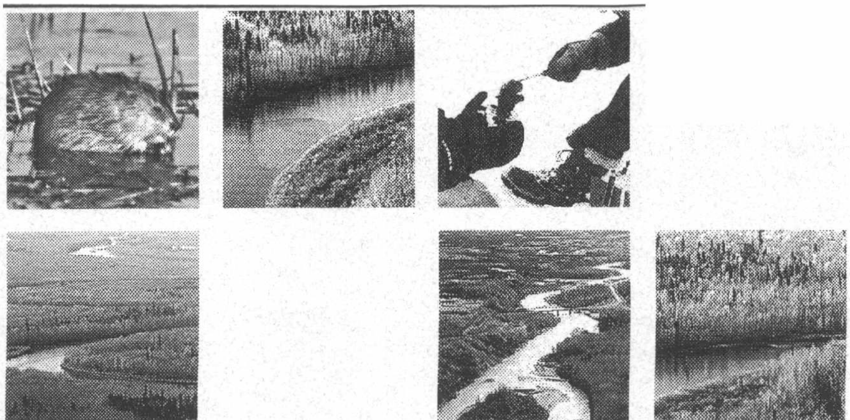
Canada Alberta Northwest Territories

Northern River Basins Study



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by
Monenco Inc.

NORTHERN RIVER BASINS STUDY PROJECT REPORT NO. 3

SEDIMENT OXYGEN DEMAND INVESTIGATIONS

ATHABASCA RIVER

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PREFACE:

The Northern River Basins Study was initiated through the "Canada-Alberta-Northwest Territories Agreement Respecting the Peace-Athabasca-Slave River Basin Study, Phase II - Technical Studies" which was signed September 27, 1991. The purpose of the Study is to understand and characterize the cumulative effects of development on the water and aquatic environment of the Study Area by coordinating with existing programs and undertaking appropriate new technical studies.

This publication reports the method and findings of one project of many that were conducted as part of the Northern River Basins Study. As such, the project was governed by a specific terms of reference and is expected to contribute information about the Study Area within the context of the overall study as described by the Study Final Report. This project report has been reviewed by the Study Science Advisory Committee in regards to scientific content and has been approved by the Study Board of Directors for public release.

It is explicit in the objectives of the Study to report the results of technical work regularly to the public. This objective is served by distributing project reports to an extensive network of libraries, agencies, organizations and interested individuals and by granting universal permission to reproduce the material.

Computer modelling of the oxygen balance of the Athabasca River is being used to assess the potential water quality impacts of expanding mill development and to set appropriate effluent standards for the mills. Sediment oxygen demand (SOD) is an important variable in the oxygen balance of rivers, in particular during the winter under low flow conditions and extensive ice cover.

In 1989, an in-situ chamber method of SOD measurement was used to determine winter SOD rates in the Athabasca River. In 1990, a number of improvements were incorporated and the method used to determine temporal and spatial trends of SOD on the river. The objectives of the 1992 study were similar to those in 1990 but incorporated a number of study locations extending downstream to Fort McKay.

During low flow conditions in mid February, sampling sites suitable for the in-situ method were found in the upper reaches of the study area (e.g. Windfall bridge, Whitecourt and Smith). The method was, however, found to be somewhat limited in the lower reaches (Athabasca, Calling River and Fort McMurray) during the same low flow period. Physical constraints including an abundance of deep and soft, fine sediments, excessive ice thickness and unsuitable water depth and velocity, necessitated the development of a comparable method best suited to SOD measurement in areas of low gradient and velocity that featured an abundance of fine sediment.

The sediment core method, as it was named, was tested in March in conjunction with the chamber method at Hinton, Whitecourt, Athabasca, Alpac. Given observed river break-up in late March and its anticipated influence upon study results, measurements of SOD were not conducted at points downstream of the Alpac study location.

The principle findings of the 1992 study were as follows:

- the lowest rates of SOD was measured at Windfall bridge (mean = -0.003 $gO_2/m^2/day$) located 170 km downstream of Hinton and 30 km upstream of Whitecourt;
- the highest rates of SOD were measured at sites located immediately downstream of the Weldwood pulp mill at Hinton (mean = 0.33 $gO_2/m^2/day$) and the Millar Western Ltd. pulp mill at Whitecourt (mean = 0.53 $gO_2/m^2/day$);
- At Smith, approximately 220 km downstream of the Millar Western Ltd. pulp mill effluent, SOD rates declined (mean = 0.10 $gO_2/m^2/day$) but were higher than those measured at Windfall bridge;
- Immediately downstream of the town of Athabasca's sewage effluent, SOD rates (mean = 0.21 $gO_2/m^2/day$) approximated those measured at Hinton, Blue Ridge and Fort Assiniboine in previous Athabasca River studies;

- The Athabasca River experienced an increase in SOD over the winter months. In conjunction with low flows and stable river conditions, the build-up of SOD was likely due to the continuous addition of organic nutrients and material which result in an increase in benthic biomass and respiration. Under the influence of increasing streamflows in late March, which scour accumulations of organic material and associated organisms, SOD rates were observed to decline;

- The chamber and sediment core methods of SOD measurement were somewhat similar in design and operation and during simultaneous deployment yielded similar SOD rates. Given that the sediment core method can be used in habitats not suitable for the deployment of open or closed chambers (and vice versa), the 1992 results indicated that estimates of SOD can be obtained in most situations, regardless of site specific characteristics.

Future development of the sediment core method could focus upon the interactive effects of substrate quality and disturbance, particle resuspension, test volumes, flow rates and top-water velocity. Continuous monitoring of dissolved oxygen concentration with a meter would provide valuable information concerning maximum SOD rates and the time period required for incubation. Meter measurements would limit the potential error that may be associated with decreasing sediment core water volumes during the incubation period.

Continued measurement of SOD, particularly in the lower river reaches, will provide information valuable for river oxygen balance modelling and the development of appropriate effluent standards.

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APPENDICES

PART 1

INTRODUCTION

1.1 BACKGROUND

Pulp mill development is expanding rapidly on Alberta's northern river systems. On the Athabasca River system, new pulp mills are under various stages of development or expansion. Computer modelling of the oxygen balance of the Athabasca River is being used to assess the potential water quality impact of expanding mill development and to set appropriate effluent standards for the mills.

Sediment oxygen demand (SOD), the rate of consumption of dissolved oxygen from the water column by the substratum in aquatic systems, is an important variable in the oxygen balance of river systems. Several chemical, biological and physical factors influence the SOD rate. These include indigenous bacterial, algal and invertebrate communities, sediment nutrient concentrations and the presence of chemical reducing agents (ie. bacterial by-products such as sulphide). The temperature and dissolved oxygen concentration in the water also affect the oxygen demand rate. The SOD rate becomes increasing important during winter months when ice cover prevents or significantly reduces atmospheric reaeration.

In 1989 and 1990, the Environmental Quality Monitoring Branch of Alberta Environment undertook to develop the means and methods of in-situ measurement of winter SOD rates. These methodologies have proven effective in evaluating temporal and spatial trends of SOD in the Athabasca River and the Wapiti-Smoky River systems. They have the potential for widespread application in waterways of the Athabasca, Peace and Slave river drainages.

1.2 STUDY COMPONENTS

In 1992, Monenco Inc. was retained by the Northern River Basins Study to obtain winter measurements of SOD on the Athabasca River.

The Terms of Reference for the study is provided in Appendix A.

Working in co-operation with the Environmental Quality Branch of Alberta Environment, the specific objectives of the study were to:

- Carry out measurements of SOD on the Athabasca River in order to investigate temporal and spatial changes during the period of January to March 1992;
- Determine SOD rates using in-situ methods and procedures outlined in the document entitled "Procedures for the Use of SOD Chambers in Flowing Water" (Casey 1990) and/or with a demonstrably equivalent methodology; and
- Carry out measurements of environmental variables pertinent to SOD, and to describe relationships between these variables and the SOD rate.

Originally, the 1992 winter study was aimed at investigating SOD at nine general locations along the Athabasca River:

- Windfall Bridge;
- Whitecourt;
- Smith;
- Athabasca;
- Alpac/La Biche River;
- Calling River;
- House River;
- Fort McMurray; and
- Fort McKay.

While sampling sites suitable for the in-situ method of SOD measurement were easily found at points upstream of Athabasca, this was not the case at points downstream. In mid- to late February, attempts to install chambers at Athabasca, Alpac, Calling River, Fort McMurray and Fort McKay were unsuccessful as a result of the following physical constraints:

- **Sediment Depth and Consistency**

  Along shorelines where water velocities and depth would enable the safe deployment of SOD chambers, fine sediment depths were often greater than the height of the chambers themselves. Sediment depth tests in a number of exploratory holes indicated that sediments were so soft and deep that working in them was impossible.

- **Ice Thickness and Water Depth**

  Ice thicknesses of greater than 1 m often occurred near shore over the deep fine sediments. Experience at upstream locations (Smith, Windfall) and the drilling of a number of test holes indicated that when suitable substrates were found, the chambers could not be deployed safely since water would flood up into the hole in the ice.

  Ice jamming in the vicinity of Fort McMurray and Fort McKay, particularly near shore, made sampling impractical. Areas of thinner ice occurred only in deep, fast water where chamber deployment could not be undertaken.

  In accordance with study requirements 2) and 4) as outlined in the Terms of Reference (Appendix A), Monenco developed an alternate method of SOD measurement that could be deployed in those areas where physical constraints (sediment and water depth and ice thickness) did not permit the installation of open and closed chambers.

Termed the sediment core method of SOD measurement, sampling was carried out during 16-26 March in conjunction with the in-situ method at Hinton, Whitecourt and Athabasca. At the Alpac study location only the sediment core method was used.

In a comparison of the results obtained from sediment core and in-situ chamber measurements of SOD, Monenco has also incorporated a comparative analysis of site specific environmental variables.

PART 2

STUDY AREA

2.1 THE ATHABASCA RIVER

The Athabasca River originates in the mountains of Jasper National Park and flows in a northeasterly direction for some 1400 km to Lake Athabasca. The river's basin extends from the Rocky Mountains through foothills, boreal forest and agricultural land, to the Canadian Shield in the northeast. Factors in the basin that are relevant to Athabasca River water quality include the headwater inflow, inflows from several sizeable tributaries, and effluents from two pulp mills, one oil sands plant, and several municipalities (Noton and Shaw 1989).

2.2 STUDY LOCATIONS AND SITES

Measurements of SOD and pertinent environmental variables were obtained at six study locations during the period of 29 January to 26 March 1992. An overview of the six study locations is presented in Figure 2-1. More specific locations and sampling sites are presented in Figures 2-2 through 2-7. A summary of study locations, sampling dates and techniques is provided in Table 2-1.

2.2.1 Hinton

Near Hinton, sampling was conducted along the right bank approximately 1 km downstream of the Weldwood pulp mill and 200 m downstream of Weldwood bridge crossing. This study location included three individual sampling sites for purposes of measuring SOD with open chambers, closed chambers, and sediment cores. During 16-18 March, the river was completely ice free and discoloured.

2.2.2 Windfall Bridge

At the Windfall bridge study location, sampling was conducted along the right bank approximately 300 m downstream of the bridge near the Alberta Environment datasonde. This study location included one sampling site where closed chamber measurements were made. During 13-15 February, the river was ice-covered with the exception of a long open-water slip located in the channel thalweg upstream and downstream of the bridge crossing.

2.2.3 Whitecourt

Near Whitecourt, sampling was conducted along the right side of the wetted channel approximately 1 km downstream of the Millar Western Ltd. pulp mill effluent. Over the course of the study the channel to the south of the large island depicted in Figure 2-4 was dry. During 29-31 January and 11-13 February, one site was used to obtain closed chamber measurements. During 19-22 March, three sites were used to obtain closed chamber, open chamber and sediment core measurements. Throughout the study period, this location was ice-free with variable degrees of ice-cover along the rivers edge.

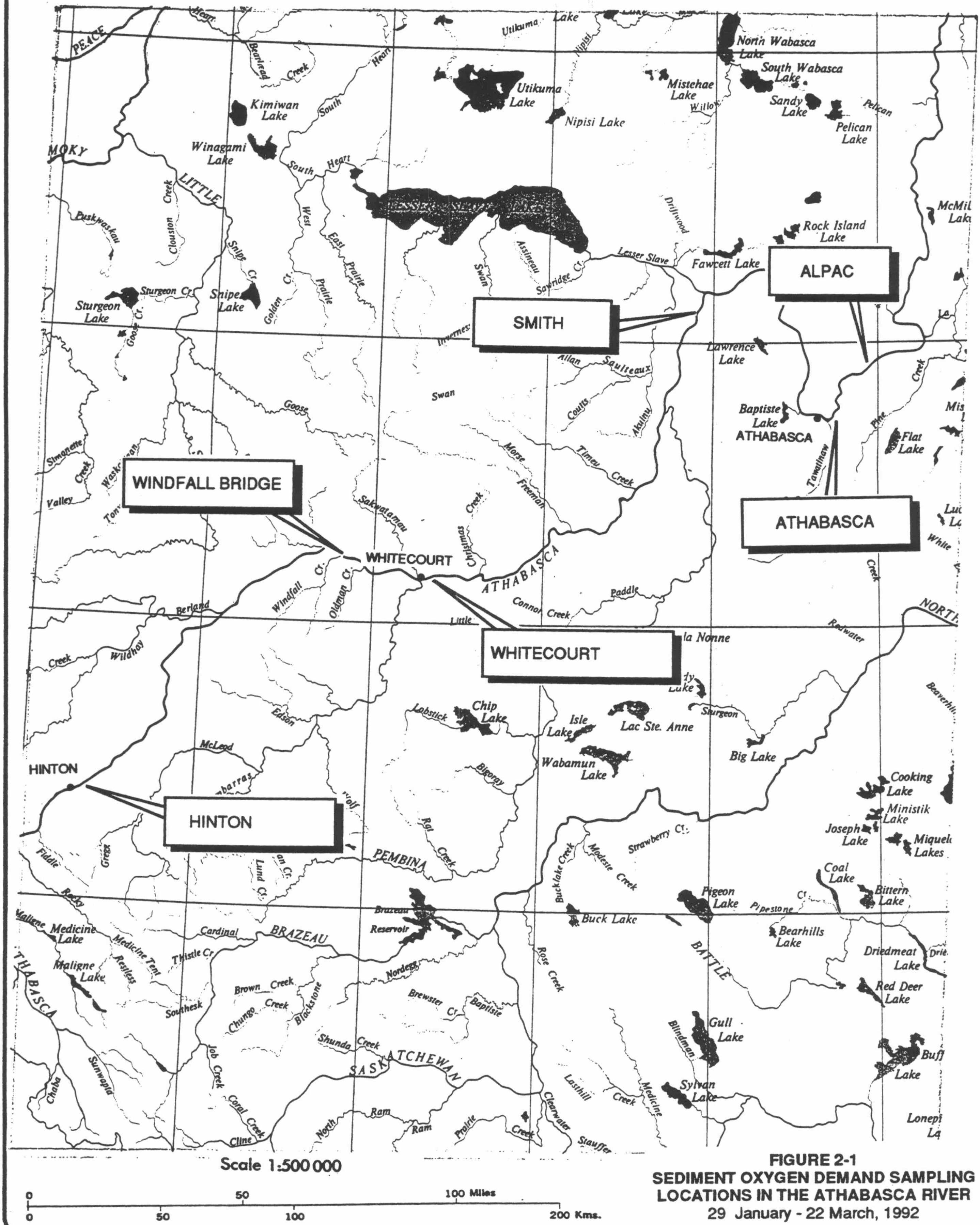

FIGURE 2-1
SEDIMENT OXYGEN DEMAND SAMPLING LOCATIONS IN THE ATHABASCA RIVER
29 January - 22 March, 1992

TABLE 2-1

Study Locations and Sampling Dates and Methods[1] Utilized During SOD Investigations on the Athabasca River 29 January - 22 March 1992

Study Location	Latitude, Longitude	Study Site[1]	Sampling Start Date (d/m/y)	METHOD OF SOD MEASUREMENT[2,3]			Time Dissolved Oxygen Sampled (hr)
				In-Situ Chambers (No.)		Sediment Cores	
				Open	Closed		
Hinton	53° 25'N, 117° 34'W	Site 1	16/03/92	5	-	-	0, 24, 48
		Site 2	16/03/92	-		5	0, 24, 48
		Site 3	17/03/92	-	4	-	0, 24
Winfall Bridge	54° 12'N, 116° 3'W	Site 1	13/02/92	-	3	-	0, 24, 48
Whitecourt	54° 9'N, 115° 40'W	Site 1	29/01/92	-	5	-	0, 24, 48
			11/02/92	-	5	-	0, 24, 48
			19/03/92	-	4	-	0, 24, 48
		Site 2	20/03/92	3	-	-	0, 24, 48
		Site 3	20/03/92	-	-	5	0, 24, 48
Smith	55°4'N, 114°5'W	Site 1	17/02/92	-	5	-	0, 24, 48
Athabasca		Site 1	22/03/92	-	-	5	0, 24, 48
		Site 2	23/03/92		5		0, 24, 48
Alpac		Site 1	24/03/92	-	-	5	0, 24, 48

Notes: 1) All study sites were located along the right bank.
2) All measurements of SOD were accompanied by measurements of pertiennt environment variables.
3) At each study site individual control chambers or cores accompanied test chambers or cores.

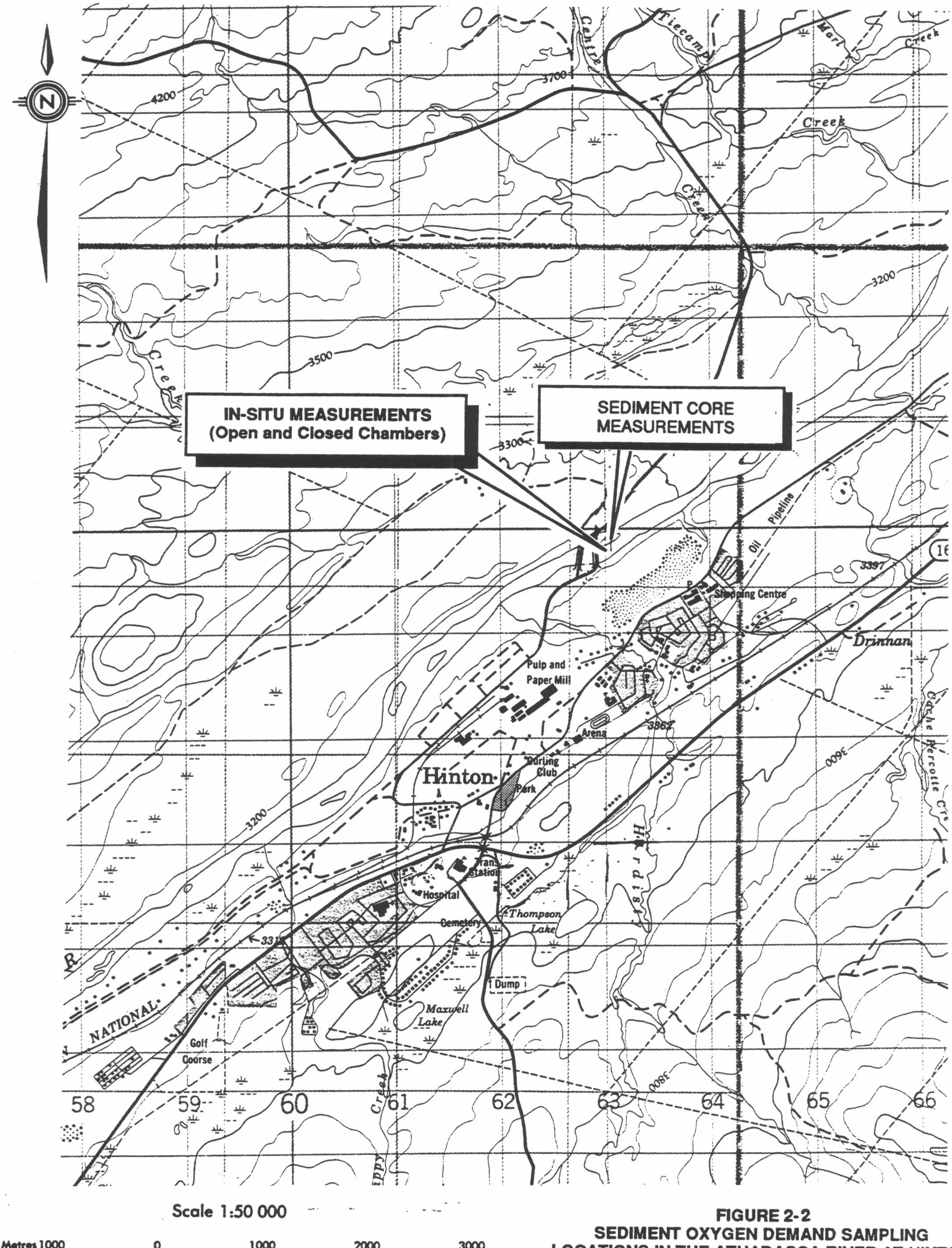

FIGURE 2-2
SEDIMENT OXYGEN DEMAND SAMPLING LOCATIONS IN THE ATHABASCA RIVER AT HINTON
16-18 March, 1992

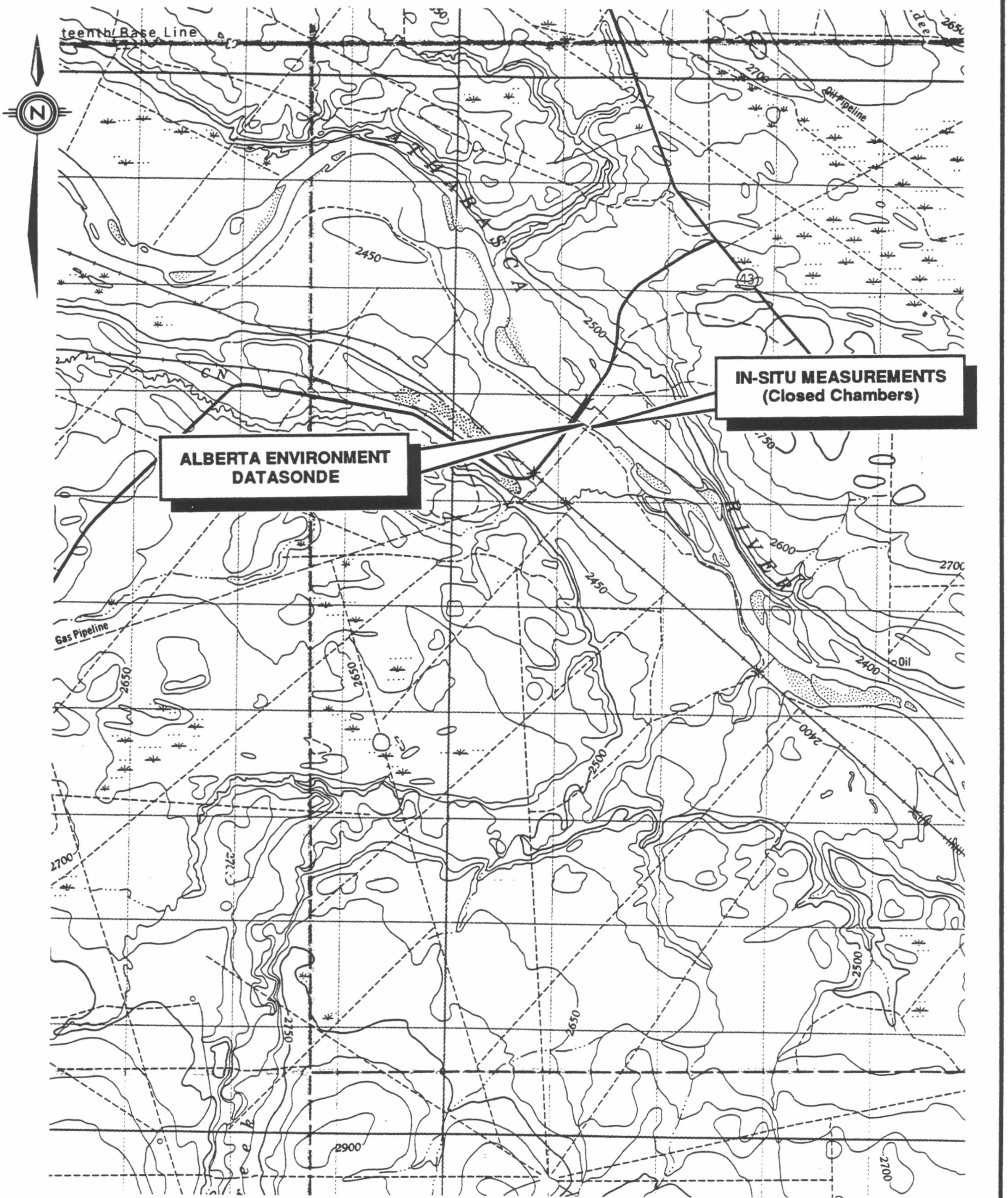

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FIGURE 2-3
SEDIMENT OXYGEN DEMAND SAMPLING LOCATIONS IN THE ATHABASCA RIVER AT WINDFALL BRIDGE
13-15 February, 1992

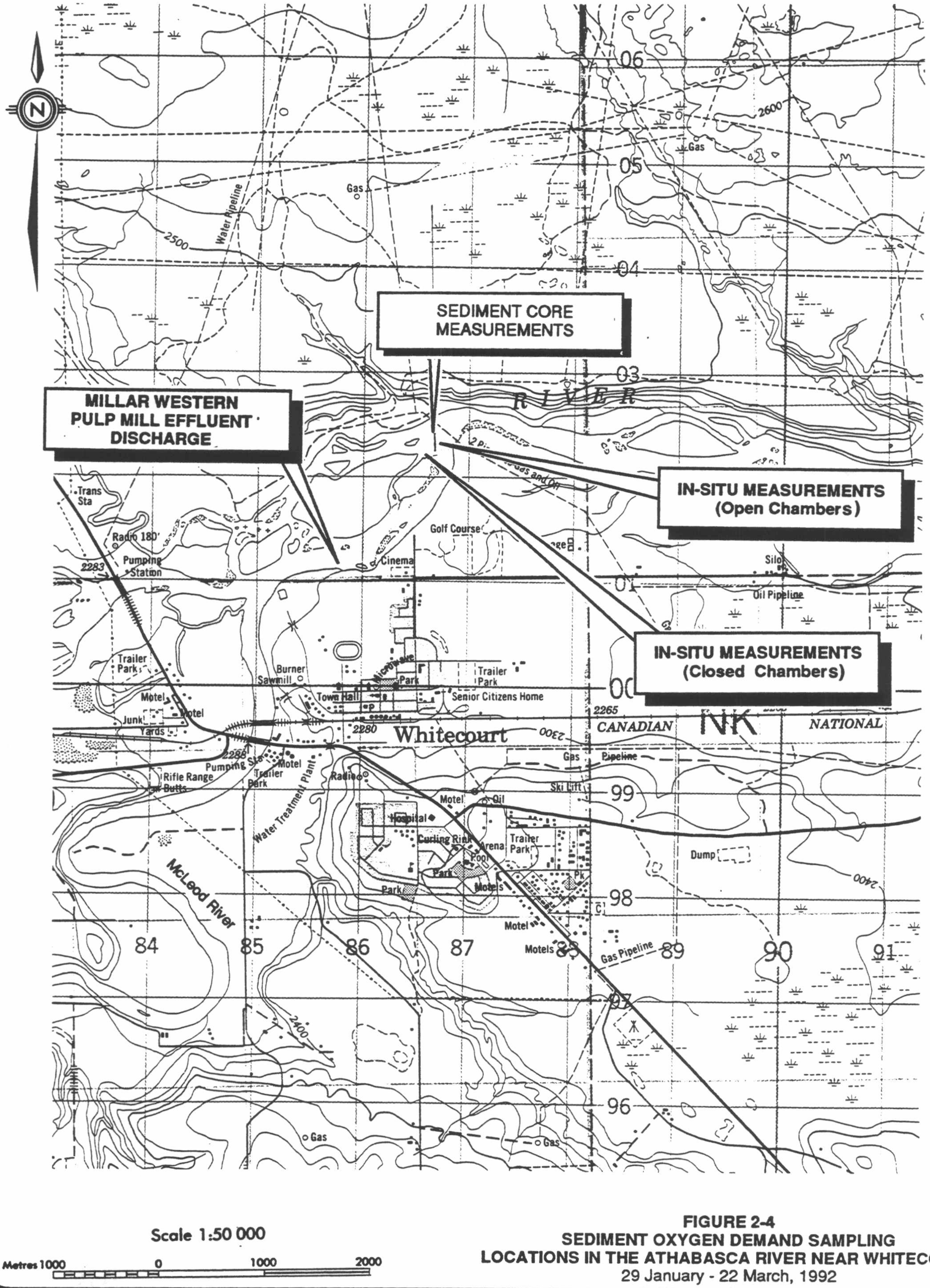

FIGURE 2-4
SEDIMENT OXYGEN DEMAND SAMPLING LOCATIONS IN THE ATHABASCA RIVER NEAR WHITECOURT
29 January - 22 March, 1992

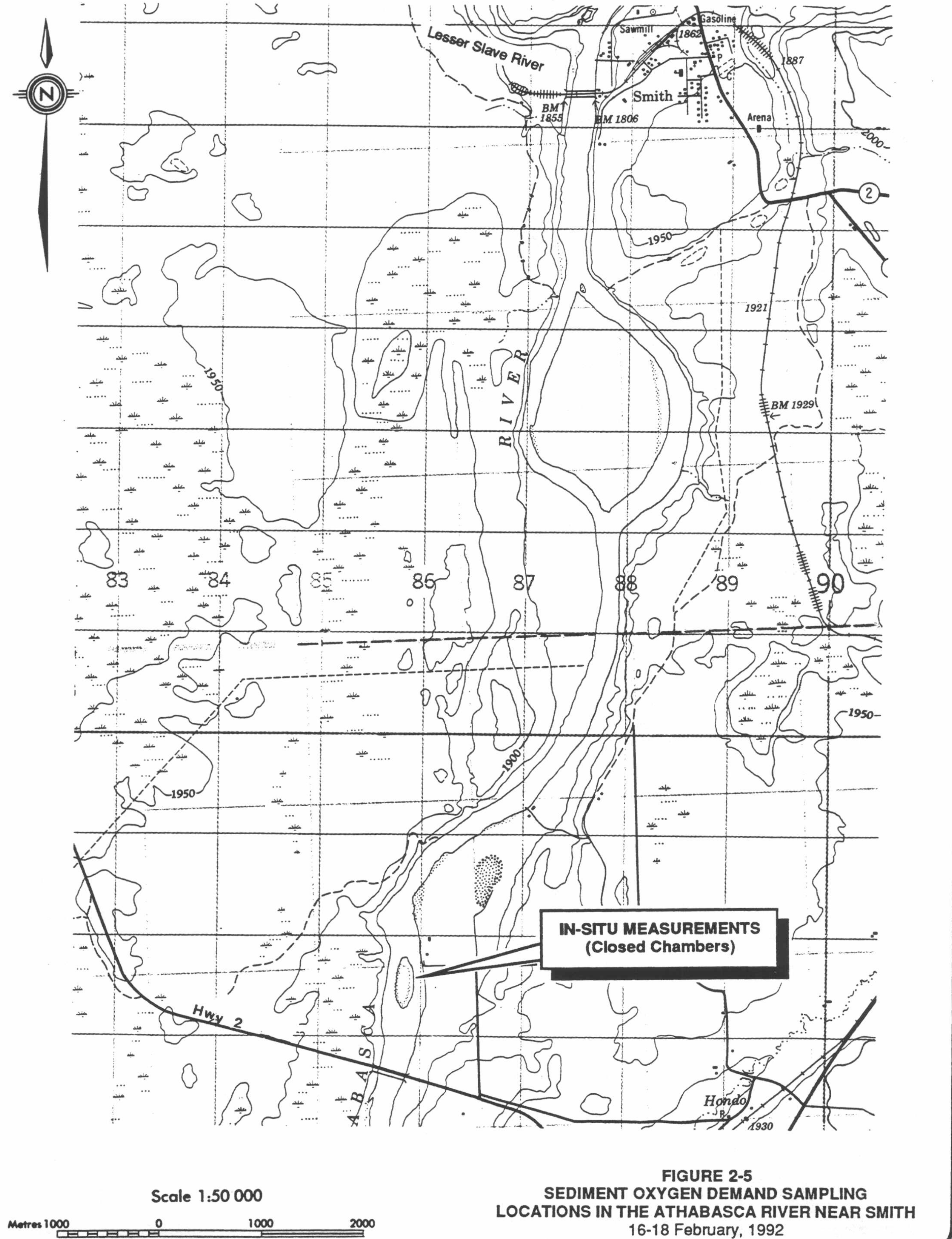

FIGURE 2-5
SEDIMENT OXYGEN DEMAND SAMPLING LOCATIONS IN THE ATHABASCA RIVER NEAR SMITH
16-18 February, 1992

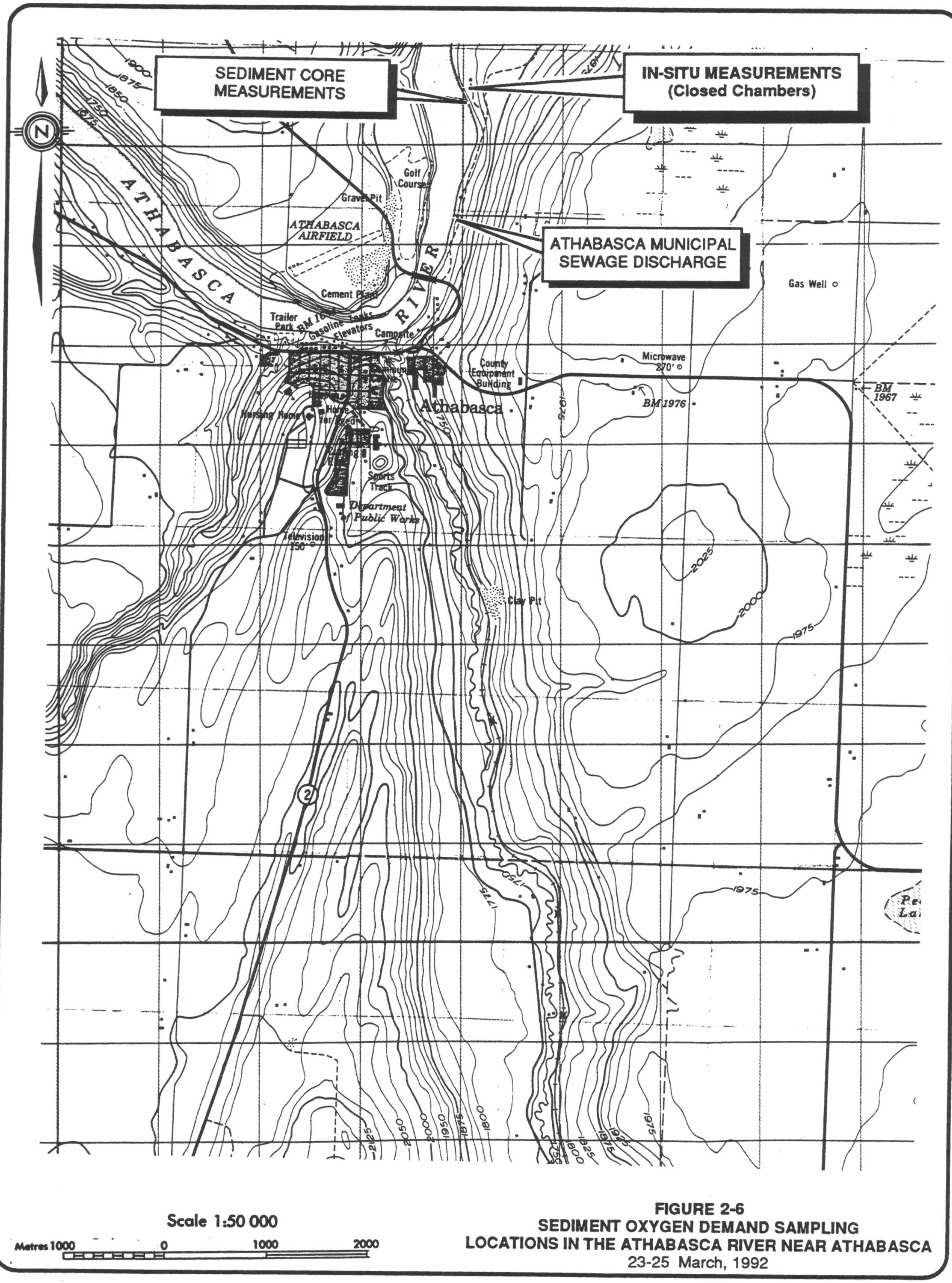

FIGURE 2-6
SEDIMENT OXYGEN DEMAND SAMPLING
LOCATIONS IN THE ATHABASCA RIVER NEAR ATHABASCA
23-25 March, 1992

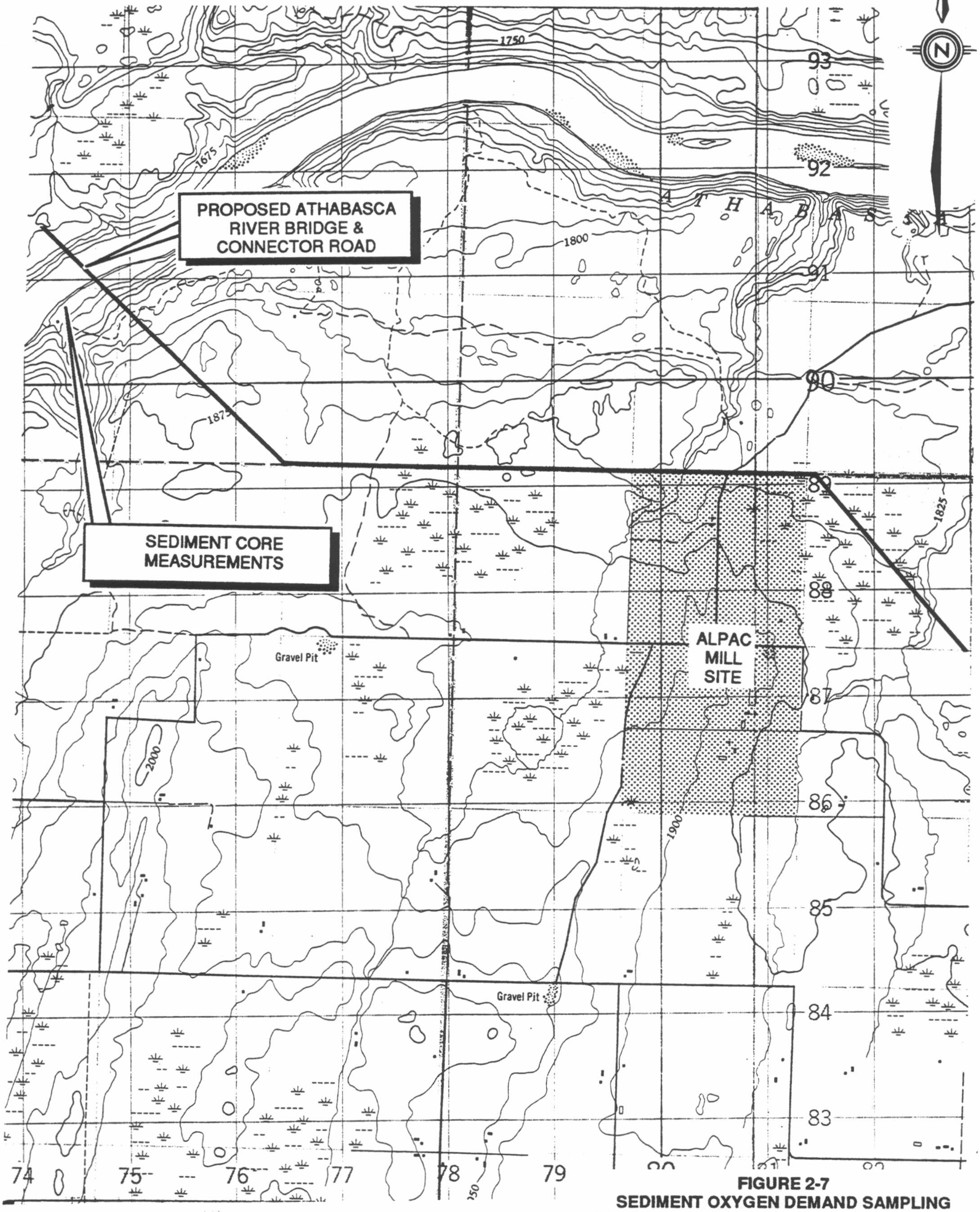

FIGURE 2-7
SEDIMENT OXYGEN DEMAND SAMPLING LOCATIONS IN THE ATHABASCA RIVER NEAR THE ALPAC SITE
24 - 26 March, 1992

Scale 1:50 000

Metres 1000 0 1000 2000

During 19-22 March, flows increased and the water was discoloured as a result of local runoff.

2.2.4 Smith

Near Smith, sampling was conducted along the right bank approximately 1 km downstream of the Highway #2 bridge crossing and 20 m downstream of the Alberta Environment datasonde. During 16-18 February, one site was used to obtain closed chamber measurements. The river was completely ice-covered. Flows were low and the water clear.

2.2.5 Athabasca

Near Athabasca, sampling was conducted in open water along the right bank approximately 1.5 km downstream of the sewage effluent discharge. This study location featured two sampling sites, one of which was suitable for the deployment of closed chambers and the other which necessitated the use of sediment core measurements. During 22-24 March, the river appeared to be nearing break-up and featured a broken ice cover with narrow open-water strips (1-2 m wide) occurring along each bank.

2.2.6 Alpac

Near the Alpac pulp mill site, sampling was conducted in open water along the right bank approximately 300 m upstream of the bridge crossing. At this study location, one sampling site was used for sediment core measurements. During 24 March, when sediment cores were collected, the river was ice covered with the exception of narrow open-water strips (1-2 m wide) occurring along the right bank. Considerable ice movement was observed near the bridge standards and other construction areas.

PART 3

MATERIALS AND METHODS

3.1 IN-SITU METHOD OF SOD MEASUREMENT

As in previous Athabasca River SOD studies conducted by Casey and Noton (1989) and Casey (1990), Monenco Inc. measured the in-situ rate of dissolved oxygen depletion over time in specially designed chambers which either contained substrate or were placed directly on top of substrate. A correction for oxygen demand by the water column was determined by using a control chamber (ie. with no substrate) and measuring the change in dissolved oxygen over the same time period. Differences between test and control chambers were estimates of SOD expressed in grams $O_2/m^2/day$.

As in the previous studies, Monenco Inc. assumed that SOD included all oxygen-consuming processes in or on the river bed.

3.1.1 Sampling Equipment

Both open and closed stainless steel chambers were used. Open chambers had an open base so that the chamber could be placed on the substrate. With closed chambers, the substrate had to be placed in the chamber. The type of chamber used depended on the substrate type and whether it was possible to obtain a seal between the substrate and the chamber. A summary of sampling equipment and a description of in-situ SOD chambers is provided in Appendix B.

3.1.2 Study Site Selection

Site selection was dictated by limitations of substrate, water depth, and velocity. Substrates that appeared representative of the general location were required. The maximum depth and velocity in which the chambers could be safely deployed was about 60 cm and 80 cm/s, respectively. At open-water study sites, a location for the chambers was found with relatively little difficulty compared to ice-covered areas. At ice-covered areas, a series of exploratory holes were drilled with an ice auger to locate representative substrate with suitable water velocity and depth. Because water depth was an important limiting factor, all sites were close to shore. In several cases the water velocity at a site was low compared to the flow in the main channel of the river. When a location was chosen, a section of the ice was quarried using an ice auger and a chain saw. The operator was able to enter the hole and install SOD chambers on the river bed.

3.1.3 Choice and Installation of SOD Chambers

Open chambers were only used in areas where a seal could be obtained between the chamber and the substrate. Closed chambers were used when a seal was impossible to achieve. Minimum disturbance was caused to the substrate when using the open chambers. During the 1989 and 1990 studies, open chambers were pushed into fine sediment to a depth of about 11 cm. During the 1992 study, open chambers were pushed into loose gravel (see part 4.2.3.1).

Closed chambers containing substrate were gently filled with river water and placed on the river bed without the lid. The chambers were left in position, without the lid, to allow the suspended sediment to settle in the chamber or flush clear in the current. The lids, with the porthole stoppers removed, were placed gently on the chamber so as not to trap air. The foam gasket was checked to insure it was fitted correctly around the edge of the lid.

The outer rubber curtain which had been placed over the base of both open and closed chambers was then spread out over the substrate. Rocks and sediment were then shovelled and placed by hand onto the curtain to the level of the handles. In the case of the open chambers, this was intended to help maintain a seal and provide additional stability in higher velocity areas. In the case of the closed chambers, the rubber curtain was used simply to provide additional stability.

While separate procedures were involved in the installation of open and closed chambers at a study site, the actual operation of the chambers was the same for both types.

3.1.4 Field Measurements

.1 Dissolved Oxygen

Immediately after each test and control chamber was installed, they were stoppered and dissolved oxygen was measured by the Winkler method (NAQUADAT no. 08101L). Samples were obtained through the tube on the top of the chamber using a hand vacuum pump to extract the water. Before taking a sample, the water vane was rotated several times to ensure the chamber contents were mixed. When water samples were extracted using the hand pump, the 1.5 cm porthole was partially opened to break the seal and allow the sample to be withdrawn. Water was pumped from the chamber into a 300 mL BOD bottle and then into a graduated 1 L filtering flask with a side-arm. The vacuum pump was attached to the side arm of the filtering flask. At least 300 mL was allowed to accumulate in the flask so that the BOD bottle was well flushed. When necessary, the entire water sampling apparatus including tubing was kept submerged in the river to avoid ice build-up. During extreme cold conditions, a Coleman backpacking stove was used to heat a pot of water in which frozen equipment (tubing, stoppers, flask) could be thawed between samples. While taking a sample, the BOD bottle was rotated and tapped lightly to dislodge air bubbles. Manganous sulphate and alkali-iodide-azide reagent power was added immediately to the samples and mixed. Sulphuric acid was added at the end of the day and the samples titrated within 24 hours.

.2 Chamber-Substrate Seal

Obtaining a seal between the open chamber and the substrate was essential. To check for leakage, 50 ml of 0.35 M NaCl solution was injected into the chamber with a hypodermic syringe through the water sample tube. Conductivity was measured in the excess water extracted for the dissolved oxygen analysis at the beginning of the incubation period, at 24 hours into the incubation period and at 48 hours, the end of incubation period. Conductivity measurements were made using a portable YSI (Yellow Springs Instrument) conductivity meter.

.3 Chamber Volume

At the end of an incubation period, the water volume of each chamber containing substrate was calculated using a depth-profile measuring device. This instrument was positioned on the chamber in place of the lid and twelve steel rods were inserted to contact the substrate, then held in position by "clips". The Plexiglas plate, with the rods inserted, was held in place on the chamber using permanently secured alignment rods. The depth of each rod in the chamber was measured and a mean depth was calculated, so that the volume of water in each chamber could be estimated.

When it seemed likely that use of the depth profile device would result in an overestimate of depth (i.e. when working in soft sediments), a ruler was used in its place. A number of depth measurements could be taken with the ruler then averaged to provide an accurate depth estimate.

.4 Pertinent Environmental Variables

A number of other variables were also recorded during the SOD measurements. These included the velocity of the water vane which would give an indication of mixing of the water in the chambers. For each location, the water velocity and depth were recorded beside the chambers. In open water areas, water velocity was recorded at 0.6 x depth (i.e. mean velocity). At ice-covered areas, velocity was measured half-way between the bottom of the ice and the substrate. Notes were also made on substrate size and associated deposits and growths.

During previous surveys, subsamples of fine sediment were collected and analyzed for percent organic content. During the Winter 1992 study, fine sediments were not abundant at those sites where the in-situ method of SOD measurement was utilized and as a result, sediment samples were not collected from chambers. Sediment samples were, however, collected from the sediment cores following incubation periods (see part 3.2.7.3).

3.2 SEDIMENT CORE METHOD OF SOD MEASUREMENT

The basic principles behind the sediment core method of SOD measurement used in the Winter 1992 study were similar to those of the in-situ chamber method of SOD measurement. Sediment oxygen demand was measured by enclosing an area of sediment in a plexiglass coring tube of known volume and measuring the change in dissolved oxygen over time. A correction for oxygen demand by the water column was determined by using a control chamber containing river water only, and measuring the change in dissolved oxygen over the same time period.

Once initial dissolved oxygen samples were withdrawn, sediment core samples were stoppered and returned to the motel room for incubation at near zero temperatures. To simulate water velocity at the "substrate-water" interface and to ensure continuous mixing, top-water was circulated at an even rate with a peristaltic pump during the entire incubation period.

As described in the following sub-sections, the method approximates that developed by McLeod and Gannon (1986) and incorporates the experience of Alberta Environment EQMB and Fisheries and Oceans Canada (Freshwater Institute).

3.2.1 Sampling Equipment

A summary of the necessary equipment and a description of the sediment core method is provided in Appendix C. An illustration of a typical coring device is also presented in the appendix.

3.2.2 Study Site Selection

As with the in-situ chamber method of SOD measurement, the actual sites selected for core sampling were dictated by limitations of water depth and velocity and substrate.

For safety reasons, core samples could only be collected in areas less than 60 cm deep and with velocities less than 60 cm/s.

Fine sediments ranging in depth from 3 to 10 cm were required for successful collection of core samples. This often meant that core sampling was carried out close to the shoreline in eddies and sidepools. Owing to timing constraints the coring device was not pole-mounted. Pole-mounting would enable the collection of sediment cores from shallow, low velocity areas where the ice is quite thick and from deeper, high velocity areas, where the deposition of fine materials occurs behind large rocks. Prior to collection of a core sample, a steel rod or rebar stake was used to estimate the depth of the sediment and to determine the substrate composition beneath the sediment layer. Under ideal conditions, fine sediments were underlain by a fine gravel or clay-gravel base which when encased in the coring device acted as a plug holding core contents in place before the device could be stoppered at the bottom end and removed from the river.

3.2.3 Sediment Core Sample Collection

Once a suitable area had been identified and disturbance to the substrate had been avoided, a plexiglass coring tube was pressed firmly into the fine sediment until the undisturbed top of sediment core was within 5 cm of the brass taps. Clear plexiglass enabled the operator to determine the height of the core in the tube and to determine whether the core maintained its original profile during collection and removal.

Once the core was correctly positioned within the tube, a neoprene rubber stopper was placed over the top end to create a partial vacuum that would help to keep the core in place until it could be sealed at the bottom and removed from the river.

Two lengths of clear Tygon tubing joined together with a removable polypropylene connector were then filled with river water and attached underwater to the brass taps on the plexiglass tube. Air bubbles were then released from the Tygon tubing (and subsequently from the plexiglass tube).

The coring device was then gently rotated out of the substrate and a neoprene stopper inserted in the bottom of the tube. In some instances, it was necessary to dig down to the bottom of the tube to accommodate stopper placement.

When the core sample was collected from shallow water, it was necessary to add water to the plexiglass tube to ensure that sufficient volume was present for the withdrawal of three 100 ml dissolved oxygen samples during the incubation period (start, middle and end).

Each core sampling unit was moved carefully to the streambank and placed in an ice-filled cooler.

3.2.4 Coring Device Seal

In the similar study using the sediment coring device as the incubation chamber, McLeod and Gannon (1986) added a 4.5 cm layer of mineral oil to the devices top-water to prevent oxygen exchange with the atmosphere when circulation of water in the core was started. The decision to use "heavy" mineral oil as a core sealant during Athabasca River SOD measurement, followed an evaluation to determine if the oil itself would create an oxygen demand in addition to that which would be attributable to river water and sediments.

Mineral oil is a colorless oily mixture of liquid hydrocarbons that are insoluble in water. The density of "heavy" mineral oil ranges between 0.875 and 0.905. Surface tension at 25°C is slightly below 35 dynes/cm (Windholz et al. 1983).

Preliminary laboratory testing involved the simultaneous incubation of two distilled water blanks, one with a layer of mineral oil the other without, at constant temperatures (0°C) and circulation rates over a period of 48 hours. Measurement of dissolved oxygen at 24 and 48 hours of incubation resulted in significant but equal decreases to a common, final dissolved oxygen concentration. Common, final dissolved oxygen concentrations in distilled water blanks with and without an oil layer would indicate that the oil itself did not create an oxygen demand. Significant but equal decreases in dissolved oxygen concentrations would suggest that oxygen diffusion was not influenced by the oil layer. Thus, the mineral oil layer did not influence the measurement of Athabasca River water and sediment oxygen demand.

In using the sediment core method in the field, the assumption was made that the nature of the river water and river sediments would not influence the diffusion rate provided that water temperatures, circulation rates, barometric pressure and other environmental variables were held constant.

Given the potential for disturbance of sediment core during transport and the resultant surface aeration, the mineral oil layer should remain an integral part of the sediment core method.

3.2.5 Field Measurements

.1 Initial Dissolved Oxygen Content

Immediately after the mineral oil had been added to each plexiglass tube, an indelible felt pen was used to mark the water level in each plexiglass tube. Measurements of water depth were later used to determine volumes necessary for calculation of SOD rates.

Single 100 ml samples were withdrawn from the polypropylene connector for the purpose of determining water column dissolved oxygen concentration.

To obtain a dissolved oxygen sample, the neoprene stopper was first removed from the top of the plexiglass tube. While pinching the Tygon tubing to control the flow, the polypropylene connector was separated and water was allowed to fill and overflow the sample bottle.

Dissolved oxygen was measured by the Winkler method (NAQUADAT no. 08101L). Manganous sulphate and alkaline-iodide-azide reagent powders were added immediately to the sample and mixed. Sulphuric acid was added at the end of the day and the samples were titrated within 24 hours.

.2 Pertinent Environmental Variables

As with the in-situ chamber method of SOD measurement, a number of environmental variables were measured while collecting core samples. These included the water velocity and depth beside each core as well as estimates of substrate size, deposits and growths.

3.2.6 Transport of Samples

Prior to the transport of core samples back to the motel room, additional ice was packed around each plexiglass tube to ensure near river water temperatures were maintained and to provide additional stability. Plastic garbage bags were placed over the samples to prevent light penetration and possible photosynthetic activity.

3.2.7 Sample Incubation

Upon return to the motel room, the Tygon tubing of each sediment coring device was connected to the head of a peristaltic pump. For a brief period of approximately five seconds, the pump was run at the highest setting in order to squeeze any remaining air bubbles out of the Tygon tubing. Air bubbles could be observed escaping out of the mineral oil layer in the plexiglass tubes. The pumping rate was then decreased to a medium setting and the entire apparatus left undisturbed for 24 hours. In an attempt to simulate site conditions, pump circulation rates were adjusted to a common level which caused mixing in the water column but which did not promote excessive resuspension and circulation of fine sediment particles.

3.2.8 Sediment Core Measurements

.1 Dissolved Oxygen

After 24 hours of incubation the pump was turned off. Dissolved oxygen samples were collected and concentrations determined in the manner described in Part 3.2.4.1. The new water levels in each plexiglass tube were marked with an indelible felt pen and later used to determine final volumes necessary for the calculation of 48-hour SOD rates.

.2 Sediment Core Volumes

Once the incubation period was completed, a ruler was used to measure the average depth of water overlying the sediment in each plexiglass tube. Depth measurements were made prior to collection of both the 24-hour and 48-hour dissolved oxygen samples. Within the plexiglass tube, 2.0 cm of depth was equivalent to a volume of 25.0 ml. The volume of the Tygon tubing (60 ml) was then added to each volume estimate.

.3 Pertinent Environment Variables

Following the incubation period of 48 hours, core samples were released from the plexiglass tubes into wide mouth glass jars and kept cool (4°C). The samples were subsequently taken to Norwest Labs in Edmonton for analysis of percent organic content and percent total organic content. Following laboratory extraction of any residual mineral oil not removed from the core samples by field personnel, percent organic content was calculated by drying the sediment to a constant weight at 105°C and then igniting the sample at 550°C for one hour before calculating the percent change in weight.

3.3 CALCULATION OF SOD

Sediment oxygen demand for both the in-situ chamber and sediment core methods was calculated using the following formula:

$$SOD\ (gO_2/m^2/day) = 0.024\ \frac{V}{A}\ (b_1 - b_2)$$

where,

0.024 = constant, converting mg/L/h to $g/m^2/day$

$= \frac{24\ (h)}{1000\ (mg)}$

V = volume of water in chamber (litres)

= area of base (m^2) x mean depth (m) x 1000

A = area of chamber base in square meters

b_1 = change in DO inside chamber with substrate (mg O_2/L/h)

b_2 = change in DO inside "blank" chamber (control for water column) containing no substrate (mg O_2/L/h).

In calculating the 48-hour sediment core SOD rate, modification of the volume estimate was necessary since volume was decreased each time a sample was withdrawn. Given that one-half of the 48-hour test was run at the initial tube volume and the other half at the 24-hour volume, the two volumes were averaged prior to calculation of the 48-hour SOD rate.

PART 4

RESULTS AND DISCUSSION

4.1 STUDY SITE CHARACTERISTICS

Summaries of hydrological and physical characteristics for each of the Winter 1992 study locations and sampling sites are presented in Tables 4-1 through 4-3. Appendix D provides water velocities and water depths associated with individual SOD sample replicates.

4.1.1 Hydrological Characteristics

.1 River Discharges

Preliminary Athabasca River daily discharges, subject to correction, were available from two Water Survey of Canada gauging stations located in the study area: 07AD002 at Hinton and 07BE001 at Athabasca. Mean daily discharges that occurred during the measurement of SOD in March at Hinton and Athabasca are presented in Table 4-1.

Given that the Hinton and Athabasca gauging stations were located at the upstream and downstream ends of the study area, the mean daily discharges depicted in Table 4-2 were used in conjunction with on-site observations to estimate discharge characteristics for locations in between the gauging stations.

During 29-31 January, closed chamber SOD measurements at Whitecourt Site 1 were conducted in low and clear streamflows. Based on streamflows measured at Hinton and Athabasca, it was evident that streamflows were relatively stable at Whitecourt for at least one week prior to the measurement of SOD.

During 11-13 February, SOD measurement at Whitecourt was conducted during a period of generally decreasing streamflow. During the second day of closed chamber incubation, the water level was observed to drop approximately 5 cm. During 13-15 February, the discharge at Windfall bridge increased enough to cause water to overflow from the excavated ice hole. Sampling at Smith during 17-19 February occurred during a period of apparently decreasing streamflow, as indicated by trends occurring at Hinton and Athabasca gauging stations.

During 16-18 March, SOD measurement at Hinton was conducted within a period of slightly increasing discharge.

TABLE 4-1

Study Site - Hydrological Characteristics During SOD Investigations on the Athabasca River 29 January - 26 March 1992

Study Location	Latitude & Longitude	Study Site	Sampling Start Date (D/M/Y)	SOD Method[1]	Ice Conditions	Mean River Discharge[2,3] (m^3/S)	Range of Mean Water Velocity[4] (cm/S)	Mean Water Depth[5] (cm)	Mean Number of Water Vane Revolution[6] (per 30s)
Hinton	53° 25'N, 117° 34'W	Site 1	16/03/92	OC	Open Water	45.2[7]	29 - 42	42 - 51	5.8
		Site 2	16/03/92	SC	Open Water	45.2[7]	2 - 15	20 - 25	-
		Site 3	17/03/92	CC	Open Water	46.3[7]	56 - 65	40 - 54	7.5
Windfall Bridge	54° 12'N, 116° 3'W	Site 1	13/02/92	CC	Ice cover (>100 m)	-	15 - 22	52 - 60	2.0
Whitecourt	54° 9'N, 115° 40'W	Site 1	29/01/92	CC	Open Water	-	24 - 37	41 - 45	5.0
			11/02/92	CC	Open Water	-	28-42	40 - 45	3.5
			19/03/92	CC	Open Water	-	55 - 77	38 - 43	8.0
		Site 2	20/03/92	OC	Open Water	-	22 - 52	41 - 45	3.5
		Site 3	20/03/92	SC	Open Water	-	2 - 12	20 - 35	-
Smith	55° 4'N, 114° 5'W	Site 1	17/02/92	CC	Ice Cover (>80 m)	-	4 - 7	59 - 71	7.0
Athabasca	54° 44'N, 113° 45'W	Site 1	22/03/92	SC	Open Water	270[8]	3 - 15	15 - 30	-
		Site 2	23/02/92	CC	Open Water	269[8]	25 - 45	46 - 62	6.2
Alpac		Site 1	24/03/92	SC	Open Water	278[8]	3 - 12	15 - 20	-

Notes:
1) OC = Open Chamber, CC = Closed Chamber, SC = Sediment Core.
2) River discharge data preliminary in nature and subject to annual correction by the Water Survey of Canada.
3) Indicative of mean daily discharge for that date when SOD incubation initated.
4) Water velocity based on three measurements taken beside each chamber or core to produce a range of mean site values.
5) Mean water depth based on individual measurements taken beside each chamber or core to produce a range of mean site values.
6) Means based on range of water vane revolutions for each group of open or closed chambers.
7) Flows measured at Hinton - Water Survey of Canada Gauging Stn. 07AD002.
8) Flows measured at Athabasca - Water Survey of Canada Gauging Stn. 07BE001.

TABLE 4-2

Athabasca River Mean Daily Discharges[1] (m^3/s) as Measured at Hinton and Athbasca over the Course of the Winter 1992 SOD Study

Study Site (SOD method)	Study and Discharge Date		Athabasca River Discharge (m^3/s) Hinton (Stn. 07AD007)	Athabasca (Stn. 07BE001)
	January	24	41.5	103
		25	41.7	105
		27	41.8	108
		28	42.4	104
Whitecourt (CC)		29	42.8	99.8
		30	47.2	98.7
		31	48.0	98.0
	February	1	47.2	96.8
		2	49.2	97.8
		3	52.3	103.0
		8	31.9	113
		9	29.8	113
		10	18.0	113
Whitecourt (CC)		11	20.9	110
		12	27.7	102
Windfall Bridge (CC)		13	36.4	94.0
		14	41.3	87.6
		15	40.8	85.1
		16	38.9	82.7
Smith (CC)		17	37.8	76.5
		18	36.0	67.6
		19	30.1	62.0
		20	21.9	73.4
		21	23.5	87.4
		22	25.1	93.9
	March	13	42.5	166
		14	44.9	167
		15	45.3	168
Hinton (OC, SC)		16	45.2	173
Hinton (CC)		17	46.3	182
		18	45.5	197
Whitecourt (OC, SC)		19	45.2	216
Whitecourt (CC)		20	44.5	243
		21	42.3	268
Athabasca (SC)		22	41.4	270
Athabasca (CC)		23	40	269
Alpac (SC)		24	40.3	278
		26	39	276
		27	39.8	293
		28	42.0	323
		29	39.2	294

Notes: 1) River discharge data preliminary in nature and subject to annual correction by the Water Survey of Canada.

TABLE 4-3

Study Site Substrate Characteristics During SOD Investigations on the Athabasca River 29 January - 26 March 1992

Study Location	Latitude & Longitude	Study Site	Sampling Start Date (D/M/Y)	SOD Method[1]	Substrate Composition (%)[2]						Epilithic Growth	Substrate Deposits	Mean Total Organic Carbon (%) Mean Organic Materials (%)
					<1 cm	1-4 cm	4-7 cm	7-10 cm	10-15 cm	>15 cm			
Hinton	53° 25'N, 117° 34'W	Site 1	16/03/92	OC	5	45	45	5	0	0	Small amt., patchy algae	Patchy fine sediment	- -
		Site 2	16/03/92	SC	100	0	0	0	0	0	Small amt., patchy algae	Abundant fine sediment	0.98/1.74
		Site 3	17/03/92	CC	5	15	30	30	15	5	Small amt., patchy algae	Patchy fine sediment	- -
Windfall Bridge	54° 12'N, 116° 3'W	Site 1	13/02/92	CC	0	15	40	30	10	5	None visible	Very little sediment	- -
Whitecourt	54° 9'N, 115° 40'W	Site 1	29/01/92	CC	10	15	15	35	20	5	Abundant filamentous algae	Patchy fine sediment	- -
			11/02/92	CC	15	15	15	30	20	5	Abundant filamentous algae	Patchy fine sediment	- -
			19/03/92	CC	10	15	15	35	20	5	Moderate filamentous growth	Very little sediment	- -
		Site 2	20/03/92	OC	5	50	45	0	0	0	Small amt., patchy algae	Patchy fine sediment	- -
		Site 3	20/03/92	SC	100	0	0	0	0	0	Small amt., patchy algae	Abundant fine sediment	0.41/0.73
Smith	55° 4'N, 114° 5'W	Site 1	17/02/92	CC	5	15	30	35	5	10	Small amt.	Very little sediment	- -
Athabasca	54° 44'N, 113° 45'W	Site 1	22/03/92	SC	80	5	5	5	0	5	Very small amt.	Abundant fine sediment	0.88/1.58
		Site 2	23/02/92	CC	15	20	20	20	15	10	Very small amt.	Patchy fine sediment	- -
Alpac		Site 1	24/03/92	SC	100	0	0	0	0	0	Very small amt.	Abundant fine sediment	0.34/0.60

Notes:
1) OC = Open Chamber, CC = Closed Chamber, SC = Sediment Core.
2) Substrate Composition excludes growth and deposits.
3) Means based on 5 replicate samples from each study site.

During 19-22 March, SOD measurement at Whitecourt coincided with decreasing streamflows. During the initial stages of the open and closed chamber incubation periods, drifting ice was noted to cause considerable scour of the substrate. Drifting ice in the main channel was observed to by-pass that site where sediment cores were used to measure SOD.

During 22-26 March, SOD measurement at Athabasca and Alpac followed a long period of increasing discharge.

.2 Water Velocity

Over the period of 29 January to 22 March 1992, mean river water velocities associated with the measurement of SOD ranged from 2 cm/s at Hinton and Whitecourt to 77 cm/s also at Whitecourt (Table 4-1).

Lowest river velocities were often associated with sediment core sampling and ranged from 2 cm/s at Hinton and Whitecourt to 15 cm/s at Hinton and Athabasca.

In-situ open chamber measurements were conducted in locations where river water velocity ranged from 22 cm/s to 52 cm/s. Both low and high values were associated with the group of chambers installed at Whitecourt Site 2.

In-situ closed chamber measurements were conducted in those locations where mean river velocities ranged from 4 cm/s at Smith to 77 cm/s at Whitecourt. Low velocities encountered at the ice-covered Windfall bridge and Smith sites may have in part been related to the upwelling and eddy of water into the excavated ice-holes. If both the Windfall bridge and Smith sites are excluded from a comparison of sampling site velocities, values ranged from 24 cm/s to 77 cm/s, with both low and high values occurring at Whitecourt.

At Whitecourt Site 1, the only study location where SOD measurements were made in January, February and March, the range of mean water velocities showed a general increase with time. On 19 March 1992, the lowest river velocity beside a closed chamber was 55 cm/s.

.3 Water Depth

Mean water depths associated with the measurement of SOD ranged from 15 cm at Athabasca and Alpac to 71 cm at Smith.

Sediment core sampling was conducted in water depths ranging from 15 cm to 35 cm at Whitecourt. Fine sediments occurred at greater depths at all sites where sediment sampling was conducted. Owing to poor visibility and anticipated problems in collecting and sealing core sample devices, greater depths were not utilized during the study.

In-situ open chamber measurements were conducted in those locations where mean depth ranged from 41 cm at Whitecourt to 51 cm at Hinton.

In-situ closed chamber measurements were conducted at depths ranging from 38 cm at Whitecourt to 65 cm at Smith. At the ice-covered Windfall bridge and Smith sites, thicker shore-ice caused some measurements to be conducted in deeper water at open water sites.

.4 Water Vane Velocity

The mean number of chamber water vane revolutions per 30 seconds, ranged from 2.0 at Windfall bridge to 8.0 at Whitecourt.

Water vane velocities were lowest at the ice-covered Windfall bridge and Smith sites where it appeared that vane velocity was influenced by the upwelling of water into excavated ice holes.

4.1.2 Substrate Characteristics

.1 Substrate Composition

In previous Athabasca River SOD studies (Casey and Noten 1989, Casey 1990), substrates were generally described as consisting of either fine sediments or of a pebble-cobble mixture. During the 1992 study, sediment oxygen demand was measured with three types of substrate.

- Deep fine sediments located in side or backchannels;
- Loose gravel (1-4 cm), located in the main channel; and
- Diverse pebble-cobble (4-15 cm), located in the main channel.

At the majority of study locations and individual study sites, substrates were dominated by pebble-cobble mixtures. Loose gravel substrates occurred only at Hinton Site 1 and Whitecourt Site 2 where open chambers were installed. To varying degrees, pebble-cobble and gravel substrates had only patchy deposits of fine sediment on their surfaces.

The nature of deep fine sediments located in side and back channels appeared to be similar among the study locations. Core sample contents consisted of a very thin layer of finely divided organic particles which when disturbed remained in suspension for variable time periods. At all sites where sediment cores were collected, this fine layer had an orange tinge suggesting a high iron content. At Hinton and Whitecourt, this finely divided layer occurred over a variably sized layer of sand which in turn graded into a sand and fine gravel mixture. At Athabasca and Alpac, the finely divided layer also occurred over a sand layer which then graded into a thick layer of sandy clay and clay.

.2 Epilithic Growth

The majority of study locations and sampling sites exhibited only small amounts of attached growth. At the Windfall bridge site, no growth was visible. At Whitecourt Site 1, where closed chambers were installed in January, February and March, an abundance of filamentous algae was interspersed with a notable gelatinous covering. During the sampling period of 19-21 March, increasing streamflows appeared to have scoured a portion of this growth although its abundance remained considerably greater than at any other site. Near Smith, growth consisted of small amounts of encrusting algae with only a few signs of macrophytic algal growth. These results differed from those of the Winter 1990 study when both macrophytic and encrusting algae were commonly found on hard substrates.

The influence of site specific environmental characteristics upon the distribution and abundance of attached biological growth was demonstrated at the Whitecourt study location. At Whitecourt Site 1, where closed chambers were installed for 48 hours incubation periods in January, February and March, stable, heterogeneous substrates provided suitable conditions for the colonization by and establishment of algal and associated microbial growth. Whitecourt Site 2, in contrast, consisted of a higher proportion of smaller shifting substrate materials (gravel) that apparently discouraged the accumulation of organic material and associated benthic biomass. Whitecourt Site 3, where sediment cores were collected from deposits of deep fine sediment, did not exhibit growths of macrophytic algae but, on occasion, were characterized by a fine surface layer of gelatinous material.

.3 Substrate Organic Matter Content

Analysis of the content of organic material in Athabasca River sediments was conducted at those sites where the sediment core SOD method was utilized: Hinton Site 2; Whitecourt Site 3; Athabasca Site 1; and Alpac Site 1. Table 4-3 presents the mean percent total organic carbon and mean percent organic matter for each of these sampling sites. Appendix E provides individual percentages for each of the sediment sample replicates analyzed by Norwest Labs.

Mean total organic carbon and organic matter ranged from 0.34% and 0.60%, respectively, at Alpac to 0.98% and 1.74% at Hinton.

4.2 SEDIMENT OXYGEN DEMAND RATES

Sediment oxygen demand rates measured in the Athabasca River during the period of 29 January to 26 March 1992 are presented in Table 4-4. This table presents mean values and ranges of SOD along with the coefficient of variation for each group of chambers and sediment cores utilized during common 48 hour incubation periods. Sediment oxygen demand rates for individual test vessels are presented in Appendix F along with the decreases in dissolved oxygen that occurred in each vessel over the incubation period.

The highest rates of SOD occurred at Whitecourt and Hinton while the lowest rates occurred at Windfall bridge and Smith. Influential variables are discussed in Part 4.2.4 and 4.2.5.

4.2.1 Variation in SOD Rates

The coefficient of variation (CV), or the standard deviation expressed as a percentage of the mean, was used as a measure of the variability for groups of chambers and sediment cores at the various sampling sites.

.1 CV for In-Situ Chamber SOD Rates

At those sites where chambers were used to measure the SOD rate, CV values after 24 hours of incubation ranged from 7% at Athabasca Site 2 (5 closed chambers) to 62% at Hinton Site 1 (5 open chambers). After 48 hours, CV ranged from 18% at Athbasca Site 2 (5 closed chambers) to 51% at Smith (5 closed chambers).

The mean CV for all sites employing chambers was 34% (n=9) after 24 hours of incubation and 36% (n=8) after 48 hours of incubation. These values were similar to the 48 hour mean CV value of 35% reported by Casey (1990). Whittemore (1986) calculated the mean CV for studies using in-situ chambers for 21 sites to be 44% (range 0-151%, n=61).

A narrow range of CV values calculated for the Winter 1992 study may have been the result of using a greater sample size (5 chambers) at the majority of study locations.

.2 CV for Sediment Core SOD Rates

At those sites where sediment cores were used, CV values after 24 hours of incubation ranged from 20% at Whitecourt Site 3 to 32% at Hinton Site 2. After 48 hours CV values ranged from 18% at Whitecourt, Site 3 to 70% at Alpac, Site 1.

TABLE 4-4

Athabasca River Sediment Oxygen Demand Rates as Measured with Open Chambers, Closed Chambers and Sediment Cores Over the Period of 29 January - 26 March 1992

Study Location	Latitude & Longitude	Study Site	Sampling Start Date (D/M/Y)	SOD Method[1]	SOD ($g/m^2/day$) After 24 hrs of Incubation				SOD ($g/m^2/day$) After 48 hrs of Incubation			
					Mean	Range	N[2]	CV(%)[3]	Mean	Range	N[2]	CV(%)[3]
Hinton	53° 25'N, 117° 34'W	Site 1	16/03/92	OC	0.19	0.12 - 0.40	5	62	0.16	0.06 - 0.21	5	36
		Site 2	16/03/92	SC	0.30	0.21 - 0.46	5	32	0.23	0.12 - 0.28	5	29
		Site 3	17/03/92	CC	0.33	0.18 - 0.47	4	36		---- NV[5] ----		
Windfall Bridge	54° 12'N, 116° 3'W	Site 1	13/02/92	CC	0.003	-0.002 - 0.008	3	NA[4]	-0.002	-0.004 - 0.00	3	NA
Whitecourt	54° 9'N, 115° 40'W	Site 1	29/01/92	CC	0.17	0.07 - 0.23	5	37	0.12	0.06 - 0.18	5	38
			11/02/92	CC	0.24	0.12 - 0.34	5	36	0.16	0.09 - 0.25	5	45
			19/03/92	CC	0.53	0.38 - 0.87	4	43	0.38	0.27 - 0.61	4	41
		Site 2	20/03/92	OC	0.33	0.29 - 0.39	3	16	0.26	0.20 - 0.32	3	23
		Site 3	20/03/92	SC	0.49	0.37 - 0.62	5	20	0.24	0.18 - 0.30	5	18
Smith	55° 4'N, 114° 5'W	Site 1	17/02/92	CC	0.10	0.06 - 0.13	5	34	0.06	0.02 - 0.09	5	51
Athabasca	54° 44'N, 113° 45'W	Site 1	22/03/92	SC	0.21	0.16 - 0.27	5	23	0.19	0.08 - 0.38	5	69
		Site 2	23/02/92	CC	0.21	0.19 - 0.22	5	7	0.15	0.12 - 0.18	5	18
Alpac		Site 1	24/03/92	SC	0.25	0.15 - 0.33	5	27	0.07	0.002 - 0.13	5	70

Notes:
1) OC = Open Chamber, CC = Closed Chamber, SC = Sediment Core.
2) N = Number of test/sample replicates.
3) CV(%) = coefficient of variation or standard deviation expressed as a percentage of the mean.
4) NA = CV(%) not calculated for data with negative values.
5) NV = No values as tests discotninued after 24 hours.

The mean CV for all sites employing sediment cores was 26% (n=4) after 24 hours and 47% (n=4) after 48 hours. The highest CV (69% and 70%) occurred with the lowest mean SOD rates. Casey and Noton (1989) noted a similar occurrence and attributed it to imprecision in the Winkler method for dissolved oxygen which would be proportionately larger for lower SOD rates.

.3 Similarity in SOD Between Chambers and Sediment Cores

Sediment core sampling for the measurement of SOD was conducted in low velocity areas of fine sediment where the underlying rocky substrata would have prevented an open chamber-substrate seal and where water depths were not great enough to immerse chamber water vanes. Care was taken to select coring sites not influenced by changes in water level and drifting ice.

In spite of the obvious differences in hydrologic and substrate characteristics between closed chamber and coring sites (Tables 4-1 through 4-3), the mean 24-hour SOD rates were the same or nearly the same at each of the three study locations where both were used.

At Hinton, a closed chamber mean 24-hour SOD rate of 0.33 $gO_2/m^2/day$ (CV = 36%) compared with a sediment core device mean 24-hour SOD rate of 0.30 $gO_2/m^2/day$ (CV = 32%).

At Whitecourt, a closed chamber mean 24-hour SOD rate of 0.53 $gO_2/m^2/day$ (CV = 43%) compared with a sediment core mean 24-hour SOD rate of 0.49 $gO_2/m^2/day$ (CV = 20%). After 48 hours of incubation the mean SOD rate for the group of five closed chambers had dropped to 0.38 $gO_2/m^2/day$ (CV = 41%) while the sediment core mean rate decreased to 0.24 $gO_2/m^2/day$ (CV = 18%). It should be noted that the closed chamber mean incorporated an individual 24-hour SOD value of 0.87 $gO_2/m^2/day$ which decreased to 0.61 $gO_2/m^2/day$ after 48 hours of incubation. If this value is not included in the calculation of the mean SOD, the mean becomes 0.42 $gO_2/m^2/day$ after 24 hours and 0.30 $gO_2/m^2/day$ after 48 hours.

At Athabasca, closed chamber and sediment core mean 24-hour SOD rates were equivalent at 0.21 $gO_2/m^2/day$. The CV for the five closed chambers was 7% while the CV for the five sediment cores was 23%. After 48 hours of incubation, the mean SOD rate for closed chambers was 0.15 $gO_2/m^2/day$ (CV = 18%) and for sediment cores, 0.19 $gO_2/m^2/day$ (CV = 69%).

At Alpac, where only sediment cores were used, the mean SOD rate dropped from 0.25 $gO_2/m^2/day$ (CV = 27%) at 24 hours to 0.07 $gO_2/m^2/day$ (CV = 70%) at 48 hours.

At Hinton in February of 1989, SOD rates for rocky substrate were greater than those for fine sediments (Casey and Noton 1989). It was felt that the greater surface area of rocks versus the smooth silt surface, and possibly the greater biomass of algae, bacteria, fungi and other benthos on the more stable rocks were influential factors (see also 4.2.5.1).

On the Wapiti River downstream of the Proctor and Gamble mill in 1990, the SOD of fine sediment contained in a backwater area (0.18 $gO_2/m^2/day$) was statistically the same as that of rocky substrata in the main channel (0.16 $gO_2/m^2/day$). These rates were measured in March when the river was rising and the SOD was most likely reduced, especially in the main channel.

Localized runoff and scour in March 1992 and the predominantly rocky substrate in closed chamber locations may have been responsible for the observed similarities in chamber and sediment core SOD rates.

4.2.2 Trends in SOD During the Incubation Period

Over the 48 hour incubation periods, SOD rates decreased at all sampling sites. In general, those sites with little SOD (Windfall bridge, Smith) exhibited only slight decreases in rate. A number of other investigators have attributed decreasing rate to progressively more depleted dissolved oxygen concentrations over the course of the incubation period (Casey and Noton 1989; Hickey 1986; Newrkla and Guatilaka 1982; Edberg and Hofsten 1973; Hargrave 1969; and Edwards and Rolley 1965). The trends in SOD rate for open and closed chambers and sediment cores over the incubation period are presented in Figure 4-1.

.1 Changes in In-Situ Chamber SOD Rates

The slightest decrease in SOD rate occurred at Windfall bridge Site 1 during the period of 13-15 February. For a group of three closed chambers, the mean 24-hour SOD rate of 0.003 $gO_2/m^2/day$ decreased to a mean 48-hour SOD rate of -0.002 $gO_2/m^2/day$. Over the course of the incubation period at Windfall an initial test chamber mean dissolved oxygen concentration of 11.74 mg/L declined to 11.67 mg/L at 24 hours and to 11.65 mg/L at 48 hours. Sustained high levels of dissolved oxygen over the test period resulted in the stable SOD rates observed at the Windfall bridge site. A negative SOD value obtained at 48 hours of incubation was likely related to imprecision of the Winkler method. Negative SOD values were also reported by Casey and Noton (1989) and Casey (1990) and attributed to slight concentration errors measured with the Winkler method.

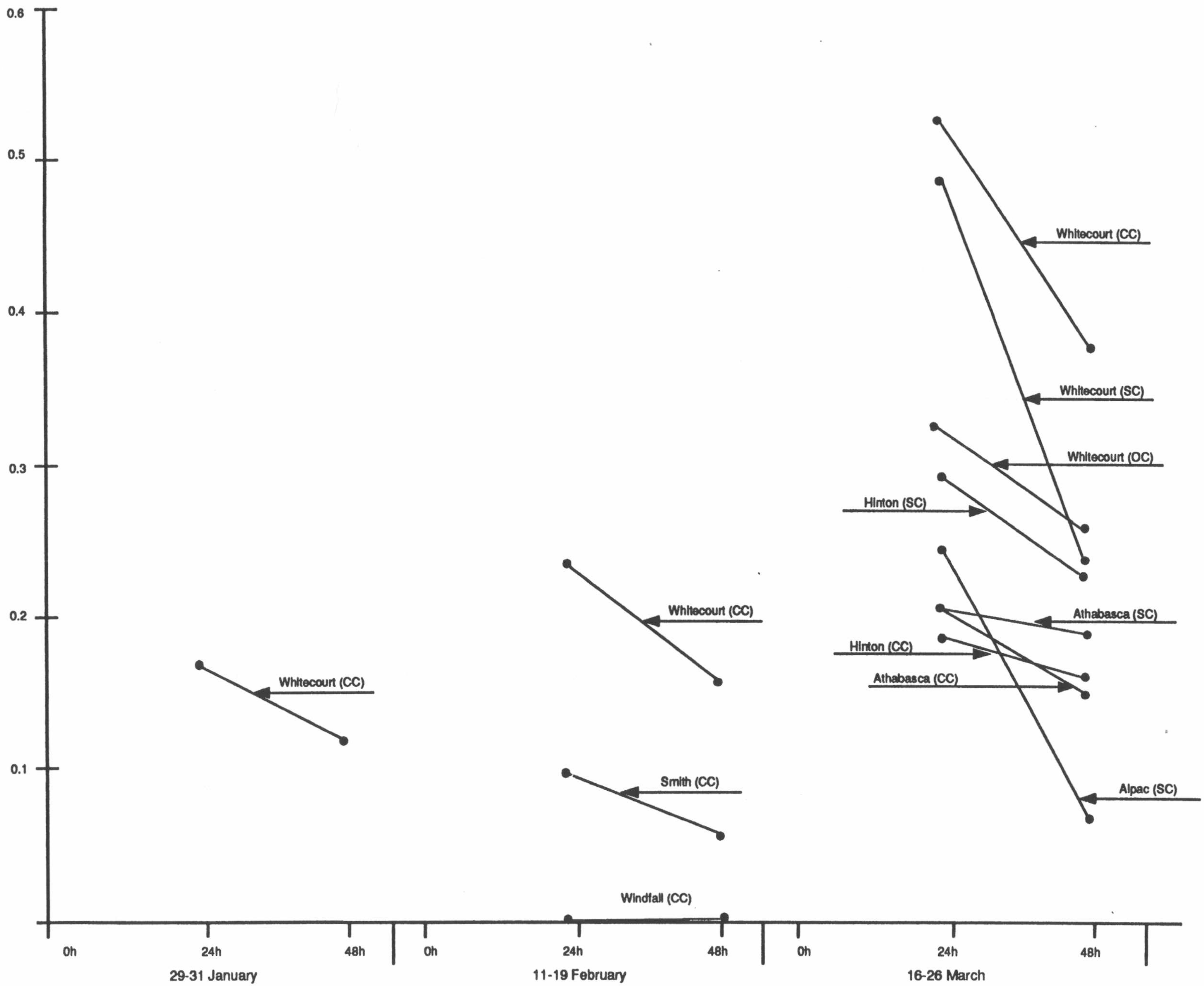

FIGURE 4-1 Athabasca River winter 1992 sediment oxygen demand rates for open chambers (OC), closed chambers (CC) and sediment coring devices (SC) as measured after 24 and 48 hours of incubation

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The greatest decease in rate occurred at Whitecourt Site 1 during the period of 19-21 March. For a group of four closed chambers, the mean 24-hour SOD rate of 0.53 $gO_2/m^2/day$ declined to a mean 48-hour SOD rate of 0.38 $O_2/m^2/day$. During the incubation period an initial test chamber mean dissolved oxygen concentration of 11.90 mg/L declined to 9.0 mg/L at 24 hours and 7.7 mg/L at 48 hours.

Comparison of SOD rates and dissolved oxygen concentrations at Windfall bridge Site 1 and Whitecourt Site 1 indicate that the SOD rate is proportional to oxygen concentration in the test water.

.2 Changes in Sediment Core SOD Rates

The smallest change in mean SOD rate as measured with the sediment core method also coincided with the lowest mean rate of SOD for all sediment core tests. At Athabasca Site 1, during the period of 22-24 March, the mean 24-hour SOD rate of 0.21 $gO_2/m^2/day$ decreased only to 0.19 $gO_2/m^2/day$ after 48 hours of incubation. An initial dissolved oxygen concentration of 11.43 mg/L decreased to 8.07 mg/L at 24 hours and 6.78 mg/L at 48 hours.

The greatest decrease in SOD rate occurred at Whitecourt Site 3, which exhibited the highest mean rate of SOD for all sediment core tests. During the period of 20-22 March, a mean 24-hour SOD rate of 0.49 $gO_2/m^2/day$ decreased to a mean 48-hour rate of 0.24 $gO_2/m^2/day$. An initial dissolved oxygen concentration of 11.92 mg/L decreased to 7.5 mg/L at 24 hours and 7.3 mg/L at 48 hours.

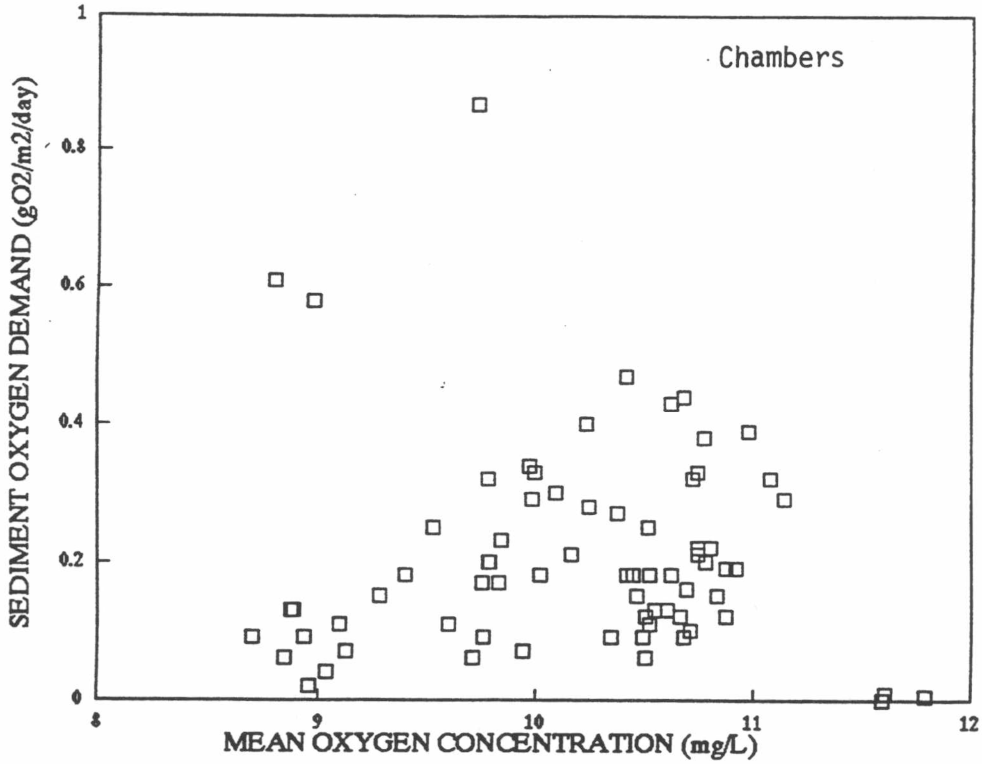
As expected, the changes in SOD rates measured with the sediment core were also proportional to dissolved oxygen concentrations in the associated water.

.3 Relationships Between Dissolved Oxygen Concentration and SOD Rate

In Figure 4-2, 24 and 48-hour chamber and core SOD rates were plotted with mean dissolved oxygen concentrations determined for 0 to 24-hour and 0 to 48-hour incubation periods.

Where chambers were concerned, the resultant plot was discernably curvilinear in nature demonstrating the first order effect of dissolved oxygen concentration. This upsweeping plot was similar to that obtained by Campbell and Rigler (1986) when tests were purposely conducted with unmixed water.

While a curvilinear relationship was much less pronounced for cores, it is worth noting that Campbell and Rigler (1986) demonstrated a levelling trend at higher dissolved oxygen concentrations when tests were conducted with continuous water circulation. The lack-of-fit for core data likely reflected the relatively small sample size used for graphical analysis.



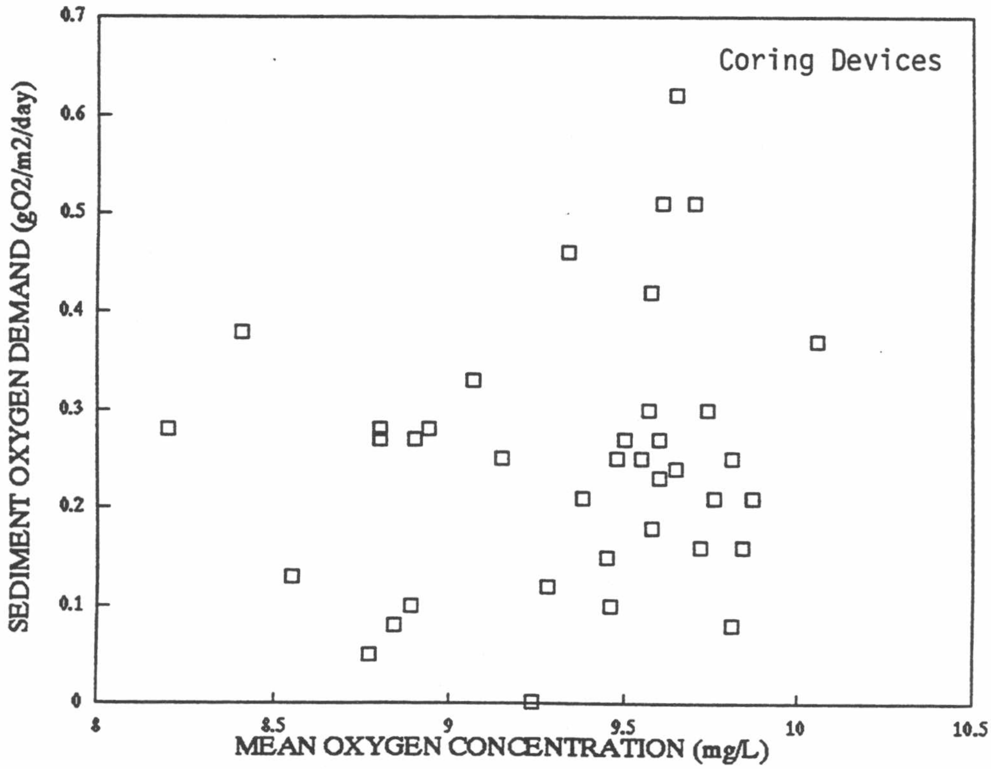


FIGURE 4-2 **The relationship between sediment oxygen demand and mean dissolved oxygen concentration as measured with chambers (top) and cores (bottom) in the Athabasca River, 29 January - 26 March 1992**

It is, however, reasonable to assume that changes in SOD over time resulted from the first order influence of ambient dissolved oxygen concentration rather than the influence of the oxygen uptake processes. It is unlikely that the oxygen demanding processes were being satisfied over the 48-hour tests. For a given concentration of dissolved oxygen (throughout an incubation period), the rate of SOD can therefore be estimated through extrapolation.

4.2.3 Temporal Changes in SOD Rates

Sediment oxygen demand was measured with closed chambers at Whitecourt Site 1 in January, February and March in order to investigate temporal changes in winter rates. The results are presented graphically in Figure 4-3 and compared with temporal changes reported by Casey (1990).

As Figure 4-3 indicates, mean SOD rates increased over the winter in both 1990 and 1992. This would suggest that there was a build-up of SOD downstream of the Millar Western Ltd. pulp mill effluent where nutrient enrichment and the direct addition of organic material increased benthic biomass and respiration.

Low flows and stable river conditions contribute to build-up of SOD since they result in the net accumulation of organic material.

During the March measurement of SOD, increases in streamflow were observed to cause the scour of epilithic growth from substrate surfaces and organic particles from the interstitial spaces. Had sampling been conducted prior to increases in streamflow it is possible that the March mean SOD rate would have been greater than that which was actually determined. As Table F-1 indicates, 24-hour SOD ranged from 0.38 to 0.87 $gO_2/m^2/day$, the latter rate being the highest rate measured during the winter 1992 study. The nature of the substrate from which this measurement was obtained may well have protected epilithic growth and organic particles from the effects of scour. If such was the case, the SOD measurement of 0.87 $gO_2/m^2/day$ may have been more typical of the winter maximum.

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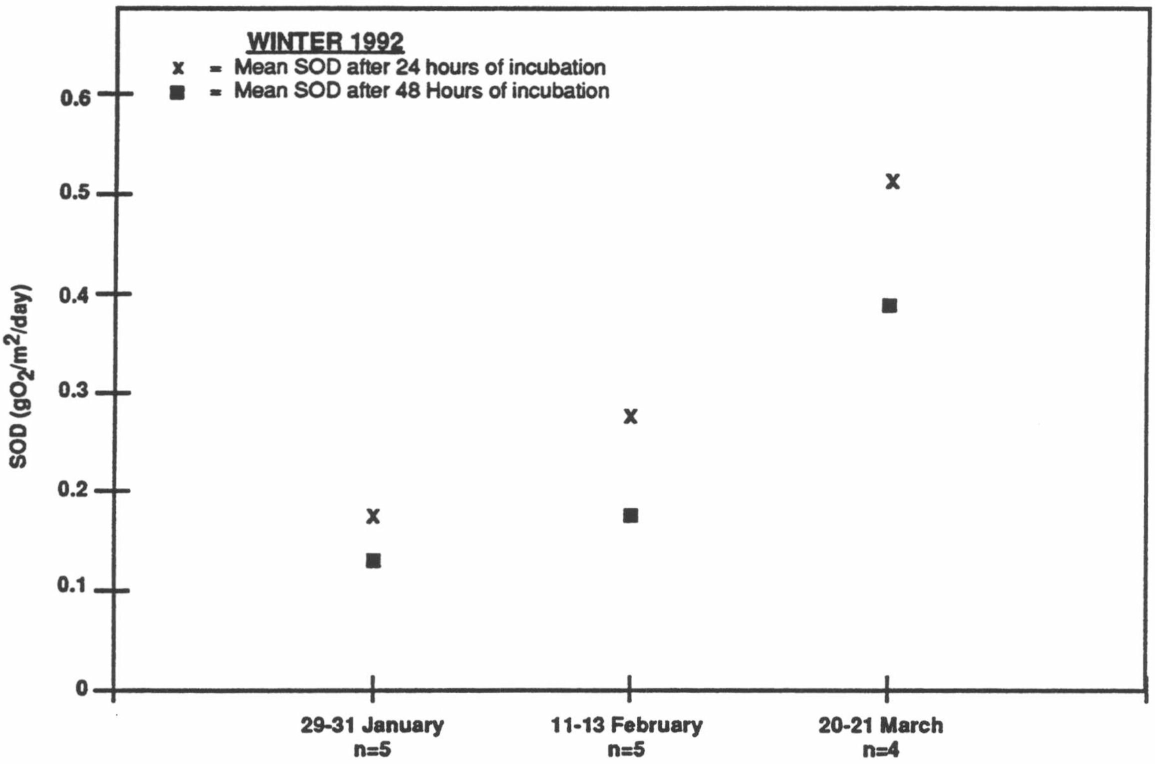

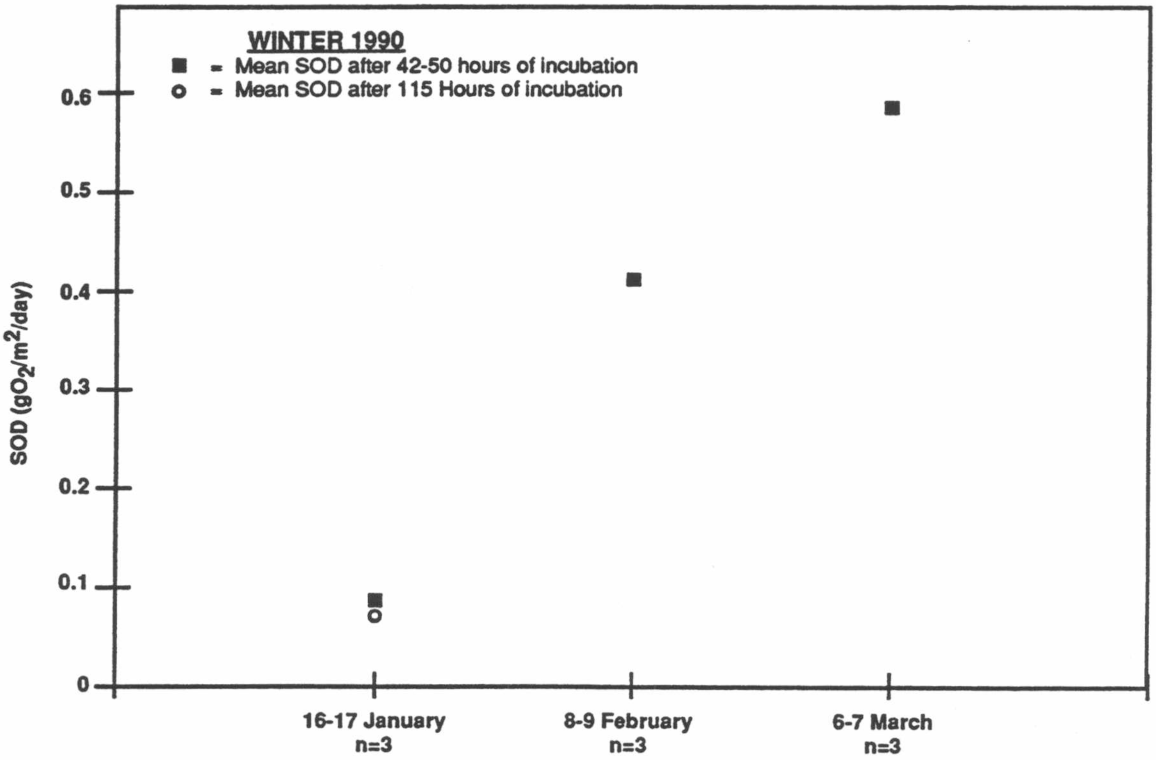

FIGURE 4-3
MEAN SEDIMENT OXYGEN DEMAND (SOD) AT WHITECOURT ON THE ATHABASCA RIVER DURING THE WINTERS OF 1990 AND 1992

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As SOD increased from month to month, so did the magnitude of the decrease of SOD during 48-hour incubation periods. In January, the mean 24-hour SOD rate dropped from 0.17 to 0.12 $gO_2/m^2/day$ at 48 hours, a difference of 0.05 $gO_2/m^2/day$. In February the difference was 0.08 $gO_2/m^2/day$ and in March 0.15 $gO_2/m^2/day$. Increasing SOD occurred in conjunction with increased oxygen depletion. In January, after 48 hours of incubation, the dissolved oxygen content decreased from 10.50 mg/L by an average of 1.71 mg/L in five chambers. In February, dissolved oxygen content decreased by an average of 2.06 mg/L in five chambers and in March by 4.17 mg/L in 4 chambers. The relationship between SOD rates and oxygen uptake has been discussed in Part 4.2.2.

4.2.4 Longitudinal Trend in SOD Rate

As a result of sampling constraints encountered at points downstream of Smith (and the need to design, construct and test an alternate method of SOD measurement) the sampling run intended for investigation of longitudinal trends was split into two distinct time periods: 11-19 February and 16-26 March.

Given the potential for considerable variation in environmental conditions between the two periods, it was felt that February and March results should be treated separately in an analysis of longitudinal trend of SOD.

.1 Longitudinal Trends in February

During 11-19 February SOD rates were obtained at Windfall bridge, Whitecourt and Smith. Closed chambers were used in each location and after 24 hours of incubation, mean SOD increased from 0.003 $gO_2/m^2/day$ at Windfall to 0.24 $gO_2/m^2/day$ at Whitecourt. Mean SOD then decreased to 0.10 $gO_2/m^2/day$ at Smith, located approximately 220 km downstream from Whitecourt.

.2 Longitudinal Trends in March

In order to depict longitudinal trends with as many study sites as possible, mean SOD measurements from 28 February-29 March 1989 and 7-14 March 1990 were combined with those of the 1992 study. The results are presented graphically in Figure 4-4. Downstream of Hinton, SOD declined reaching its lowest rate in the vicinity of Windfall bridge. At Whitecourt, SOD increased sharply followed by a rapid decline downstream to Blue Ridge. Based on the combination of 1989 and 1990 data, SOD appeared to "level off" in the vicinity of Fort Assiniboine. Between Fort Assiniboine and Smith, SOD appeared to remain somewhat constant, but at a greater rate than that observed immediately upstream of Whitecourt.

At Athabasca, where measurements were made approximately 2 km downstream of the municipal sewage discharge, SOD rates approximated those which occurred at Hinton, Blue Ridge and Fort Assiniboine in previous

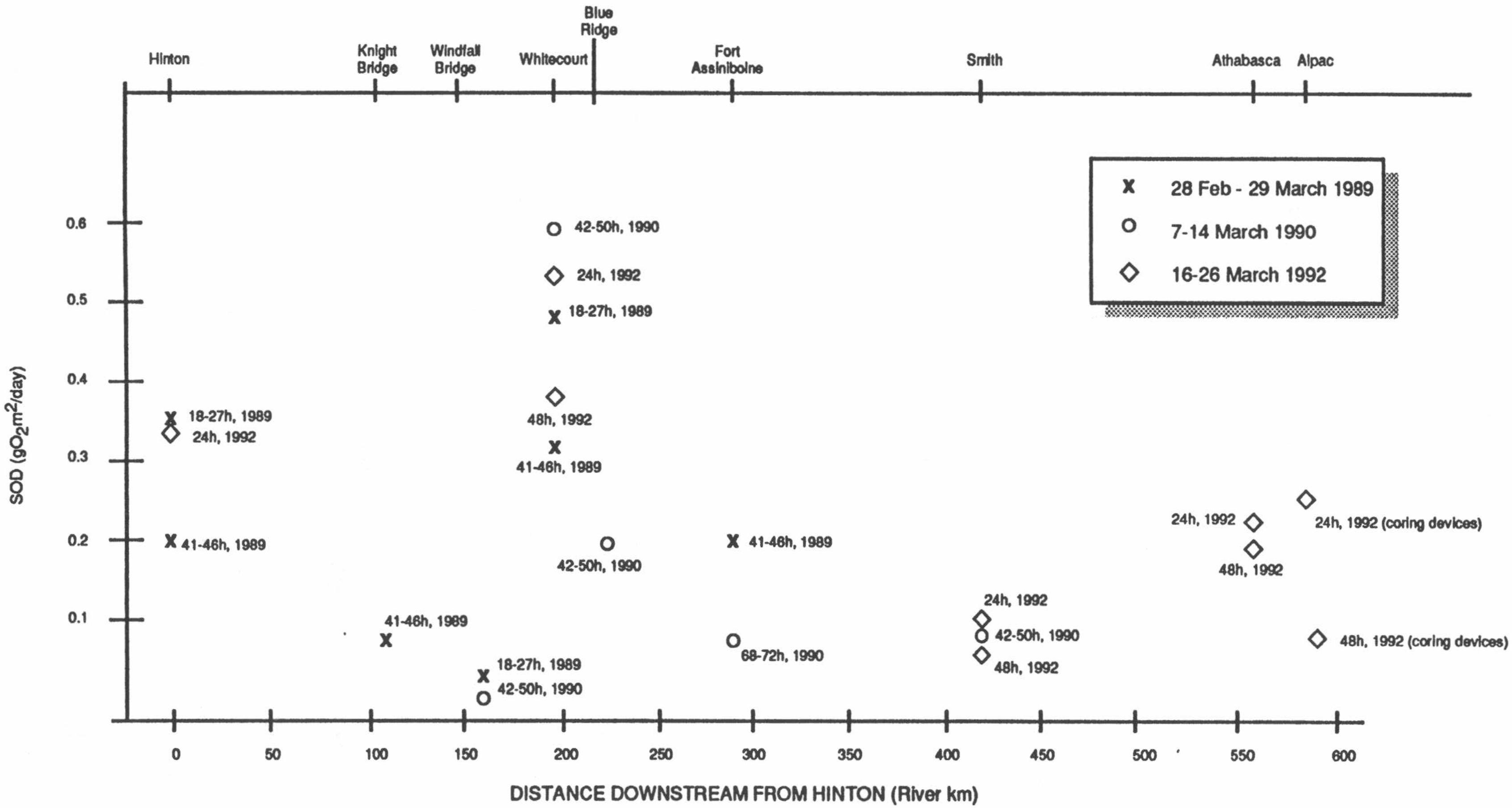

FIGURE 4-4 Athabasca River sediment oxygen demand for various study locations as measured during the periods of 28 February -29 March 1989, 7-14 March 1990 and 17-26 March 1992

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studies. Increased SOD at this point was likely related to the nearby sewage discharge but might also have been influenced by progressive changes in river characteristics. Future measurements at points upstream and downstream of the sewage discharge should help to isolate the impacts of the effluent upon SOD. Similarly, a number of study sites located between Athabasca and Fort McMurray would help to evaluate the influences upon SOD of progressive changes in river gradient, velocity, substrate composition, benthic communities and other physical, chemical and biological characteristics.

4.2.5 Influence of Environmental Variables Upon SOD

Pertinent environmental variables measured and observed during the collection of SOD data included substrate and hydrologic characteristics, degree of ice cover; substrate composition; water velocity and depth. Sediment core samples were analyzed for percent organic content. River discharge data, for Hinton and Athabasca gauging stations, was obtained from Water Survey of Canada. Summarized as site characteristics in Tables 4-1 through 4-3, the influence of these variables are discussed in light of their proximity to pulp mill and sewage effluent discharges.

.1 Substrate Composition

As discussed in Part 4.1.2.1, sediment oxygen demand was measured with three general types of substrate including deep, fine sediment, loose gravel and pebble-cobble mixture. The following patterns were observed with respect to SOD rate and substrate composition:

1) SOD rates measured on pebble-cobble substrates varied from the study low at the Windfall control location to a high at Whitecourt located 1 km downstream of the Millar Western Pulp Mill effluent discharge. Data indicated that pebble-cobble mixtures make a key contribution to the build-up of winter SOD since they provide a stable, unshifting environment with a variety of micro habitats, suitable for the establishment and maintenance of a rich flora and fauna and the deposition of particulate organics. In the vicinity of effluent discharges of inorganic nutrients and particulate organics, they are sites of increased levels of benthic biomass and respiration.

2) SOD rates measured on loose gravel substrates at Hinton and Whitecourt were lower than those measured simultaneously on pebble-cobble substrates at the same study locations. Loose gravels substrates are more prone to shifting and provide a relatively unstable environment for the establishment and maintenance of algae, bacteria, fungi and other benthos which on more stable substrates would contribute to increased rates of SOD. Loose gravel substrates located in the main channel also

appeared to have less capacity to hold, for any length of time, particulate organics associated with pulp mill and sewage effluent discharges. These particles are deposited for longer periods of time in the interstitial spaces of pebble-cobble substrates and in back channel areas where higher rates of SOD were measured.

3) SOD rates measured in fine sediments were similar to those measured simultaneously from pebble-cobble substrates at four study locations. These SOD rates were, however, measured in March when the Athabasca River was rising and the SOD was most likely reduced especially in the main channel. Similarities in March SOD rate between fine sediments and rocky substrates were also found on the Wapiti River downstream of the Proctor and Gamble mill in 1990 and attributed to increases in streamflow and scour (Casey 1990).

A relationship between sediment core SOD rate and percent organic matter was not evident. In a review of the literature on SOD, Casey and Noton (1989) determined that organic content per se is not clearly related to SOD. For example, the type of organic material may have an effect on the amount of oxygen uptake (Edberg and Hotsten 1973). Scouring flows aside, at least some of the observed similarity between SOD measured in fine sediments and on rocky substrates may be due to the levels of biologically available organic material deposited in either the interstitial spaces of pebble-cobble mixtures or in low velocity back channel areas.

.2 Water Velocity and Depth

As Figure 4-5 indicates, SOD measured from gravel and pebble-cobble substrates was not correlated with river velocity ($r = 0.26$). Water velocity at the substratum-water interface is considered to have an important effect on the measurement of SOD (James 1974, Hickey 1986, Whitehorse 1986a). Whittemore (1986a) found that an increase in water velocity at the substratum-water interface was directly related to SOD and that coincidental increase in turbulence increased the transport of soluble organic material to the sediment-water interface causing high SOD. James (1974) also found that oxygen uptake by mud was directly related to water velocity.

Velocity may exert an indirect influence on SOD rate in a more overt manner. Streamflows and water velocity play a key role in the sorting of substrate particles. In areas of high velocity, substrates consist generally of larger particles which have a rough, irregular surface. Under low, stable winter streamflow conditions, river velocity decreases while the rough irregular substrate tends to promote the deposition of finely divided particles into interstitial spaces. Where effluent discharges of inorganic nutrients and particulates are located nearby, increases in benthic biomass and an accumulation or organic material would be expected to increase the rates of SOD.

It is anticipated that there is a range of Athabasca River velocities over which observed rates of winter SOD became dependent upon substrate characteristics and proximity to a nutrient supply. During periods of increasing streamflow in the spring this range of velocity is exceeded and scour reduces the build-up of material contributing to the winter SOD.

During the 1992 study, rocky substrates incubated in closed chambers may have exhibited rates lower than expected given that water vane revolutions were not always proportionate to river velocity. By the same token, fine sediments incubated in coring devices at a constant rate of top water circulation may well have exhibited higher rates of SOD than would have occurred under natural conditions of little or no velocity in side and back channels.

As Figure 4-5 indicates, SOD was poorly correlated with river depth ($r = -0.38$). It is possible that the range of depths encountered during this study (which were constrained by safety considerations) was not sufficiently large for comparison to the corresponding SOD levels.

4.3 EVALUATION OF TECHNIQUES

4.3.1 Chamber Method of SOD Measurement

Casey and Noton (1989) described a number of potential factors that could influence in-situ measurements of SOD in the Athabasca River. These factors and their probable effect on SOD rate are presented in Table 4-5.

Method modification in a subsequent study of Athabasca River SOD (Casey 1990) reduced potential error identified in the 1989. Changes included:

- The extraction of smaller water samples from SOD chambers for dissolved oxygen determination so as to limit the entry of oxygenated water;
- The use of control chambers versus BOD bottles since the latter may result in an overestimate of water column respiration and in turn an underestimate of SOD;
- Improvement in design of the depth-profile device to obtain a more accurate measure of chamber volumes; and
- Use of a ruler to obtain a more accurate measure of chamber volume when fine sediments were involved.

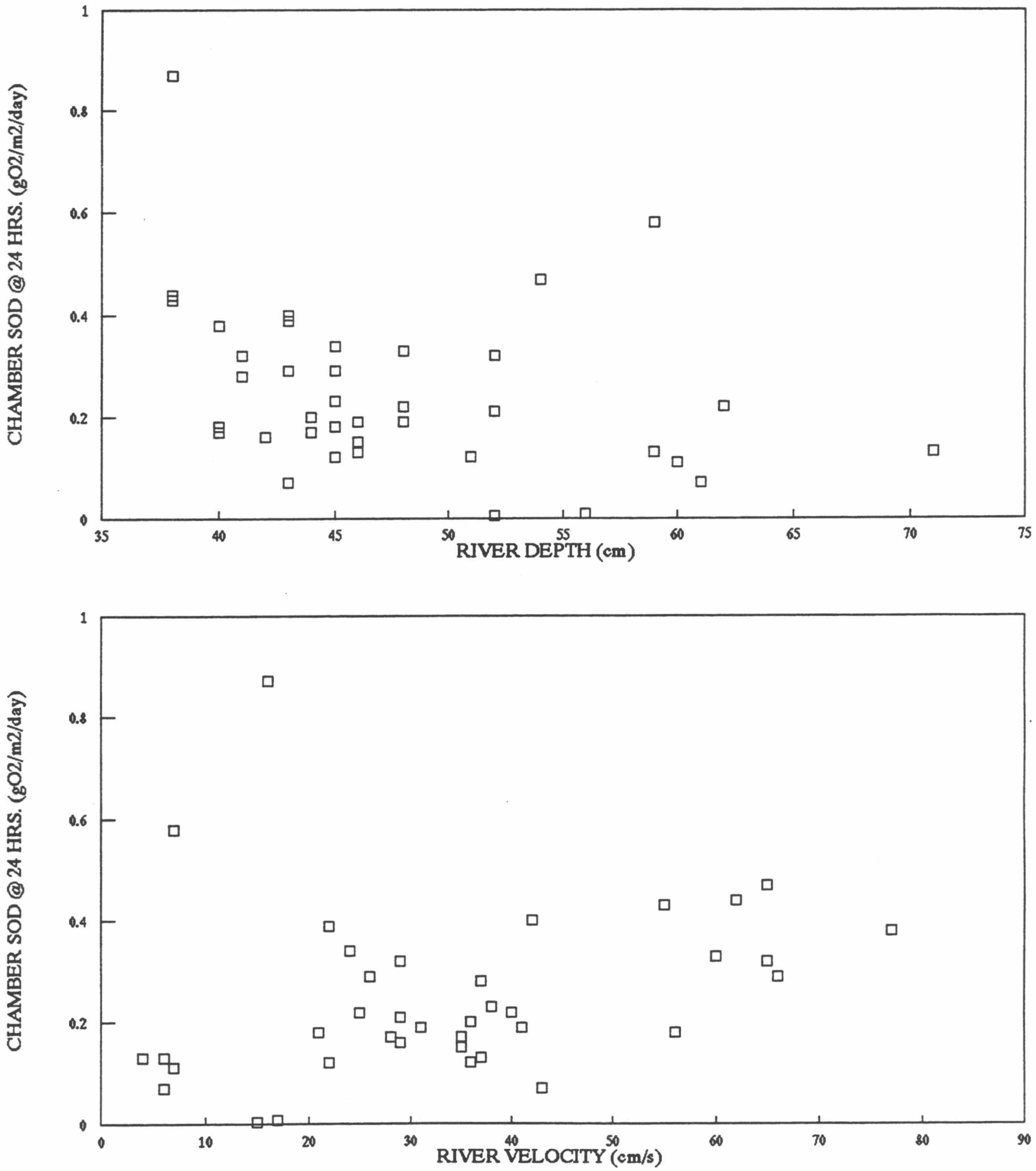

Figure 4-5 The relationships between sediment oxygen demand and river depth and river velocity as measured on rocky substrates in the Athabasca River, 29 January - 26 March1992

TABLE 4-5

Potential Factors Affecting SOD Rates for the Athabasca River

Factors affecting SOD rates as measured with in-situ chambers	Probable Effect on SOD rate
Use of chambers versus measuring the oxygen balance of the river	Underestimate
Reduced water mixing in the chamber and reduced water velocity at substratum-water interface	Underestimate
Disturbance sand mixing of sediment	No effect
Resuspension of sediment	No effect
Reduced DO concentration in chamber due to extraction of samples and use of portholes	Underestimate
Use of BOD bottles instead of blank chambers as controls for Whitecourt and Fort Assiniboine	Underestimate
Measurement error of volume of water in chamber where fine (soft) sediment utilized	Overestimate

Modified from Casey and Noton (1989)

Similar to the results for the 1989 and 1990 studies, the 1992 results demonstrated that chamber water vane velocities were not always proportional to river velocities outside the chambers (Tables 4-1 and E-1). It was felt that reduced mixing in the chambers may have caused an underestimate of SOD.

4.3.2 Sediment Core Method of SOD Measurement

The sediment core method of SOD measurement developed during the 1992 study was similar in a number of ways to the chamber method. Potential sources of error in estimating SOD are discussed in the following subsections.

.1 Core Sample Collection

Collection of undisturbed fine sediment in a plexiglass core was similar to the enclosure of fine sediment in an open chamber. The collection of an intact core presents a fundamental difference between this method and laboratory methods where sediment has often been transported to the laboratory prior to being placed in the test apparatus (e.g. Hall and Berkas 1988).

Fine sediments encountered during the 1992 study had depths of 3 cm or greater. Generally, deeper sediments occurred at greater water depths (and decreased velocity). Used in conjunction with the closed and open chambers, the sediment core method offered the flexibility of collecting sediment in those area where chambers would not be totally immersed or would be too deep, and where doubt existed as to whether a substrate-chamber seal could be achieved (locations with variable depths of fine sediment overlying cobble and rock substrates).

As discussed in Part 3.2.2, the sediment core method could be utilized over wider range of depths if pole mounted. Provided that little disturbance occurred, other devices (e.g. an Ekman dredge) could be used to collect deep water sediment samples from which an intact core could be obtained and subsequently used for SOD measurement.

.2 Sediment Core Method Seal

As discussed in Part 3.2.4, the decision to use mineral oil as a surface sealant was based upon the results of a laboratory evaluation that indicated the oil would not create an oxygen demand over and above that attributable to river water and sediments. The assumption was made that the rate of oxygen diffusion from the test and control devices would not be influenced by river water and river sediment core characteristics provided that water temperatures, circulation rates, barometric pressure and other environmental variables were held constant. Net rates of oxygen uptake would then be attributable to the river water and river sediments.

.3 Sediment Core Incubation Conditions

a) Water Temperature

While ice was continually added to the cooler which acted as a combination transport/incubation chamber, temperature differences of 1-3°C were noted in different coring devices being incubated simultaneously. While influences upon oxygen uptake were not discernable during the 1992 study, increases in water temperature do have the potential to cause an overestimate of winter SOD.

Further development of the sediment core method should focus upon the design and construction of a transport/incubation chamber that will help to eliminate variability in winter SOD rate attributable to temperature variation around 0°C.

b) Sediment Core Method Water Circulation

As discussed in Part 4.2.5.2, water velocity at the substratum-water interface is directly related to oxygen uptake.

Given that peristaltic pumping was conducted at the same rate for all cores at all study sites, the influence of core water circulation rate upon SOD was not quantified during the 1992 study. Further development of the sediment core method should focus upon pumping rates that vary in proportion to river velocity.

Irrespective of the actual pumping rate or velocity achieved, the continuous movement of water at the substratum-water interface likely increased the efficiency of oxygen uptake by the sediments. The larger substrate surface area (relative to water volumes) in conjunction with continuous mixing, may also have increased oxygen uptake efficiency.

As Table F-2 indicates, the decrease in dissolved oxygen concentration in the sediment core method controls was more than that expected for river water alone. At the three study locations where chambers and cores were deployed simultaneously, the mean decrease in oxygen content was 2.6 mg/L for control cores versus 0.05 mg/L for control chambers.

Similarly, the decreases in dissolved oxygen concentrations associated with test cores were considerably greater than would be expected for Athabasca River water and sediments incubated at near zero temperatures. As discussed in Parts 3.2.4 and 4.3.3.2, it is likely that a large proportion of the observed dissolved oxygen decrease was attributable to oxygen diffusion out of the water. Pumping rate, in addition to increasing the rates of oxygen demanding processes, likely increases the rate oxygen diffusion from core top-water. The relative rates of oxygen demanding processes and oxygen diffusion could be investigated through variation in pumping and core water circulation rate.

c) Sediment Surface Disturbances

In an attempt to simulate site conditions, pump circulation rates were adjusted to a common level which caused mixing in the water column but which did not promote resuspension and circulation of fine sediment particles.

Further development of the sediment core method should focus upon the circulation rates or velocities required to affect particle resuspension and increases in SOD rate.

d) Top-water Volume

When water samples were extracted from chambers for dissolved oxygen analysis, river water replaced the water in the chamber to maintain the volume of the test water over the course of the incubation period. When water samples were extracted from sediment cores at 24 hours, the remaining 24-hours of incubation occurred at a reduced core water volume (the initial volume minus the approximately 100 ml used for 24-hour dissolved oxygen analysis). To compensate for changes in volume the initial volume was averaged with the final volume prior to calculation of the 48-hour SOD.

Following volume adjustment, the results indicated that 48-hour sediment core SOD rates declined considerably more than did 48 chamber SOD rates measured simultaneously (Part 4.2.2).

Greater SOD rate decreases overtime are likely attributable to the interaction of relatively small test (and control) volumes with the continuous circulation of top-water over a relatively high substrate surface area.

Further adjustments to SOD over the incubation period are discussed in Part 4.2.2.3.

PART 5

SUMMARY AND CONCLUSIONS

5.0 SUMMARY AND CONCLUSIONS

The results of winter 1992 SOD investigations on the Athabasca River indicated that SOD rates were highest at sites immediately downstream of the pulp mills at Whitecourt and Hinton, and lowest at the Windfall bridge site 30 km upstream of Whitecourt and 170 km downstream of Hinton. Observed rates were comparable to those obtained during 1989 and 1990 winter studies.

Immediately downstream of the Millar Western pulp mill effluent, SOD rate increased over the winter. In conjunction with low flows and stable river conditions, the build-up of SOD was likely due to the continuous addition of nutrients and organic material which resulted in an increase in benthic biomass and respiration.

As found in previous winter SOD studies, increasing March river flows scoured accumulations of epilithic organic material and associated organisms causing reductions in SOD.

At Smith, approximately 220 km downstream of the Millar Western pulp mill effluent, SOD declined considerably but remained higher than that measured upstream of the effluent. Immediately downstream of Athabasca, SOD increased likely reflecting the influence of the municipal sewage effluent.

The simultaneous deployment of chambers in rocky substrates and the sediment core method in fine sediments yielded similar SOD values inspite of the obvious differences in substrate composition and river velocity. Given that simultaneous testing was conducted during periods of increasing river flow, suggests that scouring in the main channel reduced chamber SOD relative to sediment core SOD measurements associated with low velocity habitats. Other factors or combinations of factors may have influenced the observed similarity in SOD rates including the type and biological availability of organic matter found in each habitat. Smaller particles in the sediment cores likely enhanced oxygen uptake given increased surface area and the greater potential for microbial sediment oxidation. The relative rates of water and circulation in chambers and cores may have been another controlling factor.

The chamber and sediment core methods of SOD measurement are somewhat similar in nature. Given that the sediment core method can be deployed in habitats not suitable for open or closed chambers (and vice versa), it is felt that reasonable estimates of SOD can be obtained in most situations regardless of site specific stream characteristics. In the lower reaches of the Athabasca River or in generally low gradient reaches where particle deposition increases, there could be a greater reliance upon the sediment core method.

Future development of the sediment core method could focus upon the interactive effects of substrate quality and disturbance, particle resuspension, test volumes, flow rates and top-water velocity. Continuous monitoring of dissolved oxygen concentration with a meter would provide valuable information concerning maximum

SOD rates and the time period required for incubation. Ongoing meter measurements would negate the potential error that may be associated with decreasing sediment core water volumes during the incubation period.

PART 6

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6.0 REFERENCES

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APPENDIX A

TERMS OF REFERENCE
NORTHERN RIVERS STUDY
STREAMBED OXYGEN DEMAND INVESTIGATION
ATHABASCA RIVER

Objective

The general objective of this project is to obtain measurements of winter streambed oxygen demand (SOD) on the Athabasca River.

Requirements

1. Carry out measurements of SOD on the Athabasca River in the January-March period of 1992 at the following general locations:

   - Windfall Bridge
   - d/s of pulp mill at Whitecourt (3x)
   - Smith
   - Athabasca
   - AlPac/La Biche River reach
   - Calling River reach
   - House River reach
   - Ft. McMurray reach
   - Ft. MacKay reach

   A minimum of 5 measurements on representative substrates at each location is desired. At the location downstream of the pulp mill in Whitecourt, 5 measurements are desired in each of January, February, and march (total 15), in order to investigate temporal change in SoD during the winter.

2. The methods used in measuring SOD, should follow the procedures outlined in "Procedures for the Use of SOD Chambers in Flowing Waters" or a demonstrably equivalent method. A set o 5 open-bottom and 8 closed-bottom chambers, plus depth-measuring device, is available from Alberta Environment for use on this project, subject to return in working condition.

3. Obtain measurements of related environmental variables, such as substrate condition and particle size, organic content, depth, water velocity, etc. Assess the relationship between oxygen demand and these variables.

4. Depending on arrangements with the Project Manager, collect sediment cores from sampled sites and return them to the study office for possible SOD lab measurements by others.

5. Report any key findings during the survey to the project manager. At the end of field work, return loaned equipment to Alberta Environment. Tabulate and submit SOD values and associated measurements by 31 March 1992. Prepare a draft report on the findings by April 30, 1992. Prepare a final report incorporating review comments three weeks after receipt of the reviewed draft report. Supply 10 copies and the camera-ready original of the final report.

APPENDIX B

SAMPLING EQUIPMENT FOR THE IN-SITU CHAMBER METHOD OF SOD MEASUREMENT

B.1 SAMPLING EQUIPMENT FOR THE IN-SITU CHAMBER METHOD OF SOD MEASUREMENT

Data Sheets

SOD chambers
Extra stoppers and wire
Rubber curtains (inner-tubes)
Gear clamps
Screw driver and pliers
Bungee cords
T-posts
NaCl solution
Hypodermic syringe (50ml or greater)
Conductivity meter

Ice auger
Chain saw
Ice chisels (better than picks)
Axe and file
Shovel
Sledge hammer
Miscellaneous rope
Meter ruler

Winkler apparatus: Graduated 1 L filtering flask
with a side-arm
bottles
Vacuum hand pump
Rubber tubing or similar
Stoppers
Weighted PVC pipe to hold the water sampling apparatus
Winkler titration field kit
Single burner camp stove to thaw frozen equipment between sample collection (tubing, stoppers, flask)

Depth-measuring device
Ruler

Other apparatus necessary for measurement of other pertinent variables in the field, such as velocity meter, thermometer, epilithic algae kit, etc.

B.2 DESCRIPTION OF SOD CHAMBER FOR THE IN-SITU CHAMBER METHOD OF SOD MEASUREMENT

The sediment oxygen demand chambers were constructed according to specifications in Figure B-1. The basic design was a stainless steel base (thickness = 0.16 cm) with a removable lid (thickness = 0.32 cm). The base had a flat rim (thickness = 0.32 cm, width = 2.5 cm) attached. On the underside of the lid, a gasket made of closed-cell foam (thickness = 0.95 cm, width = 5 cm) was attached. The foam and rubber gasket made a complete seal between the base and the lid of the chamber. Four snap-down clips welded around the top of the chamber secured the lid in a water-tight seal.

In order to maintain mixing of the water inside the chamber, a mixing mechanism (termed a 'water vane') was mounted in the lid o the chamber. The water vane was constructed of stainless steel and included a central rod or axle, (diameter = 0.9 cm) with spokes (diameter = 0.45 cm) on either end. Eight spokes were welded onto the top of axle. Six spokes were welded to a nut that could be screwed onto the bottom end of the axle, on the inside of the chamber. The water vane was held securely in the lid using a pipe fitting which was screwed into the top of the lid. Between the bottom of the lid and the spokes inside the chamber, there was a metal pipe spacer (length = 4.5 cm, inner diameter = 1.1 cm) placed onto the axle to form a casing.

Polypropylene funnels (top diameter = 65 mm), with the steam removed and sealed, were fitted onto the spokes to serve as cones on the water vane. Three portholes in the lid were used to obtain measurements and water samples from inside the chamber. The portholes were closed using rubber stoppers which were attached to the lid of the chamber. The porthole used to obtain water samples was made from a 6 cm length of stainless steel tubing (outer diameter = 0.95 cm, inner diameter = 0.75 cm) welded into the lid. The other two portholes were 1.5 cm and 3 cm in diameter.

B.2.1 TYPE OF SOD CHAMBER

Two types of chamber design were used for this study, open, and closed. Open chambers were used where a satisfactory seal with the substrate could be obtained, usually on mud. They were constructed from a cylinder which was serrated with 2 cm teeth around the lower edge. The teeth and handles on the base of the chamber were used to aid in manually rotating the chamber into the substratum. Around the outside of the chamber, just above the teeth, half of a 13 inch inner-tube (cut along the circumference) was secured with gear clamps to form a curtain over the base of the chamber, to impede 'leakage' of the chambers. Closed chambers were similar to open ones except that the bottom was completely sealed, to form a water-tight chamber. They were used where a seal with the substrate could not be obtained, usually on gravel or coarser material.

APPENDIX C

EQUIPMENT FOR THE SEDIMENT CORE METHOD OF SOD MEASUREMENT

C.1 EQUIPMENT FOR THE SEDIMENT CORE METHOD OF SOD MEASUREMENT

SOD Coring Devices
Extra Neoprene Stoppers
Mineral Oil (Heavy)
Cooler (with transport rack)
Ice

Ice Auger
Axe
Chainsaw
Steel rod/rebar

Peristaltic pump
Winkler titration field kit
100 ml sample bottles
distilled water
green garbage bags (or suitable dark cover)

Apparatus for measurement of pertinent environmental variables including thermometer, flow meter, meter stick, etc.

scrub-brushes
Phosphate-free soap

C.2 DESCRIPTION OF SOD CORING DEVICE

The sediment oxygen demand coring devices (Figure C-1) were constructed according to the following specifications. The basic design consisted of 60 cm lengths of clear premium grade plexiglass tubing with an inside diameter of 6.35 cm and wall thickness of 0.32 cm. Clear plexiglass enabled the operator to determine whether an undisturbed sediment core of suitable thickness had been obtained.

Approximately 30 cm from the base of each plexiglass tube, 2 brass taps (0.64 cm in diameter and 5.0 cm long) were fastened to opposing sides of the tube. Tap installation involved the use of a 0.64 cm threader. Once the taps had been screwed partway into the tube, silicone or "aquaseal" was applied to the insertion area and threads of the tap. Once in position, a water and air tight seal was created. The seal was checked periodically and although no leaks were detected additional "aquaseal" was spread around the base of the taps.

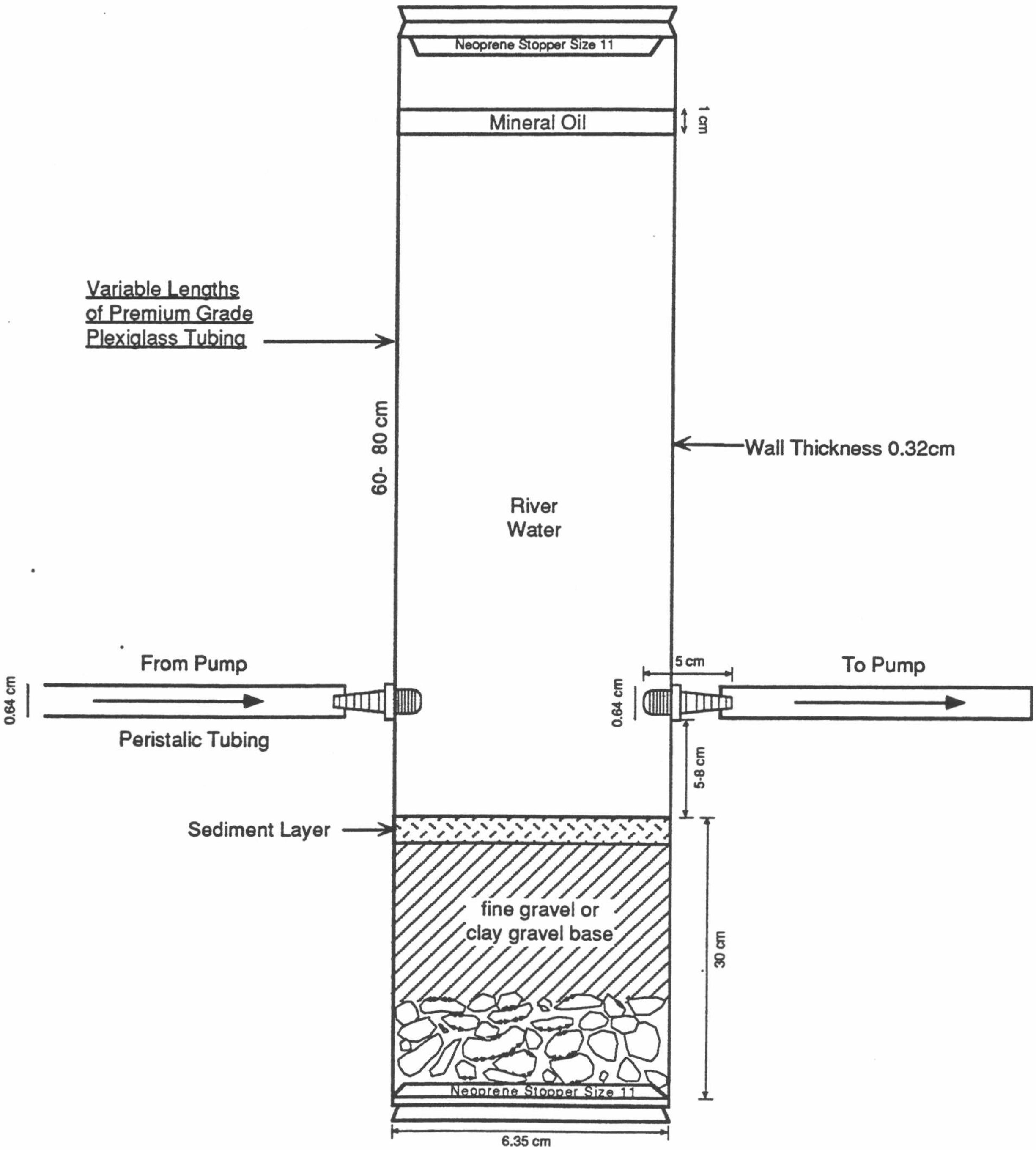
Attached to each brass tap were sections of 0.64 cm diameter Tygon tubing joined together with a removable polypropylene connector. When the sediment core sample was being collected the Tygon tubing was filled with river water and the ends attached to the brass taps underwater.

In order to prevent surface aeration, heavy mineral oil was poured into test and control coring devices to a depth of 3 mm.

After transporting core samples to the laboratory in an ice-filled cooler, the Tygon tubing of each sealed unit was attached to individual pump-heads of a Master-Flex peristaltic pump. The pump was run for 48 hours and 100 dissolved oxygen samples collected at 24 hours into the incubation period and at 48 hours, the end of the incubation period. The coring devices including Tygon tubing were kept in the dark during the entire incubation period.

At the end of incubation period, all equipment the coring devices including Tygon tubing were cleaned thoroughly with phosphate-free soap.

Monenco



DESIGN OF CORING DEIVCE USED DURING SEDIMENT OXYGEN DEMAND INVESTIGATIONS ON THE ATHABASCA RIVER DURING THE WINTER OF 1992

(Drawing not to Scale)

R57JM01

APPENDIX D

ATHABASCA RIVER WATER VELOCITIES AND WATER DEPTHS ASSOCIATED WITH INDIVIDUAL SOD SAMPLE REPLIATES, 29 JANUARY - 22 MARCH 1992

TABLE D-1

Study Site - Hydrological Characteristics Associated with Individual SOD Measurements on the Athabasca River 29 January - 22 March 1992

Study Location	Latitude & Longitude	Study Site	Sampling Start Date (D/M/Y)	SOD Method[1]	Ice Conditions	Water Velocities for Each Replicate Sample (cm/S)					Water Depth at Each Chamber (cm)					Water Vane Revolutions per 30s for each Replicate Sample				
						1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Hinton	53° 25'N, 117° 34'W	Site 1	16/03/92	OC	Open Water	29	37	42	36	35	42	46	43	51	46	6.0	4.5	6.5	7.0	5.0
		Site 2	16/03/92	SC	Open Water	2	4	15	8	4	20	23	22	25	18			NV[2]		
		Site 3	17/03/92	CC	Open Water	65	60	56	65	-	54	48	40	52	-	8.5	7.0	6.5	8.0	-
Windfall Bridge	54° 12'N, 116° 3'W	Site 1	13/02/92	CC	Ice cover (>100 m)	15	22	17	-	-	52	60	56	-	-	0.5	3.5	2.0	-	-
Whitecourt	54° 9'N, 115° 40'W	Site 1	29/01/92	CC	Open Water	28	43	36	38	35	40	43	44	45	44	3.75	5.0	5.0	6.0	5.0
			11/02/92	CC	Open Water	24	26	37	22	21	45	43	41	45	45	3.5	3.0	5.5	3.0	2.5
			19/03/92	CC	Open Water	77	55	16	62	-	40	38	38	38	-	9.0	6.5	8.0	8.0	-
		Site 2	20/03/92	OC	Open Water	66	29	22	-	-	45	41	43	-	-	8.0	5.5	2.5	-	-
		Site 3	20/03/92	SC	Open Water	12	4	8	2	6	35	30	32	24	20			N.A.		
Smith	55° 4'N, 114° 5'W	Site 1	17/02/92	CC	Ice Cover (>80 m)	7	6	4	6	7	60	61	71	59	59	1.5	1.0	0.5	1.0	1.0
Athabasca	54° 44'N, 113° 45'W	Site 1	22/03/92	SC	Open Water	8	10	3	5	15	22	26	20	28	35			N.A.		
		Site 2	23/02/92	CC	Open Water	41	31	40	25	29	46	48	48	62	52	6.5	5.0	6.0	4.0	4.5
Alpac		Site 1	24/03/92	SC	Open Water	8	6	7	12	3	15	15	20	20	15			N.A.		

Notes: 1) OC = Open Chamber, CC = Closed Chamber, SC = Sediment Cover
2) No values as tests discontinued after 24 hours of incubation

APPENDIX E

THE PERCENTAGE OF ORGANIC MATTER ASSOCIATED WITH ATHABASCA RIVER SUBSTRATES

38-67 Avenue
dmonton,AB
T6E 0P5

NORWEST LABS
(403) 438-5522
(403) 438-0396 fax

DATE 02 APR 92 13:38
P.O. NO. SOD STUDY
W.O. NO. 2 50109

MONENCO CONSULTANTS
400 MONENCO PLACE
7TH FLR. 801-6 AVE S.W.
CALGARY, AB
T2P 3W3

SOD STUDY

SAMPLE		1 HINTON 16-18 MARCH/92 #1	2 HINTON 16-18 MARCH/92 #2	3 HINTON 16-18 MARCH/92 #3	4 HINTON 16-18 MARCH/92 #4
ORGANIC MATTER					
TOT ORG CARBON	%	1.38	0.31	0.56	1.43
ORGANIC MATT %	%	2.46	0.55	1.00	2.55

Lab Manager: ____________________

9938-67 Avenue
Edmonton,AB
T6E 0P5

NORWEST LABS

(403) 438-5522
(403) 438-0396 fax

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W.O. NO. 2 50109

MONENCO CONSULTANTS
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7TH FLR. 801-6 AVE S.W.
CALGARY, AB
T2P 3W3

SOD STUDY

SAMPLE		5 HINTON 16-18 MARCH/92 #5	6 WHITECOU 20-22 MARCH/92 #1	7 WHITECOU 20-22 MARCH/92 #2	8 WHITECOU 20-22 MARCH/92 #3
ORGANIC MATTER					
TOT ORG CARBON	%	1.20	0.21	<0.05	0.05
ORGANIC MATT %	%	2.14	0.37	<0.09	0.10

Lab Manager: ____________

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dmonton,AB
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W.O. NO. 2 50109

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400 MONENCO PLACE
7TH FLR. 801-6 AVE S.W.
CALGARY, AB
T2P 3W3

SOD STUDY

SAMPLE		9 WHITECOU 20-22 MARCH/92 #4	10 WHITECOU 20-22 MARCH/92 #5	11 ATHABASC 22-24 MARCH/92 #1	12 ATHABASC 22-24 MARCH/92 #2
ORGANIC MATTER					
TOT ORG CARBON	%	1.73	<0.05	1.00	0.87
ORGANIC MATT %	%	3.08	<0.09	1.78	1.55

Lab Manager: ____________

9938-67 Avenue
Edmonton,AB
T6E 0P5

NORWEST LABS
(403) 438-5522
(403) 438-0396 fax

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W.O. NO. 2 50109

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400 MONENCO PLACE
7TH FLR. 801-6 AVE S.W.
CALGARY, AB
T2P 3W3

SOD STUDY

SAMPLE		13 ATHABASC 22-24 MARCH/92 #3	14 ATHABASC 22-24 MARCH/92 #4	15 ATHABASC 22-24 MARCH/92 #5	16 AP-PAC 24-26 MARCH/92 #1
ORGANIC MATTER					
TOT ORG CARBON	%	0.85	0.64	1.08	<0.05
ORGANIC MATT %	%	1.52	1.14	1.92	<0.09

Lab Manager: [signature]

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dmonton,AB
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(403) 438-0396 fax

DATE 02 APR 92 13:38
P.O. NO. SOD STUDY
W.O. NO. 2 50109

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CALGARY, AB
T2P 3W3

SOD STUDY

SAMPLE		17 AP-PAC 24-26 MARCH/92 #2	18 AP-PAC 24-26 MARCH/92 #3	19 AP-PAC 24-26 MARCH/92 #4	20 AP-PAC 24-26 MARCH/92 #5
ORGANIC MATTER					
TOT ORG CARBON	%	0.35	0.41	0.48	0.41
ORGANIC MATT %	%	0.63	0.73	0.85	0.73

Lab Manager: ____________________

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W.O. NO. 2 50109

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T2P 3W3

SOD STUDY

Quality Assurance Analysis

Standard Reference Material Analysis

			----STANDARD----			-----QC WITH----- ---THIS ORDER----			-HISTORICAL-- --PRECISION--		-CONTROL LIMITS-	
METHOD	ANALYSIS	-UNITS--	--DESCRIPTION---	--D.L.--	TARGET	#	MEAN	% Y	#	MEAN	LOW	HIGH
3270	ORGANIC CARBON	%	EDMONTON	.05	5.34	1	5.600	104.9	24	5.528	4.84	5.8

QC/QA Manager: ______________________

APPENDIX F

ATHABASCA RIVER SOD RATES AND DISSOLVED OXYGEN CONCENTRATION DECREASES FOR INDIVIDUAL CHAMBERS AND SEDIMENT CORES 29 JANUARY - 22 MARCH 1992

TABLE F-1

Athabasca River Sediment Oxygen Demand Rates Estimated for Individual Open Chambers, Closed Chambers and Sediment Cores Over the Period of 29 January - 26 March 1992

Study Location	Latitude & Longitude	Study Site	Sampling Start Date (D/M/Y)	SOD Method[1]	Ice Conditions	SOD ($g/m^2/day$) After Incubation Period for Each Replicate Sample: 24 hrs. 1	24 hrs. 2	24 hrs. 3	24 hrs. 4	24 hrs. 5	48 hrs. 1	48 hrs. 2	48 hrs. 3	48 hrs. 4	48 hrs. 5
Hinton	53° 25'N, 117° 34'W	Site 1	16/03/92	OC	Open Water	0.16	0.13	0.40	0.12	0.15	0.11	0.06	0.21	0.10	0.09
		Site 2	16/03/92	SC	Open Water	0.30	0.46	0.21	0.25	0.27	0.25	0.28	0.28		
		Site 3	17/03/92	CC	Open Water	0.47	0.33	0.18	0.32	-			---- NV[2] ----		
Windfall Bridge	54° 12'N, 116° 3'W	Site 1	13/02/92	CC	Ice cover (>100 m)	0.005	-0.002	0.008	-	-	-0.002	-0.004	0.00	-	-
Whitecourt	54° 9'N, 115° 40'W	Site 1	29/01/92	CC	Open Water	0.17	0.07	0.20	0.23	0.17	0.11	0.06	0.09	0.18	0.15
			11/02/92	CC	Open Water	0.34	0.29	0.28	0.12	0.18	0.25	0.20	0.18	0.09	0.09
			19/03/92	CC	Open Water	0.38	0.43	0.87	0.44	-	0.33	0.30	0.61	0.27	-
		Site 2	20/03/92	OC	Open Water	0.29	0.32	0.39	-	-	0.25	0.20	0.32	-	-
		Site 3	20/03/92	SC	Open Water	0.37	0.51	0.51	0.62	0.42	0.25	0.25	0.23	0.30	0.18
Smith	55° 4'N, 114° 5'W	Site 1	17/02/92	CC	Ice Cover (>80 m)	0.11	0.07	0.13	0.13	0.58	0.09	0.04	0.06	0.09	0.02
Athabasca	54° 44'N, 113° 45'W	Site 1	22/03/92	SC	Open Water	0.21	0.16	0.27	0.24	0.16	0.08	0.12	0.28	0.38	0.10
		Site 2	23/02/92	CC	Open Water	0.19	0.19	0.22	0.22	0.21	0.15	0.18	0.13	0.18	0.12
Alpac		Site 1	24/03/92	SC	Open Water	0.27	0.27	0.21	0.15	0.33	0.13	0.05	0.002	0.10	0.08

Notes: 1) OC = Open chambers, CC = closed chambers, SC = sediment cores.
2) NO = No values as tests discontinued after 24 hours of incubation.

TABLE F-2

Dissolved Oxygen Concentrations (mg/L) in the Water Column and the Change in Dissolved Oxygen for Individual Chambers and Sediment Cores during the Period of 29 January - 26 March 1992

Study Location	Latitude & Longitude	Study Site	Sampling Start Date (D/M/Y)	SOD Method[1]	Ice Conditions	Water Column Dissolved Oxygen (Mg/L)	Decrease in Dissolved Oxygen (Mg/L) After Incubation Period for Each Replicate Sample: 24 hrs. 1	24 hrs. 2	24 hrs. 3	24 hrs. 4	24 hrs. 5	24 hrs. Con	48 hrs. 1	48 hrs. 2	48 hrs. 3	48 hrs. 4	48 hrs. 5	48 hrs. Con
Hinton	53° 25'N, 117° 34'W	Site 1	16/03/92	OC	Open Water	11.13	0.69	0.49	1.68	0.47	0.59	+0.04	1.03	0.56	1.82	0.79	0.89	0.04
		Site 2	16/03/92	SC	Open Water	11.04	3.08	4.40	2.94	3.18	3.0	2.22	4.26	5.68	4.80	3.72	4.84	2.68
		Site 3	17/03/92	CC	Open Water	11.41	2.13	1.38	0.74	1.44	-	+0.02		NV[2]				
Windfall Bridge	54° 12'N, 116° 3'W	Site 1	13/02/92	CC	Ice cover (>100 m)	11.81	0.08	0.04	0.09	-	-	0.05	0.09	0.06	0.11	-	-	0.11
Whitecourt	54° 9'N, 115° 40'W	Site 1	29/01/92	CC	Open Water	10.50	1.12	0.54	1.32	1.53	1.23	0.10	1.59	1.01	1.39	2.40	2.16	0.20
			11/02/92	CC	Open Water	11.23	2.16	1.73	1.90	1.06	1.21	0.34	3.05	2.30	2.34	1.38	1.26	0.45
			19/03/92	CC	Open Water	11.90	2.14	2.64	4.41	2.39	-	0.02	3.71	3.70	6.26	3.00	-	0.07
		Site 2	20/03/92	OC	Open Water	11.99	1.57	1.76	1.82	-	-	+0.09	2.82	2.36	4.22	-	-	0.06
		Site 3	20/03/92	SC	Open Water	11.94	3.72	4.51	4.70	4.59	4.56	2.84	4.22	4.76	4.80	4.74	4.56	2.94
Smith	55° 4'N, 114° 5'W	Site 1	17/02/92	CC	Ice Cover (>80 m)	9.21	0.59	0.33	0.68	0.62	0.23	+0.05	0.90	0.55	0.76	0.99	0.26	0.06
Athabasca	54° 44'N, 113° 45'W	Site 1	22/03/92	SC	Open Water	11.44	3.28	3.38	3.60	3.58	3.37	2.74	3.70	4.26	5.20	6.06	4.12	3.24
		Site 2	23/02/92	CC	Open Water	11.39	1.05	1.08	1.41	1.14	1.44	0.06	1.98	2.01	1.69	1.87	1.61	0.04
Alpac		Site 1	24/03/92	SC	Open Water	10.37	2.40	2.68	2.30	1.90	2.63	1.57	3.30	2.94	2.58	3.02	3.08	2.57

Notes: 1) OC = Open chambers, CC = closed chambers, SC = sediment cores devices.
2) NV = No values as tests discontinued after 24 hours of incubation.

APPENDIX G

WATER SURVEY OF CANADA
MEAN DAILY DISCHARGE (M^3/s)
FOR THE ATHABASCA RIVER AT HINTON AND ATHABASCA
DURING THE MONTHS OF JANUARY, FEBRUARY, MARCH 1992

WATER SURVEY OF CANADA
APR 13 1992 PAGE 8
CALGARY, ALTA 15:33

ATHABASCA RIVER AT HINTON

STATION NO. 07AD002

(PRELIMINARY) DAILY DISCHARGE IN CUBIC METRES PER SECOND FOR 1992

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	41.5 B	47.2 B	38.9 B										1
2	43.1 B	49.2 B	40.2 B										2
3	43.1 B	52.3 B	42.7 B										3
4	42.3 B	51.6 B	45.1										4
5	37.9 B	43.3 B	43.8										5
6	40.6 B	41.0 B	43.1										6
7	36.1 B	34.4 B	43.9										7
8	29.2 B	31.9 B	43.0										8
9	39.8 B	29.8 B	41.4										9
10	44.9 B	18.0 B	41.1										10
11	47.5 B	20.9 B	41.6										11
12	44.4 B	27.7 B	40.7										12
13	42.9 B	36.4 B	42.5										13
14	41.1 B	41.3 B	44.9										14
15	40.5 B	40.8 B	45.3										15
16	39.8 B	38.9 B	45.2										16
17	42.2 B	37.8 B	46.3										17
18	41.0 B	36.0 B	45.5										18
19	40.5 B	30.1 B	45.2										19
20	40.7 B	21.9 B	44.5										20
21	40.9 B	23.5 B	42.3										21
22	41.0 B	25.1 B	41.4										22
23	41.2 B	27.6 B	40.0										23
24	41.5 B	34.0 B	40.3										24
25	41.7 B	40.3 B	40.8										25
26	41.8 B	54.9 B	39.0										26
27	41.9 B	52.1 B	39.8										27
28	42.4 B	42.1 B	42.0										28
29	42.8 B	41.5 B	39.2										29
30	47.2 B		38.0										30
31	48.0 B		39.5										31
TOTAL	1289.5	1071.6	1307.2										TOTAL
MEAN	41.6	37.0	42.2										MEAN
DAM3	111000	92600	113000										DAM3
MAX	48.0	54.9	46.3										MAX
MIN	29.2	18.0	38.0										MIN

B-ICE CONDITIONS

MAXIMUM INSTANTANEOUS DISCHARGE, M3/S AT ON

"Advance Information subject to correction. For private information only, pending publication in Annual Department Report."

WATER SURVEY OF CANADA
APR 15 1992 PAGE 6
CALGARY, ALTA 15:12

ATHABASCA RIVER AT ATHABASCA

STATION NO. 07BE001

STREAM JAN/89

(PRELIMINARY) DAILY DISCHARGE IN CUBIC METRES PER SECOND FOR 1992

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	DAY
1	118	96.8	99.0	261									1
2	117	97.8	116	320									2
3	116	103	136	305									3
4	115	108	146	265									4
5	113	109	151	242									5
6	108	113	153	255									6
7	107	114	159										7
8	107	113	168										8
9	105	113	176										9
10	100	113	175										10
11	98.5	110	173										11
12	96.0	102	167										12
13	94.5	94.0	166										13
14	97.3	87.6	167										14
15	95.7	85.1	168										15
16	95.0	82.7	173										16
17	102	76.5	182										17
18	107	67.6	197										18
19	106	62.0	216										19
20	101	73.4	243										20
21	98.9	87.4	268										21
22	99.4	93.9	270										22
23	101	94.0	269										23
24	103	89.8	278										24
25	105	87.5	281										25
26	108	85.0	276										26
27	108	83.1	293										27
28	104	85.5	323										28
29	99.8	91.0	294										29
30	98.7		311										30
31	98.0		286										31
TOTAL	3222.8	2718.7	6480.0										TOTAL
MEAN	104	93.7	209										MEAN
DAM3	278000	235000	560000										DAM3
MAX	118	114	323										MAX
MIN	94.5	62.0	99.0										MIN

MAXIMUM INSTANTANEOUS DISCHARGE, M3/S AT ON