. Hemorrhaging and distended blood vessels on the surface of the organ as well as within it are very common and normal. Some residual eggs (from a few up to 25% of the ovary volume) are common. It is not common for post-spawning females to stay on the spawning grounds, most spawn and leave the area immediately. However, capture location is not always reliable indicator.

REABSORBING (RB): Fish in this category are sexually mature fish which have developed to some extent for the coming spawning season but, instead of completing gonadal development or instead of spawning after completing gonadal development, these fish are reabsorbing materials from the gonads back into the body. This category represents arrested gonadal development or interrupted spawning activity. There are several reasons why a fish may terminate gonadal development or decide not to spawn after completing gonadal development. These include the condition of the fish with respect to nutrition and/or health, aspects of population dynamics or environmental cues such as improper water temperatures, poor water quality conditions or adverse water level conditions. Interrupted gonadal development can occur at any stage of development and prior to entering the reabsorbing category the fish may have been *Maturing*, undergoing *Seasonal Development* or in *Pre-spawning* condition.

Male: This condition is *extremely rare in males* and difficult to observe as reabsorption of the semen by the testes is usually a rapid process. Very rarely will a case be observed of a male actually retaining the entire contents of the testes for re-absorption. Should you suspect this condition the testes should be preserved and stage verified by a qualified biologist.

Female: This condition is primarily observed in females. Reabsorption of the eggs by the ovary is usually a lengthy process which can take up to a full year. Some females may retaining the entire contents of the ovaries for re-absorption. Identification of this stage is not always easy. Externally, the female will still have a distended abdomen if caught within a few months of the spawning season. The abdomen will feel unusually hard as compared to normally developing females. Later in the season, it will be impossible to distinguish a normally developing female from a reabsorbing one without an internal examination. Internally, reabsorbing ovaries go through a series of distinct stages. Early in the reabsorption process, the ovary is dark orange to brown in colour. The eggs are dark and flaccid. Heavy amounts of watery ovarian fluid collect at the posterior of the ovary. This fluid most often is ejected readily if the fish is handled. Later, the ovary becomes smaller and hard. The colour becomes darker and the eggs become atritic. Atritic eggs are easily identified as they are small, hard and white. Ovaries in the later stages of eggs reabsorption have few new oocytes. The remnants of the old eggs collect in the middle of the organ. New oocytes production is restricted to the periphery of the ovary. Should you suspect this condition the ovaries should be preserved and stage verified by a qualified biologist. Occasionally, females have been observed which aborted spawning activity after they had became *Ripe*. Functionally speaking, eggs at this stage are no longer connected to the ovaries and cannot be reabsorbed. Instead they remain in the body cavity. Internal examination of a fish in this condition will show the newly developed gonad as well as residual (brown, desiccated) eggs which could not be reabsorbed in the posterior portion of the body cavity.

RESTING (RS): Fish in this category are sexually mature adults which have spawned in one or more previous spawning seasons but will not spawn in the coming spawning season. These fish are different from *Reabsorbing* fish in that their gonads are either not developing or are developing too slowly to be ready for the upcoming spawning season. This is a common condition for fish which do not spawn every year (alternate year spawners).

Male: This condition is *extremely rare in males*. It can only be used as an alternative to the Green category. A few cases of males in the resting condition have been observed. They are most common in northern latitudes where the growing season is short or in ultra-oligotrophic lakes. Testes will appear flaccid and dirty-white to yellow in colour. They will be larger in size than the testes of immature fish. A good indication is the size of the testicular artery in relation to the organ. In immature fish this artery is very thin whereas in resting males the testicular artery is much larger because of prior testicular development. Should you suspect this condition the testes should be preserved and stage verified by a qualified biologist.

Female: This condition is primarily observed in females but is still relatively infrequent, affecting usually only 0.5 to 1% of the population. This stage can only be used as an alternative to the *Green* category. It is most common in northern latitudes where the growing season is short or in ultra-oligotrophic lakes. The ovaries will appear to have some oocytes but they will be few in number and arrested in their development. The colour of resting ovaries varies greatly with fish species but most often they are a light orange. They will be larger in size than the ovaries of immature fish. A good indication is the size of the ovarian artery in relation to the organ. In immature fish this artery is very thin whereas in resting females the ovarian artery is much larger because of prior egg development. Should you suspect this condition the ovaries should be preserved and stage verified by a qualified biologist.

APPENDIX V

WATER AND SEDIMENT QUALITY DATA

Table V-1A Water Quality of the Athabasca River Upstream from Fort McMurray (1976-1995)

Parameter	Units	Winter				Spring				Summer				Fall			
		median	min.	max.	n	median	min.	max.	n	median	min.	max.	n	median	min.	max.	n
Field Parameters																	
Temperature	°C	0.02	-0.4	1.5	31	11.9	0	18.3	10	18.5	14	26	31	7.7	-0.04	17	21
Dissolved Oxygen	mg/L	12.3	10.8	15.1	25	10.3	9.5	11.6	6	9.3	4.3	13	27	10.4	8.2	14.4	19
Conventional Parameters and Major Ions																	
pH	-	7.88	7.35	8.53	43	8.01	7.46	8.4	14	7.98	7.44	8.50	41	7.90	7.28	8.40	25
Conductivity	µS/cm	398	267	530	42	246	176	350	13	221	155	278	40	249	150	345	24
Colour	T.C.U.	20	<5	80	37	44	18.9	80	11	34	<5	76	25	33	5	190	17
Total Alkalinity	mg/L	169	127	231	43	102	80	125	14	98	78	118	43	110	64	158	26
Total Dissolved Solids	mg/L	243	183	355	34	159	51	496	14	144	102	398	37	158	109	214	23
Total Suspended Solids	mg/L	2.45	0.4	92.3	46	82	3	1090	15	126.5	11	1490	44	19.2	1	344	27
Total Hardness	mg/L	190	142	271	30	114	90	134	7	105	85	126	24	124	93	162	14
Calcium	mg/L	50	39	74	42	32	26	37	13	30	23	40	43	33	19	42	25
Magnesium	mg/L	13.9	10.6	21.0	42	7.8	6.2	11.0	13	7.4	5.8	9.1	43	8.7	5.4	11.6	25
Potassium	mg/L	1.8	0.1	2.7	42	1.6	1.2	3.7	12	0.9	0.1	2.1	38	0.9	0.1	1.4	26
Sodium	mg/L	16.1	11.5	24.6	43	9.0	6.7	20.5	14	5.4	3.5	11.0	44	6.9	4.0	15.2	26
Chloride	mg/L	5.2	2.7	14.0	43	3.0	1.4	19.0	14	1.5	0.5	4.6	44	2.1	<1	7.2	26
Sulphate	mg/L	39.7	27.0	58.0	43	22.2	16.1	30.0	14	17.1	11.8	36.9	41	22.0	13.0	38.1	25
Nutrients																	
Total Kjeldahl Nitrogen	mg/L	0.54	0.16	1.46	29	0.87	0.63	1.50	8	0.81	0.24	3.19	26	0.62	0.20	1.90	17
Nitrate + Nitrite	mg/L	0.16	0.13	0.19	2	-	-	-	-	<0.05	<0.05	<0.05	1	<0.05	<0.05	<0.05	1
Total Ammonia	mg/L	0.03	<0.01	0.08	17	0.02	<0.01	0.06	4	0.01	<0.01	0.02	9	0.01	<0.01	0.02	6
Total Phosphorus	mg/L	0.022	<0.003	0.179	42	0.110	0.034	2.500	13	0.128	0.025	1.300	40	0.033	0.009	0.350	24
Dissolved Phosphorus	mg/L	0.012	<0.003	0.035	19	0.013	0.006	0.026	6	0.013	<0.003	0.042	8	0.007	<0.003	0.012	6
General Organics																	
Biochemical Oxygen Demand	mg/L	0.6	<0.1	3.0	20	0.9	0.6	1.2	2	-	-	-	-	-	-	-	-
Chlorophyll "a"	µg/L	0.3	0.2	1.1	19	4.2	2	13.7	5	2.8	<1	19.0	18	1.7	<1	5.0	13
Dissolved Organic Carbon	mg/L	8.0	5.3	20.0	43	10.0	7.3	19.0	13	8.0	1.0	23.5	32	8.0	2.5	25.0	21
Total Organic Carbon	mg/L	8.5	5.7	21.0	35	13.1	7.0	22.5	10	9.5	2.0	29.5	32	9.0	3.1	26.0	19
Total Phenolics	mg/L	0.003	0.001	0.008	25	0.003	<0.001	0.006	7	0.002	<0.001	0.007	13	0.002	<0.001	0.009	9
Metals (Total)																	
Aluminum (Al)	mg/L	0.055	<0.005	0.35	36	0.844	0.2	6.9	11	0.908	0.13	11.4	31	0.23	<0.005	2.5	19
Arsenic (As)	mg/L	0.0004	0.0002	0.0007	14	0.0012	0.0008	0.0019	4	0.0012	0.0004	0.0125	13	0.001	0.0003	<0.005	9
Barium (Ba)	mg/L	0.086	0.079	0.122	13	0.0705	0.055	0.121	4	0.0705	0.059	0.15	10	0.068	0.057	0.08	5
Beryllium (Be)	mg/L	<0.001	<0.001	<0.001	3	<0.0006	<0.0002	<0.001	2	0.001	0.001	0.003	3	<0.001	<0.001	<0.001	1
Boron (B)	mg/L	0.03	0.01	0.05	2	-	-	-	-	0.04	0.04	0.04	1	0.04	0.04	0.04	1
Cadmium (Cd)	mg/L	0.001	<0.001	0.003	13	0.001	<0.001	0.002	4	<0.001	<0.0002	<0.001	12	<0.001	<0.001	<0.001	7
Chromium (Cr)	mg/L	0.003	0.001	0.006	18	0.0045	0.002	0.009	4	0.004	0.003	0.032	12	0.0025	<0.001	0.007	8
Cobalt (Co)	mg/L	0.001	<0.001	0.004	13	0.001	<0.001	0.005	4	0.002	<0.001	0.009	12	0.001	<0.001	0.003	7
Copper (Cu)	mg/L	0.001	<0.001	0.007	22	0.004	<0.001	0.009	6	0.005	0.002	0.018	16	0.0015	<0.001	0.004	10
Iron (Fe)	mg/L	0.174	0.101	0.25	11	3.21	2.7	7.51	3	3.115	2.3	10.7	6	0.352	0.254	2.42	3
Lithium (Li)	mg/L	0.0125	<0.005	0.02	2	<0.005	<0.005	<0.005	1	0.014	0.014	0.014	1	0.017	0.017	0.017	1
Mercury (Hg)	mg/L	0.0001	<0.00004	0.0005	41	0.0001	<0.00005	0.001	13	<0.0001	<0.00004	<0.0002	38	<0.0001	<0.00004	<0.0002	26
Selenium (Se)	mg/L	<0.0001	<0.0001	<0.0002	14	0.0002	<0.0002	0.0003	4	0.0002	<0.0001	0.0004	10	0.0002	<0.0001	0.0004	7
Silver (Ag)	mg/L	<0.001	<0.001	<0.001	2	<0.001	<0.001	<0.001	1	<0.001	<0.001	<0.001	1	<0.001	<0.001	<0.001	1
Strontium (Sr)	mg/L	0.34	0.32	0.36	2	0.18	0.18	0.18	1	0.22	0.22	0.22	1	0.22	0.22	0.22	1
Titanium (Ti)	mg/L	<0.05	<0.05	<0.05	2	-	-	-	-	<0.01	<0.01	<0.01	1	<0.05	<0.05	<0.05	2
Vanadium (V)	mg/L	<0.002	<0.002	<0.002	1	0.002	0.002	0.002	1	0.0045	0.004	0.005	2	-	-	-	-
Zinc (Zn)	mg/L	0.007	0.001	0.034	23	0.0145	0.002	0.025	7	0.013	0.005	0.059	15	0.007	<0.001	0.03	9
Metals (Dissolved)																	
Aluminum (Al)	mg/L	0.01	<0.01	0.02	3	0.0675	0.045	0.09	2	0.011	<0.002	0.02	2	0.02	0.02	0.02	1
Arsenic (As)	mg/L	0.0005	0.0002	0.0015	23	0.0009	<0.0005	0.0054	8	0.0009	0.0003	0.021	24	0.0006	0.0003	0.01	14
Barium (Ba)	mg/L	-	-	-	-	0.059	0.059	0.059	1	-	-	-	-	-	-	-	-
Beryllium (Be)	mg/L	<0.001	<0.001	<0.005	11	<0.001	<0.001	<0.005	3	<0.001	<0.001	<0.005	8	<0.001	<0.001	<0.001	4
Boron (B)	mg/L	0.05	<0.01	0.14	22	0.04	0.03	0.07	5	0.06	<0.01	0.12	15	0.06	0.02	0.17	11
Cadmium (Cd)	mg/L	<0.001	<0.001	<0.001	1	0.0035	<0.001	0.006	2	<0.001	<0.001	<0.001	1	-	-	-	-
Chromium (Cr)	mg/L	0.003	0.003	0.005	17	0.003	<0.003	0.004	6	0.003	0.003	0.008	23	0.003	<0.003	0.01	14
Cobalt (Co)	mg/L	0.002	0.002	0.002	1	0.003	<0.002	0.004	2	<0.002	<0.002	<0.002	1	-	-	-	-
Copper (Cu)	mg/L	<0.001	<0.001	<0.001	1	0.002	<0.001	0.003	2	0.002	0.002	0.002	1	-	-	-	-
Iron (Fe)	mg/L	0.11	0.1	0.17	5	0.1	0.06	0.136	3	0.07	0.05	0.09	3	0.12	0.12	0.12	1
Selenium (Se)	mg/L	<0.0002	<0.0002	<0.0005	20	<0.0003	<0.0002	<0.0005	6	0.0002	0.0002	0.0018	16	0.0002	<0.0002	0.0011	11
Vanadium (V)	mg/L	<0.001	<0.001	<0.001	1	<0.0015	<0.001	<0.002	2	<0.001	<0.001	<0.001	1	-	-	-	-
Zinc (Zn)	mg/L	0.002	0.002	0.002	1	<0.001	<0.001	<0.001	1	<0.001	<0.001	<0.001	1	-	-	-	-

NOTES: - = No data

Table V-1B Water Quality of the Athabasca River (1984-1997)

Parameter	Units	Near Donald Creek									Below Existing Oilsands Operations								Below Fort Creek															
		Spring			Summer			Fall			Spring			Summer			Fall		Winter				Spring				Summer				Fall			
		min.	max.	n	min.	max.	n	min.	max.	n	min.	max.	n	min.	max.	n		n	median	min.	max.	n	median	min.	max.	n	median	min.	max.	n	median	min.	max.	n
Field measured																																		
Temperature	°C	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0	-0.3	0.3	10	12.2	-	-	1	18.6	18.2	21	3	11	2.2	14.2	3
Dissolved Oxygen	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.05	11.5	13.01	10	10.3	-	-	1	8.9	8	9.3	3	9.3	9.2	12.4	3
Conventional Parameters and Major Ions																																		
Bicarbonate (HCO3)	mg/L	93	119	2	108	108	2	113	116	2	127	127	2	110	115	2	-	-	-	-	-	-	88	-	-	1	-	-	-	-	109	-	-	1
Calcium	mg/L	<0.5	30.7	2	32.5	32.5	2	27	28	2	33.6	33.6	2	28.5	33.5	2	-	-	42	37	51	10	28	20.8	32	3	27	23	32	5	31.5	25.5	37	6
Chloride	mg/L	<0.5	9.6	2	3.1	3.1	2	2.3	14.8	2	7.1	7.1	2	2	2.6	2	-	-	30.1	18.6	49	12	8	1.3	13	3	6	3	17	6	8.5	4.8	21	6
Colour	T.C.U.	90	90	2	-	-	-	60	-	1	-	-	-	150	150	2	-	-	23.13	19	32	12	-	62	90	2	58.4	35	105.6	6	54.4	23.6	80	6
Conductance	µS/cm	186	253	2	200	200	2	236	268	2	249	249	2	205	224	2	-	-	439	385	544	10	251	175	302	3	223	202	256	6	258.5	227	343	6
Dissolved Organic Carbon	mg/L	7.1	11	2	16.7	16.7	2	9.0	9.2	2	7.6	7.6	2	13	16.1	2	-	-	6.8	6	7.6	12	11	7.1	12.2	3	12.7	8.2	16.2	6	8.75	5.9	12	6
Hardness	mg/L	<1	111	2	114	114	2	100	104	2	121	121	2	101	118	2	-	-	158	136	193	11	103	75	113	3	92	78	118	6	108	95	129	6
Magnesium	mg/L	<0.1	8.4	2	8	8	2	7.9	8.2	2	8.9	8.9	2	7.2	8.2	2	-	-	12.5	11	16	10	8	5.5	8	3	7	5	8	5	7.75	6	9	6
pH		7.81	8.1	2	7.63	7.63	2	7.82	8	2	7.94	7.94	2	7.63	8	2	-	-	7.92	7.45	8.1	11	8.2	7.6	8.2	3	7.95	7.45	8.3	6	8.25	7.9	8.4	6
Potassium	mg/L	<0.1	1.2	2	0.9	0.9	2	1.2	1.4	2	1.2	1.2	2	0.7	1	2	-	-	1.5	1.2	2	11	1.5	1.3	2.3	3	0.95	0.8	1.2	6	1	0.8	1.1	6
Sodium	mg/L	<1	13.6	2	8.6	8.6	2	9.0	16.6	2	11.5	11.5	2	6	8.3	2	-	-	32.5	23	43	12	8	8	16	3	8.15	7	10	6	11.5	9	19	6
Sulphate	mg/L	<0.5	18.3	2	13.1	13.1	2	20.3	23.1	2	19.2	19.2	2	14.2	15.9	2	-	-	36	26	44	12	19	12.8	20	3	20.5	12	22.1	6	19	16	24	6
Sulphide	mg/L	<0.002	<0.002	2	-	-	-	<0.002	<0.002	1	-	-	-	<0.002	<0.002	2	-	-	-	-	-	-	<0.002	-	-	1	-	-	-	-	0.005	-	-	1
Total Alkalinity	mg/L	76	97	2	88	88	2	92	95	2	104	104	2	90	94	2	-	-	144	138	168	11	99	72	117	3	90	83	98	6	104	89	119	6
Total Dissolved Solids	mg/L	140	141	2	120	120	2	146	200	2	146	240	2	123	158	2	-	-					46	30	146	3	182	182	182	1	150	140	160	2
Total Organic Carbon	mg/L	16	16	2	-	-	-	14	14	1	-	-	-	14	14	2	-	-	-	6.1	7.7	2	17	-	-	1	16.3	-	-	1	13	-	-	1
Total Suspended Solids	mg/L	19.0	181.0	2	624.0	624.0	2	4.0	57.0	2	30.0	190.0	3.0	624.0	676.0	1	-	-	2.5	0.4	6.4	12	-	190.0	240.0	2	265.5	38.0	521.0	6.0	36.0	6.0	59.2	5
Nutrients																																		
Nitrate + Nitrite	mg/L	0.015	<0.05	2	0.110	0.110	2	0.007	0.050	2	0.003	0.003	2	0.060	0.100	2	-	-	0.200	-	-	1	0.060	-	-	1	-	-	-	-	<0.05	-	-	1
Total Ammonia	mg/L	<0.01	<0.05	2	0.04	0.04	2	<0.01	<0.05	2	<0.01	<0.01	2	0.04	<0.05	2	-	-	0.06	0.05	0.13	6	0.05	-	-	1	0.03	-	-	1	<0.05	-	-	1
Total Kjeldahl Nitrogen	mg/L	1.20	1.20	2	-	-	-	<0.2	<0.2	1	-	-	-	<0.2	<0.2	2	-	-	0.33	0.30	0.48	3	1.20	-	-	1	1.01	-	-	1	0.50	-	-	1
Total Phosphorus	mg/L	0.140	0.144	2	0.390	0.390	2	0.084	0.087	1	0.120	0.120	2	0.298	0.440	2	0.080	1	0.029	0.025	0.050	8	0.082	0.034	0.180	3	0.290	0.055	0.900	6	0.058	0.023	0.074	6
Dissolved Phosphorus	mg/L	0.020	0.020	2	-	-	-	0.022	0.022	1	-	-	-	0.019	0.019	2	<0.01	1	0.020	0.01	0.027	6	0.015	0.010	0.020	3	0.018	0.018	0.028	3	0.013	0.008	0.019	3
General Organics and Toxicity																																		
Biochemical Oxygen Demand	mg/L	3	3	2	-	-	-	8	8	1	-	-	-	3	3	2	-	-	0.5	0.2	1.4	9	-	<1	2	2	2.3	-	-	1	2	-	-	1
Chlorophyll "a"	µ/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-		-	-	0.3	0.3	0.5	3	-	6.7	9.5	2	6.3	6	8.2	5	4.4	2.6	7	5
Microtox IC50 @ 15 min	%	100	100	2	100	100	2	100	100	1	91	100	2	100	100	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microtox IC25 @ 15 min	%	100	100	2	100	100	2	100	100	1	91	100	2	100	100	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Naphthenic Acids	mg/L	<1	2	2	<1	<1	2	<1	<1	1	<1	<1	2	<1	<1	2	1	1	-	-	-	-	1	-	-	1	-	-	-	-	<1	-	-	1
Total Phenolics	mg/L	0.001	0.001	2	0.001	0.001	2	<0.001	<0.001	1	<0.001	0.002	2	<0.001	<0.001	2	<0.01	1	0.004	<0.001	0.008	12	-	0.003	0.007	2	0.004	<0.001	0.008	6	0.0045	<0.001	0.007	5
Recoverable Hydrocarbons	mg/L	<0.5	<1	2	1	1	2	0.6	<1	1	<0.5	<1	2	<0.5	<1	2	1	1	-	-	-	-	<0.5	-	-	1	-	-	-	-	0.6	-	-	1
Metals (Total)																																		
Aluminum (Al)	mg/L	0.17	5.18	2	8.64	8.64	2	0.11	2.23	2	0.15	4.05	2	10.1	14.1	2	3.89	1	0.0155	<0.005	0.04	8	3.66	-	-	1	6.13	-	-	1	2.38	-	-	1
Antimony (Sb)	mg/L	<0.0002	0.0007	2	0.0002	0.0002	2	<0.0002	0.0012	2	<0.0002	<0.0004	2	0.0003	0.0006	2	0.0005	1	-	-	-	-	<0.0004	-	-	1	-	-	-	-	0.001	-	-	1
Arsenic (As)	mg/L	0.0006	0.002	2	0.007	0.007	2	0.0005	0.0013	2	0.0008	0.0017	2	0.0057	0.007	2	0.0015	1	0.0004	0.0003	0.0006	9	0.0011	0.001	0.0017	3	0.0045	0.0006	0.0085	6	0.0008	0.0005	0.0013	6
Barium (Ba)	mg/L	0.05	0.0976	2	0.2	0.2	2	0.04	0.067	2	0.06	0.0896	2	0.21	0.232	2	0.0758	1	0.065	0.06	0.081	10	-	0.06	0.0892	2	0.0685	0.063	0.2	4	0.0584	0.055	0.063	4
Beryllium (Be)	mg/L	<0.001	<0.001	2	0.004	0.004	2	<0.001	<0.001	2	<0.001	<0.001	2	<0.001	0.004	2	<0.001	1	<0.001	-	-	1	<0.001	-	-	1	0.002	-	-	1	<0.001	-	-	1
Boron (B)	mg/L	0.043	0.05	2	0.05	0.05	2	0.03	0.09	2	0.03	0.031	2	0.033	0.05	2	0.033	1	-	-	-	-	0.035	-	-	1	-	-	-	-	0.24	-	-	1
Cadmium (Cd)	mg/L	<0.0002	<0.003	2	<0.003	<0.003	2	<0.002	<0.003	2	<0.0002	<0.003	2	0.0002	<0.003	2	<0.0002	1	0.001	<0.001	0.002	10	<0.001	-	-	3	0.001	<0.001	0.002	5	0.001	<0.002	0.002	6
Chromium (Cr)	mg/L	<0.002	0.0051	2	0.003	0.003	2	<0.002	0.0026	2	<0.002	0.0051	2	<0.002	0.0197	2	0.0043	1	0.0025	<0.001	0.004	10	0.005	0.0037	0.007	3	0.00995	0.002	0.018	6	0.003	0.0019	0.006	6
Cobalt (Co)	mg/L	0.0021	<0.003	2	<0.003	<0.003	2	0.0009	<0.003	1	0.0018	0.006	2	0.005	0.0068	2	0.0012	1	0.001	<0.001	0.003	10	0.001	<0.001	0.0021	3	0.005	<0.001	0.01	5	0.001	0.0009	0.004	6
Copper (Cu)	mg/L	<0.001	0.007	2	-	-	-	0.049	0.049	1	0.004	0.0061	2	0.0181	0.0181	2	0.0041	1	0.0015	<0.001	0.004	10	0.002	<0.001	0.007	3	0.008	0.002	0.014	5	0.002	<0.001	0.004	6
Iron (Fe)	mg/L	0.43	5.24	2	17.9	17.9	2	0.91	2.19	2	0.43	3.76	2	17.6	19.4	2	2.98	1	0.4625	0.36	0.502	8	5.04	-	-	1	16.1	-	-	1	2.41	-	-	1
Lead (Pb)	mg/L	0.0038	<0.02	2	<0.02	<0.02	2	0.0013	<0.02	2	0.0024	<0.02	2	0.0108	<0.02	2	0.0016	1	-	-	-	-	0.0031	-	-	1	-	-	-	-	0.0013	-	-	1
Lithium (Li)	mg/L	0.006	0.011	2	0.014	0.014	2	0.006	0.008	2	0.006	0.01	2	0.018	0.019	2	0.011	1	-	-	-	-	0.011	-	-	1	-	-	-	-	0.009	-	-	1
Manganese (Mn)	mg/L	0.04	0.106	2	0.509	0.509	2	0.033	0.0709	2	0.044	0.101	2	0.408	0.534	2	0.0739	1	-	-	-	-	0.12	-	-	1	-	-	-	-	0.0752	-	-	1
Mercury (Hg)	mg/L	<0.0002	<0.05	2	<0.05	<0.05	2	<0.0001	<0.05	2	<0.0002	<0.05	2	<0.0001	<0.05	2	<0.0001	1	0.0001	-	-	8	<0.0001	-	-	3	<0.0001	-	-	6	<0.0001	-	-	6
Molybdenum (Mo)	mg/L	0.0026	<0.003	2	<0.003	<0.003	2	0.0008	<0.003	2	0.0007	0.004	2	0.0018	<0.003	2	0.0009	1	-	-	-	-	0.0005	-	-	1	-	-	-	-	0.0007	-	-	1
Nickel (Ni)	mg/L	0.005	0.0051	2	<0.005	<0.005	2	0.003	<0.005	2	<0.005	0.014	2	0.009	0.0211	2	0.0071	1	-	-	-	-	0.0046	-	-	1	-	-	-	-	0.003	-	-	1
Selenium (Se)	mg/L	<0.0002	<0.0004	2	<0.0002	<0.0002	2	<0.0002	0.0007	2	<0.0002	<0.0004	2	<0.0002	0.0007	2	<0.0004	1	<0.0001	-	-	9	<0.0002	-	-	3	0.0002	<0.0002	0.0007	4	0.0002	<0.0002	0.0007	5
Silicon (Si)	mg/L	2.12	12.6	2	-	-	-	-	-	-	1.85	9.52	2	26.2	26.2	2	2.09	1	-	-	-	-	9.77	-	-	1	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	<0.001	<0.002	2	<0.002	<0.002	2	<0.0001	<0.002	2	<0.001	<0.002	2	0.0006	<0.002	2	<0.0001	1	-	-	-	-	<0.001	-	-	1	<0.0001	-	-	1	<0.0001	-	-	1
Strontium (Sr)	mg/L	0.153	0.19	2	0.229	0.229	2	0.171	0.2	2	0.168	0.21	2	0.24	0.248	2	0.192	1	-	-	-	-	0.142	-	-	1	-	-	-	-	0.172	-	-	1
Sulphur (S)	mg/L	6.6	6.6	2	-	-	-	-	-	-	7.3	7.3	2	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanium (Ti)	mg/L	0.004	0.0539	2	0.085	0.085	2	0.007	0.0254	2	0.005	0.0515	2	0.056	0.151	2	0.0386	1	-	-	-	-	0.0454	-	-	1	-	-	-	-	0.0276	-	-	1
Uranium (U)	mg/L	0.0007	<0.5	2	-	-	-	0.0004	0.0004	1	0.0006	<0.5	2	0.0012	0.0012	2	0.0004	1	-	-	-	-	0.0007	-	-	1	-	-	-	-	0.0004	-	-	1
Vanadium (V)	mg/L	<0.002	0.0125	2	0.009	0.009	2	<0.0001	<0.0001	1	0.004	0.0113	2	0.015	0.0379	2	0.0097	1	<0.002	-	-	1	0.009	-	-	1	0.023	-	-	1	0.0061	-	-	1
Zinc (Zn)	mg/L	0.019	0.812	2	0.085	0.085	2	0.14	0.14	1	0.019	0.036	2	0.064	0.095	2	0.034	1	0.004	<0.001	0.081	11	0.003	<0.001	0.039	3	0.0285	0.006	0.074	6	0.005	0.002	0.008	5
Metals (Dissolved)																																		
Aluminum (Al)	mg/L	0.241	0.241	2	0.0159	0.0159	2	0.0443	0.0443	1	0.0572	0.0572	2	0.0499	0.0499	2	0.0729	1	-	-	-	-	0.415	-	-	1	0.026	-	-	1	0.0363	-	-	1
Antimony (Sb)	mg/L	<0.0004	<0.0004	2	<0.0004	<0.0004	2	0.0006	0.0006	1	<0.0004	<0.0004	2	0.0005	0.0005	2	0.0006	1	-	-	-	-	<0.0004	-	-	1	0.006	-	-	1	0.0012	-	-	1
Arsenic (As)	mg/L	0.001	0.001	2	<0.0004	<0.0004	2	0.0005	0.0005	1	0.0006	0.0006	2	0.0006	0.0006	2	0.0006	1	-	-	-	-	0.0012	-	-	1	0.0005	-	-	1	0.0005	-	-	1
Barium (Ba)	mg/L	0.0578	0.0578	2	0.0382	0.0382	2	0.0418	0.0418	1	0.043	0.043	2	0.0506	0.0506	2	0.0396	1	-	-	-	-	0.0612	-	-	1	0.0245	-	-	1	0.0365	-	-	1
Beryllium (Be)	mg/L	<0.0005	<0.0005	2	<0.0005	<0.0005	2	<0.0005	<0.0005	1	<0.0005	<0.0005	2	<0.0005	<0.0005	2	<0.0005	1	<0.001	-	-	9	-	<0.0005	<0.001	2	<0.001	-	-	4	<0.001	-	-	4
Boron (B)	mg/L	0.024	0.024	2	0.022	0.022	2	0.022	0.022	1	0.025	0.025	2	0.018	0.018	2	0.026	1	-	-	-	-	0.026	-	-	1	0.065	-	-	1	0.025	-	-	1
Cadmium (Cd)	mg/L	<0.0001	<0.0001	2	0.0028	0.0028	2	0.0001	0.0001	1	<0.0001	<0.0001	2	0.0002	0.0002	2	0.0001	1	-	-	-	-	0.0001	-	-	1	0.0002	-	-	1	0.0001	-	-	1
Chromium (Cr)	mg/L	<0.0004	<0.0004	2	<0.0004	<0.0004	2	<0.0004	<0.0004	1	<0.0004	<0.0004	2	<0.0004	<0.0004	2	<0.0004	1	-	-	-	-	0.0007	-	-	1	<0.0004	-	-	1	<0.0004	-	-	1
Cobalt (Co)	mg/L	0.001	0.001	2	0.0002	0.0002	2	0.0003	0.0003	1	0.0003	0.0003	2	0.0002	0.0002	2	0.0003	1	-	-	-	-	0.0013	-	-	1	0.0002	-	-	1	0.0003	-	-	1
Copper (Cu)	mg/L	0.0043	0.0043	2	0.0022	0.0022	2	0.0022	0.0022	1	0.0024	0.0024	2	0.006	0.006	2	0.0042	1	-	-	-	-	0.0049	-	-	1	0.003	-	-	1	0.002	-	-	1
Iron (Fe)	mg/L	1.14	1.14	2	0.1	0.1	2	0.14	0.14	1	0.32	0.32	2	0.08	0.08	2	<0.01	1	-	-	-	-	1.93	-	-	1	0.43	-	-	1	0.14	-	-	1
Lead (Pb)	mg/L	0.00148	0.00148	2	0.0113	0.0113	2	0.00052	0.00052	1	0.00038	0.00038	2	0.00101	0.00101	2	0.00147	1	-	-	-	-	0.00198	-	-	1	0.0017	-	-	1	0.00067	-	-	1
Lithium (Li)	mg/L	0.007	0.007	2	0.007	0.007	2	-	-	-	0.007	0.007	2	0.005	0.005	2	0.007	1	-	-	-	-	0.007	-	-	1	0.009	-	-	1	0.007	-	-	1
Manganese (Mn)	mg/L	0.0744	0.0744	2	0.0034	0.0034	2	0.0114	0.0114	1	0.024	0.024	2	0.0098	0.0098	2	0.0102	1	-	-	-	-	0.0916	-	-	1	0.0253	-	-	1	0.0132	-	-	1
Mercury (Hg)	mg/L	<0.0002	<0.0002	2	<0.0002	<0.0002	2	<0.0002	<0.0002	-	<0.0002	<0.0002	2	<0.0002	<0.0002	2	<0.0002	1	-	-	-	-	<0.0002	-	-	1	<0.0002	-	-	1	<0.0002	-	-	1
Molybdenum (Mo)	mg/L	0.00038	0.00038	2	0.00046	0.00046	2	0.00064	0.00064	1	0.00054	0.00054	2	0.0009	0.0009	2	0.00075	1	-	-	-	-	0.00028	-	-	1	0.00023	-	-	1	0.00061	-	-	1
Nickel (Ni)	mg/L	0.0061	0.0061	2	0.002	0.002	2	0.0016	0.0016	1	0.0012	0.0012	2	0.0047	0.0047	2	0.0023	1	-	-	-	-	0.0056	-	-	1	0.0018	-	-	1	0.0016	-	-	1
Selenium (Se)	mg/L	<0.0004	<0.0004	2	<0.0004	<0.0004	2	<0.0004	<0.0004	1	<0.0004	<0.0004	2	<0.0004	<0.0004	2	<0.0004	1	-	-	-	-	<0.0004	-	-	1	<0.0004	-	-	1	<0.0004	-	-	1
Silicon (Si)	mg/L	2.53	2.53	2	1.99	1.99	2	2.3	2.3	1	2.2	2.2	2	2.09	2.09	2	-	1	-	-	-	-	2.72	-	-	1	2.29	-	-	1	2.4	-	-	1
Silver (Ag)	mg/L	<0.0002	<0.0002	2	<0.0002	<0.0002	2	<0.0002	<0.0002	-	<0.0002	<0.0002	2	<0.0002	<0.0002	2	<0.0002	1	-	-	-	-	<0.0002	-	-	1	<0.0002	-	-	1	<0.0002	-	-	1
Strontium (Sr)	mg/L	0.127	0.127	2	0.129	0.129	2	0.179	0.179	1	0.143	0.143	2	0.163	0.163	2	0.175	1	-	-	-	-	0.12	-	-	1	0.0893	-	-	1	0.168	-	-	1
Titanium (Ti)	mg/L	0.0023	0.0023	2	0.0003	0.0003	2	0.0009	0.0009	1	0.0007	0.0007	2	0.0009	0.0009	2	0.0004	1	-	-	-	-	0.0025	-	-	1	0.0006	-	-	1	0.0007	-	-	1
Uranium (U)	mg/L	0.00045	0.00045	2	0.00021	0.00021	2	0.00029	0.00029	1	0.00027	0.00027	2	0.00041	0.00041	2	0.00029	1	-	-	-	-	0.00045	-	-	1	<0.00005	-	-	1	0.00027	-	-	1
Vanadium (V)	mg/L	0.0012	0.0012	2	<0.0001	<0.0001	2	<0.0001	<0.0001	1	0.0002	0.0002	2	<0.0001	<0.0001	2	0.0002	1	-	-	-	-	0.002	-	-	1	0.0001	-	-	1	<0.0001	-	-	1
Zinc (Zn)	mg/L	-	-	2	0.038	0.038	2	0.014	0.014	1	0.006	0.006	2	0.027	0.027	2	0.023	1	-	-	-	-	0.015	-	-	1	0.016	-	-	1	0.019	-	-	1
Trace Organics																																		
PAHs and Alkylated PAHs	µg/L	ND	ND	2	ND	ND	2	ND	ND	1	ND	0.03	2	ND	ND	2	ND	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Target PANHs	µg/L	ND	ND	2	ND	ND	2	ND	ND	1	ND	ND	2	ND	ND	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenolics	µg/L	ND	ND	2	ND	ND	2	-	-	-	ND	ND	2	ND	ND	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Volatile Organics	µg/L	ND	ND	2	-	-	-	-	-	-	ND	ND	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

NOTES: - = No data; ND = Not detected

Table V-2 Water Quality of the Muskeg River (1972-1997)

At Mouth

Parameter	Units	Winter				Spring				Summer				Fall			
		median	min.	max.	n	median	min.	max.	n	median	min.	max.	n	median	min.	max.	n
Field measured																	
pH	-	-	-	-	-	7.8	7.8	7.9	3	8.1	7.7	8.3	3	-	8	9.2	2
Specific Conductance	µS/cm	-	-	-	-	196	-	-	1	316	-	-	1	-	-	-	-
Temperature	°C	0	-0.1	2	12	11	10	13.5	3	16	12	22	5	-	-	-	-
Dissolved Oxygen	mg/L	7.285	1.9	11.5	12	10.8	-	-	1	-	8	9	2	-	-	-	-
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	350	-	-	1	137	93	185	6	187	172	207	6	183	128	310	5
Calcium	mg/L	73.1	39.9	160	13	30.15	20.2	44.4	6	43.4	24	59	13	41.7	25.5	75.3	8
Chloride	mg/L	5.4	3.4	20.2	17	3.65	1.6	4.2	6	3.5	<1	13.5	16	4.35	1.8	18.1	8
Colour	T.C.U.	62.5	50	96	8	-	60	80	2	90	80	100	3	120	-	-	1
Conductance	uS/cm	495	259	1360	12	209	157	300	5	279	216	450	15	310	205	444	8
Dissolved Organic Carbon	mg/L	21.4	9	61	14	15.8	11	15.9	3	24	18	25.3	5	24	17	27	5
Hardness	mg/L	253	137	638	14	111	72	151	6	153	108	203	14	148	97	232	8
Magnesium	mg/L	17	9.1	58	13	8.6	5.3	9.6	6	9.9	3	13.5	15	9.55	7	10.7	8
pH	-	7.5	7.2	8.3	16	7.7	7.4	8.09	5	8.01	7.2	8.5	15	7.84	7.5	8.3	8
Potassium	mg/L	1.5	0.9	6	13	1.45	0.95	1.8	6	0.5	0.03	1.4	16	1	0.5	1.5	8
Sodium	mg/L	15.65	9	50	14	9.05	5	11.5	6	11.8	6	14.9	16	13.3	8	26.5	8
Sulphate	mg/L	4.3	2.3	10.9	15	4.9	2.4	6.6	6	4.8	0.5	31	16	3.8	0.5	10.4	8
Sulphide	mg/L	0.01	0.01	0.01	3	0.003	-	-	1	0.004	-	-	1	0.003	-	-	1
Total Alkalinity	mg/L	257	136	790	13	113	76	152	6	148	66	224	16	153	105	254	8
Total Dissolved Solids	mg/L	331	181	844	7	143	108	167	6	202	151	248	10	184	123	316	7
Total Organic Carbon	mg/L	21.7	10	63	8	-	16	20.8	2	23.75	18	29.4	6	24	19	29	3
Total Suspended Solids	mg/L	4.0	<0.4	20.4	17	1.0	<0.4	4.0	6	3.0	0.0	9.2	10	5.6	1.0	70.0	7
Nutrients																	
Nitrate + Nitrite	mg/L	0.185	0.020	0.300	4	<0.0095	-	-	6	0.050	0.013	0.055	13	0.015	<0.002	0.100	6
Total Ammonia	mg/L	0.23	0.15	1.63	7	<0.025	-	-	4	0.04	<0.01	0.05	4	0.05	0.04	0.06	2
Total Kjeldahl Nitrogen	mg/L	1.11	0.86	3.94	6	-	0.60	0.76	2	1.05	0.60	2.89	6	0.70	0.55	0.70	3
Total Phosphorus	mg/L	0.027	0.020	0.070	10	0.034	0.025	0.040	4	0.029	<0.005	0.600	11	0.045	0.016	0.600	6
Dissolved Phosphorus	mg/L	0.008	0.006	0.013	5	<0.02	-	-	1	0.015	-	-	1	0.014	-	-	1
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	0.7	0.5	4	9	3	0.8	17	3	0.5	0.4	3	3	2.3	0.6	4	2
Chlorophyll "a"	µg/L	<1	-	-	1	-	-	-	-	-	<1	<5	2	<1	-	-	3
Microtox IC50 @ 15 min	%	-	-	-	-	>100	91	100	3	>100	100	100	3	-	100	100	2
Microtox IC25 @ 15 min	%	-	-	-	-	>100	91	100	3	-	100	100	2	-	100	100	2
Naphthenic Acids	mg/L	-	-	-	-	1	<1	4	3	<1	-	-	3	<1	-	-	3
Total Phenolics	mg/L	0.007	<0.001	0.01	11	-	-	-	-	0.001	<0.001	0.011	7	0.001	<0.001	0.002	3
Recoverable Hydrocarbons	mg/L	-	-	-	-	0.5	<0.1	3	3	<0.75	<0.1	1	4	<1	-	-	3
Metals (Total)																	
Aluminum (Al)	mg/L	0.01	<0.002	0.06	12	0.01	<0.01	0.231	4	0.05	0.02	0.11	8	0.06	0.03	1.2	5
Antimony (Sb)	mg/L	-	-	-	-	-	<0.0002	<0.0004	2	-	<0.0002	0.0005	2	0.00035	<0.0002	0.0005	2
Arsenic (As)	mg/L	0.0002	0.0001	0.0006	8	0.0003	0.0002	0.0003	3	<0.0004	-	-	5	0.001	0.0002	0.014	4
Barium (Ba)	mg/L	0.052	0.048	0.072	8	0.03	0.0254	0.03	3	0.03	0.03	0.0333	4	-	0.03	0.03	3
Beryllium (Be)	mg/L	<0.001	-	-	1	<0.001	-	-	3	0.001	<0.001	0.002	4	<0.001	-	-	2
Boron (B)	mg/L	-	-	-	-	0.055	0.045	0.06	4	0.052	<0.04	0.13	5	0.04	0.034	0.16	3
Cadmium (Cd)	mg/L	0.001	0.001	0.002	8	<0.002	-	-	4	<0.001	-	-	7	0.003	<0.002	0.004	4
Chromium (Cr)	mg/L	0.003	<0.001	0.01	8	0.002	<0.0004	0.005	4	0.002	<0.0004	0.017	8	0.006	0.0007	0.008	4
Cobalt (Co)	mg/L	0.001	0.001	0.001	7	<0.003	-	-	3	0.002	<0.0005	0.007	6	0.005	0.0008	0.006	4
Copper (Cu)	mg/L	0.001	<0.001	0.003	7	0.001	0.0008	0.001	4	0.004	<0.001	0.022	5	0.001	0.001	0.004	4
Iron (Fe)	mg/L	1.374	0.88	2.9	11	0.56	0.52	0.79	4	0.84	0.59	1.3	8	1.14	0.8	1.81	4
Lead (Pb)	mg/L	0.007	-	-	1	0.011	-	-	4	0.011	0.0008	0.002	4	<0.02	0.0021	<0.02	3
Lithium (Li)	mg/L	-	-	-	-	0.007	0.006	0.008	3	0.008	0.007	0.011	3	0.008	0.007	0.008	3
Manganese (Mn)	mg/L	0.66	-	-	1	0.034	0.031	0.0393	4	0.0355	0.029	0.0403	4	0.053	0.048	0.115	3
Mercury (Hg)	mg/L	0.0001	<0.00004	0.0011	12	<0.0002	-	-	3	<0.0002	-	-	10	<0.05	-	-	5
Molybdenum (Mo)	mg/L	-	-	-	-	0.003	0.0002	0.004	3	0.003	0.0002	0.003	3	0.003	<0.0001	0.005	3
Nickel (Ni)	mg/L	-	-	-	-	<0.003	-	-	4	0.0033	0.001	0.016	4	0.005	0.0016	0.015	3
Selenium (Se)	mg/L	<0.0001	-	-	8	0.0002	-	-	3	<0.0002	-	-	4	<0.0004	-	-	2
Silicon (Si)	mg/L	-	-	-	-	1.69	1.64	2.2	3	4.23	-	-	1	4.07	3.49	4.31	3
Silver (Ag)	mg/L	-	-	-	-	<0.002	-	-	3	<0.00105	-	-	4	0.002	<0.0001	0.003	2
Strontium (Sr)	mg/L	-	-	-	-	0.091	0.0594	0.093	3	0.098	0.095	0.113	3	0.097	0.086	0.097	3
Titanium (Ti)	mg/L	<0.01	-	-	1	0.003	<0.003	0.0036	3	0.003	0.0014	0.005	3	0.006	0.006	0.0167	3
Uranium (U)	mg/L	-	-	-	-	<0.5	-	-	3	<0.0001	-	-	1	<0.5	-	-	3
Vanadium (V)	mg/L	<0.002	-	-	1	0.0015	-	-	4	0.002	0.0003	0.006	5	0.002	0.002	0.003	3
Zinc (Zn)	mg/L	0.003	<0.001	0.025	9	0.0065	0.003	0.011	4	0.015	0.008	0.115	8	0.0205	0.008	0.033	4
Metals (Dissolved)																	
Aluminum (Al)	mg/L	-	-	-	-	0.0315	-	-	1	0.0094	-	-	1	0.0269	-	-	1
Antimony (Sb)	mg/L	-	-	-	-	<0.0004	-	-	1	0.0008	-	-	1	-	-	-	-
Arsenic (As)	mg/L	<0.00075	-	-	4	<0.0004	-	-	1	-	<0.0004	<0.0005	2	<0.001	-	-	2
Barium (Ba)	mg/L	-	-	-	-	0.019	-	-	1	0.0291	-	-	1	0.024	-	-	1
Beryllium (Be)	mg/L	<0.001	-	-	7	<0.0005	-	-	1	-	<0.0005	<0.005	2	<0.0005	-	-	1
Boron (B)	mg/L	0.135	0.06	0.36	4	0.039	-	-	1	0.0715	0.01	0.16	4	0.033	0.01	0.16	3
Cadmium (Cd)	mg/L	<0.001	-	-	1	<0.0001	-	-	1	-	0.0001	<0.001	2	<0.0001	-	-	-
Chromium (Cr)	mg/L	0.004	<0.003	0.013	3	<0.0004	-	-	1	<0.003	-	-	3	0.003	<0.0004	0.004	3
Cobalt (Co)	mg/L	<0.002	-	-	1	0.0002	-	-	1	-	0.0002	<0.002	2	0.0002	-	-	1
Copper (Cu)	mg/L	0.001	-	-	1	0.0013	-	-	1	-	0.0009	<0.001	2	0.0011	-	-	1
Iron (Fe)	mg/L	0.48	-	-	1	1.03	-	-	1	-	0.12	0.41	2	0.25	-	-	1
Lead (Pb)	mg/L	-	-	-	-	0.00037	-	-	1	0.00381	-	-	1	0.0003	-	-	1
Lithium (Li)	mg/L	-	-	-	-	0.005	-	-	1	0.01	-	-	1	0.007	-	-	1
Manganese (Mn)	mg/L	-	-	-	-	0.0363	-	-	1	0.0199	-	-	1	0.03	-	-	1
Mercury (Hg)	mg/L	-	-	-	-	<0.0002	-	-	1	<0.0002	-	-	1	0.0002	-	-	1
Molybdenum (Mo)	mg/L	-	-	-	-	0.00013	-	-	1	0.00009	-	-	1	0.00008	-	-	1
Nickel (Ni)	mg/L	-	-	-	-	0.001	-	-	1	0.0008	-	-	1	0.0004	-	-	1
Selenium (Se)	mg/L	<0.0005	-	-	4	<0.0004	-	-	1	-	<0.0004	<0.0005	2	<0.0005	-	-	2
Silicon (Si)	mg/L	-	-	-	-	1.36	-	-	1	3.66	-	-	1	4.07	-	-	1
Silver (Ag)	mg/L	-	-	-	-	<0.0002	-	-	1	<0.0002	-	-	1	<0.0002	-	-	1
Strontium (Sr)	mg/L	-	-	-	-	0.0529	-	-	1	0.101	-	-	1	0.074	-	-	1
Titanium (Ti)	mg/L	-	-	-	-	0.0008	-	-	1	0.0004	-	-	1	0.0006	-	-	1
Uranium (U)	mg/L	-	-	-	-	<0.00005	-	-	1	<0.00005	-	-	1	-	-	-	-
Vanadium (V)	mg/L	<0.001	-	-	1	0.0001	-	-	1	-	<0.0001	<0.001	2	-	-	-	-
Zinc (Zn)	mg/L	<0.001	-	-	1	0.008	-	-	1	-	0.001	0.017	2	-	-	-	-
Trace Organics																	
PAHs and Alkylated PAHs	µg/L	-	-	-	-	-	-	-	-	ND	-	-	1	ND	-	-	1
PANHs	µg/L	-	-	-	-	ND	-	-	1	ND	-	-	1	ND	-	-	1
Phenolics	µg/L	-	-	-	-	ND	-	-	1	ND	-	-	1	ND	-	-	1
Volatile Organics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Lower Muskeg River

Parameter	Units	Winter				Spring				Summer				Fall			
		median	min.	max.	n	median	min.	max.	n	median	min.	max.	n	median	min.	max.	n
Field measured																	
pH	-	7.68	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Specific Conductance	µS/cm	470	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Temperature	°C	0	0	0.5	18	4.25	0	13	8	16	13	21	19	7.5	0	12	13
Dissolved Oxygen	mg/L	6.75	1.8	10.4	8	8.7	6.2	11.8	6	8.8	5.2	11.8	20	9.3	5	13.6	13
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	-	313	350	2	93	-	-	1	-	-	-	-	-	-	-	-
Calcium	mg/L	71.5	18	90	25	27.1	15.5	66	10	45.5	27.8	67.2	21	36	26.5	80.6	15
Chloride	mg/L	5.6	0.5	13	27	1.7	1.6	5.5	10	4.2	1.6	14.4	21	2.6	1.7	29.7	15
Colour	T.C.U.	47.5	25	100	14	60	40	80	5	95	30	130	14	100	30	140	10
Conductance	uS/cm	478	120	596	24	187	115	450	10	320	170	442	21	260	160	504	15
Dissolved Organic Carbon	mg/L	20	9.5	37	23	17.25	8	34	10	22.5	6	53	20	25.25	7	29	12
Hardness	mg/L	253	134	281	12	74	60	229	5	156	108	196	10	141	133	170	5
Magnesium	mg/L	17.2	5.3	21	25	7.25	4	16.9	10	10.8	7.5	13.7	21	9.4	7.7	16.9	15
pH	-	7.4	7.2	8.62	27	7.5	7.4	8.2	10	7.8	7.3	8.29	21	7.72	7.3	8.1	15
Potassium	mg/L	1.4	0.45	1.9	23	1.45	1.2	2.6	10	0.55	0.3	0.9	21	0.61	0.25	1.5	15
Sodium	mg/L	14.75	2.9	21.5	24	6.15	4.1	14.5	10	11.5	6.7	22	21	11.6	7.4	38.5	15
Sulphate	mg/L	5.1	1	42.5	25	3.9	2.8	6	10	4.9	0.5	9.1	21	4.4	0.1	11.5	15
Sulphide	mg/L	0.01	<0.002	0.01	4	0.003	-	-	1	-	-	-	-	-	-	-	-
Total Alkalinity	mg/L	259	61	333	24	101	56	254	10	170	100	232	21	136	105	267	15
Total Dissolved Solids	mg/L	303	79	476	27	138	72	297	10	195	112	276	21	162	121	319	15
Total Organic Carbon	mg/L	22	10	38	25	17.5	8	35	10	24	6	53	21	25.5	19.9	31	15
Total Suspended Solids	mg/L	6.0	1.6	72.0	27	5.2	3.6	36.0	10	2.5	0.4	6.0	21	2.8	<0.4	5.2	15
Nutrients																	
Nitrate + Nitrite	mg/L	-	<0.05	0.300	2	<0.05	-	-	1	-	-	-	-	-	-	-	-
Total Ammonia	mg/L	-	0.59	1.63	2	<0.05	-	-	1	-	-	-	-	-	-	-	-
Total Kjeldahl Nitrogen	mg/L	1.30	0.40	3.00	23	0.86	0.04	2.10	10	1.04	0.48	1.66	21	0.90	0.35	1.75	13
Total Phosphorus	mg/L	0.038	0.022	0.190	24	0.031	<0.02	0.090	10	0.025	<0.005	0.053	21	0.028	0.017	0.070	15
Dissolved Phosphorus	mg/L	<0.02	-	-	1	0.600	-	-	1	-	-	-	-	-	-	-	-
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	-	2	4	2	3	-	-	1	-	-	-	-	-	-	-	-
Chlorophyll "a"	µg/L	1	<1	6	9	-	<1	4	2	1	<1	8	6	1	1	10	7
Microtox IC50 @ 15 min	%	>99	-	-	1	>91	-	-	1	-	-	-	-	-	-	-	-
Microtox IC25 @ 15 min	%	-	-	-	-	>91	-	-	1	-	-	-	-	-	-	-	-
Naphthenic Acids	mg/L	<1	-	-	1	4	-	-	1	-	-	-	-	-	-	-	-
Total Phenolics	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Recoverable Hydrocarbons	mg/L	2	-	-	1	<0.5	-	-	1	-	-	-	-	-	-	-	-
Metals (Total)																	
Aluminum (Al)	mg/L	0.04	<0.01	0.58	23	0.07	0.03	0.231	10	0.05	<0.01	0.42	21	0.04	<0.01	0.32	13
Antimony (Sb)	mg/L	<0.0004	-	-	1	<0.0004	-	-	1	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	<0.0004	-	-	1	<0.0004	-	-	1	<0.005	-	-	1	-	0.001	<0.005	2
Barium (Ba)	mg/L	0.0712	-	-	1	0.0254	-	-	1	-	-	-	-	-	-	-	-
Beryllium (Be)	mg/L	<0.001	-	-	1	<0.001	-	-	1	-	-	-	-	-	-	-	-
Boron (B)	mg/L	0.058	-	-	1	0.045	-	-	1	-	-	-	-	-	-	-	-
Cadmium (Cd)	mg/L	-	<0.0002	0.001	2	<0.0002	-	-	1	-	-	-	-	-	-	-	-
Chromium (Cr)	mg/L	-	<0.0004	0.01	2	<0.0004	-	-	1	-	-	-	-	-	-	-	-
Cobalt (Co)	mg/L	0.0005	-	-	1	<0.0005	-	-	1	-	-	-	-	-	-	-	-
Copper (Cu)	mg/L	0.002	-	-	1	0.0008	-	-	1	-	-	-	-	-	-	-	-
Iron (Fe)	mg/L	2.42	1.9	2.9	4	0.79	-	-	1	-	-	-	-	-	-	-	-
Lead (Pb)	mg/L	-	0.0005	0.007	2	0.0004	-	-	1	-	-	-	-	-	-	-	-
Lithium (Li)	mg/L	0.012	-	-	1	0.006	-	-	1	-	-	-	-	-	-	-	-
Manganese (Mn)	mg/L	-	0.43	0.66	2	0.0393	-	-	1	-	-	-	-	-	-	-	-
Mercury (Hg)	mg/L	0.0001	<0.0001	0.0005	25	0.0001	<0.0001	0.0003	10	<0.0001	-	-	21	0.0001	<0.0001	0.0004	15
Molybdenum (Mo)	mg/L	<0.0001	-	-	1	0.0002	-	-	1	-	-	-	-	-	-	-	-
Nickel (Ni)	mg/L	0.0013	-	-	1	<0.0004	-	-	1	-	-	-	-	-	-	-	-
Selenium (Se)	mg/L	<0.0004	-	-	1	<0.0004	-	-	1	-	-	-	-	-	-	-	-
Silicon (Si)	mg/L	6.54	-	-	1	2.2	-	-	1	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	<0.001	-	-	1	<0.001	-	-	1	-	-	-	-	-	-	-	-
Strontium (Sr)	mg/L	0.178	-	-	1	0.0594	-	-	1	-	-	-	-	-	-	-	-
Titanium (Ti)	mg/L	0.05	-	-	6	0.01	0.0036	0.01	3	-	<0.05	<0.05	2	-	<0.05	<0.05	2
Uranium (U)	mg/L	<0.0001	-	-	1	<0.0001	-	-	1	-	-	-	-	-	-	-	-
Vanadium (V)	mg/L	0.0005	-	-	1	0.0004	-	-	1	-	-	-	-	-	-	-	-
Zinc (Zn)	mg/L	-	0.013	0.03	2	0.011	-	-	1	-	-	-	-	-	-	-	-
Metals (Dissolved)																	
Aluminum (Al)	mg/L	-	-	-	-	0.0315	-	-	1	-	-	-	-	-	-	-	-
Antimony (Sb)	mg/L	-	-	-	-	<0.0004	-	-	1	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	0.0004	<0.0002	0.02	23	0.0005	0.0002	0.0006	10	0.00035	<0.0002	0.005	20	0.0004	<0.0002	0.012	13
Barium (Ba)	mg/L	-	-	-	-	0.019	-	-	1	-	-	-	-	-	-	-	-
Beryllium (Be)	mg/L	-	-	-	-	<0.0005	-	-	1	-	-	-	-	-	-	-	-
Boron (B)	mg/L	0.115	0.03	0.26	14	0.11	0.039	0.2	7	0.1	0.01	0.18	9	0.135	<0.05	0.22	8
Cadmium (Cd)	mg/L	-	-	-	-	<0.0001	-	-	1	-	-	-	-	-	-	-	-
Chromium (Cr)	mg/L	0.003	<0.003	0.007	22	0.003	<0.0004	0.006	10	0.003	<0.003	0.016	21	0.003	0.003	0.007	13
Cobalt (Co)	mg/L	-	-	-	-	0.0002	-	-	1	-	-	-	-	-	-	-	-
Copper (Cu)	mg/L	-	-	-	-	0.0013	-	-	1	-	-	-	-	-	-	-	-
Iron (Fe)	mg/L	-	-	-	-	1.03	-	-	1	-	-	-	-	-	-	-	-
Lead (Pb)	mg/L	-	-	-	-	0.00037	-	-	1	-	-	-	-	-	-	-	-
Lithium (Li)	mg/L	-	-	-	-	0.005	-	-	1	-	-	-	-	-	-	-	-
Manganese (Mn)	mg/L	-	-	-	-	0.0363	-	-	1	-	-	-	-	-	-	-	-
Mercury (Hg)	mg/L	-	-	-	-	<0.0002	-	-	1	-	-	-	-	-	-	-	-
Molybdenum (Mo)	mg/L	-	-	-	-	0.00013	-	-	1	-	-	-	-	-	-	-	-
Nickel (Ni)	mg/L	-	-	-	-	0.001	-	-	1	-	-	-	-	-	-	-	-
Selenium (Se)	mg/L	0.0002	<0.0002	0.0009	22	<0.0002	-	-	10	0.0002	0.0002	0.0008	20	<0.0002	-	-	11
Silicon (Si)	mg/L	-	-	-	-	1.36	-	-	1	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	-	-	-	-	<0.0002	-	-	1	-	-	-	-	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-	0.0529	-	-	1	-	-	-	-	-	-	-	-
Titanium (Ti)	mg/L	-	-	-	-	0.0008	-	-	1	-	-	-	-	-	-	-	-
Uranium (U)	mg/L	-	-	-	-	<0.00005	-	-	1	-	-	-	-	-	-	-	-
Vanadium (V)	mg/L	-	-	-	-	0.0001	-	-	1	-	-	-	-	-	-	-	-
Zinc (Zn)	mg/L	-	-	-	-	0.008	-	-	1	-	-	-	-	-	-	-	-
Trace Organics																	
PAHs and Alkylated PAHs	µg/L	ND	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
PANHs	µg/L	ND	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Phenolics	µg/L	ND	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
Volatile Organics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Upper Muskeg River

Parameter	Units	Winter				Spring				Summer				Fall			
		median	min.	max.	n	median	min.	max.	n	median	min	max.	n	median	min.	max.	n
Field measured																	
pH	-	8.195	7.2	8.38	4	7.4	7.4	7.6	3	7.3	7.2	7.5	3	7.655	7.4	7.87	6
Specific Conductance	µS/cm	560	550	581	4	243	235	245	3	382	365	390	3	358	294	430	6
Temperature	°C	0	0	0.75	14	9	4.5	14	7	15	10.75	17	9	5	0.4	10.5	9
Dissolved Oxygen	mg/L	2.7	0.8	4.6	5	8.4	4	10	7	6.2	0	7.3	9	9.05	3.9	10.6	8
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	363	349	388	4	161	152	221	4	247	178	257	4	226	198	255	6
Calcium	mg/L	81.6	38	88	15	32.8	19	50.3	8	55.5	38	75.3	11	45.7	31	62	10
Chloride	mg/L	2.4	1.3	6	15	1.25	0.8	1.8	8	1.5	0.5	2.7	11	1.4	1.1	2.4	10
Colour	T.C.U.	100	50	200	7	70	25	80	4	85	55	100	6	100	70	150	7
Conductance	uS/cm	530	305	610	11	197	120	333	5	338	277	479	8	277	248	420	4
Dissolved Organic Carbon	mg/L	21.5	9.5	44	11	16.8	11	28	5	24.5	21.5	26	7	24.5	23	24.5	3
Hardness	mg/L	291	162	328	12	125	75	178	7	177	147	222	8	168	146	221	9
Magnesium	mg/L	22	13.8	26.8	15	9.65	6.6	12.7	8	14.4	11.5	18.2	11	13.5	11.5	16	10
pH	-	7.43	7.1	7.67	11	7.5	6.93	8.2	5	7.62	7.36	7.9	8	7.65	7.3	7.95	4
Potassium	mg/L	1.3	0.66	2.6	15	1.2	0.92	2.1	8	0.7	0.3	1.7	11	0.925	0.3	1.23	10
Sodium	mg/L	9.5	5	12.9	15	4.35	2.6	6.8	8	5.6	4.5	7.7	11	6	4.5	7	10
Sulphate	mg/L	3.5	1	5	15	3.2	1	7.6	8	4.2	0.5	9.2	11	0.55	0.1	5.4	10
Sulphide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Alkalinity	mg/L	301	162	327	15	128	76	181	8	196	146	266	11	171	127	216	10
Total Dissolved Solids	mg/L	327	198	385	15	135	79	187	8	211	147	311	11	23	20	27	10
Total Organic Carbon	mg/L	21.7	10	45	15	18	12	29	7	25	17.5	27	10	23	20.4	26.5	10
Total Suspended Solids	mg/L	10.0	0.4	78.4	15	2.8	1.2	5.6	8	4.0	1.0	7.2	11	-	-	-	-
Nutrients																	
Nitrate + Nitrite	mg/L	0.014	<0.003	0.045	4	0.003	<0.003	0.010	4	0.063	0.029	0.113	4	0.027	0.009	0.036	6
Total Ammonia	mg/L	0.82	0.58	1.04	4	0.05	0.04	0.05	3	0.14	0.13	0.16	3	0.07	0.04	0.08	6
Total Kjeldahl Nitrogen	mg/L	1.50	0.50	3.40	15	0.81	0.68	0.95	7	1.04	0.99	1.31	10	0.85	0.59	5.50	10
Total Phosphorus	mg/L	0.099	0.020	0.250	15	0.031	0.024	0.090	8	0.055	0.038	0.095	11	0.037	0.025	0.080	10
Dissolved Phosphorus	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	1.45	0.6	4.6	4	0.6	0.6	1	3	0.5	0.04	0.5	3	1.55	0.8	1.9	6
Chlorophyll "a"	µg/L	<1	-	-	3	-	-	-	-	-	-	-	-	-	<1	<1	2
Microtox IC50 @ 15 min	%	-	-	-	-	>100	-	-	1	>100	-	-	1	-	-	-	-
Microtox IC25 @ 15 min	%	-	-	-	-	>100	-	-	1	>100	-	-	1	-	-	-	-
Naphthenic Acids	mg/L	-	-	-	-	<1	-	-	1	<1	-	-	1	-	-	-	-
Total Phenolics	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Recoverable Hydrocarbons	mg/L	0.4	0.3	0.6	4	<0.1	-	-	4	0.15	0.1	0.2	4	0.25	<0.1	0.5	6
Metals (Total)																	
Aluminum (Al)	mg/L	0.03	<0.01	0.14	15	0.03	<0.01	0.22	7	0.035	0.01	0.1	8	0.02	0.01	0.12	10
Antimony (Sb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	0.0004	<0.0002	0.0004	4	0.0004	0.0004	0.0005	3	0.0002	<0.0002	0.005	4	0.00045	0.0003	0.009	8
Barium (Ba)	mg/L	-	-	-	-	0.05	-	-	1	0.04	-	-	1	-	-	-	-
Beryllium (Be)	mg/L	-	-	-	-	<0.001	-	-	1	<0.001	-	-	1	-	-	-	-
Boron (B)	mg/L	0.06	0.05	0.06	4	0.02	<0.01	0.06	4	0.025	0.02	0.04	4	0.035	0.01	0.05	6
Cadmium (Cd)	mg/L	<0.001	-	-	4	<0.001	-	-	4	<0.001	-	-	4	<0.001	-	-	6
Chromium (Cr)	mg/L	<0.001	-	-	4	0.001	<0.001	0.008	4	0.001	<0.001	0.014	4	0.001	<0.001	0.008	6
Cobalt (Co)	mg/L	-	-	-	-	<0.003	-	-	1	0.005	-	-	1	-	-	-	-
Copper (Cu)	mg/L	<0.001	-	-	4	<0.001	-	-	4	<0.001	-	-	3	<0.001	-	-	6
Iron (Fe)	mg/L	6.2	-	-	1	1.055	0.89	1.95	4	2.71	0.91	3.02	4	1.17	1.05	1.5	3
Lead (Pb)	mg/L	0.002	0.002	0.002	4	<0.002	-	-	4	<0.002	-	-	4	<0.002	-	-	6
Lithium (Li)	mg/L	-	-	-	-	0.007	-	-	1	0.006	-	-	1	-	-	-	-
Manganese (Mn)	mg/L	1.15	0.561	1.5	4	0.027	0.023	0.072	4	0.135	0.032	0.16	4	0.066	0.058	0.084	6
Mercury (Hg)	mg/L	0.0001	<0.00005	0.0002	15	0.0001	<0.00005	0.0002	7	<0.0001	-	-	10	0.0001	<0.00005	0.0043	10
Molybdenum (Mo)	mg/L	-	-	-	-	0.004	-	-	1	<0.003	-	-	1	-	-	-	-
Nickel (Ni)	mg/L	<0.001	-	-	4	0.002	0.001	0.003	4	0.001	<0.001	0.006	4	<0.001	-	-	6
Selenium (Se)	mg/L	0.00055	<0.0002	0.0009	4	0.0004	0.0003	0.0004	3	<0.0002	-	-	3	0.0004	0.0002	0.0009	6
Silicon (Si)	mg/L	-	-	-	-	2.93	-	-	1	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	-	-	-	-	<0.002	-	-	1	<0.002	-	-	1	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-	0.108	-	-	1	0.094	-	-	1	-	-	-	-
Titanium (Ti)	mg/L	<0.05	-	-	3	-	<0.003	<0.01	2	-	0.009	<0.05	2	<0.05	-	-	1
Uranium (U)	mg/L	-	-	-	-	<0.5	-	-	1	-	-	-	-	-	-	-	-
Vanadium (V)	mg/L	<0.001	-	-	4	0.001	0.001	0.003	4	<0.001	-	-	4	0.001	<0.001	0.002	6
Zinc (Zn)	mg/L	0.0055	0.002	0.024	4	0.0015	0.001	0.054	4	0.001	<0.001	0.025	4	0.011	0.002	0.02	6
Metals (Dissolved)																	
Aluminum (Al)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Antimony (Sb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	0.0005	<0.0002	0.005	11	0.0005	0.0003	0.0007	4	0.00025	0.0002	0.0006	6	-	<0.0002	0.0003	2
Barium (Ba)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Beryllium (Be)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boron (B)	mg/L	0.105	0.04	0.23	10	0.13	0.1	0.14	3	0.07	0.02	0.09	4	0.075	0.03	0.11	4
Cadmium (Cd)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (Cr)	mg/L	0.003	<0.003	0.005	11	0.005	<0.003	0.008	3	0.003	0.003	0.006	4	<0.003	-	-	4
Cobalt (Co)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper (Cu)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iron (Fe)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lead (Pb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithium (Li)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manganese (Mn)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mercury (Hg)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Molybdenum (Mo)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel (Ni)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Selenium (Se)	mg/L	0.0002	<0.0002	0.0007	11	0.00035	<0.0002	0.0009	4	0.0002	<0.0002	0.0005	6	-	<0.0002	<0.0002	2
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanium (Ti)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Uranium (U)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vanadium (V)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc (Zn)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trace Organics																	
PAHs and Alkylated PAHs	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PANHs	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenolics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Volatile Organics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

NOTES: - = No data; ND = Not detected

Table V-3 Water Quality of Jackpine Creek (1976-1997)

Parameter	Units	At Mouth Winter median	min.	max.	n	Spring median	min.	max.	n	Summer median	min.	max.	n	Fall median	min.	max.	n
Field measured																	
pH	-	-	7	7.1	2	7.55	7	7.7	4	7.5	7.2	7.6	4	7.8	7.4	8	4
Specific Conductance	µS/cm	-	-	-	-	-	153	160	2	-	243	267	2	-	215	215	2
Temperature	°C	0	0	0	5	9	4.5	12	8	15.5	13	17	8	6.5	0	9	6
Dissolved Oxygen	mg/L	-	2.3	6	2	9.5	6	12.2	8	7.2	3.6	8	9	8.2	4.2	14.4	7
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	-	-	-	-	-	92	98	2	165	155	176	4	118	102	144	4
Calcium	mg/L	32	32	68	3	14.55	11.5	18.5	6	26.5	20.5	33.1	10	24.5	20.8	26.5	9
Chloride	mg/L	2.3	2.2	2.9	3	1.35	0.5	1.8	6	1.25	0.7	6.3	10	1.7	0.8	3	9
Colour	T.C.U.	-	-	-	-	-	80	80	2	82.5	65	100	4	140	130	150	4
Conductance	µS/cm	250	250	480	3	127	101	167	4	180	151	250	7	185	175	188	7
Dissolved Organic Carbon	mg/L	28	22	31	3	17	8	30	4	22.5	20.5	30	4	19	5	24	5
Total Hardness	mg/L	121	121	239	3	57	43	71	6	99	76	123	10	85	76	99	7
Magnesium	mg/L	10	10	19	3	5	3.5	6	6	7.9	6	9.8	10	7.2	5.9	7.9	9
pH	-	7.1	7	7.3	3	7.6	7.3	7.9	4	7.575	6.5	8.3	8	7.5	7.2	7.88	7
Potassium	mg/L	0.7	0.5	0.9	3	0.85	0.6	2.2	6	0.1	0.01	0.53	10	0.65	0.5	1.15	9
Sodium	mg/L	14.5	14.5	18	3	9.1	6	13.5	6	11.25	10	15.3	10	13	9	14	9
Sulphate	mg/L	6.7	6.3	6.9	3	3.8	1.7	6	6	3.1	0.5	10	10	1.3	<0.5	3.4	9
Sulphide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.006	0.006	2
Total Alkalinity	mg/L	134	134	256	3	74	50	87	6	126	89	144	10	101	83	118	9
Total Dissolved Solids	mg/L	136	136	302	3	84	63	102	6	142	106	196	10	124	109	176	9
Total Organic Carbon	mg/L	31	27	33	3	21.15	9	31	6	26.75	17.3	35.4	10	27	20	39	9
Total Suspended Solids	mg/L	13.0	4.0	82.0	5	5.3	<0.4	12.8	8	2.0	<0.4	103.0	10	3.0	<0.4	30.0	#
Nutrients																	
Nitrate + Nitrite	mg/L	-	-	-	-	-	<0.003	<0.003	2	0.010	<0.003	0.016	4	<0.05	-	-	5
Total Ammonia	mg/L	-	-	-	-	-	0.03	0.03	2	0.07	0.05	0.15	4	<0.05	-	-	5
Total Kjeldahl Nitrogen	mg/L	0.45	0.30	3.74	3	0.82	0.58	2.57	6	1.29	0.80	1.69	10	0.80	0.35	2.28	9
Total Phosphorus	mg/L	0.140	0.050	0.238	5	0.020	0.010	0.060	8	0.025	<0.005	0.380	10	0.020	0.010	0.110	#
Dissolved Phosphorus	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.014	0.013	0.014	2
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	-	-	-	-	-	0.6	0.8	2	0.8	0.5	0.8	3	<3	-	-	4
Chlorophyll "a"	µg/L	-	<1	<1	2	-	-	-	-	-	-	-	-	1	<1	11	4
Microtox IC50 @ 15 min	%	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
Microtox IC25 @ 15 min	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Naphthenic Acids	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	1	1	1	1
Total Phenolics	mg/L	-	-	-	-	-	-	-	-	0.001	-	-	1	0.002	0.001	0.01	3
Recoverable Hydrocarbons	mg/L	-	-	-	-	-	<0.1	<0.1	2	0.3	0.2	1.8	3	0.5	0.4	0.5	4
Metals (Total)																	
Aluminum (Al)	mg/L	0.07	0.04	0.59	3	0.09	<0.01	0.35	5	0.05	0.01	0.3	6	0.04	<0.01	0.09	9
Antimony (Sb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.0004	-	-	2
Arsenic (As)	mg/L	-	-	-	-	-	0.0004	0.0004	2	0.005	0.0003	0.008	6	0.0004	0.0002	0.0006	4
Barium (Ba)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.024	0.024	0.025	2
Beryllium (Be)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	2
Boron (B)	mg/L	-	-	-	-	-	0.05	0.06	2	0.05	0.02	0.05	4	0.04	0.02	0.04	4
Cadmium (Cd)	mg/L	-	-	-	-	-	<0.001	<0.001	2	<0.0055	-	-	4	<0.001	-	-	4
Chromium (Cr)	mg/L	-	-	-	-	-	<0.001	<0.001	2	0.008	0.001	0.006	4	0.0016	<0.001	0.002	4
Cobalt (Co)	mg/L	-	-	-	-	-	-	-	-	-	<0.01	<0.01	2	0.0028	0.0014	0.0041	2
Copper (Cu)	mg/L	-	-	-	-	-	<0.001	<0.001	2	0.003	<0.001	0.01	4	0.0024	<0.001	0.0235	4
Iron (Fe)	mg/L	-	-	-	-	-	0.26	0.47	2	0.955	0.48	1.3	4	1.12	0.32	2.83	5
Lead (Pb)	mg/L	-	-	-	-	-	0.005	0.006	2	0.011	0.002	0.02	4	0.002	0.0012	0.0057	4
Lithium (Li)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.0085	0.008	0.009	2
Manganese (Mn)	mg/L	-	-	-	-	-	<0.004	0.014	2	0.076	0.02	0.14	4	0.0463	0.02	0.0734	4
Mercury (Hg)	mg/L	<0.0001	-	-	3	<0.0001	-	-	6	<0.0001	-	-	10	<0.00005	-	-	9
Molybdenum (Mo)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.0003	<0.0001	0.0005	2
Nickel (Ni)	mg/L	-	-	-	-	-	<0.001	<0.001	2	<0.0105	-	-	4	0.0018	<0.001	0.0061	4
Selenium (Se)	mg/L	-	-	-	-	-	0.0003	0.0004	2	0.00515	0.0003	0.012	4	<0.0004	-	-	4
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	-	-	-	-	-	-	-	-	<0.02	-	-	1	<0.0001	-	-	2
Strontium (Sr)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.0782	0.0777	0.0786	3
Titanium (Ti)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.05	-	-	3
Uranium (U)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.0001	-	-	2
Vanadium (V)	mg/L	-	-	-	-	-	<0.001	<0.001	2	<0.006	-	-	4	0.0014	<0.001	0.0019	4
Zinc (Zn)	mg/L	-	-	-	-	-	0.001	0.003	2	0.02	<0.001	0.04	4	0.0266	0.023	0.029	4
Metals (Dissolved)																	
Aluminum (Al)	mg/L	-												0.075	0.058	0.092	2
Antimony (Sb)	mg/L	-												-	<0.0004	0.0005	2
Arsenic (As)	mg/L	0.001	0.0005	0.001	3	0.00065	<0.0005	0.0136	4	0.00035	<0.0002	0.0017	4	0.001	<0.0002	0.009	7
Barium (Ba)	mg/L	-												-	<0.017	0.017	2
Beryllium (Be)	mg/L	-												-	<0.0005	<0.0005	2
Boron (B)	mg/L	0.05	0.01	0.25	3	0.105	0.02	0.3	4	0.125	0.03	0.19	6	0.043	0.01	0.13	7
Cadmium (Cd)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.001	-	-	4
Chromium (Cr)	mg/L	0.003	<0.003	0.008	3	<0.003	-	-	3	<0.003	-	-	4	<0.003	-	-	7
Cobalt (Co)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0002	0.0002	2
Copper (Cu)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0022	0.0027	2
Iron (Fe)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.32	0.34	2
Lead (Pb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0007	0.0017	2
Lithium (Li)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	0.008	0.008	0.008	1
Manganese (Mn)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.044	0.044	2
Mercury (Hg)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.002	0.002	2
Molybdenum (Mo)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00008	0.0001	2
Nickel (ni)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0004	0.0013	2
Selenium (Se)	mg/L	0.0005	<0.0005	0.0014	3	<0.0005	-	-	4	0.0002	<0.0002	0.0003	4	<0.0005	-	-	7
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	3.78	3.83	2
Silver (Ag)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.0002	-	-	2
Strontium (Sr)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0707	0.0714	2
Titanium (Ti)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0004	0.0005	2
Uranium (U)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.00005	-	-	2
Vandium (V)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0002	0.0003	2
Zinc (Zn)	mg/L		-	-	-	-	-	-	-	-	-	-	-	-	0.016	0.02	2
Trace Organics																	
PAHs and Alkylated PAHs	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PANHs	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenolics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Volatile Organics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Parameter	Units	Lower Jackpine Creek Winter median	min.	max.	n	Spring median	min.	max.	n	Summer median	min.	max.	n	Fall median	min.	max.	n
Field measured																	
pH	-	-	7.3	7.3	2	7.6	-	-	1	7.9	-	-	1	-	8.2	8.3	2
Specific Conductance	µS/cm	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Temperature	°C	0	0	0	4	8.9	6	11	4	15	14	18.8	4	-	6.5	7	2
Dissolved Oxygen	mg/L	-	5	5.8	2	10.6	10.4	12	4	8.4	7.6	10.8	5	9.3	9.2	12	3
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	-	-	-	-	-	-	-	-	-	166	167	2	-	302	514	2
Calcium	mg/L	-	35	77.5	2	-	13.5	20	2	29.9	22	33.5	5	48.5	24	119	5
Chloride	mg/L	-	3.4	9.2	2	-	1.2	2.1	2	2.2	1	8.6	5	3.3	1.5	16	5
Colour	T.C.U.	-	-	-	-	-	-	-	-	-	65	65	2	-	-	-	-
Conductance	µS/cm	-	270	550	2	-	115	175	2	220	190	240	5	340	187	551	5
Dissolved Organic Carbon	mg/L	-	13	34	2	-	12	28	2	-	11.5	27	2	-	12.5	27	2
Total Hardness	mg/L	-	130	276	2	-	51	75	2	110	83	117	5	171	86	362	5
Magnesium	mg/L	-	10.4	20	2	-	4.2	6	2	8.1	6.7	8.5	5	12	6.2	15.5	5
pH	-	-	7.5	8	2	-	7.3	8.3	2	7.7	7.1	7.9	5	7.5	7.4	7.8	5
Potassium	mg/L	-	0.6	1.7	2	-	1	2.2	2	0.2	0.1	0.4	5	0.5	0.5	3.5	5
Sodium	mg/L	-	14.5	24	2	-	6.8	10.5	2	11.5	10.5	15.1	5	13.6	12.5	35.9	5
Sulphate	mg/L	-	2.3	13.2	2	-	4.5	6	2	5.8	0.1	6.7	5	0.5	0.5	4.9	5
Sulphide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Alkalinity	mg/L	-	141	303	2	-	56	99	2	136	99	145	5	182	103	422	5
Total Dissolved Solids	mg/L	266	147	385	2	96	74	117	2	168	112	200	5	202	108	466	5
Total Organic Carbon	mg/L	-	15	41	2	-	12	28	2	28.5	12.5	30.6	5	27.5	20	32	3
Total Suspended Solids	mg/L	12.0	2.8	18.4	4	1.9	<1	16.4	4	2.8	0.4	3.2	5	6.8	2.8	20.0	5
Nutrients																	
Nitrate + Nitrite	mg/L	-	-	-	-	-	-	-	-	-	0.015	0.027	2	-	<0.002	<0.002	2
Total Ammonia	mg/L	-	-	-	-	-	-	-	-	-	0.12	0.22	2	-	-	-	-
Total Kjeldahl Nitrogen	mg/L	-	0.50	1.23	2	-	0.86	1.02	2	0.91	0.84	1.50	5	0.64	0.30	0.65	3
Total Phosphorus	mg/L	0.071	0.040	0.133	4	0.030	0.020	0.060	4	0.026	<0.005	0.038	5	0.030	0.020	0.080	5
Dissolved Phosphorus	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	-	-	-	-	-	-	-	-	-	<5	<5	2	-	-	-	-
Chlorophyll "a"	µg/L	-	<1	<1	2	-	-	-	-	-	-	-	-	1	<1	24	3
Microtox IC50 @ 15 min	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microtox IC25 @ 15 min	%	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Naphthenic Acids	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Phenolics	mg/L	-	-	-	-	-	-	-	-	-	0.007	0.008	2	-	-	-	-
Recoverable Hydrocarbons	mg/L	-	-	-	-	-	-	-	-	-	0.6	1.5	2	-	-	-	-
Metals (Total)																	
Aluminum (Al)	mg/L	-	0.03	0.07	2	-	0.08	0.34	2	<0.01	-	-	3	0.06	<0.01	0.16	3
Antimony (Sb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	-	-	-	-	-	-	-	-	0.008	0.005	0.011	3	-	0.008	0.02	2
Barium (Ba)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Beryllium (Be)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boron (B)	mg/L	-	-	-	-	-	-	-	-	-	0.043	0.05	2	-	-	-	-
Cadmium (Cd)	mg/L	-	-	-	-	-	-	-	-	-	<0.01	<0.01	2	-	-	-	-
Chromium (Cr)	mg/L	-	-	-	-	-	-	-	-	-	<0.01	<0.01	2	-	-	-	-
Cobalt (Co)	mg/L	-	-	-	-	-	-	-	-	-	<0.01	<0.01	2	-	-	-	-
Copper (Cu)	mg/L	-	-	-	-	-	-	-	-	-	<0.005	<0.005	2	-	-	-	-
Iron (Fe)	mg/L	-	-	-	-	-	-	-	-	-	0.51	0.52	2	-	-	-	-
Lead (Pb)	mg/L	-	-	-	-	-	-	-	-	-	<0.02	<0.02	2	-	-	-	-
Lithium (Li)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manganese (Mn)	mg/L	-	-	-	-	-	-	-	-	-	0.02	0.023	2	-	-	-	-
Mercury (Hg)	mg/L	-	<0.0001	0.0003	2	-	<0.0001	<0.0001	2	<0.0001	-	-	5	0.0002	<0.0001	0.0045	3
Molybdenum (Mo)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel (Ni)	mg/L	-	-	-	-	-	-	-	-	-	<0.02	<0.02	2	-	-	-	-
Selenium (Se)	mg/L	-	-	-	-	-	-	-	-	-	0.004	0.012	2	-	-	-	-
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	-	-	-	-	-	-	-	-	-	<0.02	<0.02	2	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanium (Ti)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Uranium (U)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vanadium (V)	mg/L	-	-	-	-	-	-	-	-	-	<0.01	<0.1	2	-	-	-	-
Zinc (Zn)	mg/L	-	-	-	-	-	-	-	-	-	0.03	0.1	2	-	-	-	-
Metals (Dissolved)																	
Aluminum (Al)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Antimony (Sb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	-	<0.001	0.02	2	-	0.0011	0.0011	2	-	0.0014	0.004	2	<0.001	-	-	1
Barium (Ba)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Beryllium (Be)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boron (B)	mg/L	-	0.08	0.12	2	-	0.11	0.33	2	0.1	0.04	0.12	3	0.08	0.06	0.11	3
Cadmium (Cd)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (Cr)	mg/L	-	<0.003	<0.003	2	-	<0.003	<0.003	2	<0.003	-	-	1	0.003	<0.003	0.004	3
Cobalt (Co)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper (Cu)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iron (Fe)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lead (Pb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithium (Li)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manganese (Mn)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mercury (Hg)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Molybdenum (Mo)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel (ni)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Selenium (Se)	mg/L	-	<0.0005	0.0007	2	-	<0.0005	<0.0005	2	-	<0.0002	<0.0002	2	<0.0005	-	-	1
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanium (Ti)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Uranium (U)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vandium (V)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc (Zn)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trace Organics																	
PAHs and Alkylated PAHs	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
PANHs	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Phenolics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Volatile Organics	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Parameter	Units	Upper Jackpine Creek Winter median	min.	max.	n	Spring median	min.	max.	n	Summer median	min.	max.	n	Fall median	min.	max.	n
Field measured																	
pH	-	7.85	-	-	1	7.8	-	-	1	8	-	-	1	7.8	-	-	1
Specific Conductance	µS/cm	537	-	-	1	167	-	-	1	265	-	-	1	220	-	-	1
Temperature	°C	0	0	1	13	7.75	0	12.5	8	15.75	11.5	18.25	14	6.5	0	11.4	12
Dissolved Oxygen	mg/L	5.9	3.3	10.3	6	10.25	5.3	14.4	8	7.75	5.2	12	16	9.8	6.3	12.6	12
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	-	349	404	2	80	77	124	5	-	122	172	2	-	133	141	2
Calcium	mg/L	69	22.5	91	19	18	11.5	78.5	13	30	20	52.2	18	25.75	18.5	59.2	14
Chloride	mg/L	12	1.9	17	19	1.7	0.7	17.2	13	2.05	1	14.4	18	2	1.2	7	14
Colour	T.C.U.	60	30	120	11	80	30	90	7	100	45	120	9	115	35	150	9
Conductance	µS/cm	498	194	660	18	150	100	550	12	227	130	371	17	197	120	436	13
Dissolved Organic Carbon	mg/L	23	11.5	89	17	14.25	8	28	12	24.25	18.5	51.5	16	25.6	22	36	10
Total Hardness	mg/L	259	103	317	9	58	43	283	9	104	75	126	11	102	96	111	6
Magnesium	mg/L	17	7.2	22	19	4.5	3.5	21	13	8.8	5.7	12.7	18	7.7	6	15.6	14
pH	-	7.75	7.38	8.65	19	7.62	7.19	8.3	12	7.7	7.25	8.4	17	7.58	7.26	7.93	13
Potassium	mg/L	1.5	0.25	2.2	17	1.1	0.7	2.5	13	0.425	<0.01	0.9	18	0.565	0.2	1	14
Sodium	mg/L	25.25	10.9	30	18	9.5	5.5	30.5	13	12.55	10.7	22	18	12.05	8.7	20.5	14
Sulphate	mg/L	5.3	1	14	19	4	1.1	6.4	13	4.4	1.3	8.2	18	4.55	0.1	9.8	14
Sulphide	mg/L	-	<0.002	<0.01	2	0.005	0.004	0.005	3	-	-	-	-	-	-	-	-
Total Alkalinity	mg/L	273	97	348	18	79	46	324	13	128	86	198	18	110	80	232	14
Total Dissolved Solids	mg/L	330	117	551	19	108	67	363	13	145	85	233	18	125	94	271	14
Total Organic Carbon	mg/L	23.75	12	96	18	19	9	28	12	27	19	51.5	17	25.5	23.5	39.5	13
Total Suspended Solids	mg/L	6.0	<0.4	459.0	19	4.8	<0.4	15.6	13	2.6	<0.4	27.6	18	4.4	<0.4	52.0	14
Nutrients																	
Nitrate + Nitrite	mg/L	-	0.190	0.800	2	0.050	<0.003	0.060	5	-	<0.003	<0.03	2	-	<0.003	<0.003	2
Total Ammonia	mg/L	1.60	-	-	1	0.05	0.01	0.70	5	<0.05	-	-	3	-	0.01	0.03	2
Total Kjeldahl Nitrogen	mg/L	0.86	0.35	4.05	17	0.80	<0.05	2.42	12	1.04	<0.2	1.60	18	0.82	0.54	3.40	11
Total Phosphorus	mg/L	0.044	0.006	0.330	18	0.022	0.017	0.080	13	0.030	<0.005	0.088	18	0.024	0.010	0.060	14
Dissolved Phosphorus	mg/L	<0.02	-	-	1	<0.02	-	-	3	-	-	-	-	-	-	-	-
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	-	2	4	2	2	0.9	3	5	0.4	-	-	1	-	0.6	1.2	2
Chlorophyll "a"	µg/L	1	<1	3	6	1.54	1.45	5	4	1	<1	7	3	1	<0.001	3	5
Microtox IC50 @ 15 min	%	>99	-	-	1	>91	91	100	4	100	-	-	1	>100	-	-	1
Microtox IC25 @ 15 min	%	-	-	-	-	>100	-	-	1	>100	-	-	1	>100	-	-	1
Naphthenic Acids	mg/L	<1	-	-	1	<1	-	-	4	-	<1	<1	2	<1	-	-	1
Total Phenolics	mg/L	-	-	-	-	0.005	<0.001	0.01	4	-	<0.001	<0.001	2	<0.001	-	-	1
Recoverable Hydrocarbons	mg/L	<1	-	-	1	<0.5	-	-	5	<0.5	-	-	3	-	0.4	<1	2
Metals (Total)																	
Aluminum (Al)	mg/L	0.0475	<0.01	0.51	16	0.07	0.011	0.36	13	0.055	<0.01	0.7	16	0.04	<0.01	0.15	10
Antimony (Sb)	mg/L	<0.0004	-	-	1	0.0004	<0.0004	0.001	4	<0.0002	-	-	1	<0.0002	-	-	1
Arsenic (As)	mg/L	<0.0004	-	-	1	0.0004	<0.0004	0.0008	5	0.0004	0.0003	0.004	2	0.0006	0.0002	0.001	4
Barium (Ba)	mg/L	0.11	-	-	1	0.0164	0.015	0.04	4	0.02	-	-	1	0.02	-	-	1
Beryllium (Be)	mg/L	<0.001	-	-	1	0.001	<0.001	0.003	4	-	<0.001	<0.001	2	0.001	-	-	1
Boron (B)	mg/L	0.094	-	-	1	0.049	0.048	0.07	5	-	0.05	0.1	2	-	0.03	0.03	2
Cadmium (Cd)	mg/L	-	<0.0002	<0.001	2	<0.0002	-	-	5	<0.001	-	-	3	-	<0.001	0.004	2
Chromium (Cr)	mg/L	-	<0.0004	<0.01	2	<0.0004	-	-	5	-	<0.001	0.004	2	-	<0.001	0.012	2
Cobalt (Co)	mg/L	0.0007	-	-	1	<0.0005	-	-	4	-	<0.0005	<0.003	2	0.009	-	-	1
Copper (Cu)	mg/L	0.0009	-	-	1	0.001	0.0007	0.003	5	<0.001	-	-	1	-	<0.001	<0.001	2
Iron (Fe)	mg/L	-	2.25	2.4	2	0.47	0.35	0.77	5	-	0.87	0.93	2	-	0.57	0.58	2
Lead (Pb)	mg/L	-	0.0004	0.005	2	0.0003	0.0002	0.004	5	-	<0.002	<0.02	2	-	<0.002	<0.02	2
Lithium (Li)	mg/L	0.022	-	-	1	0.007	0.007	0.011	4	0.008	-	-	1	0.009	-	-	1
Manganese (Mn)	mg/L	-	0.0749	0.08	2	0.0217	0.0201	0.034	5	-	0.028	0.051	2	-	0.016	0.021	2
Mercury (Hg)	mg/L	0.0001	<0.0001	0.0007	19	<0.0002	-	-	13	<0.0001	-	-	18	<0.0001	-	-	12
Molybdenum (Mo)	mg/L	0.0001	-	-	1	0.00015	0.0001	0.006	4	<0.003	-	-	1	0.003	-	-	1
Nickel (Ni)	mg/L	0.0012	-	-	1	0.0004	<0.0004	0.011	5	-	0.002	<0.005	2	-	<0.001	<0.005	2
Selenium (Se)	mg/L	<0.0004	-	-	1	<0.0004	-	-	5	<0.0002	-	-	3	-	<0.0002	<0.0002	2
Silicon (Si)	mg/L	-	6.65	8	2	1.045	0.979	1.23	4	-	-	-	-	2.9	-	-	1
Silver (Ag)	mg/L	<0.001	-	-	1	<0.001	-	-	4	-	<0.0001	<0.002	2	0.005	-	-	1
Strontium (Sr)	mg/L	0.266	-	-	1	0.06215	0.0616	0.082	4	0.089	-	-	1	0.094	-	-	1
Titanium (Ti)	mg/L	<0.05	-	-	4	0.0046	0.0016	0.007	6	<0.05	-	-	4	-	0.008	<0.05	2
Uranium (U)	mg/L	0.0001	-	-	1	<0.0001	-	-	4	<0.0001	-	-	1	<0.5	-	-	1
Vanadium (V)	mg/L	0.0004	-	-	1	0.0002	<0.0002	0.011	5	-	0.002	0.005	2	-	<0.001	<0.002	2
Zinc (Zn)	mg/L	-	0.011	0.025	2	0.008	0.001	0.025	5	-	0.001	0.433	2	-	0.002	0.186	2
Metals (Dissolved)																	
Aluminum (Al)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Antimony (Sb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	0.0003	<0.0002	0.002	17	0.00055	<0.0002	0.0026	8	0.0005	<0.0002	0.0007	15	0.0003	<0.0002	0.0011	9
Barium (Ba)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Beryllium (Be)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boron (B)	mg/L	0.13	0.01	0.28	16	0.13	0.08	0.18	7	0.105	0.03	0.18	16	0.125	0.04	0.48	10
Cadmium (Cd)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (Cr)	mg/L	0.003	<0.003	0.008	15	0.003	<0.003	0.006	8	0.003	<0.003	0.008	15	0.003	<0.003	0.008	10
Cobalt (Co)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Copper (Cu)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Iron (Fe)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lead (Pb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Lithium (Li)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Manganese (Mn)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mercury (Hg)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Molybdenum (Mo)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel (ni)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Selenium (Se)	mg/L	<0.0002	-	-	16	<0.0002	-	-	8	0.0002	<0.0002	0.0009	15	<0.0002	<0.0001	0.0002	7
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silver (Ag)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Strontium (Sr)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanium (Ti)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Uranium (U)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Vandium (V)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zinc (Zn)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Trace Organics																	
PAHs and Alkylated PAHs	µg/L	-	-	-	-	ND	-	-	1	ND	-	-	1	ND	-	-	1
PANHs	µg/L	-	-	-	-	ND	-	-	1	ND	-	-	1	ND	-	-	1
Phenolics	µg/L	-	-	-	-	ND	-	-	1	ND	-	-	1	ND	-	-	1
Volatile Organics	µg/L	-	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-

NOTES: - = No data; ND = Not detected

Table V-4 Other Muskeg River Tributaries (1976-1997)

Parameter	Units	Muskeg Creek															
		Winter				Spring				Summer				Fall			
		median	min.	max.	n	median	min.	max.	n	median	min.	max.	n	median	min.	max.	n
Field measured																	
pH	-	7.675	7.3	7.88	4	-	7.6	7.7	2	-	7.9	8.1	2	7.57	7.26	7.8	5
Specific Conductance	µS/cm	306	80	400	4	-	156	158	2	-	219	223	2	196	92	240	5
Temperature	°C	0	0	0.5	12	6.95	1	13.5	6	16	11	20	7	3.75	0	11	8
Dissolved Oxygen	mg/L	10.675	7.3	11.5	4	11.4	9.4	13.4	5	6.3	2.4	10.4	7	11.7	8.6	14.5	7
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	177	169	229	4	96	73	134	4	141	120	205	4	130	119	189	5
Calcium	mg/L	37	28	54	13	15.05	9.5	37.8	8	23.3	18	45	11	21.2	19.1	43.7	10
Chloride	mg/L	2.5	1.3	3.8	13	1.35	0.38	2.5	8	1.3	0.7	5.5	11	1.3	0.3	1.6	10
Colour	T.C.U.	100	100	120	4	80	75	100	3	100	100	105	3	175	150	200	4
Conductance	µ/S	305	250	450	10	147	97	310	6	203	150	370	9	222	192	291	5
Dissolved Organic Carbon	mg/L	33.5	21	41	10	16.45	12	40	6	28	18	32.5	7	26.5	6	31	5
Hardness	mg/L	146	114	210	13	60	38	150	8	95	73	165	11	83	76	162	10
Magnesium	mg/L	12.8	10.4	18.2	13	5.5	3.5	13.5	8	8.5	6.5	12.8	11	7.25	6.8	12.9	10
pH	-	7.2	7	7.56	10	7.17	7.08	7.8	6	7.7	6.9	8	9	7.425	7.2	8.08	6
Potassium	mg/L	1.8	0.7	3.3	13	1.5	0.8	2.1	8	0.6	0.08	2	11	0.925	0.3	1.2	10
Sodium	mg/L	20	14	30	13	12.3	7	22	8	14	10.6	23.5	11	15.6	6	19	10
Sulphate	mg/L	6.4	3	14.2	13	4.95	3.1	8.6	8	4.85	0.5	10.4	10	2.95	0.5	6.9	10
Sulphide	mg/L	<0.002	-	-	1	0.005	-	-	1	0.009	-	-	1	-	-	-	-
Total Alkalinity	mg/L	168	132	252	13	79	46	179	8	115	92	230	11	109	98	155	10
Total Dissolved Solids	mg/L	196	129	296	13	87	61	204	8	123	108	224	11	125	106	166	10
Total Organic Carbon	mg/L	33.5	30	41	13	21	13	40.5	7	28.75	25	36	10	30	25.6	53	9
Total Suspended Solids	mg/L	4.8	0.5	50.8	13	4.5	1	37.6	8	3.8	2.0	21.0	10	1.2	0.8	3.2	10
Nutrients																	
Nitrate + Nitrite	mg/L	0.097	0.032	0.100	4	<0.003	-	-	4	0.018	0.004	0.005	4	0.010	<0.003	0.015	5
Total Ammonia	mg/L	0.46	0.21	0.66	4	0.05	0.04	0.08	3	0.05	0.05	0.05	3	0.04	0.03	0.05	4
Total Kjeldahl Nitrogen	mg/L	1.71	0.50	3.20	13	1.13	0.70	2.43	7	1.22	<0.2	3.2	10	0.82	0.45	1.25	9
Total Phosphorus	mg/L	0.052	<0.02	0.470	13	0.030	0.022	0.080	8	0.034	0.010	0.2	11	0.033	0.016	0.043	10
Dissolved Phosphorus	mg/L	<0.02	-	-	1	0.020	-	-	1	0.022	-	-	1	-	-	-	-
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	2.55	1.5	8.6	4	0.9	0.8	3	3	0.8	0.7	3	3	2.05	0.2	4.9	4
Chlorophyll "a"	µg/L	2	<1	13	3	1.17	-	-	1	2	-	-	1	<1	-	-	4
Microtox IC50 @ 15 min	%	>99	-	-	1	-	91	100	2	>100	-	-	1	<100	-	-	1
Microtox IC25 @ 15 min	%	-	-	-	-	>100	-	-	1	>100	-	-	1	<100	-	-	1
Naphthenic Acids	mg/L	1	-	-	1	-	<1	<1	2	-	<1	<1	2	<1	-	-	1
Total Phenolics	mg/L	-	-	-	-	0.011	-	-	1	<0.001	-	-	1	-	-	-	-
Recoverable Hydrocarbons	mg/L	1.05	0.9	2	4	<0.3	-	-	4	<0.3	-	-	4	0.4	0.1	0.7	5
Metals (Total)																	
Aluminum (Al)	mg/L	0.04	<0.01	0.133	13	0.066	<0.01	0.39	7	0.03	0.02	0.14	7	0.02	<0.01	0.04	10
Antimony (Sb)	mg/L	<0.0004	-	-	1	<0.0004	-	-	1	0.0008	-	-	1	-	-	-	-
Arsenic (As)	mg/L	0.0004	0.0003	0.0005	4	0.0003	-	-	3	<0.005	-	-	5	0.0003	0.0002	0.012	7
Barium (Ba)	mg/L	0.029	-	-	1	-	0.013	0.02	2	-	0.0161	0.03	2	0.04	-	-	1
Beryllium (Be)	mg/L	<0.001	-	-	1	-	<0.001	<0.001	2	-	<0.001	<0.001	2	<0.001	-	-	1
Boron (B)	mg/L	0.081	0.06	0.1	4	0.062	0.05	0.11	4	0.06	0.06	0.07	4	0.03	<0.01	0.08	5
Cadmium (Cd)	mg/L	<0.001	-	-	4	<0.001	-	-	4	<0.001	-	-	4	<0.001	-	-	5
Chromium (Cr)	mg/L	<0.001	-	-	4	0.001	<0.0004	0.004	4	0.00185	<0.001	0.003	4	0.001	<0.001	0.011	5
Cobalt (Co)	mg/L	<0.0005	-	-	1	-	<0.0005	<0.003	2	-	<0.0005	<0.003	2	0.006	-	-	1
Copper (Cu)	mg/L	<0.001	-	-	4	<0.001	-	-	4	0.001	<0.001	0.0013	3	<0.001	-	-	5
Iron (Fe)	mg/L	1.15	0.92	1.31	4	0.47	0.13	0.72	4	0.61	0.57	0.7	4	0.39	0.25	1.74	5
Lead (Pb)	mg/L	0.002	0.0002	0.002	4	0.005	0.0002	0.006	4	<0.00285	-	-	4	0.002	<0.002	0.02	5
Lithium (Li)	mg/L	0.009	-	-	1	-	0.006	0.008	2	-	0.01	0.014	2	0.007	-	-	1
Manganese (Mn)	mg/L	0.174	0.097	0.543	4	0.0146	<0.004	0.048	4	0.031	0.0207	0.106	4	0.021	0.013	0.092	5
Mercury (Hg)	mg/L	0.0001	<0.00005	0.0006	13	<0.0001	-	-	7	<0.0001	-	-	10	0.0001	<0.00005	0.0012	9
Molybdenum (Mo)	mg/L	<0.0001	-	-	1	-	0.0001	<0.003	2	-	0.0002	<0.003	2	<0.003	-	-	1
Nickel (Ni)	mg/L	0.001	-	-	4	<0.0026	-	-	4	0.00235	<0.001	0.01	4	0.001	<0.001	0.01	5
Selenium (Se)	mg/L	0.00035	<0.0002	0.0005	4	<0.0004	-	-	3	0.0003	-	-	3	0.00045	0.0002	0.0008	4
Silicon (Si)	mg/L	5.05	-	-	1	-	0.472	1.1	2	3.54	-	-	1	3.74	-	-	1
Silver (Ag)	mg/L	<0.001	-	-	1	-	<0.001	<0.002	2	-	<0.0001	<0.002	2	0.003	-	-	1
Strontium (Sr)	mg/L	0.11	-	-	1	-	0.0443	0.084	2	-	0.0811	0.102	2	0.089	-	-	1
Titanium (Ti)	mg/L	<0.05	-	-	3	<0.001	-	-	3	0.01	0.0022	0.01	3	-	0.007	<0.05	2
Uranium (U)	mg/L	<0.0001	-	-	1	-	<0.0001	<0.5	2	<0.0001	-	-	1	<0.5	-	-	1
Vanadium (V)	mg/L	<0.001	-	-	4	<0.001	-	-	4	<0.002	0.0008	0.001	4	<0.001	-	-	5
Zinc (Zn)	mg/L	0.0045	0.004	0.01	4	0.0065	0.002	0.025	4	0.0105	<0.001	0.039	4	0.004	0.002	0.024	5
Metals (Dissolved)																	
Arsenic (As)	mg/L	0.001	0.0002	0.004	9	<0.0005	-	-	4	0.0004	<0.0002	0.0009	5	-	0.0002	<0.001	2
Boron (B)	mg/L	0.15	0.01	0.32	9	0.175	0.1	0.2	4	0.14	0.05	0.21	7	0.1	0.04	0.17	5
Chromium (Cr)	mg/L	0.003	<0.003	0.007	9	0.003	<0.003	0.004	3	<0.003	-	-	3	<0.003	-	-	5
Selenium (Se)	mg/L	0.0005	<0.0002	0.0006	9	<0.0005	-	-	4	0.0002	0.0002	0.0002	5	-	<0.0002	0.0012	2

Parameter	Units	Shelley Creek											
		Winter				Spring				Summer			
		median	min.	max.	n	median	min.	max.	n	median	min.	max.	n
Field measured													
pH	-	7.65	-	-	1	-	-	-	-	-	-	-	-
Specific Conductance	µS/cm	501	-	-	1	-	-	-	-	-	-	-	-
Temperature	°C	0	0	0.9	5	-	8.7	9.4	2	-	12	21.5	2
Dissolved Oxygen	mg/L	3.7	-	-	1	-	6.6	12.2	2	-	6.1	6.3	2
Conventional Parameters and Major Ions													
Bicarbonate	mg/L	351	-	-	1	73	-	-	1	-	136	136	2
Calcium	mg/L	64.5	28	76	5	11.5	10.1	18	3	23.45	20	26.8	4
Chloride	mg/L	2.9	1.2	5	5	0.6	<0.5	1.4	3	1.3	0.9	1.8	4
Colour	T.C.U.	60	-	-	1	90	-	-	1	-	105	105	2
Conductance	µ/S	510	270	600	5	122	110	170	3	209	155	224	4
Dissolved Organic Carbon	mg/L	32	15	40	5	14	10	37	3	24.75	19	33	4
Hardness	mg/L	243	114	280	5	45	40	68	3	89	77	100	4
Magnesium	mg/L	20	10.7	23	5	4	3.5	5.7	3	7.3	6.5	8	4
pH	-	7.2	6.9	7.4	5	7.3	7.3	7.5	3	7.75	7.7	8.2	4
Potassium	mg/L	1.4	0.7	2.5	5	1	0.7	1.9	3	0.1	0.07	0.3	4
Sodium	mg/L	27	10	30	5	8.3	8	13	3	13.25	12	15	4
Sulphate	mg/L	6.6	5.8	10.1	5	5.5	3.5	7.1	3	5.25	2.9	8.6	4
Sulphide	mg/L	<0.002	-	-	1	0.005	-	-	1	-	0.01	0.01	2
Total Alkalinity	mg/L	284	138	323	5	60	54	88	3	106	96	111	4
Total Dissolved Solids	mg/L	290	139	376	5	70	68	112	3	129	110	190	4
Total Organic Carbon	mg/L	33.5	21	41	5	21	10	37	3	29	20.5	33	4
Total Suspended Solids	mg/L	14.0	1.2	114.4	5	3.2	2.0	6.8	3	2	<0.4	5.0	5
Nutrients													
Nitrate + Nitrite	mg/L	<0.05	-	-	1	<0.05	-	-	1	<0.05	-	-	3
Total Ammonia	mg/L	0.51	-	-	1	<0.05	-	-	1	<0.05	-	-	3
Total Kjeldahl Nitrogen	mg/L	2.33	0.80	2.84	4	0.92	0.70	1.06	3	0.20	<0.2	1.76	5
Total Phosphorus	mg/L	0.200	0.140	0.560	5	0.020	<0.02	0.050	3	0.025	0.020	0.026	4
Dissolved Phosphorus	mg/L	<0.02	-	-	1	<0.02	-	-	1	-	0.017	0.017	2
General Organics and Toxicity													
Biochemical Oxygen Demand	mg/L	5	-	-	1	<2	-	-	1	-	2	4	2
Chlorophyll "a"	µg/L	13	-	-	1	0.89	-	-	1	-	-	-	-
Microtox IC50 @ 15 min	%	>99	-	-	1	>91	-	-	1	-	-	-	-
Microtox IC25 @ 15 min	%	-	-	-	-	-	-	-	-	-	-	-	-
Naphthenic Acids	mg/L	1	-	-	1	<1	-	-	1	<1	-	-	3
Total Phenolics	mg/L	-	-	-	-	0.003	-	-	1	<0.001	-	-	3
Recoverable Hydrocarbons	mg/L	<1	-	-	1	<0.5	-	-	1	<0.5	-	-	3
Metals (Total)													
Aluminum (Al)	mg/L	0.05	<0.01	1.44	5	0.04	0.033	0.12	3	-	0.038	0.043	2
Antimony (Sb)	mg/L	<0.0004	-	-	1	<0.0004	-	-	1	-	0.0005	0.0005	2
Arsenic (As)	mg/L	0.0011	-	-	1	0.0004	-	-	1	<0.0004	-	-	3
Barium (Ba)	mg/L	0.0574	-	-	1	0.0076	-	-	1	-	0.014	0.0145	2
Beryllium (Be)	mg/L	<0.001	-	-	1	<0.001	-	-	1	<0.001	-	-	3
Boron (B)	mg/L	0.023	-	-	1	0.057	-	-	1	-	0.047	0.059	2
Cadmium (Cd)	mg/L	<0.0002	-	-	1	<0.0002	-	-	1	0.0002	0.0002	0.0002	3
Chromium (Cr)	mg/L	<0.0004	-	-	1	<0.0004	-	-	1	-	<0.0004	0.0018	2
Cobalt (Co)	mg/L	0.0026	-	-	1	<0.0005	-	-	1	<0.0005	-	-	3
Copper (Cu)	mg/L	0.0012	-	-	1	0.0012	-	-	1	-	0.0009	0.001	2
Iron (Fe)	mg/L	7.92	-	-	1	0.09	-	-	1	-	0.39	0.61	2
Lead (Pb)	mg/L	0.0004	-	-	1	0.0003	-	-	1	-	0.001	0.0298	2
Lithium (Li)	mg/L	0.007	-	-	1	0.006	-	-	1	-	0.008	0.015	2
Manganese (Mn)	mg/L	2.29	-	-	1	0.0126	-	-	1	-	0.0457	0.0477	2
Mercury (Hg)	mg/L	<0.0001	-	-	4	<0.0001	-	-	3	0.0001	0.0001	0.0002	4
Molybdenum (Mo)	mg/L	<0.0001	-	-	1	0.0001	-	-	1	-	0.0002	0.0002	2
Nickel (Ni)	mg/L	0.0019	-	-	1	0.0011	-	-	1	-	0.0011	0.0026	2
Selenium (Se)	mg/L	<0.0004	-	-	1	<0.0004	-	-	1	<0.0004	-	-	3
Silicon (Si)	mg/L	7.18	-	-	1	0.464	-	-	1	-	3.07	3.2	2
Silver (Ag)	mg/L	<0.001	-	-	1	<0.001	-	-	1	<0.0001	-	-	3
Strontium (Sr)	mg/L	0.154	-	-	1	0.04	-	-	1	-	0.0863	0.0879	2
Titanium (Ti)	mg/L	0.0059	-	-	1	0.0007	-	-	1	-	<0.0004	0.0017	2
Uranium (U)	mg/L	0.0001	-	-	1	<0.0001	-	-	1	<0.0001	-	-	3
Vanadium (V)	mg/L	0.0009	-	-	1	<0.0002	-	-	1	-	<0.0002	0.0007	2
Zinc (Zn)	mg/L	0.027	-	-	1	0.005	-	-	1	-	0.028	0.103	2
Metals (Dissolved)													
Arsenic (As)	mg/L	0.001	<0.001	0.0024	4	-	0.0005	0.0005	2	-	0.0002	0.0005	2
Boron (B)	mg/L	0.1	0.015	0.32	4	-	0.08	0.24	2	-	0.12	0.19	2
Chromium (Cr)	mg/L	<0.003	-	-	4	-	0.003	0.003	2	-	-	-	-
Selenium (Se)	mg/L	<0.0005	-	-	4	-	0.0005	0.0005	2	-	0.0002	0.0002	2

Parameter	Units	Upper Muskeg Creek Drainage															
		Winter				Spring				Summer				Fall			
		median	min.	max.	n	median	min.	max.	n	median	max.	min.	n	median	max.	min.	n
Field measured																	
pH	-	7.485	6.8	7.98	6	7.7	7.3	7.9	5	7.4	7.2	7.7	5	7.76	7.39	8.5	8
Specific Conductance	µS/cm	475	420	566	4	163	145	172	3	248	237	270	3	233.5	181	250	6
Temperature	°C	0.5	0	1	6	12	10	12.5	5	16.7	16	18	5	5	2	8	8
Dissolved Oxygen	mg/L	4.65	0.4	10.6	6	10.1	6.7	12	5	5.8	2.3	10	5	10.2	2.8	12.8	8
Conventional Parameters and Major Ions																	
Bicarbonate	mg/L	284	226	451	5	102	93	105	4	170	113	181	6	137	116	149	7
Calcium	mg/L	50	36	64.3	5	16.3	14	23.6	4	29.4	21.2	31	6	23.4	18.3	25.9	7
Chloride	mg/L	3.3	1.6	6.9	5	1.35	0.8	3.3	4	1.25	0.9	4.3	6	1.4	0.8	2.1	7
Colour	T.C.U.	200	100	350	5	80	60	100	4	100	65	100	5	150	100	200	6
Conductance	µ/S	636	-	-	1	155	-	-	1	220	193	231	3	221	-	-	1
Dissolved Organic Carbon	mg/L	-	-	-	-	-	-	-	-	33.2	-	-	1	29.6	-	-	1
Hardness	mg/L	188	146	279	5	65	59	79	4	114	82	119	6	87	75	103	7
Magnesium	mg/L	16.3	13.6	28.7	5	5.8	4.9	5.9	4	9.45	7	10.1	6	7.6	7	9.2	7
pH	-	7.8	-	-	1	7.8	-	-	1	7.69	7.6	7.7	3	7.61	-	-	1
Potassium	mg/L	1.1	0.99	1.7	5	0.775	0.6	1.2	4	0.365	0.1	0.53	6	0.7	0.56	1.15	7
Sodium	mg/L	28	26.3	55.7	5	10.75	7.2	15.3	4	17.35	10	20.3	6	17	8.5	20	7
Sulphate	mg/L	8.5	4.7	13.4	5	3.05	2.1	4.1	4	1.75	0.8	4.9	6	3.6	1.7	10.6	7
Sulphide	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Alkalinity	mg/L	233	185	370	5	84	77	86	4	140	93	148	6	112	95	122	7
Total Dissolved Solids	mg/L	260	200	504	5	93	80	166	4	146	108	246	6	125	100	135	7
Total Organic Carbon	mg/L	36.1	23	42.4	5	21.75	17.7	24.5	4	30.5	18.5	37	5	28.3	24	32.1	6
Total Suspended Solids	mg/L	10.7	8.8	81.0	6	1.0	<0.4	4.0	5	2.8	<0.4	77.0	6	2.8	1.0	17.0	9
Nutrients																	
Nitrate + Nitrite	mg/L	0.020	<0.003	0.430	5	<0.004	-	-	4	<0.011	-	-	6	0.006	0.003	0.012	7
Total Ammonia	mg/L	1.04	0.13	2.80	5	0.04	0.03	0.04	4	0.08	0.05	0.15	5	0.03	0.03	0.05	6
Total Kjeldahl Nitrogen	mg/L	1.48	1.06	3.44	5	0.67	0.60	0.74	4	0.84	0.80	0.98	5	0.87	0.70	0.92	6
Total Phosphorus	mg/L	0.135	0.063	0.55	6	0.019	0.015	0.1	4	0.032	0.018	0.06	5	0.019	0.012	0.12	8
Dissolved Phosphorus	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
General Organics and Toxicity																	
Biochemical Oxygen Demand	mg/L	1.5	1	15.4	5	1.1	0.8	1.2	4	1.2	0.6	1.2	5	1.15	0.5	2.1	6
Chlorophyll "a"	µg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Microtox IC50 @ 15 min	%	-	-	-	-	-	-	-	-	>100	-	-	1	>100	-	-	1
Microtox IC25 @ 15 min	%	-	-	-	-	-	-	-	-	>100	-	-	1	>100	-	-	1
Naphthenic Acids	mg/L	-	-	-	-	-	-	-	-	<1	-	-	1	<1	-	-	1
Total Phenolics	mg/L	0.006	-	-	1	0.012	-	-	1	-	0.007	0.012	2	-	-	-	-
Recoverable Hydrocarbons	mg/L	0.6	0.3	1	5	<0.1	-	-	4	0.7	0.1	6.7	6	<0.4	-	-	7
Metals (Total)																	
Aluminum (Al)	mg/L	0.04	<0.01	0.31	4	0.02	<0.01	0.04	3	0.06	0.01	1.2	6	0.02	<0.01	0.1	7
Antimony (Sb)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic (As)	mg/L	0.0011	0.0007	0.0015	4	0.0004	0.0003	0.0006	3	0.0009	0.0002	0.006	5	0.0004	0.0003	0.0006	6
Barium (Ba)	mg/L	-	-	-	-	-	-	-	-	0.02	-	-	1	0.02	-	-	1
Beryllium (Be)	mg/L	-	-	-	-	-	-	-	-	<0.001	-	-	1	0.001	-	-	1
Boron (B)	mg/L	0.125	0.08	0.17	4	0.07	0.04	0.12	3	0.04	0.01	0.19	6	0.07	<0.01	0.1	7
Cadmium (Cd)	mg/L	<0.001	-	-	4	<0.001	-	-	3	<0.002	-	-	6	0.001	<0.001	0.003	7
Chromium (Cr)	mg/L	<0.001	-	-	4	<0.001	-	-	3	<0.0055	-	-	6	0.001	<0.001	0.013	7
Cobalt (Co)	mg/L	-	-	-	-	-	-	-	-	-	<0.003	<0.01	2	0.004	-	-	1
Copper (Cu)	mg/L	<0.001	-	-	4	0.001	<0.001	0.002	3	<0.001	-	-	5	<0.001	-	-	7
Iron (Fe)	mg/L	3.295	1.4	4.49	4	0.43	0.2	0.53	3	0.64	0.37	2.45	6	0.46	0.15	0.76	7
Lead (Pb)	mg/L	0.002	<0.002	0.003	4	0.004	0.002	0.006	3	<0.011	-	-	6	0.002	<0.002	0.02	7
Lithium (Li)	mg/L	-	-	-	-	-	-	-	-	0.006	-	-	1	0.008	-	-	1
Manganese (Mn)	mg/L	0.452	0.27	1.83	4	0.01	<0.004	0.026	3	0.0465	0.023	0.08	6	0.012	0.008	0.036	7
Mercury (Hg)	mg/L	<0.0001	-	-	4	<0.00005	-	-	3	0.00005	0.00003	0.00016	5	<0.000075	-	-	6
Molybdenum (Mo)	mg/L	-	-	-	-	-	-	-	-	<0.003	-	-	1	0.005	-	-	1
Nickel (Ni)	mg/L	0.001	<0.001	0.002	4	<0.001	-	-	3	<0.0035	-	-	6	0.001	<0.001	0.01	7
Selenium (Se)	mg/L	0.0004	0.0003	0.0005	4	0.0003	0.0003	0.0004	3	0.002	0.0002	0.012	5	0.00025	0.0002	0.0009	6
Silicon (Si)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	2.46	-	-	1
Silver (Ag)	mg/L	-	-	-	-	-	-	-	-	<0.02	-	-	3	<0.002	-	-	1
Strontium (Sr)	mg/L	-	-	-	-	-	-	-	-	0.051	-	-	1	0.072	-	-	1
Titanium (Ti)	mg/L	-	-	-	-	-	-	-	-	<0.003	-	-	1	0.007	-	-	1
Uranium (U)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	<0.5	-	-	1
Vanadium (V)	mg/L	<0.001	-	-	4	<0.001	-	-	3	<0.005	-	-	6	0.001	<0.001	0.003	7
Zinc (Zn)	mg/L	0.006	0.002	0.013	4	0.002	0.002	0.003	3	0.02	0.001	0.13	6	0.003	0.001	0.024	7
Metals (Dissolved)																	
Arsenic (As)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Boron (B)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chromium (Cr)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Selenium (Se)	mg/L	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

NOTES: - = No data

Table V-5 Water Quality of Isadore's Lake and Mills Creek (1997)

Parameter	Units	Isadore's Lake									
		Winter		Summer		Fall		Spring		Fall	
			n		n		n		n		n
Field measured											
pH	-	7.65	1	-	-	-	-	-	-	-	-
Specific Conductance	µS/cm	501	1	-	-	-	-	-	-	-	-
Temperature	°C	0.9	1	-	-	-	-	-	-	-	-
Dissolved Oxygen	mg/L	3.7	1	-	-	-	-	-	-	-	-
Conventional Parameters and Major Ions											
Bicarbonate	mg/L	351	1	154	1	166	1	289	1	289	1
Calcium	mg/L	76	1	0.13	1	38	1	95.4	1	87.3	1
Chloride	mg/L	1.2	1	2.7	1	2.4	1	2.2	1	2.7	1
Colour	T.C.U.	60	1	20	1	20	1	5	1	15	1
Conductance	µS/cm	542	1	319	1	349	1	697	1	594	1
Dissolved Organic Carbon	mg/L	15	1	11	1	9	1	5	1	7	1
Hardness	mg/L	277	1	154	1	164	1	345	1	319	1
Magnesium	mg/L	21.1	1	15.1	1	16.9	1	25.9	1	24.5	1
pH	-	7.2	1	8.4	1	8	1	8	1	8	1
Potassium	mg/L	0.8	1	1.8	1	1.8	1	2	1	2	1
Sodium	mg/L	10	1	7	1	6	1	4	1	4	1
Sulphate	mg/L	5.8	1	37.4	1	38.2	1	118	1	83.6	1
Sulphide	mg/L	<0.002	1	0.009	1	0.002	1	<0.002	1	0.003	1
Total Alkalinity	mg/L	287	1	129	1	136	1	237	1	237	1
Total Dissolved Solids	mg/L	290	1	236	1	220	1	390	1	894	1
Total Organic Carbon	mg/L	21	1	12	1	12	1	6	1	8	1
Total Suspended Solids	mg/L	24.0	1	2.0	1	6.0	1	7.0	1	<2	1
Nutrients											
Nitrate + Nitrite	mg/L	<0.05	1	<0.05	1	0.070	1	0.050	1	<0.05	1
Total Ammonia	mg/L	0.51	1	<0.05	1	0.11	1	<0.05	1	<0.05	1
Total Kjeldahl Nitrogen	mg/L	0.80	1	0.40	1	0.40	1	<0.2	1	<0.2	1
Total Phosphorus	mg/L	0.140	1	0.016	1	0.012	1	0.042	1	<0.002	1
Dissolved Phosphorus	mg/L	<0.02	1	0.008	1	0.012	1	0.050	1	<0.002	1
General Organics and Toxicity											
Biochemical Oxygen Demand	mg/L	5	1	<2	1	2	1	2	1	3	1
Chlorophyll "a"	µg/L	-	-	-	-	-	-	1	1	-	-
Microtox IC50 @ 15 min	%	>99	1	-	-	-	-	>91	1	-	-
Microtox IC25 @ 15 min	%	-	-	-	-	-	-	>91	1	-	-
Naphthenic Acids	mg/L	1	1	<1	1	1	1	<1	1	<1	1
Total Phenolics	mg/L	-	-	<0.001	1	<0.001	1	<0.001	1	<0.001	1
Recoverable Hydrocarbons	mg/L	<1	1	<0.5	1	<0.5	1	<0.5	1	<0.5	1
Metals (Total)											
Aluminum (Al)	mg/L	0.368	1	0.018	1	0.062	1	0.055	1	0.031	1
Antimony (Sb)	mg/L	<0.0004	1	<0.0004	1	0.0007	1	<0.0004	1	0.0006	1
Arsenic (As)	mg/L	0.0011	1	<0.0004	1	0.0018	1	<0.0004	1	<0.0004	1
Barium (Ba)	mg/L	0.0574	1	0.0003	1	0.0545	1	0.16	1	0.117	1
Beryllium (Be)	mg/L	<0.001	1	<0.001	1	<0.001	1	<0.001	1	<0.001	1
Boron (B)	mg/L	0.023	1	0.009	1	0.042	1	0.039	1	0.025	1
Cadmium (Cd)	mg/L	<0.0002	1	<0.0002	1	0.0003	1	<0.0002	1	<0.0002	1
Chromium (Cr)	mg/L	<0.0004	1	0.0014	1	<0.0004	1	<0.0004	1	<0.0004	1
Cobalt (Co)	mg/L	0.0026	1	<0.0005	1	<0.0005	1	<0.0005	1	<0.0005	1
Copper (Cu)	mg/L	0.0012	1	0.0009	1	0.0066	1	0.0008	1	0.0008	1
Iron (Fe)	mg/L	7.92	1	0.21	1	<0.01	1	0.82	1	0.05	1
Lead (Pb)	mg/L	0.0004	1	0.0087	1	0.0009	1	0.0002	1	0.0003	1
Lithium (Li)	mg/L	0.007	1	0.007	1	0.009	1	0.008	1	0.008	1
Manganese (Mn)	mg/L	2.29	1	0.0005	1	0.0434	1	0.0707	1	0.0466	1
Mercury (Hg)	mg/L	<0.0002	1	0.0001	1	<0.0001	1	<0.0002	1	<0.0001	1
Molybdenum (Mo)	mg/L	<0.0001	1	<0.0001	1	0.0008	1	<0.0001	1	<0.0001	1
Nickel (Ni)	mg/L	0.0019	1	0.001	1	0.0012	1	0.0008	1	<0.0004	1
Selenium (Se)	mg/L	<0.0004	1	<0.0004	1	<0.0004	1	<0.0004	1	<0.0004	1
Silicon (Si)	mg/L	7.18	1	0.103	1	0.661	1	3.14	1	2.41	1
Silver (Ag)	mg/L	<0.001	1	<0.0001	1	<0.0001	1	<0.0001	1	<0.0001	1
Strontium (Sr)	mg/L	0.154	1	0.0002	1	0.22	1	0.273	1	0.233	1
Titanium (Ti)	mg/L	0.0059	1	0.0012	1	0.0009	1	0.0019	1	0.0013	1
Uranium (U)	mg/L	0.0001	1	<0.0001	1	0.0002	1	<0.0001	1	<0.0001	1
Vanadium (V)	mg/L	0.0009	1	0.0004	1	<0.0002	1	<0.0002	1	<0.0001	1
Zinc (Zn)	mg/L	0.027	1	0.013	1	0.012	1	0.009	1	0.008	1
Metals (Dissolved)											
Aluminum (Al)	mg/L	-	-	-	-	0.0346	1	-	-	0.023	1
Antimony (Sb)	mg/L	-	-	-	-	0.0005	1	-	-	0.0004	1
Arsenic (As)	mg/L	-	-	-	-	0.0016	1	-	-	<0.0004	1
Barium (Ba)	mg/L	-	-	-	-	0.0538	1	-	-	0.118	1
Beryllium (Be)	mg/L	-	-	-	-	<0.0005	1	-	-	<0.0005	1
Boron (B)	mg/L	-	-	-	-	0.044	1	-	-	0.027	1
Cadmium (Cd)	mg/L	-	-	-	-	0.0003	1	-	-	<0.0001	1
Chromium (Cr)	mg/L	-	-	-	-	<0.0004	1	-	-	<0.0004	1
Cobalt (Co)	mg/L	-	-	-	-	0.0002	1	-	-	0.0003	1
Copper (Cu)	mg/L	-	-	-	-	0.0015	1	-	-	0.0013	1
Iron (Fe)	mg/L	-	-	-	-	0.02	1	-	-	0.03	1
Lead (Pb)	mg/L	-	-	-	-	0.00034	1	-	-	0.00029	1
Lithium (Li)	mg/L	-	-	-	-	0.009	1	-	-	0.008	1
Manganese (Mn)	mg/L	-	-	-	-	0.0335	1	-	-	0.0428	1
Mercury (Hg)	mg/L	-	-	-	-	<0.0002	1	-	-	<0.0002	1
Molybdenum (Mo)	mg/L	-	-	-	-	0.0007	1	-	-	0.00006	1
Nickel (Ni)	mg/L	-	-	-	-	0.0008	1	-	-	<0.0001	1
Selenium (Se)	mg/L	-	-	-	-	<0.0004	1	-	-	<0.0004	1
Silicon (Si)	mg/L	-	-	-	-	0.654	1	-	-	3.5	1
Silver (Ag)	mg/L	-	-	-	-	<0.0002	1	-	-	<0.0002	1
Strontium (Sr)	mg/L	-	-	-	-	0.202	1	-	-	0.228	1
Titanium (Ti)	mg/L	-	-	-	-	0.0003	1	-	-	0.0011	1
Uranium (U)	mg/L	-	-	-	-	<0.00014	1	-	-	<5E-05	1
Vanadium (V)	mg/L	-	-	-	-	<0.0001	1	-	-	<0.0001	1
Zinc (Zn)	mg/L	-	-	-	-	0.017	1	-	-	0.01	1

NOTES: - = No data

Table V-6 Water Quality of Alsands Drain, Fall 1997

Parameter	Units	Alsands Drain		
		Fall 1997		
		min.	max.	n
Conventional Parameters and Major Ions				
Bicarbonate	mg/L	299	302	2
Calcium	mg/L	81.6	109.3	2
Chloride	mg/L	1.8	2.45	2
Colour	T.C.U.	50	60	2
Conductance	uS/cm	486	629	2
Dissolved Organic Carbon	mg/L	15	17.5	2
Hardness	mg/L	254	335	2
Magnesium	mg/L	12.1	14.9	2
pH	-	7.4	7.5	2
Potassium	mg/L	2.2	2.35	2
Sodium	mg/L	4	6.5	2
Sulphate	mg/L	21.9	101.95	2
Sulphide	mg/L	0.006	0.0085	2
Total Alkalinity	mg/L	245	247	2
Total Dissolved Solids	mg/L	328	440	2
Total Organic Carbon	mg/L	19	22	2
Total Suspended Solids	mg/L	2.0	4.0	2
Nutrients				
Nitrate + Nitrite	mg/L	<0.05	<0.05	2
Total Ammonia	mg/L	0.05	0.30	2
Total Kjeldahl Nitrogen	mg/L	0.90	1.25	2
Total Phosphorus	mg/L	0.009	0.017	2
Dissolved Phosphorus	mg/L	0.005	0.008	2
General Organics and Toxicity				
Biochemical Oxygen Demand	mg/L	4	5.5	2
Naphthenic Acids	mg/L	1	1	2
Total Phenolics	mg/L	0.003	0.0035	2
Recoverable Hydrocarbons	mg/L	<0.05	<0.05	2
Metals (Total)				
Aluminum (Al)	mg/L	0.032	0.0345	2
Antimony (Sb)	mg/L	<0.0004	<0.0004	2
Arsenic (As)	mg/L	0.0004	0.0004	2
Barium (Ba)	mg/L	0.0984	0.1182	2
Beryllium (Be)	mg/L	<0.001	<0.001	2
Boron (B)	mg/L	0.045	0.053	2
Cadmium (Cd)	mg/L	<0.0002	<0.0002	2
Chromium (Cr)	mg/L	<0.0004	<0.0004	2
Cobalt (Co)	mg/L	0.0005	0.00055	2
Copper (Cu)	mg/L	0.002	0.00255	2
Iron (Fe)	mg/L	0.68	0.7	2
Lead (Pb)	mg/L	0.0002	0.0003	2
Lithium (Li)	mg/L	0.009	0.009	2
Manganese (Mn)	mg/L	0.205	0.244	2
Mercury (Hg)	mg/L	<0.0001	<0.0001	2
Molybdenum (Mo)	mg/L	<0.0001	<0.0001	2
Nickel (Ni)	mg/L	<0.0004	<0.0004	2
Selenium (Se)	mg/L	<0.0004	<0.0004	2
Silicon (Si)	mg/L	1.65	2.95	2
Silver (Ag)	mg/L	<0.0001	<0.0001	2
Strontium (Sr)	mg/L	0.198	0.2245	2
Titanium (Ti)	mg/L	0.001	0.0011	2
Uranium (U)	mg/L	0.0001	0.0002	2
Vanadium (V)	mg/L	0.0002	0.0002	2
Zinc (Zn)	mg/L	0.009	0.0095	2

Table V-7 Water Quality of Muskeg Drainage Waters Compared with Stream Water in the Muskeg River Basin

Parameter	Units	Muskeg Drainage Water[1]	Muskeg Drainage Water[2]	Muskeg River, Jackpine Creek, Shelley Creek and Muskeg Creek (Seasonal Median Values)			
				Winter	Spring	Summer	Fall
Conventional Parameters and Major Ions							
pH	-	7.13	-	7.45	7.60	7.80	7.60
Conductance	µS/cm	481	137	480	167	255	226
Total Dissolved Solids	mg/L	263	-	299.5	111	174	156
Total Suspended Solids	mg/L	29	-	6.15	4.8	3	3
Calcium	mg/L	85.0	17.0	69.0	20.0	33.1	30
Magnesium	mg/L	12	4.9	17.1	6.0	9.0	8.5
Potassium	mg/L	0.9	0.6	1.5	1.3	0.5	0.775
Sodium	mg/L	4.4	4.1	15.1	8.2	11.8	12.3
Bicarbonate	mg/L	317	81	349	100	171	183
Chloride	mg/L	<0.05-<0.5	2.4	4.75	1.7	2.1	2.0
Sulphate	mg/L	<0.1-3.1	5.9	5.1	4.1	4.5	3.3
Sulphide	mg/L	<0.005	-	<0.002	0.005	0.009	0.0055
Sulphur	mg/L	1	-	-	-	-	-
Total Hardness	mg/L	261	-	242	72	116	111
Total Alkalinity	mg/L	260	-	256	85	141	119
Total Organic Carbon	mg/L	10.2	-	25.0	18.0	25.5	25.5
Dissolved Inorganic Carbon	mg/L	67.5	-	-	-	-	-
Dissolved Organic Carbon	mg/L	9.8	-	23.0	15.8	24.0	24.0
Oil and Grease	mg/L	<2	-	<1	<0.1	<0.5	<1
Chemical Oxygen Demand	mg/L	29	-	-	-	-	-
Biochemical Oxygen Demand	mg/L	6.4	-	1.5	1	0.75	1.65
Total Phenolics	mg/L	<0.001	-	7	0.009	<0.001	0.002
Nutrients							
Nitrate + Nitrite	mg/L	<0.03-0.016	-	0.100	<0.003	<0.1	<0.05
Total Ammonia	mg/L	0.17	-	0.53	<0.05	<0.05	0.04
Total Kjeldahl Nitrogen	mg/L	0.34	-	1.30	0.83	<0.2	0.82
Total Phosphorus	mg/L	<0.1	-	0.052	0.030	<0.005	0.031
Metals (Totals)							
Aluminum (Al)	mg/L	0.33	-	0.04	<0.01	<0.005	<0.01
Barium (Ba)	mg/L	0.15	-	0.052	0.02	0.029	0.027
Beryllium (Be)	mg/L	<0.001-0.001	-	<0.001	<0.001	<0.001	<0.001
Boron (B)	mg/L	0.03	-	0.06	0.05	0.05	0.03
Cadmium (Cd)	mg/L	<0.0002	-	<0.001	<0.001	<0.001	<0.001
Chromium (Cr)	mg/L	0.011	-	<0.001	<0.001	<0.001	<0.001
Cobalt (Co)	mg/L	<0.0003-0.031	-	0.0010	<0.0005	<0.0005	0.00505
Copper (Cu)	mg/L	0.0035	-	<0.001	<0.001	<0.001	<0.001
Iron (Fe)	mg/L	4.44	-	1.41	0.56	0.84	0.925
Lead (Pb)	mg/L	<0.0003	-	0.0020	<0.02	<0.02	<0.002
Lithium (Li)	mg/L	0.006	-	0.009	0.007	0.01	0.008
Manganese (Mn)	mg/L	0.357	-	0.4865	0.0235	0.04115	0.053
Molybdenum (Mo)	mg/L	<0.003-0.003	-	0.00205	0.0002	<0.003	0.00175
Nickel (Ni)	mg/L	<0.0005-0.003	-	<0.001	<0.001	0.0023	<0.001
Silicon (Si)	mg/L	6.82	-	6.595	1.1	3.19	3.74
Silver (Ag)	mg/L	<0.0001	-	<0.001	<0.001	<0.0001	<0.0001
Strontium (Sr)	mg/L	0.137	-	0.154	0.0616	0.094	0.087
Titanium (Ti)	mg/L	0.012	-	<0.05	<0.01	<0.005	<0.05
Uranium (U)	mg/L	<0.0004	-	0.0001	-	<0.0001	<0.0001
Vanadium (V)	mg/L	<0.002-0.005	-	<0.001	<0.001	<0.001	<0.001
Zinc (Zn)	mg/L	0.020	-	0.008	0.006	<0.001	0.016

NOTES:

[1]Median values or range; n=4; data from Syncrude, Aurora Mine, February and March, 1997.

[2]Means for 144 samples of standing water in muskeg (Schwartz 1980).

Table V-8 Sediment Quality in the Athabasca River, Muskeg River and Jackpine Creek (1997)

Parameter	Units	Athabasca River at Donald Creek	Athabasca River at Fort Creek	Athabasca River at Fort Creek	Muskeg River at Mouth	Muskeg River upstream Jackpine Creek	Jackpine Creek at Mouth
Total Organic Carbon	%	0.67	2.98	1.67	2.98	4.5	2.0
Recoverable Hydrocarbons	mg/kg	423	1080	1300	3440	3690	5660
Metals							
Aluminum (Al)	mg/kg	10700	8160	7420	2970	5820	3060
Barium (Ba)	mg/kg	168	147	142	40.1	118	34.4
Beryllium (Be)	mg/kg	<1	<1	<1	<1	<1	<1
Cadmium (Cd)	mg/kg	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Calcium (Ca)	mg/kg	17500	18400	18700	50600	5650	2380
Chromium (Cr)	mg/kg	19.0	22.9	17.4	6.9	12.3	7.8
Cobalt (Co)	mg/kg	7	7	7	3	4	2
Copper (Cu)	mg/kg	15	15	15	7	10	7
Iron (Fe)	mg/kg	15000	15500	15500	11200	23000	5430
Lead (Pb)	mg/kg	9	8	8	<5	<5	<5
Magnesium (Mg)	mg/kg	5680	6340	6390	3240	1390	855
Manganese (Mn)	mg/kg	381	380	384	373	620	124
Molybdenum (Mo)	mg/kg	<1	<1	<1	<1	<1	<1
Nickel (Ni)	mg/kg	16	21	17	6	9	6
Potassium (K)	mg/kg	1990	1470	1320	741	744	520
Silver (Ag)	mg/kg	<1	<1	<1	<1	<1	<1
Sodium (Na)	mg/kg	244	140	134	<100	121	<100
Strontium (Sr)	mg/kg	52	53	53	75	27	16
Sulphur (S)	mg/kg	1540	1930	1970	2530	2780	1080
Thallium (Tl)	mg/kg	<1	<1	<1	<1	<1	<1
Tin (Sn)	mg/kg	<5	<5	<5	<5	<5	<5
Titanium (Ti)	mg/kg	54	20	16	17	19	18
Vanadium (V)	mg/kg	28	19	18	9	16	11
Zinc (Zn)	mg/kg	53.0	58.0	56.8	26.4	37.9	22.2
Antimony (Sb)	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Arsenic (As)	mg/kg	5.6	5.1	5.1	1.0	2.4	1.2
Mercury (Hg)	mg/kg	0.05	0.05	0.06	0.04	0.04	0.03
Selenium (Se)	mg/kg	0.8	0.5	0.5	<0.1	0.6	0.1
PAHs and Alkylated PAHs							
Naphthalene	µg/g	<0.01	0.005	0.006	<0.003	0.003	<0.003
Acenaphthylene	µg/g	<0.01	<0.003	<0.003	<0.003	0.004	<0.003
Acenaphthene	µg/g	<0.01	<0.003	<0.003	<0.003	<0.003	<0.003
Fluorene	µg/g	<0.01	<0.003	0.004	<0.003	<0.003	<0.003
Dibenzothiophene	µg/g	<0.01	<0.003	0.19	<0.003	0.005	0.005
Phenanthrene	µg/g	0.01	0.012	0.012	0.007	0.009	<0.003
Anthracene	µg/g	<0.01	<0.003	<0.003	<0.003	<0.003	<0.003
Fluoranthene	µg/g	<0.01	0.006	0.005	0.003	0.006	0.004
Pyrene	µg/g	<0.01	0.011	0.008	0.012	0.015	0.006
Benzo(a)anthracene/Chrysene	µg/g	0.02	0.027	0.023	0.035	0.057	0.034
Benzo(b&k)fluoranthene	µg/g	0.01	0.018	0.018	0.014	0.034	0.023
Benzo(a)pyrene	µg/g	<0.01	0.006	0.006	0.013	0.016	0.015
Indeno(c,d-123)pyrene	µg/g	<0.01	0.006	0.005	0.006	0.009	<0.003
Dibenzo(a,h)anthracene	µg/g	<0.01	<0.003	<0.003	<0.003	<0.003	<0.003
Benzo(ghi)perylene	µg/g	<0.01	0.007	0.006	0.012	0.010	0.010
Methyl naphthalene	µg/g	<0.02	0.015	0.015	<0.003	<0.003	<0.003
C2 sub'd naphthalene	µg/g	0.02	0.03	0.04	<0.02	0.03	0.02
C3 sub'd naphthalene	µg/g	0.03	0.06	0.05	0.04	0.03	0.04
C4 sub'd naphthalene	µg/g	<0.02	0.06	0.05	0.06	0.16	0.09
Biphenyl	µg/g	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Methyl biphenyl	µg/g	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
C2 sub'd biphenyl	µg/g	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Methyl acenaphthene	µg/g	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Methyl fluorene	µg/g	<0.02	<0.02	<0.02	<0.02	0.02	0.02
C2 sub'd fluorene	µg/g	<0.02	0.04	0.05	0.06	0.15	0.08
Methyl phenanthrene/anthracene	µg/g	<0.02	0.03	0.02	0.04	0.09	0.08
C2 sub'd phenanthrene/anth.	µg/g	0.03	0.12	0.12	0.10	0.26	0.19
C3 sub'd phenanthrene/anth.	µg/g	0.04	0.14	0.13	0.18	0.60	0.21
C4 sub'd phenanthrene/anth.	µg/g	0.04	0.05	0.09	0.11	0.21	0.10
Methyl dibenzothiophene	µg/g	<0.02	0.03	0.02	<0.02	0.03	0.03
C2 sub'd dibenzothiophene	µg/g	0.02	0.10	0.09	0.11	0.30	0.15
C3 sub'd dibenzothiophene	µg/g	0.04	0.20	0.20	0.21	0.58	0.25
C4 sub'd dibenzothiophene	µg/g	0.05	<0.02	<0.02	0.24	0.56	0.28
Methyl fluoranthene/pyrene	µg/g	0.03	0.05	0.04	0.07	0.07	0.03
Methyl B(a)A/chrysene	µg/g	0.03	0.03	0.04	0.07	0.12	0.05
C2 sub'd B(a)A/chrysene	µg/g	0.05	0.09	0.08	0.13	0.20	0.09
Methyl B(b&k)F/B(a)P	µg/g	0.03	0.03	0.04	0.09	0.12	0.12
C2 sub'd B(b&k)F/B(a)P	µg/g	0.03	0.03	0.04	0.10	0.19	0.10