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

VOLUME I

Review of Available Data on the Muskeg River

Prepared For

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	and	
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ABSTRACT

The available literature on the Muskeg River and its tributaries was critically reviewed as a background for monitoring studies conducted on the river in 1980. The review indicated that the literature provides a basic description of the ecology of selected streams within the Muskeg River basin. The description, particularly the water quality and periphyton portions, suffers from certain inconsistencies in the data both within and among studies, and from unresolved disagreements in interpretation among investigators. Baseline data available on hydrology, benthic invertebrates, plankton and fish are generally useful, but additional information is desireable on streamflow near the Alsands site, the benthic fauna of soft substrates (particularly chironomids), specific areas of critical habitat for fish, and the numbers of Arctic grayling using the river.

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INTRODUCTION

Alsands Energy Limited intends to mine tar sands from a large area in the Muskeg River drainage. In preparation for strip mining, Alsands removed the forest from the mine and plant sites, trenching these areas to drain the muskeg. Water from the plant site was drained westward into the forest; water from the minesite was drained into the Muskeg River (Figure 1).

As a condition of its permit to construct the muskeg the drainage system, Alberta Environment required Alsands to conduct a monitoring program to assess:

1. "the quality of water being discharged";
2. "the impact of muskeg drainage on vegetation and wildlife habitat of the receiving waterbodies"; and
3. "the impact on aquatic habitat in the receiving stream course".

Alberta Fish and Wildlife were specifically concerned that dissolved oxygen, biochemical oxygen demand, suspended solids and pH be monitored in the Muskeg River. Subsequently, the Research Management Division (RMD) of Alberta Environment initiated a jointly-funded project with Alsands to:

1. summarize the results of Alsands' monitoring

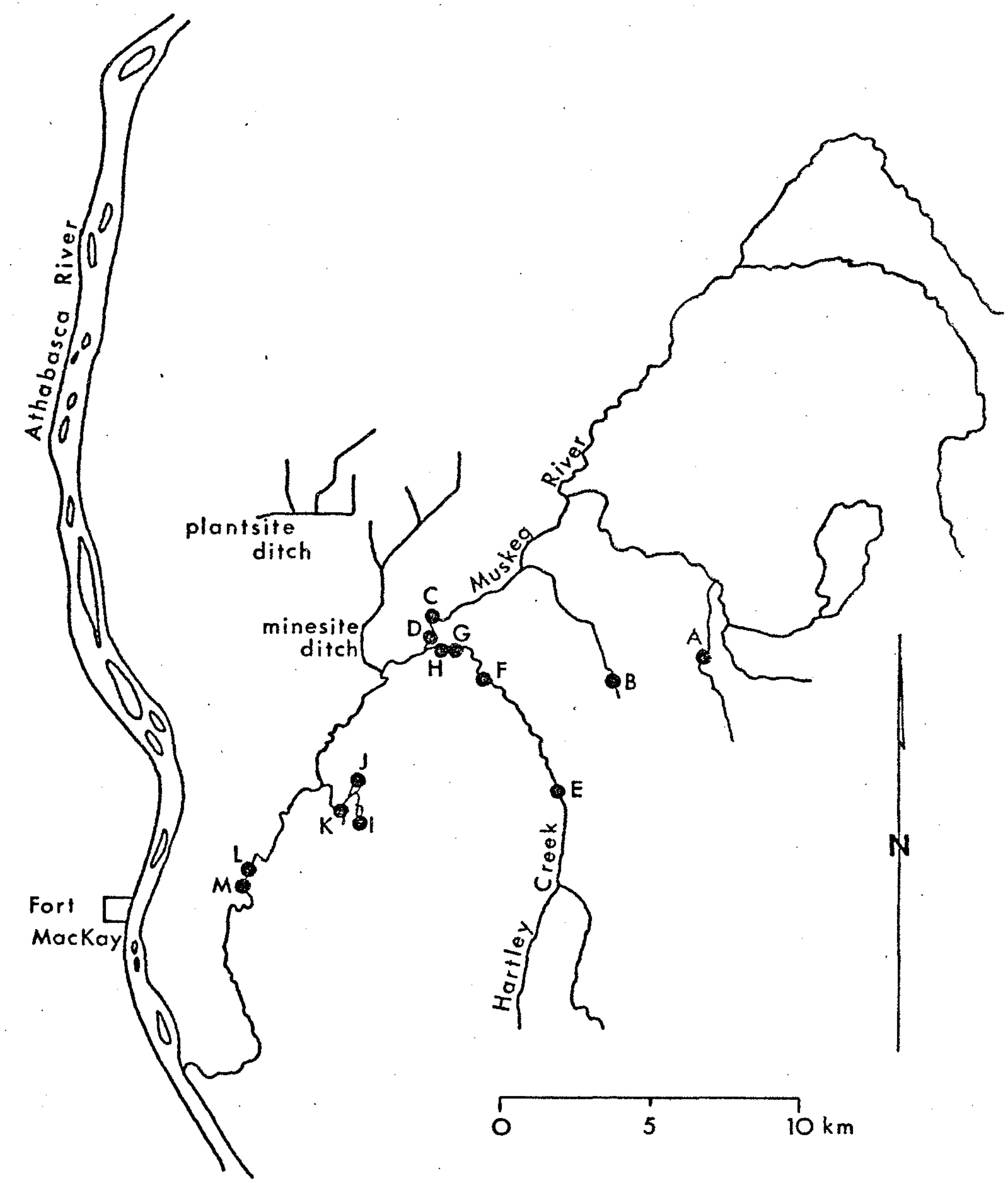

FIGURE 1. The study area, showing sampling stations mentioned in the text.

program;

2. present a general rationale of, and recommendations for, similar monitoring programs that may be operated in future in the Tar Sands area, based on Alsands' experiences with its monitoring program; and
3. provide basic data on fish life history, distribution and movements in the fall and early winter periods in the Muskeg River.

The studies reported here were designed to meet the above six objectives.

This volume (Volume I) critically reviews the publicly available literature on watercourses in the Muskeg basin as background to the monitoring studies, and to meet the requirements of Alberta Environment as outlined in the terms of reference of the Alberta Environment-Alsands Energy Limited joint study agreement. Other limited-distribution literature was included if it was at hand. Because the monitoring study was primarily biological, studies of stream biology were emphasized in the review.

HYDROLOGY

Data Sources

The principal sources of hydrological data on the Muskeg River are the Water Survey of Canada gauging stations 11 km upstream of the Athabasca confluence, and on Hartley Creek 0.4 km above the Muskeg confluence. The former station was installed in 1974, the latter in 1975. Summary data from these stations were provided by the Inland Waters Directorate (1977, 1978, 1979, 1980, in prep.), Loeppky and Spitzer (1977), and Warner and Spitzer (1979). Additional data and a detailed hydrological analysis of the Muskeg River are reported by Akena and Froelich (1979). Schwartz (1979, 1980) conducted a detailed hydrogeochemical study in the basin to determine sources of flow to the Muskeg River, and Neill and Evans (1979) included Muskeg River data in a regional study of surface water hydrology. Selected summary hydrological data on the river have also been reported by Shell (1975), Alsands (1978) and Walder et al (1980). Campbell (1980) monitored drainage flows from Alsands' cleared development area, and Delamore (1981) assessed theoretically the effects of clearing and ditching at the Alsands site on runoff and snowmelt from the area.

Drainage Basin and Channel Features

The Muskeg River originates in uplands east of the Alsands lease, and flows approximately 90 km to the Athabasca River. The total drainage area is 1456 km^2, approximately 25% (368 km^2) of which is drained by Hartley Creek, the principal tributary (Inland Waters Directorate 1977).

The Muskeg River proper flows almost entirely over outwash sand deposits, but most of its tributaries, including Hartley Creek, drain ground moraine to the east (Bayrock 1971, as modified by Schwartz 1979:20). Much of the drainage basin is wetland, mostly muskeg and fens, comprising 70% of the total area in the case of the Alsands study area (Alsands 1978:149). Drainage from muskeg contributes more than 50% to the streamflow in the Muskeg River (Schwartz 1980).

The upper 35 km and the lower 12 km of the Muskeg River have a moderate to steep gradient, but the central segment is nearly flat, averaging about 0.04% grade (Alsands 1978:272). The lower segment of Hartley Creek has a moderate average gradient of 0.21% (Alsands 1978:273).

The channel of the low-gradient central segment of the Muskeg River is strongly meandering, frequently dammed by beavers, and moderately deep, commonly exceeding 2m during high flow periods. The bottom is predominantly sand and silt with large boulders, logs, sticks and detritus common in some sections. Rubble and riffle areas are scarce. Willows and grasses crowd the banks, the former overhanging extensively along much of the reach. The lower moderate to steep segment of the river has more frequent sections of riffles and rapids. The substrates in such sections are gravel, cobble and boulder (Walder et al 1980). The lower end of Hartley Creek is sandy or silt-bottomed with occasional riffles. Willows overhang the creek at many points.

Streamflow

The mean annual hydrograph for the Muskeg River for the period of record (1974-1979), and the 1980 hydrograph, are plotted in Figure 2. Typically, winter flows reach a minimum in March, and are mainly groundwater discharge (Schwartz 1980). Spring runoff peaks in May, and drainage of muskeg contributes most of the moderate flow observed in June through August (Schwartz 1980). Flows commonly increase again in September and October. Low winter flows are reached again by December.

In 1980, runoff in the Muskeg River differed substantially from the normal pattern. Winter flows through March were similar to the six-year average, but spring runoff and streamflows through July were far below average. In contrast, September streamflows were well above the mean for the previous

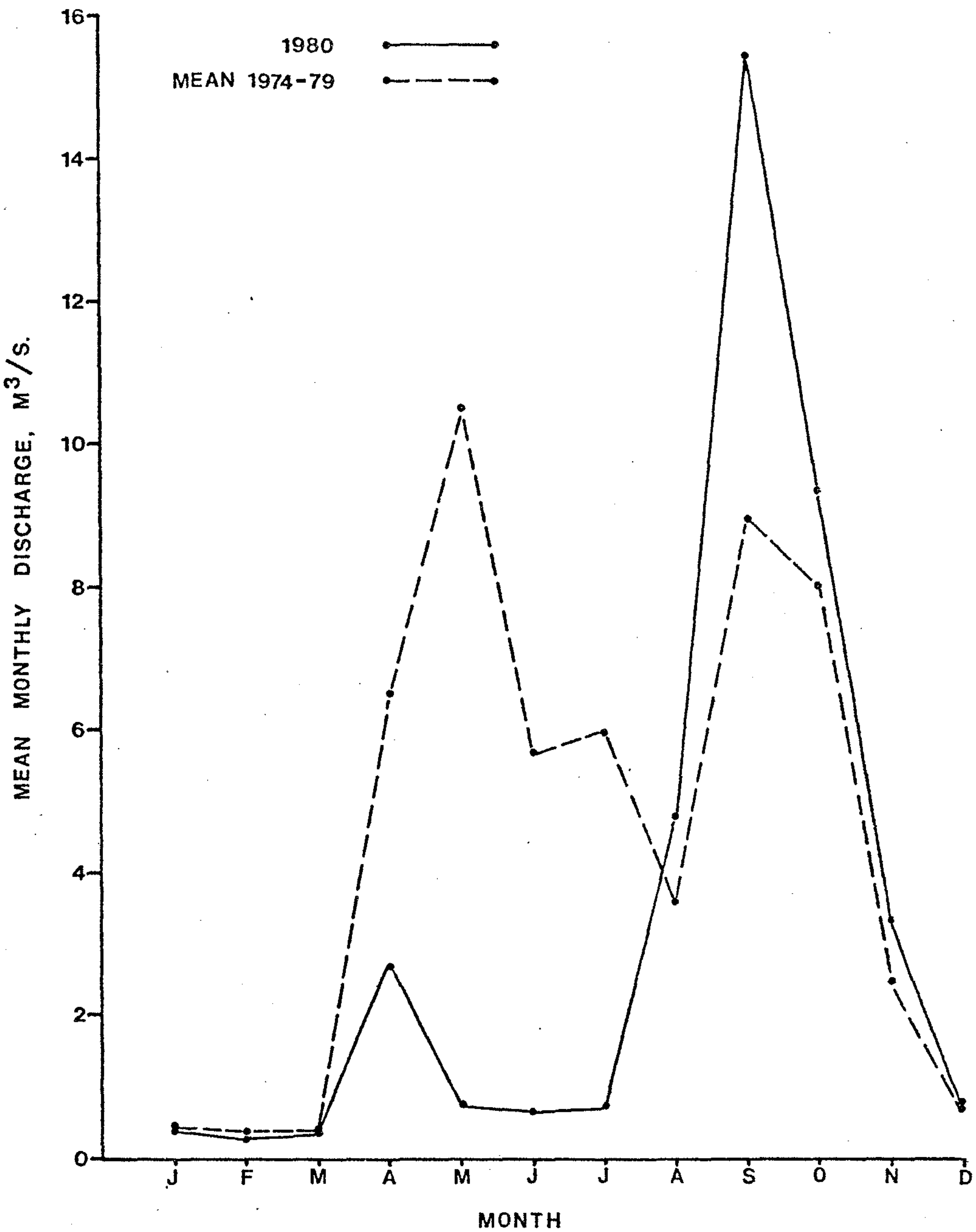

Figure 2. Annual hydrographs for 1980 (solid line) and the mean for the previous six years (broken line) at Muskeg River gauging station 07DA008. The 1980 data are advance information subject to correction. Data from Inland Waters Directorate (1977, 1978, 1979, 1980 in preparation).

six years.

Contributions to Muskeg River flows from the drainage program at the Alsands site were studied by Campbell (1980) and are summarized in Table 1. Estimated discharges to the river were usually in the order of 0.1 to 0.2 m^3/s, but on April 12 a ditch wall failed, causing a sudden flood discharge of heavily-silted water from a small lake into the Muskeg River. An estimated 28,000 m^3 of water entered the river over a period of approximately 4.5 hours, a mean discharge of approximately 1.7 m^3/s. The peak instantaneous flow, however, was estimated to be 21.7 m^3/s, a quantity comparable to the maximum instantaneous discharge for 1980 of 18.8 m^3/s recorded at the stream gauging station on the Muskeg River, September 23 (Inland Waters Directorate, in prep.).

Delamore (1981, see Appendix A, this report), on the basis of theoretical considerations, concluded that clearing and ditching of the Alsands 5-year minesite would have increased rainfall runoff from the area by about 20%. Because the 5-year minesite comprises far less than 1% of the Muskeg River drainage basin area, the impact of only a 20% increase in runoff should have had an insignificant impact on runoff in the area. Delamore (1981) was unable to estimate the effect of clearing and ditching on snowmelt runoff because pre- and post clearing snowpack data were unavailable.

Table 1 Summary of results of the drainage ditch flow monitoring program for 1980 at the Alsands site (Campbell 1980).

DATE OF MEASUREMENT	PLANT SITE (m^3/sec)		5-YEAR MINE SITE (m^3/sec)	
February 9	3.8×10^{-3}	Estimated	7.5×10^{-3}	Estimated
February 23	2.2×10^{-2}	Estimated	2.2×10^{-2}	Estimated
March 8	2.2×10^{-2}	Estimated	2.2×10^{-2}	Estimated
March 22	2.2×10^{-2}	Estimated	7.5×10^{-2}	Estimated
March 29	2.2×10^{-2}	Estimated	7.6×10^{-2}	Estimated
April 7	2.2×10^{-2}	Estimated	5.10×10^{-2}	*
April 11	2.2×10^{-2}	Estimated	2.11×10^{-1}	* Instantaneous discharge
April 17	1.67×10^{-1}	*	6.30×10^{-1}	* of 2.13×10^{1} m^3/sec
April 21	2.03×10^{-1}	*	2.04×10^{-1}	* April 12
April 28	1.67×10^{-1}	*	2.89×10^{-1}	*
May 6	7.50×10^{-2}	*	No measurement due to low flow	
May 12	-		-	
May 23	1.50×10^{-1}	*	No flow	
May 29	1.50×10^{-1}	*	4.0×10^{0}	Estimated
June 6	1.61×10^{-1}	*	1.0×10^{-1}	Flow too low to measure
June 17	1.48×10^{-1}	*	1.0×10^{-1}	Estimated Flow too low to measure
June 22	1.16×10^{-1}	*	1.0×10^{-1}	Estimated Flow too low to measure
June 27	8.58×10^{-2}	*	1.0×10^{-1}	Estimated Flow too low to measure
July 6	1.13×10^{-1}	*	1.0×10^{-1}	Estimated Flow too low to measure
July 13	1.10×10^{-1}	*	1.0×10^{-1}	Estimated Flow too low to measure
July 25	1.09×10^{-1}	*	1.0×10^{-1}	Estimated Flow too low to measure
August 5	4.48×10^{-1}	*	2.0×10^{-1}	Estimated Flow too low to measure
August 15	3.12×10^{-1}	*	2.0×10^{-1}	Estimated Flow too low to measure
August 26	2.61×10^{-1}	*	1.5×10^{-1}	Estimated Flow too low to measure
September 4	1.62×10^{-1}	*	1.4×10^{-1}	Estimated Flow too low to measure
September 22	2.40×10^{-1}	*	1.4×10^{-1}	Estimated
October 2	1.60×10^{-1}	*	2.0×10^{-1}	Estimated
October 28	2.73×10^{-1}	*	8.3×10^{-2}	Estimated

* Velocity measurement with bucket wheel flow meter

WATER QUALITY

Data Sources and Summary Data

The principal studies of surface water quality in the Muskeg River basin were made by Akena (1979) and Schwartz (1979, 1980). Akena and Froelich (1979) provided additional water quality information not covered by Akena (1979). Shell (1975) sampled five locations between 1973 and 1975, and Campbell (1980) monitored suspended solids in the ditches draining the Alsands site in 1980. Crowther (1979) and Hickman et al (1979) studied selected water quality parameters in Hartley Creek and the Muskeg River, respectively. Lutz and Hendzel (1976) reported baseline concentrations of metals in sediments for a station near the mouth of the Muskeg River.

Tables 2 and 3 present observed maxima and minima of numerous water quality parameters in the Muskeg River and Hartley Creek for the period July 1976 to October 1977, illustrating the approximate range of values naturally found in these waters. Data for stations elsewhere in the Muskeg drainage basin are presented in Tables 4 and 5.

Table 2 Analyses of Muskeg River water, Station M, July 1976 to October 1977. Units are mg/L unless specified otherwise. Station location as in Figure 1. Number of samples, 15. AOSERP survey data.

PARAMETER	MINIMUM	MAXIMUM
Calcium	16.5	82.0
Magnesium	4.5	18.5
Sodium	4.9	38.5
Potassium	0.5	2.6
Chloride	1.7	29.7
Sulphate	0.1	9.5
Total Alkalinity (as $CaCO_3$)	64.6	577.0
pH (units)	7.3	8.2
Carbonate	0	0
Bicarbonate	78.7	352.3
Total Hardness (as $CaCO_3$)	59.7	280.9
Fluoride	0.06	0.14
Silica	2.2	25
Conductivity @ 25°C (μS/cm)	126	520
Threshold Odour No.	2	16
Colour	20	110
Tannin & Lignin	0.8	1.7
Total Filtrable Residue	80	365
Total Filtrable Residue Fixed	68	308
Total Non-Filtrable Residue	<0.4	10.0
Total Non-Filtrable Residue Fixed	<0.4	6.0
Turbidity (JTU)	0.65	17.0
Surfactants	<0.02	0.14
Humic Acids	<1	9
Total Organic Carbon	8	35
Total Inorganic Carbon	10	61
Total Dissolved Organic Carbon	7	34
Nitrite + Nitrate Nitrogen	0.003	0.31
Ammonia Nitrogen	<0.01	0.57
Total Kjeldahl Nitrogen	0.35	1.66
Total Phosphorus	0.017	0.09
Phenols	<0.003	0.02
Orthophosphate P	<0.001	0.018
Oil & Grease	<0.1	3.5
Sulphide	<0.05	<0.05
Cyanide	<0.01	<0.01
Chlorophyll *a*	<0.001	0.003
Chemical Oxygen Demand (COD)	34	88.4

Continued....

Table 2 (Continued)

PARAMETER	MINIMUM	MAXIMUM
Cadmium	<0.001	<0.001
Hexavalent Chromium	<0.003	0.003
Copper	<0.001	0.026
Iron	0.45	3.85
Lead	<0.002	0.021
Manganese	0.015	0.97
Silver	<0.001	0.005
Zinc	0.002	0.091
Vanadium	<0.001	<0.001
Selenium	<0.0002	0.0009
Mercury	<0.0001	0.0004
Arsenic	<0.0002	0.012
Nickel	<0.001	0.010
Aluminum	<0.01	0.22
Cobalt	<0.002	0.006
Boron	0.10	0.26

Table 3 Analyses of Hartley Creek water, Station H, July 1976 to October 1977. Units are mg/L unless specified otherwise. Station location as in Figure 1. Number of Samples, 17. AOSERP survey data.

PARAMETER	MINIMUM	MAXIMUM
Calcium	11.5	91
Magnesium	3.5	21.8
Sodium	5.5	30
Potassium	0.20	2.5
Chloride	1	17
Sulphate	0.1	12.5
Total Alkalinity (as $CaCO_3$)	46.4	348.2
pH (units)	7.2	8.2
Carbonate	0	0
Bicarbonate	56.6	424.5
Total Hardness (as $CaCO_3$)	43.1	317
Fluoride	0.05	0.24
Silica	1.7	16.8
Conductivity @ 25°C (μS/cm)	105	660
Threshold Odour No. (T.O.N.)	2	4
Colour (APHA)	30	130
Tannin & Lignin	0.85	2.4
Total Filtrable Residue	11.7	420
Total Filtrable Residue Fixed	49	383
Total Non-Filtrable Residue	0.4	459
Total Non-Filtrable Residue Fixed	<0.4	400
Turbidity (J.T.U.)	0.9	320
Surfactants	<0.02	0.13
Humic Acids	<1	18
Total Organic Carbon	9	36
Total Inorganic Carbon	9	57
Total Dissolved Organic Carbon	8	34
Ammonia Nitrogen	0.01	0.29
Total Kjeldahl Nitrogen	0.35	2.25
Total Phosphorus	<0.005	0.33
Orthophosphate P	<0.005	0.02
Phenols	<0.001	0.022
Oil & Grease	<0.1	1.9
Sulphide	<0.05	<0.05
Cyanide	<0.01	<0.01
Chlorophyll *a*	<0.001	<0.001
Nitrite + Nitrate N	<0.01	0.05

Continued....

Table 3 (Continued)

PARAMETER	MINIMUM	MAXIMUM
Chemical Oxygen Demand	40	107
Cadmium	<0.001	<0.001
Hexavalent Chromium	<0.003	0.005
Copper	<0.001	0.028
Iron	<0.43	4.95
Lead	<0.002	<0.002
Manganese	0.009	0.42
Silver	<0.001	0.002
Zinc	0.002	0.048
Vanadium	<0.001	<0.001
Selenium	<0.0005	0.0007
Mercury	<0.0001	0.0007
Arsenic	<0.0005	0.0026
Nickel	<0.002	0.004
Aluminum	<0.01	0.45
Cobalt	<0.001	<0.002
Boron	0.01	0.48

Table 4 Muskeg River water analyses, various locations, 1972 to 1975. Units are mg/L unless specified otherwise. Sampling locations as in Figure 1. Data from Shell (1975).

	Location									
Station	**	B	A	D	D	L	C	C	C	C
Date	8/72	4/73	4/73	4/73	10/73	2/74	5/74	7/74	10/74	2/75
<u>Physical Analysis</u>										
Temperature, C	15.0				0.6	0.0	3.3	16.1	4.4	1.1
Colour (Cl-pt)					130	65	90	115	100	40
Conductivity @ 25C, µS/cm	375				220		162	237	369	530
Suspended Solids				7	3	6	3	3	4	10
Total Solids				162		482	144	230	270	362
Turbidity (JTU)	3				3	<25	<25	2	5	23
<u>Chemical Analysis</u>										
pH (units)	8.3	7.0	7.5	7.6	7.9	7.5	7.6	7.5	7.9	8.2
Total Hardness (as $CaCO_3$)	180	40	50		145	271	84	126	179	268
Calcium	57					74	24	42	52	78
Magnesium	8					21	6	5	12	18
Sodium and Potassium	15				14	16	6	19	13	18
Bicarbonate						350	104	159	235	354
Carbonate						0	0	0	0	0
Chloride	2				1	8	6	22	7	10
Hydroxide						0	0	0	0	0
Sulphate	20					7	5	5	4	7
Total Dissolved Solids				155	243	476	151	252	323	487
Alkalinity (as $CaCO_3$)	176	60	60		150	287	85	130	192	290
Silica (as Si)						7	3	4	5	5
Organics (oil and grease)				2	3	<1	2	2	<1	2
Organic Carbon					33	26	17	30	30	
Dissolved Oxygen	8.0				11.9	6.0	5.1	8.8	9.2	3.5
Phenols (mg/L)				<2	<2	<2	<2	<2	<2	<2
Sulphides				<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01
Total Phosphate	0.2	nil	0.03	0.4	<0.05	0.2	0.2	<0.1	<0.1	0.2
Ammonia Nitrogen	0.7			1.3		1.6	0.5	0.7	0.5	1.5
Nitrate Nitrogen	<0.1					0.3	0.7	0.1	0.4	0.4
Organic Nitrogen				1	0.9		2	9	<1	<1
Chemical Oxygen Demand (COD)				57	44	67	61	53	46	50
Biochemical Oxygen Demand (BOD)				2	<1	4	2	0	1	1

** Alberta Department of Lands and Forests, Fish and Wildlife Division, Lab Sample No. 6493, Lower Muskeg River, August 24, 1972.

Table 5 Hartley Creek water analyses, various locations, 1972 to 1975. Units are mg/L unless specified otherwise. Sampling locations as in Figure 1. Data from Shell (1975).

	Location						
Station	E	F	E	G	G	G	G
Date	4/73	10/73	4/74	5/74	7/74	10/74	2/75
Physical Analysis							
Temperature, C		0.0	0.0	2.8	15.6	4.4	1.1
Colour (Cl-Pt)		130	60	100	125	95	40
Conductivity @ 25 C, µS/cm		160		116	184	238	588
Suspended Solids	4	2	9	9	5	4	8
Total Solids (Calculated)	134		560	113	180	281	544
Turbidity (JTU)		3	<25	<25	3	3	11
Chemical Analysis							
pH (units)	7.6	8.0	8.1	7.3	7.5	8.0	8.2
Total Hardness (as $CaCO_3$)		90	299	60	98	104	275
Calcium			82	19	31	27	79
Magnesium			3	3	5	9	19
Sodium and Potassium		13.6	25	4	8	16	32
Bicarbonate			404	67	116	149	381
Carbonate			0	0	0	0	0
Chloride		1	12	5	11	8	8
Hydroxide			0	0	0	0	0
Sulphate			5	6	4	5	7
Total Dissolved Solids	130	210	551	104	175	214	536
Alkalinity (as $CaCO_3$)		105	331	55	95	122	312
Silica (as Si)			8	2	3	3	5
Organics (oil & grease)	1	3	<1	<1	2	<1	1
Organic Carbon		29	26	<1	30	32	27
Dissolved Oxygen		13.5	6.8	5.7	9.2		4.4
Phenols (mg/L)	<2	<2	<2	<2	<2	<2	<2
Sulphides	<0.01	<0.05	<0.01	<0.01	<0.01	<0.01	<0.01
Total Phosphate	0.02	<0.05	0.4	0.1	<0.1	<0.1	0.3
Ammonia Nitrogen	0.94		1.6	0.5	0.9	0.9	0.9
Nitrate Nitrogen			0.8	0.6	0.3	0.2	0.7
Organic Nitrogen	1	0.84		3	17	<1	<1
Chemical Oxygen Demand (COD)	59	52	65	44	55	63	39
Biochemical Oxygen Demand (BOD)	2	<1	4	1	1	1	2

Water Temperature

Water temperature data for the Muskeg River and Hartley Creek at the gauging stations have been summarized by Akena (1979). Temperatures remain at 0°C under ice cover from November to March and, in the Muskeg River, can reach 20°C in June or July. Hartley Creek at the gauging station is usually somewhat cooler in summer, reaching a maximum of only about 17°C; however warmer temperatures have been recorded further upstream (Crowther 1979).

Colour

Colour in Hartley Creek water at the gauging station does not show a clearly consistent seasonal variation (Akena 1979). During the winters of 1976-1977 and 1977-1978, the lowest colour values (approximately 30 to 50 units) were observed from late December to early April, and from late March to mid-June, respectively. The highest values (90 to 130 units) were observed from late June to late December 1977. As shown in Table 2, the range in colour values is slightly lower in the Muskeg River at the gauging station.

Dissolved Oxygen

Akena (1979) recorded no consistent seasonal trends in percentage saturation of dissolved oxygen in waters of the Muskeg River basin, but did not sample in winter. Minima approaching 50% saturation, and supersaturation maxima of more than 110%, were observed at various times at the gauging stations on Hartley Creek and the Muskeg River. Late April to early May values elsewhere in the basin varied widely (27 to 105%).

Suspended Solids and Turbidity

Akena and Froelich (1979) conducted a detailed study of suspended sediments in the Muskeg River and Hartley Creek in 1976 and 1977. Concentrations were greatest during the spring freshet in April, reaching 40 mg/L in the Muskeg River at the gauging station, and 40 to near 60 mg/L in Hartley Creek at the gauging station. Concentrations at both stations were nearly always well below 10 mg/L from May to November. Winter measurements were not made.

The results of Campbell's (1980) suspended sediments monitoring program at the Alsands site are summarized in Table 6. Water entering the Muskeg River from the minesite drainage ditch carried a high suspended solids load (relative to that typical

Table 6 Total suspended solids (mg/L) in waters in the plantsite and five-year minesite drainage ditches (Campbell 1980).

DATE	PLANT SITE OUTFALL AREA	MINE SITE OUTFALL AREA
February 9	299	351
February 23	413	390
March 8	308	417
March 24	307	274
April 13	-	5,100
April 17	488	548
May 6	39	89
May 23	121	No flow
June 13	65	42
June 27	42	14
July 11	40	8
July 25	67	No sample taken
August 25	18	4
September 4	29	8
September 22	No sample taken	
October 2	18	2
October 28	22	4

of natural watercourses) from February to April. The extremely high value for April 13 is due to the flood arising from the drainage ditch failure April 12, described under Hydrology. A retention pond constructed from late April to mid-May reduced suspended sediment loads substantially thereafter.

Akena (1979) found that turbidity tended to be highest during periods of high runoff in the Muskeg River and Hartley Creek, but was also high in winter, when the streams were at or near base flow. He suggested, however, that the high winter values could have been artifacts of the sampling procedure necessary during the period of ice cover, which could have disturbed the bottom sediments. The highest values he reported for the open-water season (17 JTU, Muskeg River; 25 JTU, Hartley Creek) are not particularly high for muskeg streams (eg; Clifford 1978).

Turbidity and suspended solids are not measures of the same thing, and are not necessarily closely correlated. Turbidity is a measure of the ability of water to transmit light, and is influenced by suspended organic and inorganic particles, colloids, and water colour. Suspended sediments (commonly measured as total fixed nonfilterable residue) is a measure by weight only of suspended inorganic particulate matter (APHA 1975). As Akena and Froelich (1979) noted, these differences account, in part, for their inability to predict suspended sediment concentrations from turbidity measurements in waters of the Muskeg basin.

Conductivity, Alkalinity, Hardness and Major Ions

Akena (1979) and Schwartz (1979, 1980) showed that the concentrations of most major ions were negatively correlated with discharge, undoubtedly as a result of simple dilution. Maximum concentrations were found in winter at base flow, and minimum concentrations occurred during high runoff events, usually in spring. Parameters showing this seasonal pattern were calcium, magnesium, bicarbonate, sodium, chloride and conductivity. Hardness and alkalinity, measures of alkaline earth metals (mainly Ca and Mg) and carbonates (mainly HCO_3), respectively, would show a similar seasonal pattern.

Two other major ions, sulphate and potassium, failed to show the seasonal pattern just outlined. Akena (1979) suggested that a combination of anaerobic sulphate reduction by bacteria, and the formation of insoluble ion pairs or metal complexing was responsible for the variable sulphate concentrations observed. Schwartz (1979:29), however, suggested the variability in sulphate concentrations was the result of poor laboratory determinations possibly caused by high concentrations of organic materials, and considered the data to be unreliable.

Potassium concentrations tended to be high in winter in the Muskeg River and Hartley Creek, but remained high even during the spring runoff, and reached minimum values in mid-summer (Akena 1979, Schwartz 1980). Akena (1979) suggested that uptake of potassium by plants in the drainage basin accounted for the low concentrations in summer, and that release of potassium from decomposing plants produced the higher concentrations observed in winter and spring. Schwartz (1979, 1980) suggested that surface runoff was the chief contributor of potassium to the streams in early spring, dissolving (Schwartz 1980) potassium ions present in the leaf litter, but indicated that studies to date have not been sufficiently detailed to fully explain the potassium cycle in the drainage basin.

Akena (1979) and Schwartz (1980) found evidence that disposal of groundwater from the Alsands test pit caused distinct increases in sodium and chloride concentrations in the Muskeg River at least as far downstream as the gauging station. The Alsands discharge water apparently caused the highest sodium and chloride values recorded at the gauging station. These concentrations (38.5 mg/L Na and 29.7 mg/L), however, were only modestly higher than the maxima recorded for these ions at unaffected stations elsewhere in the drainage basin (30.5 mg/L Na and 22 mg/L Cl; Akena 1979, Table 4, this report).

Saline discharges can have profound effects on aquatic biota (Machniak 1977). The elevated concentrations of Na and Cl observed in the Muskeg River by Akena (1979) and Schwartz (1980) would probably be relatively innocuous, but concentrations might have been far higher and much more damaging immediately below the discharge point of the test pit effluent. This point is above the Hartley Creek confluence, and the flow is much lower there than at the gauging station. It is possible, therefore, that aquatic communities for an undetermined distance downstream from the Alsands test pit discharge have already been affected, and are no longer natural.

pH

Akena (1979) reported the pH of surface waters in the Muskeg River basin to range mostly from 7.1 to 8.2. Within this range, pH showed no clear seasonal variations.

Organic Carbon

Dissolved and total organic carbon values tend to be similar in surface waters in the Muskeg River basin, indicating that, in general, only a small proportion of organic carbon is particulate in this watershed (Akena 1979). The available data show wide variations in TDOC concentrations (from 8 to 89 mg/L) and no consistent seasonal trend.

Phosphorus

Orthophosphate phosphorus concentrations in surface waters in the Muskeg River basin range from 3 µg/L to 90 µg/L; total phosphate phosphorus ranges from 5 to 560 µg/L (Akena 1979). In Hartley Creek over a one-year period, highest concentrations of total phosphate phosphorus were found in winter and the lowest were found in spring (Akena 1979:95). In the Muskeg River, however, the seasonal pattern was not so clear, being confounded by relatively wide fluctuations in concentration.

Akena (1979) believed that certain increases in total phosphate phosphorus concentrations at the gauging station coincided with periods of disposal of Alsands test pit water into the river, during all but one disposal period. He suggested ways in which the disposal water could have induced higher concentrations in the river, despite the low concentrations of total phosphate phosphorus in the test pit water, but the absence of supporting data weakens these hypotheses. In fact, the data indicate (Akena 1979:94) that total phosphate phosphorus concentrations clearly increased during only two of five disposal periods (September to October 1976 and June to July 1978). During another (September to October 1978), concentrations increased, then decreased. At the end of a fourth short disposal period (September 1977), concentrations were lower than they had been prior to disposal; and during a fifth disposal period (June to August 1977), concentrations of total phosphate phosphorus in the river were approximately the same as those prior to, or at the beginning of, pit water disposal. Akena (1979) offered arguments to help explain the deviation of the 1977 summer data from his hypothesis, but the available data are simply not adequate to convincingly detect the influence of pit water disposal on most water quality parameters in the Muskeg River, apart from the sodium and chloride effects already discussed. The data were collected for survey purposes, so were not obtained at close enough intervals, or close enough to the effluent source to serve a monitoring function. Most importantly, data were not available from a control station to provide a direct comparison to natural conditions pertaining at the time of pit water discharge.

Nitrogen

Akena (1979) studied variations in the concentration of a number of nitrogen forms in surface waters of the Muskeg River basin. He found no clear seasonal variations in total Kjeldahl nitrogen (TKN) concentrations, most values of which ranged from

0.3 to 3.2 mg/L. Ammonia nitrogen (NH_3-N) was usually highest in mid-winter (0.4 to 0.6 mg/L at the Muskeg River gauging station) and lowest in spring and summer (less than 0.1 mg/L), but some exceptions were noted. Higher values of NH_3-N (0.3 to 0.4 mg/L) were found in July or August at some stations, and a sudden decrease in February 1978 to less than 0.1 mg/L from 0.5 - 0.75 mg/L was noted at two stations.

Akena's (1979:114) data on nitrite plus nitrate nitrogen ($NO_2^- + NO_3^-$ - N) show apparent cycles in concentration. Peaks tended to occur in March or early April, June or July, and November or December; minima tended to occur in January or February, April or May, and late July to October. Detectable concentrations of NO_2^--N were reported for certain dates on which dissolved oxygen was also high, but no explanation for these anomalous results was offered. As Akena (1979:112) recognized, nitrite is rapidly oxidized to nitrate in the presence of oxygen. The most likely possible explanations of the results are that either the nitrite or dissolved oxygen determinations were erroneous, or that the samples became deoxygenated during storage, permitting nitrite to build up. If the latter is correct, the determinations for phosphates, organic carbon and other nitrogen forms in the samples in question may also be unreliable, since they were determined from the same unpreserved samples as nitrite nitrogen (Akena 1979:180).

Akena's (1979:119) data show no clear seasonal trends in concentrations of dissolved organic nitrogen (DON) in the Muskeg River or Hartley Creek at the gauging stations, except that they were distinctly higher in Hartley Creek in January (2.0 to 3.9 mg/L) than at any other time of the year. Most other determinations at both stations ranged between 0.5 and 1.5 mg/L.

Silica

Akena (1979) found that minimum concentrations of reactive silica (0.5 to 9.0 mg/L) were found in late April to early June in the Muskeg drainage basin. Maxima usually occurred in winter, and ranged from 9.4 to 29.8 mg/L.

Trace Elements and Minor Constituents

Akena (1979) studied numerous trace elements and minor constituents in surface waters of the Muskeg River drainage basin. His reported maxima and minima are presented in Table 7. Akena (1979:163) suggested that removal of humic substances during metal analysis could have removed large amounts of metals as well; hence the available data may underestimate the true natural concentrations.

Table 7 Ranges in concentrations of trace elements and minor constituents in surface waters of the Muskeg River drainage (from Akena 1979). Units are mg/L.

CONSTITUENT	MINIMUM	MAXIMUM
Selenium	< 0.005	0.0016
Arsenic	< 0.001	0.0025
Boron	0.01	0.48
Mercury	< 0.0001	0.0043
Silver	< 0.005	0.010
Cadmium	< 0.001	0.006
Cobalt	0.002	0.011
Hexavalent Chromium	0.002	0.190
Lead	< 0.003	0.032
Vanadium	< 0.001	0.006
Nickel	< 0.004	0.024
Copper	< 0.02	0.250
Zinc	< 0.05	0.091
Aluminum	< 0.01	0.60[a]
Iron	< 0.3	43.5
Manganese	0.003	1.0[a]

a. Much higher values were recorded, but these samples may have been contaminated (Akena 1979:152).

PERIPHYTON

Periphyton is defined, for the purposes of this review, as the microbiota (primarily bacteria, fungi, algae and protozoa) that grow upon substrates. Periphytic organisms may be further classified on the basis of the type of substrate upon which they grow: *epilithic* (on rock), *epipelic* (on sediment), *epiphytic* (on plants) and *epipsammic* (on sand).

Baseline studies of periphyton in the Muskeg River basin have been conducted by Lock and Wallace (1979a, b) and Hickman et al (1979). Experimental studies to determine the effects of environmental variables or potential pollutants on periphyton have been reported by Barton and Wallace (1980) and Lock and Wallace (1979a, b). Data on periphyton presented by Crowther (1979) and Hartland-Rowe et al (1979) evidently are the same as those reported by Lock and Wallace (1979a:4-34), and are not additional information.

The reports by Lock and Wallace (1979a) and Hickman et al (1979) are interim reports only. Parts of these reports have been reviewed in some detail in the hope that apparent discrepancies in the data or analyses will be taken into consideration when the final reports are prepared.

Bacteria

Lock and Wallace (1979a) documented the total number of bacteria colonizing "standardized natural substrates" of granite 1 cm thick by 15 cm in diameter. The discs were installed on rocky substrate in Hartley Creek and the Muskeg River for the period May to December, 1977.

In both streams, most bacterial counts fell within the range $10^7/cm^2$ to $10^8/cm^2$. Peak numbers were observed from spring to early summer, and in early winter; minimum numbers were found in later summer.

Bacterial counts showed the same seasonal pattern as did epilithic algae biomass (as measured by chlorophyll a), and were positively correlated with algal biomass estimates. Lock and Wallace (1979) favoured the hypothesis that the epilithic bacteria were responding to the growth of epilithic algae, perhaps by using extra-cellular products of photosynthesis. They recognized that the converse hypothesis, that the algae were responding to the growth of epilithic bacteria, was also supportable, but could not postulate a mechanism for such a response. A third possibility is that both algal biomass and bacterial numbers were responding independently, but in a similar way to variations in one or more environmental parameters that were not measured in their study.

In a later study (April to November 1978), Lock and Wallace (1979b) compared counts of epilithic bacteria on granite "standardized natural substrates" kept in the light and in shade in the Muskeg River. They believed (Lock and Wallace 1979:21) that bacterial numbers in light and shade were similar. In fact their data show that bacterial counts on the shaded substrates were lower than on the light-exposed substrates in July, August and November - three of the five comparable sampling dates (Lock and Wallace 1979b:10-11). This observation is more consistent with their other findings that epilithic bacteria numbers were positively correlated with chlorophyll *a* levels, which in turn were lower on the shaded substrates than on the light-exposed substrates in August and November. Again, Lock and Wallace (1979b) favoured the hypothesis that epilithic bacteria numbers were responding to variations in extracellular and lytic products of the algal cells.

Algae

Artificial Substrates

Lock and Wallace (1979a) studied seasonal variations in chlorophyll *a*, a measure of total algal biomass, on "standardized natural substrates" (see Bacteria section, above) placed in rocky-bottomed sections of Hartley Creek and the Muskeg River, over the period May through December, 1977. In both streams, chlorophyll *a* levels were high in July and December, and low in August. The Muskeg River substrates exhibited higher maximum levels of chlorophyll *a* (20.1 to 22.6 μg/cm^2) than those in Hartley Creek (3.0 to 3.3 μg/cm^2); otherwise epilithic chlorophyll *a* concentrations were similar in the two streams[1].

Lock and Wallace (1979a:32-34) suggested several hypotheses to account for their observed data. They noted that there were no massive increases in plant nutrients that could have stimulated algal growth assuming that the algae were nutrient-limited initially. They suggested instead that water temperature and light intensity could have acted together to stimulate warm-water, light-adapted species to peak in early summer, and cool-water species adapted to low light to peak in early winter. The summer minimum, they suggested, could have been due to high light and temperature inhibition, or to sloughing of the algal-bacterial film from mechanical damage caused by the grazing of invertebrates, themselves stimulated to increase by the previous algal peak.

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1. There is a discrepancy in chlorophyll units in the text (ng/cm^2; Lock and Wallace 1979a:11) and Tables (μg/cm^2) in this report. The tabulated units are the same order of magnitude as those reported for the same substrates in the Muskeg River in a later report (Lock and Wallace 1979b), so μg/cm^2 is considered to be the correct unit.

In a later study, Lock and Wallace (1979b) partially shaded half of their "standardized natural substrates" and exposed the other half to the natural light regime in the Muskeg River, to test their hypothesis that photoinhibition caused the summer minimum in algal biomass. They found that chlorophyll *a* was higher on the shaded substrates than on the exposed substrates in May and June, but was much lower on the shaded substrates in August and November. In July, chlorophyll *a* levels on shaded and unshaded substrates were similar.

Lock and Wallace (1979b) argued that the May and June results supported the hypothesis that photoinhibition is at least partly responsible for the midsummer decline in algal biomass, but acknowledged that improper operation of the shade complicated interpretation of the data. The principal difficulties were that the shade passed highly variable proportions of the available light, and that there was no continuous record of the amount of light reaching the substrates. The authors further argued that temperature was unlikely to have caused the midsummer decline, because water temperatures at the shaded and unshaded substrates were identical, but chlorophyll *a* levels declined from May to June only on the unshaded substrates. The levels on the shaded substrates in May and June were not significantly different.[1]

Natural Substrates

All the periphyton studies discussed so far have been done with artificially-shaped, uniform discs of granite that have been colonized by periphyton by being incubated in the study streams for periods up to several months. Such "standardized natural substrates" are arguably different from the irregularly-shaped, variously-sized stones of other rock materials that dominate the riffle areas in the Muskeg River and Hartley Creek, and could have unnatural periphyton communities.

Lock and Wallace (1979a), in a separate study, documented the epilithic algae on truly natural stones in the Muskeg River to ensure that the natural algal flora was being investigated. They took their samples at the same station on the river at which the granite discs had been installed, and over the same time period that the granite disc flora was studied. Chlorophyll *a* levels on natural stones and granite discs showed similar seasonal variations, and weights of chlorophyll *a* per unit area

1. The point on the graph for unshaded chlorophyll *a* in June appears to be significantly lower than that in May, but is apparently misplotted at 1.4 $\mu g/cm^2$ instead of 1.9 $\mu g/cm^2$ (Lock and Wallace 1979b, cf. Table 2, Figure 3).

were usually similar on comparable dates, particularly after July. The findings tend to support the assumption that the granite discs accurately mimic true natural substrates, but comparisons of species composition and productivity, necessary to fully test the assumption, have not been reported.

In the study of epilithic algae on natural substrates, Lock and Wallace (1979a) recorded seasonal variations in abundance of algae, in total and by taxonomic division. From May to August 1977, total algal numbers fluctuated widely around a mean of approximately $10^{10}/m^2$. A peak of $7 \times 10^{10}/m^2$ was reached in October and the minimum, $10^9/m^2$, was reached in December.

Blue-green algae (Cyanophyta) dominated as a group, *Phormidium tenue, Lyngbya aeruginso-caerulea, Aphanocapsa* sp. and *Chamaesiphon incrustans* being the dominant blue-green species. Diatoms (Bacillariophyta), particularly *Synedra ulna, Nitzschia fonticola, Achnanthes minutissima* and *Gomphonema olivaceum* were the second most abundant group. Green algae (Chlorophyta), dominated by *Draparnaldia* spp., *Cladophora glomerata* and *Ulothrix* sp. were third in importance.

Lock and Wallace (1979a) observed that algae formed films on the rocks that increased in thickness, then detached and were swept away in the current. They noted that periods of maximum discharge did not correspond to periods of minimal algal numbers, therefore (they argued) high discharge does not necessarily cause massive detachment of benthic algae. In fact, inspection of their data on discharge and total algae/m^2 suggests there may be a positive correlation between discharge and algal abundance.

Lock and Wallace (1979a:46-47) could reach few conclusions regarding factors affecting algal populations in the Muskeg River, but did state that benthic algae appeared "at no time" to be subjected to limited nutrients. They did not elaborate, and arguments touching on this matter elsewhere in the report (Lock and Wallace 1979a:32), that water chemistry data showed no massive increases in plant nutrients that could have stimulated algal growth, are not convincing. Nutrients may not show massive increases because algae are taking them up fast enough to keep ambient concentrations low, as they often were in this study (eg; PO_4-P usually ≤6 μg/L; Lock and Wallace 1979a:23).

Species composition, standing crop and productivity of epilithic algae on natural rock substrates were studied from May to December, 1978 by Hickman et al (1979) at the same site studied by Lock and Wallace (1979a, b) in the Muskeg River. Species composition in 1978 was evidently similar to that in 1977. Blue-green algae were always dominant (53 to 99.6%), followed by diatoms (up to 22%) and green algae. The most abundant species were the blue-greens *Lyngbya aerugineo-caerulea* and *Phormidium tenue*; the diatoms *Synedra ulna, Nitzschia fonticola* and *Synedra rumpens*; and the green alga *Draparnaldia* sp.

Chlorophyll *a* values did not show the same seasonal trend in 1978 (Hickman et al 1979) as in 1977 (Lock and Wallace 1979a), and were not consistently lower or higher. The 1978 fall chlorophyll *a* maximum was much lower than the 1977 fall maximum. Total numbers of algae were much more variable in 1977 than 1978. The data for the two years were not compared by Hickman (et al 1979); consequently no explanations for the differences were suggested.

Primary productivity, measured by the C^{14} method on enclosed natural rock substrates, was high in 1978, ranging from 6.9 to 107.8 $mgC/m^2/h$ (mean 26.5 $mgC/m^2/h$) (Hickman et al 1979). Maximum carbon fixation was recorded in spring, when noncirculating chambers were being used. Circulating-water experimental chambers, which more closely duplicated flowing-water habitat, were used in the early winter and thereafter when carbon fixation rates were low.

The authors contended that the non-circulating chambers underestimated true productivity, but their data presented in support of this intuitively-reasonable contention are inconclusive (Hickman et al 1979:84). In four comparisons of circulating and non-circulating chambers, each conducted in different AOSERP-area rivers (not the Muskeg River), circulating chambers appeared to measure clearly higher production in two tests, lower production in one test and virtually identical production to that in non-circulating chambers in one test. No measure of the (probably high) variability associated with the production estimates was given, and differences were not tested statistically[1], so it is not at all clear that the non-circulating chambers underestimated productivity.

Hickman et al (1979) also examined the effect of shading on primary productivity, by conducting simultaneous C^{14} experiments in the light and under the experimental shade erected by Lock and Wallace (1979b). No data were presented, but the authors reported that, "on average", shading approximately halved primary productivity. Hickman et al (1979) did not report the dates on which the experiments were run, so the relationship of their findings to the shading experiments of Lock and Wallace (1979b) are unknown.

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1. Results of a comparison presented elsewhere in the report (Hickman et al 1979:85) of midstream and near-bank productivity may be pertinent here. Statistically-significant differences could not be found between numerous paired means of productivity measurements that differed far more than those in the tests of circulating and non-circulating chambers.

Apparently large differences in mean primary productivity were reported in numerous comparisons of mid-stream and near-bank sites in the Muskeg River (Hickman et al 1979:85). Only three out of 18 of these comparisons showed statistically significant differences, however. The failure to demonstrate statistically-significant differences between means that appeared to be distinctly different suggests that small-scale spatial variability in epilithic algal productivity is very high in the Muskeg River.

Hickman et al (1979) analyzed their data for five rivers in a preliminary way by calculating correlation coefficients for numerous pairs of biotic and environmental variables in an effort to discover what factors were controlling the epilithic algae. The results must be viewed with considerable caution. Details of the analysis are not described, but it appears that more than 180 separate correlations were calculated, and that a relatively high probability of a Type I error ($P<0.10$) - that there was a significant correlation when in fact there was not - was accepted. There is no indication of whether transformations were used to linearize the data or make them conform to other assumptions of the analysis. Because of the large number of separate analyses and high probability level accepted, it is very likely that some of the significant correlations found are in fact spurious. On the other hand, significant non-linear correlations may have been overlooked if linearizing transformations were not attempted. Finally, the authors seemed to accept a significant correlation between two variables as indicating that changes in the environmental variable caused changes in the biotic variable. This view is implicit, for example, in the statement "Dissolved silica only appeared to be limiting to diatom growth in two rivers..." (Hickman et al 1979:86) which was based on the evidence of significant negative correlations between silica concentration and diatom "growth" (abundance?). In some cases it would have been just as plausible (possibly more plausible) to argue that changes in the biotic variable (eg; diatom abundance) caused changes in the environmental variable (eg; silica concentrations); or that the two variables responded independently, but in a similar (positive correlation) or opposite (negative correlation) way, to changes in one or more other variables.

If the data of Hickman et al (1979) for the Muskeg River alone are re-examined, with the level of statistical significance set at 5% to reduce the probability of accepting a spurious correlation, no correlations are found between standing crop (numbers or chlorophyll *a*?) of epilithic algae and dissolved nutrients, temperature or irradiance. Primary productivity is negatively correlated with pH ($p<0.01$), positively correlated with "carbon"[1] ($p<0.01$) and negatively correlated with algal standing crop (numbers or chlorophyll *a*?) ($p<0.05$).

The authors implied (Hickman et al 1979:92) that the positive correlations indicated that pH, "carbon" and algal standing crop controlled primary productivity of epilithic algae in the Muskeg River. No mechanisms for control were suggested and, as was noted earlier, cause-effect relationships cannot be demonstrated on the basis of statistically-significant correlations alone. The negative correlation between standing crop and primary productivity does suggest the possibility of a competitive effect, perhaps for light or nutrients, that becomes more intense as the algal film on the rocks becomes progressively thicker. Other reasonable hypotheses undoubtedly could be advanced, but any one of them would require experimental verification before standing crop (or, by extension, pH or carbon) could be said to control algal productivity in the Muskeg River.

Hickman et al (1979:92,95) stated that discharge was inversely correlated with population size and standing crop in the Muskeg River, but the data suggest a more complex relationship. Chlorophyll *a* weight per unit area fluctuated widely from

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1. There is no indication in the report of what form of carbon is meant, or where the data came from, since carbon was apparently not analyzed in the water samples taken for the study.

May to July 1978, but discharge during the same period was declining quite steadily (Hickman et al 1979, compare Figures 2 and 41). If there is a correlation between discharge and chlorophyll *a* during this period, it would appear to be positive, not negative. During the very high discharge period in September and October, chlorophyll *a* remained at a low level, rising only when the flood abated in November. The total population size of epilithic algae (cells/cm^2) showed a gradual downward trend from May to July, (Hickman et al 1979, Figure 42) again suggesting a possible positive correlation with discharge during this period. Numbers rose in August with rising discharge, then dropped and remained at low (but not minimal) numbers during the September to October high discharge period. It therefore appears that only the very high fall discharges could have reduced total epilithic algal numbers and biomass. The fact that Lock and Wallace (1979a) observed no reduction in cell numbers attributable to high discharge in 1977 may be due to the relatively low fall discharge peak in the Muskeg River that year.

The contention of Hickman et al (1979) and Lock and Wallace (1979a), that nutrients are not limiting to algal standing crops in the Muskeg River, requires verification, perhaps by enrichment experiments. Their argument in favour of their conclusion, to the extent that one has been raised, has been, in effect, that nutrients cannot be limiting because nutrient concentrations in the water are uncorrelated (statistically or graphically) with algal standing crops. Concentrations of limiting nutrients, however, are not necessarily correlated with the standing crops they limit (eg; Schindler et al 1973).

None of the investigators working on periphyton in the Muskeg River considered the possible effects of the discharge of Alsands test pit water on their results. Akena (1979), however, noted a distinct increase in sodium and chloride due to test pit discharge at a point near or at the principal periphyton study site. He also noted an extraordinary decline in diatom numbers in 1977 during a period of pit water discharge, implying that the discharge could have caused the decline.

Composition of the Epilithic Film

The epilithic bacteria and algae discussed in previous sections form part of a "film" attached to rocks in the streams of the Muskeg and other watersheds. Other components of the film have been studied in a preliminary way by Lock and Wallace (1979a, b).

Adenosine triphosphate (ATP) is present only in living matter and was used as a measure of total epilithic living biomass in Hartley Creek and the Muskeg River by Lock and Wallace (1979a). ATP was highest on granite discs immediately after ice-out, dropped sharply to a minimum in June or July, rose to a minor peak in August, dropped somewhat in September or October and rose again in November. This seasonal pattern of ATP concentration was quite different from that shown by epilithic algal biomass and bacterial abundance. Elsewhere in their report, Lock and Wallace (1979) found that ATP on granite discs did not show the same response to light and darkness as did algal biomass and bacterial abundance. In one case, high ATP levels were associated with a high biomass of bryozoans. On the basis of these observations, Lock and Wallace (1979a:79) suggested that ATP may more accurately reflect the animal portion of the epilithic film. An alternative explanation would be that the film is, at least at times, dominated by fungal or microinvertebrate biomass.

Lock and Wallace (1979a) used scanning and transmission electron microscopy to make some preliminary observations on the epilithic film formed on granite discs and epoxy resin incubated in the Muskeg River. In August, approximately one-half the bulk of the film consisted of a non-living fluffy, "polysaccharide-like" slime matrix. Blue-green algae were closest to the substrate, suggesting to the authors that this group might be the primary colonizer of newly-exposed surfaces. An unidentified organism with plate-like cells stacked together was also common in the film.

In October the film was thicker (2-3 mm) than in August and was extensively perforated by holes which the authors suggested could have been made by the chironomids and oligochaetes which occupied the films. The October film was composed primarily of stalked diatoms, mostly *Gomphonema* and *Navicula*, and was therefore very different from the August film in structure.

Lock and Wallace (1979a) suggested that mechanical disruption by the invertebrates could cause the film to eventually slough off, perhaps accounting for some of the population and biomass declines observed. They further suggested that, because of the large surface area of the fluffy slime matrix, the film could enhance the ability of the micro-organisms to assimilate dissolved matter from the flowing water, through ion exchange and adsorption mechanisms.

Data on microinvertebrates inhabiting the surface film of granite discs set in the Muskeg River were supplied without comment by Lock and Wallace (1979b). Mean numbers usually fell within the range of 10 to 100/100 cm^2 and showed no consistent differences between shaded and light-exposed granite discs. Biomass estimates in mg/100 cm^2 were also provided, but there is no indication of whether these are in wet or dry weight units.

Effects of Oil Contamination on Periphyton

Barton and Wallace (1980) conducted a series of experiments to study the effect of crude oil and other petroleum products on periphytic communities in the Muskeg River. In one experiment, they showed that crude oil contamination caused elevated bacterial and algal numbers, and increased algal biomass (chlorophyll *a*), on limestone bricks dipped in oil and incubated for one month in the river. Crude oil caused elevated bacterial numbers in both the light and in deep shade, but had no effect on algal numbers and biomass in deep shade.

The increase in algal abundance observed was due mostly to increases in diatoms, different species dominating the oiled and control bricks. In contrast, blue-green algae showed a general increase in cell numbers on oiled bricks, with no distinct shift in species composition.

Diatoms were much more abundant in the light than in the shade on both oiled and control bricks, but blue-green algae were equally abundant in the light and in the shade on both oiled and unoiled bricks. Chlorophyll *a* was higher on light-exposed bricks than on shaded bricks (Barton and Wallace 1980:113). This latter observation, made on populations that developed from late July to late August 1977, is consistent with those made by Lock and Wallace (1979b) a year later in August and November, and does not support their hypothesis that photoinhibition causes a summer minimum in algal biomass in the Muskeg River.

The finding that crude oil had a stimulating effect on algal standing crops provides an additional reason for not accepting, without experimental verification, the contention (Lock and Wallace 1979a, Hickman et al 1979) that nutrients are not limiting to algal standing crops in the Muskeg River. Although the mechanism of the stimulating effect is unknown, Barton and Wallace (1980:162) suggested several ways that the crude oil may directly or indirectly increase the supply of a presumably limiting nutrient that would lead to increased standing crops of algae and bacteria.

In another experimental study, Barton and Wallace (1980) investigated the effects of various hydrocarbon fractions on eplithic algae and bacteria in the Muskeg River. Limestone bricks were allowed to become colonized, then were dipped in the test liquids and replaced in the stream. The algae and bacteria showed a variety of responses, depending on the fraction tested. All responses were short-term and usually of small magnitude. Barton and Wallace (1980) suggested that the limited nature of the effects may have been due, in part, to the hydrocarbon fractions not becoming incorporated in the wet biological film during short-term exposure.

In a third experiment, Barton and Wallace (1980) demonstrated that naturally-occurring epilithic micro-organisms in the Muskeg River are capable of degrading substantial quantities oil. Degradation was more rapid at 20°C than at 4°C.

PLANKTON

The plankton of streams in the Muskeg River basin has been briefly surveyed by Lock and Wallace (1979a), Hickman et al (1979) and Corkum and McCart (1981).

Lock and Wallace (1979a) observed no consistent seasonal trends in abundance of suspended bacteria (range 10^5 to 10^6 cell/mL) and chlorophyll *a* (range <0.1 to 2.9 μg/L) in Hartley Creek and the lower Muskeg River. Algae were thought to be benthic forms that had become entrained in the flowing water, but neither bacterial abundance nor chlorophyll *a* levels were related to discharge in 1977. Furthermore, planktonic chlorophyll *a* was significantly correlated with epilithic chlorophyll *a* only in Hartley Creek. In the Muskeg River, peaks of planktonic chlorophyll *a* sometimes corresponded to minimal chlorophyll *a* in the epilithic community, most clearly in May to June and in the fall. In August, however, there were concurrent sharp declines in both planktonic and epilithic chlorophyll *a*.

Hickman et al (1979) reported that the phytoplankton at their lower Muskeg River station was comprised of a mixture of non-epilithic and senescing epilithic algae. *Microcystis aeruginosa* and desmids, thought to have originated in muskeg pools, dominated a spring peak in standing crop. Hickman et al (1979:98) believed that the standing crop of planktonic algae depended upon discharge rates, but their data for the Muskeg River, and that of Lock and Wallace (1979a) already mentioned, suggest that other factors must also play a role. For example, in 1978, a sizeable peak in planktonic chlorophyll *a* was recorded in July, a month when discharge was very low (Hickman et al 1979, compare Figures 2 and 47).

Corkum and McCart (1981) surveyed the phytoplankton of the upper Muskeg River and one of its tributaries in September 1980. Phytoplankton abundance was low, and was attributed by those authors to downstream transport as a result of the flood conditions pertaining at the time.

BENTHOS

Although any plant or animal associated with the streambed of rivers or lake bottoms may be categorized as benthos, this section of the report deals only with benthic macroinvertebrates, defined as those retained by a U.S. Standard No. 30 sieve (0.595 mm opening) (Weber 1973). Benthic invertebrates are important in energy transfer from lower plants and animals to fish, birds, and mammals. Benthic macroinvertebrate populations are generally considered to be sensitive to the effects of disturbance and are favoured by many researchers involved in biomonitoring streams and rivers (Gaufin and Tarswell 1956; Wilhm 1967, 1970; McCart and Mayhood 1980).

To date, most reports of benthic macroinvertebrates within the Muskeg drainage area have been baseline studies or general review articles (Crowther 1979, Crowther and Griffing 1979, Hartland-Rowe et al 1979, AEL et al 1980, Corkum and McCart 1981). Barton and Wallace's (1980) work is the only experimental attempt to study the effects of oil sands development on macroinvertebrates in the study area.

Crowther (1979) conducted a descriptive ecological investigation of Hartley Creek a portion of which was also reported in an AOSERP publication (Hartland-Rowe et al 1979). A major thrust of Crowther's (1979) thesis was to compare Hartley Creek with the Bigoray River, a brownwater stream in west-central Alberta which has been studied in detail for over 10 years (Clifford 1969, 1970a, 1970b, 1972a, 1972b, 1972c, 1972d, 1976, 1978; Clifford et al 1973; Hayden and Clifford 1974; Boerger and Clifford 1975).

Trichoptera larvae dominated the taxa of Hartley Creek (after the Chironomidae) both numically and in terms of biomass. Crowther (1979) presents life history patterns for seven species of caddisflies based on collections made during the open water season. He suggests that the higher faunal density in Hartley Creek compared to the Bigoray River is due to increased substrate heterogeneity and current velocity as well as winter pond refuges in the former stream. Evidently, trichopteran larvae change their feeding mechanism from filter feeders to shredders when shifting from riffle to pool habitats. Cluster analysis was used to identify species assemblages in the two habitats.

Hartland-Rowe et al (1979) present a baseline study of three sampling sites located along a 4 km stretch of Hartley Creek. Some life history data are presented for three species of stonefly (Plecoptera) nymphs. Although stonefly nymphs were not the dominant taxa, their univoltine life cycle was relatively simple to study.

Crowther and Griffing (1979) examined the trophic status of macroinvertebrates based on a reconnaissance of the Ells, MacKay, Steepbank, Hangingstone, and Muskeg rivers conducted during October 1978. Macroinvertebrates were grouped into trophic categories based on Grafius and Anderson (1973) and Wiggins (1977). Upstream (though not headwater) areas were dominated by algae-detrital and detrital trophic groups; downstream sites were composed mainly of omnivores and detritivores. Number of taxa and benthic density (based on kick samples) increased upstream. Based on these data,Crowther and Griffing (1979) developed an energy flow model for a "typical" tributary in the AOSERP area with upstream energy sources being shifted downstream for consumption.

Crowther and Griffing's (1979) study was based on one reconnaissance survey in October during high water conditions and hence, the data should be treated with caution. Since benthic composition often changes during flood conditions (Hynes 1970), it is possible that the kick samples collected are not representative of the community under normal flow conditions.

Corkum and McCart (1981) used regression analysis to predict the distribution of functional groups of aquatic invertebrates, based on feeding mechanisms (after Cummins 1973), at stream sites on the upper Muskeg River. They showed that stream width independently predicted the distribution of shredders, collectors (filterer-gatherers), collectors (gatherers), piercers and predators, but not scrapers. Cluster analysis of the same data describing functional groups produced no observable groupings among sample sites. Since this study was based on one collecting period, 22-26 September 1980, and during flood conditions, the authors (like Crowther and Griffing 1979) may have examined no more than microhabitat preferences.

Barton and Wallace (1980) undertook a qualitative survey of the Muskeg (five sites) and Steepbank (seven sites) rivers in which kick samples were taken at four or five sampling times between July 1976 and 1977. The mean per cent composition of animals from all collections was used to derive values for a Per Cent Similarity Coefficient and Coefficient of Community, each of which was used in a Bray-Curtis ordination analysis (Bray and Curtis 1957). Using these two ordinators, five habitats based on substrate type (fill, rubble, oil sand, muskeg or brook) were delineated for the entire sampling area. Site clusters based on macroinvertebrate data were very loose. Actually, the sites when clustered together appear to represent upper, middle and lower reaches of the rivers.

Barton and Wallace (1980) present life history patterns based on size classes (total nymphal body length) for six mayfly species and nine stonefly species. All three patterns of life history development (fast seasonal, slow seasonal, and non-seasonal) described by Hynes (1970) are represented by insects in the Muskeg and Steepbank rivers (Barton and Wallace 1980). These authors also record the relative abundance of aquatic invertebrates collected in the Muskeg, Steepbank, and Athabasca rivers. Unfortunately, the terms (frequent, common, etc.) are not defined.

The experimental study by Barton and Wallace (1980) on the effects of oil sands and fluctuating water levels on the macroinvertebrate composition of the Steepbank river is an exception to the descriptive monitoring studies commonly conducted in the AOSERP Study Area. These authors found a less diverse macroinvertebrate community associated with oil sands than with limestone rubble. In particular, there were significantly fewer burrowing and negatively phototrophic forms on oil sands (analogous to bedrock) than on the limestone rubble. Typically, more organisms (numbers and kinds) are found on rubble than bedrock (Percival and Whitehead 1929). Because of the design of the Barton and Wallace study, it is unclear, however, whether differences in benthic composition were due to the presence/absence of bitumen or to difference in substrate type (asphalt bedrock versus rubble).

Barton and Wallace (1980) conducted a field experiment in the lower reaches of the Muskeg River from July 24 to August 7, 1977, to determine the colonization of limestone bricks exposed to oil by micro and macrobenthic organisms. Macroinvertebrates increased on oiled bricks exposed to a natural light regime.

In another experimental study of the Muskeg River (Barton and Wallace 1980), organisms were exposed to synthetic crude oil as well as naphtha, gas-oil, and kerosene from June to December 1977. No obvious differences occurred in benthic community structure through time or with the different oil components.

Barton and Wallace (1979) examined the effects of an experimentally introduced instantaneous spill (0.11 m^3) of oil sands tailing sludge on macroinvertebrate along a 30-m reach of the Muskeg River on 2 October 1976, about 1 km upstream above its confluence with the Athabasca River. Four weeks after the oil spill, there was a 60% reduction in the standing crop of benthic invertebrates. Samples from the experimentally treated area contained significantly lower numbers of all invertebrate groups with the exceptions of the Oligochaeta, Elmidae and Chironomini.

Although Chironomidae dominate (at least by numbers and frequently by biomass) the insect fauna in brownwater streams of Alberta (Boerger 1978, Clifford 1978, Bond and Machniak 1979, Crowther 1979, Corkum and McCart 1981), the group has been poorly studied. Lack of interest in the chironomids is due to taxonomic difficulties, complex multivoltine life cycles and sampling effort. All chironomid species overwinter in the larval stage and in northern latitudes, growth is reduced (Oliver 1971, Boerger 1978).

Other taxa associated with chironomids differ among brownwater streams. Clifford (1978) characterizes his study site on the Bigoray river, in central Alberta, as a "chironomid-ostracod" stream. Evidently, ostracods are a minor component of the aquatic fauna of AOSERP area streams, but this may be due to collecting techniques and utilization of large mesh nets. Crowther (1979) reported a chironomid-trichopteran complex in Hartley Creek. In the upper

Muskeg River, Corkum and McCart (1981) showed that chironomids, sphaerids and oligochaetes dominated the macroinvertebrate community. These different taxonomic associations probably result from interactions of biological, physical and chemical factors of the stream and its valley.

FISH

Of thirty-one species of fish reported within the lower Athabasca drainage and the Peace-Athabasca Delta (Paetz 1973, AEL et al 1980), 16 species have been collected from the Muskeg River Drainage (Griffiths 1973; Shell Canada Ltd. 1975; Bond and Machniak 1977, 1979, Walder et al, 1980) (Tables 8 and 9).

The Land Inventory Division of Alberta Energy and Natural Resources has mapped sport fish capabilities for the province on 1:250 000 NTS topographical maps. Watersheds are subdivided on their ability to support warm or cold water fish. A further subdivision identifies specific limiting factors for sport fisheries. The Muskeg watershed, which drains a large area of bog and muskeg, has only a limited sport fish potential (Griffiths 1973, Alberta Land Inventory 1977). Fish habitat in the river channel is greatly reduced due to extreme water fluctuations and shallow pools.

Using techniques of the Research Analysis Branch of the British Columbia Ministry of Environment (Wrangler and Seidner 1979), Bond and Machniak (1979) present a biophysical map of the Muskeg watershed. Based on stream gradient, flow, channel formation and other characteristics, five reaches of the Muskeg River are distinguished and described. Other biophysical maps have been prepared for several tributaries of the lower Athabasca River including the Muskeg River and Hartley Creek (Walder et al 1980).

TABLE 8 Watershed: Muskeg Drainage - Muskeg River

Taxa	Common Name	Occurrence * a	b	d
Salmonidae				
Salmo gairdneri	rainbow trout			
Salvelinus malma	Dolly Varden			
Salvelinus namaycush	lake trout			
Coregonidae				
Coregonus artedii	lake cisco			
Coregonus clupeaformis	lake whitefish	x	x	
Coregonus zenithicus	shortjaw cisco			
Prosopium williamsoni	mountain whitefish	x		
Thymallidae				
Thymallus arcticus	Arctic grayling	x	x	x
Hiodontidae				
Hiodon alosoides	goldeye			
Esocidae				
Esox lucius	northern pike	x	x	x
Cyprinidae				
Chrosomus eos	northern redbelly dace			
Chrosomus neogaeus	finescale dace			
Couesius plumbeus	lake chub	x	x	
Hybognathus hankinsoni	brassy minnow			
Notropis atherinoides	emerald shiner			
Notropis hudsonius	spottail shiner	x		
Pimephales promelas	fathead minnow			
Platygobio gracilis	flathead chub			
Rhinichthys cataractae	longnose dace	x		x
Semotilus margarita	pearl dace	x		x
Catostomidae				
Catostomus catostomus	longnose sucker	x	x	x
Catostomus comersoni	white sucker	x	x	x
Gadidae				
Lota lota	burbot	x	x	
Gasterosteidae				
Culaea inconstans	brook stickleback	x		x
Pungitius pungitius	ninespine stickleback			
Percopsidae				
Percopsis omiscomaycus	trout-perch	x		
Percidae				
Etheostoma exile	Iowa darter			
Perca flavescens	yellow perch		x	
Stizostedion v. vitreum	walleye	x		
Cottidae				
Cottus cognatus	slimy sculpin	x		x
Cottus ricei	spoonhead sculpin			

* a = Bond and Machniak 1977, 1979;
b = Griffiths 1973;
d = Walder et al 1980.

TABLE 9 Watershed: Muskeg Drainage - Hartley Creek

Taxa	Common Name	Occurrence * a	c	d
Salmonidae				
Salmo gairdneri	rainbow trout			
Salvelinus malma	Dolly Varden			
Salvelinus namaycush	lake trout			
Coregonidae				
Coregonus artedii	lake cisco			
Coregonus clupeaformis	lake whitefish			
Coregonus zenithicus	shortjaw cisco			
Prosopium williamsoni	mountain whitefish		x	
Thymallidae				
Thymallus arcticus	Arctic grayling	x	x	x
Hiodontidae				
Hiodon alosoides	goldeye			
Esocidae				
Esox lucius	northern pike		x	
Cyprinidae				
Chrosomus eos	northern redbelly dace			
Chrosomus neogaeus	finescale dace			
Couesius plumbeus	lake chub	x		
Hybognathus hankinsoni	brassy minnow			
Notropis atherinoides	emerald shiner			
Notropis hudsonius	spottail shiner			
Pimephales promelas	fathead minnow			
Platygobio gracilis	flathead chub			
Rhinichthys cataractae	longnose dace		x	
Semotilus margarita	pearl dace			x
Catostomidae				
Catostomus catostomus	longnose sucker	x	x	
Catostomus comersoni	white sucker	x	x	x
Gadidae				
Lota lota	burbot			
Gasterosteidae				
Culaea inconstans	brook stickleback	x		x
Pungitius pungitius	ninespine stickleback			
Percopsidae				
Percopsis omiscomaycus	trout-perch			
Percidae				
Etheostoma exile	Iowa darter			
Perca flavescens	yellow perch			
Stizostedion v. vitreum	walleye			
Cottidae				
Cottus cognatus	slimy sculpin	x		x
Cottus ricei	spoonhead sculpin			

* a = Bond and Machniak 1977, 1979;
c = Shell Canada Ltd. 1975

Although the techniques for gathering biophysical data for watersheds are sound (Wrangler and Seidner 1979, Chamberlin and Humphries 1977, Shera and Grant 1980), workers merely associate fish fauna with the data base within each stream reach. While it is useful to have a storage bank of biophysical data for watersheds within a physiographic region, the benefits of the system are left to the user, i.e. the system is set up as a storage base of descriptive watershed parameters, not as a predictive tool to be used in stream management.

Bond and Machniak (1977, 1979) studied the fish fauna of the Muskeg River during spring and summer, in the years 1976 to 1978. Fish movement between the Athabasca and Muskeg rivers was monitored (28 April to 30 July 1976, 28 April to 15 June 1977) 1 km upstream from the mouth of the tributary using a two-way counting fence. Of 6153 fish which passed through the upstream fence in 1976, most were white suckers (46%), longnose suckers (46%), Arctic grayling (5%), and northern pike (2%). Of 5275 fish trapped in 1977, white suckers (56%) and longnose suckers (31%) were dominant. Because grayling are often the first species to migrate upstream after ice-out (and fish counting fences are not erected until ice has cleared), their population size is frequently underestimated.

Spawning of longnose suckers (*Catostomus catostomus*) begins in late April (Bond and Machniak 1979). Upstream movement was initiated prior to fence installation as the water temperature approached 5°C. Spawning of white suckers (*Catostomus commersoni)* began as water temperature approached 10°C. Although young-of-the-year and adult longnose and white suckers were abundant in the lower Muskeg River and Hartley Creek, none was collected in the upper reaches of the Muskeg. Numerous beaver dams prevent migratory species from reaching the headwater regions of the watershed. Adult suckers leave the Muskeg River in mid May and continue to do so throughout the summer. Fry hatch by the end of May and most drift out of the watershed during the summer. Bond and Machniak (1979) suggest that most fry and adult suckers overwinter in Lake Athabasca.

Although northern pike (*Esox lucius*), walleye (*Stizostedion vitreum*), mountain whitefish (*Proscpium williamsoni*), and lake whitefish (*Coregonus clupeaformis*) may feed in the lower reaches of the Muskeg River, these species are not known to spawn in the watershed (Bond and Machniak 1979). Lake whitefish and walleye may utilize the mouth of the Muskeg River as resting sites during fall migrations on the Athabasca River.

Several species of small fish (brook stickleback, lake chub, slimy sculpin, longnose dace, and, probably, pearl dace) are year-round residents of the Muskeg River. Brook stickleback are most abundant in the upper watershed where they occur together with pearl dace. Lake chub are abundant in the mid reaches of the watershed, while slimy sculpin and longnose dace inhabit the lower reaches.

Corkum and McCart (1981) found few fish and fish species in the upper Muskeg River. One northern pike was caught after 79.5 h of gillnetting. Ten pearl dace, six longnose suckers, and five brook sticklebacks were retrieved from baited minnow traps (76.25 h of effort).

High water levels in the autumn have frequently impeded fish monitoring programs in the Muskeg River (Machniak 1979). During October 1980, the downstream movement of fish was monitored in the Muskeg River (T. Dickson, personal communication). Despite high water levels, a full counting fence across the river was maintained from October 15-16 and 28-29; partial fences were maintained periodically from 28 September to 27 October. The following fishes and their relative abundance were reported moving downstream (T. Dickson, personal communication):

Fish	N	% of Catch
White Suckers	576	64.9
Northern Pike	205	23.1
Longnose Sucker	76	8.6
Arctic Grayling	25	2.8

Evidently, white suckers and northern pike retreat to the Athabasca River to overwinter.

Within the Alsands lease area, RWES (1980) collected seven fish species from 12 lakes. Northern pike were collected in gillnets from the oxbow lake. Other fish (brook stickleback, pearl dace, finescale dace, longnose sucker, white sucker and trout-perch) were captured in lakes and streams by beach seining and electrofishing. Apparently, suckers and pike which previously occupied the deep upland lakes are now absent (RWES 1980). At present, brook sticklebacks are in three of the upland lakes (#5, 6 and 8). In addition, pearl dace and finescale dace were collected from one lake.

SUMMARY AND CONCLUSIONS

General Evaluation

The available literature on the Muskeg River and its tributaries provides a basic description of stream ecology in the Muskeg River basin. This description, however, suffers from certain inconsistencies in the data both within and among studies, and from unresolved disagreements in interpretation among investigators. The latter problem appears to have arisen from a failure of the major investigators, especially those working on periphyton, to fully integrate their observations with those of others working on the same river, often on the same ecological communities.

Below, the various categories of available information on the Muskeg River are evaluated regarding their value as background information for biological monitoring of the Muskeg River.

Hydrology

The available information adequately characterizes the hydrological regime of the Muskeg River for the purposes of biological monitoring. The continuously monitored gauging stations on Hartley Creek and Muskeg River provide reliable streamflow data that can be related to biological information gathered on these streams. It would be useful to monitor flows of the Muskeg River above Hartley

Creek near the Alsands site, or at least to relate flows there to flows at the gauging stations by regression methods, but this has not yet been done.

Water Quality

The available studies are generally adequate to characterize the water quality of the Muskeg River and Hartley Creek; however, certain of the data upon which the principal study (Akena 1979) is based have been questioned implicitly or explicitly by its author or others (e.g., Schwartz 1980), and may be unreliable. Certain interpretations of the data by Akena (1979) require experimental verification.

Periphyton

Studies to date have provided good baseline data, particularly on epilithic algae at a single riffle site on the Muskeg River. Interpretations of these data have often been contradictory both within and among studies. At the least, they require verification experimentally or by further field observation.

Plankton

The existence of a plankton community in the Muskeg River has been documented, but its origin has not been satisfactorily determined. Because of the large number of beaver ponds and slow-flowing sections in the upper Muskeg drainage, both zooplankton and phytoplankton could be abundant upstream but this possibility has not been adequately studied.

Benthic Invertebrates

Good baseline data are available for a small number of sites on Hartley Creek and the Muskeg River, most of them riffle locations. Data on the fauna of the predominant soft substrate habitat is sparse, and there is little quantitative information on chironomids, the dominant invertebrates in terms of numbers.

Fish

Fish studies in the Muskeg River have quantitatively documented movements of several important fish species into (and, to a certain extent, out of) the river, and have established that it is an important rearing stream for suckers and (possibly) Arctic grayling. Specific areas of critical habitat (spawning, rearing, and overwintering) have not been adequately identified. The number of grayling using the stream has not been satisfactorily determined.

Seasonal Events in the Muskeg River

Despite weaknesses in the data as summarized above, the available literature provides a basic outline of some of the important biological events in the Muskeg River. These are outlined in a seasonal format below.

Winter (November to mid-April)

Discharge is minimal, but fairly stable under ice. Winter flows, consisting mainly of groundwater discharge, reach minimum values in March. Major ions are inversely correlated with discharge; therefore, maximum concentrations of calcium, magnesium, bicarbonate, sodium, chloride, and conductivity occur during winter base flow conditions. Constant minimum water temperatures ($T=0^oC$) occur from November to March. Highest benthic biomass occurs during this period. Some growth of winter stoneflies, tipulids, and chironomids occurs. Overwintering fish residents include brook stickleback, lake chub, slimy sculpin, longnose dace, and pearl dace.

Spring (mid-April to May)

Spring runoff peaks in May after ice breakup and accordingly, the major ions decrease. Suspended solids and turbidity, however, are often greatest during high discharge levels. Typically, in other brown-water streams (e.g., Bigoray River), increasing amounts of nitrates, phosphates, and organic material are drained from the land and enter the river channels resulting in an increase of water colour. Water temperatures begin to rise rapidly in late April. Willows begin to leaf. Several stonefly species of the genera *Zapada* and *Taeniopteryx* begin to emerge, as do the first terrestrial insects. The reproductive period of most insects begins in May. The upstream migration of Arctic grayling, northern pike, and longnose and white suckers commonly starts in April during or before ice breakup.

Summer (June to August)

Muskeg drainage contributes most of the moderate flow in this period. Water levels tend to decrease by mid-summer. Water temperatures continue to increase to about 20^{O}C in the Muskeg River, but to lower levels in Hartley Creek. The previous year's leaf litter has disappeared. The present year's trees are in full leaf. Algal populations tend to increase. The density of aquatic macrophytes begins to increase. This is the maximum period of reproduction for aquatic invertebrates, maximum species diversity occurring in August. Maximum numbers of terrestrial insects drop into the river channels during this season. No major migratory movements of fish are observed.

Autumn (September to October)

Discharge levels increase in September and October, often creating flood conditions. Filamentous algae is abundant, aquatic macrophytes reach their maximum density and leaf fall begins. Beaver dams, if not flooded over, impede the downstream flow of leaf litter. Maximum flood levels are present for macroinvertebrate food processing. Corixids and ceratopogonids exhibit maximum population densities. Although young-of-the-year Arctic grayling may overwinter in pools, white suckers and pike retreat to the Athabasca River and overwinter. With rapid decreases in water temperature, ice forms along the stream margins.

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APPENDIX A

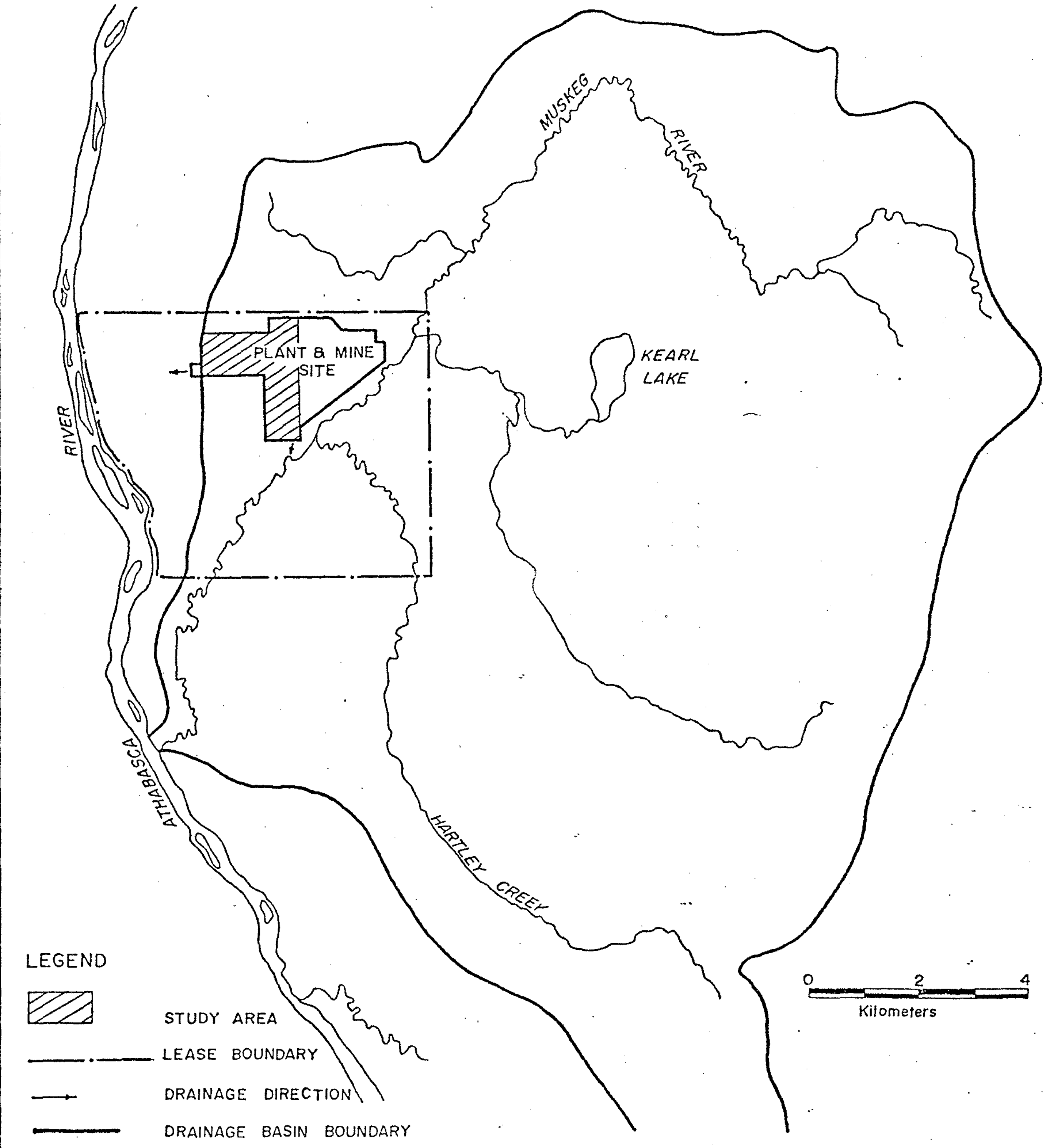
INTRODUCTION

Alsands Ltd. intend mining an oil sand lease located approximately 64 km (40 mi.) north of Fort McMurray in the Muskeg River watershed, east of the Athabasca River. During February and March 1980, an area of 13.9 km^2 (5.4 mi^2) was cleared of timber to provide a site for the plant and first 5 years of mining operation. Following the clearing, a drainage network was constructed at the site to drain the area in preparation for construction and mining. Figure 1 shows the location of the study area relative to the Muskeg river watershed and Figure 2 shows the approximate layout of the ditch network.

This report has been prepared by Hardy Associates (1978) Ltd. for Aquatic Environments Ltd. to describe the effects of the clearing and ditching on the hydrology of the Muskeg River watershed. In particular, the changes in runoff derived from snowmelt and rainfall are addressed in an attempt to quantify the variation in runoff contribution to streamflow before and after clearing.

2.0 PHYSICAL CHARACTERISTICS OF THE SITE

The runoff quantity from snowmelt and rainfall is controlled by topography, climate, soils and vegetation. Each parameter is briefly described below according to the site conditions.



FROM ALSANDS, 1979

HARDY ASSOCIATES (1978) LTD.
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AQUATIC ENVIRONMENTS LTD
STUDY AREA RELATIVE TO
MUSKEG RIVER DRAINAGE BASIN

K 5451

Fig 1

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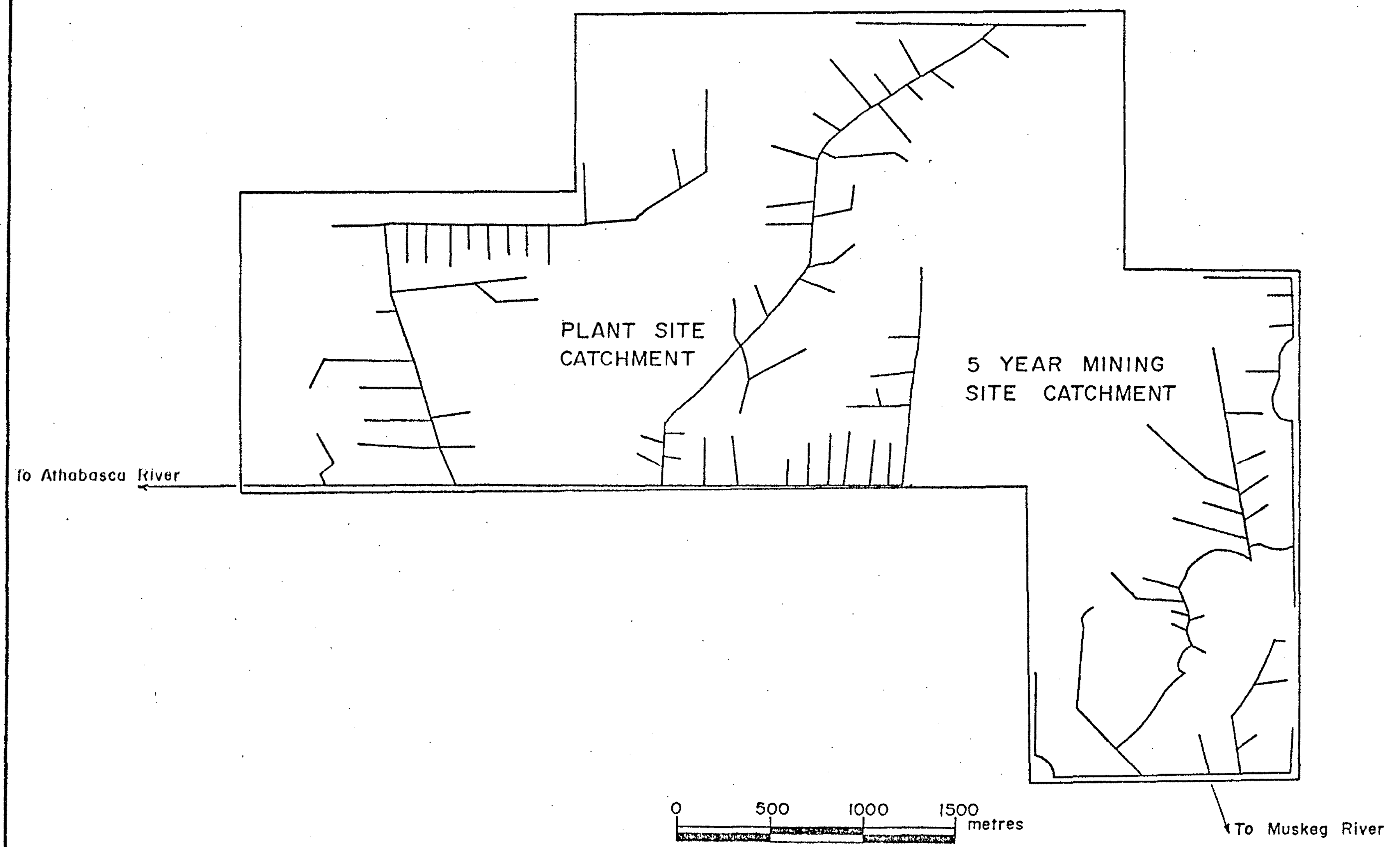

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ALSANDS PLANT AND 5-YEAR MINING SITES
SHOWING DRAINAGE DITCH LAYOUT

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Fig 2

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Topography

The Alsands plant and mine site is located approximately 64 km (40 mi.) north of Fort McMurray in the Muskeg River Basin, east of the Athabasca River. The site is situated on an extensive plateau where overland flow predominates and there are few streams. Elevations in the area range from 292 m (958 ft.) to 302 m (991 ft.) a.s.l.. Because of the low relief drainage is poor and large sections of the site are covered with standing water, bogs and fens (muskeg).

Climate

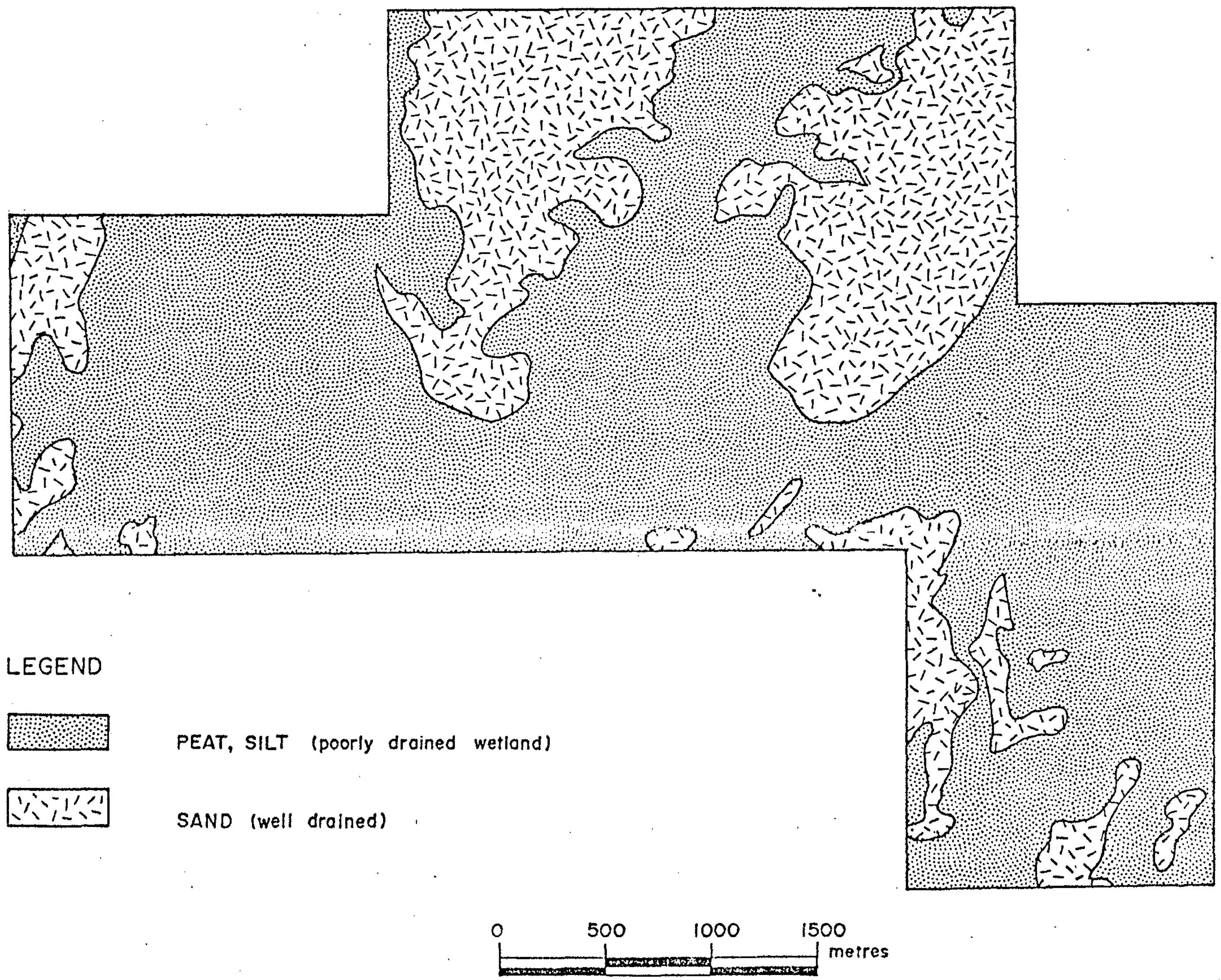
The Alsands area has a subarctic continental climate with short summers and long, cold winters. The mean annual temperature is $0^{o}C$ ($32^{o}F$). At Fort McMurray, the mean frost free period for 1941-1970 was 67 days. Winds are low most of the year. During the 30 year period from 1941 to 1970, the mean annual precipitation recorded at Fort McMurray airport was 435 mm (17.1 inches) with 70 percent falling as rain, the rest as snow. Maximum and minimum monthly precipitations occur in July and February respectively. Evapotranspiration in the area is high compared with other areas of similar latitude (Neill & Evans).

Soils

Surficial soils in the region include glacial deposits of gravel, sand, and silt; and post-glacial deposits of wind and water borne sand and gravel. Approximately 70 percent of the study area is overlain by peat. Figure 3, a simplified diagram of the soil and drainage conditions, shows the distribution of surficial deposits over the plant and mine sites. The widespread presence of organic soils acts to retard surface runoff.

Vegetation

The distribution of vegetation types over the plant and mine sites prior to clearing is shown in Figure 4. Prior to clearing, the boundaries between vegetation types coincided with changes in ground moisture conditions resulting from small changes in relief. Forests of aspen poplar and jack pine grew on well drained site; black spruce and tamarack grew in poorly drained areas; and muskeg or fen was found on very poorly drained areas which contained standing water during the growing season. Approximately 70 percent of the plant and mine sites consisted of muskeg and fen vegetation.



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SURFICIAL SOILS ON STUDY AREA

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Fig 3

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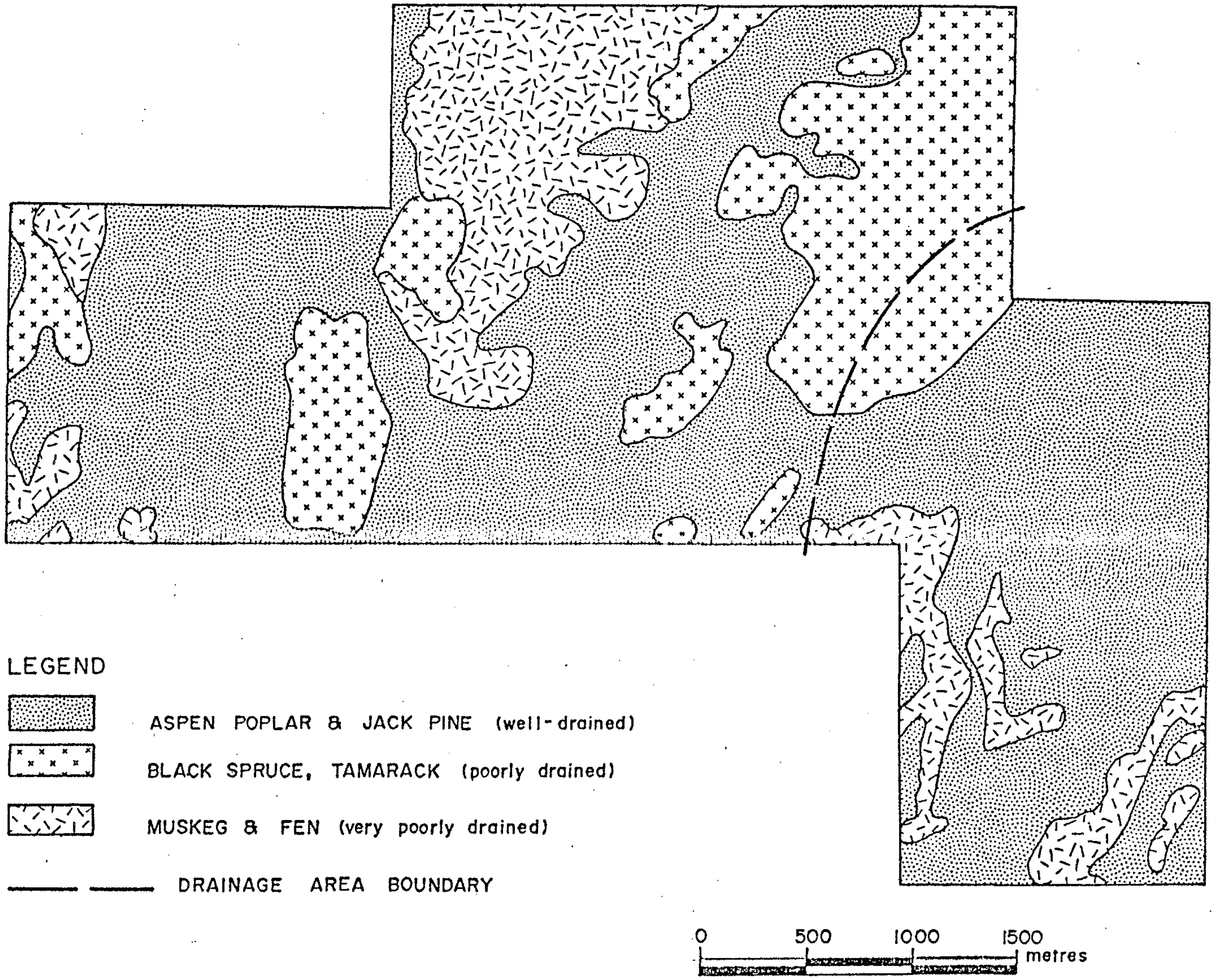

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VEGETATION COVER ON STUDY AREA
(BEFORE CLEARING)

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Fig 4

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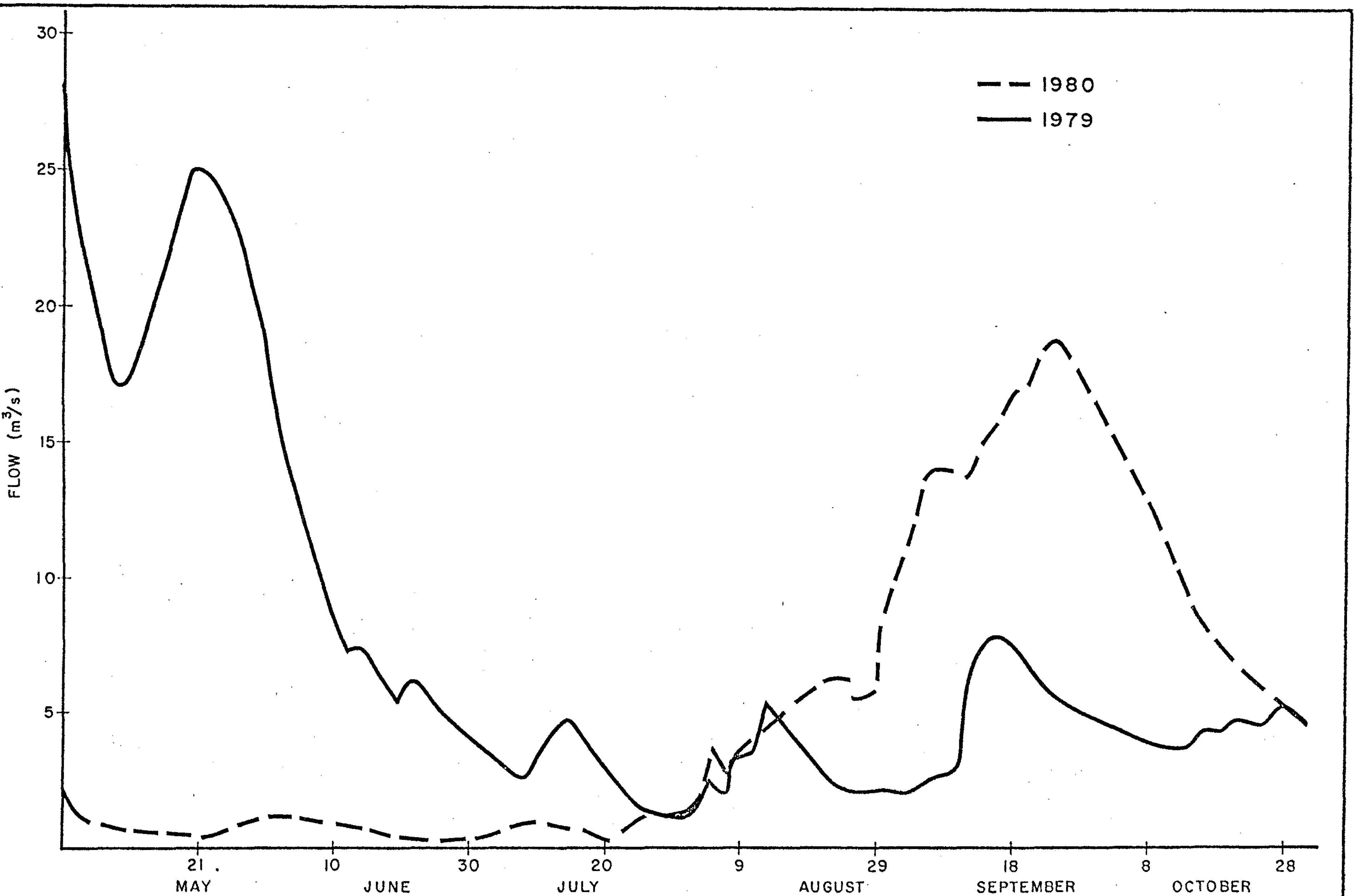
During the clearing operation, all trees were felled and removed and the ditch networks were constructed. Thus the remaining vegetation consists of muskeg, mosses and grasses. Most of the poorly drained areas are now drained so that much of the muskeg is now replaced by grasses.

3.0 RUNOFF

The runoff from the plant and "5 year" mining site is now measured periodically but was not monitored prior to clearing. Consequently the effect of clearing on the runoff from the site cannot be determined directly. Thus hydrographs from Water Survey of Canada (WSC) data for the Muskeg River for 1979 and 1980, before and after clearing, were compared (Figure 6). However, no significant change attributable to the clearing operations could be distinguished since the change in runoff is not large enough to noticeably affect flows in the Muskeg River, recorded at the WSC station (No. 07DA008). The station is approximately 11 km (7 mi) downstream of the discharge point of the outlet ditch from the "5 year" mining area. The changes in runoff from the study area were assessed using the methodology of the Rational Formula to evaluate the impact of clearing on runoff from rainfall.



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ANNUAL HYDROGRAPHS FOR MUSKEG RIVER
STATION NO. 07DA 008

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FIG. 6

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The Rational Formula is an empirical method used to estimate peak runoff rates from catchments up to 2.6 km^2(1 mi^2) in area. It is expressed as

$$q = C\ i\ A \qquad (1)$$

where q is the peak rate of runoff for a given return period (in cfs or acres in/hr.)

C is a runoff coefficient which accounts for several basin characteristics that affect the rainfall-runoff relationship.

i is the rainfall intensity (in inches/hr.)

and

A is the area of the catchment (in acres).

The area was subdivided into two drainage areas as shown in Figure 4. These areas approximate the plant site and the "5 year" mining area. Using a planimeter the areas were determined to be 9.1 km^2(3.6 mi^2) and 4.8 km^2 (1.8 mi^2) respectively. The plant site drains to the west towards the Athabasca River while the 5 year mining area drains south to the Muskeg river.

The derivation of the runoff coefficient C is based on an empirical process which accounts for the effects of rainfall intensity, topography, surface and channel storage, infiltration, and vegetation cover on the rainfall-runoff relationship in each catchment. In this case the method developed by Turner (1961) was used for the calculation of C. This method uses a ranking system for each of the above physical parameters, according to the effect of each parameter on runoff. Table 1 has been developed from Turner's work, for the study area. In this table a particular physical parameter for the study area is compared in the table and allocated a number depending on whether it permits low, normal, high or extreme runoff. The same method is applied to all of the parameters. Then the allocated numbers are summed and divided by 100 to give C.

The rainfall intensity was determined from intensity-frequency-duration curves for the Muskeg River Area (Figure 5) for a return period of 10 years using a duration equal to the time of concentration of each basin. The curves were derived from Bruce, (1968). The use of the intensity-frequency-duration curves requires the computation of the times of concentration for each site.

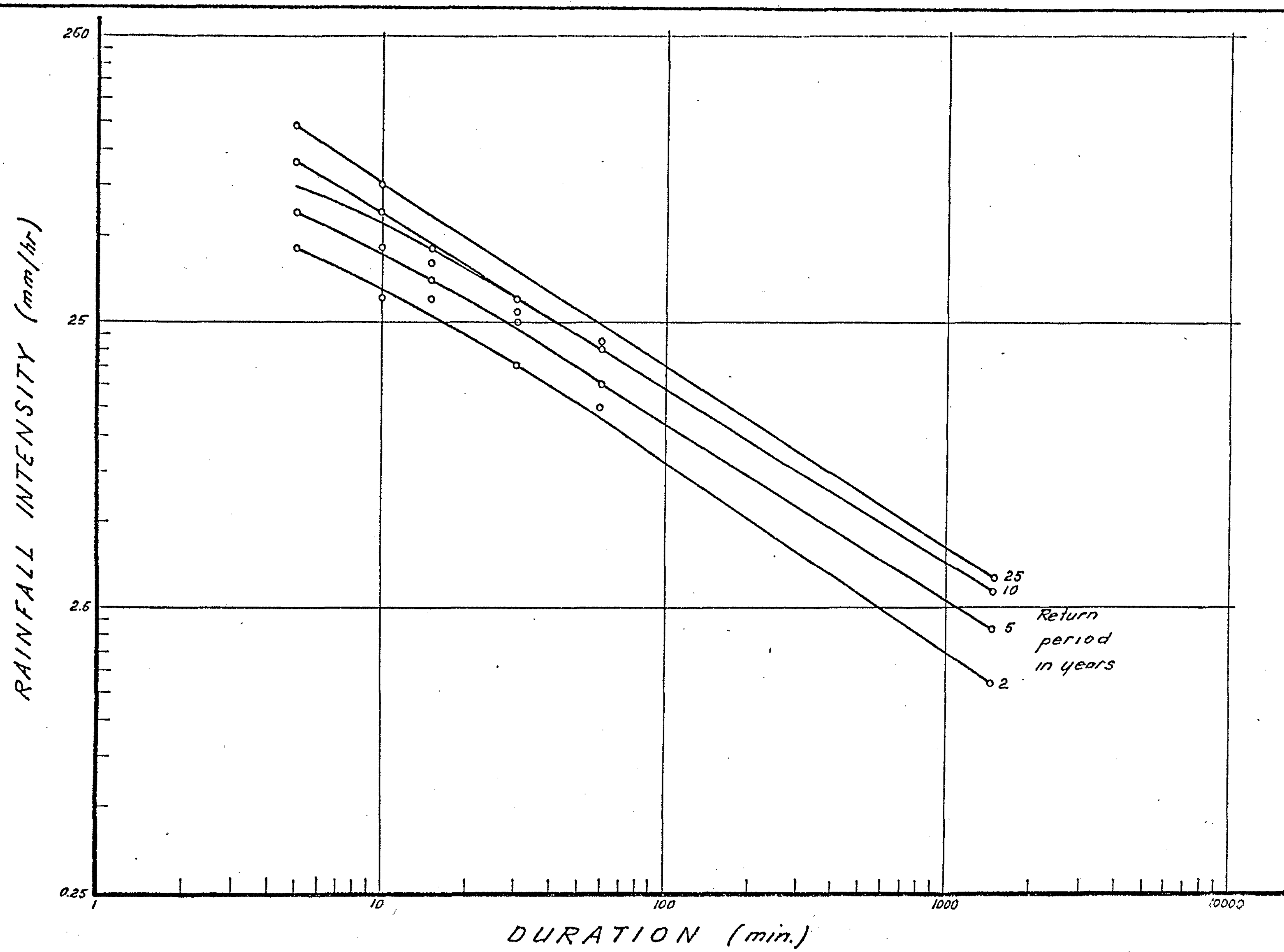
The time of concentration is defined as the length of time required for the whole catchment to contribute runoff to the outlet or the time required for water to travel from the most remote part of the basin to the outlet. For small catchments with an area between 0.4 km^2

TABLE 1

Estimation of Coefficient of Runoff C for use in the Rational Formula

CATCHMENT CHARACTERISTICS	RUNOFF - PRODUCTING CHARACTERISTICS Extreme	High	Normal	Low
Rainfall Intensity	(15) 1"-2" per hour	(10) 0.5" per hour	(5) 0.5" per hour	(0) < 0.5" per hour
Relief	(10) Steep, rugged country with ave. slope above 20%	(5) Hilly, with average slopes of 10%-20%	(0) Rolling with average slopes of 5-10%	(0) Relatively flat land with average slope 0-5%
Surface retention-Stream and surface storage	(25) Negligible; few surface depressions; water courses steep with thin film of overland flow	(15) Well defined system of small water courses	(10) Considerable surface depressions; overland flow is signicant; some ponds and swamps	(5) Poorly defined & meandering stream courses; large surface storage;
Infiltration	(25) No effective soil cover; either solid rock or thin mantle of negligible infiltration capacity	(20) Slow water infiltration;	(15) Loam soils or well structured clay soils	(10) Deep sands or well aggregated soils
Cover	(30) No effective plant cover	(20) Less than 10% of area with plant cover	(15) About 50% of area with plant cover	(5) About 10% of area with with plant cover

Adapted from: Turner, A.K. "Rainfall Losses in Relation to Runoff for Small Catchments" Jour. Inst. Engrs. Australia Vol.32 (1960)



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RAINFALL-FREQUENCY-DURATION-INTENSITY GRAPH FOR STUDY AREA

FIG. 5

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($0.16\ mi^2$) and 4 km^2($1.6\ mi^2$) acres, an empirical formula known as the Bransby - Williams formula is commonly used to estimate the time of concentration from catchment parameters. The Bransby - Williams equation is

$$t_c = \frac{0.88\ L}{M^{0.1}\ H^{0.2}} \tag{2}$$

where t_c is time of concentration (in hours)

L is maximum length of water travel (in miles)

M is catchment area (in square miles)

and

H is average slope of catchment (in percent)

Using the above method, times of concentration of 220 min. and 140 min. were obtained for the plant site and mine site catchments. These times were entered into the rainfall intensity - frequency - duration graph (Figure 5) giving rainfall intensities of 8.9 mm/hr (0.35 in/hr) and 11.7 mm/hr (0.46 in/hr) respectively.

Applying the physical conditions at the study area and the rainfall intensities for the two sites, Table 1 was used to obtain C values for before and after clearing for the two sites. Table 2 shows the development of the C factors and the reasoning for the ranking selection.

TABLE 2

Derivation of Runoff Coefficient C for Alsands Plant & Mine Site Catchments

	BEFORE CLEARING				AFTER CLEARING			
	Plant Site Catchment		Mine Site Catchment		Plant Site Catchment		Mine Site Catchment	
	No.	Reason for Choice	No.	Reason for Choice	No.	Reason for Choice	No.	Reason for Choice
Rainfall Intensity	0	i = 0.35 in/hr	0	i = 0.46 in/hr	0	i = 0.35 in/hr	0	i = 0.46 in/hr
Relief	0	almost flat max slope = 0.17%	0	almost flat max slope = 0.28%	0 0	almost flat max slope = 0.17%	0 0	almost flat max slope = 0.28%
Retention & Storage	4	Meandering streams, large areas of standing water	4	Meandering streams, large areas of standing water	10	Defined system of small watercourses; Some poorly drained areas.	10	defined system of small watercourses; some poorly drained areas.
Infiltration	14	From Fig 3 64% peat, silt 36% sand .64x16+.36x10=13.8	15	From Fig 3 81% peat, silt 19% sand .81x16+.19x10=14.9	12	More infiltration once ditches installed because ditches cut into sands underlying peat in some areas.	13	More infiltration once ditches installed because ditches cut into sands underlying peat in some areas.
Cover	6	From Fig 4 18% poplar, pine 20% spruce, tamarack 62% muskeg, fen 0.18x4+0.82x6=5.6	6	From Fig 4 7% poplar, pine 7% spruce, tama- 86% muskeg, fen 0.07x4+0.93x6=5.9	7	In former treed areas, ground cover more developed. 0.18x14+0.82x6=7.4		In former treed areas, ground cover more developed. 0.07x14+0.93x6=6.6
TOTAL	24		25		29		30	
C	0.24		0.25		0.29		0.30	

The methodology gave the following results:

	C-value Before Clearing	C-value After Clearing	C-value Percent Change
Plant Site	0.24	0.29	21%
Mine Site	0.25	0.30	20%

To check the runoff coefficient, the average annual flow in the Muskeg River, as recorded by the W.S.C., was divided by the Muskeg River drainage basin area (1455 km^2, 562 mi^2) and the average annual precipitation (435 mm, 17.14 in.). This gave a runoff coefficient of 0.24 for the uncleared site, which corresponds to the values derived using the ranking system.

Prediction of the effects of the clearing on the runoff from snowmelt is difficult. No suitable theoretical models are available to relate the snowpack depth to the runoff without field measurement of the snowpack depth before and after clearing. Theoretical models are difficult to apply due to the large number of variable physical characteristics. Clearing of trees changes wind patterns and hence snow accumulation. The larger the open space, the more snow that is directly exposed to the heat of direct sunlight and thus greater and sooner runoff volumes occur at freshet.

Neill and Evans,(1979)found that in 1976 runoff from snow represented 33 percent of the water content of the late winter snowpack. The rest was lost to evaporation and infiltration. The 1976 runoff coefficient for snowmelt was calculated to be 0.18 by Neill and Evans.

Swanson and Hillman, (1977) have carried out a study of the effects of clear-cutting in west-central Alberta. From literature and field studies, they concluded that clear-cutting causes higher instantaneous flows early in the season and greater overall runoff volumes at freshet. In addition, storm-flow peaks could be up to 5 times higher and annual streamflow up to 30 percent greater for logged catchments.

4.0 CONCLUSIONS

Using a ranking procedure for determining the runoff coefficient based on hysical parameters, it has been estimated that clearing of the Alsands plant site and 5 year mining site may have increased the runoff from those sites by 20 percent. The magnitude of this increase is similar to those reported by Swanson and Hillman (1977).

Without tree cover, snowmelt occurs earlier and faster than before clearing as the snowpack has a greater exposure to sunlight. Storm flows from the cleared areas could be more than 3 times greater than those experienced before clearing. The increased flows are due to lower interception by vegetation and faster drainage due to the drainage networks.

At present the cleared area at the Alsands lease represents less than 1 percent of the drainage basin of the Muskeg River. Approximately 2/3 of the cleared area now drains to the Athabasca River, forming an insignificant percentage of the drainage basin of the river. Consequently the clearing of the plant site and 5 year mine site should have an insignificant impact on the runoff in the area. However, future clearing of the rest of the lease and the adjoining leases in conjunction with the proposed mining activities will have a significant effect on the hydrologic regime of the area.

5.0 RECOMMENDATIONS

This report has quantified the possible changes in runoff conditions for the cleared and drained Alsands plant site and 5 year mining area. The conclusions are based on a consideration of the change in physical characteristics of the drainage basin and on available references. To clearly define the changes in runoff due to the clearing operation, the runoff hydrograph for the cleared areas should be compared with the runoff hydrograph for an uncleared area. At present the outlet ditches from the plant site and mine site are monitored. The hydrographs for these ditches should be compared with the hydrograph for a section of the Muskeg River upstream of the cleared area. By measuring the flow at two points along the river and determining the drainage area contributing to the increase in flow between the points, a hydrograph could be compiled for the uncleared area. With comparison of the hydrographs, the full effect of clearing on runoff could be obtained and used for predicting future changes associated with further clearing.

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Respectfully Submitted,

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KGD/lt

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