CHEMICAL AND BIOLOGICAL MONITORING OF MUSKEG DRAINAGE AT THE ALSANDS PROJECT SITE

VOLUME II

Monitoring and Fish Studies

Prepared For

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SUMMARY OF IMPACTS

The chief impacts on water quality were large increases of suspended sediments and turbidity in the spring, and elevated nutrient (nitrogen and phosphorus) concentrations immediately below the minesite ditch outfall in early summer. The former problem was caused primarily by a mid-April flood resulting from the breach of a lakeshore during maintenance of the minesite ditch; the latter by application of fertilizer to the minesite drainage area during seeding operations. Much silt rich in fine particulate organic matter (FPOM) was deposited below the outfall by the April flood.

Biological communities in the Muskeg River showed a variety of responses to Muskeg drainage. There is evidence that drainage from the minesite ditch (probably the April flood) reduced the biomass of periphytic algae, but increased the abundance of certain invertebrates and predators, in a stony area a short distance below the outfall (Station 4) in late April--early May. Scour or siltation of the algae, and an increase in food for detritivores (in the form of FPOM) were suggested as the causes of the algal decrease and invertebrate increase, respectively.

No impact on the invertebrate fauna of fine sediments was detected until June, when reductions in total invertebrate biomass and in the abundance of certain detritivores and predators was noted at Station 4. It was suggested that some "conditioning" effect of the FPOM-rich sediments deposited by the April flood, such as oxygen reduction from active decomposition, was responsible for the invertebrate decreases on fine sediments.

In July, total biomass of algae on glass slides, and the abundance of certain detritivores and Hydra on simulated "sunken wood" substrate, both increased at Station 4 in response to muskeg drainage activities. The algal biomass increase was attributed to nutrient (nitrogen and phosphorus) enrichment from fertilization and seeding in the minesite ditch drainage area. The increase in detritivores was thought to be due to the presence of abundant food, in the form of FPOM, deposited by the April flood. Hydra was suggested to be responding to possible contributions of zooplankton food from the settling pond on the minesite ditch less than 300 m upstream from Station 4.

Only algal biomass on glass slides showed evidence of environmental impact as far downstream as Station 3. All other impacts were confined to the river segment from some point upstream of Station 3 to the Alsands site. In no case did any particular impact persist over as many as two sampling periods, although siltation at Station 4 may have had varying effects on the biota from mid-April until at least July.

There were no obvious impacts of muskeg drainage on fish populations. The fish studies were not designed primarily to detect impacts, but to fill in gaps in the present knowledge of fish life histories in the drainage.

Siltation and flooding by drainage water stressed white spruce (yellowing of lower needles) and drowned herbaceaus species at the outlet of the plantsite drainage ditch. An area of 12.6 ha was affected. Willow shrubs and black spruce forest were continuously inundated and silted at the lower end of the minesite ditch over an area of 1.8 ha, but this vegetation is often flooded, and little damage was noted. In portions of pine forest in the area that was flooded and silted, rapid recovery and rapid invasion of bare silt by shrubs and herbs is expected.

ACKNOWLEDGEMENTS

Marianne Lines carried out much of the field work for the monitoring studies. Dave Halstead and Steve Smith conducted most of the fall fish trapping in the face of trying field conditions. Bob Saunders, D. Halstead and M. Lines did the identifications and counts of benthic invertebrates. D. Arscot, J. Boyd, W. Charney, L. Corkum, R. LePage, M. Stawsky, E. Strasser and K. Strong-Duffin provided considerable field and/or laboratory assistance at various times. Bob Lickacz of Hardy Associates (1978) Limited, Edmonton, and George Dyson of United Petrolabs, Calgary, provided advice on some points of water chemistry. M. Spitzer of the Water Survey of Canada supplied preliminary hydrological data for our use. Peter McCart was responsible for the overall management of the study for AEL, and D. Dabbs managed the project for Alsands Energy Limited. The report was edited by Joyce McCart and typed by Evelin Oelke.

Authors Reid and Stushnoff of Hardy Associates conducted the terrestrial vegetation study and wrote that section of the report. Gordon Walder began the computer storage system, ran all the computer analyses and advised on the various statistical analyses used. T. Dickson was responsible for the fall fish studies in the lower

Muskeg River, and R. Green analyzed the periphyton samples. Both Dickson and Green provided extensive draft reports on aspects of the fish and periphytic algae studies, respectively, upon which those sections of the present report are partly based. The report, except for the terrestrial vegetation section, was written by D. Mayhood, who is solely responsible for any errors in interpretation.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

1.0 INTRODUCTION

Volume I of this report reviewed the publicly available literature on stream environments in the Muskeg River basin as background to the monitoring studies. This volume (Volume II) describes the results of the studies, discusses their effectiveness, and makes suggestions about the design of similar monitoring programs that might be established in future in the AOSERP area.

The 1980 monitoring studies were intended to both monitor the effects of Alsands' muskeg drainage on aquatic habitats and terrestrial vegetation, and to form the basis of a long-term program to monitor the effects of the Alsands development on aquatic habitats in the Muskeg River over the life of the project. The long-term, routine monitoring program was to be designed based on the experience with the 1980 studies, which would test methods and examine the suitability of various biological parameters for biomonitoring.

To meet these objectives, a variety of biological and water quality attributes were studied within the zones of potential impact and in control areas. Measures of water quality, such as suspended solids, dissolved oxygen, major ion, metal and nutrient concentrations, were studied to obtain direct information on physical and chemical impacts at the time of sampling. Periphytic algae and

benthic macroinvertebrates were sampled by several methods to detect the biological effects of physical and chemical changes in water quality. Biological monitoring had the potential of detecting impacts that occurred prior to sampling, and provided a direct measure of biological damage, usually the matter of greatest human concern. Benthic invertebrates were selected for study because they are commonly rated as the most generally useful group for biomonitoring (eg Hellawell 1977). Periphytic algae were sampled because they could be particularly useful for monitoring the effects of nutrient loading and turbidity (Hellawell 1977).

A fish sampling program was conducted in conjunction with the monitoring studies to supplement available life history information on species inhabiting the Muskeg River basin.

Previous studies on the fish fauna of the drainage (reviewed in Volume I) showed that Hartley Creek and the Muskeg River, at and below the Alsands development area, provide spawning and rearing habitat for Arctic grayling and two species of suckers. In addition, yearly grayling may overwinter in the lower Muskeg River, several species of small fish reside in the watershed year-round and small numbers of other large species (eg northern pike) use the watershed for at least part of the year.

One deficiency in the available baseline data on fish populations in the Muskeg River drainage is the lack of information on overwintering locations, and on the distribution and numbers of spawners, eggs, fry and juveniles at specific locations and times.

Without such data, only very large changes in the fish populations could be detected during routine monitoring studies.

A second deficiency in the available data is that the importance of the river as Arctic grayling habitat has not been adequately quantified. Angling results indicate the summer population density is larger than spring trapping results have suggested (Bond and Machniak 1979). Despite two attempts, Bond and Machniak (1977, 1979) did not obtain a complete count of the number of Arctic grayling entering the Muskeg River in spring. Because the fish had begun their migration prior to break-up, a counting fence could not be installed in time. Their 1978 attempt to count grayling as the fish moved out of the river in the fall was thwarted by high water.

The 1980 fish studies were conducted in an attempt to provide some of this missing baseline information. Specifically, the objectives of the fish studies were:

1. To locate and describe overwintering areas of yearling Arctic grayling and, if possible, to quantify (as catch per unit effort or direct counts) the importance of each site to the population;
2. To locate and quantify the importance of spawning and rearing areas of suckers and grayling;
3. To monitor and enumerate downstream migrant fish, particularly grayling, in the fall;
4. To survey small fish populations in the Muskeg River in the fall and early winter; and

5. To determine, if possible, the effects of Alsands' activities in 1980 on the relative abundance, distribution, and fall migrations of Muskeg River fish, from a comparison of the 1980 results to previously-reported results.

In the winter of 1979-80, as part of the requirements for approval of drainage ditch construction, Alberta Environment requested Alsands to develop a monitoring program to assess the impact of the two drainage ditches on neighbouring lands and receiving bodies of water.

Prior to removal of the peat and initiation of construction of the Alsands mining and processing complex, extensive muskeg areas, including ponds, would need to be drained. The two points of discharge would be the proposed tailings pond area and the Muskeg River area about 1 km south of Alsands' temporary camp.

Hardy Associates (1978) Ltd. was contracted to assess the impact of the discharged water on vegetation and wildlife habitat. The purpose of their investigation was two-fold:

1. To determine the extent and type of vegetation damage; and
2. To define the short and long-term effects of flooding and siltation on vegetation.

This report presents the methods that were used to carry out the study, the results of the field observations, and the conclusions made.

2.0 WATER QUALITY

2.1 Methods

Water samples were collected on the dates and at the locations shown in Table 1. The locations of the principal sampling stations are illustrated in Figure 1; other stations not sampled on a regular basis are described in the text.

The program involved taking monthly water samples in 500 ml polyethylene bottles at stations 4, 5, 9 and 10 from March to December, and analyzing them for biochemical oxygen demand (BOD), pH, conductivity, suspended solids and turbidity. Bimonthly samples were collected at all 10 stations in one litre glass bottles for more detailed analysis. Sampling was more frequent and more locations were sampled during periods of flood discharge in April, and during seeding and fertilizing of the minesite ditch area in June. February and March biweekly samples taken from the two drainage ditches by Hardy Associates (1978) Limited are discussed in this report. Analyses conducted, sample preservation, and analytical methods used are outlined in Table 2.

All analyses, except those of the field measurements and the samples taken during the June fertilization monitoring, were done by

Table 1. Water analyses and collections conducted as part of Alsands' monitoring program, Muskeg River drainage 1980. Numbered stations are shown in Figure 1, unnumbered stations described in the text. Parameters in the "short" and "long" lists are as in Table 2.

Date	Stations	Parameters
80/03/25	1 to 10	long list
80/04/03	1 to 7, 8 stations on minesite ditch	short list
80/04/10	1 to 7, 6 stations on minesite ditch	short list
80/04/14	1 to 7, 9, 6 other stations on Muskeg River, Athabasca R. and minesite ditch	short list, not including dissolved oxygen
80/05/01	1 to 10	long list
80/05/31 to 80/06/01	3 stations on minesite ditch and Muskeg River at outfall	suspended solids, turbidity (collected by Alsands staff)
80/06/03	4, 5, 9, 10, 1 additional site on the minesite ditch	short list
80/06/19-20	2 to 7, 3 others on minesite ditch (sampled before and after fertilizer application)	orthophosphate, total PO_4, K, SO_4, NO_3, Kjeldahl N dissolved oxygen
80/06/24	same as 80/06/19-20	same as 80/06/19-20
80/06/30 to 80/07/01	same as 80/06/19-20	same as 80/06/19-20
80/07/11	1 to 10	long list
80/08/14	4, 5, 9, 10	short list
80/09/10-11	1 to 10	long list
80/10/09	4, 5, 9, 10	short list
80/11/12	1 to 10	long list
80/12/18	4, 5, 9, 10	short list

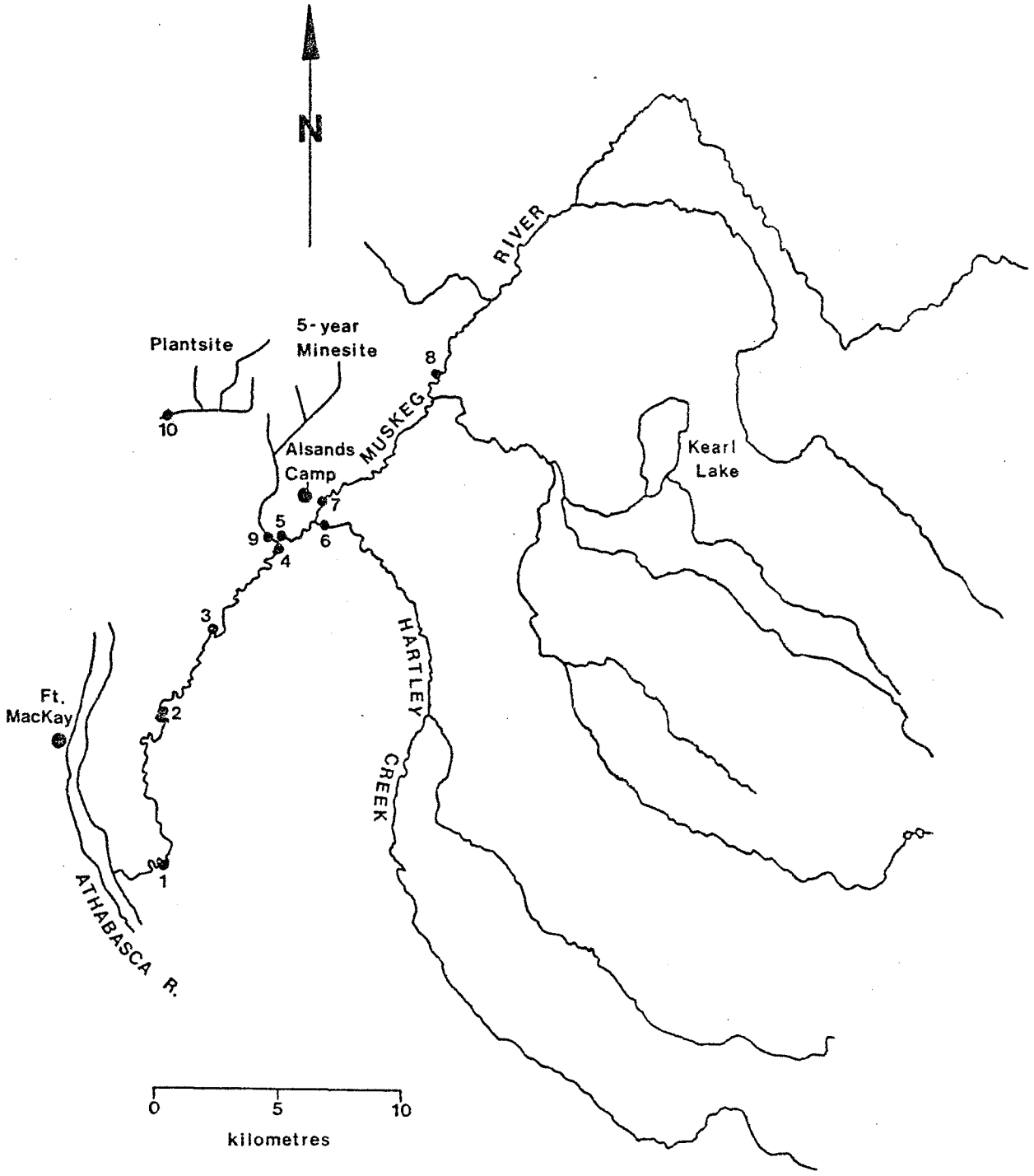

Figure 1. Location of sampling stations for water quality, periphyton and benthic invertebrates, 1980.

Table 2. Analytical and preservation methods for chemical parameters. Methodology from Standard Methods for the Examination of Water and Wastewater. 14th Edition, 1975; Metals-Methods Manual for Water and Wastes, D.O.E., Alberta. Asterisks indicate parameters measured monthly (short list); all were measured bimonthly (long list).

Parameter	Sample Preservation	Analytical Method	Sensitivity
*Temperature	field measurement	mercury pocket thermometer	1 C
*BOD	refrigerated	5-day incubation	n/a
*Dissolved Oxygen	field measurement	Hach Kit OX-10	1 mg/L
*pH	refrigerated	meter	0.01 unit
*Conductivity	refrigerated	meter	0.01 1 µS/cm
Alkalinity	none (kept cool)	acid titration	1 mg/L
Total Hardness	none (kept cool)	calculation from Ca, Mg measurements	1 mg/L
*Suspended Solids	none (kept cool)	gravimetric	1 mg/L
Total Dissolved Solids	none (kept cool)	gravimetric	1 mg/L
*Turbidity	none (kept cool)	turbidimetric	1 NTU
Colour	none (kept cool)	colorimetric (visual comparison)	10 units
NH_3^+	0.5 mL conc. H_2SO_4/500 mL	electrode	1 mg/L
NO_3^-	same as above	colorimetric	0.1 mg/L
NO_2^-	same as above	colorimetric	0.1 mg/L
TKN	same as above	Kjeldahl distillation	0.1 mg/L

Continued . . .

Table 2. Continued.

Parameter	Sample Preservation	Analytical Method	Sensitivity
PO_4^{-3}	same as above	colorimetric (SnCl)	10 µg/L
TOC	none (kept cool)	carbon analyser	1 mg/L
SO_4^{-2}	none (kept cool)	turbidimetric	10 mg/L
Cl	none (kept cool)	argentometric titration	1 mg/L
Ca, Mg, Na, K	none (kept cool)	atomic absorption	0.1 mg/L
As	0.5 mL conc. HCl/500 mL	colorimetric silver diethyldithiocarbamate)	5 µg/L
Hg	same as above	atomic absorption (cold vapour)	0.2 µg/L
Cr, Cu, Fe, Mn, Ni, Pb, V, Zn	same as above	atomic absorption (carbon red)	1 µg/L
Phenols	H_3PO_4 + $CuSO_4$	Chloroform extraction	1 µg/L
Oil and Grease	0.5 mL conc. H_2SO_4/500 mL	Freon extraction	1 mg/L

the Edmonton laboratory of Hardy Associates (1978) Limited, to which the samples were sent either on the day of collection or within 24 hours of collection. Samples for the fertilization monitoring program were sent within 24 hours of collection to the Calgary laboratory of United Petrolabs Limited.

2.2 Results and Discussion

Detailed results are presented in Appendix A at the end of this volume. Most data are summarized graphically in the following sections. Emphasis has been placed on comparing measurements at stations 4, 5 and 9, because Station 4 was potentially most affected, Station 5 was the most immediate control, and Station 9 was an effluent station. Stations 6, 7 and 8 provide information on the degree of variability in upstream (control) conditions; data from stations 1, 2 and 3 should show various degrees of recovery or detect downstream influences not attributable to minesite drainage. Samples from Station 10 provided information on the quality of water affecting terrestrial vegetation at the outlet of the plantsite drainage ditch.

2.2.1 Water Temperature

Table 3 summarizes water temperatures, usually measured at the time of water sample collection. Maximum-minimum water tempera-

Table 3. Water Temperatures, Muskeg River drainage, March to December, 1980.

1980 Date	Station									
	1	2	3	4	5	6	7	8	9	10
03/21-25	0	0	0	0	0	0	0	0	0	frozen
04/03	0	0	0	0	0	0	0		0	
04/10				0	1	2	1		0	
05/01	15	11	14	11	11	13	13	13	11	17
06/03				15	15					
06/19		19	19	17	18	20	20		17	
06/20		20	20	19	18	18	19		20	
06/23-24		19	19	19	19	21	20		20	
07/11	18	20	20	20	20	20	20	18	20	16
08/14				16	16				18	19
09/10-11	10	10	10	10	10	10	11	10	10	8
10/09				7	7				8	4
11/12	0	0	1	1	0	0	1	0	0	1
12/18									0	0

tures below Station 7 during the spring spawning period, and near the mouth of the Muskeg River from late September through October, were measured as part of the fish studies and are presented in that section.

Unfrozen water at all stations remained at 0 C until early April, warming rapidly thereafter to reach 11 to 15 C at stream stations by 1 May. By mid-June, water temperatures at many stations reached 20 C, and a maximum of 21 C was observed at Hartley Creek Station 6 in late June. In the July sampling period, temperatures were relatively uniform, at 18 to 20 C in the streams, but the few mid-August measurements suggest that some cooling had begun by then. At 10 to 11 C, the streams were much cooler in mid-September, and by late October and early November, temperatures near freezing were common and extensive ice was forming along the banks and in the shallow water of the Muskeg River. Station 6 of Hartley Creek was frozen over when visited 2 November 1980.

Water temperatures at stations 4 and 5 were not observed to differ by more than 1 C, and were most frequently identical. The temperature of minesite drainage water was usually identical to that at Station 5, and was not observed to differ by more than 2 C. Although these are "instantaneous" temperature data and do not show diel, day-to-day, or even weekly variations, they are sufficient to demonstrate that the Muskeg drainage water did not cause large or consistent changes in the water temperatures of the Muskeg River. The greatest differences observed fall well within the 1977 Alberta Water

Quality Objectives (temperatures not to be increased more than 3 C above ambient water temperature)(Alberta Environment 1977).

The water temperatures recorded in 1980 suggested a more rapid spring warming and a longer period near 20 C in summer than was observed in 1977 and 1978 by Akena (1979). Hartley Creek was found to reach much higher temperatures in 1980 than in 1977 and 1978. Because Akena (1979) also measured water temperatures only at the time of monthly sample collection, these differences may largely reflect short-term differences due to the prevailing weather at the time of sampling.

2.2.2 Water Colour

Figure 2 summarizes the observations on water colour made in 1980. At most stream stations, colour tended to be lowest, but still distinctly yellow, in May and July (20 to 30 units). March colour values were somewhat higher (usually 40 to 60 units), and September samples showed the maximum colour levels recorded at all stream sites (100 to 110 units). November colour figures for all stream stations were intermediate between the September and March values (60 to 70 units).

In contrast to the pattern in the streams, colour in the minesite drainage water decreased from February to March and increased from May to November, but exceeded 60 units only in February. In the plantsite drainage water, colour was very high (120 to 250 units) in the March and November samples, but did not exceed 40 units during the open-water period.

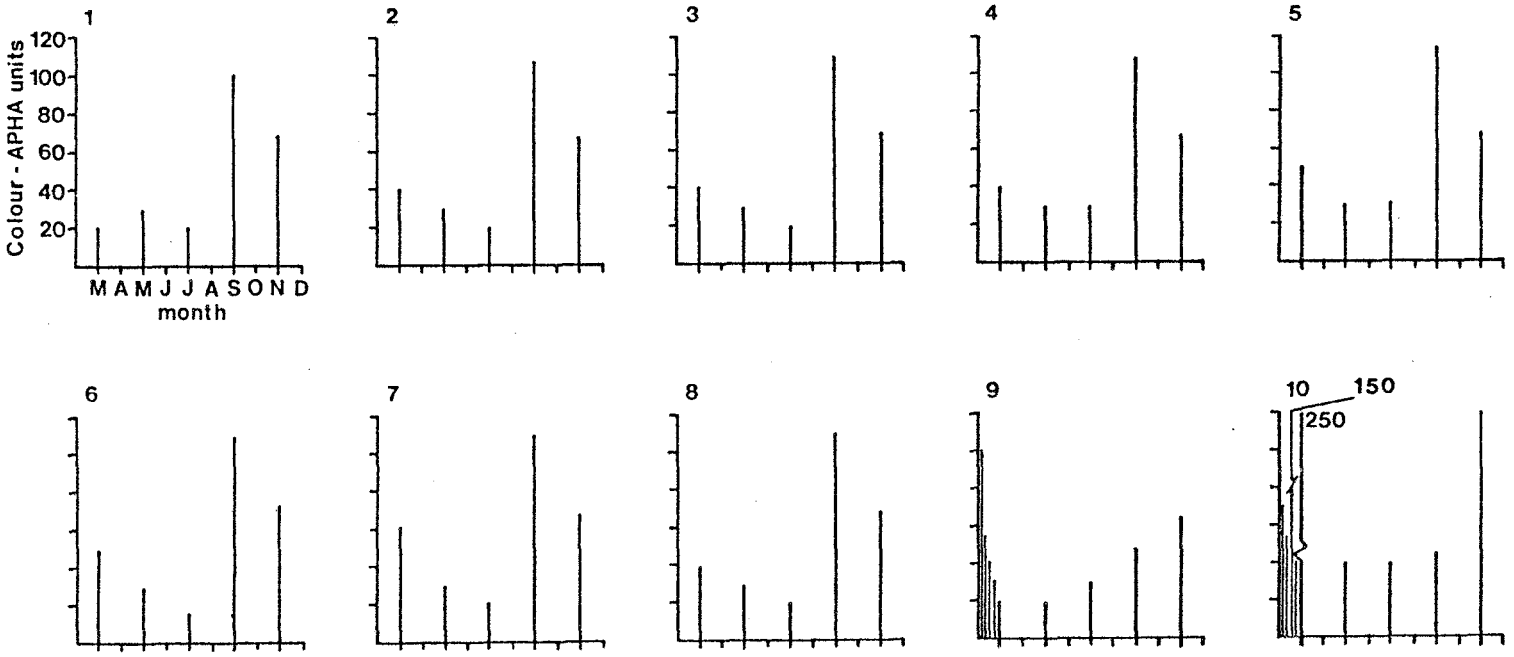

Figure 2. Water colour observations, Muskeg River drainage, February to November 1980.

Water colour at stations 4 and 5 was nearly identical on all sampling dates. The data provide no evidence that the generally less coloured minesite drainage water affected the water colour of the Muskeg River; therefore the minesite drainage met the Alberta Water Quality Objectives (colour not to be increased more than 30 units above the natural value)(Alberta Environment 1977).

Seasonal variations in water colour at all stream sites studied in 1980 differed from those discussed by Akena (1979) for the summer 1976 to summer 1978 period. In the 1976 to 1978 study, summer colour values in Hartley Creek (used as an example by Akena) were high, exceeding 80 units in June, July and August. The reason for the lower summer values in 1980 is not known, but probably reflects natural year-to-year variation.

2.2.3 Dissolved Oxygen and BOD

Dissolved oxygen data in units (mg/L) of concentration are summarized in Figure 3; Figure 4 presents the results expressed as percent saturation.

The lowest levels of dissolved oxygen were found during the late winter survey (March) when concentrations ranged from 1 to 3 mg/L (7 to 22% saturation) at most stream stations. Exceptions were Station 6 on Hartley Creek, which was anoxic, and Station 4, which had a concentration of 11 mg/L (81% saturation). Concentrations were not less than 5 mg/L, the Alberta Water Quality Objective (Alberta Environment 1977), on any other dates sampled, and were nearly always higher than 7.5 mg/L.

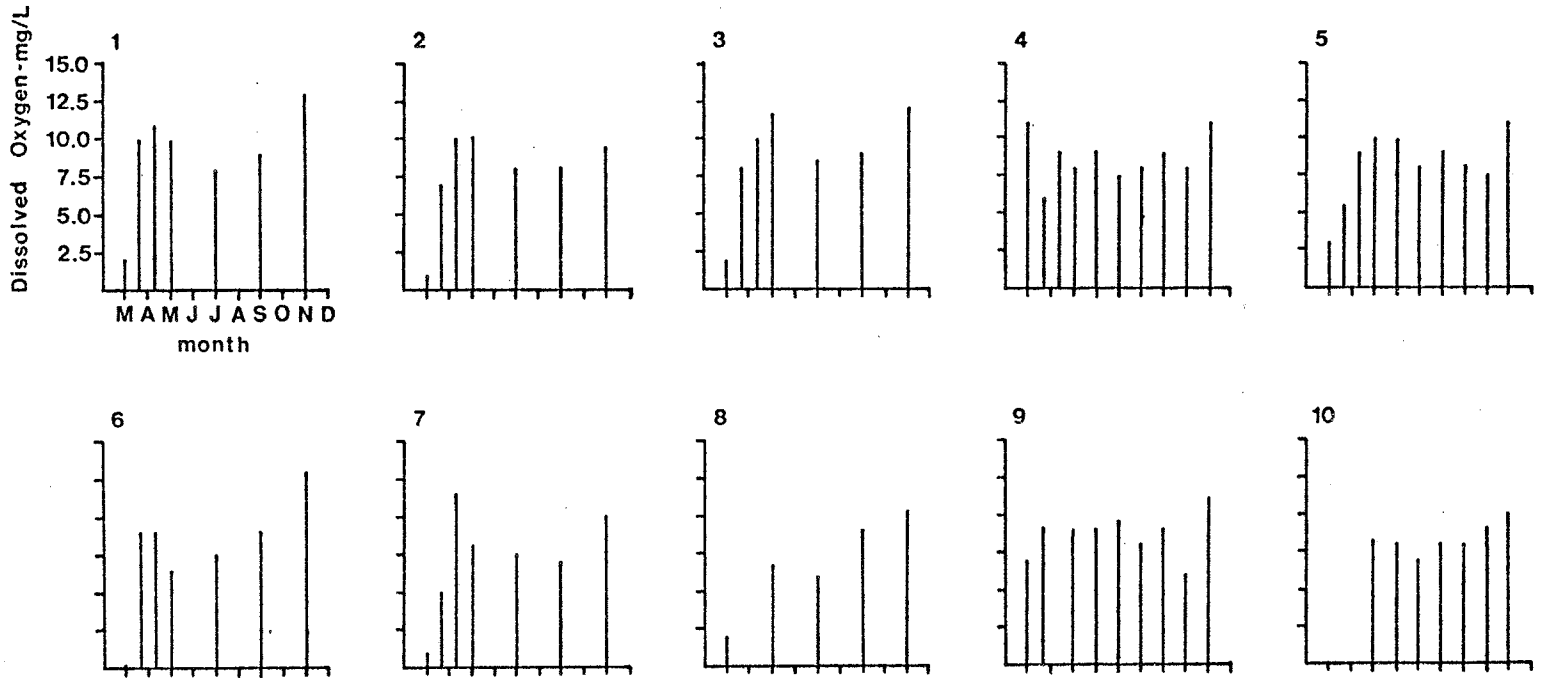

Figure 3. Dissolved oxygen concentrations, Muskeg River drainage, March to November, 1980. April data are for (from left to right) 3 and 10 April.

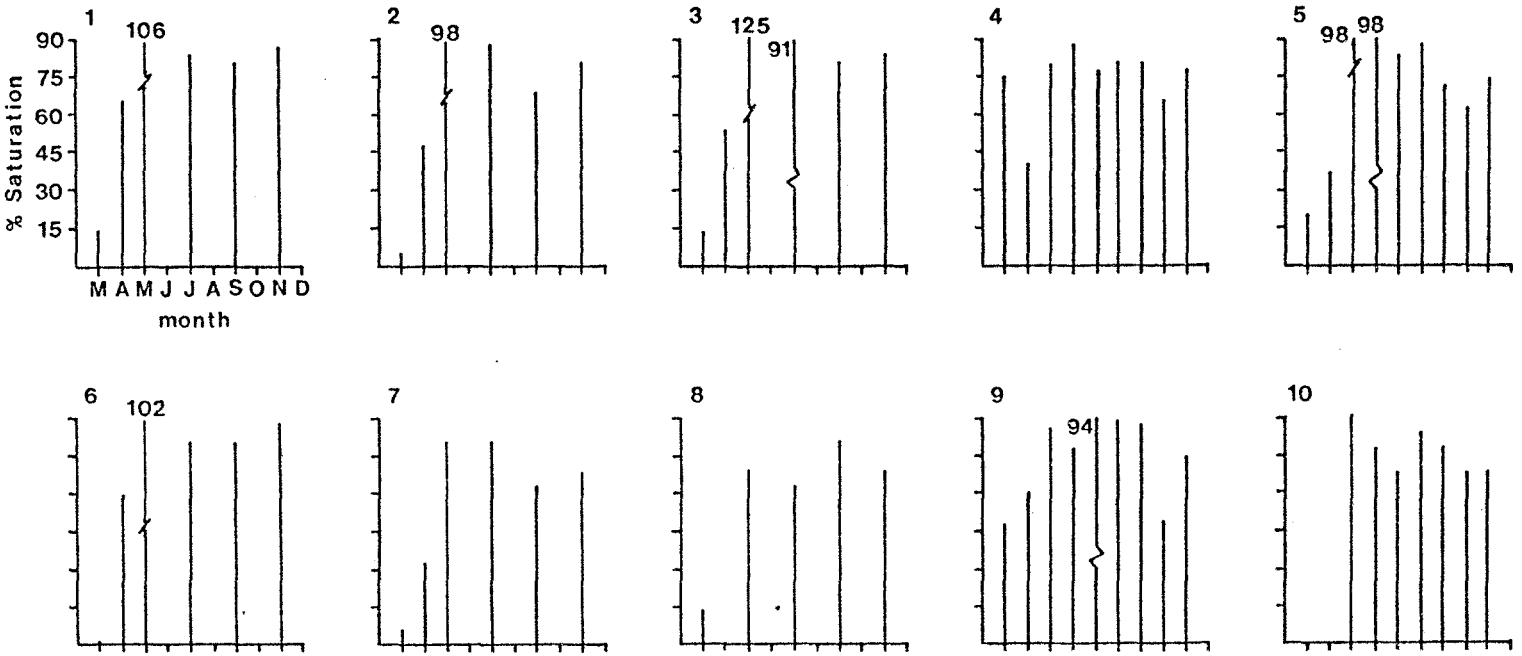

Figure 4. Dissolved oxygen as percentage saturation, Muskeg River drainage, March to November 1980. April data displayed are for 3 April. Calculated from the nomogram of Hutchinson (1957:582).

Stations 4 and 5 often differed in dissolved oxygen concentration and percentage saturation, but most differences were small. In March, Station 4 had clearly elevated dissolved oxygen relative to all other stations sampled. The entry of the minesite drainage water 100 m upstream (dissolved oxygen 7 mg/L, 48% saturation) undoubtedly augmented by agitation at the outfall and by flow over the ice surface, appears to have caused the higher dissolved oxygen at Station 4.

In April, dissolved oxygen was the same as or slightly higher than that at Station 5 while in May, dissolved oxygen at Station 4 was 2 mg/L and 20 percentage points lower than at Station 5. From June through August, the differences in percentage saturation and concentrations were less than 10 percentage points and 1 mg/L, with Station 4 values lower than those at Station 5.

In May and July, however, dissolved oxygen percent saturation values had reached the Station 5 control levels by Station 3, and percent saturation levels at Station 4 were higher than those at Station 8, a natural (control) site. From September to November, dissolved oxygen concentrations at Station 4 again were slightly higher than, or equal to, those at Station 5; percentage saturation was consistently slightly higher at Station 4 (2 to 8 percentage points).

In April, and sometimes in fall and early winter, Biochemical Oxygen Demand (BOD) was higher in the minesite drainage water than at the control stations (Figure 5). On 14 April and in September, this higher BOD water appeared to cause higher BOD's at Station 4.

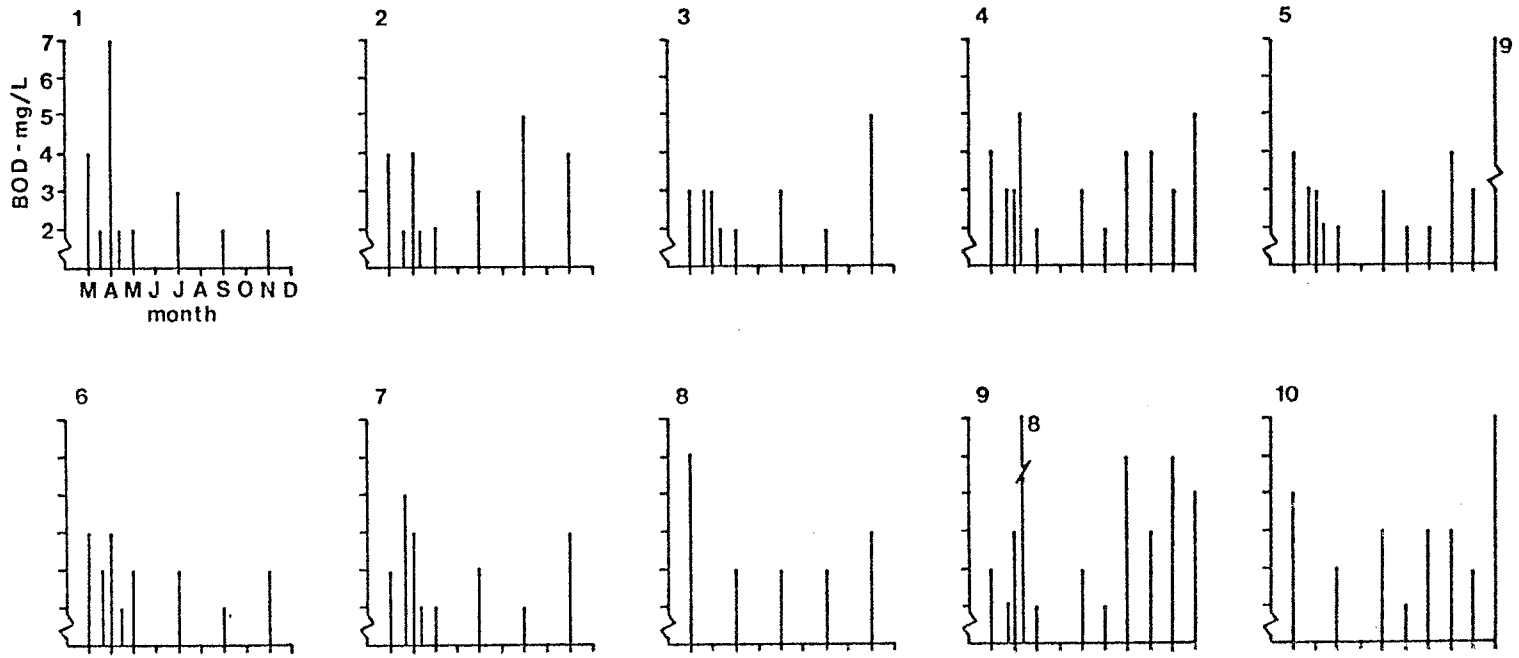

Figure 5. Biochemical oxygen demand, Muskeg River drainage, March to December, 1980.

A large flood that eroded part of the minesite drainage area on 12 to 13 April has been described elsewhere in this report (Volume I, p.8). The flood was probably responsible for the deposition of a thick layer of fine organic material observed in deep water and along the banks at Station 4, and upstream to the minesite drainage discharge point (This material was observed after the flood, but was not noted under the ice during a late winter survey of fish habitat--see Fish Studies). This organic material could be responsible for the high BOD found at Station 9 on 14 April, and its decomposition could have produced the somewhat depressed oxygen levels found at Station 4 from May to August.

On 3 and 10 April, the minesite drainage water below the road culvert was not confined to a single channel, but was permitted to run across the forest floor in an attempt to filter suspended solids there, and reduce the load contributed to the river. Several of the many small watercourses in the forest were sampled on both dates to determine the effects of this water treatment on several physical and chemical attributes. The results are summarized in Table 4.

On 3 April, at two sites in the single channel, dissolved oxygen was 9 mg/L above and at the road crossing, and BOD was 2 mg/L above the road crossing and 5 mg/L below the road crossing. In four channels sampled along the minesite drainage in the forest below the crossing, dissolved oxygen was 10 to 11 mg/L ($x = 10.8$). In six channels, BOD was 2 to 7 mg/L ($x = 4.0$). On 10 April, two sites in the main channel at, or just below, the road crossing each had a BOD of 4 mg/L and one had a dissolved oxygen concentration of 9 mg/L. At four

Table 4. Selected chemical and physical attributes of the minesite drainage water at sites above, within and below the forested area near the drainage ditch outfall, April 1980. Sites D1, D2, D9 and D10 are above or just within the forested area, all others are well within or below the forested area. Units are mg/L unless noted otherwise

Date	Site	pH @ 20C	Conduc-tivity us/cm @ 25 C	Turbi-dity NTU	Sus-pended Solids	BOD	Dis-solved oxygen	Temp. C
80/04/03	D1	7.48	0.408	140	660	5	9	0
	D2	7.89	0.408	155	580	2	9	0
	D3	7.89	0.408	160	640	2	10	0
	D4	7.91	0.384	45	150	4	11	0
	D5	7.92	0.402	72	200	3	11	0
	D6	7.78	0.420	95	380	3	11	0
	D7	7.66	0.432	60	140	5	-	-
	D8	7.71	0.396	15	8	7	-	-
80/04/10	D9	7.56	0.384	170	672	4	-	-
	D10	7.75	0.371	190	684	4	9	-
	D11	7.53	0.384	220	862	5	8	-
	D12	7.86	0.378	34	44	10	6	0
	D13	7.56	0.366	260	1048	3	9	0
	D14	7.59	0.444	155	504	5	8	0

other forest channels sampled below the road crossing, dissolved oxygen ranged from 6 to 9 mg/L (x = 7.8), and BOD ranged from 3 to 10 mg/L (x = 5.8).

Taken together, the data indicate only that dissolved oxygen and BOD tended to vary widely from place to place among the various discharge channels. They show no clear effect of "forest filtration" on dissolved oxygen or BOD, although the 3 April data suggest a slight increase in dissolved oxygen concentration as the water passed through the woods.

On 14 April, shortly after the flood, the BOD of triplicate samples taken at the mouth of the Muskeg River was 3.3 + 0.7 mg/L (x + SE)(Table 5). Thirty meters upstream, on the Athabasca River, the BOD was 3.7 + 0.9 mg/L (N=3), and 100 m below the mouth on the Athabasca River, a single BOD was 3 mg/L. These data suggest that the Muskeg River water had no detectable effect on the BOD of Athabasca River water at that time.

2.2.4 Suspended Solids and Turbidity

Suspended solids concentrations at the ten standard sampling stations are shown in Figure 6. More detailed data collected by Hardy Associates for the plantsite and minesite drainage ditches were presented in Volume I (p. 19).

Suspended solids did not exceed 18 mg/L at any of the stream stations in March, nor 17 mg/L on April 3, despite high concentrations in the minesite ditch. On 10 April, however, high suspended solids

Table 5. Selected chemical and physical attributes ($\bar{x}$ ± SE) of water at various distances from the Athabasca-Muskeg confluence, April 14, 1980.

	Athabasca 30 m upstream	Muskeg 30 m upstream	Athabasca 100 m downstream
pH @ 20 C	7.97 ± 0.02	7.83 ± 0.02	7.81
conductivity, mS/cm @ 25 C	0.252 ± 0	2.228 ± 0	0.228
turbidity, NTU	26 ± 0.6	60 ± 0.6	55
suspended solids, mg/L	126 ± 3.3	132 ± 2.3	150
BOD, mg/L	3.7 ± 0.9	3.3 ± 0.7	3
number of samples	3	3	1

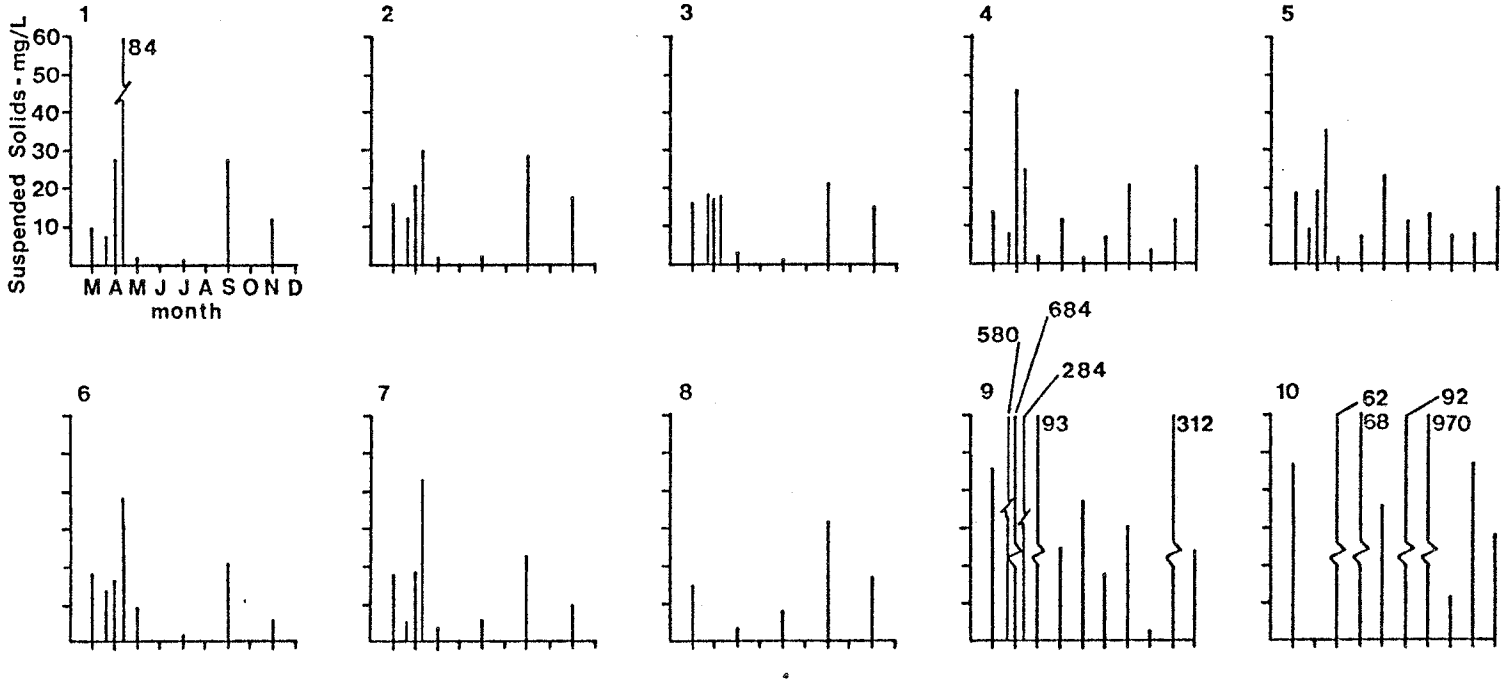

Figure 6. Suspended solids concentrations, Muskeg River drainage, March to December 1980. The datum plotted for Station 4 for 3 April (left bar) refers to a point approximately 4.5 km below the station.

concentrations in the water of the minesite drainage ditch (up to 1084 mg/L, depending on the channel sampled), caused suspended solids loads at Station 4 to be increased by approximately 28 mg/L over the 17 to 19 mg/L recorded at the three control stations sampled. The ditch water formed an obvious plume for only about 50 m in the Muskeg River, and suspended solids concentrations at Station 4, 100 m below the outfall, were relatively low, indicating that much of the sediment settled out within the first 100 m below the outfall. At a point approximately 4.5 km below Station 4, and at stations 3 and 2, suspended solids concentrations were at or near control concentrations. Slightly elevated concentrations, not necessarily attributable to the influence of the minesite drainage water, were again encountered at Station 1 (27 mg/L).

A sudden flood in the minesite drainage that occurred April 12 was briefly described in Volume I (p.8). This flood extensively eroded the ditch area immediately upstream of the outfall into the Muskeg River. The flood contributed massive quantities of sediment to the river, as evidenced on 14 April by a thick layer of black mud on the ice and banks near the discharge outlet, and by reddish brown sediment on the banks and ice the remainder of the distance to the Athabasca River. Brown to red-brown Muskeg River water was distinguishable as a plume in the Athabasca River, extending at least 1 km downstream from Alexander Island along the east bank. All but a small flow from the drainage ditch had been blocked by Alsands crews when most samples were taken on 14 April.

On 13 April, Hardy Associates (Volume I, p.19) recorded a suspended solids concentration of 5100 mg/L in the minesite drainage ditch near the outfall. On 14 April, concentrations in the small amount of drainage water still flowing was 284 mg/L near the road crossing and 972 mg/L at the outfall. Control concentrations at stations 5 to 7 were 34 to 41 mg/L; 50 m below the outfall suspended solids were higher at 62 mg/L. At Station 4, concentrations had declined to 25 mg/L, below control concentrations, and at stations 2, 3 and a point 4.5 km below Station 4, concentrations were at or below control concentrations. At Station 1, suspended solids were 84 mg/L, probably indicating the end of the slug of flood water from 12 to 13 April. At the mouth of the Muskeg River, the mean suspended solids concentration ($\pm$ SE) was 132 $\pm$ 2.3 mg/L (N=3)(Table 5). Thirty metres above the Muskeg mouth on the Athabasca River, mean suspended solids concentrations were also relatively high at 126 $\pm$ 3.3 mg/L (N=3), so that the Muskeg River water had little effect on Athabasca River concentrations: 100 m downstream from the Muskeg River mouth, suspended solids were only 150 mg/L (N=1).

During a helicopter survey of the Muskeg River on 14 April, no other source of silt was observed that could have produced the higher suspended solids concentrations found at the lower end of the river. Bare ground at a recently-constructed bridge across the river near kilometre 20 (cf. Walder et al 1980) was examined as a possible silt source, but there was no evidence of recent substantial erosion.

After the April flood, minesite drainage water was diverted to a point approximately 700 m below Station 4 until late May, while a

settling pond was built above the road crossing. This water was very clear after passing through a swampy area, but it eroded the bank at the outfall, picking up suspended solids (93 mg/L, Station 9, May 1). From 10 to 20 m^3 of bank material had been eroded by May 1, forming a mudbar that extended into the centre of the Muskeg River (approximately 7 m). Because Station 4 had been bypassed by the minesite drainage water in May, Station 4 suspended solids did not differ from that at the control stations. Stations 1, 2 and 3 were likewise unaffected, showing that suspended solids had settled out by the time the water reached Station 3.

By the time of the June sampling period, the minesite drainage water had been restored to its original channel after passing through the new settling pond constructed above the road crossing. Thereafter, minesite drainage water, at worst, only slightly increased suspended solids above control concentrations. The increase was never greater than 8 mg/L, and sometimes decreases were noted, possibly caused by the impounding effect of the large mudbar at the outfall.

Prior to the 14 April flood, the minesite drainage water was permitted to flow through the forest, unchanneled, to "filter-out" suspended solids. On 3 April, suspended solids were 580 and 660 mg/L in the single channel at and above the road crossing (Table 4). After flowing through the forest, the drainage water had suspended solids concentrations ranging from 8 to 380 mg/L (mean 176 mg/L, N=5); part-way through the forest, concentrations were still 640 mg/L (N=1). On 10 April, drainage water at or near the road crossing had suspended solids concentrations of 672 to 684 mg/L (N=2). Below the forest,

suspended solids at four points were 44, 504, 862 and 1048 mg/L. The latter two values were found in water in the main channels, which had been eroded out of the forest. Taken together, these observations suggest that, initially, "forest filtration" was effective in reducing suspended solids contributions to the Muskeg River, but that subsequent erosion tended to confine the water to a single main channel. This reduced the filtration effect, and in fact added sediments to the river, above what the single channel would have contributed (as indicated by upstream levels of suspended solids). The April 14 flood eroded much of the area in which sediment had previously been deposited, so that in this particular instance, little net benefit was gained by filtering drainage water through the forest.

The Alberta Water Quality Objective for suspended solids is that they should be increased not more than 10 mg/L over background concentrations (Alberta Environment 1977). This objective must have been greatly exceeded at all stations below the minesite outfall, and in the Athabasca River 100 m below the Muskeg River mouth, as a result of the 12 April flood. On 10 April, the objective was exceeded at Station 4, but on all other sampling dates the objective was met.

High turbidity in the minesite drainage water caused increased turbidity at Station 4 in March and on 10 April, and the slug of 12 to 13 April flood water was detectable by the elevated turbidities at stations 1 and 2 on 14 April (Figure 7). On the latter date, a turbidity of 60 $\pm$ 0.6 NTU ($\bar{x} \pm$ SE, N=3) was recorded at the mouth of the Muskeg River (Table 5). One hundred metres downstream on the Athabasca River, turbidity was increased to 55 NTU (N=1), 29 NTU

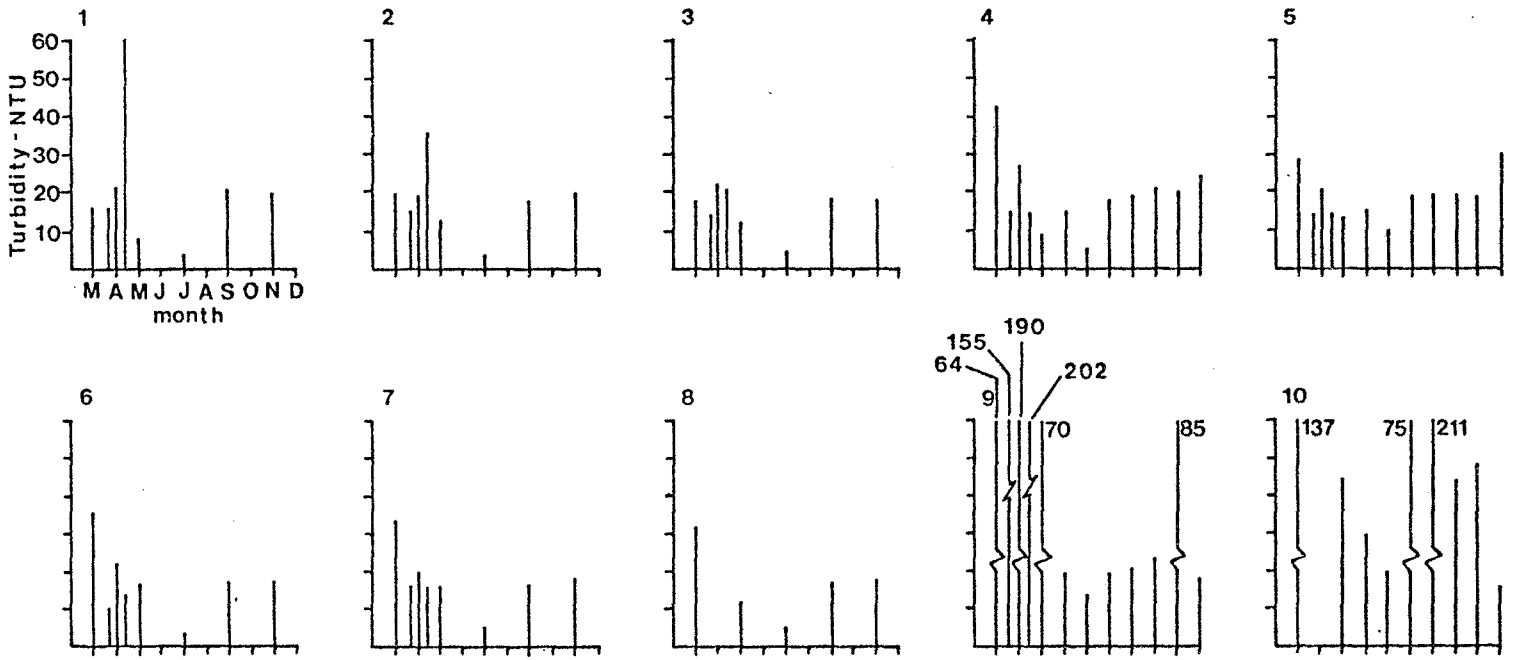

Figure 7. Turbidity in waters of the Muskeg River drainage, March to December 1980. The datum plotted for Station 4, 3 April (left bar) refers to a point approximately 4.5 km below the station.

above the control levels found 30 m above the Muskeg River ($\bar{x} \pm SE$ = 26 $\pm$ 0.6, N=3). In May, high turbidity drainage water diverted past Station 4 caused no increase in turbidity at Station 3. The addition of the settling pond apparently reduced turbidity in the minesite drainage water on most sampling occasions after May, and turbidities were, at worst, only slightly elevated at Station 4 thereafter.

The Alberta Water Quality Objectives for turbidity are expressed in Jackson turbidity units (JTU). Turbidity data in this report are expressed in nephelometric turbidity units (NTU), because the nephelometric method is more sensitive to low turbidity levels (Standard Methods 1975). The two units of measurement cannot be satisfactorily cross-calibrated (Standard Methods 1975:131), so it is not possible to determine whether the water quality objectives were exceeded.

The effects of "forest filtration", discussed previously in this section, on turbidity, were similar to its effects on suspended solids. On 3 April, turbidity in the minesite drainage ditch at or above the road crossing were 155 and 140 NTU (Table 4). Partway through the forest, the turbidity was still high, at 160 NTU. After passing through the forest, water at five discharge points had turbidities ranging from 15 to 95 NTU (mean 57.4 NTU). On 10 April, however, turbidities at or near the road crossing were 170 to 190 NTU (N=2). At four points in, or below, the forest area, turbidities of 34, 155, 220 and 260 NTU were found, the latter in the main channel that had been eroded since the previous sampling date. It appears that "forest filtration" was initially effective in reducing the turbidity

of the minesite drainage water, but that later erosion actually increased turbidity levels.

2.2.5 pH, Conductance and Major Ions

The pH differed little among the stream stations--seldom more than 0.3 units on comparable sampling dates (Figure 8). The pH at Station 4 in July was approximately 0.5 units higher than that at Station 5 on the same date, but was within 0.03 to 0.23 units of that at the other three control stations. The minesite drainage water thus had little effect on pH in the Muskeg River, and was not altered by more than 0.5 units from the background value, the Alberta Water Quality Objective (Alberta Environment 1977).

The pH was not obviously affected by "forest filtration" (see discussion of suspended solids) of the minesite drainage water. On 3 April, the pH at two locations near or above the road crossing was 7.48 and 7.89 (Table 4). In six samples taken within and below the forest, pH ranged from 7.66 to 7.92. On 10 April, the pH at two locations at or near the road crossing was 7.56 and 7.75. In four samples taken in or below the forest, pH ranged from 7.53 to 7.86.

The effect of the 12 to 13 April flood water on pH in the Athabasca River was examined on 14 April (Table 5). One hundred metres below the Muskeg River confluence on the true right bank, pH was 7.81, the same as the Muskeg River flood water (7.83), but slightly lower than the pH at the control site 30 m above the confluence (7.97 + 0.02, N=3). This change is within the Alberta Water Quality Objective

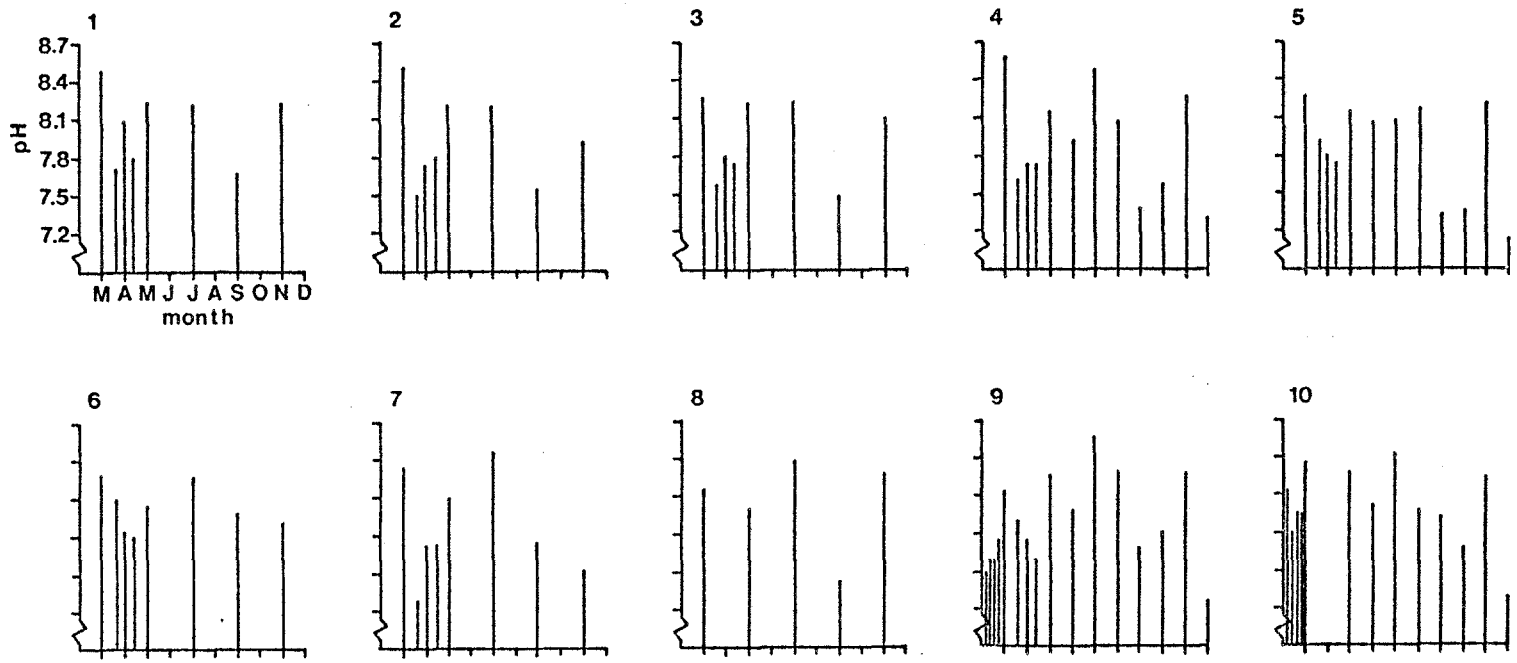

Figure 8. pH of waters in the Muskeg River drainage, February to December, 1980. The datum plotted for Station 4, April 3 (left bar) refers to a point approximately 4.5 km below the station.

(not more than a 0.5 unit change, Alberta Environment 1977). In any case, the flood water entering the Athabasca River on April 15 had a pH that differed from control concentrations in the Muskeg River (stations 5, 6 and 7) by not more than 0.11 units.

Akena (1979) reported that most pH measurements for the Muskeg River drainage in 1976 to 1977 fell within the range 7.12 to 8.2, approximately the same as that found in 1980 (mostly 7.2 to 8.3, Figure 8).

Conductivity, a measure of total dissolved solids, tended to be highest during low-flow periods and lowest during high-flow periods (Figure 9, cf. Figure 2, Volume I). A similar pattern was noted for the period 1976 to 1978 by Schwartz (1980) and reflects the relatively greater contribution of high-conductivity groundwater during periods of low flow.

Conductivity of the minesite ditch water was higher than that of Muskeg River water on all sampling dates except 25 March and 3 April (Figure 9). The drainage water caused only a barely-detectable increase in conductivity at Station 4 in comparison to Station 5 on most sampling dates. Higher conductivity on 3 April was found at stations 1, 2, 3 and approximately 4.5 km below Station 4 in comparison to that at two of three control stations. Minesite drainage water at the time had conductivity no greater than that at control stations, so probably did not cause the slight increases observed.

"Forest filtration" (see discussion of Suspended Solids) had no consistent effect on the conductivity of the minesite drainage water (Table 4). Conductivity at or above the road crossing was 0.408

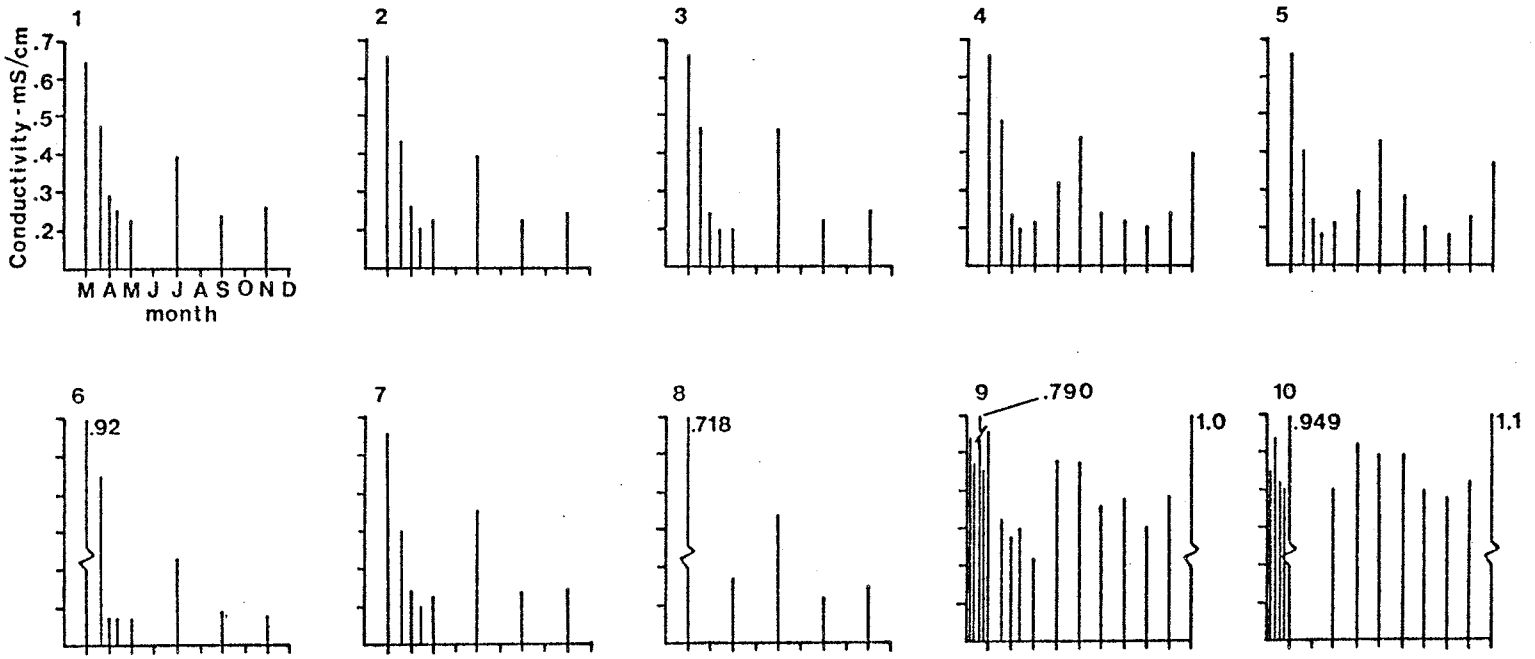

Figure 9. Conductivity at 25°C of waters in the Muskeg River drainage, February to December, 1980. The datum plotted for 3 April at Station 4 refers to a point 4.5 km below the station.

mS/cm on 3 April; below or in the forest area it ranged from 0.384 to 0.432 mS/cm. On 10 April, conductivity ranged from 0.371 to 0.384 mS/cm at or near the road crossing, and was 0.366 to 0.444 mS/cm in or below the forest.

On 14 April, the flood water from the Muskeg River slightly reduced conductivity in the Athabasca River 100 m below the confluence (Table 5). The conductivity, pH, turbidity, suspended solids and BOD data indicate there was little mixing of Athabasca and Muskeg River water within 100 m downstream of the confluence.

The sum of constituents, of which conductivity is a measure, was calculated for each detailed analysis in the manner recommended by Thomas (1953). The two measures were related by the least-squares regression equation

$$S = 0.6013C - 8.7857 \quad r^2 = 0.97 \quad N = 33 \ .$$

where S is sum of constituents in mg/L, and C is conductivity in µS/cm @ 25 Celsius, when analyses that failed various checks for internal consistency were eliminated. This equation will slightly underestimate the true sum of constituents because the data used to derive it rarely included the concentration of sulphate, which was measured at a detection limit of 10 mg/L, but was probably present at a few mg/L (Schwartz 1980:15).

The major ions in the natural waters of the Muskeg River system are calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), sulphate ($SO_4^{=}$) and chloride (Cl^{-}) (Schwartz 1980). At most pH values recorded (<8.4),

carbonate ($CO_3^=$) ion is present only at insignificant concentrations (Hutchinson 1957:657). In terms of reactive concentrations (milliequivalents per litre), the approximate order of ion dominance is $Ca^{++} > Mg^{++} > Na > K$ for cations and $HCO_3^- > SO_4^= > Cl$ for anions. The relative concentrations of Mg^{++} and Na^+ among the cations is variable, but Na^+ concentrations tend to be relatively high. The relative concentrations of $SO_4^=$ and Cl^- is not clear because of analytical problems in the $SO_4^=$ data of Akena (1979) and Schwartz (1980), and because of the high detection limit for $SO_4^=$ in the data presented here, but Cl^- concentrations tend to be relatively high.

Figures 10 to 14 summarize the 1980 data on major ions at ten stations in the Muskeg drainage, and show the impact of minesite drainage water on major ion concentrations in the Muskeg River on the dates sampled.

On 25 March (Figure 10), major ion concentrations at stations 1 to 4 were within the range found at control stations on the Muskeg River, even though the minesite drainage water being added just above Station 4 was more dilute with respect to Mg^{++}, Na^+, K^+ and Cl^-. Station 6 on Hartley Creek differed substantially from the other control stations. The total ion concentration of the water was higher in Hartley Creek, due mostly to much higher Na^+ and Cl^- concentrations. Hartley Creek in winter is characteristically higher in Na^+ and Cl^- than is Muskeg River water (Schwartz 1980: 15-16).

On 1 May (Figure 11), Station 4 differed from Station 5 only in having a slightly higher concentration of Cl^-. None of the

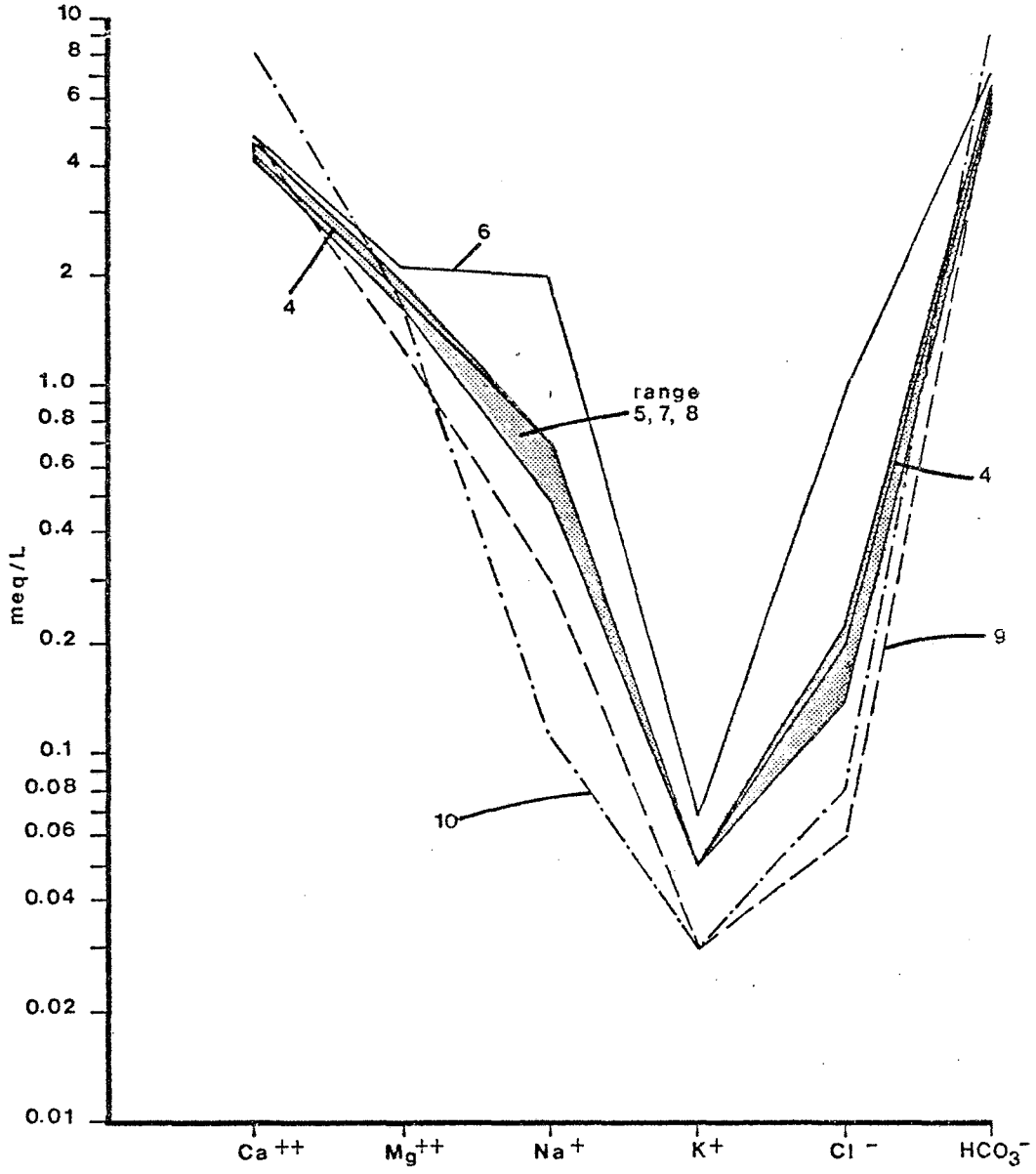

Figure 10. Major ion diagram, Muskeg River drainage, 25 March 1980. Numbers denote stations. Results for stations 1 to 3 fell within the control range (shaded).

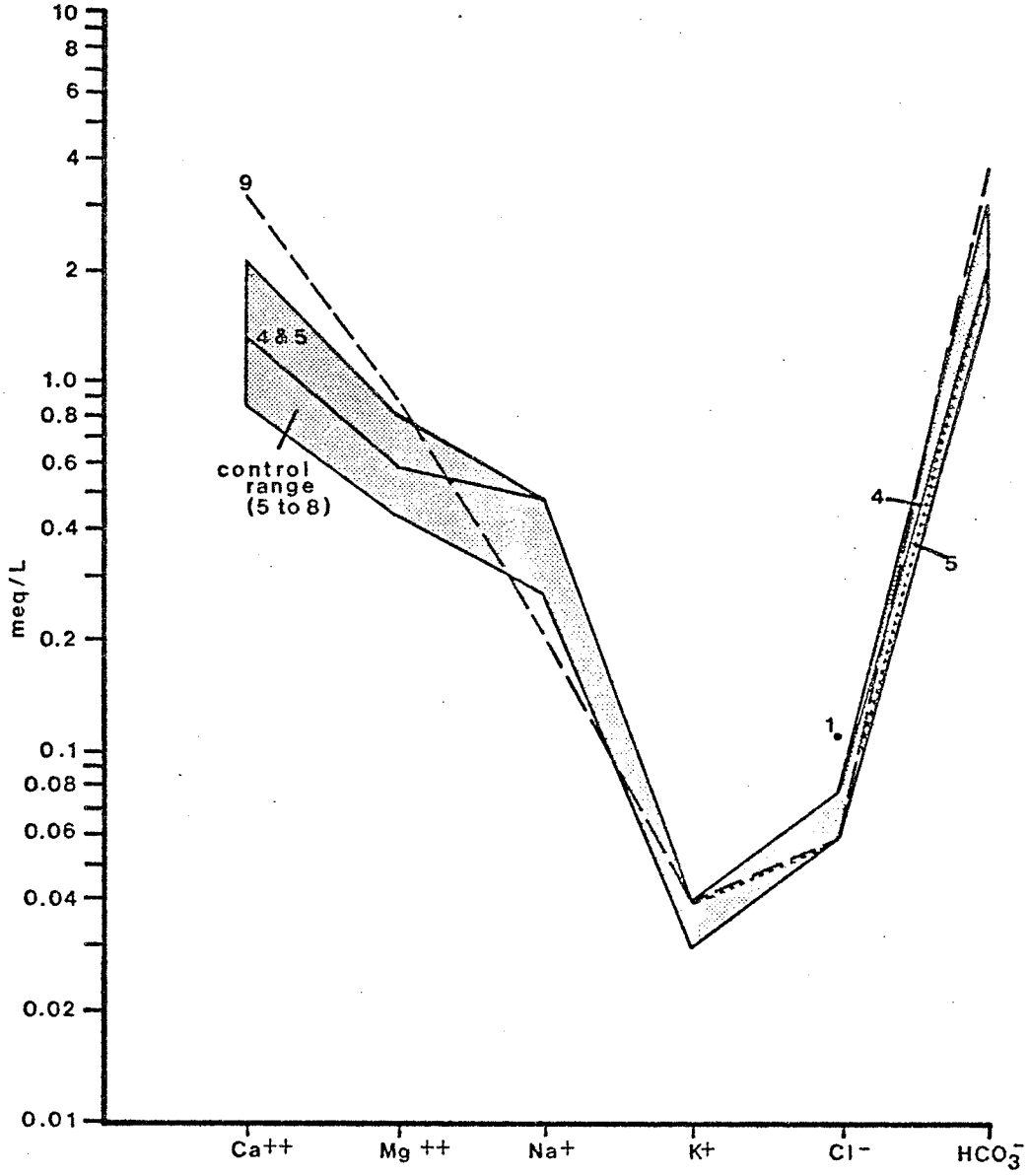

Figure 11. Major ion diagram, Muskeg River drainage, 1 May 1980. Numbers denote stations. Stations 1 to 3 fell within the control range except as noted.

stations below the outfall had concentrations of major ions beyond the range recorded at the control stations, except Station 1, which had a slightly higher concentration of Cl^-. These small differences were probably not caused by the minesite drainage water, which had a lower concentration of Cl^- than that at stations 4 or 1.

The 11 July samples were the only collections to show detectable levels of sulphate (at a limited of 10 mg/L) in stream water, so $SO_4^=$ was added to the ionic diagram for that month (Figure 12). To draw the diagram it was necessary to assume a value for $SO_4^=$ when it was below the detection limit. This value was arbitrarily set at 1.4 meq/L, and is not a measured concentration.

In July (Figure 12), ionic composition at Station 4 differed slightly from that at Station 5, but was well within the range found at the four control stations. The minesite drainage water (Station 9) was slightly higher in Ca^{++}, Mg^{++} and HCO_3^-, and slightly lower in Na^+ and Cl^-, than the control water. Of the downstream stations (1 to 3), ion concentrations outside the control range were found only at Station 3, where Ca^{++} was slightly higher.

Chloride concentrations at Station 4 were slightly higher than the control range in September (Figure 13), but the other major ions were within the range. Other downstream stations also differed slightly from the control stations. Station 2 had a higher Ca^{++} concentration, and Station 3 was slightly higher in K^+ and lower in Cl^-. None of the deviations from control concentrations were large, however.

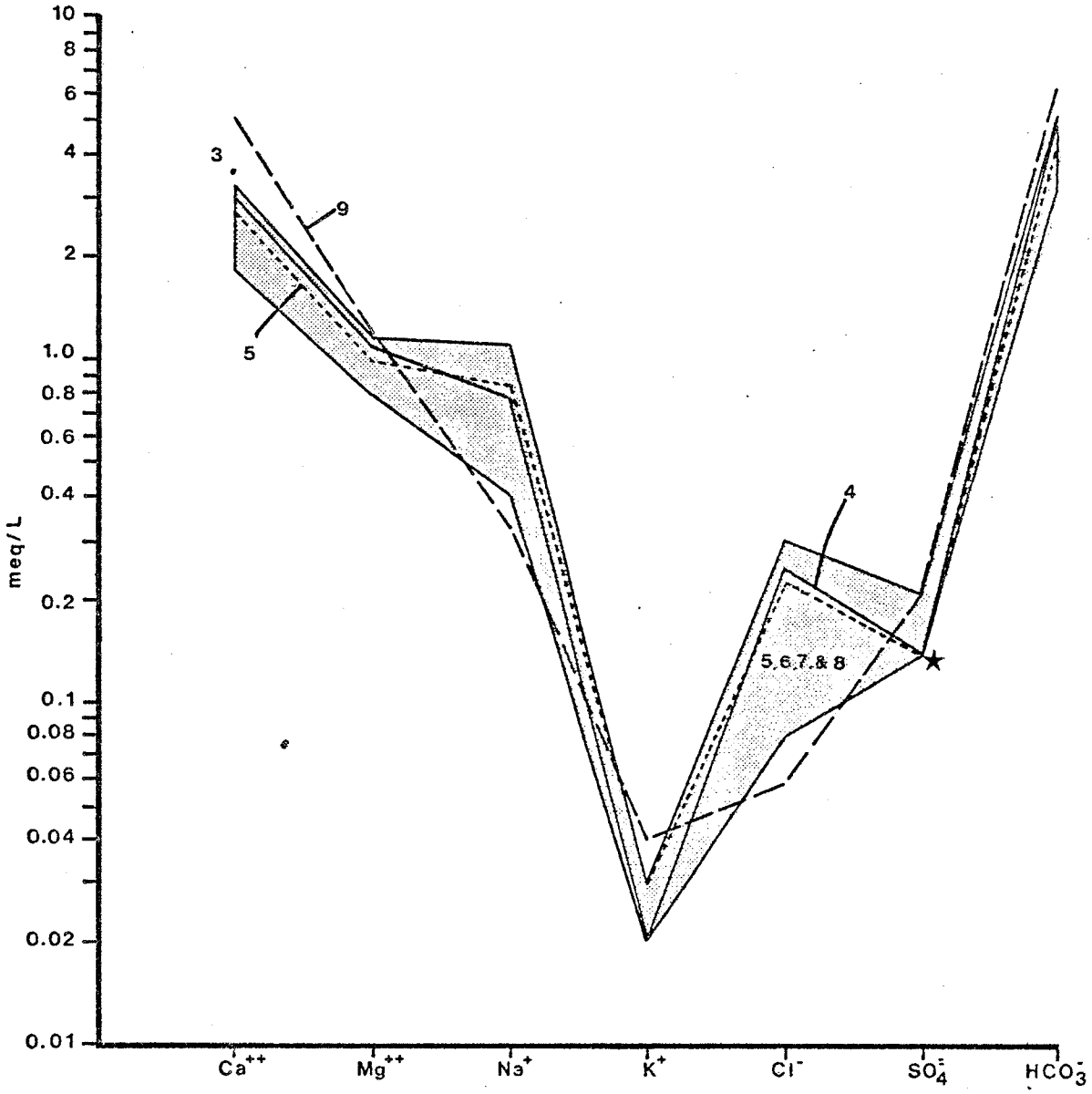

Figure 12. Major ion diagram, Muskeg River drainage, 11 July 1980. Numbers denote stations. The starred point for sulphate was set arbitrarily so that values below the 10 mg/L detection limit could be plotted. Data for stations 1 to 3 fell within the control range (shaded), except as noted.

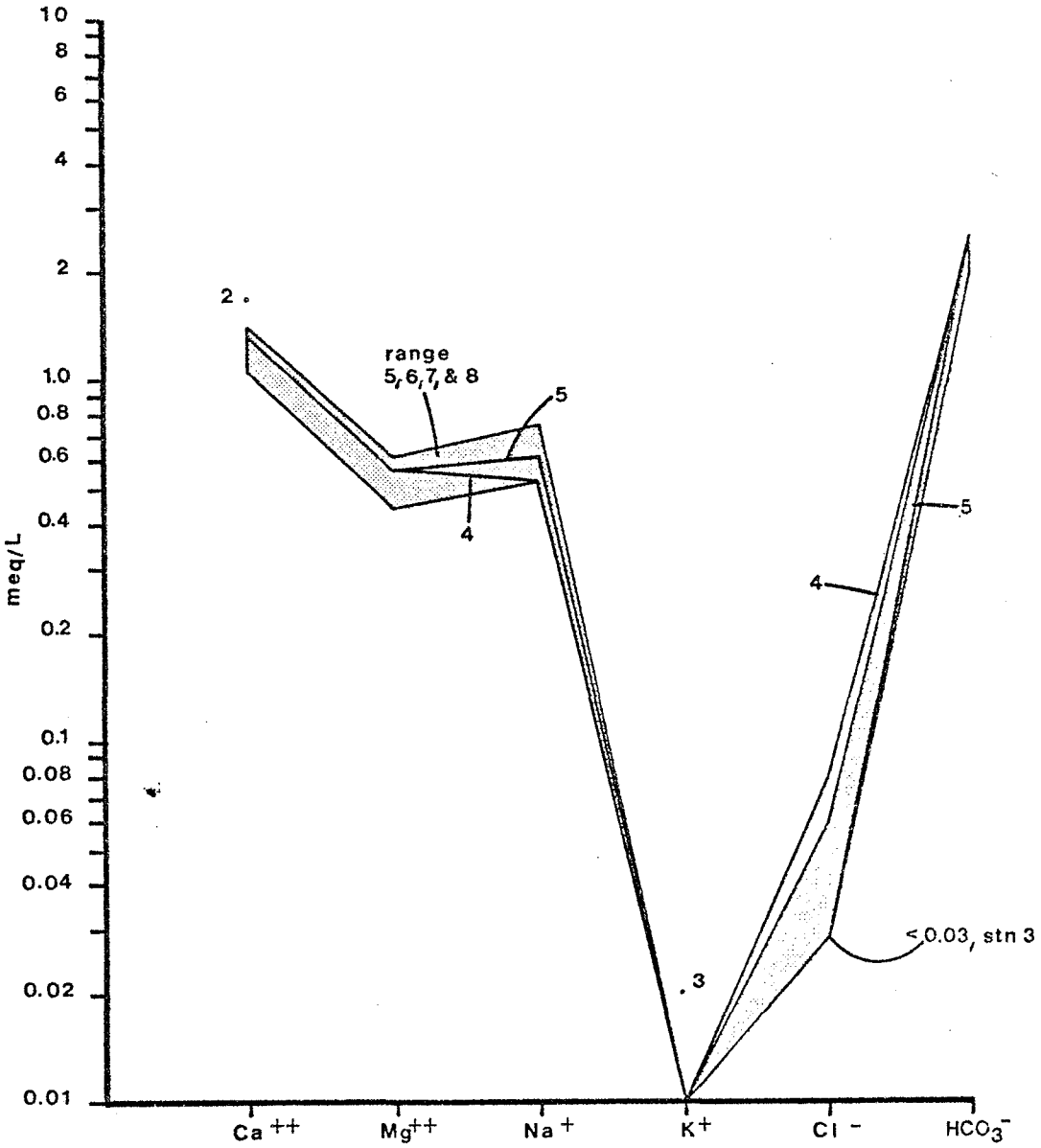

Figure 13. Major ion diagram, Muskeg River drainage, 10-11 September 1980. Numbers denote stations. Data for stations 1 to 3 fell within the control range except where noted otherwise. Station 9 was omitted (ions did not balance).

In November (Figure 14), all down-stream stations had major ion concentrations within the control range, except at Station 4, where Na^+ was just above the range.

2.2.6 Total Inorganic Carbon

Total inorganic carbon (TOC), a measure of organic loading, tended to be lowest in the March, May and July sampling periods at most stream stations (Figure 15). Highest concentrations were found in September, at a time of high discharge due to rainfall. TOC concentrations in the minesite drainage ditch were substantially higher than those at the control stations only in March. There was no clear increase in TOC at Station 4 or other downstream stations that could be attributed to the influence of minesite drainage water.

The maximum TOC listed by Seidner (1980) for the Muskeg River (35 mg/L) and Hartley Creek (36 mg/L) in 1976-77 were equalled or exceeded only in September in 1980 at stations 1, 4, 5, 6 and 7, but only at Station 1 (43 mg/L) was the September 1980 TOC concentration greater than 36 mg/L. Higher TOC levels were recorded twice in the drainage ditches in winter, however (Figure 15).

2.2.7 Nitrogen and Phosphorus

Ammonia-, nitrate- and nitrite-nitrogen were below the detection limit at all 10 stations on all five sampling dates in 1980.

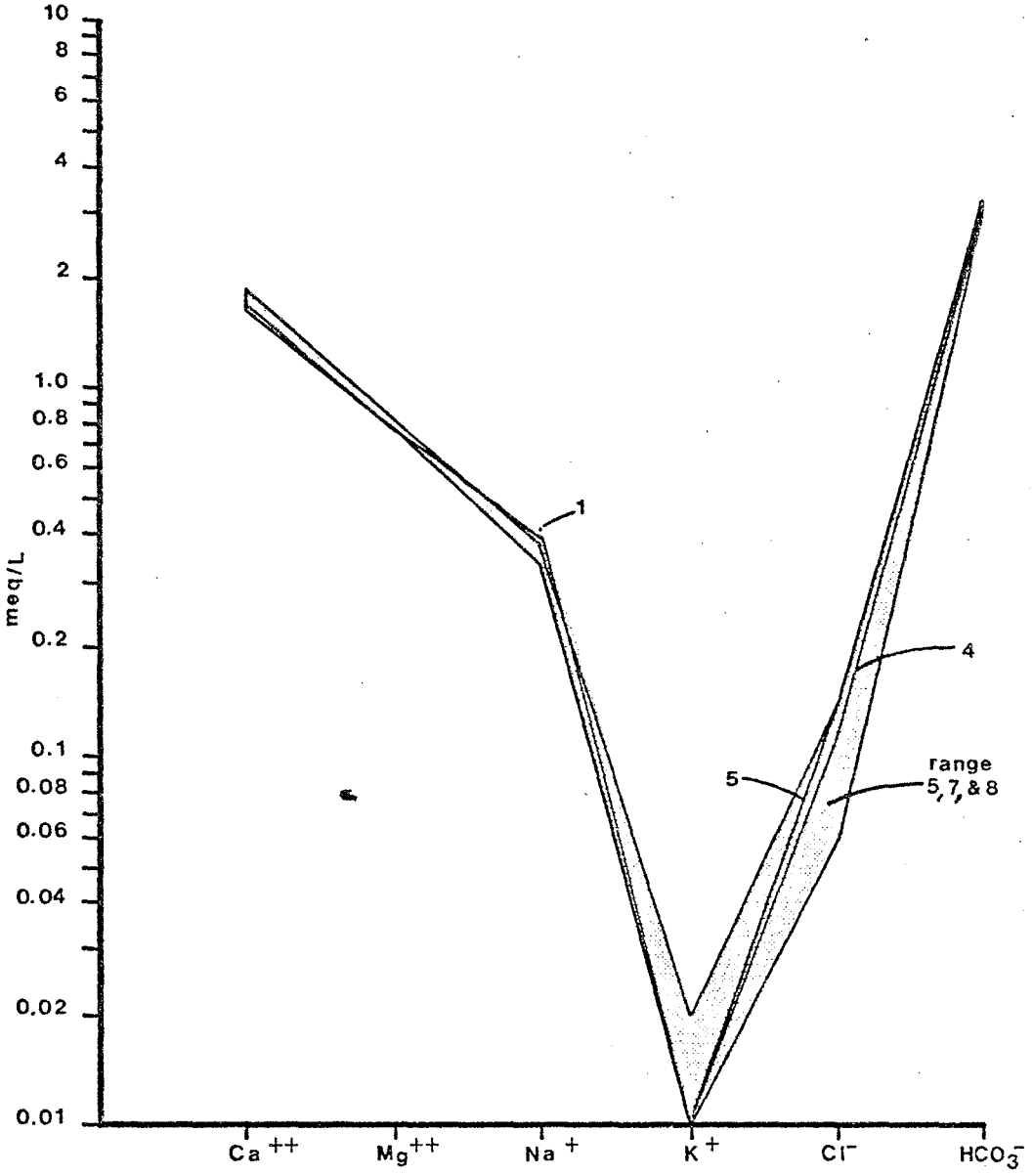

Figure 14. Major ion diagram, Muskeg River drainage, 12 November 1980. Numbers denote stations. Values for stations 1 to 3 fell within the control range except where noted otherwise. Stations 6 and 9 not included (ions did not balance).

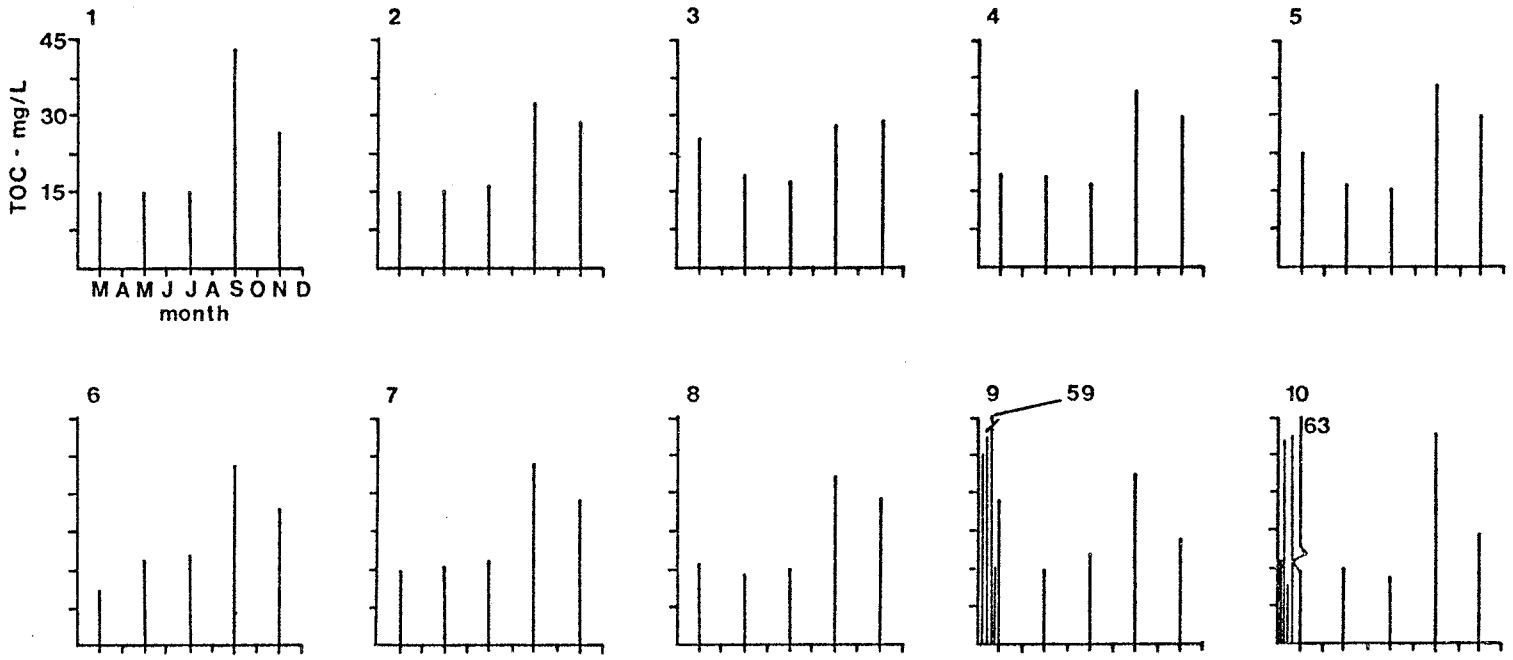

Figure 15. Total organic carbon (TOC) concentrations, Muskeg River drainage, February to November 1980.

The detection limit for ammonia-N was 1 mg/L; that for nitrate- and nitrite-N was usually 0.1 mg/L.

Total Kjeldahl nitrogen (TKN) concentrations, an indicator of organic nitrogen, were uniformly low at all stream stations on all sampling dates (Table 6). The maximum concentration observed at these stations was 2.4 mg/L, and TKN was commonly undetected at a limit of 1 mg/L. TKN exceeded the maximum reported for the Muskeg River by Seidner (1980) of 1.66 mg/L in 5 of 20 samples from stations 1 to 4, and equalled the maximum in 2 of 20 samples from the control stations 5 to 8. TKN concentrations in the minesite and plantsite drainage ditches tended to be marginally higher than those at the stream sites, but exceeded 3.7 mg/L only on the early February sampling date, when concentrations were 16 and 26 mg/L, respectively, in the two ditches.

Total phosphate (as phosphorus), like TKN, was uniformly low at all the stream stations on all sampling dates (Table 7). Maximum concentrations of 0.060 mg/L were found at stations 6 and 8 on 25 March, well below the maxima previously reported for the Muskeg River and Hartley Creek of 0.09 and 0.33 mg/L, respectively (Seidner 1980). Total phosphate concentrations were always low in the drainage ditches also.

On 20 June 1980, the cleared areas on the Alsands site were seeded and fertilized. Stream and ditch water was monitored for phosphates, nitrogen, potassium and sulphate before and after application to determine the effect of fertilization on water quality. The results are presented in Table 8. Station 9a is immediately

Table 6. Total Kjeldahl nitrogen concentrations (mg/L), Muskeg River drainage, February to November, 1980.

Date	Station 1	2	3	4	5	6	7	8	9	10
80/02/09									16	26
80/02/23									3.7	2.4
80/03/08									2.8	1.9
80/03/24									1.1	1.1
80/03/25	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
80/05/01	1.5	1.8	1.4	2.2	<1	<1	<1	1.2	1.5	3.2
80/07/11	1.9	1.4	1.8	2.4	1.7	1.5	1.4	1.7	1.4	1.6
80/09/	<1	<1	1.1	<1	<1	<1	<1	<1	2.7	1.4
80/11/12	1.2	1.6	1.3	1.5	1.2	1.4	1.2	1.2	1.7	2.2

Table 7. Total phosphate (as P) in mg/L, Muskeg River drainage, February to November 1980.

Date	Station 1	2	3	4	5	6	7	8	9	10
80/02/09									<0.001	<0.001
80/02/23									0.04	0.03
80/03/08									<0.01	<0.01
80/03/24									0.03	0.04
80/03/25	0.02	0.03	0.03	0.03	0.04	0.06	0.04	0.06	0.06	0.03
80/05/01	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.03	0.03	0.03
80/07/11	0.02	0.01	0.01	0.02	0.03	0.01	0.02	0.02	0.01	0.02
80/09/10-11	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
80/11/12	0.02	0.01	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.04

Table 8. Results of nutrient monitoring for fertilization study, June and July, 1980.

		Station							
		9a	9b	2	3	4	5	6	7
Before Treatment: June 19-20, 1980									
Ortho Phosphate	P	0.010	0.015	0.005	0.020	0.020	0.010	0.010	0.005
Total Dissolved Phosphate	P	0.055	0.040	0.025	0.025	0.025	0.015	0.025	0.035
Potassium	K	1.400	1.500	0.800	0.800	0.800	0.800	0.600	1.100
Sulphate	SO_4	41.000	34.000	18.000	21.000	21.000	25.000	8.200	5.200
Nitrate	N	0.100	0.070	0.060	0.080	0.110	0.090	0.100	0.060
Kjeldahl Nitrogen	N	1.650	1.500	0.950	1.100	1.300	1.100	0.950	1.200
After Treatment: June 20, 1980									
Ortho Phosphate	P	0.950	1.750	<0.005	0.005	0.075	0.020	<0.005	<0.005
Total Dissolved Phosphate	P	0.950	1.760	0.050	0.025	0.075	0.035	0.035	0.035
Total Phosphate	P	1.550	2.150	0.055	0.040	0.075	0.055	0.040	0.060
Potassium	K	3.200	3.500	0.800	0.800	1.000	0.800	0.600	0.900
Sulphate	SO_4	15.500	15.500	4.800	4.800	7.000	7.500	7.700	7.500
Nitrate	N	0.200	0.060	0.010	0.020	0.100	0.060	0.050	0.060
Kjeldahl Nitrogen	N	6.500	6.250	1.000	1.000	1.650	1.250	0.950	0.900

Continued . . .

Table 8. Continued.

		Station							
		9a	9b	2	3	4	5	6	7
June 24, 1980									
Ortho Phosphate	P	0.030	0.520	0.010	0.020	0.035	0.015	0.020	0.026
Total Dissolved Phosphate	P	0.035	0.520	0.040	0.050	0.140	0.055	0.050	0.070
Total Phosphate	P	0.110	0.755	0.055	0.060	0.165	0.075	0.060	0.095
Potassium	K	1.700	2.400	0.800	0.900	1.000	0.700	0.700	1.200
Sulphate	SO_4	14.500	16.500	5.000	5.500	6.700	7.500	8.200	6.700
Nitrate	NO_3	0.040	0.110	0.010	0.030	0.060	0.040	0.030	0.020
Total Kjeldahl Nitrogen	N	1.700	3.300	1.000	1.150	1.150	1.100	0.850	1.750
June 30 - July 1, 1980									
Ortho Phosphate	P	0.020	0.025	0.010	0.015	0.005	0.015	0.010	0.015
Total Dissolved Phosphate	P	0.090	0.125	0.075	0.060	0.095	0.050	0.055	0.065
Total Phosphate	P	0.110	0.220	0.090	0.060	0.160	0.105	0.085	0.110
Potassium	K	1.400	1.600	0.800	0.800	1.000	0.700	0.700	0.900
Sulphate	SO_4	15.700	15.700	5.200	6.700	10.300	7.500	8.000	7.500
Nitrate	NO_3	0.030	0.020	0.040	0.050	0.020	0.050	0.040	0.040
Total Kjeldahl Nitrogen	N	0.650	0.530	0.510	0.500	1.100	0.620	0.600	0.700

upstream of the settling pond; 9b is immediately downstream of the pond.

Immediately after fertilization (the same day), phosphate, potassium, and total Kjeldahl nitrogen increased markedly in the drainage ditch water (9a and 9b), but water in the Muskeg River (Station 4) was not clearly affected.

Four days later on 24 June 1980, phosphate, potassium and Kjeldahl-N concentrations had returned to near pre-treatment levels at Station 9a, but were still clearly elevated at Station 9b. At Station 4 on the Muskeg River, phosphates (total dissolved and total) were elevated above pretreatment and control station levels, but other monitored constituents were not obviously affected. Further downstream at Stations 2 and 3, levels of all monitored constituents were similar to pretreatment and control concentrations.

Ten to eleven days after treatment (30 June to 1 July), levels of monitored constituents were near or at pretreatment levels at Station 9a, but total dissolved phosphates and total phosphates were still elevated above pretreatment concentrations at Station 9b. At station 4 on the Muskeg River, phosphates were higher than pretreatment or control station levels, but levels of other monitored constituents had returned to near pretreatment and control concentrations. Downstream stations on the Muskeg River (2 and 3) continued to show no effect of the fertilization treatment on water quality.

By 11 July 1980, 21 days after treatment, concentrations of most monitored constituents, including phosphates, had decreased to

pretreatment and control levels (Table 7). Kjeldahl-N was slightly higher at station 4, but not at stations 5 or 9.

Station 7, a control station, appeared to show a slight but prolonged increase in phosphates during the monitoring period, although other constituents remained relatively unchanged. Station 7 was close to the area where fertilizer was loaded onto the helicopter for spreading. It may be that windblown fertilizer caused the apparent slight increase in phosphates at this station.

Sulphates appeared to show a sharp decrease at most stations from pretreatment to immediate post-treatment sampling times. This was caused by a change in sensitivity of a laboratory procedure used by the analysts, and is not a real change in concentration (Dr. G. Dyson, 1980, Senior Chemist, United Petro Laboratories, personal communication).

The results outlined above show that fertilization had a distinct but short-term and spatially-restricted effect on the quality of the water in the Muskeg River and the minesite drainage ditch.

2.2.8 Metals

Iron (Fe), manganese (Mn), copper (Cu), nickel (Ni), vanadium (V), zinc (Zn), chromium (Cr), lead (Pb), arsenic (As) and mercury (Hg) were determined from unfiltered samples, therefore the following data all refer to total concentrations.

Total iron concentrations ranged from 0.017 to 1.06 mg/L at the eight stream stations during the five sampling periods in 1980

(Table 9). All concentrations were below the means previously reported for the Muskeg River and Hartley Creek of 1.42 and 1.1 mg/L, respectively (Seidner 1980). Similarly low concentrations of iron were found in the drainage water at stations 9 and 10. The data provide no clear evidence of a change in iron in Muskeg River water that is attributable to the influence of minesite drainage water.

Total manganese at the eight stream stations ranged from 0.007 to 1.096 mg/L during the five periods sampled (Table 10). Both limits thus lie beyond the previously reported minima and maxima of 0.015 to 0.97 mg/L, and 0.009 to 0.42 mg/L for the Muskeg River and Hartley Creek, respectively (Seidner 1980). The mean Mn concentration reported by Seidner (1980) for the Muskeg River (0.21 mg/L) was attained only once in the Muskeg River in the 1980 samples, at Station 8 on March 25 (0.294 mg/L). Total Mn in the drainage waters (stations 9 and 10) ranged from 0.022 to 0.804 mg/L, within the previously reported range for natural waters in the drainage basin. The data provide no evidence of a change in total Mn in Muskeg River water attributable to the effects of minesite drainage.

Total copper concentrations at the stream sites ranged from less than 1 to 25 µg/L (Table 11), within the range recorded for 1976 and 1977 in the Muskeg River and Hartley Creek (<1 to 26 µg/L and <1 to 28 µg/L, respectively) by Seidner (1980). Minesite drainage water had total copper concentrations of from <1 to 26 µg/L. In the plantsite drainage water, the range of total copper concentrations was from 2 to 25 µg/L. There was no evidence that

Table 9. Total iron (mg/L), Muskeg River drainage, February to November 1980.

Date	Station 1	2	3	4	5	6	7	8	9	10
80/02/09									0.29	1.00
80/02/23									0.92	0.54
80/03/08									0.13	0.03
80/03/24									0.12	0.13
80/03/25	0.061	0.047	0.040	0.048	0.114	0.036	0.047	0.017	0.037	0.095
80/05/01	0.45	0.64	0.62	0.64	0.68	0.30	0.92	1.06	0.13	0.32
80/07/11	0.096	0.091	0.092	0.105	0.107	0.104	0.111	0.102	0.090	0.124
80/09/10-11	0.35	0.38	0.35	0.35	0.35	0.30	0.35	0.33	0.56	1.45
80/11/12	0.13	0.13	0.13	0.13	0.13	0.12	0.14	0.14	0.14	0.14

Table 10. Total manganese (mg/L) Muskeg River drainage, February to November 1980.

Date	Station 1	2	3	4	5	6	7	8	9	10
80/02/09									0.15	0.35
80/02/23									0.38	0.45
80/03/08									0.065	0.022
80/03/24									0.077	0.072
80/03/25	0.009	0.007	0.037	0.035	0.043	0.096	0.027	0.294	0.065	0.804
80/05/01	0.037	0.058	0.060	0.052	0.058	0.005	0.043	0.070	0.036	0.100
80/07/11	0.033	0.010	0.001	0.022	0.050	0.024	0.034	0.014	0.032	0.071
80/09/10-11	0.107	0.043	0.037	0.046	0.033	0.038	0.028	0.053	0.102	0.104
80/11/12	0.080	0.092	0.095	0.092	0.095	0.071	0.094	0.101	0.113	0.111

Table 11. Total copper (µg/L), Muskeg River drainage, February to November 1980.

Date	Station 1	2	3	4	5	6	7	8	9	10
80/02/09									7	7
80/02/23									26	26
80/03/08									8	13
08/03/24									13	10
80/03/25	6	7	3	6	10	6	9	17	11	29
80/05/01	5	<1	<1	<1	<1	3	<1	25	14	2
80/07/11	19	19	8	7	14	3	4	<1	9	13
80/09/10-11	1	<1	3	6	<1	<1	3	<1	2	2
80/11/12	2	<1	2	<1	<1	2	2	<1	<1	2

minesite drainage water seriously increased total copper concentrations in the Muskeg River.

Total nickel concentrations frequently exceeded the 1976-77 maximum of 10 µg/L reported by Seidner (1980) for the Muskeg River, even at the control stations (Table 12). Two very high concentrations were found: 100 µg/L at the plantsite drainage ditch in late February, and 333 µg/L at Station 4 in July. Concentrations of nickel up to 46 µg/L were found at the control stations. Nickel concentrations were considerably higher at Station 4 than at the control stations on 11 July and 10 to 11 September.

Seidner (1980) never found detectable concentrations of total vanadium (detection limit µg/L) in the 1976-77 samples from Muskeg River and Hartley Creek. In contrast, total vanadium ranged from 29 to 109 µg/L at the four control stations on two 1980 sampling dates (Table 13). Similarly high concentrations, up to 126 µg/L, were usually found on the same sampling dates at the four downstream stations (1 to 4), and in the minesite drainage water (Station 9). With the exception of Station 1 on May 1, vanadium concentrations were below the 1 µg/L detection limit on all other sampling dates at all stream sites and in the drainage ditch.

Because of the high vanadium levels at the control sites, some natural mechanism must explain the results. The high concentrations occurred during low-flow periods in March and July, when groundwater contributes a relatively greater proportion to flow. Vanadium in groundwater therefore may account for the high stream concentrations found.

Table 12. Total nickel concentrations (µg/L), Muskeg River drainage, February to November 1980.

Date	Station 1	2	3	4	5	6	7	8	9	10
80/02/09									25	35
80/02/23									54	100
80/03/08									12	20
80/03/24									18	18
80/03/25	17	8	23	28	12	46	31	19	23	69
80/05/01	17	8	12	10	10	11	17	14	23	24
80/07/11	15	8	19	333	16	9	18	15	13	22
80/09/10-11	<1	3	<1	43	<1	<1	7	<1	<1	<1
80/11/12	<1	2	4	<1	<1	<1	<1	3	3	2

Table 13. Total vanadium concentrations (µg/L) Muskeg River drainage, February to November, 1980.

Date	Station 1	2	3	4	5	6	7	8	9	10
80/02/09									70	140
80/02/23									<1	<1
80/03/08									-	-
80/03/24									-	-
80/03/25	78	126	89	113	76	109	65	69	107	276
80/05/01	20	<1	<1	<1	<1	<1	<1	<1	<1	24
80/07/11	17	1	24	41	41	29	70	32	81	62
80/09/10-11	<1	<1	<1	<1	<1	<1	<1	<1	<1	< 1
80/11/12	<1	<1	<1	<1	<1	<1	<1	<1	<1	< 1

Total zinc concentrations never reached the maximum 1976-77 concentration of 91 µg/L recorded by Seidner (1980) for the Muskeg River and Hartley Creek (Table 14). Levels of zinc at the control stations ranged from <1 to 28 µg/L, and often exceeded those at downstream stations (range <1 to 12 µg/L). Concentrations of total zinc reached 59 µg/L in the minesite drainage ditch in February, but on most other occasions were at or near the 1 µg/L detection limit, and had caused no large increases in zinc in the Muskeg River below the outfall.

Total chromium concentrations at the stream stations did not reach the 16 µg/L maximum reported by Seidner (1980) for the Muskeg River in 1976-77, but the late March sample from Hartley Creek had a higher chromium content than Seidner's previously-reported maximum of 10 µg/L (Table 15). Detectable concentrations occurred only during low-flow periods in March and July, suggesting that groundwater, which contributes a relatively high proportion of the flow at such times, was responsible for the relatively high concentrations of chromium. Concentrations of chromium were higher at Station 4 than at Station 5 in both March and July, but higher concentrations occurred at other control stations in March.

Lead was seldom found at detectable concentrations (>1 µg/L) at the stream stations, but was occasionally high in the drainage water. In September, lead at downstream stations 1 and 4 reached 9.8 and 5 µg/L, respectively.

At control stations 7 and 8, concentrations of 3 and 8 µg/L, respectively, were found. A September lead concentration of 3

Table 14. Total zinc concentrations (µg/L), Muskeg River drainage, February to November 1980.

	Station									
Date	1	2	3	4	5	6	7	8	9	10
80/02/09									<1	<1
80/02/23									59	35
80/03/08									<1	<1
80/03/24									<1	<1
80/03/25	6	<1	4	4	7	28	10	11	4	5
80/05/01	<1	12	<1	4	<1	<1	<1	<1	<1	<1
80/07/11	11	3	6	2	3	2	<1	7	27	35
80/09/10-11	6	3	3	2	8	5	5	7	5	<1
80/11/12	<1	<1	<1	<1	<1	<1	2	2	1	1

Table 15. Total chromium concentrations (µg/L), Muskeg River drainage, February to November 1980.

	Station									
Date	1	2	3	4	5	6	7	8	9	10
80/02/09									5	10
80/02/23									2	<1
80/03/08									3	6
80/03/24									9	11
80/03/25	11	8	3	4	2	10	3	15	32	15
80/05/01	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
80/07/11	4	1	2	10	5	3	4	1	8	10
80/09/10-11	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
80/11/12	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1

µg/L was found in the plantsite drainage water (Station 10). In November, total lead concentrations at stations 9 and 10 were 21 and 26 µg/L, respectively. The November sample from Station 1 had a concentration of 13 µg/L total lead. February and March samples collected by Hardy Associates showed lead concentrations of 125 µg/L in the minesite drainage water on 23 February, and 16 to 61 µg/L in February in the plantsite drainage water. In all other samples, lead concentrations were below the detection limit.

Arsenic and mercury were found at detectable concentrations (>5 µg/L and > 0.2 µg/L, respectively) only in winter in the drainage water. Arsenic reached 56 µg/L at Station 10 on 20 and 24 March µg/L at Station 9 on 23 February and 24 March. The highest mercury concentration found was 0.4 µg/L at Station 9 on 23 February.

2.2.9 Phenol, and Oils and Grease

Concentrations of phenol were nearly always below the 0.001 mg/L detection limit. In February, phenol at 4 and 8 mg/L was found at Station 10, and Station 9 samples had phenol concentrations of 8 mg/L. The only other detectable concentrations were found in July, when stations 7 to 10 had phenol levels of 0.001 mg/L.

Oils and grease were at detectable concentrations (> 1 mg/L) only in February in the drainage ditch water. At Station 10, these concentrations were 20 and 30 mg/L on two dates; at Station 9, they were 20 and 90 mg/L on two dates.

2.3 Conclusions

The most pronounced effects of muskeg drainage on the water quality of the Muskeg River were increases in suspended solids and turbidity, especially as a result of the April flood accident, and a temporary, short-term increase in nutrient concentrations immediately below the minesite drainage outfall caused by a fertilizer application to the ditched areas during seeding operations. Dissolved oxygen concentrations at Station 4 may have been slightly decreased temporarily by decomposition of organic sediment contributed by the April flood, and were certainly increased at Station 4 in March by aeration of water at the ditch outfall. Other water quality changes arising from the addition of minesite drainage water were usually slight, when they were detectable at all.

3.0 BENTHIC INVERTEBRATES

3.1 Methods

3.1.1 Selection of Stations and Substrate Types

The most common benthic habitat in the Muskeg River is depositional, in which the dominant substrates are the fine sediments sand, silt and mud (Walder et al 1980). For this reason, the benthic fauna of fine sediments was monitored most closely. It is in depositional areas that siltation, an important possible impact from muskeg drainage, would be heaviest. Sunken wood and other large debris is another common substrate type in the Muskeg River, as is stony bottom, although the latter is relatively more important in the erosional habitat of the lower reaches. Both of these hard substrate types were sampled at most stations in one period to determine if invertebrate communities of various substrates responded in the same ways to muskeg drainage.

Benthic invertebrates were collected at the ten stations sampled regularly for water quality (Figure 1). Stations 1 and 2 were erosional habitats characterized by stony substrate, and were selected

to represent the lower reaches of the Muskeg River, where the habitat type is common. Stations 3 to 10 were primarily depositional sites with fine sediment substrate, although short sections of stony substrate were present at or near stations 3, 4, 6 and 7.

The primary intention of the sampling design was to establish permanent stations that could be used to monitor the impact on the benthos of the Alsands project as a whole over the long term, not just to determine the effects of muskeg drainage on the river in 1980. The purpose in sampling regularly the benthos of the stony substrates at stations 1 and 2 was to provide a basis for comparison in subsequent years on the substrate type characteristic of the lower reaches of the Muskeg River. Good control sites on stony substrate above the Alsands lease are scarce or absent, so stations 1 and 2 are of little value in assessing impacts within sampling periods. The results of sampling at these stations are presented with the results of sampling on soft substrates (stations 3 to 8) in Section 3.2 only because it is a convenient way of summarizing the data, and not because stations 1 and 2 were expected to provide information on impact due to Muskeg drainage.

The ditch sites, stations 9 and 10, were not directly comparable to the river sites. They were sampled to determine if they were being colonized by benthic invertebrates. The degree of colonization, and the type of colonizing taxa, were examined to determine, under the most adverse conditions, how detrimental the muskeg drainage water might be.

For the purposes of the 1980 study, Station 4 is the principal impact station because it is just 100 m below the minesite drainage outfall, expected to be the most important source of any environmental impact. Station 3 is a "recovery" station several kilometres below the outfall. It would be expected to show less impact than Station 4, and should provide a measure of the degree of recovery from an impact at that point. Stations 5, 6, 7 and 8 are all considered control stations because they are all upstream of the expected impact point. Station 5 is the main control station because it is just 100 m above the minesite outfall, and only 200 m above the main impact station (4), which it closely resembles in its physical characteristics. Stations 6, 7 and 8 differ from stations 3, 4 and 5 in being narrower and deeper, and having lower discharge. Samples from stations 6, 7 and 8 provide a measure of the differences that occur naturally in the drainage, and that are unrelated to the effects of the minesite drainage water.

3.1.2 Field and Laboratory Methods

No practical sampler was available at the time the study was conducted that would sample all substrate types adequately[1],

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1. AEL has recently developed a lightweight, battery-operated airlift sampler that is useable in shallow or deep water without diver assistance, requires no compressed-air tanks and shows promise of being able to sample most substrates. This sampler should be tested in subsequent monitoring studies on the river.

therefore several sampling techniques had to be adopted. Fine sediments (stations 3 to 8) were sampled with an Ekman grab (15.24 cm^2). Triplicate samples were collected at each site at 3 random distances (table of random numbers or blind stick toss) across the width of the stream. Samples were sieved in the field (mesh aperture 0.47 mm) and stored in 10% formalin (4% formaldehyde) and Rose Bengal dye (100 mg of dye per litre of preservative) in whirlpac plastic bags for final sorting in the laboratory. The dye stains the animals pink, improving sorting efficiency (Lackey and May 1971).

Stony substrate at stations 1 and 2 were sampled with a 30 cm diameter Neill cylinder sampler (Neill 1938) fitted with a net of 0.77 mm mesh aperture. Randomly-allocated triplicate samples were collected and stored in the manner described above for Ekman samples.

Natural wood and debris substrates are difficult to sample quantitatively, so an artifical substrate, the multiplate sampler of Hester and Dendy (1962), was used to mimic sunken wood and debris. Each sampler consisted of nine tempered masonite plates (7.4 cm^2) separated by plastic washers and strung on a stainless steel eyebolt locked with a wingnut. The total surface area available for colonization was 1034.6 cm^2. Three multiplate samplers were set in place at random distances (table of random numbers) across a transect at each station 1 to 7 on 15 to 17 May and at Station 8 on 2 June, the next date on which a helicopter became available. At stations 1 and 2 the samplers were wedged into the gravel and cobble substrate to hold them in the current. At stations 3 to 8, the samplers were suspended

on a line from a rope stretched across the river above the water. Each suspended sampler was weighted with two one-ounce fishing sinkers wired to the bottom of the eyebolt, and was provided with enough line so that it would rest on the bottom. During high water in late August through early October, however, many samplers were lifted off the bottom by the current. Two additional transects of three multiplate samplers each were set at Station 5.

The multiplate samplers were permitted to colonize until the July sampling period, then were retrieved for the first time. Each was dismantled, the organisms and attached matter were scraped into whirlpac bags containing 10% formalin and Rose Bengal, the device was reassembled and returned to its location in the river. Thereafter, the samplers were retrieved at the regular benthic sampling periods (see below). At Station 5, one of the three sets of multiplate samplers was retrieved in July, it and another set were collected in August, and it was intended that all three sets be collected in October, to test the effects of incubation time on colonization. By October, however, many of the multiplate samples at Station 5 and elsewhere had been lost to the September high water or to beaver activity.

Small areas of stony bottom were found unexpectedly at stations 3, 4, 6 and 7. It was decided to sample them once (April to May) because certain taxa common on this substrate type (eg many Ephemeroptera, Plecoptera and Trichoptera) are likely to be good indicators of drainage-related impact. The stony substrate at Station 7 was deep, so the cylinder sampler could not be used and a kick

technique was substituted. Kick samples were also taken at stations 1 and 2 so they could be compared directly to the other stations sampled.

The kick samples were taken randomly (see description for Ekman samples) by holding a D-frame pond net (mesh aperture 0.77 mm) on the bottom and kicking up the substrate for 30 seconds in approximately a 0.15 m^2 area immediately upstream of the net mouth. Kick samples were preserved and stored as described for the Ekman samples.

The sample schedule for all sample types is presented in Table 16.

In the laboratory, the benthic invertebrates were hand-sorted from the accompanying debris. Identifications were made to the lowest taxon possible, with the aid of the keys and descriptions in the references listed in Table 17, and each taxon was enumerated. The total biomass of each sample was estimated as volume to the nearest 0.1 ml by liquid displacement, after the samples had been drained and briefly blotted on paper towelling.

3.1.3 Data Analysis

Two approaches were tried in the data analysis. If the impact of muskeg drainage was massive and catastrophic, a large decline in both total numbers and total biomass of benthic invertebrates could be expected. Total numbers and total biomass

Table 16. Sampling dates (mo/d) and methods, 1980.

Method	Station									
	1	2	3	4	5	6	7	8	9[a]	10[b]
Ekman			04/26 06/02 07/13 08/17[c] 10/13	05/02 06/03 07/11 08/16[c] 10/09	04/30 06/03 07/11 08/15[c] 10/10	04/28 06/04 07/12 08/17[c] 10/11	04/24 06/04 07/10 08/16 10/11	05/02 06/03 07/12 08/14 10/11		05/04 06/04
cylinder	05/04 06/03 07/12 08/15 10/11	05/04 06/02 07/09 08/16 10/08								
kick	05/02	04/26	05/01	04/24		04/28	04/24		07/11 08/17[c] 10/09	07/13 18/14[c] 10/09
multiplate	07/12 08/15 10/11[d]	07/09 08/16 10/08[d]	07/13 08/17[c] 10/13[d]	07/11 08/16[c] 10/09[d]	07/11 08/15[c] 10/10	07/12 08/17[c] 10/11	07/10 08/16 10/11[d]	07/12 08/14 10/11		

[a] drainage ditch diverted during first two sampling periods

[b] sampling method changed to kicks after June because Ekmans were ineffective

[c] samples lost by the air transporter

[d] samples lost to beaver activity or flooding

Table 17. References used for identification of benthic invertebrates.

General Reference:	Pennak (1978), Edmondson (1959), Merritt and Cummins (1978)
Hirudinea:	Davies (1971), Klemm (1972)
Ephemeroptera:	Edmunds et al (1976)
Plecoptera:	Baumann et al (1977), Baumann (1975)
Hemiptera:	Brooks and Kelton (1967)
Trichoptera:	Wiggins (1977)
Chironomidae:	unpublished keys of A. Hamilton and O. Saether, Freshwater Institute, Winnipeg, Manitoba, Pankratova (1970), Oliver et al (1978), Saether (1977)
Mollusca:	Clarke (1973),Burch (1972)

therefore were examined in analysis of variance to test this hypothesis. If the impact of muskeg drainage was less severe, changes in the composition of the benthic invertebrate communities would be expected, in which the abundance of certain taxa or groups of taxa might increase or decrease.

Testing of the latter hypothesis was complicated by the necessity to deal with large numbers of species. To reduce the problem to a manageable size, it was necessary to consider only the most informative taxa. Rare taxa usually provide little information, so for each sample type, only those taxa comprising at least 10% of any one sample, or found in at least 10% of the samples, were considered. Many taxa still remained after selection by the "10% rule", so principal component analysis (PCA) was used to reduce the number of variables to be considered still further.

Principal component analysis is described in detail by Morrison (1976), and Green (1979) discusses applications of PCA in environmental studies. The following introductory description is adapted from Marriott (1974).

Principal components analysis transforms a set of variables (eg species abundances) $x_1 \ldots x_p$ to a new set $y_1 \ldots y_p$ such that

1. Each new variable (principal component) is a linear combination of the old variables for example

$$y_i = a_{i1}x_1 + a_{i2}x_2 + \ldots a_{ip}x_p;$$

2. The sum of square of the coefficients a_{ij}, $j = 1 \ldots p$, is unity, and

3. Of all possible combinations of this type, y_1 (the first principal component) accounts for the greatest proportion of the total variance (eg, in species abundance), y_2 accounts for the greatest proportion of the remaining variance (ie the residual variance after the effect of the first component is removed), y_3 accounts for the greatest proportion of the remaining variance not accounted for by the first two components, and so on, until the complete set of principal components has been defined. PCA thus defines a new set of variables that are uncorrelated with each other and are arranged in order of decreasing variance explained.

The first few principal components may account for most of the variability in the original data, and these few can then be used in any further analysis in place of the original data, with minimal loss of information. In some cases the principal components of taxon abundance data may have a clear ecological meaning themselves, but even if they do not they can be interpreted in terms of the abundance of the constituent taxa.

In this study, PCA was done on the covariance matrix so that the absolute abundances of the taxa would be accounted for (Marriott 1974:20, Morrison 1976:268, Green 1979). One was added to all abundance data, then the data were transformed to logarithms (the log (x + 1) transformation) before all statistical analyses were performed.The principal cpomponent analyses and analyses of variance were done with the aid of the BMDP package of computer programs (Dixon and Brown 1979) on the Honeywell/Multics system at the University of Calgary computing centre.

In the data analysis the following general procedure was adopted. The data were tested in an analysis of variance to determine if there were differences among all stations taken together, and (if Station 5 had been sampled) if there was a difference between stations 4 and 5. Because the comparison of stations 4 and 5 was implicit in the sampling design (see also Section 3.1.1), the a priori F-test was appropriate (Winer 1971), and was used. If stations 4 and 5 were found to differ (ie, if an impact was detected), or (when Station 5 had not been sampled) if the overall analysis of variance showed differences among stations, all stations were compared to determine the extent and degree of impact. An a posteriori test, the Newman-Keuls procedure (Winer 1971) was used for multiple comparisons because the decision to make the comparisons depended on the outcome of the initial analysis of variance and/or F-tests.

A hypothetical example of the use and interpretation of an analysis may clarify the approach. Station 4 is found to differ from

Station 5 in an F-test, so all stations are compared. All control stations and the recovery station are found to be similar, and Station 4 differs from all these except one control station. The interpretation would be that a detectable impact on the river benthic fauna occurred but was restricted to the region upstream of Station 3 to Station 4. The impact, however, was not measurably different from the influence of the natural environment at at least one location in the drainage basin.

3.1.4 Other Sampling

An attempt was made in October to determine whether invertebrate drift below the drainage outfall was changed in comparison to drift measured above the outfall. Because quantities of frazil ice kept clogging the nets, no quantitative analysis was possible.

It had been proposed to measure heavy metal concentrations in selected benthic taxa at a control and an impact station, but despite intensive effort, not enough material from any single taxon could be collected for a proper chemical analysis. Lutz and Hendzel (1976) encountered similar difficulties, and for the Muskeg River were able to analyze metals only in a single major taxon (Hemiptera). The species constituting a major taxon may be very different in their ecology, and may differ among stations. Comparisons among stations

with respect to metal concentrations in major taxa, though possible, would have little meaning and were not attempted in this study.

3.2 Results and Discussion

3.2.1 Multiplate Samples

Only the July data were analyzed for the multiplate samplers, because most of the August samples were lost by the transporter, and because many of the October samples could not be recovered due to beaver damage and flood loss. Total benthic invertebrate abundance and biomass data are summarized in Table 18.

The total abundance and biomass results show the value of using a standardized substrate in benthic sampling. The 95% confidence limits of the means are very narrow in most cases--much narrower than those found for many of the natural substrate samples (see following section). The relatively high precision of the multiplate data means that statistical comparisons will be quite sensitive to differences among the stations.

Table 19 presents the results of analyses of variance on benthic invertebrate mean abundance and mean biomass among the eight stream stations. There were significant differences in both measures among stations. Stations 4 and 5 did not differ in mean abundance, but did differ in mean biomass.

Table 18. Geometric mean abundance and biomass of benthic invertebrates, and 95% confidence limits, multiplate samplers, July 1980.[1]

Station	number/sample GM	number/sample 95% conf. limits	ml/sample GM	ml/sample 95% conf. limits	n
1	96.9	45.4 - 206	0.60	∿0 - 2.0	3
2	20.2	5.2 - 71.6	0.23	0.10 - 0.38	3
3	29.1	2.6 - 251	0.53	0.20 - 0.95	3
4	200	78.6 - 508	0.59	∿0 - 2.9	3
5	95.5	49.2 - 184	2.9	0.26 - 11	3
6	90.5	31.7 - 255	0.59	∿0 - 2.2	3
7	51.7	31.1 - 85.3	0.45	∿0 - 2.2	3
8	58.6	18.8 - 179	0.38	∿0 - 1.4	3

1. Figures are backcalculated from log (x + 1)-transformed data.

Table 19. Summary of analyses of variance, benthic invertebrate abundance (top) and biomass (bottom), multiplate samplers, July 1980.

numbers/sample

Source	SS	d.f.	MS	F	P
Station	2.04450	7	0.29207	7.36	0.0005
4 vs. 5	0.15294	1	0.15294	3.86	>0.05
Error	0.63475	16	0.03967		
Total	2.67925	24			

ml/sample

Source	SS	d.f.	MS	F	P
Station	0.48885	7	0.06984	4.64	0.0053
4 vs. 5	0.22140	1	0.22140	14.7	<0.005
Error	0.24098	16	0.01506		
Total	0.72983	24			

The differences in mean biomass among all the stations were examined in more detail to determine the relationship of Station 4 to the other stations (Table 20). These data show, that, although biomass at Station 4 was lower than at Station 5, it was not detectably different from that at the three other control stations (6 to 8). The relatively high biomass at Station 5 was due to just nine specimens of the large leech Nephelopsis obscura, which occurred in slightly lower numbers in the samples from the other stations--probably a fortuitous occurrence.

Principal components were analyzed to determine if the muskeg drainage water affected the composition of the invertebrate communities in "submerged wood" habitat. The first three principal components (PC's) together accounted for 69.5% of the total variance in the abundance data, and the first PC alone accounted for 38.7% (Table 21).

In interpreting the principal components, the coefficients (loadings) due to the abundances of the various taxa are examined. Taxa with the largest absolute values of the coefficients have the greatest influence in determining the PC score of a sample. Positive coefficients contribute to a positive value for the PC; negative coefficients contribute to negative values for the PC.

In the present case, PC 1 can be roughly interpreted as a comparison of the abundances of Tricorythodes, Paraleptophlebia, Hydra, Micropsectra and Oligochaeta to those of Heptagenia, Pteronarcys, and Baetis, because these taxa have the heaviest

Table 20. Multiple comparisons of mean log (x + 1) millilitres per sample (biomass) by the Newman-Keuls procedure, multiplate samples, July 1980. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in biomass of benthic invertebrates per sample.

Stn.	$\bar{x}$ log (x + 1) ml/sample	n	Station 2	8	7	3	4	1	6	5
2	0.091	3								
8	0.139	3								
7	0.160	3								
3	0.184	3								
4	0.202	3								
1	0.204	3								
6	0.207	3	1.637 -							
5	0.586	3	6.986**	6.309**	6.013**	5.674**	5.420**	5.392**	5.349**	

Station	2	8	7	3	4	1	6	5

- P > 0.05

** P < 0.01

Table 21. Principal component coefficients (loadings) for the first three PC's, log (x + 1) taxon abundance, multiplate samples, July 1980.

Taxon	PC 1	PC 2	PC 3
Hydra	0.366	0.546	0.109
Oligochaeta	0.283	0.006	0.137
Glossiphonia	0.008	0.080	-0.046
Helobdella	0.083	-0.055	0.006
Gammarus	0.023	0.155	-0.075
Baetis	-0.226	-0.067	0.139
Heptagenia	-0.451	-0.117	0.231
Paraleptophlebia	0.489	-0.331	-0.166
Tricorythodes	0.501	-0.335	0.249
Pteronarcys	-0.421	-0.076	0.194
Acroneuria	-0.088	0.012	0.023
Polycentropus	0.086	0.057	0.183
Lepidostoma	-0.023	-0.004	0.141
Microtendipes	0.042	-0.035	0.055
Parachironomus	0.026	-0.027	0.034
Paralauterborniella	0.026	-0.049	-0.114
Micropsectra	0.308	0.065	0.343
Rheotanytarsus	-0.151	-0.073	0.097
Tanytarsus	0.129	0.026	-0.049
Ablabesmyia	0.180	-0.007	0.058
Larsia	0.067	-0.038	-0.094
Corynoneura	-0.034	0.040	0.077
Polypedilum (s.s.)	0.012	-0.053	-0.028
Variance explained	1.335	0.601	0.458
% total variance	38.7	17.5	13.3
cumulative % t.v.	38.7	56.2	69.5

loadings on PC 1, the former set being positive, the latter negative (Table 22). It is evident from Table 23, however, that Heptagenia and Pteronarcys were collected only at stations 1 to 3, and Baetis was found only at Station 1, so that PC 1 at stations 4 to 8 is primarily a measure of the abundance of the positive-loading taxa, Tricorythodes, Paraleptophlebia, Hydra, Micropsectra and Oligochaeta (the "Tricorythodes group"). PC 2 is primarily a comparison of the abundance of Hydra to that of Tricorythodes and Paraleptophlebia, and PC 3 is mostly a measure of Micropsectra and Tricorythodes abundance (stations 4 to 8) or Heptagenia abundance (stations 1 and 2), although the coefficients are rather low (Tables 22).

Analyses of variance on the scores of the first three principal components showed differences among stations for all three PC's, and in particular showed differences between stations 4 and 5 (Table 24). The differences are examined in detail in Tables 25 to 27, and are most easily interpreted by reference back to the mean abundance data for the most influential taxa (Table 23).

Station 4 had a higher PC 1 score than any other station, including all the control stations; that is, the Tricorythodes group as a whole was more abundant at Station 4 than elsewhere. It appears from Table 23 that the greater abundance of Hydra, Micropsectra and Oligochaeta at Station 4 was the most important difference in the Tricorythodes group between stations 4 and 5; ie, muskeg drainage evidently caused an increase in Hydra, Micropsectra and Oligochaeta abundance at Station 4. The increase in Hydra abundance

Table 22. Taxa with the highest absolute PC coefficients. Principal component scores are determined primarily by the log (x + 1) abundance of these taxa. (Multiplate samples July 1980)

PC 1				
Tricorythodes	0.501	vs	*Heptagenia*	-0.451
Paraleptophlebia	0.489		*Pteronarcys*	-0.421
Hydra	0.366		*Baetis*	-0.226
Micropsectra	0.308			
Oligochaeta	0.283			
PC 2				
Hydra	0.546	vs	*Tricorythodes*	-0.335
			Paraleptophlebia	-0.331
PC 3				
Micropsectra	0.343			
Tricorythodes	0.249			
Heptagenia	0.231			

Table 23. Mean numbers per sample of taxa loading most heavily on the first three principal components, multiplate samples, July 1980.

Taxa	Stations 1	2	3	4	5	6	7	8
Tricorythodes	0	0	8.0	50.3	52.0	1.0	0	0
Paraleptophlebia	0.3	0	15	11.7	33.0	57.3	3.7	2.3
Hydra	0.3	3.0	0.7	48.3	1.7	3.7	41.7	26.3
Micropsectra	0	0.3	0.7	41.3	0.3	1.0	0	0.3
Oligochaeta	0	0	1.0	18.7	0.7	6.7	0	4.3
Heptagenia	33.3	6.0	2.3	0	0	0	0	0
Pteronarcys	20.7	5.7	0.7	0	0	0	0	0
Baetis	9.0	0	0	0	0	0	0	0

Table 24. Analyses of variance and planned comparisons on the first three principal components, multiplate samples, July 1980.

Source	SS	d.f.	MS	F	P
PC 1					
Station	21.50548	7	3.07221	32.89	<0.001
Stn 4 vs 5	0.94584	1	0.94584	10.12	<0.01
Error	1.49452	16	0.09341		
Total	23.00000	23			
PC 2					
Station	20.16502	7	2.88072	16.26	<0.001
Stn 4 vs 5	3.78352	1	3.78352	21.35	<0.001
Error	2.83498	16	0.17719		
Total	23.00000	23			
PC 3					
Station	20.04492	7	2.86356	15.5	<0.001
Stn 4 vs 5	5.82170	1	5.82170	31.52	<0.001
Error	2.95508	16	0.18469		
Total	23.00000	23			

Table 25. Multiple comparisons of mean PC 1 scores per sample by the Newman-Keuls procedure, multiplate samples, July 1980. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in PC 1 scores.

Stn.	PC 1 $\bar{x}$ score	n	Station 1	2	3	7	8	6	5	4
1	-1.746	3								
2	-1.049	3	3.950*							
3	-0.008	3	9.850**	5.900**						
7	0.004	3	9.918	5.968**						
8	0.067	3	10.274**	6.324**						
6	0.536	3	12.932**	8.982**						
5	0.701	3	13.868**	9.918**	4.018^{-}					
4	1.495	3	18.367**	14.417**	8.518**	8.450**	8.093**	5.435**	4.500**	

Station	1	2	3	7	8	6	5	4

$^{-}$ $P > 0.05$

* $P < 0.05$

** $P < 0.01$

Table 26. Multiplate comparisons of mean PC 2 scores per sample by the Newman-Keuls procedure, multiplate samples, July 1980. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in PC 2 scores.

Stn.	$\bar{x}$ PC 2 score	n	Station 5	3	6	1	2	4	8	7
5	-1.253	3								
3	-0.812	3								
6	-0.734	3								
1	-0.502	3	3.090^{-}							
2	0.328	3	6.505**	4.691*	4.370*					
4	0.335	3	6.534**	4.720*	4.399*	3.444^{-}				
8	1.299	3	10.501**	8.686**	8.365**	7.412**	3.995*	3.967*		
7	1.339	3	10.665**	8.851**	8.530**	7.575**	4.160*	4.131*	0.165^{-}	
Station			5	3	6	1	2	4	8	7

$^{-}$ P > 0.05

* P < 0.05

** P < 0.01

Table 27. Multiple comparisons of mean PC 3 scores per sample by the Newman-Keuls procedure, multiplate samples, July 1980. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in PC 3 scores.

Stn.	PC 3 $\bar{x}$ score	n	Station 6	7	8	3	5	2	1	4
6	-1.153	3								
7	-0.706	3								
8	-0.677	3								
3	-0.295	3								
5	-0.226	3	3.736^{-}							
2	0.237	3	5.602*	3.801^{-}						
1	1.076	3	8.984**	7.182**	7.065**	5.526**	5.248**	3.381**		
4	1.744	3	11.676**	9.874**	9.757**	8.218**	7.940**	6.074**	2.692^{-}	

Station	6	7	8	3	5	2	1	4

$^{-}$ P > 0.05

* P < 0.05

** P < 0.01

mostly accounts for the higher PC 2 score at Station 4 compared to Station 5. Micropsectra and Tricorythodes abundances (PC 3) also were greater at Station 4 than at any control station.

Micropsectra and most Oligochaeta are detritivores that feed on fine particulate organic matter (FPOM)(Merritt and Cummins 1978, Pennak 1978). It was noted previously (see Water Quality Section) that the April flood deposited a thick layer of FPOM at Station 4, and this rich food supply might have promoted the increases in the populations of Micropsectra and Oligochaeta there. Other FPOM consumers (eg; Trichorythodes, Paraleptophlebia) did not respond in the same way, however.

It is not obvious why Hydra should have increased in response to the muskeg drainage water, and only a tentative hypothesis can be suggested. Hydra is a predator in small invertebrates, especially Cladocera, Copepoda, small insects and annelids (Pennak 1978). Some of the drainage water came from small lakes, including the settling pond less than 300 m above Station 4. It is possible that planktonic Crustacea from the lakes drained by the ditch system increased the food supply of Hydra in the Muskeg River, permitting a larger population to build up. Some support for this interpretation comes from the fact that stations 7 and 8, which also had high Hydra counts, lie just below or within nearly-lentic areas within which a crustacean plankton community could be expected, but stations 3, 5 and 6, all of which had low Hydra numbers, are far downstream from lentic areas. In a German study, Hydra was a dominant organism

downstream from a small pond, and was most common when Cladocera and Copepoda were abundant (Knöpp 1952, in Hynes 1970).

In a similar manner, differences among the other stations may be explained. Stations 1 and 2 had lower PC 1 scores than all other stations because they had substantial numbers of the taxa that loaded negatively on PC 1 (Heptagenia, Pteronarcys and Baetis), whereas the other stations usually had none of these, but did have large numbers of the positive-loading taxa (Table 23). Both stations 1 and 2 are erosional, stony-bottom types, and the most important negatively-loading taxa may be erosional forms (Merritt and Cummins 1978). As mentioned above, stations 7 and 8 had high numbers of Hydra, but Tricorythodes and Paraleptophlebia numbers were low (Tables 23) leading to the high PC 2 scores at these two stations (Table 26).

The species composition of the communities found on the multiplate samplers suggests that the samplers adequately mimic "submerged wood" habitat, as they were intended to do. Of the eight most informative species in the principal component analysis, seven (Tricorythodes, Paraleptophlebia, Hydra, Micropsectra, Heptagenia, Baetis and Pteronarcys) are characteristically or commonly associated with submerged logs, branches, sticks, roots and debris (Merrit and Cummins 1978, Pennak 1978, Edmunds et al 1976).

In summary, it appears that the muskeg drainage water had a subtle enrichment effect on the invertebrate fauna of submerged wood habitat in the Muskeg River during the June to early July period in 1980. The effect was detectable at Station 4, 100 m below the outfall,

did not extend as far downstream as Station 3, and consisted of increases in abundance primarily of Hydra, Micropsectra and Oligochaeta.

3.2.2 Kick Samples

It was not possible, in many cases, to choose closely comparable stations for kick sampling. Above Station 2, only occasional small, isolated patches of stony bottom suitable for kick sampling were found, so the choice of sampling sites was limited. The sites sampled at stations 1 to 3 were boulder, cobble and sand riffles up to 50 cm deep, and the site sampled at Station 4 was similar but from 50 to 75 cm deep. The two control sites were quite different from each other, that at Station 6 being a rapid riffle 30 to 40 cm deep, and that at Station 7 being a one-metre deep, boulder, cobble and silt glide. Of the two, Station 6 appeared to be the more comparable to the downstream stations.

The differences in the physical attributes of the sampling station make it difficult to interpret unambiguously any biological differences among them. In the following discussion, a difference in a biological parameter at Station 4 was interpreted as impact-related only if the Station 4 value was higher or lower than that at all other stations. This criterion is based on the assumption that, since the physical attributes at Station 4 did not appear to be extreme among all the stations, neither should the benthic community be so;

therefore an extreme biological measurement is probably an indication of impact from the minesite drainage water.

Table 28 presents the total invertebrate abundance and biomass data for the kick samples. Analyses of variance (Table 29) showed there were differences in both abundance and biomass among the six stations sampled, but multiple comparisons (Tables 30 and 31) showed that Station 4 did not differ from all other stations with respect to either total abundance or biomass. There was therefore no convincing evidence of an impact of muskeg drainage on these two parameters.

Principal components were analyzed to determine if drainage water had an effect on the composition of benthic communities in stony habitat. PC 1 accounted for 26.1% of the total variance of invertebrate abundance (Table 32), and is roughly interpretable as "abundance of detritivores and predators", because nearly all coefficients are positive and apply to taxa known to consume decaying organic matter (especially FPOM), or to taxa that are at least partly predatory (Merritt and Cummins 1978, Pennak 1978, Edmunds et al 1976, Wiggins 1977). In fact, the highest coefficients apply to just eight detritivore taxa (Table 33). Only six taxa loaded negatively on PC 1, all of them lightly.

An analysis of variance indicated differences existed among the stations in PC 1 scores (Table 34), and multiple comparisons (Table 35) demonstrated that Station 4 had a higher mean PC 1 score than all other stations (that is, the detritivore and predator taxa

Table 28. Geometric mean abundance and biomass of benthic invertebrates, and 95% confidence limits, kick samples April - May 1980.[1]

	number/m²		ml/m²		
Station	GM	95% conf. limits	GM	95% conf. limits	n
1	233	53.8 - 1000	0.7	variance = 0	3
2	686	406 - 1160	2.2	0.5 - 5.8	5
3	445	173 - 1140	14.4	0.8 - 134	2
4	2490	1070 - 5770	16.4	9.8 - 27.2	3
6	3200	1660 - 6160	7.5	5.4 - 10.4	3
7	281	74.9 - 1050	3.2	0.9 - 8.3	5

1. All figures are backcalculated from log (x + 1)-transformed data.

Table 29. Summary of analyses of variance, benthic invertebrate abundance (top) and biomass (bottom), kick samples, April - May 1980.

log (x + 1) numbers/m²

Source	SS	d.f.	MS	F	P
Station	3.75074	5	0.75015	9.54	0.0003
Error	1.17931	15	0.07862		
Total	4.93005	20			

log (x + 1) ml/m²

Source	SS	d.f.	MS	F	P
Station	2.37582	5	0.47516	11.5	0.0001
Error	0.61840	15	0.04123		
Total	2.99422	20			

Table 30. Multiple comparisons of log (x + 1) numbers of benthic invertebrates per m^2 by the Newman-Keuls procedure, kick samples, April-May 1980. Cell values are the studentized range statistic, Q, calculated as suggested by Winer (1971:216). Stations linked by lines do not differ in invertebrate abundance/m^2

Stn.	$\bar{x}$ log (x + 1) no./m^2	n	Station 1	7	3	2	4	6
1	2.370	3						
7	2.451	5						
3	2.469	2						
2	2.837	5	2.960 -					
4	3.396	3	6.502**	5.989**	5.875	3.543*		
6	3.506	3	7.200**	6.686**	6.572**	4.240*	0.697 -	

Station	1	7	3	2	4	6

- P > 0.05
* P < 0.05
** P < 0.01

Table 31. Multiple comparisons of log (x + 1) volume (biomass) per m^2 by the Newman Keuls procedure, kick samples, April-May 1980. Cell values are the Studentized range statistic, Q, calculated as suggested by Winer (1971:216). Stations linked by lines do not differ in invertebrate biomass/m^2

Stn.	$\bar{x}$ log (x + 1) ml/m^2	n	Station 1	2	7	6	3	4
1	0.230	3						
2	0.511	5						
7	0.619	5	3.404^{-}					
6	0.931	3	6.135**	3.676*	2.730^{-}			
3	1.188	2	8.384**	5.924**	4.980**			
4	1.242	3	8.857**	6.398**	5.452**	2.722^{-}		
Station			1	2	7	6	3	4

\- $P > 0.05$
* $P < 0.05$
** $P < 0.01$

Table 32. Principal component coefficients (loadings) for the first four PC's, log (x + 1) taxon abundance, kick samples, April/May 1980.

Taxon	PC 1	PC 2	PC 3	PC 4
Oligochaeta	0.399	-0.445	0.045	0.106
Glossiphonia	0.058	-0.160	0.065	-0.053
Helobdella	0.062	-0.359	0.252	-0.160
Pisidium	0.708	-0.448	-0.135	-0.195
Sphaerium	-0.048	-0.138	0.153	0.070
Hyalella	0.053	-0.244	-0.014	-0.045
Heptagenia	0.102	0.335	0.084	-0.085
Leptophlebia	0.105	-0.057	-0.002	0.273
Pteronarcys	-0.190	0.137	-0.203	-0.022
Isoperla	0.010	0.146	0.041	-0.096
Dubiraphia	0.239	-0.230	0.166	-0.298
Optioservus	0.663	0.565	-0.185	-0.058
Psychomyia	0.004	0.128	-0.159	0.259
Polycentropus	-0.018	-0.349	0.193	0.002
Brachycentrus	-0.062	0.142	-0.078	0.090
Lepidostoma	0.773	-0.174	-0.332	0.097
Hexatoma	0.047	-0.026	-0.024	0.081
Bezzia/Palponyia	-0.256	-0.250	0.211	-0.040
Simulium	0.899	0.498	0.040	-0.377
Chrysops	0.135	-0.242	0.209	-0.236
Micropsectra	0.348	-0.088	0.605	0.276
Thienemannimyia gp.	0.112	-0.063	0.137	0.028
Cricotopus/Orthocladius	-0.131	0.499	0.712	0.118
Diplocladius	0.610	0.030	-0.009	0.653
Eukiefferiella	0.007	0.661	0.201	-0.179
Parakiefferiella	0.434	-0.031	0.491	0.035
Polypedilum (s.s.)	0.067	-0.457	0.159	-0.174
Variance explained	3.439	2.625	1.691	1.139
% total variance	26.1	20.0	12.9	8.6
cumulative % t.v.	26.1	46.1	59.0	67.6

Table 33. Taxa with absolute PC coefficients of at least 0.250. Principal component scores are determined primarily by the log (x + 1) abundance of these taxa.

PC 1				
Simulium	0.899			
Lepidostoma	0.773			
Pisidium	0.708			
Optioservus	0.663	vs	*Bezzia/Palpomyia*	-0.256
Diplocladius	0.610			
Parakiefferiella	0.434			
Oligochaeta	0.399			
Micropsectra	0.348			
PC 2				
Eukiefferiella	0.661		*Polypedilum* (s.s.)	-0.457
Optioservus	0.565		*Pisidium*	-0.448
Cricotopus/			Oligochaeta	-0.445
Orthocladius	0.499	vs	*Helobdella*	-0.359
Simulium	0.498		*Polycentropus*	-0.349
Heptagenia	0.335		*Bezzia/Palpomyia*	-0.250
PC 3				
Cricotopus/				
Orthocladius	0.712		*Lepidostoma*	-0.332
Micropsectra	0.605	vs		
Parakiefferiella	0.491			
Helobdella	0.252			
PC 4				
Diplocladius	0.653		*Simulium*	-0.377
Micropsectra	0.276	vs	*Dubiraphia*	-0.298
Leptophlebia	0.273			
Psychomyia	0.259			

Table 34. Analyses of variance on the first four principal components of log (x + 1) benthic taxon abundance, kick samples, April/May 1980.

Source	SS	d.f.	MS	F	P
PC 1					
Station	18.33170	5	3.66634	32.96	<0.001
Error	1.66830	15	0.11122		
Total	20.00000	20			
PC 2					
Station	15.36715	5	3.07343	9.95	<0.001
Error	4.63285	15	0.30886		
Total	20.00000	20			
PC 3					
Station	10.99664	5	2.19933	3.66	0.023
Error	9.00336	15	0.60022		
Total	20.00000	20			
PC 4					
Station	13.47579	5	2.69516	6.20	0.003
Error	6.52421	15	0.43495		
Total	20.00000	20			

Table 35. Multiple comparisons of mean PC 1 scores by the Newman-Keuls procedure, kick samples, April/May 1980. Cell values are the Studentized range statistic Q, calculated as suggested by Winer (1971:216). Stations linked by lines do not differ in PC 1 scores.

Stn.	$\bar{x}$ PC 1 score	n	Station 1	7	3	6	2	4
1	-1.267	3						
7	-0.896	5	1.977^{-}					
3	-0.356	2	4.854**	2.877^{-}				
6	0.399	3	8.877**	6.900**	4.023*			
2	0.676	5	10.353**	8.376**	5.499**	1.476^{-}		
4	1.471	3	14.590**	12.613**	9.735**	5.712**	4.236**	

Station	1	7	3	6	2	4

$^{-}$ P > 0.05

* P < 0.05

** P < 0.01

taken together were more abundant at Station 4). The detritivores may have been responding to the FPOM contributed in the muskeg drainage water (see Water Quality section), and the predators to the increased detritivore abundance.

PC 2 accounted for 20.0% of the total variance in the abundance data (Table 32), and can be interpreted as a comparison of abundances of erosional and depositional taxa. To the extent that can be determined, all of the taxa with positive coefficients are characteristic of lotic-erosional (swift) habitats, and all of the taxa with negative coefficients are commonly found in lotic-depositional (slow) habitats (Merritt and Cummins 1978, Edmunds et al 1976, Pennak 1978, Wiggins 1977). The taxa of uncertain identity, Cricotopus/Orthocladius and Bezzia/Palpomyia, have at least some known members typical of erosional and depositional habitat, respectively. Whether habitat is erosional or depositional is determined largely by current speed, therefore it is reasonable to interpret differences in PC 2 scores as being due to differences in current speed at the stations.

Analysis of variance demonstrated that mean PC 2 scores differed significantly among stations (Table 34). Multiple comparisons showed that stations 1, 2, 3, 4 and 7 did not have significantly different PC 2 scores, but that the mean PC 2 score for Station 6 was significantly higher than those at all other stations (Table 36); ie, the higher PC 2 score at Station 6 reflects the effects of a higher

Table 36. Multiple comparisons of mean PC 2 scores by the Newman-Keuls procedure, kick samples, April/May 1980. Cell values are the Studentized range statistic Q, calculated as suggested by Winer (1971:216). Stations linked by lines do not differ in PC 2 scores.

Stn.	PC 2 $\bar{x}$ score	n	Station 4	7	3	2	1	6
4	-0.961	3						
7	-0.847	5						
3	0.103	2						
2	0.175	5						
1	0.329	3	4.125^{-}					
6	1.684	3	8.458**	8.093**	5.055*	4.825*	4.333**	
			4	7	3	2	1	6

$^{-}$ P > 0.05

* P < 0.05

** P < 0.01

current speed at that station. There was no detectable impact-related effect on PC 2.

PC 3 and PC 4 do not have an obvious ecological interpretation (Tables 32 and 33). They are comparisons of abundances of certain positive-loading to negative-loading taxa after the effects of detritivore-predator abundance and current speed have been removed, and can be thought of as kinds of indices of community composition. Analyses of variance on them showed that both PC's differed among stations (Table 34), and multiple comparisons provided evidence that Station 4 differed only from one other station, having a lower PC 4 score than Station 2 (Tables 37 and 38). No evidence of an impact-related effect was apparent.

3.2.3 Ekman and Cylinder Samples[1]

Total abundance and total biomass of benthic invertebrates collected in the Ekman and cylinder samples are summarized in Table 39. The 95% confidence limits for the means are very wide in most cases--much wider than those in either the kick sample or multiplate sample data. The multiplate samples all come from identical substrates and would be expected to be much less variable than those from natural substrates. The Ekman and cylinder samplers sampled smaller areas (0.0232 m^2 and 0.0707 m^2, respectively) than did the

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1. These sample types are considered together for convenience only, not because they are considered directly comparable (See Section 3.1).

Table 37. Multiple comparisons of mean PC 3 scores by the Newman-Keuls procedure, kick samples, April/May 1980. Cell values are the Studentized range statistic Q, calculated as suggested by Winer (1971:216). Stations linked by lines do not differ in PC 3 scores.

Stn.	$\bar{x}$ PC 3 score	n	Station 1	3	4	2	7	6
1	-0.884	3						
3	-0.670	2						
4	-0.446	3						
2	-0.351	5						
7	0.747	5						
6	1.118	3	4.592⁻					
Station			1	3	4	2	7	6

⁻ $P < 0.05$ (very nearly significant - critical value = 4.595)

This test is less sensitive (more conservative) than the initial analysis of variance (Winer 1971), hence the apparent contradiction (the analysis of variance found significant differences among means).

Table 38. Multiple comparisons of mean PC 4 scores by the Newman-Keuls procedure, kick samples, April/May 1980. Cell values are the Studentized range statistic Q, calculated as suggested by Winer (1971:216). Stations linked by lines do not differ in PC 4 scores.

Stn.	$\bar{x}$ PC 4 score	n	Station 4	6	3	1	7	2
4	-1.123	3						
6	-0.633	3						
3	-0.428	2						
1	-0.080	3						
7	-0.001	5	3.023^{-}					
2	1.273	5	6.456**	5.136*	4.583*	3.646^{-}		

Station	4	6	3	1	7	2

$^{-}$ P > 0.05

* P < 0.05

** P < 0.01

Table 39. Geometric mean abundance and biomass of benthic invertebrates, and 95% confidence limits, Ekman and cylinder samples, four 1980 sampling periods.[1].

Station	Sampling Period	numbers/m² GM	numbers/m² 95% conf. limits	ml/m² GM	ml/m² 95% conf. limits	n
1	April/May	1 120	562 - 2 250	4.7	2.9 - 7.1	3
	June	593	356 - 982	2.8	variance = 0	3
	July	1 650	676 - 4 030	4.2	variance = 0	3
	October	557	292 - 1 060	8.8	4.8 - 15.6	3
2	April/May	4 250	143 - 126 000	10.9	≈0 - 157	3
	June	1 180	108 - 12 800	2.4	≈0 - 13.7	3
	July	1 460	141 - 14 900	5.5	0.8 - 23.2	3
	October	95.2	20.9 - 422	1.4	variance = 0	3
3	April/May	4 260	456 - 39 800	4.3	variance = 0	2
	June	5 830	145 - 233 000	15.7	0.1 - 261	3
	July	3 110	343 - 28 100	19 2	0.8 - 230	3
	October	3 710	61.1 - 221 000	23.6	≈0 - 1 000	3
4	April/May	723	47.7 - 10 700	4.3	variance = 0	3
	June	1 140	585 - 2 200	4.3	variance = 0	3
	July	2 250	134 - 37 600	24.5	3.8 - 135	3
	October	451	4.2 - 39,000	7.0	0.4 - 45.9	3
5	April/May	1 340	220 - 8 090	10.8	0.9 - 73.2	3
	June	6 000	834 - 43 200	24.4	8.3 - 68.3	3
	July	1 090	32.3 - 35 600	17.0	3.6 - 69.9	3
	October	753	528 - 1 070	4.3	variance = 0	2

Continued . . .

Table 39. Continued

Station	Sampling Period	numbers/m² GM	numbers/m² 95% conf. limits	ml/m² GM	ml/m² 95% conf. limits	n
6	April/May	604	29.7 - 11 900	5.5	1.8 - 14.2	3
	June	1 780	1 010 - 3 140	14.0	∿0 - 392	3
	July	1 950	58.8 - 63 500	4.3	variance = 0	3
	October	1 420	14.2 - 133 000	11.1	1.1 - 69.8	3
7	April/May	4 580	956 - 22 000	54.8	21.2 - 139	3
	June	5 160	1 160 - 23 000	37.0	0.8 - 793	3
	July	811	214 - 3 060	34.8	10.3 - 112	3
	October	1 440	31.3 - 64 000	18.4	0.2 - 326	3
8	April/May	1 830	661 - 5 040	54.6	15.0 - 192	3
	June	1 870	545 - 6 430	28.5	18.8 - 42.9	3
	July	551	6.2 - 42 300	81.5	3.4 - 1 530	3
	October	700	31.4 - 15 200	11.1	1.1 - 69.8	3

[1]. All figures are back-calculated from log (x + 1)-transformed data.

kick technique (approximately 0.1500 m^2), and the kick and the cylinder methods were both used on similar substrate. It is possible that the high variability of the Ekman and cylinder samples was a result of sampling patchily-distributed populations in which the "patches" covered approximately the same areas as the cylinder and Ekman sampled. If so, either larger (eg; kick technique) or smaller sampling areas would tend to reduce the sample variances (Elliott 1971:70, Green 1979:39). In future sampling, the kick technique would appear to be preferable to the cylinder sampler for this reason, and some soft-sediment sampler other than the Ekman grab should be tested to see if the very large variances can be reduced.

Two-way analysis of variance of the total abundance data found no significant interaction between sampling period and station (Table 40). Mean abundances differed significantly among stations and times, but Station 4 did not differ in mean abundance from Station 5 in any sampling period.

In a two-way analysis of variance of the mean benthic biomass, a significant interaction was found (Table 41). Examination of the simple effects revealed that mean biomass differed among stations in all four sampling periods, but that only in June did Station 4 and 5 differ. Multiple comparisons of the June data provided evidence that biomass at Station 4 was lower than that at control stations 7 and 8, as well as Station 5, but was not different from that recorded at control station 6 or at the recovery station 3

Table 40. Analysis of variance and planned comparisons, benthic invertebrate abundance in log (x + 1) no/m², Ekman and cylinder samples, 1980.

Analysis of Variance

Source	SS	d.f.	MS	F	P
Station	4.30748	7	0.61535	2.95	0.0095
Period	2.77462	3	0.92487	4.46	0.0067
Station x Period	6.79627	21	0.32363	1.56	0.0906
Error	12.86690	62	0.20753		
Total	26.74527	93			

Planned comparisons: Stn. 4 vs Stn. 5 by period

Period	$F_{1, 62}$*	P
April-May	0.51	>0.05
June	3.78	>0.05
July	0.72	>0.05
October	0.29	>0.05

*$F = \dfrac{(\bar{x}_1 - \bar{x}_2)^2}{\text{MS error } (\frac{1}{n_1} + \frac{1}{n_2})}$

Table 41. Analysis of variance and planned comparisons, benthic invertebrate biomass in log (x + 1) ml/m², Ekman and cylinder samples, 1980.

Analysis of Variance

Source	SS	d.f.	MS	F	P
Station	8.73417	7	1.24774	12.95	
Period	0.62788	3	0.20929	2.17	
Station x Period	4.63088	21	0.22052	2.29	0.0062
Error	5.97350	62	0.09635		
Total	16.96643	93			

Simple effects: Stations

Period	SS	d.f.	MS	F	P
April-May	3.84084	7	0.54869	5.69	<0.001
June	3.53953	7	0.50565	5.25	<0.001
July	3.79041	7	0.54149	5.62	<0.001
October	2.08088	7	0.29727	3.08	<0.005

Simple effects: Periods

Station	SS	d.f.	MS	F	P
1	0.25691	3	0.08564	0.89	>0.05
2	0.83037	3	0.27679	2.87	<0.05
3	0.77950	3	0.25984	2.70	<0.05
4	0.90732	3	0.30244	3.14	<0.025
5	0.75050	3	0.25017	2.60	<0.05
6	0.40068	3	0.13356	1.39	>0.05
7	0.31468	3	0.10489	1.09	>0.05
8	1.15892	3	0.38631	4.01	<0.01

Planned comparisons: Stn. 4 vs Stn. 5 by period

Period	$F_{1, 62}$	P
April-May	1.90	>0.05
June	7.21	<0.01
July	0.35	>0.05
August	0.50	>0.05

(Table 42). Station 3, however, did not differ from any of the control stations.

It appears that muskeg drainage caused a decrease in total benthic invertebrate biomass at Station 4 in June 1980. The biomass was no lower there, however, than that produced as a result of natural events at at least one location (Station 6) uninfluenced by the minesite drainage water, and the impact was restricted to less distance downstream than Station 3.

Community composition was examined by an analysis of the principal components of taxon abundance. The first PC accounted for 21.4% of the total variance in the data (Table 43), and apparently represents a comparison of the abundances of depositional taxa and erosional taxa. The taxa with the largest negative coefficients (Table 44) were found almost exclusively at stations 1 and 2, the two erosional sites, whereas the taxa with the largest positive coefficients were seldom found there, although they were common at one or more of the depositional sites. Most of the observed distributions of taxa relative to depositional and erosional habitat match those reported by Merritt and Cummins (1978), but occasional differences were observed. Larsia and Tanytarsus, both reported as lotic-erosional by Merrit and Cummins, were found almost exclusively at depositional sites in this study. Micropsectra, considered as a depositional form by Merrit and Cummins, was primarily an erosional form in the Ekman-cylinder samples.

Table 42. Multiple comparisons by the Newman-Keuls procedure of log (x + 1) benthic invertebrate biomass (ml/m²), Ekman and cylinder samples, June 1980. Cell values are the Studentized range statistic Q, Stations linked by lines do not differ in invertebrate biomass/m².

Stn.	log (x + 1) $\bar{x}$ biomass	n	Station 2	1	4	6	3	5	8	7
1	0.529	3								
1	0.580	3								
4	0.724	3								
6	1.175	3								
3	1.223	3	3.813⁻							
5	1.405	3	4.814*	4.533*	3.742*					
8	1.470	3	5.171**	4.890*	4.099*					
7	1.580	3	5.775**	5.495**	4.704*	2.225⁻				
Station			2	1	4	6	3	5	8	7

- P > 0.05
* P < 0.05
** P < 0.01

Table 43. Principal component coefficients (loadings) for the first three PC's, log (x + 1) taxon abundance/m², Ekman and cylinder samples, April to October 1980.

Taxon	PC 1	PC 2	PC 3
Oligochaeta	1.14	-0.197	0.429
Helobdella	0.421	0.131	0.319
Pisidium	0.203	0.612	0.602
Sphaerium	0.484	0.169	-0.140
Hyalella	0.253	0.169	0.163
Gammarus	0.076	0.050	-0.035
Baetis	-0.056	0.039	0.180
Heptagenia	-0.336	0.142	0.083
Leptophlebia	-0.113	-0.135	0.061
Paraleptophlebia	-0.011	0.007	-0.097
Ephemerella	-0.072	0.010	0.028
Tricorythodes	-0.019	0.238	-0.191
Pteronarcys	-0.306	0.077	0.229
Acroneuria	-0.054	0.028	0.012
Dubiraphia	0.093	0.058	0.080
Optioservus	-0.625	0.287	0.318
Psychomyia	-0.154	0.054	0.083
Polycentropus	0.055	0.056	0.091
Brachycentrus	-0.290	0.107	0.189
Limnephilus	0.030	-0.012	0.008
Lepidostoma	-0.224	0.180	0.100
Hexatoma	-0.101	0.160	-0.105
Bezzia/Palpomyia	0.687	0.162	-0.285
Simulium	-0.207	0.050	0.291
Chrysops	0.290	-0.012	-0.186
Cryptochironomus	0.141	0.108	-0.212
Dicrotendipes	0.042	-0.010	0.003
Microtendipes	-0.003	0.209	-0.111
Paralauterborniella	0.303	0.067	-0.302
Paratendipes	0.170	0.116	0.189
Polypedilum (Pentapedilum)	-0.046	0.023	0.038
Saetheria	-0.024	0.059	-0.012
Stenochironomus	-0.006	-0.030	-0.003
Cladotanytarsus	-0.058	0.276	-0.195
Micropsectra	-0.240	0.769	-0.248
Rheotanytarsus	-0.169	0.112	0.137
Tanytarsus	0.327	0.068	0.056
Ablabesmyia	0.061	0.088	0.005
Larsia	0.490	0.243	0.085

Continued . . .

Table 43. Concluded.

Taxon	PC 1	PC 2	PC 3
Procladius	0.992	0.098	0.140
Cricotopus	-0.068	0.123	0.267
Cricotopus/Orthocladius	-0.220	0.355	0.210
Heterotrissocladius	-0.014	0.020	-0.161
Parakiefferiella	-0.080	0.069	-0.016
Thienemanniella	-0.028	0.020	0.033
Polypedilum (s.s.)	0.281	0.599	-0.458
Variance explained	4.941	2.127	1.884
% total variance	21.4	9.2	8.1
cumulative % t.v.	21.4	30.6	38.7

Table 44. Taxa with absolute PC coefficients of at least 0.250 on the first three principal components. Principal component scores are determined primarily by the log (x + 1) abundance/m² of these taxa (Ekman and cylinder samples 1980).

PC 1				
Oligochaeta	1.140		*Optioservus*	-0.625
Procladius	0.992		*Heptagenia*	-0.336
Bezzia/Palpomyia	0.687	vs	*Pteronarcys*	-0.306
Larsia	0.484		*Brachycentrus*	-0.290
Sphaerium	0.484			
Helobdella	0.421			
Tanytarsus	0.327			
Paralauterborniella	0.303			
Chrysops	0.290			
Polypedilum (s.s.)	0.281			
Hyalella	0.253			
PC 2				
Micropsectra	0.769			
Pisidium	0.612			
Polypedilum	0.599			
Cricotopus/ Orthocladius	0.355			
Optioservus	0.287			
Cladotanytarsus	0.276			
PC 3				
Pisidium	0.602		*Polypedilum*	-0.458
Oligochaeta	0.429		*Paralauterborniella*	-0.302
Helobdella	0.319		*Bezzia/Palpomyia*	-0.285
Optioservus	0.318	vs		
Simulium	0.291			
Cricotopus	0.267			

Because taxa with negative coefficients were almost entirely restricted to stations 1 and 2, differences in PC 1, if any, among the remaining stations are attributable to differences in the abundance of taxa having positive coefficients. The taxa with the highest positive coefficients (Table 44) are detritivores or predators, and most of the detritivores consume FPOM (Merritt and Cummins 1978, Pennak 1978, Edmunds et al 1976, Wiggins 1977).

Analysis of variance on PC 1 demonstrated significant differences in mean PC 1 scores among stations and periods, but Station 4 differed from Station 5 only in June (Table 45). Station 4 had a lower PC 1 score (ie, fewer of the selected detritivores and predators taken together) than did Station 5, but there was no evidence that it differed from any of the other control stations, or from the recovery station, Station 3 (Table 46). The muskeg drainage water evidently reduced certain detritivores and predators on fine substrate at Station 4 in June, but not below abundances found naturally at control stations unaffected by the drainage water. The effect was not evident at Station 3, the recovery station, suggesting that the impact was restricted to the reach near the outfall.

PC 2 accounted for only 9.2% of the total variance in the abundance data (Table 43). Only six taxa had negative coefficients for this component, and none of these was large. Six other taxa, all detritivores, had relatively high positive coefficients (Table 44), so that PC 2 reflects their abundance to a large extent.

Table 45. Analysis of variance and planned comparisons on the first principal component of log (x + 1) taxon abundance/m^2, Ekman and cylinder samples, 1980.

Analysis of variance Source	SS	d.f.	MS	F	P
Station	54.74792	7	7.82113	24.98	<0.0001
Period	6.51216	3	2.17072	6.93	0.0004
Station x Period	10.12197	21	0.48200	1.54	0.0975
Error	19.09545	61	0.31304		
Total	90.47750	92			

Planned comparisons: Stn 4 vs 5 by period Period	$F_{1,61}$	P
April - May	0.060	>0.05
June	6.83	<0.025
July	0.01	>0.05
October	0.11	>0.05

Table 46. Multiple comparisons of mean PC 1 scores per sample by the Newman-Keuls procedure, Ekman and cylinder samples for June 1980. Cell values are the Studentized range statistic Q, calculated as suggested by Winer (1971). Stations linked by lines do not differ in PC 1 scores.

Stn.	PC 1 $\bar{x}$ score	n	Station 1	2	4	6	3	8	5	7
1	-1.438	3								
2	-0.926	3	1.526^{-}							
4	0.238	3	4.997**	3.470*						
6	0.423	3	5.548**	4.022*						
3	1.023	3	7.337**	5.811**						
8	1.032	3	7.364**	5.838**						
5	1.432	3	8.557**	7.030**						
7	1.498	3	8.754**	7.227**	3.757^{-}					

Station	1	2	4	6	3	8	5	7

$^{-}$ $P > 0.05$

* $P < 0.05$

** $P < 0.01$

This test is less sensitive (more conservative) than the planned-comparison F-test between means (Winer 1971), which provided convincing evidence that the mean PC 1 score for Station 4 differed from that of Station 5.

An analysis of variance found that PC 2 differed among stations only in May and July (Table 47). Mean PC 2 scores did not differ between stations 4 and 5 in any sampling period, so there was no evidence of an impact from muskeg drainage on this component.

PC 3 had no clear ecological interpretation and accounted for only an additional 8.1% of the total variance (Tables 43 and 44), so was not analyzed further.

The May, June and July Ekman samples from Station 4 were collected from the fine organic silt deposited by the mid-April flood from the minesite drainage ditch. The fact that no evidence of a change in the benthic community was found in the early May samples suggests that the initial impact of the flood, if any, was short-lived and not very large. The depression of the abundance of certain taxa noted in June suggests that the sediments had become less habitable, perhaps because of rapid decay and a consequent reduction in oxygen in the sediments. A small decrease in dissolved oxygen in the open water at Station 4, possibly indicative of organic decomposition in the sediments, was noted from May through August (see Water Quality section).

3.2.4 Benthic Fauna of the Drainage Ditches

The benthic fauna of the plantsite drainage ditch (Station 10) was very sparse. No animals were found in the May Ekman samples,

Table 47. Analysis of variance and planned comparisons on the second principal component of log (x + 1) taxon abundance/m², Ekman and cylinder samples, 1980.

Analysis of Variance

Source	SS	d.f.	MS	F	P
Station	15.01180	7	2.14454	3.72	
Period	11.47431	3	3.82447	6.63	
Station x Period	29.82554	21	1.42026	2.46	0.0033
Error	35.17211	61	0.57659		
Total	91.48376	92			

Simple effects: Stations

Period	SS	d.f.	MS	F	P
April - May	10.12109	7	1.44587	2.51	<0.05
June	3.67548	7	0.52507	0.91	>0.05
July	25.91274	7	3.70182	6.42	<0.001
October	2.49396	7	0.35628	0.62	>0.05

Simple effects: Period

Station	SS	d.f.	MS	F	P
1	5.21454	3	1.73818	3.01	<0.05
2	9.44424	3	3.14808	5.46	<0.005
3	6.72505	3	2.24168	3.89	<0.025
4	0.49812	3	0.16604	0.29	>0.05
5	3.81868	3	1.27289	2.21	>0.05
6	0.09417	3	0.03139	0.05	>0.05
7	8.03584	3	2.67861	4.64	<0.01
8	2.99393	3	0.99798	1.73	>0.05

Planned comparisons: Stn 4 vs Stn 5 by period

Period	SS	$F_{1,61}$	P
April - May		0.95	>0.05
June		0.31	>0.05
July		1.34	>0.05
October		0.80	>0.05

and only three chironomids and one trichopteran were found in the June Ekman collections. Subsequent collections were made by kick sampling, so that a large area could be sampled (0.25 m^2 per sample). In the three July kick samples, a total of only 27 chironomids, 1 mayfly, 1 oligochaete, 3 blackfly larvae and 1 caddisfly were found, and no invertebrates were found in the three October kick samples (the August samples were lost in transit). The plantsite drainage ditch thus appears to be very unfavourable habitat for benthic invertebrates.

The minesite drainage ditch (Station 9) was not sampled in the April-May or June periods because the drainage water had been diverted out of the channel. The July samples, however, taken below the pond outfall, revealed a diverse chironomid fauna consisting of at least 18 genera, and reaching a mean total abundance of 484/m^2. In addition, Simulium larvae were common (155/m^2), and occasional specimens of Gammarus lacustris, Dolichopodidae, Mollibdella gradis (Hirudinea), and Dytiscidae were collected. The August samples were lost in transit, but in October a moderately abundant benthic fauna was again found (total abundance 103/m^2). The October samples contained, in addition to eight species of chironomid, the net-spinning caddisfly Hydropsyche (32/m^2), Gammarus lacustris (12/m^2), Simulium, Chrysops (deerfly larva), Leptophlebia, and three leeches of the species Erpobdella punctata and Dina parva.

Hydropsyche is often common below lake outlets (eg; Hynes 1970), but is not tolerant of heavy siltation. Its occurrence at Station 9 in October is evidence that heavy siltation was not a

problem in the minesite ditch below the settling pond in that month. Taken together, the July and October results show that Station 9 was a satisfactory habitat for many benthic invertebrates, and suggest that water of satisfactory quality was being contributed to the Muskeg River at those times.

3.3 Conclusion

The conclusions of the benthic invertebrate studies are summarized in Table 33.

The response of the benthic community to Alsands' Muskeg drainage program was complex. Benthic invertebrates inhabiting fine sediments showed no detectable response to muskeg drainage initially (April-May), even though large quantities of sediment had been deposited in their habitat only two weeks prior to sampling as a result of the mid-April ditch wall failure. At the same time, there was no evidence that certain detritivores and predators in the benthic fauna of stony substrates increased, but that the effect was restricted to the zone upstream from Station 3 to Station 4.

The fauna of fine sediments did show a response to muskeg drainage in June, when both the total benthic biomass, and the abundance of certain detritivores and predators was reduced at Station 4. The fauna had recovered by some point upstream of Station 3. The impact was undetectable by July, nor was it detected in October.

Table 48. Summary of impacts on the Muskeg River benthic fauna of muskeg drainage water from the minesite drainage ditch, 1980.

Period	Substrate	Impact	
		Station 4 (main impact station)	Station 3 (recovery)
April-May	fine sediments	nil	
	stony	increase in certain detritivores, predators	nil
June	fine sediments	decrease in total biomass of benthic invertebrates	nil
		decrease in certain detritivores, predators	nil
July	fine sediments	nil	
	sunken wood	increase in certain detritivores, predators	nil
October	fine sediments	nil	

The benthic fauna of sunken wood substrate, studied in July, showed a response to muskeg drainage similar to that exhibited by the fauna of stony habitat in April-May; ie, the abundance of certain detritivores and predators increased. The impact was undetectable as far downstream as Station 3.

The findings that detritivores and predators decreased in fine sediments in June, but increased on stony substrate in April-May and on sunken wood substrate in July, are not necessarily contradictory. Environmental conditions and taxonomic composition were different in the various sampling periods and on the various substrates.

A detailed experimental study would have been required to fully explain the above results, but one reasonable hypothesis could be advanced. The most pronounced impact on water quality by muskeg drainage was siltation (see Water Quality section), and the most obvious physical impact on Station 4 was the deposition of a thick layer of silt laden with fine particulate organic matter (FPOM) in the depositional zone. It therefore seems likely that siltation was chiefly responsible for the observed impacts.

Possible mechanisms for the impacts were touched upon in Section 3.2, and relate primarily to the role of FPOM. Briefly, the deposited FPOM would have served as a food source for most of the detritivores impacted at Station 4, and those on solid substrates responded by increasing in abundance. Certain predators on solid substrates likewise increased in abundance, perhaps in part in

response to the increased abundance of detritivore prey, but in one case (*Hydra*) possibly in response to prey contributed from the plankton of the settling pond. FPOM would have decomposed in the depositional zone at Station 4, reducing oxygen in the fine sediment habitat, reducing the habitability of this substrate to benthic invertebrates and thus reducing the numbers of certain of them.

The finding that a diverse and moderately abundant benthic invertebrate community inhabited the minesite drainage ditch below the settling pond (Station 9) in July and October suggests that the quality of the drainage water was satisfactory on those dates, and should have had little impact on benthic communities downstream. The near-absence of benthic invertebrates at Station 10, however, shows that muskeg drainage activities can produce aquatic habitats that are nearly uninhabitable to bottom fauna.

4.0 PERIPHYTIC ALGAE

4.1 Methods

4.1.1 Selection of Stations and Substrate Types

Stations 1 to 8 (Figure 1), were sampled for periphytic algae. The rationale for the selection of these stations for chemical and biological monitoring is described at length in Section 3.1.1.

Stones were selected as the principal natural substrate for sampling of periphytic algae. Several quantitative methods have been described for sampling submerged rock (eg Hynes 1970:56-59), and in most streams stones are plentiful. Unfortunately, stones in the Muskeg River above Station 2 are usually in inaccessibly deep water, are silted over, or are absent altogether. Other hard substrates, such as submerged wood, roots, branches and twigs, are plentiful above Station 2, but are difficult to sample quantitatively. Some sunken wood substrates were sampled in this study, but only incidentally in an attempt to describe the natural flora on hard substrates at certain stations where stones could not be sampled. Only samples from stones were used in the analysis of environmental impact on natural algal communities.

During the first sampling trip, it was found that no stones were available for sampling at stations 5, 7 or 8, which comprised three of the four control stations selected for study. To overcome this problem, it was decided to collect samples from a parallel series of artificial substrates (glass microscope slides) incubated at all stations.

4.1.2 Field and Laboratory Methods

Periphytic algae were sampled from stones at all stations except 5, 7 and 8 with a Stockner toothbrush sampler (Stockner and Armstrong 1971), a device based on the brush and suction principle described by Douglas (1958). Randomly-allocated triplicate samples were made at each site as follows. Three points were chosen at random distances (table of random numbers or blind stick toss) along a transect across the stream. At each point five, (April-May) or three (all other times) stones were selected without looking, and the sample removed. Each replicate was thus a composite of three or five brushings. The replicates were stored in separate four-ounce screwtop jars, to which a few drops of Lugol's solution was added.

Plexiglass racks of glass microscope slides (McCart et al 1977) were incubated at each sampling station. At stations 3 to 8, each rack was suspended approximately 30 cm below the surface from a plastic float anchored by a line in a slow-flowing area. At stations 1

and 2, the samplers were placed directly on the bottom in stony riffles. As was discussed with respect to benthic invertebrate samples, the slide samples at stations 1 and 2 were not intended to be directly comparable to those from upstream stations, but to provide baseline data for this substrate type in habitat typical of the lower reaches of the river.

Slides were set in place during the April-May sampling trip, and were sampled during the subsequent collection periods. Slides were allocated at random to triplicate samples from each rack. The slides were scraped clean each time, and the algae were stored in 4 oz jars of filtered river water (see below), preserved with a few drops of Lugol's solution.

River water filtered through Whatman GF/C filters was used for topping up the periphyton samples in the field. These glass fibre filters retain particles down to 1.2µm in diameter with 98% efficiency, according to the manufacturer's specifications, considerably smaller than the minimum dimension of any of the unicellular algal species found in this study.

The schedule for sampling periphytic algae is presented in Table 49.

In the laboratory, samples for identification were thoroughly agitated and subsamples were pipetted to settling chambers. The volume of the subsamples depended upon the density of the original sample (ie, amount of silt, detritus, etc). Settling time was based upon a standard rate of three hours per centimetre of chamber height.

Table 49. Sampling dates (mo/d) for periphytic algae, Muskeg River and Hartley Creek, 1980.

Sampling Method	1	2	3	4	5	6	7	8
Stockner	05/02	05/02	05/01	05/02		05/02		
	06/03	06/02	06/02	06/03		06/04		
	07/12	07/09	07/12	07/11		07/12		
	08/15	08/16	08/17	08/16	08/15[a]	08/17		08/14[a]
	10/12	10/08	b	b	b	b		b
Slides	06/03	06/02	06/02	06/03	06/03	06/04	06/04	06/03
	07/12	07/09	07/12	07/11	07/11	07/12	07/10	07/12
	08/15	08/16	08/17	08/16	08/15	c	08/16	08/14
	c	c	c	c	10/10		10/11	10/11

a. samples taken from branches, sunken wood, and other debris

b. sampling not possible because of high water

c. samplers lost due to high water or beaver activity.

The subsamples were then examined whole using a Leitz Diavert Inverted Microscope equipped with phase contrast illumination. The algae were identified to the species level where possible with the enumerations (as cells/cm^2) and identifications carried out at magnifications of 750X and up to 1750X, respectively.

For the complete identification of diatoms a concentration amount of the subsamples was pipetted onto a coverslip and ashed in a muffle furnace (560° C ± 10° C) for 15 min. The cleaned diatoms were then mounted in Piccolyte and examined under a Wild M12 Microscope. This method allowed accurate identifications of diatoms in the whole subsample by comparison with cleaned diatoms in the ashed sample. In order to convert the cells/cm^2 to biomass values it was necessary to estimate the volumes of cells of the various species. Volume estimates were made by approximation using geometric shape or shapes that most closely resembled the shape of the cell (Findenegg, 1969).

Identifications were based mainly upon the works of Bourrelly (1966, 1968, 1970), Cleve-Euler (1951-1955), Desikachary (1959), Hilliard (1966, 1967), Hustedt (1927-1964), Foged (1974), Nygaard (1977), Prescott (1962), Patrick and Reimer (1966, 1975), Skuja (1948, 1964), Sreenivasa and Duthie (1975), Whitford and Schumacher (1973).

Not all the slide samples were analyzed because they were taken only as a supplement to the natural substrate samples. All samples have been retained for possible future reference.

It had been proposed to use chlorophyll a as the measure of periphyton biomass. The samples were taken, but the analytical results were considered unreliable, and the method of volumetric estimation noted above was substituted.

4.1.3 Data Analysis

Biomass, usually as chlorophyll a, has often been found useful as an overall indicator of algal responses to environmental conditions (eg; Vollenweider 1974). Changes in the total quantity of algae could reasonably be expected in response to siltation (decline) or nutrient enrichment (increase), two of the most pronounced impacts on water quality in this study (Section 2.0). In the data analysis, log (x + 1)--transformed total algal biomass was analyzed in analysis of variance to detect differences among stations that could be related to impact from muskeg drainage.

Some environmental changes may have had selective effects on the flora, causing changes in the species composition of the algal communities. Testing of this hypothesis required that the large number of species variables be reduced to a manageable quantity. This reduction was accomplished first, by selecting species according to the "10% rule", then by reducing the number of variables still further through principal component analysis. Both procedures are described above in Section 3.1.3.

4.2 Results and Discussion

4.2.1 Taxonomic Composition

The composition of the periphytic algal flora is summarized by major group in Appendix Tables B1 to B9. Table 50 summarizes the taxonomic composition by species.

A total of 244 species from eight major groups (Divisions) was recorded in the study. More than half (53.7%) were Bacillariophyta (diatoms), which accounted for 131 species. None of the remaining Divisions accounted for more than 20% of the species. Chlorophyta (green algae) were represented by 47 species (19.3%), Chrysophyta (yellow-brown algae) by 26 species (10.7%), Cyanophyta (blue-green algae) by 23 species (9.4%), Cryptophyta (cryptomonads) by 9 species (3.7%), and Rhodophyta (red algae) and Pyrrhophyta (dinoflagellates) each by 1 species (0.4%).

The number of alga species found in this study is higher than that found in other similar studies on rivers in Alberta, including several in the AOSERP area (Table 51). The relative proportion of the total number of species comprised by major groups, however, is about the same as in other studies. Differences in the number of species recorded in these studies is not necessarily related to ecological conditions in the waters examined, but may merely

Table 50. Species composition, single cell volume, maximum abundance, month of maximum abundance, and substrate type colonized, periphytic algae in the Muskeg River and Hartley Creek, 1980.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrate[3]
Chlorophyta											
Ankistrodesmus convolutus	40	1/2	1/3	2/3	1/2	1/2	2/0	0/2	0/2	6/6	SGW
A. falcatus	60	1/0	2/0	2/2	2/2	2/2	2/0	0/2	2/0	5-8/6-8	SGW
A. falcatus var. *acicularis*	340	2/0	1/2	2/0	0/2	0/2	2/0			6/6	SG
Bulbochaete sp.	400				3/0					7/0	S
Carteria klebsii	180		1/0							7/0	S
Chaetophora sp.	625	2/0								8,10/0	S
Chlamydomonas spp.	80	2/2	2/0	2/0	2/0	1/0	1/0			5,6/6	SGW
Coelastrum microporum	268			2/0						8/0	S
Closterium dianae	28 000					0/1				0/10	G
Cl. gracile	8 200								1/0	10/10	W
Cl. leibleinii	26 363				1/0		1/0			5,8/0	S
Closterium spp.	24 980		2/0	1/0					1/0	5,8/0	SW
Cosmarium spp.	9 430	2/0	2/0							5/0	S
Crucigenia quadrata	30	2/0	2/0	2/0	0/3					7/7	SG
Dictyosphaerium primarium	20	3/0	3/3	3/3	3/2				0/3	6/6	SG
Euastropsis richteri	80						1/0			7/0	S
Koliella longiseta	85					1/0				8/0	W
Monoraphidium arcuatum	80	1/0									S
Mougeotia spp.	3 000	3/3	0/3			0/3	1/0	2/0		8/8	SG
Nephrocytium agardhianum	120		2/0							8/0	S
Oedogonium spp.	1 145		2/3	2/0	2/2		2/0		2/0	5,7,8/8	SWG
Oocystis borgei	420			1/0							S

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides) [1] Station 1	2	3	4	5	6	7	8	Month of [2] Maximum natural /slides	Substrate[3]
Chlorophyta (Continued)											
Oocystis parva	38	1/0	2/0		2/0		2/0			7,8/0	S
Pediastrum boryanum	80			3/0						7/0	S
P. duplex	60		3/0							8/0	S
P. tetras	28		2/0							7/0	S
Platymonas sp.	120					1/0				8/0	W
Scenedesmus abundans	38				2/0					8/0	S
S. arcuatus var. *platydisca*	38	1/0	2/0		0/2					8/7	SG
S. bijuga	38	1/2	2/0	3/0	2/2	2/0				7/5,6	GW
S. denticulatus	50	1/0			3/0	2/2	3/0			7/7	SG
S. dimorphus	180		2/0			2/0				8/0	SW
Scenedesmus longus	58		2/0	2/0						7/0	S
S. obliquus	220	2/2	0/2	2/0	3/2			0/2		7/6,7	GS
S. quadricauda	180		2/0	2/0	2/2	0/2	2/0	0/2		7/7	SG
S. serratus	38		1/0		2/0					6/0	S
Scourfieldia complanata	20		1/0							7/0	S
Spirogyra spp.	16 960		1/0	2/3	1/2	0/2	1/0		0/2	8/5,7	SG
Stigeoclonium stagnatile	5 000	3/0	3/3				4/0				SG
St. nanum	462	0/3	3/0	3/0		0/2	3/0			5,7/8	SG
Tetraedron minimum	150	1/2	2/0	1/0	1/1	0/1	2/0		1/0	8/8	SGW
T. minimum var. *tetralobatum*	75		2/0							7/0	S
T. caudatum	110			1/0						8/0	S
Ulothrix subtillissima	435	2/0								10/0	S
Zygnema spp.	18 000			2/0						7/0	S

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrate[3]
Cyanophyta											
Anabaena flos - aquae	50	2/0	2/0	3/0			4/0			7/0	S
A. variabilis	45		0/3				3/0			6,8/5	SG
Anabaena spp.	50	2/0	1/3	3/0	3/0	2/0	2/0			8/8	SWG
Calothrix spp.	60	2/0								7/0	S
Chaemaesiphon incrustans	20		0/2	2/0	2/2			0/3		5/6,10	SG
Chroococcus limneticus	180			2/0			2/0			7,8/0	S
Chr. minutus	60			2/0						8/0	S
Coelosphaerium kutzingianum	20							0/3		0/7	G
Gloeocapsa rupestris	38			2/0	2/0	1/0	2/0		0/3	5,7/10	SWG
Gomphosphaeria lacustris	45			0/4						0/6	G
Lyngbya aerugineo - caerulea	45		2/0				3/0			6,8/0	S
L. birgei	235	3/0								5/0	S
Meriamopedia glauca	25		3/0		0/2		2/0			8/8	SG
Rostoc paludosum	35		3/0				4/4			7/5	SG
Oscillatoria amoena	50		3/0							10/0	S
O. agardhii	50	3/0	4/0	3/0	3/0		4/0			5,7/0	S
O. limnetica	10		3/0		2/0					7/0	S
O. limosa	70			0/2			3/0			6/6	SG
O. minnesotensis	32		3/0	3/0					0/3	5,7/8	SG
Phormidium tenue	10	4/4	4/4	4/3	4/0	3/2	4/0	0/3	0/4	5,7-10/6,8	SGW
Rivularia haematites	50	2/0	2/0				3/0			6/0	S
Tolypothrix distorta	235						3/0			8/0	S

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrate[3]
Chrysophyta											
Bitrichia chodatii	80			1/0						6/0	S
Chromulina spp.	20		1/0	2/0	1/0					6,7/0	S
Chrysochromulina parva	20	0/1		1/0	1/0					5,7/6	SG
Chrysococcus rufescens	100	4/3	4/3	3/3	3/2	2/2	3/0	0/3	0/3	6/6	SGW
Dinobryon crenulatum	260			1/0						5/0	S
D. divergens	260	1/0	1/0	2/3	2/1			0/2		6/6	SG
D. sertularia	240	2/0	2/2	2/0	2/0	0/2	2/0	0/2		6,8/6	SG
D. sociale	280	2/0	3/0	2/0	2/1	1/1		0/3		6/6	GSW
Epipixis gracilis	60				1/0	0/1				6/7	SG
E. tubulosa	60			0/1		0/1				0/7	G
Kephyrion littorale	30		1/2	1/	0/1		2/0		0/2	7/6	SG
Mallomonas akrokomos	880		1/0							6/0	S
M. crassisquama	2 415		1/0							6/0	S
M. tonsurata	509	2/2	3/0	2/2	0/2		1/0		0/2	6/6	SG
Monosiga varians var. *vagans*	78		2/0							6/0	S
Ochromonas spp.	33		1/0	2/0						6/0	S
Pseudokephyrion pseudospirale	35	2/0	2/0	2/0	1/0		2/0	0/1		6,7/7	SG
P. striatum	40	1/0	1/1		1/0				0/2	6/6	SG
P. undulatissimum	45			2/0			1/0			7/0	S
Pseudopedinella erkensis	120		1/0							6/0	S
Salpingoeca frequentissima	60		0/2			0/1				0/6	G
Stenocalyx monilifera	30		1/0				1/0			6,7/0	S
Spiniferomonas bourrellii	66		3/0						0/2	6/6	SG
Synura petersenii	180	2/0	2/0	1/0	1/2			0/2		6/6	SG

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrate[3]
Xanthophyta											
Tribonema utriculosum	1 256		3/0		0/3		3/0		0/3	6/6,7	SG
T. bombycinum	1 256						3/0			7/0	S
Bacillariophyta											
Achnanthes lanceolata	140	2/0	2/2	2/2	1/0	1/2	2/0	0/2	0/2	5-7/5,7,8	SGW
A. lanceolata var. *dubia*	130			2/0			1/0			6/0	S
A. linearis	180	1/0			2/0	1/0	1/0		0/2	7/5	GSW
A. microcephala	130			2/0						8/0	S
A. minutissima	150	3/2	3/3	3/2	3/3	2/2	2/0	0/3	2/3	5-8/5-7	SGW
Achnanthes spp.	120	1/0	2/0	2/0						5,8/0	S
Amphora ovalis	2 500	1/0	2/2	2/0	1/2					6-8/7,8	SG
Am. perpusilla	180		1/0							8/0	S
Amphipleura pellucida	3 200	3/2	3/2	1/0	2/2	2/2	2/0	0/2	1/2	5/6-10	SGW
Anomoeneis vitrea	360	1/0					0/2			7/6	GS
Caloneis ventricosa	1 200	1/0								10/0	S
Cocconeis pediculus	3 680	0/2	0/2	2/0	1/0		1/0			6,7/6	SG
Co. placentula var. *lineata*	1 200	2/5	2/4	3/4	3/5	2/4	3/0	0/4	2/4	5,7/6-8	SGW
Cyclotella glomerata	220	2/0	2/2	2/0							SGW
Cy. meneghiana	750	1/0	1/0	2/0	2/0	1/0	1/0		2/2	8/8	GSW
Cy. stelligera	80			0/2	2/0		3/0		0/2	6/6	SG
Cymatopleura solea	50 774			1/0		1/0	1/0			5,6,8/0	SW
Cymbella affinis	1 800		1/0							5/0	S
Cymbella cistula	12 560		2/0	2/0	0/1					8/6	GS

Continued. . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrates[3]
Cymb. cymbiformis var. / *nonpunctata*	7 950					1/0				8/0	SW
Cymbella lunata	240		2/0							8/0	S
Cymbella lanceolata	292 491			0/2	1/0	2/2				8/8,6	GSW
Cymbella minuta	280	2/2	3/2	3/2	2/2	1/1	2/0	0/2	0/2	5/6-10	SGW
Cymbella microcephala	120			2/0					1/0	7/0	SW
Cymbella minuta f. *latens*	140		1/2							8/8	SG
Cymb. prostrata var. / *auerswaldii*	2 200	1/0								8/0	S
Cymbella sinuata	120	1/0	1/0		2/0	0/1		0/2		7/6,10	SG
Denticula tenuis	200					0/1				0/10	SG
Diatoma hiemale var./ *mesodon*	12 600	2/0								5/0	S
Di. tenue	160	3/0	2/2	3/2	2/2	0/2	3/0			5,6/6	SG
Di. tenue var. *elongatum*	450	2/0	3/3				2/0			5,8/8	SG
Di. vulgare	22 600	2/0	1/0	1/0						10/0	S
Diploneis oblongella	880		1/0							7/0	S
Entomoneis paludosa	33 650			0/2		0/2				0/5	G
Epithemia sorex	3 800	4/0	2/0	2/0	1/0	2/2	2/0			5/10	SGW
Epithemia turgida	12 000	3/2	2/2	2/2	2/1	1/2	2/0	0/2	0/2	5/6,8	SGW
Eunotia arcus var. *bidens*	480								0/1	0/10	G
Eunotia adnata	360			0/2						0/8	G
Eunotia curvata	452	1/0	0/2		1/2	1/2		0/2	0/2	5-8/6-10	SGW
Eunotia flexuosa	4 500					1/0				8/0	W

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrates[3]
Bacillariophyta (Continued)											
Eunotia formica	8 200					1/0				8/0	W
Eunotia pectinalis var. *minor*	335				0/2	1/2		0/2	0/2	8/8,10	WG
Eunotia spp.	848		1/0	1/0		0/2		0/3			SG
Fragilaria capucina	200	0/3				0/2			2/3	8/8	WG
F. capucina var. *mesolepta*	200					2/0	1/0			8/0	SW
F. construens	200		2/0	1/0						5,8/0	S
F. construens var. *binodis*	260		0/2	2/0					0/2	6/6	SG
F. crotonensis	480			2/0						7/0	S
F. pinnata	120		1/0		1/1		2/0			7/7	SG
F. vaucheriae	220	3/0	2/0	2/0	2/0		2/0			5/0	S
F. virescens	210	3/0	3/0	3/3	2/3	2/3	2/0	0/3		5,8/6-8	SGW
Fragilaria spp.	320			1/0	0/2	0/2				6/6,10	SG
Frustulia rhomboides	45 200		1/0		0/1	0/2	1/0	0/2	0/2	5,7/6,8	SG
Gomphonema acuminatum	1 885	2/0	2/2	2/2	1/2	0/2	2/0	0/2	0/2	5,7,8/6,8	SG
G. acuminatum var. *elavus*	1 017		2/0							5/0	S
G. angustatum	350	2/0	3/2	3/0	2/0		2/0		1/0	5,8/6	SGW
G. dichotomum	460					0/1				0/10	G
Gomphonema brebissonii	1 300			1/2				0/2		6/6	SG
G. affine	2 412			1/0						6/0	S
G. gracile	210					0/1			0/4	0/10	G
G. intricatum	1 400	2/2		2/2	1/0	0/2	1/0	0/2	0/3	5,6/10	SG
G. olivaceum	420	3/0	1/0						0/1	10/10	SG
G. parvulum	340	3/3	2/2	2/2	2/2	2/2	2/2	0/3	1/3	5/6,8	SGW

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrates[3]
Bacillariophyta (Continued)											
G. subclavatum var./ *commutatum*	904	2/0								5/0	S
G. truncatum	1 492	3/0	3/2	2/2	2/2	1/2	2/0	0/2	2/2	5/6,8,10	SGW
G. ventricosum	7 380			2/2						8/6	G
Gomphonema spp.	280	3/2	3/3	3/2	3/2	0/2	2/0	0/3	2/4	5/8	SGW
Gyrosigma acuminatum	46 158		1/0	0/2	2/1	0/2	1/0	0/2		8/6,8	GS
Hantzschia amphioxys	1 230				0/1					0/6	G
Hannea arcus	750				2/0					6/0	S
Hannea arcus var. *amphioxys*	385								0/1	0/10	G
Melosira varians	1 000		3/3	3/3	2/2	2/2	1/0		1/2	5,8/6,8	SGW
Meridion circulare	1 000			0/2	2/0					5/6	SG
Navicula angusta	480		1/0	2/0		0/1	1/0	0/2		8/7	SG
N. arvensis	75		1/0		0/1	0/2				7,8/8	SG
N. aurora	2 800		2/0							8/0	S
N. capitata	280	1/0	2/0	2/0	0/2	1/2		0/2	2/0	5,8/6-8	SG
N. cryptocephala	400	3/2	3/2	3/2	2/2	2/3	3/0	0/3	2/3	5-7/6,8	SG
N. cryptocephala var. *venter*	220	1/0	1/0	3/0	2/0	0/1	2/0	0/2	0/2	5/8	SG
N. cuspidata	131 125						1/0			5/0	S
N. elginensis	1 050	1/0			0/1					7/7	SG
N. elginensis var. *rostrata*	1 050		2/0			1/1				8/10	SW
N. lanceolata	425		1/0							7/0	S
N. menisculus	340	1/0	2/0		1/0					8/0	S

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrates[3]
Bacillariophyta (Continued)											
N. pupula var. *rectangularis*	460	1/0	2/0	2/2	2/0		1/0		0/1	5,6,8/6	SG
Navicula radiosa	3 240		2/0	2/2	0/2	1/0	2/0		1/2	5-7/6,8	SGW
N. reinhardtii	9 350			1/0		0/2	1/0			6/6	SG
N. rhynococephala	1 850			1/0	1/2	0/1		0/2		6,8/8	SG
N. salinarum var. *intermedia*	920	1/2	2/3	3/2	2/2	2/3	2/0	0/2	0/2	8/6,8	SGW
N. tripunctata	1 884	3/2	2/2	2/2	2/2	1/2	2/0		0/2	5/6-8	SGW
N. tuscula	1 450		1/0							7/0	S
N. viridula	2 200		2/0			0/2	1/0	0/2	1/2	8/8	SGW
Navicula spp.	400	3/0	2/2	2/0	1/2	0/3	2/0	0/2	2/2	10/5	SGW
Neidium binode	520		2/0							8/0	S
Nitzschia acicularis	110	2/2	2/3	3/3	2/2	2/2	2/0	0/2	2/3	5,6/6	SGW
Nit. amphibia	80					0/1					G
Nit. capitellata	550		2/0				1/0			5,8/0	S
Nit. dissipata	300	2/2	1/2	2/0	2/0	0/1	2/0			5-7/6	SG
Nit. dissipata var. *media*	1 800					0/1		0/2		0/6	G
Nit. fonticola	145			1/0			1/0			8,10/0	S
Nit. linearis	750		1/2	2/0	1/2	1/2			1/0	6/6,8	SGW
Nit. palea	325	1/0	2/2	1/0	2/0	2/2	2/0	0/2	2/2	8/7-10	SGW
Nit. reota	2 120		1/0	0/2	1/0					8/6	GS
Nit. sigma	280		0/2	1/0	2/1	1/2	2/0	0/3	0/2	7,8/6	SGW
Nit. sigmoidea	15 150		1/0		2/0					6/0	S
Nit. vermicularis	8 245	1/0	2/2	2/2	1/2	0/2	1/0		1/3	5,6,8/6	SGW
Nitzschia spp.	350	3/3	4/3	3/3	3/3	2/4	3/0	0/3	2/4	8/5,10	SGW

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrates[3]
Bacillariophyta (Continued)											
Pinnularia bieeps	9 220	0/2	1/0		1/0					7,8/8	SG
P. mesolepta	6 800		1/0	1/0	0/2	0/1				6,7/8	SG
P. viridis	53 000				1/0				1/0	7,8/0	SW
Pinnularia spp.	7 250			2/0	1/1	0/2	1/0	0/2		5/6	SG
Rhoicosphenia curvata	320		2/0	2/0	0/2	0/2	2/0			5,6,8/8	SG
Rhopalodia gibba	6 100	2/2	2/2	3/2	2/0	1/1	2/0		1/0	7,8/6-8	GSW
Rhop. gibba var. *ventricosa*	19 079	2/0	1/2	2/0		0/2	2/0	0/2	2/0	5-8/6,8	SGW
Stauroneis anceps	1 480			1/0		0/2			1/0	8/8	SGW
S. smithii	420			1/0						7/0	S
Stephanodiscus hantzschia	172		2/0							6/0	S
Surirella angustata	1 462		2/0	2/2	2/1	0/2	2/2	0/2	1/0	5-8/6-8	SGW
Su. linearis	75 285			1/0						6/0	S
Synedra acus	1 800	2/0		2/0						5,6/0	S
Sy. amphicephala var. *austriaca*	320	2/0								5/0	S
Sy. cyclopum	426		1/0							5/0	S
Sy. delicatissima var./ *angustissima*	2 500					0/1				0/10	G
Sy. radians	260	0/2	3/3	2/2	2/2	1/2			1/2	8/6	SGW
Sy. ulna	4 240	4/2	3/2	4/2	3/2	1/2	4/0	0/2	0/3	5/6	SGW
Sy. ulna var. *chasena*	8 810					0/2				0/8	G
Sy. ulna var. *subaequalis*	9 232		0/2	0/2					0/2	8/8	GW
Sy. ulna var. *danica*	9 232	2/0	2/0	2/2	2/2	2/2	2/0	0/2	0/2	5-8/6,8	SGW
Sy. tenera	280	1/0	1/0	3/0	2/0	0/2	1/0			5/8	SG

Continued . . .

Table 50. Continued.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural/slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrates[3]
Bacillariophyta (Continued)											
Synedra spp.				2/0	2/3	0/2	2/0	0/3		6/6	SG
Tabellaria fenestrata	650		1/3							5/8	SG
Euglenophyta											
Euglena acus	4 500						1/0		0/2	6/6	SG
E. gracilis	2 200				1/0		1/0			7/0	S
Phacus caudatus	1 200		2/0						0/2	8/8	SG
Trachelomonas hispida	12 073		1/0				2/0				S
T. hispida var. coronata	12 073		1/0							6/0	
T. volvocina	1 440		1/0			2/0	1/0			8/0	SW
Cryptophyta											
Chroomonas coerulea	45			2/0		1/0	1/0			8/0	SW
C. nordstedtii	120						1/0			8/0	S
Cryptomonas brevis	800	1/0			1/0					5,8/0	S
Cr. erosa	2 000				1/0					5/0	S
Cr. marssonii	480	2/0	2/0	1/0	1/0					6,7/0	S
Cr. ovata	2 200		1/0					0/2		5/6	SG
Cryptomonas spp.	800		1/2	2/2			2/0	0/2		5,7/6	SG
Rhodomonas minuta	132	1/0	3/0	1/2			1/0			6,7/6	SG
R. minuta var. nannoplanktonica	40		1/0							6,7/0	S

Continued . . .

Table 50. Concluded.

Taxon	Single Cell Volume (μm^3)	Maximum abundance (natural slides)[1] Station 1	2	3	4	5	6	7	8	Month of[2] Maximum natural /slides	Substrates[3]
Rhodophyta											
Audouinella violacea	960	4/0	3/0				3/0			5/0	S
Pyrrhophyta											
Peridinium inconspicuum	1 380			1/0						5/0	S

[1] order-of-magnitude index: 1 < 100 cells/cm²
2 101 - 1000 cells/cm²
3 1001 - 10 000 cells/cm²
4 10 000 - 100 000 cells/cm²
5 > 100,000 cells/cm²

[2] number of month: 5 late April - early May
6 June
7 July
8 August
10 October

[3] S = stones; W = wood; G = glass slides

Table 51. Percentage of total number of species of periphytic algae by botanical Division, several Alberta river studies.

	Present Study	Athabasca River[1]	Mackay River[2]	S.Sask. River[3]	5 AOSERP Rivers[4]
Number of species	244	191	142	201	197
Chlorophyta	19.3	17.8	17.6	22.4	16.2
Cyanophyta	9.4	11.0	16.9	12.9	16.8
Chrysophyta	10.7	8.9	5.6	< 6.5	0.5
Baccilariophyta	53.7	61.3	56.3	58.2	63.4
Euglenophyta	2.4	-	2.1	-	0.5
Cryptophyta	3.7	1.0	1.4	-	1.0
Pyrrophyta	0.4	-	-	-	-
Rhodophyta	0.4	-	-	-	1.5

[1] McCart et al (1977) - glass slides

[2] McCart et al (1978) - glass slides, plexiglass plates

[3] Green and Davies (1980) - stones

[4] Hickman et al (1979) - stones, plankton

reflect differences in the number of samples, types of substrate or number of stations examined.

Total algal abundance and biomass was of similar order of magnitude on natural substrates (mainly rocks) and glass slides, usually ranging from 1 x 10^5 cells/cm^2 to 1 x 10^6 cells/cm^2, and 0.1 x 10^5 to 10 x 10^5 $\mu m^3/mm^2$, respectively, on both substrate types (Table 52). There were some differences in taxonomic composition, however. Thirty-one of 33 slide samples were dominated, in terms of abundance, by diatoms, but diatoms and blue-green algae usually dominated the natural substrate samples. One epiphytic diatom in particular, Cocconeis placentula variety lineata, dominated the slide samples, and was generally much less abundant on the natural substrate samples (Table 50). This species has been reported as a dominant on artifical substrates in the Athabasca (McCart et al 1977) and MacKay (McCart et al 1978) rivers, suggesting that it is a species particularly adept at colonizing new areas.

The data of Table 50 seem to suggest many other differences between the algal floras of glass slides and natural substrates, but these must be interpreted with caution. Apparent differences in abundance of single species on slides and stones at each station may just reflect differences in the number of samples examined (fewer slide samples were taken at most stations, natural substrates were sampled only rarely at stations 5, 7 and 8) or differences in microenvironment. The slide substrates were not intended to mimic any particular natural substrate in any case. Apart from the dominance of

Table 52. Geometric mean and 95% confidence limits of total biomass of periphytic algae, Muskeg River drainage, 1980. Only samples used in the impact analysis are included. Data have been back-calculated from the log (x + 1) - transformed abundances.

Station	Sampling Period	Stockner samples 10^5 µm³/mm² GM	95% conf. limits	n	Slide samples 10^5 µm³/mm² GM	95% conf. limits	n
1	April-May	35.95	10.04 - 128.66	3			
	June	0.39	0.11 - 1.32	3			
	July	0.10	0.08 - 0.11	3			
	August	0.05	0.02 - 0.14	3			
2	April-May	8.53	2.58 - 28.26	3			
	June	0.56	0.14 - 2.19	3			
	July	0.82	0.29 - 2.33	3			
	August	6.73	2.96 - 15.28	3			
3	April-May	12.13	6.73 - 21.86	3			
	June	3.67	0.29 - 45.74	3	7.11	0 - 560,000	2
	July	2.96	0.93 - 9.38	3	5.75	0.08 - 408.15	2
	August	2.34	0.52 - 10.60	3	5.19	0.06 - 430.01	2
4	April-May	2.53	0.88 - 7.30	3			
	June	0.80	0.02 - 32.56	3	1.57	0.41 - 5.98	2
	July	3.76	0.34 - 41.84	3	14.28	7.72 - 26.40	3
	August	0.54	0.02 - 15.60	3	9.04	0.82 - 100.00	2
5	June				4.28	2.25 - 8.17	2
	July				0.95	0.75 - 1.19	3
					3.99	0.08 - 187.11	2

Continued . . .

Table 52. Concluded.

Station	Sampling Period	Stockner samples 10^5 µm³/mm² GM	95% conf. limits	n	Slide samples 10^5 µm³/mm² GM	95% conf. limits	n
5	August				3.99	0.08 - 187.11	2
6	April-May	12.21	0.97 - 153.40	3			
	June	2.80	0.45 - 17.52	3			
	July	5.90	1.45 - 23.96	3			
	August	1.89	0.79 - 4.53	3			
7	June				0.94	0 - 913,000	2
	July				5.84	0.03 - 978.41	2
	August				3.64	0.45 - 28.91	2

the slides by Cocconeis placentula var. lineata and the generally lesser importance of blue-greens on slides, the glass samplers were colonized by a wide range of other algae that were common on natural substrates in the river, and the abundances achieved by these species on glass was comparable to that on natural substrates (Table 50). Few species were found only on the slides, and these were invariably present in low numbers. In general, the slides were colonized by a reduced (but still substantial) number of the periphytic alga species found naturally in the river, usually at densities similar to those achieved on natural substrates. Evidence of environmental impact detected in the slide sample data therefore has some meaning in terms of possible damage done to natural algal communities in the river.

Two other major studies (Lock and Wallace 1979, Hickman et al 1979) have reported algal species data for a location at or near our Station 2. The most abundant algal species in the present study correspond most closely to those reported by Lock and Wallace (1979), but there are many differences. Many of the most abundant genera we report (Table 50) are listed merely as "present" by Hickman et al (1979). Differences among these studies could easily be due to differences in exact location sampled, year sampled, season sampled, or sampling method, but it would be worthwhile to arrange for an exchange of samples among investigators to reduce as much as possible differences arising from the taxonomic preferences of the various phycologists.

In the June samples, particularly the Stockner samples from stations 1 and 2, algae which are typically constituents of the

plankton of lentic waters, especially small chrysophytes and cryptomonads, were remarkably common. The chrysophytes alone accounted for approximately 70% of the total numbers and 40 to 70% of the total biomass at stations 1 and 2 in June. These were certainly not truly epilithic at the time of sampling, and it seems most likely that their abundance in the samples is an artifact of the Stockner sampling method. Water drawn into the sampler as the plunger is lifted contaminates the sample with phytoplankton. In the great majority of stream studies this poses no problem, because plankton concentrations are usually low in streams, and the "phytoplankton" consists usually of small numbers of detached benthic algae. In the Muskeg River, however, a substantial temporary phytoplankton population could develop in the many kilometres of near-lentic channel and connected pools above Station 2, particularly during periods of low flow, and these algae would be swept downstream with rising water levels. In the present case, the Stockner samples were collected during a short period of increased flow after a long period of low-flow conditions (Inland Waters Directorate, in prep.), and it is most likely that the upstream near-lentic areas are the source of the planktonic algae in the collections.

It should be noted that the slide samples in June also had higher numbers of chrysophytes and other typical plankters in June, but the absolute numbers and proportion of total numbers were much lower than those cited above (Appendix B). This suggests that some plankters settle on the slides and/or are introduced into the samples in the adherent water.

In view of the problem of possible sample contamination, the scraping method employed by Hickman et al (1979) is clearly better suited than is the Stockner method to sampling in the Muskeg River, and ought to be adopted for natural substrate sampling in subsequent studies.

4.2.2 Impact Analysis: Stockner Samples

Only the samples from the April-May, June, July and August sampling periods from stations 1, 2, 3, 4 and 6 were used in these analyses. Because of the high water, it was not possible to collect a complete set of samples in October, and Stockner samples from stations 5 and 8 were taken in only one sampling period from sunken wood, roots and other large debris hard substrates. No stones were accessible for sampling at stations 5, 7 and 8.

The Stockner samples used were taken from approximately the same stony areas used for the benthic invertebrate kick samples. As noted in the Benthic Invertebrate section, there was little choice of stony sampling sites possible above Station 2, so those selected were often not closely comparable. Station 6, the only available control station, was a swifter site than the others, for example. (The sites were briefly described in Section 3.2.2). As for the kick samples, it was necessary in the analysis of the Stockner data to judge any differences at Station 4 as evidence of impact only if the Station 4 value was clearly greater or less than that at all other stations,

on the assumption that Station 4 was not physically extreme, and therefore should not show extremes in its algal community.

The rationale followed in the impact analysis is analoguous to that used in the impact analysis of the benthic invertebrate data, and is described more fully in Sections 3.1 and 3.2.

Table 52 summarizes the total biomass of periphytic algae in the Stockner samples. An analysis of variance of these data (Table 53) demonstrated differences among stations in all four sampling periods, but multiple comparisons provided evidence that Station 4 was "extreme" only in the April-May period, when it had a lower biomass than any other station (Tables 54 to 57). The samples were taken just two to three weeks after the mid-April flood from the minesite ditch, and the biomass reduction is consistent with damage from scour or obliteration by silt.

Principal components of the species abundance data were analyzed to examine differences in community structure among stations. PC 1 accounted for 19.3% of the total variance in the data (Table 58), and can be interpreted as a comparison of planktonic species, which have high negative coefficients, and species typically associated with substrates, which have high positive coefficients (Table 59). As was pointed out in the previous section (4.2.1), plankters were abundant only in the June samples, and then primarily at stations 1 and 2. At other times and sites, therefore, PC 1 is primarily a measure of overall abundance of periphytic algae.

Table 53. Analysis of variance of total algal biomass, Stockner samples, 1980.

Source	SS	d.f.	MS	F	P
Station	7.07575	4	1.76894	18.12	
Period	10.36440	3	3.45480	35.38	
Station x Period	11.23058	12	0.93588	9.58	<0.001
Error	3.90569	40	0.09764		
Total	32.57642	59			

Simple Effects: Station

Period	SS	d.f.	MS	F	P
April/May	2.05132	4	0.51283	5.25	<0.005
June	2.22977	4	0.55744	5.71	<0.001
July	6.28305	4	1.57076	16.09	<0.001
August	7.74214	4	1.93554	19.82	<0.001

Simple Effects: Period

Station	SS	d.f.	MS	F	P
1	14.74088	3	4.91362	50.32	<0.001
2	3.36367	3	1.12122	11.48	<0.001
3	0.90897	3	0.30299	3.10	<0.05
4	1.42503	3	0.47501	4.86	<0.01
6	1.15642	3	0.38547	3.95	<0.025

Table 54. Multiple comparisons of total algal biomass, Stockner samples, April-May 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations joined by lines do not differ in total algal biomass.

Station	mean log (x + 1) $\mu m^3/mm^2$	n	Station 4	2	3	6	1
4	5.403	3					
2	5.931	3	2.927*				
3	6.084	3	3.775*				
6	6.087	3	3.791*				
1	6.556	3	6.391**	3.464⁻			

Station	4	2	3	6	1

⁻ P > 0.05
* P < 0.05
** P < 0.01

Table 55. Multiple comparisons of total algal biomass, Stockner samples, June 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in total algal biomass.

Station	mean log (x + 1) $\mu m^3/mm^2$	n	Station 1	2	4	6	3
1	4.594	3					
2	4.747	3					
4	4.905	3	1.724^{-}				
6	5.447	3	4.728**	3.880*	3.004*		
3	5.564	3	5.377**	4.529*	3.653*	0.648^{-}	

Station	1	2	4	6	3

$^{-}$ P > 0.05
* P < 0.05
** P < 0.01

Table 56. Multiple comparisons of total algal biomass, Stockner samples, July 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in total algal biomass.

Station	mean log (x + 1) µm³/mm²	n	Station 1	2	3	4	6
1	3.980	3					
2	4.912	3	5.166**				
3	5.471	3	8.265**	3.099*			
4	5.575	3	8.841**	3.675*			
6	5.771	3	9.928**	4.762**	1.663⁻		

Station	1	2	3	4	6

⁻ P > 0.05
* P < 0.05
** P < 0.01

Table 57. Multiple comparisons of total algal biomass, Stockner samples, August 1980, by the Newman-Keuls procedure. Call values are the Studentized range statistic Q. Stations linked by lines do not differ in total algal biomass.

Station	mean log (x + 1) $\mu m^3/mm^2$	n	Station 1	4	6	3	2
1	3.730	3					
4	4.737	3	5.582**				
6	5.277	3	8.575**	2.993*			
3	5.370	3	9.091**	3.509*			
2	5.828	3	11.629**	6.047**	3.054⁻		

Station	1	4	6	3	2

⁻ $P > 0.05$
* $P < 0.05$
** $P < 0.01$

Table 58. The first two principal components of algal species abundance, Stockner samples, 1980

Species	Coefficents PC 1	PC 2
Chlamydomonas spp.	-0.517	0.589
Stigeoclonium nanum	0.216	-0.142
Ankistrodesmus convolutus	-0.280	0.380
A. falcatus	0.253	-0.092
Dictyosphaerium primarum	-0.808	0.841
Scenedesmus denticulatus	-0.049	-0.347
Sc. obliquus	-0.058	-0.315
Tetraëdron minimum	-0.116	-0.175
Anabaena spp.	-0.028	-0.558
Anabaena flos - aquae	0.002	-0.421
Nostoc paludosum	0.145	-0.525
Oscillatoria agardhii	0.828	-0.054
O. minnesotensis	0.029	-0.040
Phormidium tenue	0.014	0.259
Rivularia haematites	-0.025	-0.125
Chrysococcus rufescens	-0.761	0.668
Dinobryon sertularia	-0.135	0.326
Dinobryon sociale	-0.734	0.631
Mallomonas tonsurata	-0.652	0.558
Pseudokephyrion pseudospirale	-0.458	0.228
Ps. undulatissimum	-0.225	0.292
Diatoma tenue	0.792	0.700
Dia. tenue var. *elongatum*	0.375	-0.062
Fragilaria vaucheriae	0.277	-0.010
F. virescens	0.776	0.148
Synedra radians	-0.046	0.229
Sy. tenera	0.226	0.213
Sy. ulna	-0.012	0.640
Sy. ulna var. *danica*	0.147	0.060
Melosira varians	0.637	0.493
Achnanthes lanceolata	0.226	-0.079
Ach. minutissima	0.586	-0.204
Cocconeis placentula var. *lineata*	0.615	-0.114
Amphipleura pellucida	0.598	0.295
Amphora ovalis	0.019	-0.072
Cymbella minuta	0.587	0.008
Gomphonema spp.	0.696	0.502
G. acuminatum	0.392	0.042
G. angustatum	0.912	0.596
G. intricatum	0.157	0.229

Continued . . .

Table 58. Concluded.

Species	Coefficients PC 1	PC 2
G. parvulum	0.694	0.127
G. truncatum	0.810	0.454
Navicula	0.118	-0.198
Navicula cryptocephala	0.935	-0.089
Navicula cryptocephala var. *venter*	0.291	-0.248
Navicula salinarum var. *intermedia*	0.098	-0.758
Navicula punctata	0.389	0.281
Epithemia sorex	0.495	-0.302
Epithemia turgida	0.580	-0.351
Rhopalodia gibba	0.326	-0.309
Rh. gibba var. *ventricosa*	0.216	0.004
Surirella angustatum	0.461	0.314
Nitzschia spp.	0.810	-0.462
Nitzschia acicularis	-0.210	0.736
Nitzschia dissipata	0.282	0.296
Nitzschia vermicularis	0.082	0.304
Rhodomonas minuta	-0.461	0.059
Audouinella violacea	0.614	0.247
Variance explained	16.612	8.206
% total variance	19.3	9.5
cumulative % total variance	19.3	28.8

Table 59. Species with the highest absolute coefficients (>0.250) for the first two PC's, algal abundance in Stockner samples, 1980.

PC 1

Phormidium tenue	1.42	vs	*Dictyosphaerium primarum*	-0.808
Synedra ulna	1.20		*Chrysococcus rufescens*	-0.791
Navicula cryptocephala	0.935		*Dinobryon sociale*	-0.734
Gomphonema angustatum	0.912		*Mallomonas tonsurata*	-0.692
Oscillatoria agardhii	0.828		*Chlamydomonas* spp.	-0.517
G. truncatum	0.810		*Rhodomonas minuta*	-0.461
Nitzschia spp.	0.810		*Pseudokephyrion pseudospirale*	-0.458
Diatoma tenue	0.792		*Ankistrodesmus convolutus*	-0.280
Fragilaria virescens	0.776			
Gomphonema spp.	0.696			
G. parvulum	0.694			
Melosira varians	0.637			
Cocconeis placentula var. *lineata*	0.615			
Audouinella violacea	0.614			
Amphipleura pellucida	0.598			
Cymbella minuta	0.587			
Achnanthes minutissima	0.586			
Epithemia turgida	0.580			
Epithemia sorex	0.495			
Surirella angustatum	0.461			
Gomphonema acuminatum	0.392			
Navicula punctata	0.389			
Navicula cryptocephala var. *venter*	0.291			
Nitzschia dissipata	0.282			
Fragilaria vaucheriae	0.277			
Synedra tenera	0.266			
Ankistrodesmus falcatus	0.253			

PC 2

Dictyosphaerium primarum	0.841	vs	*Navicula salinarum* var. *intermedia*	-0.758
Nitzschia acicularis	0.736		*Anabaena* spp.	-0.558
Diatoma tenue	0.700		*Nostoc paludosa*	-0.525
Chrysococcus rufescens	0.668		*Nitzschia* spp.	-0.462
Synedra ulna	0.640		*Anabaena flos-aquae*	-0.421
Dinobryon sociale	0.631		*Epithemia turgida*	-0.351
Gomphonema angustatum	0.596			

Continued . . .

Table 59. Concluded.

PC 2			
Chlamydomonas spp.	0.589	*Scenedesmus denticulatus*	-0.347
Mallomonas tonsurata	0.558	*S. obliquus*	-0.315
Gomphonema spp.	0.502	*Rhopalodia gibba*	-0.309
Melosira varians	0.493	*Epithemia sorex*	-0.302
Gomphonema truncatum	0.454		
Ankistrodesmus convolutus	0.380		
Dinobryon sertularia	0.326		
Surirella angustatum	0.314		
Amphipleura pellucida	0.295		
Pseudokephyrion undulatissimum	0.292		

Analysis of variance of the PC 1 data provided evidence of differences among stations in the April-May, June and August sampling periods, but not in the July period (Table 60). Multiple comparisons (Tables 61 to 63) provided no evidence that Station 4 was "extreme" with respect to PC 1 in any of these sampling periods, so there is no evidence of any impact-related effect on this component.

PC 2 accounted for a much smaller proportion of the total variance than PC 1, only 9.5% (Table 58), and has no obvious ecological interpretation (Table 59). Several of the species with high positive coefficients are typically planktonic, but these will have been influential only in the June data, particularly at stations 1 and 2. In the remainder of the samples PC 2 is primarily a comparison of positively-to negatively-loading periphytic species.

An analysis of variance of the PC 2 data showed clear differences among stations and dates, with no station-date interaction (Table 64). Multiple comparisons (Tables 65 to 68) provided no evidence that Station 4 was "extreme" with respect to PC2 on any sampling date, therefore there was no evidence of any impact-related effect with respect to PC 2.

The remaining principal components each accounted for only a small proportion of the total variance in the data (<8%), and were not expected to provide much more additional information on differences in community composition. They were therefore not examined further.

Table 60. Analysis of variance of PC 1 scores, Stockner samples, 1980

Analysis of variance

Source	SS	d.f.	MS	F	P
Station	4.09767	4	1.02442	6.95	
Period	30.98182	3	10.32727	70.03	
Station x Period	18.02170	12	1.50181	10.18	<0.001
Error	5.89881	40	0.14747		
Total	59.00000	59			

Simple Effects: Station

Period	SS	d.f.	MS	F	P
April-May	3.33385	4	0.83346	5.65	<0.01
June	12.60479	4	3.15120	21.37	<0.001
July	1.08377	4	0.27094	1.84	>0.05
August	5.09699	4	1.27425	8.64	<0.001

Simple Effects: Period

Station	SS	d.f.	MS	F	P
1	19.91385	3	6.63795	45.01	<0.01
2	23.25587	3	7.75196	52.57	<0.001
3	3.78614	3	1.26205	8.56	<0.001
4	0.91426	3	0.30476	2.07	>0.05
6	1.13352	3	0.37784	2.56	>0.05

Table 61 Multiple comparison of mean PC 1 scores, Stockner samples, April-May 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in PC 1 scores.

Station	PC 1 $\bar{x}$ score	n	Station 4	6	3	2	1
4	0.382	3					
6	0.796	3	1.867^{-}				
3	1.148	3	3.455*				
2	1.577	3	5.390**				
1	1.623	3	5.597**	3.730^{-}			

Station	4	6	3	2	1

$^{-}$ P > 0.05
* P < 0.05
** P < 0.01

Table 62. Multiple comparisons of mean PC 1 scores, Stockner samples, June 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in PC 1 scores.

Station	PC 1 $\bar{x}$ score	n	Station 2	1	4	3	6
2	-2.142	3					
1	-1.873	3	1.213^{-}				
4	-0.312	3	8.254**	6.635**			
3	-0.223	3	8.655**	7.442**			
6	0.053	3	9.900**	8.687**	1.646^{-}		

Station	2	1	4	3	6

$^{-}$ P > 0.05
**P < 0.01

Table 63. Multiple comparisons of mean PC 1 scores, Stockner samples, August 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in mean PC 1 scores.

Station	PC 1 $\bar{x}$ score	n	Station 1	4	6	3	2
1	-0.970	3					
4	-0.251	3	3.243*				
6	0.112	3	4.880**				
3	0.194	3	5.250**	2.007^{-}			
2	0.804	3	8.001**	4.758**	3.121^{-}		

Station	1	4	6	3	2

$^{-}$P > 0.05
*P < 0.05
**P < 0.01

Table 64. Analysis of variance of PC 2 scores, Stockner samples, 1980

Analysis of variance: PC 2					
Source	SS	d.f.	MS	F	P
Station	4.08837	4	1.02209	6.20	<0.001
Period	44.82198	3	14.94066	90.64	<0.001
Station x Period	3.49656	12	0.29138	1.77	>0.05
Error	6.59309	40	0.16483		
Total	59.00000	59			

Table 65. Multiple comparisons of mean PC 2 scores, Stockner samples, April-May 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in mean PC 2 scores.

Station	PC 2 $\bar{x}$ score	n	Station 6	1	4	2	3
6	0.233	3					
1	0.652	3					
4	0.715	3					
2	0.836	3					
3	0.975	3	3.165^{-}				

Station	6	1	4	2	3

$^{-}$ $P > 0.05$

This test is less sensitive (more conservative) than the overall analysis of variance F test (Winer 1971), which provided strong evidence among stations.

Table 66 Multiple comparisons of PC 2 scores, Stockner samples, June 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in mean PC 2 score.

Station	PC 2 $\bar{x}$ score	n	Station 6	1	4	2	3
6	0.162	3					
1	1.028	3	3.694*				
4	1.046	3	3.771*				
2	1.176	3	4.326*				
3	1.674	3	6.450**	2.756^{-}			

Station	6	1	4	2	3

$^{-}$P > 0.05
*P < 0.05
**P < 0.01

Table 67. Multiple comparisons of mean PC 2 scores, Stockner samples, July 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in mean PC 2 score.

Station	PC 2 $\bar{x}$ score	n	Station 6	3	1	4	2
6	-1.503	3					
3	-1.259	3					
1	-0.916	3					
4	-0.871	3	2.696^{-}				
2	-0.428	3	4.586*	3.545^{-}			

Station	6	3	1	4	2

$^{-}$P > 0.05
*P < 0.05

Table 68. Multiple comparisons of mean PC 2 scores, Stockner samples, August 1980, by the Newman-Keuls method. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in mean PC 2 score.

Station	PC 2 $\bar{x}$ score	n	Station 3	6	4	2	1
3	-1.068	3					
6	-0.854	3					
4	-0.807	3					
2	-0.431	3					
1	-0.364	3	3.003^{-}				

Station	3	6	4	2	1

$^{-}P > 0.05$

This test is less sensitive than the overall analysis of variance F test (Winer 1971), which provided strong evidence of a difference among stations in PC 2 scores.

4.2.3 Impact Analysis: Slide Samples

The artificial substrate samples were added to the program on short notice to supplement the natural substrate data, which could be obtained consistently for only five of the eight stations. Some slide samples were analyzed from all stations for at least one sampling date, but for the purposes of impact assessment effort was concentrated on the analysis of the samples from control stations 5 and 7, main impact station 4, and recovery station 3. Only samples from the latter four sites were used in the impact analysis. The high water during September and early October, and beaver damage, made many samplers irretrievable, so no samples from October were used for the impact analysis.

The mean biomass data are summarized in Table 52. Analysis of variance of these data showed a significant interaction between station and sampling period, and examination of the simple effects showed significant differences among stations only in June and July, but not in August (Table 69). The planned comparisons of stations 4 and 5 showed a significant difference between the two stations only in July (Table 69). Multiple comparisons (Table 70) showed the reason for this difference. Station 5 had a lower biomass than any of the other three stations, which did not differ among themselves. The difference in June was restricted to Station 3 vs Station 7; all other

Table 69. Analysis of variance and planned comparisons of mean biomass ($\mu m^3/mm$) of attached algae on glass slides, 1980.

Source	SS	d.f.	MS	F	P
Station	0.80579	3	0.26860	3.84	
Period	0.41326	2	0.20663	2.95	
Station x Period	2.15982	6	0.35997	5.14	0.0055
Error	0.98014	14	0.07001		
Total	4.35901	25			

Simple Effects: Station

Period	SS	d.f.	MS	F	P
June	1.02157	3	0.34052	4.86	<0.025
July	1.55242	3	0.51747	7.39	<0.005
August	0.20062	3	0.06687	0.96	>0.05

Simple Effects: Period

Station	SS	d.f.	MS	F	P
3	0.02065	2	0.01033	0.15	>0.05
4	1.08444	2	0.54222	7.74	<0.01
5	0.57911	2	0.28955	4.14	<0.05
7	0.72049	2	0.36025	5.14	<0.025

Planned comparisons: Stn 4 vs Stn 5 by period

Period	F	P
June	2.74	>0.05
July	29.74	<0.001
August	1.80	>0.05

Table 70. Multiple comparisons of mean biomass of attached algae on glass slides, July 1980, by the Newman-Keuls procedure. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in mean biomass.

Station	mean log (x + 1) $\mu m^3/mm^2$	n	Station 5	3	7	4
5	4.976	2				
3	5.759	3	4.584**			
7	5.766	3	4.625*			
4	6.155	2	6.903**	2.319^{-}		

Station	5	3	7	4

* $P < 0.05$
** $P < 0.01$
$^{-}$ $P > 0.05$

comparisons of station pairs showed insignificant differences (Table 71).

There is a fairly clear interpretation of the above findings. On 20 June 1980, after the June sampling period, large quantities of a nitrogen-phosphorus fertilizer were spread over the cleared area drained by the minesite ditch. Elevated concentrations of N and P were detected soon after in the drainage ditch and in the river downstream. (The impact on water quality is described in the Water Quality section.) It is likely that the elevated algal biomass observed at Station 4 was an enrichment effect arising from fertilization of the minesite drainage area with these important algal nutrients and, although elevated nutrient levels were not detected at Station 3, the enrichment effect on the algal communities was detectable that far downstream.

The high algal biomass detected at Station 7, well upstream from the minesite ditch outfall, was nevertheless probably caused by fertilizer N and P enrichment also. Personnel loaded the fertilizer in an open helicopter bucket within 100 m west of this site, small amounts were spilled on the ground, and downdraft from the helicopter rotors would have spread the fertilizer widely. Slightly elevated nutrient levels were detected at Station 7, and were attributable to this cause. Because the amounts were small and were added only briefly, the effect was not detectable downstream at Station 5. The continuous addition of nutrients in runoff from a large area via the minesite drainage, in contrast, evidently had an effect for a

Table 71. Multiple comparisons of mean biomass of attached algae on glass slides, June 1980, by the Newman-Keuls method. Cell values are the Studentized range statistic Q. Stations linked by lines do not differ in mean biomass.

Station	log(x + 1) $\mu m^3/mm^2$	n	Station 7	4	5	3
7	4.972	2				
4	5.196	2				
5	5.632	2	3.528^{-}			
3	5.852	2	4.704*	3.506^{-}		

Station	7	4	5	3

$^{-}$ $P > 0.05$
* $P < 0.05$

considerable distance below the outfall. The absence of any differences in algal biomass among the stations in August, however, shows that the impact did not persist for long.

Hickman et al (1979), and Lock and Wallace (1979) contended that nutrients do not limit algal standing crops in the Muskeg River. If this were so, algal standing crops would not be expected to increase with the addition of nutrients to the water. The evidence of just such a response in the present study therefore tends to support the alternative hypothesis that algal biomass is, in fact, nutrient-limited, at least at times. (See also Volume 1:36,42-43,47).

The principal components of the species abundance data were analyzed to provide information on variations in community composition. The first two PC's together accounted for only 28.5% of the total variance (Table 72). PC 1 alone accounted for 16.9% of the total variance. The components higher than PC 2 each accounted for less than 10% of the total variance and were not analyzed further.

Neither of the first two principal components had an obvious ecological interpretation (Tables 73), but PC 1 could be roughly described as a comparison of the ubiquitous diatom Cocconeis placentula var. lineata and/or the green alga Scenedesmus obliquus to all others. Analyses of variance found no significant interaction between station and period, and no significant differences among stations, for either component (Table 74). Similarly, planned comparisons found no significant differences between stations 4 and 5 for either PC in any period (Table 74). In other words, no evidence

Table 72. The first two principal components of algal species abundance, slide samples, 1980.

Species	Coefficients PC 1	PC 2
Coleochaete spp.	-0.049	-0.137
Ankistrodesmus convolutus	0.583	0.538
A. falcatus	0.018	0.175
Scenedesmus obliquus	-0.486	0.197
Tetraëdron minimum	-0.116	0.028
Mougeotia spp.	0.587	-0.614
Chamaesiphon incrustans	0.037	0.183
Oscillatoria minnesotensis	0.271	-0.290
Phormidium tenue	0.436	-0.527
Chrysococcus rufescens	0.593	0.962
Dinobryon sertularia	0.578	0.283
D. sociale	0.459	0.482
Mallomonas tonsurata	0.162	0.389
Fragilaria virescens	0.510	0.752
Synedra spp.	0.662	0.598
Sy. radians	0.024	-0.130
Sy. tenera	0.103	-0.134
Sy. ulna	0.985	-0.207
Sy. ulna var. *danica*	0.411	0.477
Cyclotella meneghiniana	0.321	0.059
Melosira varians	0.833	-0.374
Eunotia curvata	0.768	-0.662
E. pectinalis var. *minor*	0.145	-0.687
Achnanthes lanceolata	0.202	-0.018
Ach. minutissima	0.136	-0.064
Cocconeis placentula var. *lineata*	-0.675	-0.121
Rhoicofphenia curvata	0.070	-0.366
Amphipleura pellucida	0.715	-0.118
Cymbella minuta	-0.090	0.062
Gomphonema spp.	0.690	-0.480
G. acuminatum	0.416	-0.537
G. angustatum	0.298	-0.161
G. intricatum	0.087	-0.541
G. parvulum	0.708	0.071
G. truncatum	0.545	-0.557
Navicula spp.	0.805	-0.423
Navicula capitata	0.047	0.212
Navicula cryptocephala	0.494	-0.310
N. cryptocephala var. *venter*	0.111	-0.425
N. radiosa	0.245	0.051

Continued . . .

Table 72. Concluded.

Species	Coefficients PC 1	PC 2
N. rhynchocephala	0.181	-0.195
N. salinarum var. *intermedia*	-0.159	0.441
N. punctata	0.584	-0.078
Epithemia turgida	0.199	-0.266
Rhopalodia gibba	-0.066	-0.060
Surirella angustata	0.042	0.043
Nitzschia spp.	0.559	0.128
Nit. acicularis	0.958	0.708
Nit. linearis	0.223	-0.016
Nit. palea	-0.184	-0.166
Nit. sigma	0.625	0.315
Nit. vermicularis	0.527	0.455
Variance explained	11.360	7.820
% total variance	16.9	11.6
cumulative % total variance	16.9	28.5

Table 73. Species with the highest absolute coefficients (>0.250) for the first two PC's, slide samples, 1980.

PC 1

Synedra ulna	0.985	vs	*Cocconeis placentula* v. *lineata*	-0.675
Nitzschia acicularis	0.958			
Melosira varians	0.833		*Scenedesmus obliquus*	-0.486
Navicula spp.	0.805			
Eunotia curvata	0.768			
Amphipleura pellucida	0.715			
Gomphonema parvulum	0.708			
Gomphonema spp.	0.690			
Synedra spp.	0.622			
Nitzschia sigma	0.625			
Chrysococcus rufescens	0.593			
Mougeotia spp.	0.587			
Navicula punctata	0.584			
Ankistrodesmus convolutus	0.583			
Dinobryon sertularia	0.578			
Nitzschia spp.	0.559			
Gomphonema truncatum	0.545			
Nitzschia vermicularis	0.527			
Fragilaria virescens	0.510			
Navicula cryptocephala	0.494			
Dinobryon sociale	0.459			
Phormidium tenue	0.436			
Gomphonema acuminatum	0.416			
Synedra ulna var. *danica*	0.411			
Cyclotella meneghiniana	0.321			
Gomphonema angustatum	0.298			
Oscillatoria minnesotensis	0.271			

PC 2

Chrysococcus rufescens	0.962	vs	*Eunotia pectinalis* var. *minor*	-0.687
Fragilaria virescens	0.752		*Eu. curvata*	-0.662
Nitzschia acicularis	0.708		*Mougeotia* spp.	-0.614
Synedra spp.	0.598		*Gomphonema truncatum*	-0.557
Ankistrodesmus convolutus	0.538		*G. intricatum*	-0.541
Dinobryon sociale	0.482		*G. acuminatum*	-0.537
Sy. ulna var. *danica*	0.477		*Phormidium tenue*	-0.527
Nitzschia vermicularis	0.455		*Gomphonema* spp.	-0.480
Nit. salinarum var. *intermedia*	0.441			

Continued . . .

Table 73. Concluded.

PC 2				
Mallomonas tonsurata	0.389	vs	*Navicula cryptocephala* var *venter*	-0.425
Nit. sigma	0.315		*Navicula* spp.	-0.423
Dinobryon sertularia	0.283		*Melosira varians*	-0.374
			Rhoicofphenia Curvata	-0.366
			Navicula cryptocephala	-0.310
			Oscillatoria minnesotensis	-0.290
			Epithemia turgida	-0.266

Table 74. Analyses of variance and planned comparisons on the first two principal components of algal species on glass slides, 1980.

Analysis of variance: PC 1

Source	SS	d.f.	MS	F	P
Station	1.63770	3	0.54590	2.75	0.0821
Period	17.92466	2	8.96233	45.12	<0.001
Station x Period	1.14448	6	0.19075	0.96	>0.05
Error	2.78058	14	0.19861		
Total	23.48742	25			

Planned comparisons: Stn 4 vs Stn 5 by period

Period	F	P
June	3.93	>0.005
July	0.83	>0.05
August	2.55	>0.05

Analysis of variance: PC 2

Source	SS	d.f.	MS	F	P
Station	2.37154	3	0.79051	1.90	>0.05
Period	14.99382	2	7.49691	17.99	<0.001
Station x Period	1.15451	6	0.19242	0.46	>0.05
Error	5.83366	14	0.41669		
Total	24.35353	25			

Planned comparisons: Stn 4 vs Stn 5 by period

Period	F	P
June	0.24	>0.05
July	0.21	>0.05
August	1.67	>0.05

was obtained of an impact-related effect on the measures of community composition defined by the first two PC's.

4.3 Conclusion

The studies of periphytic algae on two types of substrate produced evidence of impact from muskeg drainage activities on the flora of the Muskeg River. There was evidence of a reduction of periphyton biomass on stones at Station 4 in late April and early May, possibly caused by scour or siltation arising from the mid-April drainage ditch flood. In July, the slide samples provided good evidence of an algal biomass increase due to nutrient enrichment that extended at least as far downstream as Station 3. At the same time, evidence of a similar biomass increase, also probably nutrient-induced, was found at Station 7. Fertilization of the minesite drainage area as part of seeding operations was probably the ultimate cause of the biomass increase below the minesite ditch outfall. At Station 7, windblown fertilzer from the helicopter loading area was the probable cause of the increase in algal biomass observed there.

The biomass changes found on both stones and glass slides did not persist into the sampling periods following those in which they were observed. Community composition, as measured by the first two principal components of the species-abundance data, showed no detectable response to muskeg drainage activities on either substrate type.

The July algal biomass on stones showed no evidence of nutrient enrichment effects; the algal biomass on slides did. The reason for this is almost certainly that the slide sampling design permitted the use of tests sufficiently sensitive to detect differences at the impact station. The impact criterion "Station 4 greater than, or less than, all other stations" for Stockner sample data is far less sensitive than the criterion "Station 4 greater than, or less than Station 5" used in the analysis of the slide sample data. A more sensitive impact criterion could not be used in the analysis of the Stockner data because it was necessary to sample stations that were not always closely comparable (see also Sections 3.1, 3.2.2, 4.2.2).

5.0 FISH

5.1 Methods

5.1.1 Late Winter

To locate and describe the overwintering habitat of fish in the Muskeg River and Hartley Creek, a brief survey from 21 to 25 March 1980 was undertaken. The streams were surveyed by helicopter to locate springs and areas of open water. In addition, the stream was visited, on skis, at several points for sampling.

At each sampling site, ice, snow and water depth, stream width and substrate type were recorded. Water temperature was measured with a mercury pocket thermometer, and dissolved oxygen was determined by the Hach method.

Gee minnow traps baited with sardines were placed at five locations (two above the minesite drainage discharge into the Muskeg River and three below) for a total of 290.5 hours. An electrofisher (Smith-Root Type V-A) was used in two small openings cut in the ice at Station 4. Because of thick ice and shallow water at most sites, gillnets were not set under the ice.

5.1.2 Spring Survey

A survey was undertaken from 22 April to 3 May to locate and quantify the importance of fish spawning sites in the lower Muskeg River and Hartley Creek. Two approaches were used. First, collecting gear was used to search for fish, particularly spawning or ripe males and females. Second, kick samples were used to sample selected stream locations for eggs.

The two available nonlethal methods, electrofishing and seining, were ineffective at most locations because of the deep water and steep banks throughout most of the streamlengths sampled. Gillnets (5.1 to 10.2 cm stretch mesh) were the principal means of collection, and were set transversely to the current at several locations from Station 1 to above Station 8. Captured fish were identified to species (and, when possible, sex), then checked for spawning condition by applying gentle pressure along the abdomen. Fish freely releasing eggs or milt were termed ripe, those not doing so were termed green (or immature, for small specimens), and those with flaccid bellies and exuding little or no milt or eggs were recorded as spent. Fish killed or seriously injured in the nets were dissected to determine spawning condition, but most fish were released unharmed.

On 3 May 1980, a kick samples were used to sample 10 stations for fish eggs. Along several transects at each station, the substrate was lightly disturbed with a foot just upstream of a hand-held pond net. Collections were made for five minutes at each station to standardize sampling effort.

A maximum-minimum thermometer was installed at Station 7 for the period 22 April to 4 May. The thermometer was checked and reset daily to obtain data on temperatures prevailing during the spring spawning period.

5.1.3 Early Summer Survey

A brief survey was conducted from 5 to 7 June to locate rearing areas for fry and juveniles. An electrofisher (Smith-Root Type V-A) and a 5 mm mesh seine 4 m in length were used for the collections.

5.1.4 Fall Survey

A scheduled September survey was cancelled because of the extremely high discharges that month (Volume I, Figure 2). Studies were, however, conducted from 28 September to 29 October near the mouth of the Muskeg River and from 30 October to 7 November from stations 1 to 7 in the Muskeg River and Hartley Creek. Three types of collection gear were used: gillnets, minnow seines, and minnow traps.

The gillnets were standard gangs of six 4.6 m panels, one each of 1.9, 3.8, 5.1, 6.4, 7.6 and 10.2 cm mesh (stretched measure). A 12 m seine with 6 mm main mesh and a 3 mm mesh bunt was used for collections made near the mouth of the river between 26 September and 29 October, and a 6 m seine with 5 mm mesh was used at the upstream sites between 30 October and 7 November. Gee minnow traps were baited with sardines and set for 24 hours in a wide variety of habitats.

5.1.5 Downstream Movement Study

High discharges (Figure 2, Volume I) prevented installation of a complete counting fence in the Muskeg River until mid-October, though partial fences were erected in shallower, quieter areas. The fences were installed at various sites as changing water conditions and erosion forced their relocation (Figure 16).

The main trap and fence were similar to those described and used by Bond and Machniak (1977). The trap box had a mesh of 2.5 cm hardware cloth and the wing frames had a mesh of 2.5 cm chicken wire. A smaller trap was also installed--a 1.2 m cube of 2.5 cm mesh chicken wire on a frame of 5 x 5 cm lumber. The wings for the small trap con-

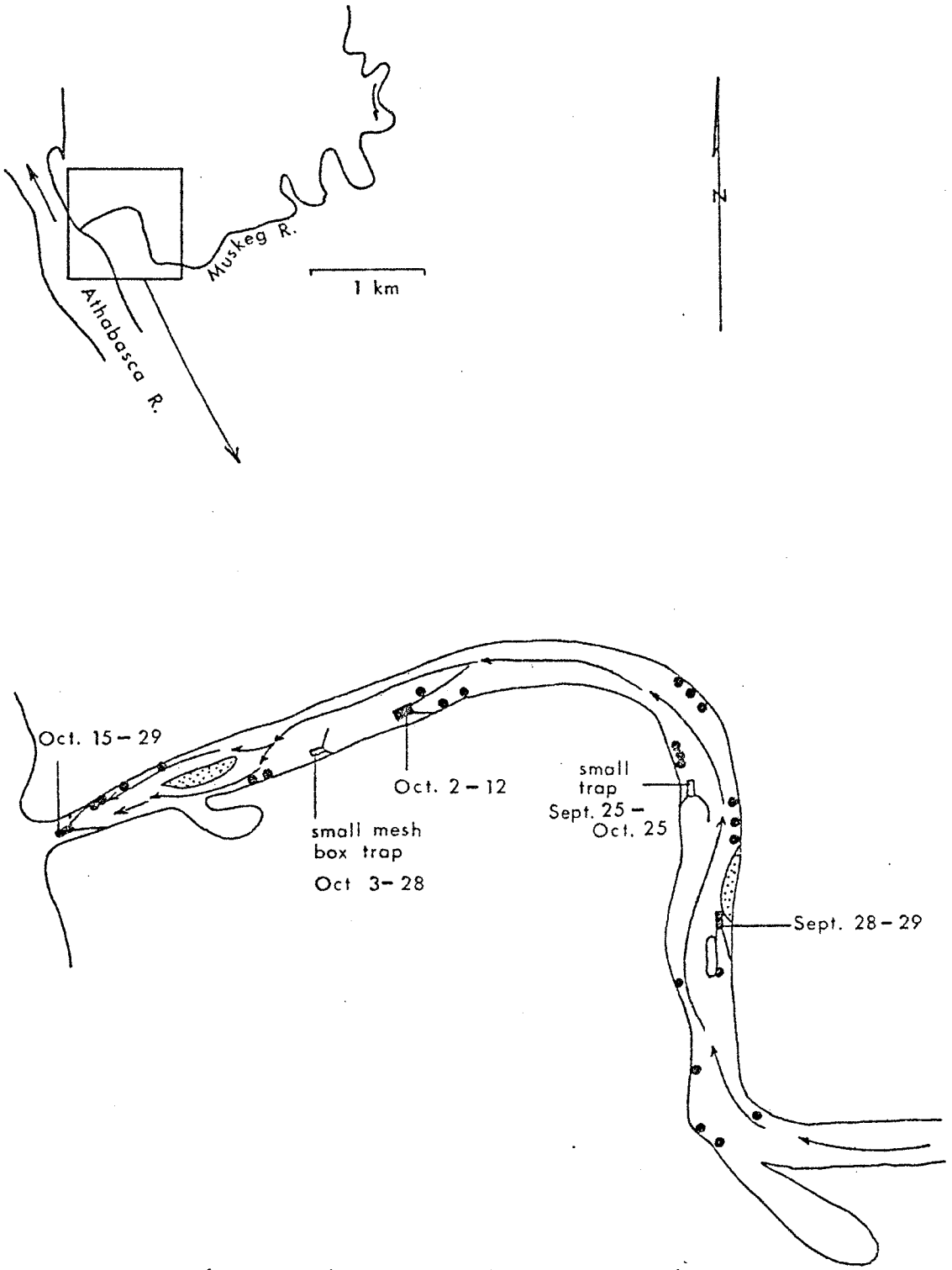

Figure 16. Trapping locations on the lower Muskeg River, fall 1980. Main fish trap, solid rectangles; minnow traps, solid circles; main current, curved arrows. Enlargement not to scale.

sisted of 1.2 x 1.8 m panels of 2.5 cm mesh chicken wire mounted on frames of 5 x 5 cm lumber. Both traps were held in place by range stakes, and 30 to 60 cm aprons on the wings of both traps were anchored with boulders, gravel, and sandbags to control erosion under the fences.

To capture small fish moving downstream, a box trap of plywood and 5 mm mesh nylon minnow seine material was installed. Wings for this trap were constructed from 6 m long minnow seines staked in place. Like the larger traps, the small fish trap blocked only a small part of the channel, but a substantial flow of stream water was directed through it.

The large traps were normally checked twice daily and the small ones once a day. At each check, fish were identified to species, counted, measured to the nearest millimetre (fork length), and released downstream of the traps. In addition, Arctic grayling were weighed to the nearest 0.5 gram.

During each trap check, the fences were inspected for holes, and the mesh was cleaned with wire brushes. Particular care was taken to keep the aprons well anchored. When leaf and debris accumulations were heavy, the fences were inspected, cleaned and repaired more frequently than twice daily.

A maximum-minimum thermometer was installed near the mouth of the river, and was checked and reset daily. Daily discharge records were available from the gauging station just downstream from Station 2 (Inland Waters Directorate, in preparation).

5.2 Results and Discussion

5.2.1 Late Winter Survey

At the time of the survey, the Muskeg River and Hartley Creek were almost entirely frozen over. Some open pools of water were found near the Stanley Creek confluence, and some very small areas of open-water were found at locations (f) and (i), shown in Figure 17. Physicochemical conditions at 19 locations (Figure 17) are summarized in Table 75.

Unfrozen water was found on top of the ice at four locations on the Muskeg River (1,4, 5 and k). The overflow water at Station 4 had deposited a thin layer of reddish-brown sediment on the ice, and had clearly come from the minesite drainage ditch. Drainage ditch water had also flowed over the ice surface at Station 5. The origin of superficial water at stations 1 and k is unknown.

Ice cover, except at the two small open-water sites sampled, ranged in thickness from 40 to 120 cm (mean 62.3 cm), and in most areas was covered with snow from 1 to 35 cm (mean 18.4 cm) in depth. Water depths at the 19 stations sampled ranged from 10 to 106 cm (mean 50.2 cm), but only five sites had water depths exceeding 50 cm.

Dissolved oxygen did not exceed 3 mg/L except at Station 4 (11 mg/L), and was 0 mg/L at Station 6 on Hartley Creek, where a dead

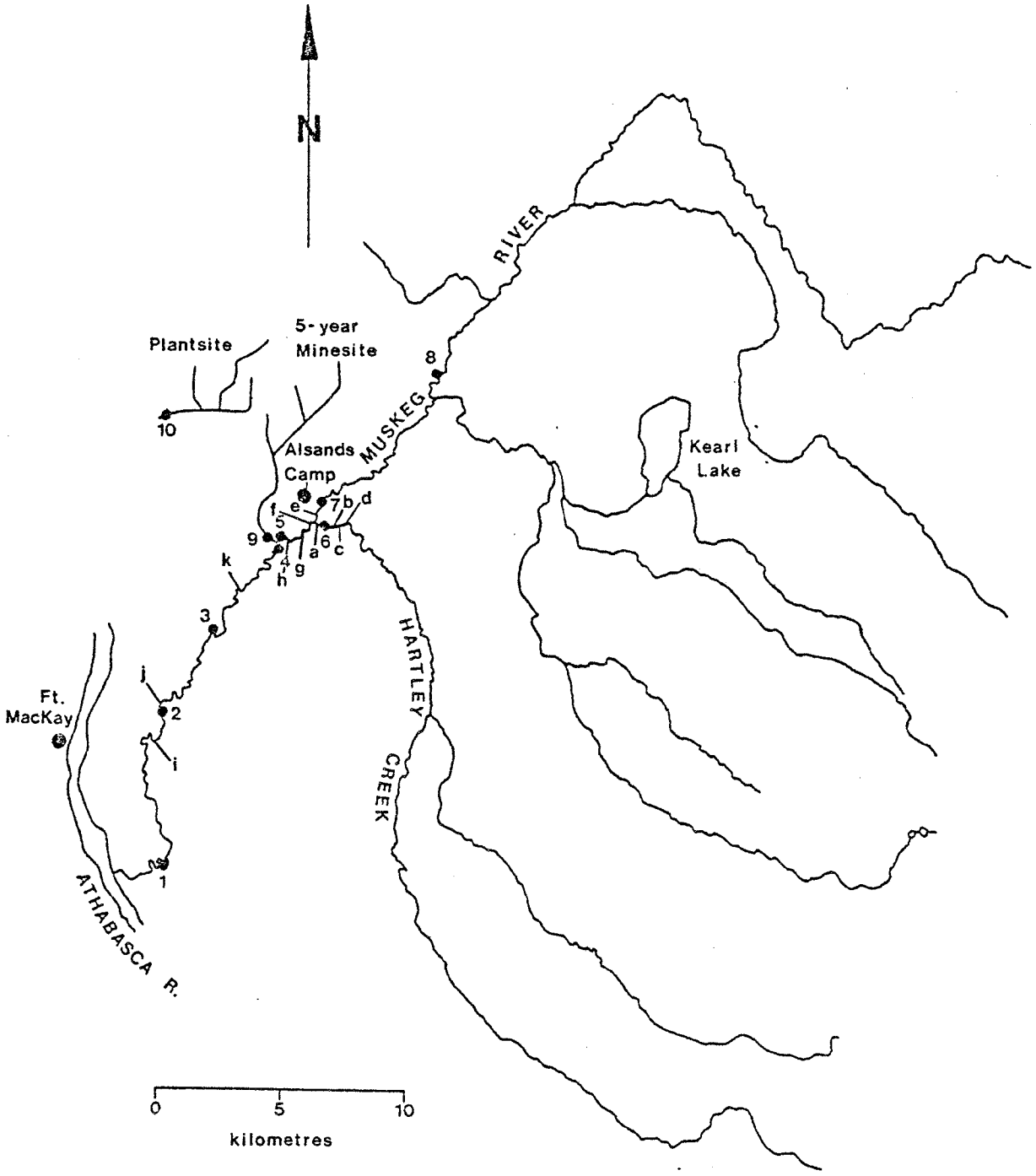

Figure 17. Location of sampling stations, late winter survey, March 21-25, 1980.

Table 75. Late winter physico-chemical conditions, Muskeg River and Hartley Creek, March 21 - 25, 1980. Water temperature at all stations was 0°C.

Station	Water Cover Thickness (cm)				Water Depth(cm)	D.O. (mg/L)	Substrate	Stream Width (m)
	Top Layer							
	Snow	Ice	Water	Ice				
1	0	12	7	81	30	2	sand/gravel	15
2	6	0	0	120	40	1	cobble	15
3	12	0	0	66	70	2	silt/sand	12
4	0	8	12	51	28	11	sand/cobble	12
5	0	11	5	92	35	3	silt/sand	12
6	35	0	0	70	90	0	sand/sticks	2.5
7	35	0	0	40	34	1	cobble/sticks	7
8	25	0	0	62	90	2	silt/sand/sticks	7
a	35	0	0	70	50	1	mud	5
b	35	0	0	67	30	-	silt/sand	-
c	0	0	0	65	10	-	silt/sand/rocks	5
d	35	0	0	62	45	2	sand/silt	4
e	35	0	0	67	55	3	silt/sand	10
f	0	0	0	0	30	-	rocky riffle	-
g	35	0	0	70*	90*	2	-	15
h	33	0	0	59	40	2	Silt/sand/boulder	10
i	0	0	0	0	30	1	cobble	15
j	28**	0	0	84**	106**	-	silt/sand/cobble	16
k	1	5	18	57	50	2	sand	10
Mean	18.4			62.3	50.2	2.3		
n	19			19	19	15		

* means of measurements at two holes
** means of measurements at three holes

Table 76. Fish species caught in the Muskeg River and Hartley Creek, 1980.

Common Name	Scientific Name	Code
mountain whitefish	*Prosopium williamsoni* (Girard)	MTWT
Arctic grayling	*Thymallus arcticus* (Pallas)	GRAY
northern pike	*Esox lucius* Linnaeus	PIKE
pearl dace	*Semotilus margarita* (Cope)	PLDC
lake chub	*Couesius plumbeus* (Agassiz)	LKCB
finescale dace	*Chrosomus neogaeus* (Cope)	FSDC
longnose dace	*Rhinichthyes cataractae* (Valenciennes)	LNDC
white sucker	*Catostomus commersoni* (Lacépède)	WTSK
longnose sucker	*Catostomus catostomus* (Forster)	LNSK
trout-perch	*Percopsis omiscomaycus* (Walbaum)	TRPH
burbot	*Lota lota* (Linnaeus)	BURB
brook stickleback	*Culaea inconstans* (Kirtland)	BRST
slimy sculpin	*Cottus cognatus* Richardson	SLSC

Table 77. Summary of fish collections, Muskeg River and Hartley Creek, spring 1980. UNKN = unknown (fish seen but not netted); G = green, R = Ripe, S = Spent, I = Immature

Date	Stn.	Method	No. hauls area seined seconds shocked hours gillnetted	Species	Fish Caught: Males G	Males R	Males S	Females G	Females R	Females S	I or G	Total
80/04/22	7	electrofisher	303 s	WTSK							1	1
				UNKN								1
	4	gillnet, 15 m 5.1 cm mesh	14.5 h	GRAY	1							1
80/04/23	2	minnow seine, 4 m long	5 hauls, 108 m²									0
		gillnet, 15 m 5.1 cm mesh	4.75 h	GRAY	2			1				3
		electrofisher	697 s	PLDC								1
	7	gillnet, 10 m 6.4 cm mesh	8 h	GRAY	8			2				10
80/04/24	7	electrofisher	100 s	UNKN								1
	F6	electrofisher	268 s	UNKN								1
80/04/26	3	gillnet, 15 m 5.1 cm mesh	26 h	WTSK							1	1
				PIKE	4			4			6	14
				GRAY	1							
80/04/26	2	gillnet, 15 m 10.2 cm mesh	18.5 h	PIKE				1				1
				WTSK				1				1
				GRAY		1						1
				LNSK		3		3				6

(Continued)

Table 77. Summary of fish collections, Muskeg River and Hartley Creek, spring 1980. UNKN = unknown (fish seen but not netted), G = green, R = ripe, S = spent, I = immature. Concluded.

Date	Stn.	Method	No. hauls area seined seconds shocked hours gillnetted	Species	Fish Caught							
					Males			Females				
					G	R	S	G	R	S	S	Total
80/ 04/27	F10	gillnet, 15 m	18 h	PIKE		2						2
	7	gillnet, 10 m 6.4 cm mesh	13.5 h	PIKE		2		1		2	2	7
				LNSK		2						2
				WTSK	1	1		4			2	8
80/04/28	F12	gillnet, 10 m 6.4 cm mesh	23 h	GRAY						1		1
				LNSK		15		2				17
80/04/29	F13	gillnet 14 m 6.4 cm mesh	22.5 h									0
	2	gillnet, 10 m 5.1 cm mesh	1.5 h	GRAY		2		1	1	2	1	8*
				LNSK		6		2				9*
				PIKE	1	1						3*
80/04/30	3	drift gillnet	375 m^2									0
80/05/02	1	gillnet, 15 m 6.4 cm mesh	1.25 h									0

* one fish of each species escaped

Table 78. Maximum - minimum thermometer readings, 75 m below Station 7, Muskeg River, spring 1980.

Date	Time Read	Temperature °C Maximum	Minimum	Comments
80/04/22	1445 h MST	5	5	installed
80/04/23	0730 h MST	6	5	
80/04/24	0815 h MST	6.5	3.5	
80/04/25	0830 h MST	11	4	
80/04/26	0800 h MST	9	4	
80/04/27	0830 h MDT	12	7	
80/04/28	0730 h MDT	11	8.5	
80/04/29	0730 h MDT	12.5	9	
80/04/30	0730 h MDT	13	10	
80/05/01	0730 h MDT	13	9.5	
80/05/02	0730 h MDT	13.5	9	
80/05/03	0730 h MDT	14.5	10	
80/05/04	0730 h MDT	15	10	removed

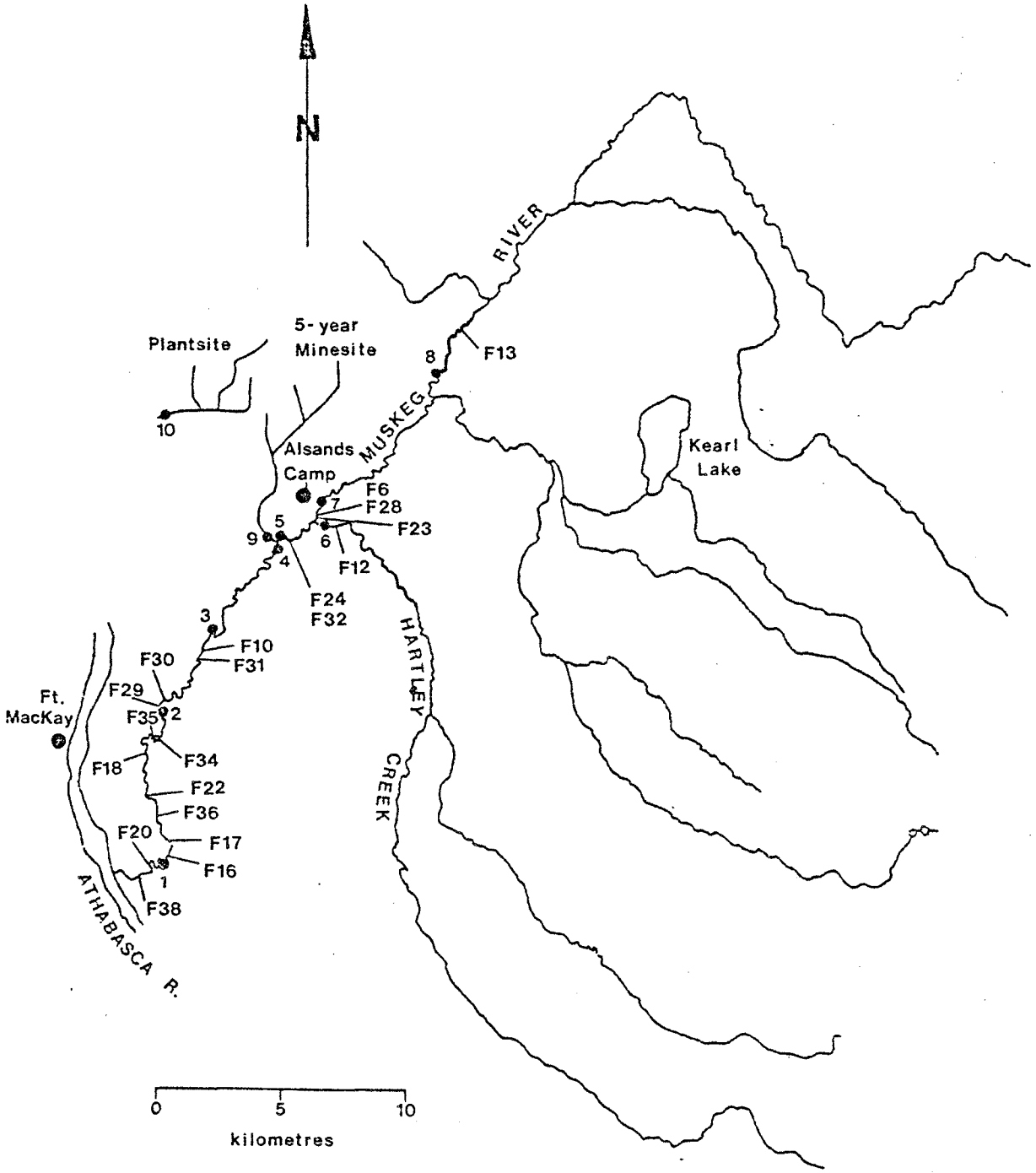

Figure 18. Locations of fish sampling stations, Muskeg River and Hartley Creek, 1980. Positions of F16 to F23 are approximate only.

On 27 April, a mature, green male was taken at Station 3, and a ripe male was collected at Station 2. A spent male was taken on 29 April at the Water Survey of Canada gauging station on Hartley Creek (Site F12). Two spent and one ripe female grayling, and one ripe male grayling, were collected at Station 2 on 29 April.

A total of 34 longnose suckers was collected at several sites from stations 2 to 7 on the Muskeg River, and at the gauging station on Hartley Creek, between 26 and 29 April. All of the 26 males examined were ripe, but none of the seven females was ripe.

A total of 26 longnose suckers was observed in two small riffle areas on 3 May, one 50 m downstream of the minesite drainage outfall and the other at Station 4. These fish behaved as though they were about to spawn, with several males surrounding each female, then the females moving away. In 15 minutes of observation, however, no spawning was observed.

Ten white suckers were captured in the Muskeg River between 26 and 29 April. None of the six mature females was ripe, but one of the two identified males was. The remaining two fish were immature or green and were released.

Twenty-seven northern pike were captured between stations 2 and 7 from 26 to 29 April. Two spent females were taken at Station 7 on 28 April, but the remaining seven identified females were green. Five of the 11 identified males were classified as ripe when caught, but several more ran some milt when they were being removed from the

nets, even though they were classed as green upon dissection.

The results of the fish egg survey are presented in Table 79. The eggs were of two size classes with mean diameters ± SE (n) of 1.9 mm ± 0.001 (50), and 3.2 mm ± 0.03 (47). Ranges for the egg diameters of the two size classes were 1.6 to 2.1 mm, and 2.8 to 4.1 mm, respectively. All eggs found were translucent, not opaque, indicating that they were alive at the time of collection.

The presence of many eggs at a site constitutes firm evidence of spawning, either at the site or immediately upstream. The most eggs, all in the small size class, were found at Site E8 (Figure 19), a riffle area of cobble and boulders covered extensively by aquatic moss. Most large eggs were found at Site E7, a boulder and cobble riffle area at Station 4, 100 m below the minesite ditch outfall. Eggs of both size-classes were usually found in predominantly rocky-bottomed areas. Eggs at Site E1, a sandy pool at Station 2, were common, but might have drifted down from the riffle area immediately upstream (Site E2).

The eggs were evidently from at least two species, but could not be identified. Pike eggs range in diameter from 2.5 to 3 mm; grayling eggs from 2.7 to 4.3 mm (Scott and Crossman 1973). Ripe eggs in the ovaries of longnose sucker are 2.8 to 3 mm in diameter (Scott and Crossman 1973), but undoubtedly swell somewhat during water hardening. No data are available on the diameter of white sucker eggs, but it is probably similar to the egg diameter of the closely-related longnose sucker. The large size class of eggs found could belong to

Table 79. Numbers of fish eggs collected in 5 minute timed kick collections, Muskeg River, May 3, 1980. Station locations as shown in Figure 19.

Egg Diameter (mm)	Station									
	E1	E2	E3	E4	E6	E7	E8	E9	E10	E 11
1.6 - 2.1	9	5	1	0	0	27	0	4	0	11
2.8 - 4.1	5	8	0	0	0	7	224	2	0	4
damaged*	31	40	0	0	0	0	0	6	0	0
Total	45	53	1	0	0	34	224	12	0	15

* wrinkled by preservative

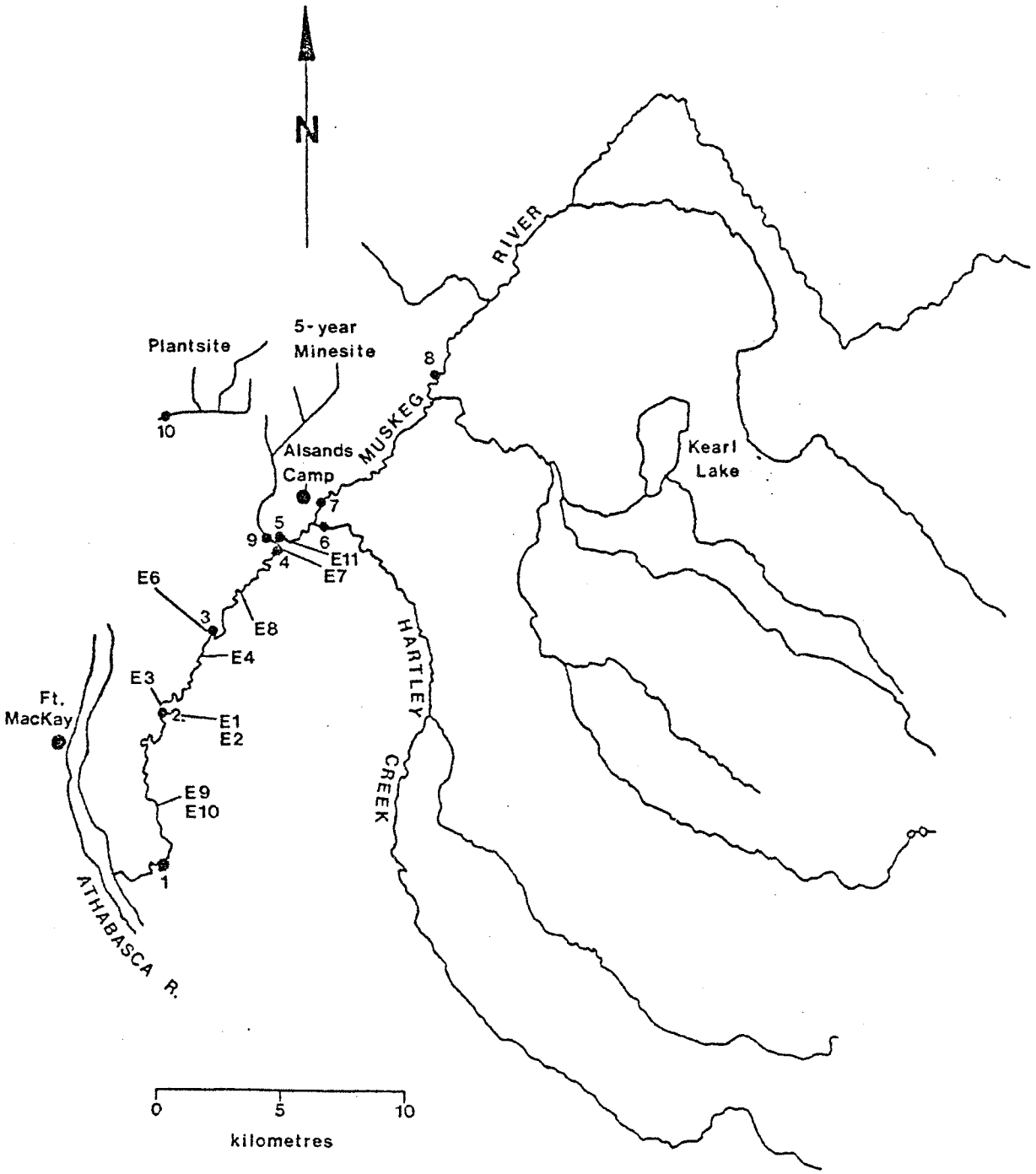

Figure 19. Location of egg sampling sites, Muskeg River, 3 May 1980.

any of the four principal spring-spawning species. The small size class may be eggs of one of the small species inhabiting the river.

The data on grayling, though meagre, suggest spawning by this species in the Muskeg drainage began by approximately 27 to 29 April in 1980. Water temperatures at this time were averaging about 10 C, near the upper limit of temperatures at which spawning has been observed in this species (Ward 1951, Tack 1972). Bond and Machniak (1979a) believed that grayling probably spawned in the Muskeg River in the last week of April and first week of May in 1976 and 1977. Station 2, a station with large gravel riffles and sand and boulder-bottomed pools, showed the best evidence of grayling spawning because of the presence of ripe and spent females there. The results of the egg survey confirmed that at least one of the large fish species spawns at Station 2.

The limited data on the two sucker species indicates only that short, rocky-bottomed sections near Station 4 are probably used for spawning by longnose suckers. The egg survey results demonstrated that at least one of the large fish species spawns there.

As indicated by the spent females found at Station 7, some northern pike had spawned by 28 April; however, precise spawning locations were not identified.

5.2.3 Early Summer Survey

The results of the early summer survey are presented in Table 80.

Young-of-the-year Arctic grayling were found at sites F17 and F18 on 5 June, and at Site F22 on 7 June. The fry ranged in length from 27 to 35 mm and had no yolk sacs.

Grayling hatch in 13 to 18 days at 7 to 11 C at a length of 8 mm, and retain the yolk sac for eight days (Scott and Crossman 1973:393). The fry caught 5 to 7 June probably hatched approximately 15 to 21 May, if spawning occurred in the last week of April, as the results suggest. The fry had, therefore, grown rapidly since hatching. They had time to drift a considerable distance downstream from the spawning sites, so their occurrence at sites F17, F18 and F22 does not necessarily mean that grayling spawn near these locations.

Bond and Machniak (1979) found grayling fry (numbers not reported) in the first week of June 1977 at Station 2 and near the mouth of the Muskeg River. They captured grayling fry in the third week of June 1976 and 1977 at Station 2, near the mouth of Hartley Creek and near the Muskeg River mouth. Fry captured in the first week of June 1977 ranged from 18 to 27 mm in length; those caught in the third week of June in 1976 and 1977 ranged from 27 to 42 mm. Grayling fry caught in 1980 were slightly longer than those caught at a

Table 80. Summary of fish collections, Muskeg River and Hartley Creek, early summer 1980.

Date	Stn.	Method	Area seined distance and seconds electrofished	Fish Caught
80/06/05	F16	electrofisher	500 m, 945 s	nil
	F17	seine	900 m²	4 GRAY, fork lengths 30 - 36 mm,500 (approx) sucker fry 16 mm in length
	F18	seine	420 m²	8 GRAY young of the year 28 - 34 mm 4 PIKE young of the year or juveniles
		electrofisher	335 s	nil
80/06/06	F20	seine	615 m²	60 sucker fry ca. 20 mm 1 LNDC 1 PLDC or LKCB 1 MTWF, fork length 30 mm 1 TRPH, fork length 65 mm
	2	electrofisher	450 m, 1532 s	5 PLDC or LKCB (4 40-43 mm, 1 96 mm) 1 GRAY 312 mm fork length
	F22	electrofisher	450 m, 707 s	100 PLDC or LKCB 40-45 mm 1 PIKE, fork length 452 mm
80/06/07	F22	seine	3 hauls, not quantitative	32 GRAY, fork length 27 - 35 mm 12 PLDC or LKCB 300 (approx) sucker fry ca. 20 mm
80/06/07	F23	electrofisher	35 m, 347 s	1 LNSK, fork length 161 mm 3 PLDC or LKCB, fork lengths 90, 86, 82 mm
	F24	electrofisher	175 m, 796 s	6 PLDC or LKCB, fork lengths 33, 64, 83, 85, 90, 113 mm 1 LNDC, fork lengths, 61 mm 2 WTSK, 1 ripe male, fork lengths 337, 376 mm 1 BRST, mature female, fork lengths 55 mm 1 PIKE - escaped 3 dace - escaped 5 suckers - escaped

comparable time in 1977, approximately the same size as those caught one to two weeks later in 1976 and 1977.

Four pike young-of-the-year (lengths 26 to 34 mm) were caught 5 June 1980 at Site F18. Pike eggs can hatch in four to five days at 18 to 20 C, but usually hatch in 12 to 14 days at "prevailing" water temperature, apparently somewhat above 11 C (Scott and Crossman 1973:359). The young are 6 to 8 mm at hatching, remaining inactive for 6 to 10 days while resorbing the yolk sac (Scott and Crossman 1973). These data suggest the pike caught 6 June had been spawned at least 18 to 24 days earlier (12 to 18 May). To account for the growth observed, the spawning probably took place one or two weeks earlier than that. Bond and Machniak (1979) captured two pike fry 23 and 30 mm in length near the mouth of the Muskeg River on 12 June 1977. They caught four pike fry (lengths not given) on 22 June 1978, near Site F22.

Several hundred sucker late mesolarvae or early metalarvae were found at Site F17 on 5 June 1980. Large numbers of sucker metalarvae were caught 6 June at Site F20, and 7 June at Site F22. Specimens retained for identification were poorly preserved, so the descriptions of sucker larvae by Fuiman (1979), and Fuiman and Whitman (1979), could not be used to identify the fry to species.

According to summary reviews by Scott and Crossman (1973), both longnose and white sucker eggs probably hatch in two weeks at water temperatures of approximately 10 to 15 C, and the larvae remain

in the gravel for one to two weeks before emerging. These data suggest the larvae caught in June 1980 hatched from eggs spawned in the first or second week of May, within the period found by Bond and Machniak (1977, 1979) for white and longnose suckers spawning in 1976 and 1977.

Bond and Machniak (1977) present length-frequency data for sucker fry caught 15 to 16 June 1976 in the Muskeg River and Hartley Creek. The great majority, possibly 90%, were between 16 and 23 mm in fork length, approximately the same size as those caught 5 to 7 June 1980 (this study).

The principal small fish species collected was either lake chub or pearl dace. All specimens checked in the laboratory were lake chub, but workers could not consistently separate the two species in the field, particularly in the case of the numerous small specimens caught. Bond and Machniak (1979) reported lake chub to be far more abundant than pearl dace in the lower Muskeg River.

Other small fish found were: one longnose dace and one brook stickleback at Site F24, and a troutperch at Site F20. A single young-of-the-year mountain whitefish (fork length 30 mm) collected at Site F20 is evidence of some spawning by this species in the Muskeg River. Bond and Machniak (1979) found no evidence of spawning by mountain whitefish in the Muskeg River in 1976 and 1977.

5.2.4 Fall Survey

Results of the fall and early winter survey are presented in Tables 81 to 84.

Minnow traps were fished for a total of 240 trap-days near the mouth of the Muskeg River from 30 September to 27 October, inclusive, and for 59 trap-days in the remainder of the river below the Alsands camp from 31 October to 7 November, inclusive. Longnose sucker and lake chub and/or pearl dace were by far the most frequently caught small fish near the mouth, with white suckers a distant third. Above the mouth area, only a single unidentified sucker was caught and brook stickleback were the most abundant fish in the catches. All but one of the fish caught in minnow traps upstream of the mouth area were taken at a single site, Station 5. Limited seining also captured small numbers of small suckers (both species) near the mouth, but seining at upstream locations was impractical because of fouling of the net by floating ice.

Longnose suckers caught in minnow traps near the Muskeg mouth ranged from 35 to 60 mm fork length, and were probably all underyearlings. Bond and Machniak (1979) reported that young-of-the-year longnose suckers in the Muskeg River reached about 50 mm. White suckers caught in the minnow traps ranged from 30 to 80 mm fork length, within the range for young-of-the-year reported by Bond and Machniak (1979).

Table 81. Summary of minnow trapping results, mouth area of the Muskeg River, fall 1980.

Date Checked	Number of Traps	Approx. Fishing Time(h)	Catch								
			LKCB or PLDC	WTSK	LNSK	TRPH	BURB	FSDC	BRST	SLSC	TOTAL
80/09/30	3	72					1				1
80/10/01	3	24			1						1
80/10/02	3	24			1						1
80/10/03	9	24		3	17						20
80/10/04	9	24	1	3	22						26
80/10/05	9	24	3		1						4
80/10/06	9	24		1							1
80/10/07	9	24									0
80/10/08	9	24	2			1					3
80/10/09	9	24	4	1		1					6
80/10/10	9	24									0
80/10/11	9	24	2								2
80/10/12	9	24	1		4						5
80/10/13	9	24	14	1	9		2				26
80/10/14	9	24	1		1						2
80/10/15	9	24	26	1	6						33
80/10/16	9	24									0
80/10/17	9	24									0
80/10/19	9	48	2		1						3
80/10/20	9	24	1			1					2
80/10/21	9	24									0
80/10/22	9	24									0
80/10/23	9	24	8					3	1		12
80/10/24	9	24						2			2
80/10/25	9	24					1				1
80/10/27	9	48	1	2	3		1			1	8
Totals		720	66	12	66	3	5	5	1	1	159
Mean catch/10 trap-days			2.8	0.5	2.8	0.1	0.2	0.2	0.04	0.04	6.6

Table 82. Minnow trap catches, upstream sites on the Muskeg River and Hartley Creek, fall 1980.

Date Checked	Station	Number of Traps	Approx. Fishing Time(h)	BRST	UNID. SUCK	BURB
80/10/31	7	3	24			
80/11/01	2	3	21			
80/11/02	2	3	22			
80/11/03	6	3	17			
80/11/04	F29	4	24			
80/11/05	F30	4	22.5			
	F31	4	41			
	F32	4	22.5			
	5	4	18	15	1	
80/11/07	F34	4	43.5			
	F35	3	44			
	F36	4	43			
	F37	4	43.5			1
	Total		386	15	1	1
	mean catch/10 trap-days			2.5	0.2	0.2

*200 m upstream of this station
**500 m upstream of this station

Table 83. Summary of seining results, Muskeg River, fall 1980. Muskeg River mouth area is shown in Figure 16.

Date	Station/ Location	Number of hauls, area	Catch and fork lengths
80/10/05	Muskeg R. mouth area	2 hauls	3 LNSK, 60 mm 1 SLSC, 70 mm
80/10/08	Muskeg R. mouth area	6 hauls	2 PIKE; 350, 400 mm 2 WTSK, 60 mm 1 LNSK, 50 mm 1 TRPH, 60 mm
80/10/09	Muskeg R. mouth area	2 hauls	2 PIKE; 250, 370 mm
80/10/22	Muskeg R.	3 hauls	1 SLSC, 35 mm 2 GRAY; 317,323 mm 1 LNSK, 35
80/10/31	2	6 hauls, 460 m^2	nil (much floating ice)
80/11/04	Muskeg R. mouth	8 hauls	1 SLSC

Table 84. Summary of gillnetting results, Muskeg River, fall 1980.

Date Lifted	Station/ Location	Fishing Time(h)	Catch				
			LNSK	GRAY	WTSK	PIKE	Total
80/10/31	7	22					0
80/11/01	2	18.5	1		1		2
80/11/02	2	21					0
80/11/04	F28	39	1	1			2
	F29	18.5					0
80/11/05	F30	41			1		1
	F31	21	1				1
	F32	11			1		1
	5	21.5		1			1
80/11/07	F34	43.5		3		1	4
	F35	44					0
	F36	43					0
	1	43.5	5	3	1	3	12
	F38	43	—	—	—	—	0
		441.5	8	8	4	4	24

The near-absence of young-of-the-year suckers in the Muskeg River minnow trap catches in late fall and early winter does not necessarily mean these fish were not present in the locations trapped. It is possible that low temperatures kept the fish too inactive to enter the traps.

Over 400 net-hours of gillnetting in the Muskeg River, from 31 October to 7 November, produced only a small number of suckers, grayling and pike. No concentrations of any of the four species were found at the 13 locations sampled, tending to confirm the suggestion of Bond and Machniak (1979) that these species (except possibly some young-of-the-year) do not overwinter in the Muskeg drainage. Alternatively, low water temperatures during the sampling period could have kept catches low by reducing the activity and movements of the fish.

5.2.5 Downstream Movement Study

The results of the study of fall downstream movements are summarized in Table 85 and Figure 20.

Very few fish were captured by the partial fences, and none were caught in the small fish trap. After the complete fence was closed on 16 October, the number of fish caught increased, but the catches remained low (less than 20 individuals of each species) for at least four days. Small runs of white sucker and northern pike were

Table 85. Numbers of fish caught by the large fish traps, Muskeg River, fall 1980.

Date	White Sucker	Northern Pike	Longnose Sucker	Arctic Grayling	Burbot	Mountain Whitefish	Total	Trap Number
Sept. 27	1						1	2
28		1					1	2
Oct. 13		1					1	1
15		2					2	4
16	5	3	1		2		11	4
17	18	3	11	1			33	4
18	10	1	3				14	4
19	4	2					6	4
20	12	6	7		1		26	4
21	25	9	5	1			40	4
22	84	22	6	2			114	4
23	75	28	4	3			110	4
24	125	20	10	3	1		159	4
25	103	41	12	15	1	1	173	4
26	57	36	6				99	4
27		2					2	4
28	37	20	6				63	4
29	20	8	5				33	4
Totals	576	205	76	25	5	1	888	
% Total	64.9	23.1	8.6	2.8	0.6	0.1		

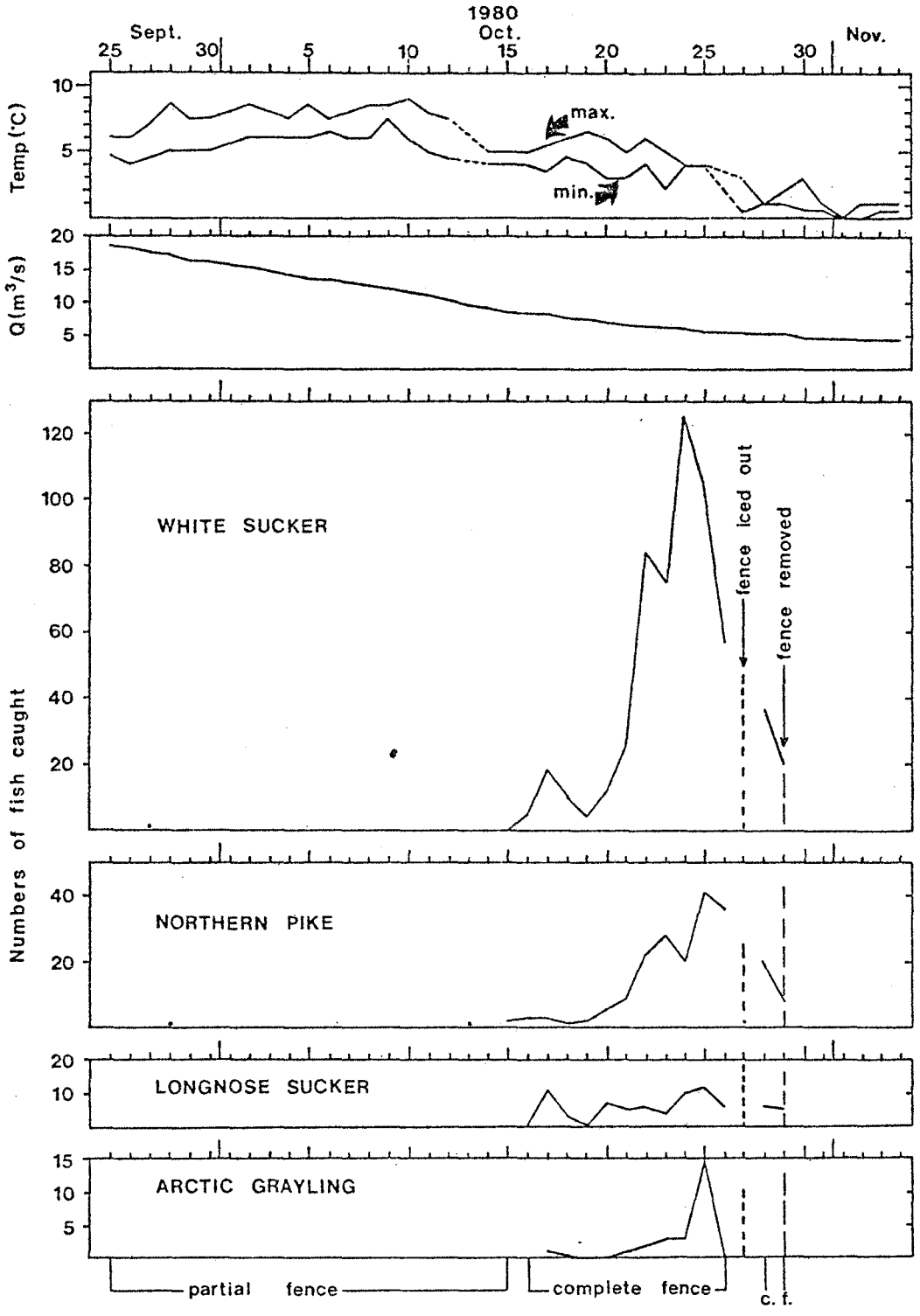

Figure 20. Maximum and minimum temperatures, discharge (Q), and numbers of fish caught in the large fish traps, Muskeg River, fall 1980. Discharge data are provisional (Inland Waters Directorate, in prep.). Note different scale for Arctic grayling.

enumerated between 21 and 29 October, after which the fence was removed because of heavy flows of drifting ice. The migrations took place during steadily falling river discharge and generally declining water temperatures (Figure 5), but there was no sudden, large change in either factor that might have triggered the runs.

The downstream run of white suckers totalled at least 575 fish, and consisted almost entirely of fish less than 350 mm fork length. Bond and Machniak (1977, 1979) counted total upstream spring migrations of 2839 white suckers in 1976 and 2920 in 1977. Most of the fish less than 350 mm for length (primarily immatures) remained in the Muskeg drainage after the end of the spawning period. The 1980 results support the suggestion (Bond and Machniak 1979) that many immature white suckers remain in the Muskeg River until freeze-up.

The 205 pike caught moving downstream in 1980 had a size distribution similar to that of the 433 moving upstream in 1977 (Bond and Machniak 1979). Bond and Machniak (1979) found their fish to be mostly immature. The combined results suggest that small numbers of pike, mostly immatures, use the Muskeg drainage as a feeding area in the open-water season, and that a substantial proportion of them remain in the drainage until just before freeze-up.

Bond and Machniak (1977, 1979) counted very few longnose suckers less than 300 mm in fork length (immatures) moving upstream in

spring of 1976 and 1977. In fall 1980, none of the 76 downstream migrants of this species exceeded 220 mm (Figure 21). The combined results suggest small numbers of immature longnose suckers use the Muskeg drainage as a feeding area, remaining there until freeze-up, if not longer.

Only 25 grayling were captured by the downstream trap. Their mean fork length + SE was 304 + 13.7 mm (range 110 to 382 mm) and their mean weight was 397 + 29.9 g (range <20 to 623 g).

The reason for the absence of a sizeable downstream migration of grayling during the fall fence study is not clear. Bond and Machniak (1979) note the several hundred grayling migrating upstream in the spring evidently remain throughout the summer, and that, in 1978, at least some fish remained until 13 October. Machniak and Bond (1979) found that Arctic grayling moved out of the nearby Steepbank River in early October at the same time the immature white suckers migrated downstream. More than 70% of the Steepbank grayling run occurred over a two-day period when steadily falling water temperatures had reached minima of 1 C or less.

In the present study, grayling were present in the Muskeg River until at least 7 November in 1980 (Table F10). It may be that the fall grayling run was not missed by the partial fences operated from 27 September to 15 October, but occurred after the full fence was removed 20 October, and possibly after 7 November. Alternatively, grayling in the Muskeg River may not have a distinct downstream run in fall, but may move down in small numbers from late summer through fall.

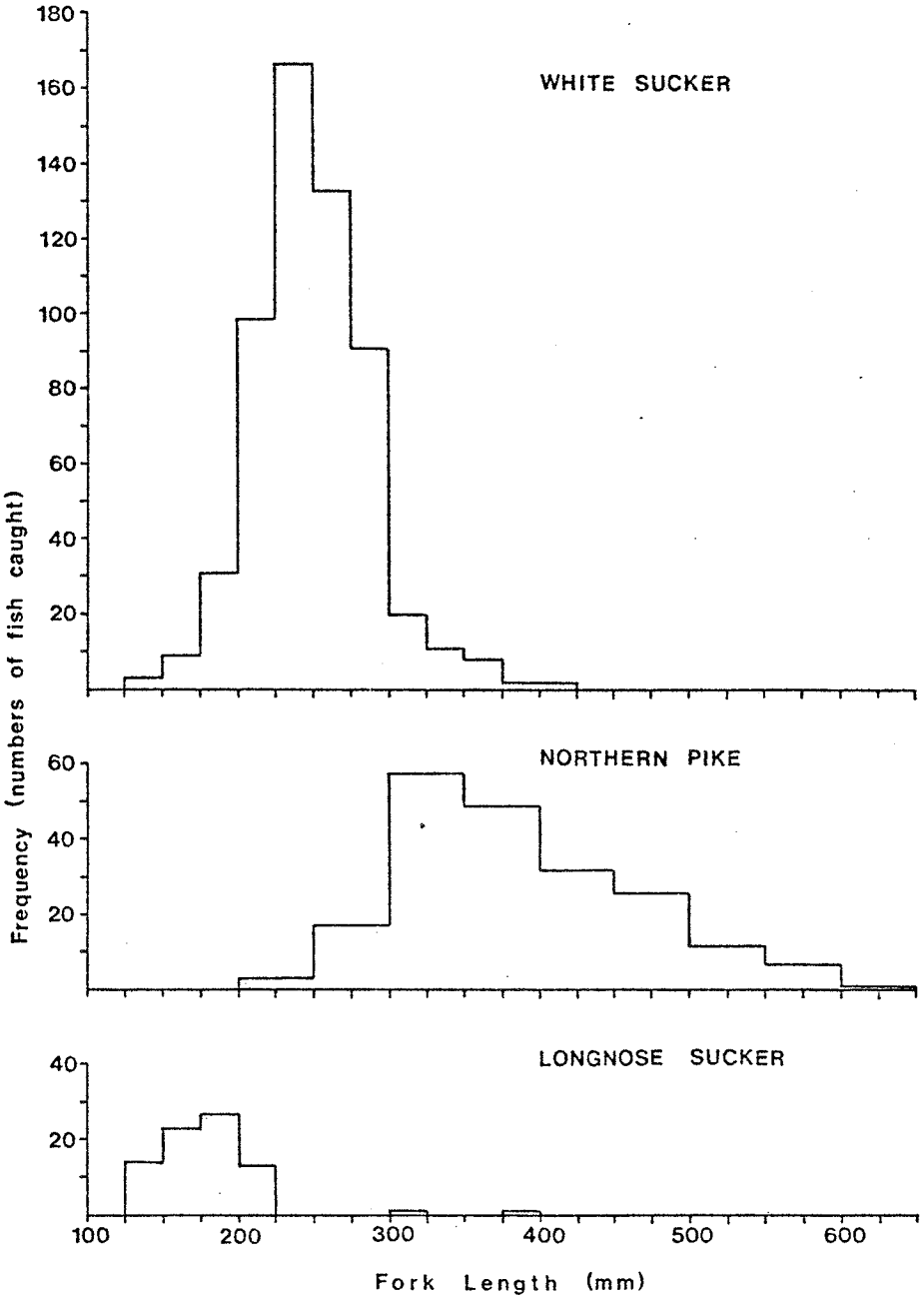

Figure 21. Length-frequency distributions of white sucker, northern pike and longnose sucker caught in the downstream traps, Muskeg River, fall 1980.

5.3 Conclusions

In late winter 1980, low dissolved oxygen levels and shallow water depths in the Muskeg River and Hartley Creek made these streams unfavourable overwintering habitats at most locations sampled. Whether any species of economic value overwintered there in 1980 is not known.

Fish spawning locations were found at several locations in the Muskeg River drainage near and downstream from the Alsands development area. Some longnose suckers probably spawn at Station 4, 100 m below the minesite drainage ditch outfall, and some Arctic grayling probably spawn at Station 2. Unidentified fish eggs, denoting spawning sites, were found at several points, particularly in stony areas, from the Muskeg River off the Alsands runway to Station 2.

Young-of-the-year grayling, suckers and at least some pike rear in the Muskeg River at and downstream from Station 2. Rearing may occur further upstream also, but it was difficult to effectively sample small fish above that point.

Late fall sampling tended to confirm Bond and Machniak's (1979) contention that few pike, grayling or suckers overwinter in the Muskeg drainage, with the possible exception of young fish. Small runs of white suckers and pike moved out of the river in late October just before freeze-up, but no distinct fall downstream run of other species, including Arctic grayling, was detected.

In the initial stages of a routine monitoring study on the Muskeg River, only very large changes in the fish populations would be detectable because detailed "before" data on certain critical periods and life history stages (eg numbers of eggs or spawning and rearing fish at specific locations and times) are unavailable. For example, any catastrophic effects due to muskeg drainage, such as the total failure of a year-class, would show up in the small fish surveys, but substantial reductions in hatching success would not be demonstrable. Some effects, however, such as year class weaknesses or differences in growth, may become apparent when data from subsequent years are compared to the baseline data on older fish provided by Bond and Machniak (1977, 1979).

The evidence from the present study is limited, and does not reveal any clear effect, adverse or otherwise, of Alsands' Muskeg drainage on the fish populations of the Muskeg River. The minesite drainage water raised late winter dissolved oxygen levels in the immediate vicinity of the outfall (Station 4), a beneficial effect, but there is no evidence that this area is used by overwintering fish. Small numbers of longnose suckers probably used this area for spawning in 1980, and eggs of one or more large fish species found here and elsewhere in 1980 were alive when collected. It is not known, however, whether more spawning occurred at the location in previous years. The spawning times of grayling, pike and suckers appeared to be nearly identical to those documented in 1976 and 1977 by Bond and Machniak (1977, 1979a), but the data are not complete for 1980. The size of

young-of-the-year suckers, pike, and grayling in 1980 was similar to, or slightly greater than, that of young-of-the-year collected on comparable dates in 1976 and 1977, but whether their abundance was similar is not known.

6.0 TERRESTRIAL VEGETATION

6.1 Methods

Prior to the field survey, maps and air photos of the water discharge areas were reviewed. A brief field reconnaissance of the two water discharge areas was carried out on 4 and 5 August 1981. A combination of helicopter and foot access was used to visit the sites.

At each site, notes were made of any symptoms of vegetation stress such as yellowing of leaves or needles, dieback of growing shoots, and the presence of root suckers or adventitious roots. The timing of the field examination allowed nearly a full growing season for symptoms of vegetation stress to develop, yet the observations were early enough to avoid including effects of early fall frosts. Unidentified plant specimens were collected for later identification.

Notes were made on site factors such as depth and distribution of standing water, and, in the Muskeg River area, depth and distribution of new sediment. The presence of debris and silt marks indicating previous high water marks was also recorded. Photos (35 mm) of the vegetation and site conditions were taken from both the air and the ground.

6.2 Results and Discussion

Vegetation stress symptoms due to flooding and sedimentation were evident in both discharge areas. Because water discharge rates and sediment in the two areas differed, each is described separately in terms of predisturbance vegetation, current site conditions, symptoms of vegetation stress, and impact on vegetation.

6.2.1 Tailings Pond Area (NW 1/4 32-95-10-W4)

The vegetation of the tailings pond area is characterized by aspen poplar forest 10 to 20 m high growing on well to imperfectly drained soils. The terrain is level to gently undulating (Figure 22, Plate 1). White spruce is occasionally present as full sized trees but more frequently as saplings. The understory consists of a variety of shrubs and herbs (Plate 2). A list of plants encountered in the study area including common and scientific names appears in Table 86. For a more detailed description and map of the vegetation of the lease area see the impact assessment report by the Alsands Project Group (1978).

Interspersed along the drainage ditch is a scrub black spruce-tamarack-sedge fen on low lying poorly drained soils. The water table is at or near the surface. This fen is not patterned, but

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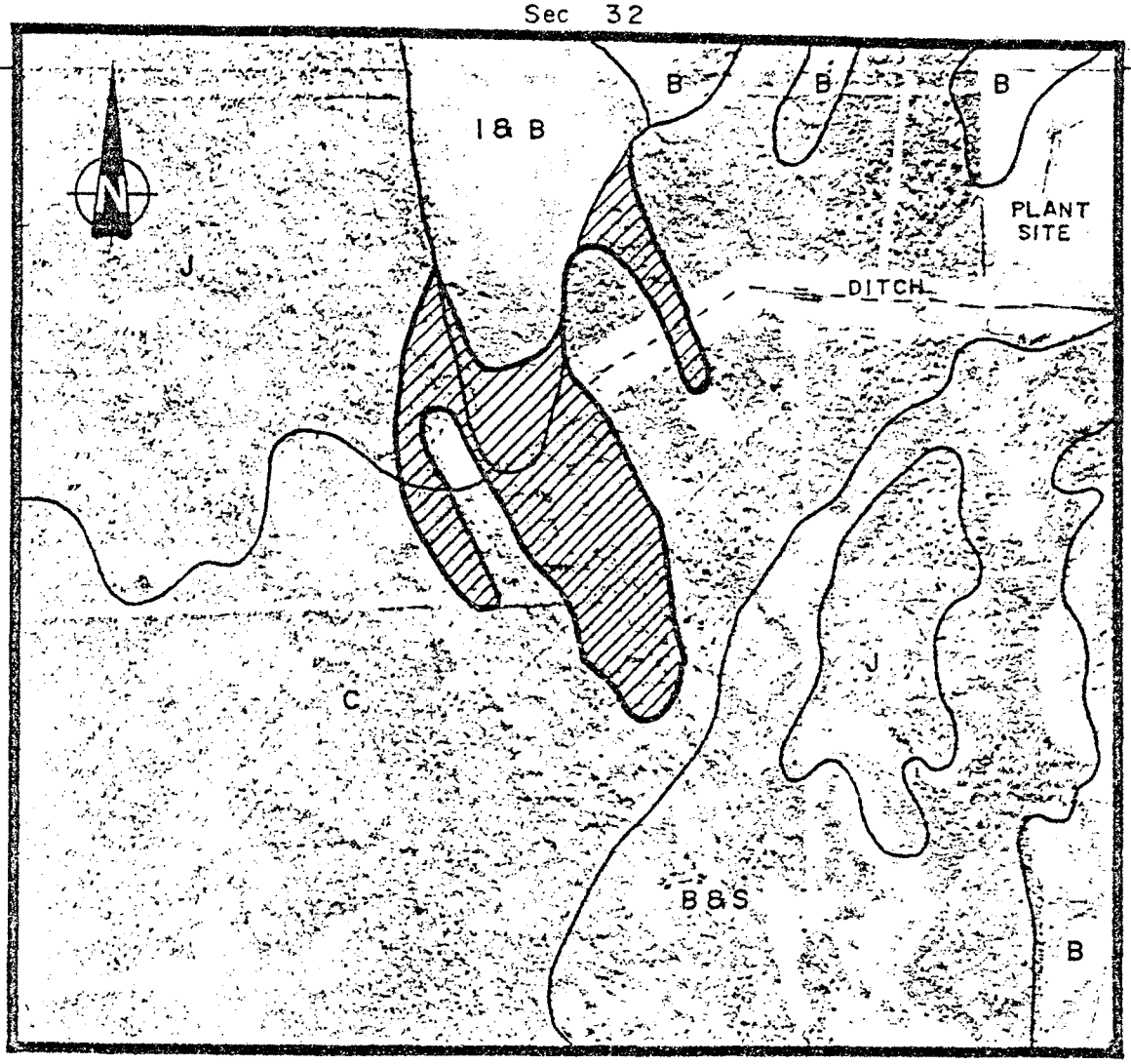

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LEGEND

SCALE 1: 10,000

PRODUCTIVE FOREST TYPES

C Poplar Forest

S Black Spruce - Tamarack - Jack Pine Forest

J Poplar - Jack Pine Forest

NON FOREST TYPES

B Scrub Black Spruce - Tamarack - Sedge Fen

I Shrub

Area of Impact

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Figure 22. VEGETATION OF TAILINGS POND DISCHARGE AREA

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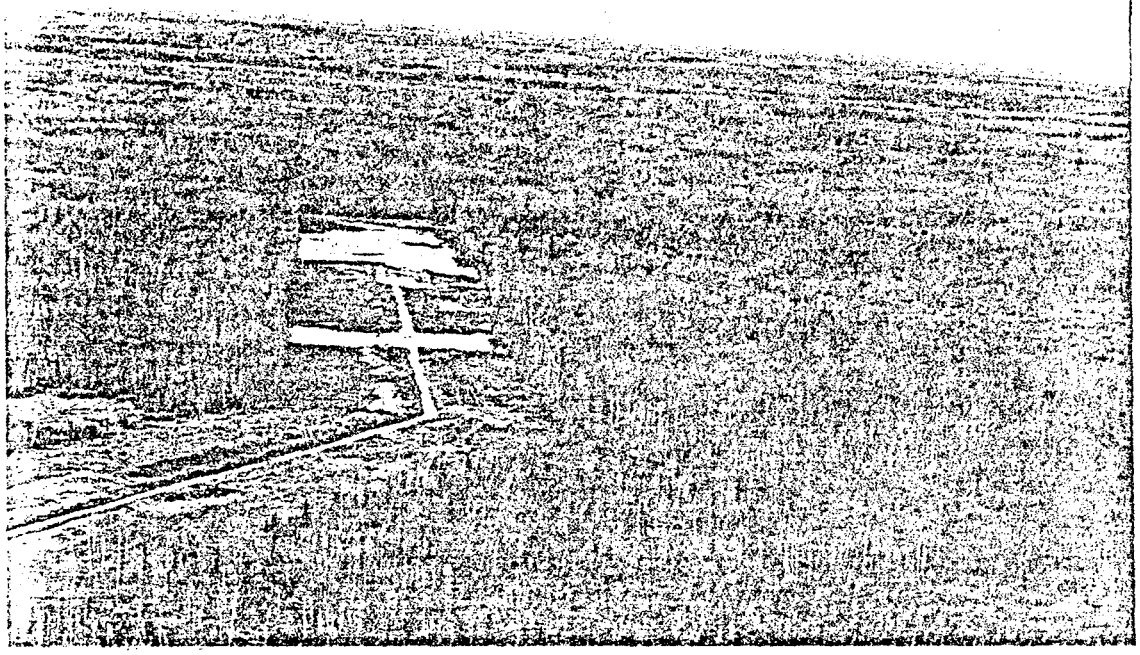


Plate 1. Aerial view showing the tailings pond discharge area. Aspen poplar forest is surrounding scrub black spruce-tamarack sedge fen on right. Yellowing of aspen is due to a recent tent catapillar investation.

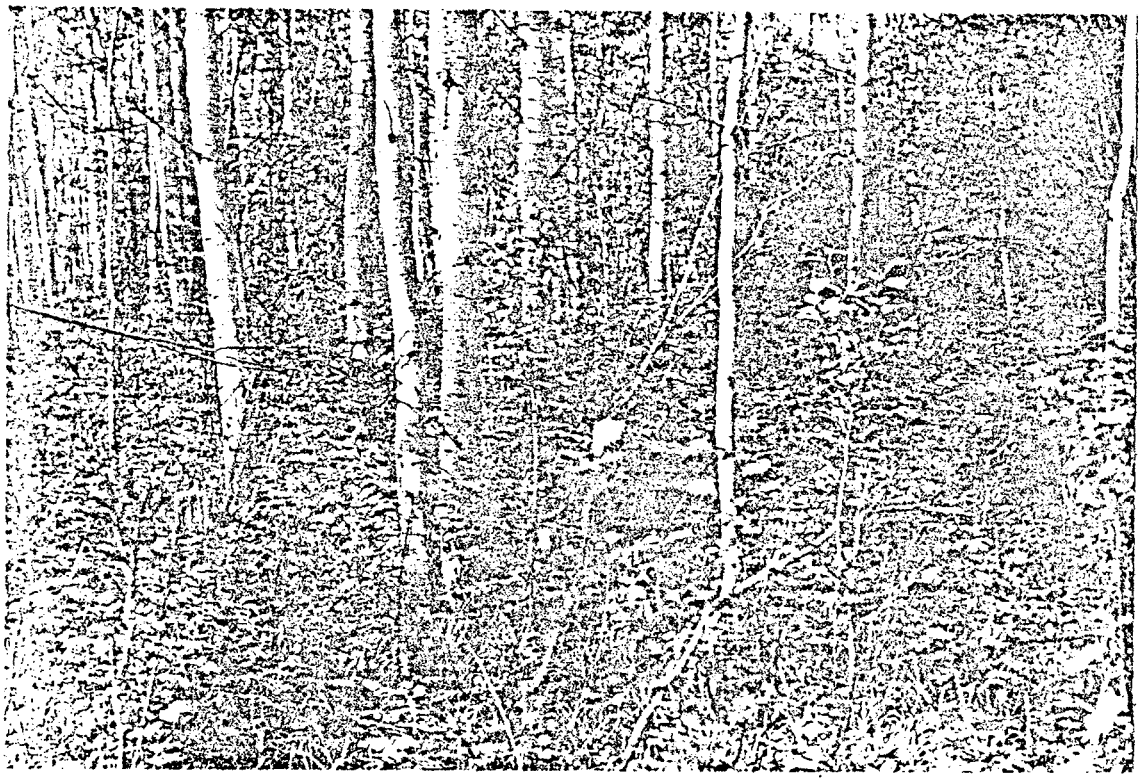


Plate 2. Understory of aspen forest near tailings pond discharge area showing abundant shrubs and tall herbs.

Table 86. Common and Scientific Names of Plants Encountered in the Study Area.

Common Name	Scientific Name
Trees	
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Jack pine	*Pinus banksiana*
Aspen	*Populus tremuloides*
Shrubs	
Saskatoon berry	*Amelanchier alnifolia*
Swamp birch	*Betula glandulosa*
Current	*Ribes* sp.
Prickly rose	*Rosa acicularis*
Wild red raspberry	*Rubus strigosus*
Willow	*Salix* spp.
Low bush cranberry	*Viburnum edule*
Herbs	
Yarrow	*Achillea millefolium*
Anemone	*Anemone* sp.
Sedges	*Carex* spp.
Bunchberry	*Cornus canadensis*
Larkspur	*Delphinium glaucum*
Fireweed	*Epilobium angustifolium*
Horsetail	*Equisetum* spp.
Wild strawberry	*Fragaria virginiana*
Northern bedstraw	*Galium boreale*
Feathermoss	*Hylocomium* spp.
Bluebell	*Martensia paniculata*
Palmate-leaved colts foot	*Petasites palmatus*
Bulrush	*Scirpus* spp.
Sphagnum moss	*Sphagnum* spp.
Meadow rue	*Thalictrum venulosum*
Cattail	*Typha latifolia*

consists of a ring of stunted trees around a central shrub and sedge covered area.

The tailings pond discharge was made up of clear water containing small amounts of sediment. The majority of the water flowed into the area soon after snowmelt. Because of the depressional topography of the area, continued slow drainage fromn the cleared plant site, and summer rains, much of the affected area remained under water at depths up to 60 cm for the entire growing season. The extent of the affected area (about 12.6 ha) is shown in Figure 22.

Although the aspen was flooded (Plate 3), the first symptoms of stress appeared in white spruce as yellowing and browning of the lower needles (Plate 4). The willow and rose shrubs did not appear to be stressed at this time. The herb layer was completely covered by water except along the edges of the flooded area, where damage was indicated by yellowing of leaves (Plate 5). Since the fen area is normally subject to high water levels, the scrub spruce-tamarack-sedge vegetation was not showing any evidence of stress or damage.

The impact of continued drainage water discharge is likely to affect the aspen poplar forest most seriously. If the current high water levels remain for the next two to three years, first white spruce then aspen are likely to die from lack of oxygen in the rooting zone. Shrubs, except perhaps willow, as well as most herbs are also likely to die out. Initial invading species scattered among the dead tree trunks are likely to be aquatic herbs such as cattail, and sedges with willow and dwarf birch. The scrub black spruce-tamarack

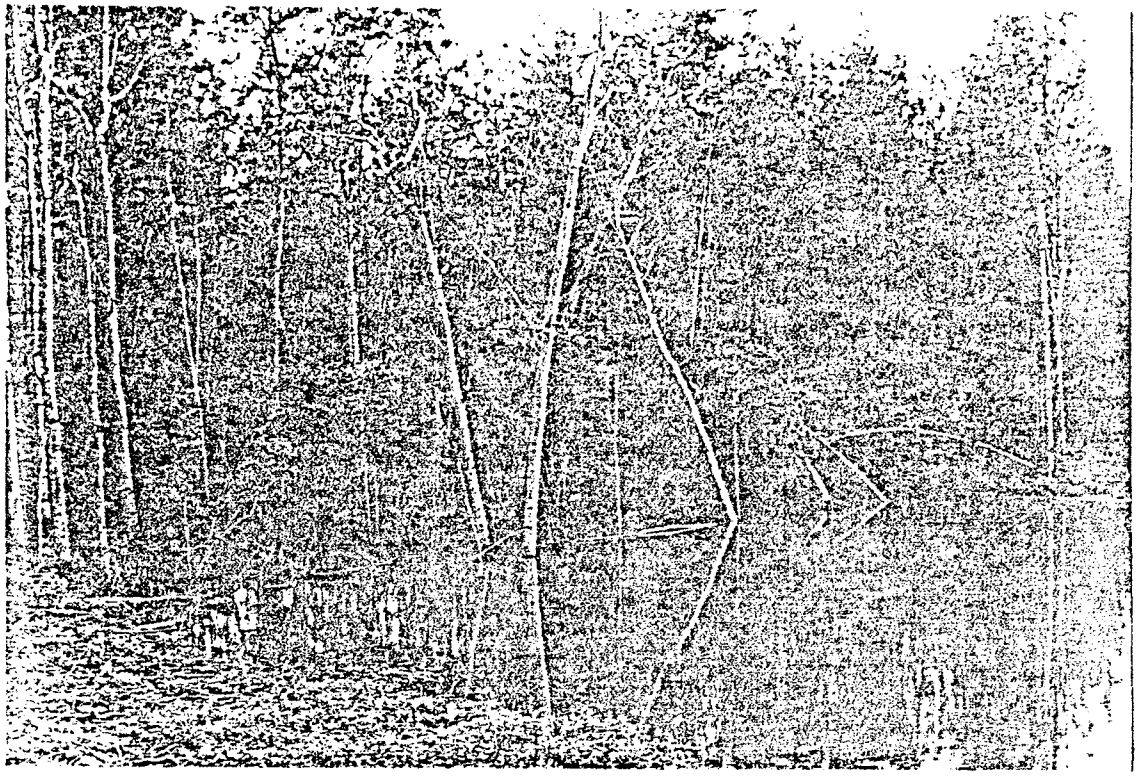


Plate 3. Flooded aspen and willow are not showing signs of stress at this time.

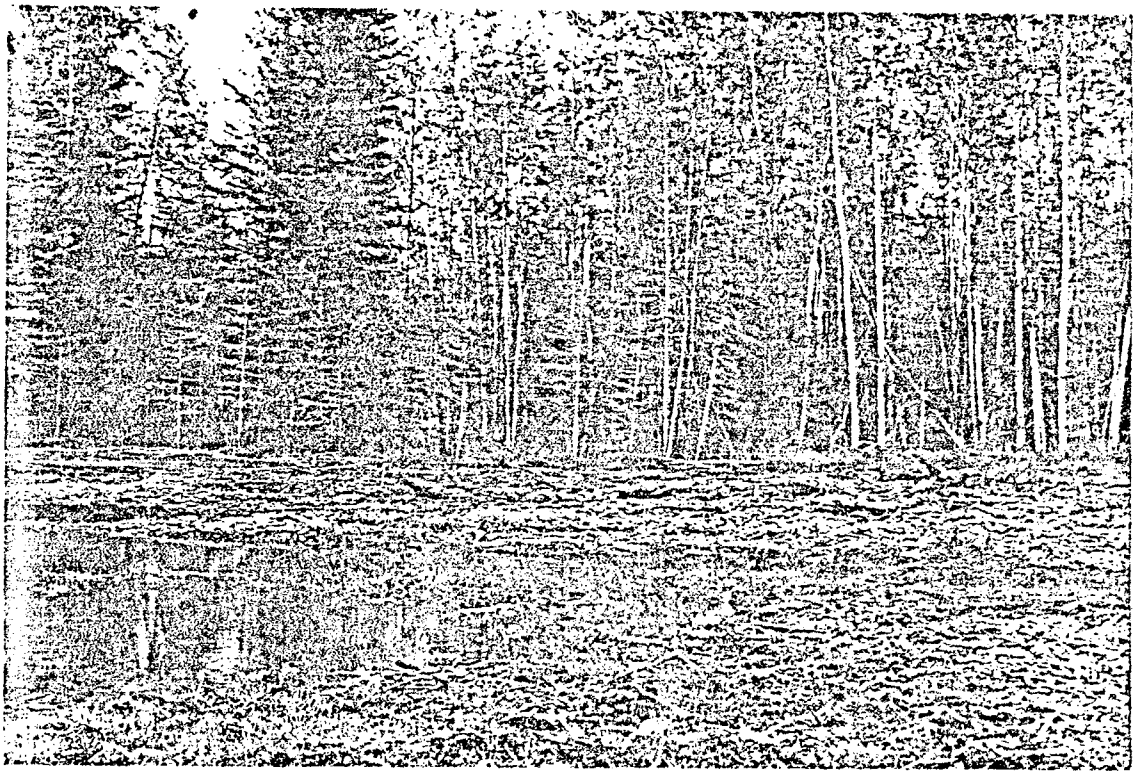


Plate 4. White spruce in flooded low area where the yellowing of needles, particularly noticeable on the lower branches, is the result of flooding.

Plate 5. Shrub and herbaceous cover growing in an area of shallow flooding. The yellowing of leaves indicates some stress caused by flooding.

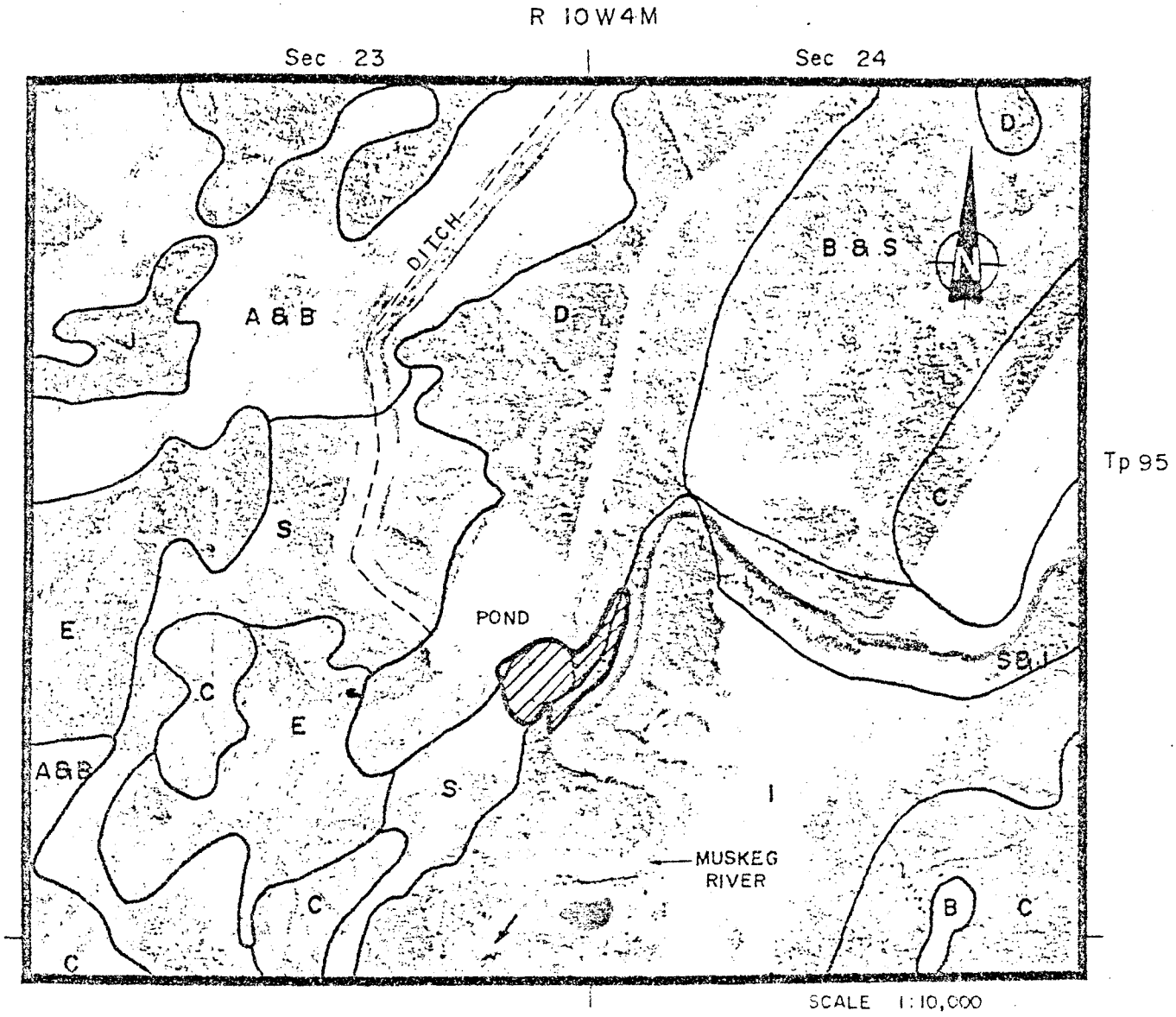
fen area will probably remain unaffected by the higher water levels. Consequently, water discharge into the tailings pond area will probably result in the replacement of upland aspen forest by aquatic and fen vegetation types. In the event that the water level drops, a return to the upland aspen forest is likely.

6.2.2 Muskeg River Area (SE 1/4 93-95-10-W4)

The vegetation of the Muskeg River area is characterized by jack pine forest on well drained soils on the bench above the river (Figure 23, Plate 6). Codominant trees include aspen and scattered white spruce; a variety of shrubs and herbs makes up the lower strata.

A black spruce-tamarack-jack pine forest is found on an imperfectly to poorly drained area below the bench. The central part of this low area and the banks of the Muskeg River are characterized by willow shrub.

The Muskeg River discharge at the time of flooding had a high sediment load. A flood height of up to 60 cm was indicated by silt marks and the debris caught in the vegetation (Plate 7). Subsequently, the water level dropped as the discharge flowed into the Muskeg River, leaving behind a considerable amount of sediment. The extent of the affected area (about 1.8 ha) is shown in Figure 23. On the basis of flood duration and the thickness of sediment, the following three impact zones were identified.



LEGEND

PRODUCTIVE FOREST TYPES

- C Poplar Forest
- D Jack Pine Forest
- E Poplar - Spruce Forest
- S Black Spruce - Tamarack - Jack Pine Forest
- J Poplar - Jack Pine Forest

NON FOREST TYPES

- A Scrub Black Spruce - Moss Muskeg
- B Scrub Black Spruce - Tamarack - Sedge Fen
- I Shrub
- Area of Impact

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Figure 23. VEGETATION OF MUSKEG RIVER DISCHARGE AREA

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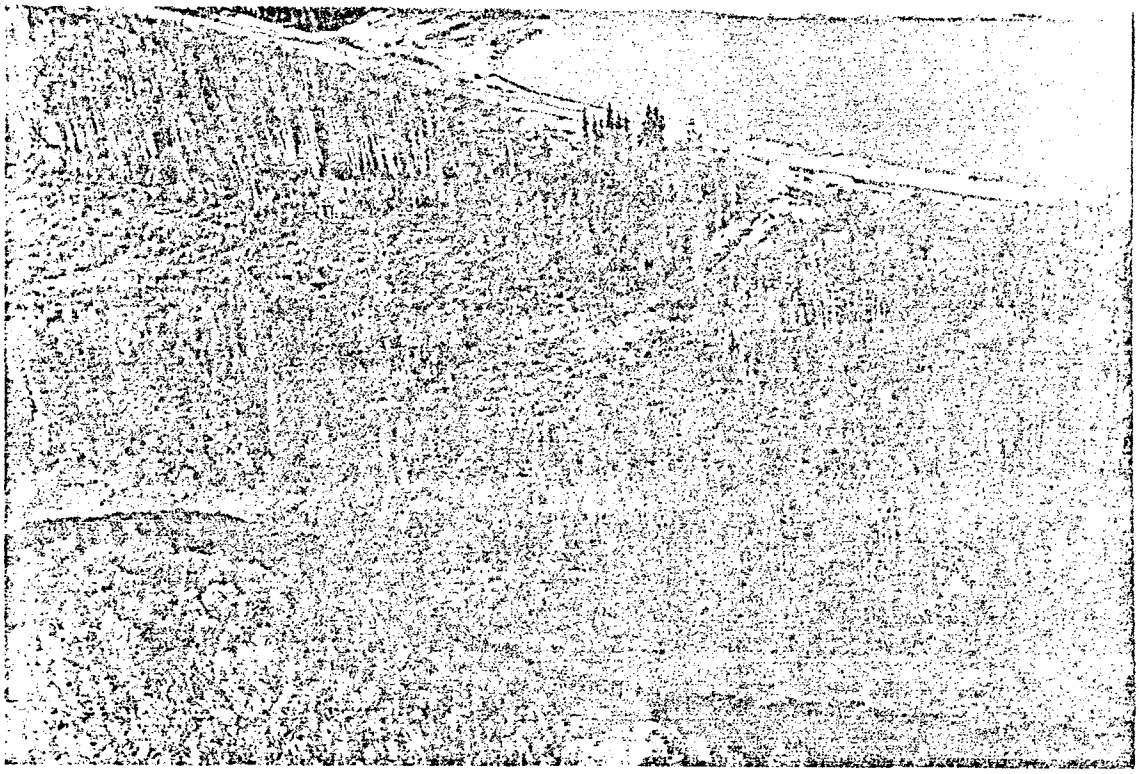

Plate 6. Aerial view showing the Muskeg River discharge area. Vegetation consists of jack pine forest with aspen on well drained soils, and black spruce-tamarack-jack pine forest with some willow shrub on imperfectly to poorly drained soils.

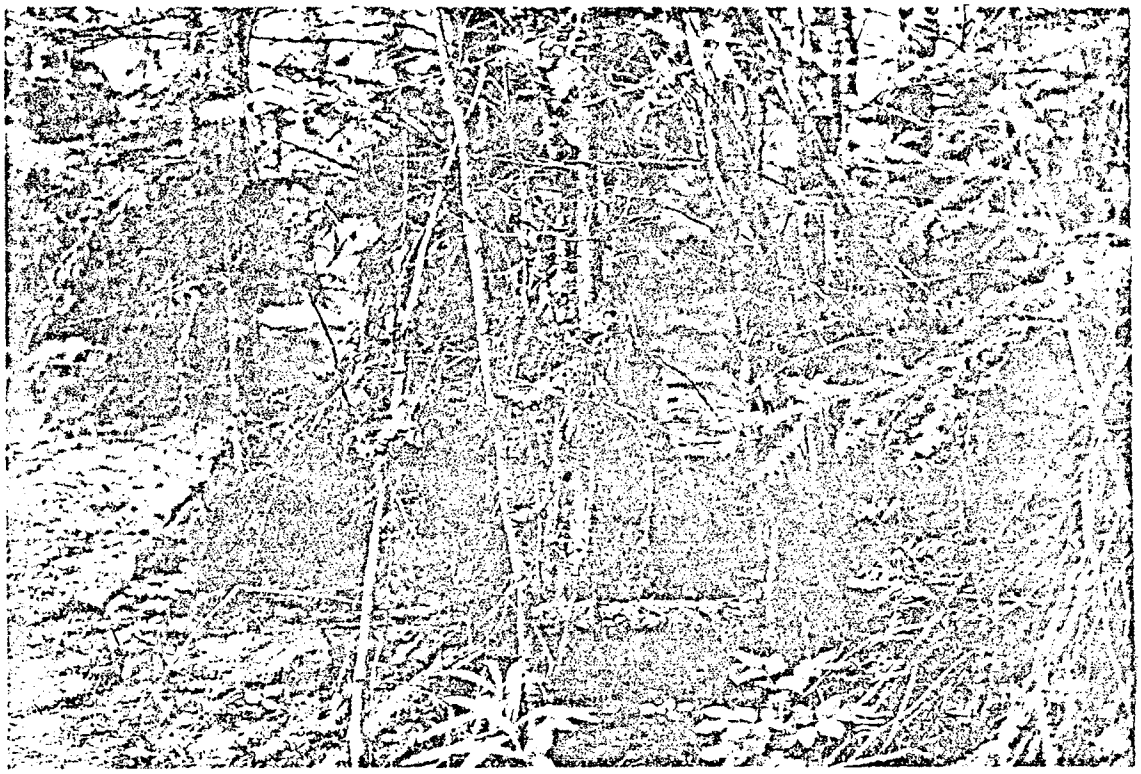

Plate 7. The depth of flooding up to 60 cm is indicated by the silt marks and debris on the vegetation.

Zone 1 - High Impact

Zone 1 comprises the willow shrub and black spruce-tamarack-jack pine forest areas. At the time of the study, these areas were flooded by discharge waters. The sediment thickness was estimated to be over 20 cm; however, an accurate measurement could not be made at the time of the field survey. Symptoms of vegetation stress included the production of new willow shoots, the yellowing and browning of black spruce needles (Plate 8), and dieback of the growing tips of black spruce.

Zone 2 - Moderate Impact

This zone occupies the lower slope positions characterized by jack pine forest. The area, except for minor depressions, was no longer flooded; however, the surface was covered by 10 to 18 cm of sediment. Pine trees were not growing in the immediate area, but several white spruce showed yellowing of needles and dieback of growing leaders (Plate 9). As well, the white spruce was responding by forming new adventitious roots from the part of the trunk buried by sediment. Many shrubby species, including willow, prickly rose, and low bush cranberry, were responding by producing new shoots. Herbaceous species were invading the sediment with a ground cover of

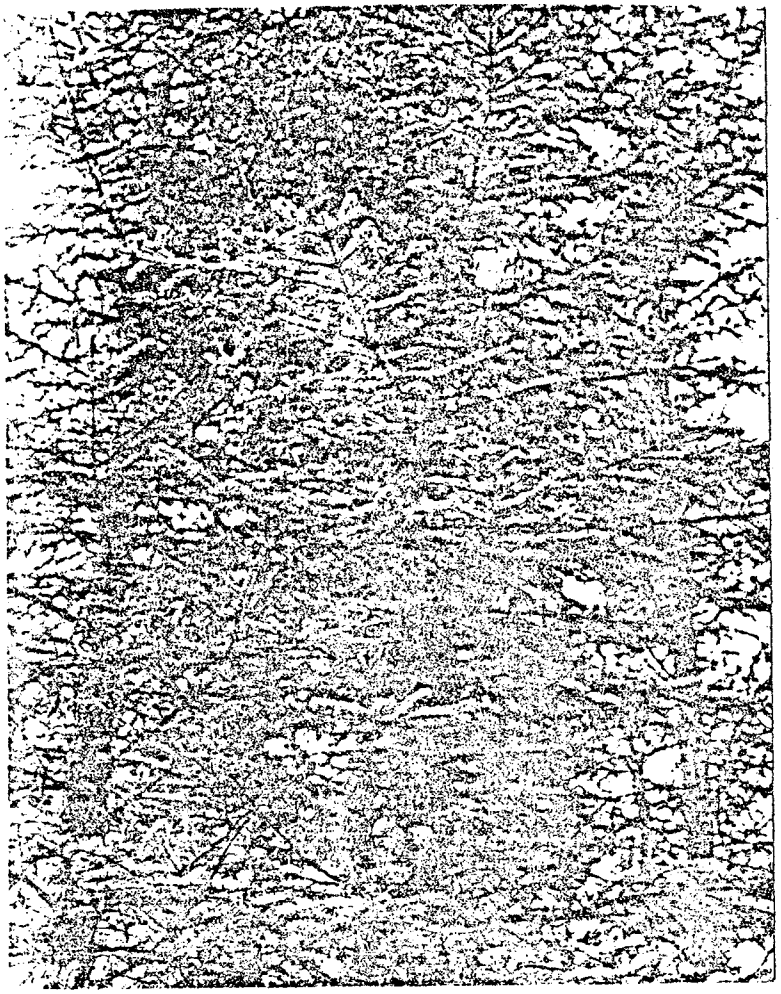

Plate 8. Stress due to flooding on black spruce is indicated by yellowing and browning of needles.

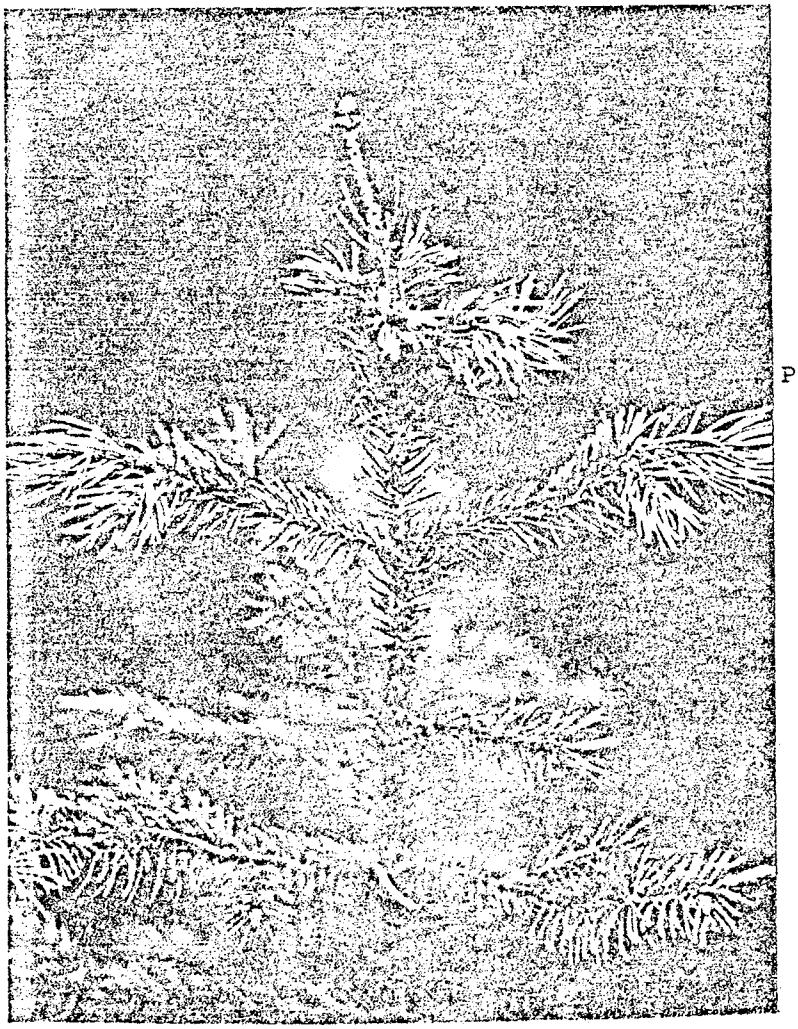

Plate 9. Die back of leaders and browning of needles of white spruce are symptoms of stress due to flooding.

nearly 50% by sending up new shoots from underground rhizomes and stolons (Plate 10).

Zone 3 - Light Impact

This zone is found under the jack pine forest higher on the bench above the Muskeg River. At the time of the study, the area was no longer flooded; however, about 1 cm of sediment had been deposited throughout. The only affect of this sediment was the burial of feathermosses located in depressions. Otherwise the vegetation was not affected.

The impact of continued drainage water discharge into the Muskeg River will probably not have much effect on the vegetation of this area. This lack of impact could be maintained providing that the rate of water flow is controlled and that most of the sediment settles in the pond north of the road. The continued flooding in the willow shrub and black spruce forest is not likely to have much effect. The sediment deposited in the pine forest is likely to be rapidly invaded by shrubs and herbs. The white spruce trees affected by flooding are likely to recover next year.

6.3.0 Conclusions

The impact of drainage water on the vegetation near the two discharge points was minimal. At the tailings pond discharge, the

Plate 10. Rapid invasion by herbaceous species that have been buried by sediment is primarily accomplished by rhizomes and stolons.

major effect of current flooding was on white spruce, which was showing yellowing of lower needles; and on herbaceous species, most of which have drowned. If the flooding remains, aspen and several shrubs are likely to die out and be replaced by willow and swamp birch.

At the Muskeg River discharge, there has been continuous flooding and high sedimentation of a willow shrub and black spruce forest. Since the vegetation of these areas is often subject to flooding, little impact is expected. In the portions of the pine forest subjected to sedimentation, rapid recovery by stressed trees and rapid invasion of bare surfaces by shrubs and herbs is expected.

In order to confirm the long term impact of discharge water on vegetation, annual surveys are recommended. Prior to a survey, any new aerial photography of the area should be reviewed. Field surveys should take place in late July or early August to avoid symptoms of vegetation damage caused by early fall frosts.

7.0 LITERATURE CITED

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8.0 APPENDICES

APPENDIX A: WATER QUALITY ANALYSES

All detailed analyses were checked for internal consistency by a variety of methods to detect any gross analytical errors.

In a perfectly accurate complete analysis, the sum of all the cations in milliequivalents per litre (meq/L) must exactly equal the sum of all the anions. In practise, there is usually a slight discrepancy between the sums, because analytical methods are never perfectly accurate and because all ions are not usually included in an analysis.

In the present study, ion balance was checked by the method of Thomas (1953); ie, the difference between major cation and anion concentrations was expressed as a percentage of total ions. Calculations were checked if the percent difference exceeded the limits in Table A1. If sulphate, which had a high detection limit, was not found in the analysis, the ion balance was recalculated including sulphate at a concentration just below the detection limit. If the ion balance was still outside the acceptance range, it was considered likely that there was a serious error in the reported concentration of one or more major ions, and these data were not used in any subsequent analysis.

Table A1 Limits of expected values for calculations used to check the accuracy of detailed water analyses. Analyses having one or more values falling outside the expected ranges were treated as described in the text.

TDS (mg/L)	Absolute Value [1] $\frac{\Sigma cations - \Sigma anions}{\Sigma ions} \times 100$	Range [1] TDS - sum constituents (mg/L)	Range [2] TDS and Conductivity	Range [2] sum.constit. and Conductivity
<100	7	-6 to +20		
101-200	5	-8 to +30		
201-300	4	-12 to +40	0.55 to 0.75	
301-500	4	-14 to +45	(at all TDS)	
501-1000	3	-16 to +50		

[1] slightly modified from Dole, cited in Thomas (1953:40)

[2] Hem (1970:235)

For most analyses, total dissolved solids (TDS) was determined gravimetrically. This permitted a check to be made on the analysis by a comparison of sum of constituents (calculated as recommended by Thomas 1953) to TDS, which should be within a few mg/L of each other in most natural waters (Thomas 1953, Hem 1970). In the present data, TDS would generally be expected to exceed the sum of constituents, because silica was not included in the analysis and sulphate was analyzed only at a high detection limit. When TDS - sum of constituents exceeded the acceptance limits in Table A1, the difference was recalculated by including sulphate at a concentration just below the detection limit in the sum of constituents. If the difference was still outside the acceptance limits, it was determined if silica at a concentration within the previously-reported range (Seidner 1980) could account for the remainder of the difference. If not, the other ratios used to check the analysis were examined to determine which measure was most likely in error so that this datum could be removed from any further analysis.

Conductivity, sum of constituents and TDS are all approximate measures of the same thing; ie, the dissolved salts present in water. The latter two can be expected to have an approximately constant relationship to conductivity, depending in part on the ion species present. The ratio of TDS (or sum of constituents) to conductivity can be expected to fall within the range 0.55 to 0.75 (Hem 1970). When these ratios fell outside the expected range, it was determined if sulphate at a concentration just below the detection

limit, and (for sum of constituents/conductivity) silica within the known range (Seidner 1980) could account for the discrepancy. If not, the other ratios used to check the analysis were examined to determine which datum was most likely in error so that it could be excluded from further consideration in the data analysis.

Table A2. Water analyses, Muskeg River drainage, March 25, 1980. All units are mg/L except ion balance (calculated from meg/L), pH, conductivity and colour. Ion balances in parentheses were calculated assuming sulphate was present just below the detection limit.

	Station									
	1	2	3	4	5	6	7	8	9	10
Calcium	88	85	83	85	88	96	82	93	95	163
Magnesium	20	20	20	21	20	26	21	23	16	17
Sodium	14	13	14	16	15	46	16	11	6.9	2.5
Potassium	1.9	1.9	1.9	2.0	2.0	2.9	2.0	2.0	1.3	2.0
Chloride	5	7	7	7	8	35	5	5	2	3
Sulphate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<35
Total alkalinity (as $CaCO_3$)	302	296	290	294	290	364	290	314	298	410
pH @ 20°C	8.48	8.50	8.25	8.57	8.27	8.30	8.33	8.15	8.12	8.36
Total hardness (as $CaCO_3$)	302	294	289	298	302	346	291	327	303	477
Conductivity µS/cm @ 25°C	647	661	661	647	661	920	661	718	661	949
Suspended solids	10	16	16	14	17	18	18	15	45	54
Turbidity, NTU	16	20	18	43	29	36	33	32	64	137
Colour, APHA units	20	40	40	40	50	50	60	40	20	250
BOD	4	4	3	4	4	4	3	6	3	5
TOC	14	15	25	18	23	11	15	16	28	63
Phenols	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Oils and grease	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total phosphate (as P)	0.02	0.03	0.03	0.03	0.04	0.06	0.04	0.06	0.06	0.03
Ammonia-N	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrite-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Kjeldahl	2.3	2.3	1.9	2.3	1.6	1.3	1.3	1.4	1.2	1.2
Iron	0.061	0.047	0.040	0.048	0.114	0.036	0.047	0.017	0.037	0.095
Manganese	0.009	0.007	0.037	0.035	0.043	1.096	0.027	0.294	0.065	0.804
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	0.011	0.008	0.003	0.004	0.002	0.010	0.003	0.015	0.032	0.015
Copper	0.006	0.007	0.003	0.006	0.010	0.006	0.009	0.017	0.011	0.029

Continued . . .

Table A2. Continued.

	Station									
	1	2	3	4	5	6	7	8	9	10
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	0.017	0.008	0.023	0.028	0.012	0.046	0.031	0.019	0.023	0.069
Vanadium	0.078	0.126	0.089	0.113	0.076	0.109	0.065	0.069	0.107	0.276
Zinc	0.006	0.001	0.004	0.004	0.007	0.028	0.010	0.011	0.004	0.005
Sum of constituents	310	305	300	308	307	424	300	322	300	469
$\frac{\Sigma cations - \Sigma anions}{\Sigma ions} \times 100$	4.1	3.1	3.6	5.1 (3.4)	5.6 (3.8)	4.2 (3.0)	5.0 (3.3)	4.8 (3.1)	3.1	7.7 (3.5)
$\frac{\text{Sum of constituents}}{\text{Conductivity}}$	0.48[a]	0.46[a]	0.45[a]	0.48[a]	0.46[a]	0.46[a]	0.45[a]	0.45[a]	0.45[a]	0.49[a]

[a] Ion balances satisfactory, but sum of constituents is unusually low, and/or conductivity is unusually high. Addition of any realistic concentration of silica (up to 25 mg/L, Seidner 1980) and sulphate just below the detection limit to the sum of constituents does not bring the ratio within the expected range. Conductivity error possible.

Table A3. Water analyses, Muskeg River drainage, May 1, 1980. All units are mg/L except ion balance (calculated from meg/L), pH, conductivity and colour. Ion balances and ratios in parentheses were calculated by assuming sulphate was present just below the detection limit.

	Station									
	1	2	3	4	5	6	7	8	9	10
Calcium	33	32	30	26	27	17	33	43	64	117
Magnesium	7.6	7.9	7.2	6.9	7.1	5.3	8.4	10	11	15
Sodium	10	9.7	9.5	11	11	11	10	6.2	4.8	6.0
Potassium	1.5	1.4	1.5	1.4	1.5	1.3	1.5	1.5	1.4	1.3
Chloride	4	3	2	3	2	2	3	3	2	2
Sulphate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total alkalinity (as $CaCO_3$)	118	116	118	108	110	84	124	152	188	322
pH @ 20°C	8.26	8.19	8.21	8.18	8.15	8.04	8.08	8.01	8.26	8.29
Total hardness (as $CaCO_3$)	114	112	104	93	97	64	117	148	205	354
Conductivity, µS/cm @ 25°C)	228	228	204	216	215	170	233	275	324	503
Suspended solids	1	2	3	2	2	9	4	3	93	62
Turbidity, NTU	8	13	12	9	13	17	16	12	70	44
Colour, APHA units	30	30	30	30	30	30	30	30	20	40
BOD	2	2	2	2	2	3	2	3	2	2
TOC	15	15	18	18	16	17	16	14	15	16
Phenols	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Oils and grease	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total phosphate (as P)	0.02	0.02	0.02	0.03	0.04	0.04	0.04	0.03	0.03	0.03
Ammonia-N	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrite-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Kjeldahl-N	1.5	1.8	1.4	2.2	<1	<1	<1	1.2	1.5	3.2
Iron	0.45	0.64	0.62	0.64	0.68	0.30	0.92	1.06	0.13	0.32
Manganese	0.037	0.058	0.060	0.052	0.058	0.005	0.043	0.070	0.036	0.100
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	0.005	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.025	0.014	0.002
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	0.017	0.008	0.012	0.010	0.010	0.011	0.017	0.014	0.023	0.024
Vanadium	0.020	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.024

Continued . . .

Table A3. Continued.

	Station									
	1	2	3	4	5	6	7	8	9	10
Zinc	<0.001	0.012	<0.001	0.004	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Total dissolved solids	168	136	138	144	148	107	172	188	220	372
Sum of constituents	126	124	122	114	115	87.2	131	156	196	335
$\frac{\Sigma\text{cations} - \Sigma\text{anions}}{\Sigma\text{ions}} \times 100$	5.5 (1.5)	6.3 (2.1)	2.4	3.2	4.0	2.0	5.0 (1.1)	2.7	6.5 (3.8)	6.2 (4.6)*
$\frac{\text{TDS}}{\text{Conductivity}}$	0.74	0.60	0.68	0.67	0.69	0.63	0.74	0.68	0.68	0.74
$\frac{\text{Sum of constituents}}{\text{Conductivity}}$	0.56	0.54 (0.59)	0.60	0.53 (0.57)	0.53 (0.58)	0.51 (0.57)	0.56	0.57	0.60	0.67
TDS - sum of constituents	40 (30)	12	16	30	33 (23)	19	41** (31)	32 (22)	24	37

* excess cations
** most likely TDS in error (TDS/cond. relatively high, other checks OK).

Table A4. Water analyses, Muskeg River drainage, July 11, 1980. All units are mg/L except in balance (calculated from meg/L), pH, conductivity and colour. Figures in parentheses were calculated by assuming sulphate was present just below the detection limit.

	Station									
	1	2	3	4	5	6	7	8	9	10
Calcium	60	61	72	61	56	36	58	65	101	112
Magnesium	12	12	13	13	12	9.4	13	14	15	12
Sodium	14	14	13	18	20	17	26	9.5	7.6	5.3
Potassium	0.9	0.9	1.1	0.9	1.3	1.0	0.8	0.8	1.6	1.3
Chloride	7	8	5	9	8	6	11	3	2	2
Sulphate	<10	<10	<10	<10	<10	<10	10	10	10	10
Total alkalinity (as $CaCO_3$)	220	230	254	236	230	160	246	234	314	296
pH @ 20°C	8.24	8.20	8.25	8.48	8.08	8.25	8.45	8.37	8.49	8.42
Total hardness (as $CaCO_3$)	199	202	233	206	189	128	198	220	314	329
Conductivity, µS/cm @ 25°C	396	396	456	432	432	336	456	432	575	587
Suspended solids	1	1	1	1	23	1	6	8	37	36
Turbidity, NTU	4	4	4	5	10	4	5	5	14	20
Colour, APHA units	20	20	20	30	30	20	20	20	30	40
BOD	3	3	3	3	3	3	3	3	3	4
TOC	15	16	17	17	16	18	16	15	18	13
Phenols	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.001	0.001	0.001
Oils and grease	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total phosphates (as P)	0.02	0.01	0.01	0.02	0.03	0.01	0.02	0.02	0.01	0.02
Ammonia-N	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<1	<1	<0.5	<1
Nitrite-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<1	<1	<1	<1
Total Kjeldahl-N	1.9	1.4	1.8	2.4	1.7	1.5	1.4	1.7	1.4	1.6
Iron	0.096	0.091	0.092	0.105	0.107	0.104	0.111	0.102	0.090	0.124
Manganese	0.033	0.010	0.001	0.022	0.050	0.024	0.034	0.014	0.032	0.071
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	0.004	0.001	0.002	0.010	0.005	0.003	0.004	0.001	0.008	0.010
Copper	0.019	0.019	0.008	0.007	0.014	0.003	0.004	<0.001	0.009	0.013
Lead	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	0.015	0.008	0.019	0.333	0.016	0.009	0.018	0.015	0.013	0.022

Continued . . .

Table A4. Continued.

	Station									
	1	2	3	4	5	6	7	8	9	10
Vanadium	0.017	0.001	0.024	0.041	0.041	0.029	0.070	0.032	0.081	0.062
Zinc	0.011	0.003	0.006	0.002	0.003	0.002	<0.001	0.007	0.027	0.035
Total dissolved solids	265	269	301	281	285	225	299	285	385	387
Sum of constituents	226	234	265	244	237	166	267	243	326	321
$\frac{\Sigma cations - \Sigma anions}{\Sigma ions} \times 100$	0.2	-1.7	0.4	-0.6	-1.5	-0.4	-3.1	-1.4	0.7	5.0[d]
$\frac{TDS}{Conductivity}$	0.67	0.68	0.66	0.65	0.66	0.67	0.66	0.66	0.67	0.66
$\frac{Sum\ of\ constituents}{Conductivity}$	0.57	0.59	0.58	0.56	0.55	0.49[a] (0.52)	0.59	0.56	0.57	0.55
TDS - sum of constituents	39	35	36	37	48 (38)	59[a] (49)	32	42[b]	59[c]	66[d]

[a] TDS/conductivity is within the expected range, therefore the sum of constituents is most likely too low. Because the ions balance, either an ion pair or an unionized constituent might have been omitted from the analysis. Silica at 10 mg/L (well within the known range for this creek) added to sum of constituents would bring the ratios into the expected range.

[b] Omission of silica could have made the sum of constituents slightly too low.

[c] Omission of silica probably cannot explain the discrepancy between TDS and sum of constituents. Because all other ratios are within the expected ranges, it is not apparent what the cause of the large difference is.

[d] The ion balance shows an excess of cations. Because the sum of constituents appears to be low in comparison to TDS, it appears most likely that an important anion was underestimated.

Table A5. Water analyses, Muskeg River drainage, 1980. All units are mg/L except ion balance (calculated from meg/L), pH, conductivity, turbidity and colour. Figures in parentheses were calculated by assuming that sulphate was present just below the detection limit. Collected 10-11 September, 1980.

	Station									
	1	2	3	4	5	6	7	8	9	10
Calcium	28	32	28	27	27	21	28	21	98	101
Magnesium	6.8	7.4	6.7	6.8	6.8	5.3	7.1	7.1	15	12
Sodium	12	14	13	12	14	15	12	17	7.1	3.8
Potassium	0.5	0.5	0.6	0.5	0.4	0.4	0.4	0.5	1.7	1.5
Chloride	1	1	<1	3	1	2	2	2	<1	1
Sulphate	<10	<10	<10	<10	<10	<10	<10	<10	50	78
Total alkalinity (as $CaCO_3$)	124	122	120	120	120	100	128	102	282	221
ph @ 20°C	7.69	7.57	7.51	7.38	7.32	7.96	7.73	7.46	7.69	7.94
Total hardness (as $CaCO_3$)	98	110	97	95	95	74	99	82	306	301
Conductivity, µS/cm @ 25C	240	228	222	224	204	192	240	222	479	503
Suspended solids	28	29	21	21	13	21	23	32	31	970
Turbidity, NTU	21	18	19	19	19	17	17	17	21	211
Colour, APHA units	101	107	110	108	110	110	110	110	47	45
BOD	2	5	2	4	2	2	2	3	6	4
TOC	43	34	28	35	36	36	36	34	34	42
Phenols	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Oils and grease	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total phosphate (as P)	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03
Ammonia-N	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nitrite-N	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Kjeldahl-N	<1	<1	1.1	<1	<1	<1	<1	<1	2.7	1.4
Iron	0.35	0.38	0.35	0.35	0.35	0.30	0.35	0.33	0.56	1.45
Manganese	0.107	0.043	0.037	0.046	0.033	0.038	0.028	0.053	0.102	0.104
Arsenic	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chromium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	0.001	<0.001	0.003	0.006	<0.001	<0.001	0.003	<0.001	0.002	0.002
Lead	0.0098	<0.001	<0.001	0.005	<0.001	<0.001	0.003	0.004	<0.001	0.003
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	<0.001	0.003	<0.001	0.043	<0.001	<0.001	0.007	<0.001	<0.001	<0.001

Continued . . .

Table A5. Continued.

	Station									
	1	2	3	4	5	6	7	8	9	10
Vanadium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	0.006	0.003	0.003	0.002	0.008	0.005	0.005	0.007	0.005	<0.001
Total dissolved solids	159	150	149	152	137	127	162	140	311	332
Sum of constituents	123	129	121	122	122	104	127	109	342	331
$\frac{\Sigma cations - \Sigma anions}{\Sigma ions} \times 100$	-0.2	6.8 (2.7)	3.0	-0.6	2.2	2.1	-2.1	6.5 (1.7)	-1.6	1.5
$\frac{TDS}{Conductivity}$	0.66	0.66	0.67	0.68	0.67	0.66	0.68	0.63	0.65	0.66
$\frac{Sum\ of\ constituents}{Conductivity}$	0.51 (0.55)	0.57	0.55	0.54 (0.59)	0.60	0.54 (0.59)	0.53 (0.57)	0.49[a] (0.54)	0.71	0.66
TDS - sum of constituents	36 (26)	21	28	30	15	23	35 (25)	31 (21)	-31[b]	1

[a] Either the sum of constituents is too low or the conductivity is too high. The TDS/conductivity ratio is well within the expected range, suggesting that the conductivity measurement is accurate, therefore the sum of constituents is probably too low. Silica within the known range for the Muskeg River (Seidner 1980), if added to the sum of constituents, would place the sum of constituents/conductivity ratio within the expected range.

[b] There is no obvious explanation for the high sum of constituents relative to TDS; in fact, the latter would be expected to slightly exceed the former in this analysis. The major ion and TDS determinations are not reliable for this sample.

Table A6. Water analyses, Muskeg River drainage, 1980. All units are mg/L, except ion balance (calculated from meg/L), pH, conductivity, turbidity and colour. Figures in parentheses were calculated by assuming that sulphate was present just below the detection limit. Collected 12 November 1980.

	Station									
	1	2	3	4	5	6	7	8	9	10
Calcium	36	34	35	33	32	20	35	37	106	122
Magnesium	9.4	9.0	9.3	9.0	9.2	6.0	10	10	17	16
Sodium	9.4	8.8	8.7	8.7	8.6	9.0	8.6	7.4	6.0	4.2
Potassium	0.6	0.6	0.5	0.5	0.5	0.3	0.5	0.6	1.6	1.4
Chloride	4	4	5	4	5	2	2	5	1	2
Sulphate	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Total alkalinity (as $CaCO_3$)	152	150	150	146	142	104	156	156	300	314
pH @ 20°C	8.22	7.93	8.12	8.29	8.21	7.93	7.52	8.28	8.28	8.25
Total hardness (as $CaCO_3$)	128	122	126	119	118	75	128	133	334	370
Conductivity, µS/cm @ 25°C	260	250	250	240	230	180	250	250	480	520
Suspended solids	12	18	15	12	8	6	10	17	312	47
Turbidity, NTU	20	20	18	20	19	17	18	18	85	48
Colour, APHA units	69	66	70	67	68	73	70	68	65	120
BOD	2	4	5	3	3	3	4	4	6	3
TOC	27	29	29	30	30	27	29	29	18	19
phenols	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Oils and grease	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total phosphate (as P)	0.02	0.01	0.03	0.02	0.02	0.02	0.02	0.01	0.01	0.04
Ammonia-N	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrate-N	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nitrite-N	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Total Kjeldahl N	1.2	1.6	1.3	1.5	1.2	1.4	1.2	1.2	1.7	2.2
Iron	0.13	0.13	0.13	0.13	0.13	0.12	0.14	0.14	0.14	0.14
Manganese	0.080	0.092	0.095	0.092	0.095	0.071	0.094	0.101	0.113	0.111
Arsenic	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Chromium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Copper	0.002	<0.001	0.002	<0.001	<0.001	0.002	0.002	<0.001	<0.001	0.002
Lead	0.013	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.021	0.026

Continued . . .

Table A6. Continued.

	Station									
	1	2	3	4	5	6	7	8	9	10
Mercury	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Nickel	<0.001	0.002	0.004	<0.001	<0.001	<0.001	<0.001	0.003	0.003	0.002
Vanadium	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Zinc	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.002	0.002	0.001	0.001
Sum of constituents	151	147	149	143	141	100	150	154	312	335
$\frac{\Sigma\text{cations} - \Sigma\text{anions}}{\Sigma\text{ions}} \times 100$	-2.3	-4.5	-3.8	-4.3	-4.2	-6.2[a]	-3.6	-3.8	7.4[b] (5.7)	9.2[b] (7.6)
$\frac{\text{Sum of constituents}}{\text{Conductivity}}$	0.58	0.59	0.60	0.60	0.61	0.56	0.60	0.62	0.65	0.64

[a] Anions exceed cations. Error in analysis of one or more major ions.

[b] Cations exceed anions. Error in analysis of one or more major ions.

Table A7. Water quality analyses minesite drainage ditch at the outfall area (Station 9), winter 1980. Data collected by Hardy Associates (1978) Limited. All units are mg/L unless noted otherwise. Asterisks mark values outside of the expected range.

Sample	Feb. 9	Feb. 23	Mar. 8	Mar. 8
Calcium	112	128	122	74
Magnesium	21	19	27	18
Sodium	1.2	6.3	8.3	7.0
Potassium	1.3	1.3	2.1	1.5
Chloride	3	6	3	2
Sulphate	<10	<10	<10	<10
Total alkalinity (as $CaCO_3$)	354	367	424	286
pH @ 20°C	7.52	7.62	7.60	7.74
Carbonate	< 1	< 1	< 1	< 1
Biocarbonate	431	447	517	349
Total hardness (as $CaCO_3$)	333	397	415	259
Fluoride	0.10	< 0.10	0.21	0.10
Silica	5.9	9.8	2.6	2.0
E.C. mS/cm @ 25°C	0.64	0.59	0.79	0.54
Threshold odor No.	2	2	2	4
Color, APHA units	100	55	40	30
Total filt. residue	351	390	417	274
Surfactants	< 1	< 1	< 1	< 1
Total organic carbon	37.0	40.0	59	22
Total inorganic carbon	65.5	110.0	96	69
Total carbon	102.5	150.0	155	91
Nitrate & nitrite nitrogen	< 1	< 1	< 1	< 1
Ammonia nitrogen	< 1	< 1	< 1	< 1
Total Kjeldahl nitrogen	16	3.7	2.8	1.1
Total phosphorus	< 0.01	0.04	< 0.01	0.03
Ortho phosphorus	< 0.01	< 0.01	< 0.01	< 0.01
Phenol	8	8	< 0.001	< 0.001
Oil & grease	90	20	< 1	< 1
Sulfide	< 0.01	< 0.01	< 0.01	< 0.01
Chemical oxygen demand	212	70	20	20
Cadmium	< 0.0001	0.0004	< 0.0001	< 0.0001
Hexavalent chromium	0.005	0.002	0.003	0.009
Copper	0.007	0.26	0.008	0.013
Iron	0.29	0.92	0.13	0.12
Lead	< 0.001	0.125	< 0.001	< 0.001

Continued . . .

Table A7. Concluded

Sample	Feb. 9	Feb. 23	Mar. 8	Mar. 28
Manganese	0.15	0.38	0.065	0.077
Silver	0.0007	0.0005	-	-
Zinc	< 0.0001	0.059	< 0.001	< 0.001
Vanadium	0.070	< 0.001	-	-
Selenium	0.004	< 0.001	< 0.001	< 0.001
Mercury	0.0002	0.0004	< 0.0002	< 0.0002
Arsenic	< 0.005	0.020	< 0.005	< 0.020
Nickel	0.025	0.054	0.012	0.018
Aluminum	0.31	0.07	0.08	0.10
Cobalt	0.015	0.030	0.022	0.031
Boron	0.32	0.02	5.78	2.44
Sum of constituents	358	392	426	279
$\frac{\text{Ecations - Eanions}}{\text{Eions}} \times 100$	2.1	5.4 (4.0)	1.0	-1.7
Sum of constituents ÷ conductivity (uS/cm)	0.56	0.67	0.54*	0.52*

Table A8. Water quality analyses, plantsite drainage ditch at the outfall area (Station 10), winter 1980. Data collected by Hardy Associates (1978) Limited. All units are mg/L unless specified otherwise. Asterisks mark values outside the expected range.

Sample	Feb. 9	Feb. 23	Mar. 8	Mar. 24
Calcium	87	136	100	94
Magnesium	21	15	16	17
Sodium	5.0	4.1	4.2	4.7
Potassium	1.5	1.5	1.4	1.7
Chloride	4	6	1	2
Sulphate	<10	<10	10	<10
Total alkalinity (as $CaCO_3$)	300	400	310	312
pH @ 20°C	8.15	7.84	7.95	7.93
Carbonate	< 1	< 1	< 1	< 1
Biocarbonate	366	488	378	380
Total hardness (as $CaCO_3$)	304	401	316	304
Fluoride	0.35 *	0.10	0.11	0.10
Silica	0.1	8.9	2.4	2.5
E.C. mS/cm @ 25°C	0.54	0.65	0.60	0.60
Threshold odor No.	2	2	4	2
Colour APHA units	70	55	150	40
Total filt. residue	299	413	308	307
Surfactants	< 1	< 1	< 1.0	< 1
Total organic carbon	16.5	40.0	12	41
Total inorganic carbon	52.5	110.0	78	74
Total carbon	79.0	150.0	90	115
Nitrate & nitrite nitrogen	< 1	< 1	< 1	< 1
Ammonia nitrogen	< 1	< 1	< 1	< 1
Total Kjeldahl nitrogen	26	2.4	1.9	1.1
Total phosphorus	< 0.01	0.03	< 0.01	0.04
Ortho phosphorus	< 0.01	< 0.01	< 0.01	< 0.01
Phenol	4	8	< 0.001	< 0.001
Oil and grease	20	30	< 1	< 1
Sulfide	< 0.01	< 0.01	< 0.01	0.01
Chemical oxygen demand	40	110	30	35
Cadmium	< 0.0001	0.0003	< 0.0001	< 0.0001
Hexavalent chorium	0.010	< 0.001	0.006	0.011
Copper	0.007	0.026	0.013	0.010
Iron	1.00	0.54	0.03	0.13

Continued . . .

Table A8. Continued

Sample	Feb. 9	Feb. 23	Mar. 8	Mar. 24
Lead	0.016	0.061	< 0.001	0.001
Manganese	0.35	0.45	0.022	0.072
Silver	0.0010	0.0003	-	-
Zinc	< 0.001	0.035	< 0.001	< 0.001
Vanadium	0.14	< 0.001	-	-
Selenium	0.004	< 0.001	< 0.001	< 0.001
Mercury	0.0002	< 0.0002	< 0.0002	< 0.0002
Arsenic	< 0.005	0.010	< 0.005	0.056
Nickel	0.035	0.100	0.020	0.018
Aluminum	0.09	0.16	0.10	0.18
Cobalt	0.020	0.029	0.010	0.012
Boron	0.40	< 0.02	4.11	1.78
Sum of constituents	301	413	326	312
$\frac{\Sigma\text{cations} - \Sigma\text{anions}}{\Sigma\text{ions}} \times 100$	2.3	0.9	0.6	0.2
Sum of constituents ÷ conductivity (μS/cm)	0.56	0.64	0.54*	0.52*

Table A9. "Short list" analyses of water quality, regular stations, Muskeg River drainage, 1980.

1980 Date (m/d)	Stn.	pH @ 20 C	Conductivity mS/cm @ 25 C	Turbidity NTU	susp. solids, mg/L	BOD mg/L	DO mg/L	Temp. C
03/22	1						2	0
03/22	2						1	0
03/24	3						2	0
03/22	4						11	0
03/22	5						3	0
03/21	6						0	0
03/24	7						1	0
03/24	8						2	0
03/23	9						7	0
04/03	1	7.74	0.456	14	8	2	10	0
	2	7.53	0.444	14	12	2	7	0
	3	7.59	0.456	14	17	3	8	0
	5	7.89	0.396	15	10	3	6	0
	6	8.15	0.539	11	12	3	9	0
	7	7.32	0.396	14	5	5	5	0
04/10	1	8.11	0.270	21	27	7	11	
	2	7.72	0.258	19	21	4	10	
	3	7.78	0.240	22	17	4	10	
	4	7.74	0.228	27	46	3	9	0
	5	7.77	0.219	21	18	3	9	1
	6	7.84	0.175	22	17	4	9	2
	7	7.71	0.249	20	19	4	9	1
04/14	1	7.80	0.288	58	84	2		
	2	7.78	0.198	34	28	2		0
	3	7.67	0.192	21	18	2		1
	4	7.64	0.180	15	25	5		
	5	7.70	0.180	15	34	2		
	6	7.77	0.156	16	37	2		
	7	7.70	0.191	13	41	2		
05/01	1						10	15
	2						10	11
	3						12	14
	4						8	11
	5						10	11
	6						10	13
	7						8	13

Continued . . .

Table A9. Continued.

1980 Date (m/d)	Stn.	pH @ 20 C	Conduc-tivity mS/cm @ 25 C	Tur-bidity NTU	susp. solids mg/L	BOD mg/L	DO mg/L	Temp. C
05/01	8						7	13
	9						9	11
	10						8	17
06/03	4	7.94	0.315	15	11		9	15
	5	8.02	0.292	15	7		10	15
	9	7.97	0.580	20	25		9	
	10	8.02	0.630	30	68		8	
06/19	2						7	19
	3						8	19
	4						7	17
	5						6	18
	6						9	20
	7						7	20
	9						9	17
06/20	2						9	20
	3						8	20
	4						6	19
	5						7	18
	6						8	18
	7						8	18
	9						9	20
06/23-24	2						7	19
	3						7	19
	4						5	19
	5						6	19
	6						8	21
	7						7	20
	9						11	20
07/01	2						9	18
07/01	3						9	18
07/01	4						8	16
07/01	5						8	17
06/30	6						8	19
06/30	7						7	19
07/01	9						11	17

Continued . . .

Table A9. Continued.

1980 Date (m/d)	Stn.	pH @ 20 C	Conduc-tivity mS/cm @ 25 C	Tur-bidity NTU	susp. solids mg/L	BOD mg/L	DO mg/L	Temp. C
07/10	1						8	18
	2						7	20
	3						8	20
	4						7	20
	5						8	20
	6						7	20
	7						8	20
	8						6	18
	9						9	20
	10						7	16
08/14	4	8.07	0.240	18	7	2	8	16
	5	8.17	0.275	19	11	2	9	16
	9	8.31	0.469	19	18	2	9	18
	10	8.00	0.584	75	92	2	8	19
09/10-11	1						9	10
	2						8	10
	3						9	10
	4						9	10
	5						8	10
	6						9	10
	7						7	11
	8						9	10
	9						9	10
	10						8	8
10/09	4	7.59	0.200	21	4	4	8.0	7
	5	7.65	0.180	19	7	4	7.6	7
	9	7.82	0.410	23	3	4	5.8	8
	10	7.69	0.470	44	12	4	9.0	4
11/12	1						0	13
	2						0	12
	3						1	12
	4						1	11
	5						0	11
	6						0	13
	7						0	10
	8						0	10

Continued . . .

Table A9. Concluded.

1980 Date (m/d)	Stn.	pH @ 20 C	Conductivity mS/cm @ 25 C	turbidity NTU	susp. solids mg/L	BOD mg/L	DO mg/L	Temp. C
11/12	9						0	11
	10						1	10
12/18	4	7.29	0.390	24	26	5		
	5	7.11	0.370	30	20	9		
	9	7.28	1.00	18	24	6		
	10	7.29	1.10	16	28	7		

Table A10. "Short list" analyses of water quality, occasional stations, Muskeg River drainage, 1980

1980 Date (m/d)	Location	pH @ 20 C	Conductivity mS/cm @ 25 C	Turbidity NTU	susp. solids, mg/L	BOD mg/L	D.O. mg/L	Temp. C
03/21	Hartley Cr. 100 m above Muskeg confluence						1	0
	Hartley Cr. 500 m above Muskeg confluence						2	
	Muskeg R. 20 m above Hartley confluence						3	0
	Muskeg R. 20 m below Hartley confluence						2	0
03/22	Muskeg R. off the end of the runway						2	1
	Muskeg R. at Texaco road ford						1	0
03/23	Muskeg R. grid reference VU687437						2	0
04/03	Muskeg R. grid reference VU687437	7.55	0.456	15	9	3	6	0
04/10	Muskeg R. grid reference VU687437	7.82	0.236	22	19	3		
04/14	Muskeg R. grid reference VU687437	7.66	0.198	22	33	2		
	Muskeg R. 50 m below ditch outfall	7.60	0.180	14	62	2		
	minesite ditch outfall	7.70	0.420	247	972	7		
05/31-	minesite ditch outfall			5	26			
06/01	Muskeg R. immediately below outfall			10	88			
	Muskeg R. immediately above outfall			15	6			
06/03	minesite ditch outfall	7.80	0.595	20	36			

APPENDIX B

PERIPHYTIC ALGAE DATA

Table B1 The total density (cells/cm²), biomass and per cent composition of major algal groups (Divisions) collected with Stockner samples (n=3) at stations along the Muskeg River, April-May, 1980.

Division	Station 1			2			3		
	A	B	C	A	B	C	A	B	C
Cyanophyta	44.6	32.6	41.8	79.5	87.0	85.7	45.8	68.8	53.5
Chlorophyta	-	-	0.2	0.7	2.5	0.4	11.0	0.3	1.3
Chrysophyta	-	-	0.2	0.2	-	<0.1	0.3	0.3	-
Bacillariophyta	43.4	52.7	38.9	19.4	10.4	9.2	42.5	30.7	43.9
Euglenophyta	-	-	-	0.1	-	-	-	-	-
Cryptophyta	-	-	-	-	<0.1	-	-	-	1.3
Pyrrophyta	-	-	-	-	-	-	0.3	-	-
Rhodophyta	12.0	14.7	18.9	-	-	4.5	-	-	-
Total density cells/cm²	151,682	198,964	302,021	132,709	457,340	204,130	89,698	231,093	184,652
Total biomass, mg/cm²	0.202	0.432	0.520	0.068	0.098	0.952	0.099	0.152	0.102
No. of species	20	21	29	34	33	28	29	27	21

Table B1. The total density (cells/cm²), biomass and per cent composition of major algal groups (Divisions) collected with Stockner samples (n=3) at stations along the Muskeg River, April-May 1980.

Division	Station 4 A	4 B	4 C	6 A	6 B	6 C
Cyanophyta	48.8	74.6	37.8	7.5	45.2	84.1
Chlorophyta	0.8	2.2	1.2	-	-	0.4
Chrysophyta	0.8	0.3	1.2	-	-	-
Bacillariophyta	48.2	22.8	59.8	92.5	51.2	12.8
Euglenophyta	-	-	-	-	-	-
Cryptophyton	1.5	-	-	-	-	-
Pyrrophyta	-	-	-	-	-	-
Rhodophyta	-	-	-	-	3.6	2.7
Total density cells/cm²	19,549	81.056	37,846	63,474	100,128	133,206
Total biomass mg/cm²	0.017	0.036	0.072	0.232	0.217	0.036
No. of species	22	24	16	14	26	20

Table B2. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) collected with Stockner samplers (N=3) at stations along the Muskeg River, June 1980.

Division	Station 1			2			3		
	A	B	C	A	B	C	A	B	C
Chlorophyta	23.2	23.1	27.1	30.7	17.6	12.5	11.3	13.2	6.5
Cyanophyta	-	-	-	-	-	-	29.8	-	8.6
Chrysophyta	71.4	69.9	61.8	60.4	73.4	77.8	27.0	24.9	12.2
Bacillariophyta	4.1	6.9	9.0	6.1	4.5	2.8	31.9	61.5	71.9
Euglenophyta	-	-	-	-	0.4	-	-	-	0.7
Cryptophyta	1.4	-	2.0	2.8	4.1	6.9	-	0.5	-
Total density cells/cm²	21,780	17,127	19,701	31,588	36,356	21,456	28,059	61,090	41,422
Total biomass, mg/cm²	0.003	0.003	0.007	0.007	0.008	0.003	0.012	0.094	0.044
No. of species	19	17	20	20	23	18	27	45	39

Table B2. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) collected with Stockner samplers (N=3) at stations along the Muskeg River, June 1980.

Division	Station 4 A	4 B	4 C	6 A	6 B	6 C
Chlorophyta	17.6	18.2	0.9	3.5	1.4	2.2
Cyanophyta	29.7	20.5	41.9	11.6	14.3	62.1
Chrysophyta	32.4	7.6	9.5	8.1	10.0	14.6
Bacillariophyta	18.9	53.8	47.6	76.7	73.1	20.9
Euglenophyta	-	-	-	-	1.1	0.2
Cryptophyta	1.4	-	-	-	-	-
Total density cells/cm²	7,326	39,336	15,645	25,628	13,880	79,715
Total biomass mg/cm²	0.003	0.043	0.005	0.043	0.012	0.043
No. of species	23	34	21	29	24	29

Table B3. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) collected with Stockner samplers (n=3) at stations along the Muskeg River, July 1980.

Division	Station 1			Station 2			Station 3		
	A	B	C	A	B	C	A	B	C
Chlorophyta	21.6	14.7	8.4	9.4	3.5	19.0	27.3	29.2	11.7
Cyanophyta	18.2	36.4	81.5	33.0	81.2	41.8	6.1	2.2	26.4
Chrysophyta	-	-	-	3.5	-	-	6.1	2.2	2.5
Bacillariophyta	50.0	48.8	9.2	31.7	15.4	18.4	51.5	61.8	57.7
Euglenophyta	-	-	-	1.2	-	-	-	-	-
Cryptophyta	10.4	-	0.8	21.2	-	20.9	9.1	4.5	1.8
Total density, cells/cm²	2,574	1,743	7,395	8,438	51,405	23,542	19,668	17,711	48,574
Total biomass mg/cm²	0.001	0.001	0.001	0.006	0.009	0.012	0.018	0.030	0.046
No. of species	20	13	15	29	28	27	26	34	29

Table B3. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) collected with Stockner samplers (n=3) at stations along the Muskeg River, July 1980.

Division	Station 4 A	4 B	4 C	6 A	6 B	6 C
Chlorophyta	32.3	29.3	8.5	2.5	22.9	1.4
Cyanophyta	16.9	5.3	68.2	38.0	63.5	90.9
Chrysophyta	1.6	4.0	0.3	17.4	4.2	1.4
Bacillariophyta	48.4	61.3	23.0	38.0	7.7	6.0
Euglenophyta	0.8	-	-	2.5	0.2	0.2
Cryptophyta	-	-	-	1.7	1.5	<0.1
Total density, cells/cm²	24,676	22,350	94,764	24,079	205,024	353,726
Total biomass mg/cm²	0.020	0.115	0.023	0.031	0.258	0.076
No. of species	24	29	19	29	31	32

Table B4. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) collected with Stockner samplers (n=3) at stations along the Muskeg River, August 1980.

Division	Station 1 A	1 B	1 C	2 A	2 B	2 C	3 A	3 B	3 C	4 A
Chlorophyta		4.8	0.9	5.0	11.8	25.0	4.3	7.8	8.8	-
Cyanophyta		73.3	80.9	4.2	35.6	50.7	26.1	23.4	42.5	72.4
Chrysophyta	15.4	1.2	4.6	0.2	-	-	-	2.1	-	-
Bacillariophyta	76.8	19.4	13.5	90.4	52.6	24.3	69.6	66.7	48.7	27.6
Euglenophyta	-	-	-	0.2	-	-	-	-	-	-
Cryptophyta	7.7	1.2	-	-	-	-	-	-	-	-
Rhodophyta	-	-	-	-	-	-	-	-	-	-
Total density, cells/cm²	518	1,646	4,259	311,708	62,878	44,104	10,281	21,009	33,674	4,666
Total biomass, mg/cm²	0.001	<0.001	<0.001	0.188	0.060	0.048	0.017	0.029	0.040	0.002
No. of species	10	13	19	42	31	32	20	32	26	10

Table B4. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) collected with Stockner samplers (n=3) at stations along the Muskeg River, August 1980.

Division	Station 4 B	4 C	5 A	5 B	5 C	6 A	6 B	6 C	8 A	8 B
Chlorophyta	1.6	12.5	10.9	38.5	6.2	1.6	0.6	2.4	12.3	4.3
Cyanophyta	41.9	34.7	38.2	9.2	46.2	80.4	91.7	89.1	-	25.7
Chrysophyta	-	-	1.8	3.1	-	-	-	-	-	-
Bacillariophyta	56.5	53.1	45.5	49.2	46.2	18.0	7.0	8.5	87.7	70.0
Euglenophyta	-	-	1.8	-	1.5	-	-	-	-	-
Cryptophyta	-	-	1.8	-	-	-	-	-	-	-
Rhodophyta	-	-	-	-	-	-	0.6	-	-	-
Total density, cells/cm2	18,476	7,301	16,390	9,685	9,685	24,825	93,274	49,021	3,835	10,430
Total biomass, mg/cm²	0.023	0.005	0.066	0.013	0.049	0.014	0.019	0.017	0.013	0.030
No. of species	21	17	21	27	24	14	24	24	24	21

Table B5. The total density (cells/cm2), represented as per cent composition, of major algal groups (Divisions) collected with Stockner samples (n=3) at stations along the Muskeg River, October 1980.

Division	Station 1 A	1 B	1 C	2 A	2 B	2 C
Chlorophyta	11.0	-	7.7	27.4	20.3	-
Cyanophyta	56.7	58.3	85.5	65.3	48.1	-
Chrysophyta	-	-	-	-	-	15.4
Bacillariophyta	32.3	41.7	6.8	7.3	31.6	77.0
Euglenophyta	-	-	-	-	-	-
Cryptophyta	-	-	-	-	-	7.7
Total density, cells/cm²	44,700	17,880	23,234	12,313	7,844	768
Total biomass mg/cm²	0.027	0.008	0.011	0.012	0.009	0.001
No. of species	23	9	10	9	9	11

Table B6. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) colonizing slides (n=1) at stations along the Muskeg River, June 1980

Division	Station 1	2	3	4	5	7	8
Chlorophyta	0.7	11.3	6.2	10.1	4.9	2.9	6.6
Cyanophyta	6.4	16.5	53.3	3.6	-	-	24.9
Chrysophyta	2.1	6.7	3.5	6.5	6.9	16.0	10.8
Bacillariophyta	90.7	65.2	36.0	79.8	88.2	80.1	57.8
Euglenophyta	-	-	-	-	-	-	0.5
Cryptophyta	-	0.3	1.0	-	-	1.0	-
Total density cells/cm²	135,762	33,128	69,938	17,187	24,846	31,106	103,092
Total biomass mg/cm²	0.153	0.025	0.188	0.019	0.046	0.028	0.074
No. of species	16	40	37	42	35	30	28

Table B7. The total density (cells/cm²), represented as per cent composition of major algal groups (Divisions) colonizing slides at stations along the Muskeg River, July 1980.

Division	Station 1		4			5			7
	A	B	A	B	C	A	B	C	A
Chlorophyta	2.7	-	0.2	1.8	8.6	11.4	14.6	5.8	1.2
Cyanophyta									10.5
Chrysophyta						3.2	2.3	1.5	0.1
Bacillariophyta	97.3	100.0	99.8	98.2	91.4	85.3	83.1	92.8	88.2
Euglenophyta									
Cryptophyta									
Total density, cells/cm²	98,318	68,670	89,598	120,118	158,922	6,649	14,170	15,042	83,167
Total biomass, mg/cm²	0.116	0.081	0.108	0.140	0.171	0.006	0.010	0.010	0.087
No. of species	6	6	14	16	16	17	13	8	15

Table B8. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) colonizing slides (n=1) at stations along the Muskeg River, August 1980.

Division	Station 1	2	3	4	5	7	8
Chlorophyta	2.2	6.0	4.4	2.1	8.7	1.8	0.5
Cyanophyta	10.7	14.2	-	1.5	-	15.7	34.9
Chrysophyta	-	-	-	1.9		-	
Bacillariophyta	87.0	79.8	95.6	94.5	91.3	82.4	64.1
Euglenophyta	-	-	-	-	-	-	0.5
Total density, cells/cm²	155,543	153,472	44,690	57,116	13,843	34,662	43,164
Total biomass, mg/cm²	0.154	0.203	0.074	0.074	0.054	0.043	0.042
No. of species	15	31	18	19	29	25	30

Table B9. The total density (cells/cm²), represented as per cent composition, of major algal groups (Divisions) colonizing slides along the Muskeg River, October, 1980

	Station									
	5			5			7	8		
Division	A	B	C	A	B	C	A	A	B	C
Chlorophyta			3.0							
Cyanophyta	55.1						14.2	7.5	28.6	10.3
Chrysophyta										
Bacillariophyta	42.9	100.0	97.0	100.0	100.0	100.0	85.8	92.5	71.4	89.7
Euglenophyta	2.0									
Cryptophyta										
Total density cells/cm²	9,751	4,796	6,567	13,734	38,805	22,345	30,845	140,640	75,428	25,506
Total biomass mg/cm²	0.006	0.007	0.018	0.016	0.053	0.027	0.025	0.093	0.042	0.018
No. of species	11	20	13	16	12	14	12	15	18	16

APPENDIX C

Upper left: 20 m above minesite drainage main discharge site, looking downstream, 22 March 1980.

Upper right: main discharge point, minesite drainage ditch, 22 March 1980.

Lower left: Station 3, looking downstream 24 March 1980. Water on the ice flowed out of the hole drilled for sampling.

Upper left: Station 1, looking downstream, 12 October 1980.

Upper right: Station 2, looking downstream from ford, 8 October 1980.

Lower left: Station 3, looking downstream, 13 October 1980.

Lower right: Station 4, looking upstream, 9 October 1980.

Upper left: Station 5, looking upstream, 10 October 1980.

Upper right: Station 6, looking upstream, 12 October 1980.

Lower left: Station 7, looking downstream, 11 October 1980.

Lower right: Station 8, looking downstream, 11 October 1980.

Left: Station 9, 5 m below culvert from settling pond, looking downstream.

Right: Station 10, 10 m upstream of outlet culvert, looking upstream.