REGIONAL WATER QUALITY OF THE AOSERP STUDY AREA

VOLUME II: DISCUSSION OF 1976 AND 1977 DATA

by

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ABSTRACT

A regular program of water quality sampling has been instituted throughout the region of current oil sands development in northeastern Alberta. The goals of this program were to provide a base of background information on an extensive number of water quality parameters to enable the employment of predictive techniques and at the same time to obtain an understanding of natural water quality loadings and processes. The data collected has been stored under NAQUADAT codes at Alberta Environment, Water Quality Control Branch.

The following trends were concluded from the set of data covering the first two years of sampling (1976 and 1977):

1. Definite relationships of discharge with major ionic species were demonstrated for most of the tributaries in the region. The relationship at each site, attributable to the geology and physiography of the basins, ranged in character from the highly variable hard waters of the MacKay and Hangingstone rivers to the relatively stable soft waters of the Firebag and Richardson rivers emanating from the Precambrian Shield. Disruptions in typical patterns could be discerned for Poplar Creek which had been subject to diversion influence. In the stretch of the Athabasca River flowing through the oil sands development area, dilution behaviour typical of the tributaries was noted. Man made ionic loadings to the Athabasca River could not be discerned from the data.

2. A high variation in the turbidity regimes of the tributaries was noted throughout the area. The tributaries varied, from the highly enduring turbidity of the Hangingstone River to the consistently clear Firebag River. In most streams and rivers, there were at least brief episodes of high suspended solids as measured by both nonfilterable residue and nonfilterable residue fixed. Many smaller tributaries showed high duration of an organic component of the nonfilterable residue, likely caused by muskeg input. The above average suspended materials regimes of tributaries adjacent to oil sands activities were not above the range for the region.

3. Throughout the region, the maximum total dissolved organic carbon levels varied between 10 and 45 ppm. Occurrences of maxima typically corresponded to allochthonous inputs during spring and autumn, but anomalous behaviours were exhibited by a relatively constant regime in Poplar Creek and an irregular pattern in Bridge Creek Diversion which appear to be a consequence of development activities.

4. Maximum total phosphorus levels ranged from 0.1 to 0.5 ppm throughout the region. No single controlling factor was discernible from the data and tributaries affected by mining activity showed no significant departure from the regional pattern.

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1. INTRODUCTION

1.1 STUDY AREA OVERVIEW

The Alberta Oil Sands Environmental Research Program (AOSERP) study area is located in northeastern Alberta (Figure 1). It encompasses approximately 28 600 km^2 including most of the mineable area of the Athabasca deposit of oil sands. This vast deposit, which is one of several oil sands deposits in Alberta, contains 600 x 10^9 barrels of bitumen (Berkowitz and Spreight 1975). The development of this deposit is currently underway with two surface mines operating north of Fort McMurray, Great Canadian Oil Sands Ltd. (GCOS)[1] and Syncrude Canada Ltd. Also, a number of pilot in situ thermal recovery operations are being developed in the study area south of Fort McMurray, including Texaco Canada Ltd. and Amoco Petroleum Ltd. (Malden 1978).

The surface water originating in and passing through this study area flows through an extensive network of different types of interconnected water courses ranging from muskeg and lakes to small and large rivers. In addition to providing essential habitat for the aquatic fauna that already exists in these water courses, this water serves as a source for domestic, commercial, industrial, and recreational use.

The primary industrial use of water in the area now is for oil sands mining and processing. Current oil sands technology for both surface operations and in situ recovery requires the intake of water for use in processing and, for most operations, the discharging of some type of effluent into the water-ways. Presently, the first oil sands processing plant, GCOS, has a license to discharge process water into the Athabasca River. Although other surface mining plants, under present licence restrictions, will not be allowed that type of discharge, many will require discharge of mine depressurization water, as does Syncrude Canada Ltd. Most in situ processing of oil sands

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[1] GCOS amalgamated with Sun Oil Company in August 1979, after the writing of the report was completed, to become Suncor, Inc.

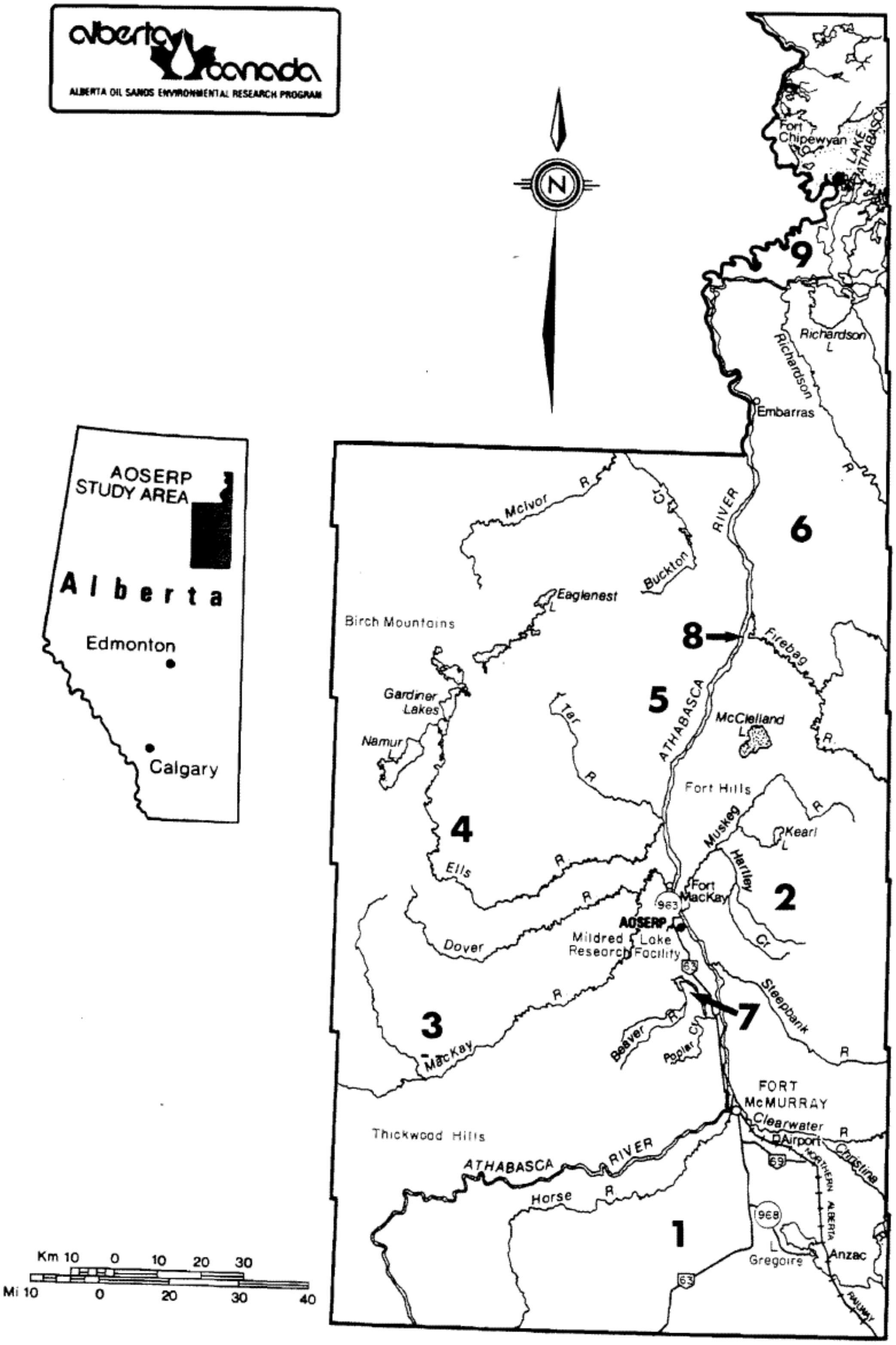

Figure 1. The Alberta Oil Sands Environmental Research Program study area and regions of water sampling activity.

requires the withdrawal of water from either the surface water or the groundwater systems, in addition to perturbation of the groundwater system. Some kinds of in situ operations may require either discharge or impoundment of waste water (Humphreys 1979).

More general use of the regional water supply is demonstrated in the Athabasca River Delta and the neighbouring region in Wood Buffalo National Park. These areas support a commercial fishery, an important trapping industry, and a significant waterfowl population. Each kind of use of water has its own set of water quality measurements. Naturally, for use of water for human consumption or for safeguarding aquatic fauna, higher standards are called for than with most other uses. Development and expansion of the oil sands industry in the AOSERP area will place demands on the surface water system and maintenance of its quality, especially with regard to the aquatic fauna, is of increasing concern.

1.2 WATER QUALITY SAMPLING PROJECTS AND REPORTS

In order to gather information on the state of baseline water quality and to detect any changes that might be caused by current oil sands developments, a number of projects involving water sampling and analysis were initiated by AOSERP, starting in February 1976. Initially, a number of groups contacted by AOSERP collected and analyzed water samples with project goals in mind (Korchinski in revision; Costerton and Geesy 1979; Strosher and Peake 1977, 1978; Akena 1979; Froelich 1980).

At the beginning of 1977, a regionally co-ordinated sampling program was initiated, to be conducted for AOSERP by the Water Quality Control Branch, Pollution Control Division of Alberta Environment. This program was to run for at least three years and was aimed at the entire range of surface water: the mainstem Athabasca and Clearwater rivers, their tributaries, the lakes, and the Peace-Athabasca Delta. All data points gathered by this project were combined with data collected by the other AOSERP projects and stored in the National Water Quality Data Bank (NAQUADAT) coded computer files at Water Quality

Control Branch of Alberta Environment. See Akena (in prep.) for availability of these data which constitute a public record of AOSERP activity.

The intention of this report was to summarize and interpret the first run of all data collected from the oil sands area (February 1976 to December 1977). Such an interpretive summary was to generally define the baseline water quality in the AOSERP study area, to provide a preliminary identification of naturally operating processes, and to initially indicate development perturbations affecting the water quality.

1.3 OBJECTIVES OF THE WATER QUALITY SAMPLING PROGRAM

One eventual goal of the regional sampling program was to provide well-founded background data for an extensive number of water quality parameters so that the data base may be used to assist in the evaluation of various types of oil sands development employing predictive methods. Calculated effects of current and alternate policies could be assessed by comparison with pre-development conditions established by the baseline study. To lay the foundation for this goal, it was deemed necessary to establish as wide a base as possible. Also, in order to broaden the data base, data collected prior to AOSERP that could be validated was to be included in the base.

Meeting a second goal was of a more immediate concern: that of obtaining an initial understanding of the natural water quality loadings and processes in the AOSERP study area and establishing baseline conditions of water quality for current and future studies.

Specific objectives set for the project conducted by Water Quality Control Branch were:

1. To provide regional baseline water quality data, including the Athabasca Delta area;
2. To provide data on the variation of water quality parameters with time at the mouths of important stream basins. This will be used in future studies to confirm the general accuracy of calibrated water models by comparing predicted level with measured levels;

3. To identify significant naturally occurring water quality parameters which may be included in procedures for predicting water quality;
4. To provide a preliminary assessment of the contributions of water originating in or passing through the AOSERP area on the water chemistry in the Athabasca Delta area; and
5. To provide water quality information for concurrent studies.

1.4 REGIONAL WATER SAMPLING SITES

Grab samples of lake, river, and stream water were collected at various locations in and near the AOSERP study area commencing in February 1976. Samples collected by other AOSERP projects were taken bi-monthly, quarterly, or less frequently, according to individual project specifications which tended to be site specific. When the regional sampling project was commenced by the Water Quality Control Branch in April 1977, most samples were taken on a monthly basis throughout the region.

In order to provide a basis for judging the coverage of water sampling activity, as well as being handy for the purposes of describing water quality data,a broad geographical classification of watersheds was made. The following regions were described (see Figure 1):

1. The watersheds south of Fort McMurray between the Athabasca-Clearwater mainstem. Within the study area, this comprises the Horse and Hangingstone rivers (having basins of 2180 and 914 km^2, respectively) and includes all runoff from the north slopes of Stoney Mountain;
2. The watersheds east of the Athabasca River between the Firebag and Clearwater rivers. This area is mainly covered by the Muskeg and Steepbank river basins. These basins are of similar size (1460 and 1370 km^2, respectively);

3. The MacKay River basin which is a large (5230 km^2) watershed on the west side of the Athabasca River;
4. The Ells River basin (2476 km^2) which drains the large chain of headwater lakes in the Birch Mountains;
5. A group of small tributaries draining the east slopes of Birch Mountains;
6. The Firebag (6030 km^2) and Richardson (2950 km^2) river basins, both of which rise in the Canadian Shield in Saskatchewan.
7. Watersheds in the current surface mining area. These comprise the small basins of Poplar Creek and Beaver River;
8. The mainstem trunk of the Athabasca and Clearwater rivers; and
9. The Peace-Athabasca Delta. This area is the ultimate recipient of water flowing through the study area.

These divisions, being primarily geographical, serve well for preliminary regional consideration of water quality data. A more precise regionalization, based on physiographic considerations and surficial geology, has been carried out (Yaremko 1978). Although that regionalization addressed primarily hydrometric considerations, its structure is remarkably similar to the one presented here.

The 1976-1977 water sampling activity in these regions is presented in Tables 1, 2, and 3. The sampling sites are indicated in Figure 2 and a precise description of each site has been provided elsewhere (Akena in prep.). A detailed schedule of sampling activity for the mainstem Athabasca and Clearwater rivers is presented in Table 4 where the differences in activities of project-oriented objectives (three projects operated in the period of February 1976 to February 1977) and regional objectives (starting June 1977) are apparent.

The AOSERP Mildred Lake Research Facility (Figure 1) was used as a base for all sampling with the exception of far northern locations. Truck, jet-boat, snowmobile, and helicopter were used as required to reach sampling sites. At the time of sampling, measurements of pH, specific conductance, dissolved oxygen, and temperature

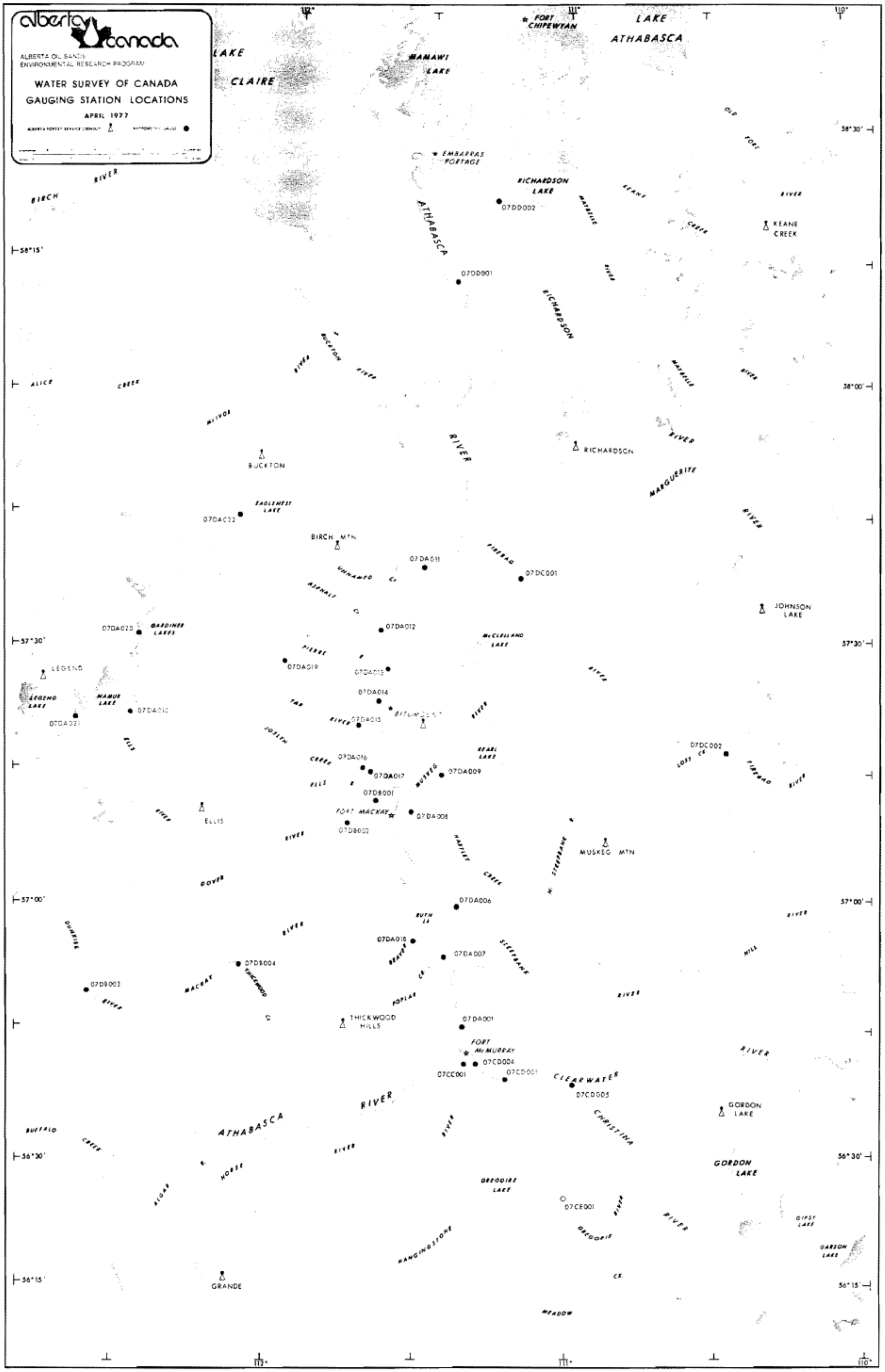

Figure 2. Water quality sampling and gauging station locations.

Table 1. Water sampling activity in tributaries.

Region Figure 1	Site (Figure 2) Code: Figure 4	Code: Water Survey Canada	Name	Annual Frequency 1976	1977
1	1.2	00AT07CD0040	Hangingstone River at Hwy 63	8[a]	11[a]
	1.3	00AT07CD0100	Saline Creek	5	3
	1.4	00AT07CC0030	Horse River at Abasands Park	3	2[a]
	1.5	00AT07CC0300	Horse River at Mouth	0	4
2	2.1	00AT07DA0060	Steepbank River	6[a]	11[a]
	2.2	00AT07DA0080	Muskeg River	[a]	[a]
	2.3	00AT07DA0090	Hartley Creek	[a]	[a]
3	3.1	00AT07DB0040	Thickwood Creek	3	10[a]
	3.2	00AT07DB0020	Dover River	2[a]	11[a]
	3.3	00AT07DB0030	Dunkirk River	4[a]	12[a]
	3.4	00AT07DB0010	MacKay River		
	3.5	00AT07DB0011	MacKay River at Hwy 63	7[a]	11[a]
4	4.4	00AT07DA0100	Upper Ells River	2[a]	11[a]
	4.5	00AT07DA0170	Lower Ells River Above Joslyn Cr.	2[a]	13[a]
	4.6	00AT07DA0160	Joslyn Creek	2[a]	7[a]
		00AT07DA0098	Ells River near Mouth #1	2	0
		00AT07DA0099	Ells River near Mouth #2	1	0
5	5.1	00AT07DA0190	Upper Tar River	2	9[a]
	5.2	00AT07DA0150	Lower Tar River	2[a]	11[a]
	5.3	00AT07DA0151	Tar River near Mouth	3	1
	5.4	00AT07DA0140	Calumet River	1[a]	10[a]
	5.5	00AT07DA0141	Calumet River near Mouth	6	0
	5.6	00AT07DA0130	Pierre River	2[a]	8[a]
	5.7	00AT07DA0131	Pierre River near Mouth	4	0
	5.8	00AT07DA0120	Asphalt Creek	2[a]	8[a]
	5.9	00AT07DA0121	Eymundson Creek	4	8
	5.10	00AT07DA0122	Eymundson Creek near Mouth	1	0
	5.11	00AT07DA0110	Unnamed Creek	2[a]	8[a]
	5.12	00AT07DA0111	Tributary to Unnamed Creek	1	0
		00AT07DA0115	Unnamed Creek near Mouth	2	0
6	6.1	00AT07DC0010	Firebag River	6[a]	11[a]
	6.2	00AT07DC0011	Firebag River near Mouth	0	3
	6.3	00AT07DC0020	Lost Creek	1	7[a]
	6.4	00AT07DD0020	Richardson River	0[a]	5[a]
7	7.1	00AT07DA0070	Poplar Creek	6[a]	9[a]
	7.2	00AT07DA0180	Beaver River above Syncrude	3[a]	10[a]
	7.3	00AT07DA0179	Beaver River inside Syncrude	2	0
	7.4	00AT07DA0181	Beaver River at Hwy 63	5	10
	7.5	00AT07DA0182	Bridge Creek at Hwy 63	4	8

[a] Continuous gauging conducted by Water Survey of Canada.

Table 2. Water sampling activity in lakes and the Peace-Athabasca Delta.

Region (Figure 1)	Site (Figure 2) Code: Water Survey Canada	Site (Figure 2) Name	Annual Frequency 1976	Annual Frequency 1977
1	01AT07DE0011	Gregoire Lake at weir	2	11
	01AT07CE0010	Gregoire Lake at Anzac	1	0
2	01AT07CD3000	Lake 26 km East of Fort McMurray	1	0
	01AT07DA0300	McClelland Lake	1	0
3	01AT07DB0035	Birch Lake near Snipe Creek	0	1
4	01AT07DA0220	Eaglenest Lake	0	12
	01AT07DA0200	Upper Gardiner Lake	0	11
	01AT07DA0210	Namur Lake	0	11
	01AT07DA2000	Gardiner Lake-lower site	0	4
9	00AT07DD0090	Jackfish Creek	0	5
	01AT07DD0080	Richardson Lake	1	5
	01AT07MD2000	Lake Athabasca at Sandy Point	0	4
	01AT07KF0200	Lake Claire North end of Birch River	0	4
	01AT07KF0201	Lake Claire at 28th baseline	0	3
	00AT07KF0140	Prairie River	0	5
	00AT07KF0100	Mamawi Lake Channel	0	5
	00AT07KF0101	Chenal des Quatre Fourchers	0	5
	00AT07NA0030	Riviere des Rochers	1	4
	00AT07NA0031	Riviere des Rochers at mile 217.5	0	1

Table 3. Water sampling activity in the mainstem Athabasca and Clearwater rivers.

Region (Figure 1)	Site (Figure 2) Code: Water Survey Canada	Site (Figure 2) Name	Annual Frequency 1976	Annual Frequency 1977
8	00AT07CD2300	Clearwater River	10[a]	7[a]
	00AT07CC0012	Athabasca River above Horse River	13	7
	00AT07DA0200	Athabasca River off McDonald Island	16	2
	00AT07DA0201	Athabasca River at km 10	5	2
	00AT07DA0203	Athabasca River at km 30	5	2
	00AT07DA0202	Athabasca River above GCOS	8	0
	00AT07DA0204	Athabasca River at km 42	7	4
	00AT07DA0205	Athabasca River at km 48	5	2
	00AT07DA0206	Athabasca River at km 55	5	2
	00AT07DA0207	Athabasca River at Fort MacKay	6	5
	00AT07DA0208	Athabasca River at km 84	5	2
	00AT07DA0209	Athabasca River at km 132	9	2
	00AT07DA0210	Athabasca River 21 km below Firebag	5	2
	00AT07DD0010	Athabasca River at Embarras	0[a]	4[a]
	00AT07DD0212	Athabasca River at Big Point Channel	2	5
	00AT07DD0213	Athabasca River at Fletcher Channel	1	0
	00AT07DD0214	Athabasca River at Goose Island Channel	1	0
	00AT07DA0211	Athabasca River at Embarras Channel	1	1

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[a] Continuous gauging conducted by Water Survey of Canada

Table 4. Dates of water sampling activity on the mainstem Athabasca and Clearwater rivers.

Site Code (00AT07-)	1976												1977											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
CD2300		9			13,16	28	27	18	2,29		21	10	23	26					22	18	19	14		15
CC0012		9			16	28	27	27	2,30		21	10	23	26					22	18	19	14		15
DA0200		11			14		22,28	4,9 18,24 30	2,8 15,24 28,30	6							5				21			
DA0201						28	28		2,30			10	22	26										
DA0203						28	28		2,28			12	22	26										
DA0202		12			15			26			22													
DA0204						29	29	28				12	22	26										
DA0205						29	27	30	28			11	22	25										
DA0206					15	29	27	27					22	25										
DA0207		10			14			26			17								22	18	19	14	17	19
DA0208						30	30		3	2		11	21	25										
DA0209		11			13	30	30		3				21	25										
DA0210							1,30		3	2		11	21	25										
DA0010																					28	21		
DA0212									8,20								31		5	16	27	25	30	
DA0213									10															
DA0214									10															
DA0211									10								31							

were taken using field instruments where they were available. Samples brought to the Mildred Lake facility during the day were air-shipped from Fort McMurray that same evening and reached the analytical laboratories within 24 h of collection. During the summer months, samples taken in the morning were stored in the facility's refrigerated storeroom for evening shipment. The field laboratory at the AOSERP facility proved to be an excellent place for preservative handling and calibration of field equipment.

Sample collection in the Athabasca River Delta was carried out by Alberta Environment Technical Services personnel located at Fort Chipewyan commencing in May 1977. Samples sites were reached by boat and float plane during ice-free months. After collection, the samples were refrigerated overnight and shipped by air the next day to reach the analytical laboratories within 30 h of sampling.

1.5 IMPACT RELATED WATER SAMPLING

Direct effects on the quality of the surface water could be anticipated from the discharges of Fort McMurray, GCOS, and Syncrude. Such effects from Fort McMurray and GCOS would centre on the Athabasca mainstem. Sewage discharge into the Athabasca River from Fort McMurray was below McDonald Island, between Sites DA0200 and DA0201. Process water discharge from GCOS into the Athabasca River was below Site DA0202 (see Figures 2 and 3).

Syncrude provided a more complicated situation. Figures 3 and 4 depict water courses in Zone 7 before and after development. Mine depressurization water was discharged into the Beaver River. Prior to completion of the Ruth Lake diversionary structures and, thus, effects were anticipated at Site DA0181. As completion of the Poplar Creek dam and spillway proceeded, effects were anticipated at Site DA0070. The final scheme involved the discharge of mine depressurization water into Ruth Lake for dilution prior to its entering the Poplar Creek system.

1.6 WATER SAMPLING METHODS

The procedures employed by Alberta Environment's Pollution Control Laboratory were used for sample collection and preservation

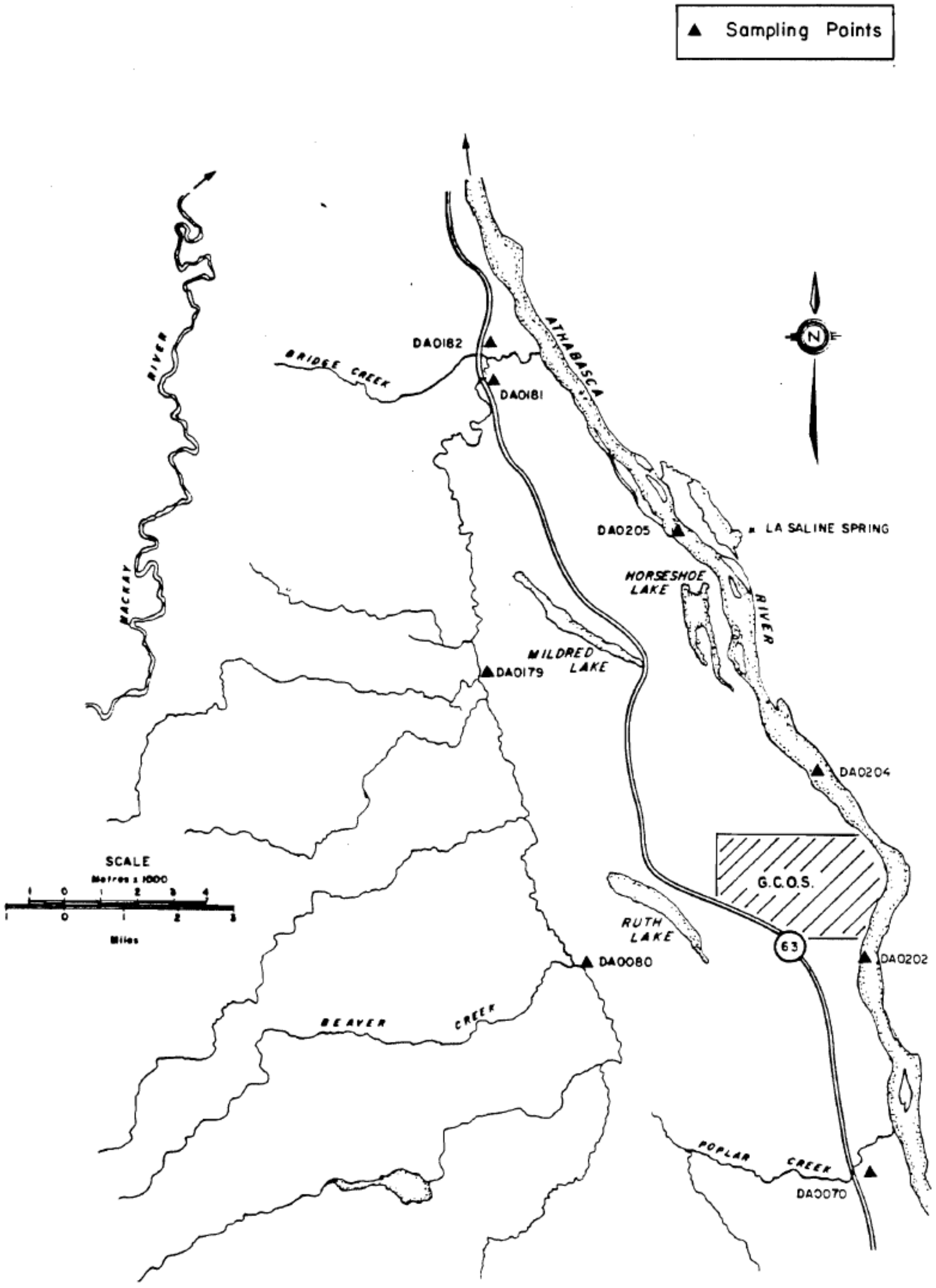

Figure 3. Beaver River and Poplar Creek drainages before Syncrude development.

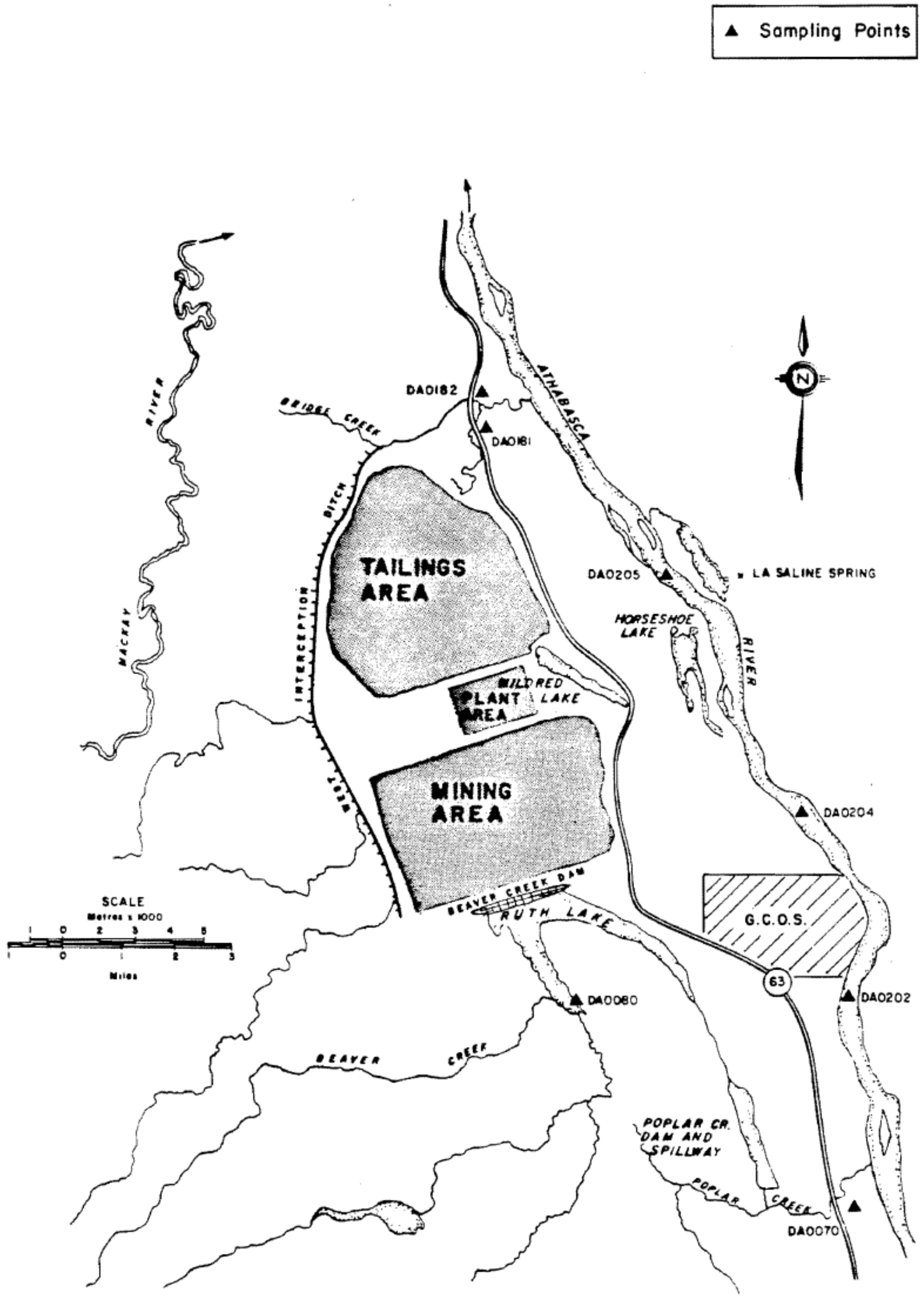

Figure 4. Beaver River and Poplar Creek drainages after Syncrude development.

(Inland Waters Directorate 1973; Murphey 1972). In some instances, numbered bottles were charged with preservative (Table 5) prior to sampling and crated in plywood shipping boxes. In others, preservative was supplied in small teflon-capped vials for addition immediately after sample collection. The choice of method for preservative addition is determined by the nature of the preservative and the analysis required. The Radiometer pH Meter, Hydrolab Conductivity Meter, and Hydrolab Dissolved Oxygen Meter were calibrated immediately before each sampling round using procedures recommended by the manufacturer. The conductivity meter was checked semi-annually with a standard potassium chloride solution and a certified mercury thermometer (see Akana in prep. for details).

Field data were noted on sheets that accompanied each batch of samples. The data included on-site water quality measurements, a cross-section locator, and the sampling technique employed. In some instances, depth integrated samples were taken and, in other instances, they were taken at a specified depth. All locator data were filed in the National Water Quality Data Bank (NAQUADAT) coded files.

Possible sources of sample contamination were monitored continually. The preservatives used were checked regularly for contaminants by both Alberta Environment, Pollution Control Laboratory, and by Chemex Labs (Alberta) Ltd. A possible source of lead contamination was the ice drilling equipment used since it was coated with a lead-based paint. The paint layer was removed using a sand blaster. Precautions were taken when sampling from lakes and ice-holes to insure that no cross-contamination of preservatives occurred. Unpreserved samples and those to be preserved after sampling were taken initially, and then bottles containing preservatives were dipped into the water in a sequence which ensured that overflow did not contain an ion that would contaminate subsequent samples.

1.7 ANALYTICAL METHODS AND LABORATORIES

Most samples were submitted for chemical analysis to Chemex Labs (Alberta) Ltd. under contracts with AOSERP and Alberta Environment. Analyses also were performed in Environment Canada, Inland

Table 5. Sample bottles and preservatives used.

Bottle Designation	Bottle Type	Preservatives	Parameters
R	1 L plastic	None	Calcium, sodium, potassium, silica, magnesium, chloride, fluoride, sulphate, pH, boron, alkalinity, specific conductance
G-1	32 oz glass	None	Odour, colour, tannins & lignins, turbidity, hexavalent chromium, surfactants, humic acids, solids--dissolved and suspended
G-1	32 oz glass	7.5 mL 33% H_2SO_4	Chemical oxygen demand, total Kjeldahl nitrogen, total phosphorus, ammonia, arsenic, selenium
OG	32 oz glass	7.5 mL 33% H_2SO_4	Oil and grease
P	32 oz glass	1 g CuSO 2 mL 85% H_3PO_4	Phenolic compounds
NC	5 oz plastic	None	Nitrate, nitrite, orthophosphate, total inorganic carbon, total organic carbon, total dissolved organic carbon
M	1 L plastic	10 mL conc. HNO_3 add after sampling	Cadmium, copper, iron, zinc, manganese, vanadium, lead, aluminum, cobalt, silver, titanium
Hg	2 oz high	2 mL solution of 0.5% HNO_3 and 5% $K_2Cr_2O_4$, add after samp sampling	Mercury
CH	32 oz plastic	1 mL 10% $MgCO_3$	Chlorophyll
PHH	40 oz glass	None	Total hydrocarbons
Cy	1 L plastic	4 mL 6N NaOH	Cyanide

Water Laboratory, Calgary, and Alberta Environment, Pollution Control Laboratory. Quality control was ensured by using various sample exchange programs among the three analytical laboratories (Akena in prep.).

Bacteriological measurements were carried out at the Provincial Health Laboratory, Edmonton, for total coliforms, fecal coliforms, and standard plate count.

All laboratories used standard analytical methods registered with NAQUADAT. The various parameters measured for the AOSERP projects are listed in Table 6 along with NAQUADAT codes for the analytical methods used (National Water Quality Data Bank 1976; American Public Health Association 1976; Pollution Control Laboratory 1977; Traversy 1971).

1.8 QUALITY CONTROL PROGRAM

All analytical quality control programs fall into one of two categories: intra-laboratory checks and inter-laboratory sample exchanges. Intra-laboratory checks, when internally administered, bring unacceptable results of analysis to the immediate attention of the analyst and, when externally administered, such checks will provide a measure of the routine precision. Sample exchanges can provide an external check on the effectiveness of an analytical laboratory's internal quality control program by giving a measure of the laboratory's accuracy. In addition, they will reveal errors in in the preparation of control samples and standards and the use of poor quality reagents. When a laboratory has prior knowledge of a test, the test tends to reflect the capability rather than routine accuracy or precision. For no prior knowledge (as in disguised samples) the reverse tends to hold.

The quality control program contained both kinds of tests. Table 7 lists all the externally administered quality control tests throughout 1976-77.

In the spring of 1977, the quality control program was strengthened by the use of a contract patterned after an example

Table 6. Parameters measured and NAQUADAT methods used.

Parameter	Methods
Conducted routinely:	
Calcium	20103 L
Magnesium	12102 L
Sodium	11103 L, 11102 L
Potassium	19103 L, 19102 L
Chloride	17203 L
Sulphate	16306 L
Total alkalinity	10101 L
pH	10301 L
Carbonate	06301 L
Bicarbonate	06201 L
Total hardness	10603 L
Fluoride	09105 L
Silica	14101 L
Conductance	02041 L
Threshold odour No.	02001 L
Colour	02011 L
Tannin & lignin	06551 L
Total filt. residue	10451 L
Total filt. residue fixed	10551 L
Total non-filt. residue	10401 L
Total non-filt. residue fixed	10501 L
Turbidity	02073 L
Surfactants	10701 L
Humic acids	06581 L
Total organic carbon	06001 L, 06048 L
Total inorganic carbon	06051 L
Total diss. organic carbon	06101 L
Total diss. inorganic carbon	06151 L
Nitrate + nitrite - nitrogen	07110 L, 07651 L
Ammonia nitrogen	07555 L
Total Kjeldahl nitrogen	07015 L, 07013 L
Total phosphorus	15406 L, 15001 L
Ortho-phosphorus	15256 L
Chemical oxygen demand	08301 L
Cadmium	48302 L, 48301 L 48101 L
Hexavalent chromium	24101 L, 24302 L
Copper	29305 L, 29306 L
Iron	29301 L, 29101 L
Iron	26394 L, 26301 L 26101 L
Lead	82302 L, 82301 L 82101 L
Manganese	25304 L, 25301 L 25101 L
Silver	47302 L, 47301 L

continued ...

Table 6. Concluded.

Parameter	Methods
Conducted routinely:	
Zinc	30305 L, 33304 L 30301 L, 30101 L
Vanadium	23003 L, 23301 L 23101 L
Selenium	34102 L, 34302 L 38101 L,
Mercury	80011 L, 80301 L
Arsenic	33104 L, 33101 L,
Nickel	28302 L, 28301 L 28101 L
Aluminum	13302 L, 13301 L
Cobalt	27302 L, 27301 L 27101 L
Boron	05106 L, 05101 L 05105 L, 05301 L
Conducted often:	
Phenol	06532 L, 06533 L
Oil & grease	06521 L
Standard plate count	36900 L
Total coliform	36001 L
Fecal coliform	36011 L
Conducted on occasion:	
Nitrite	07206 L
Chlorophyll	06711 L
Cyanide	06603 L
Total hydrocarbons	N/A
Sulphide	16101 L
Barium	56301 L
Beryllium	04301 L, 04101 L
Molybdenum	42301 L
Strontium	38301 L
Antimony	51101 L, 51301 L

Table 7. Externally administered quality control tests.

Category	Date	Test	Prior Knowledge of Chemex
Intra-laboratory	April 1977	Spiked samples and standard metals	no
	Sept. 1977	Spiked samples and standard metals	no
Inter-laboratory		Contract competition	yes
	Aug. 1976	Duplicate with PCL	no
	Sept. 1976	Duplicate with PCL	no
		PCL program	yes
	Jan. 1977	2 Duplicates with PCL	no
	Feb. 1977	Duplicate with PCL	no
	Feb. 1977	Standard exchange with PCL	yes
	March 1977	2 duplicates with PCL	no
	April 1977	2 duplicates with PCL	no
	June 1977	Standard exchange (3 labs)	yes
	July 1977	Standard exchange (3 labs)	yes
	July 1977	Contract competition (4 labs)	yes
	July 1977	PCL program	yes
	July 1977	Triplicate	no
	Aug. 1977	Triplicate	no
	Sept. 1977	Triplicate	no

in the literature (Edwards et al. 1975, 1977). See Appendix 5.1 for pertinent sections of this contract. The compliance with stricter quality control formed part of the terms of this contract. In addition to internal quality control, which formed part of the first contract, external quality control was to be provided by two government laboratories, Alberta Environment, Pollution Control Laboratory in Edmonton and Environment Canada, Inland Water Laboratory in Calgary. Authentic samples, spiked samples, or standard solutions were to be submitted simultaneously to all three laboratories. Any deviation or discrepancy between data generated in the subcontracted laboratory and that generated in the government laboratories was penalized by reduced payment for services rendered. The results of quality control tests throughout the entire program have been compiled (Akena in prep.) and generally greater accuracy was achieved as problem areas were flagged by the test results.

2. COMPLIANCE WITH WATER QUALITY CRITERIA

2.1 STANDARDS OF WATER QUALITY CRITERIA

Suitability of water source for use depends upon both the amount of water available and the quality of that water. Whatever use the water is being put to sets the specifications, so each use will have a specific set of requirements. Five broad categories of important water uses can be envisioned where the quality of the water is a critical aspect (McNeely and Neimanis 1978):

1. Domestic consumption (drinking water);
2. Protection of aquatic life;
3. Industrial applications;
4. Agricultural use; and
5. Recreation.

Each category has its own set of criteria, so it is a difficult task to construct a sweeping set of acceptable levels of constituents that define the quality of the water. Regulating agencies of both Alberta and Saskatchewan (Alberta Environment 1977; Saskatchewan Water Resources Commission 1970) have touched upon this area and have established objective levels of constituents after considering typical demands on water resources such as public water supply, industry, agriculture, recreation, and the preservation of fish, wildlife, and the aesthetics of watershed areas. Emphasis was placed on the maintenance of existing water quality where it might be affected by developments and so no definite statements on desirable levels of many parameters, such as predominant ions, are made because of wide natural variation. Acceptable levels of many parameters were assigned by both provinces and these are presented in Table 8.

Criteria respecting human consumption, based on toxicological considerations, are readily available for a wide variety of constituents (National Health and Welfare 1969). Such criteria have been divided into three guideline levels: maximum permissible, acceptable, and objective. Maximum permissible levels are standards for certain substances that are known or suspected to have adverse effects on

Table 8. Standards of water quality criteria.

Parameter[d]	General Objective[a]	Additional criteria: acceptable for drinking water[b]	Additional criteria: protection of aquatic life[c]	Summary of tightest criteria
Calcium		LE 200		LE 200
Magnesium		LE 150		LE 150
Sodium	GE 30, LE 75			NA LE 75
Potassium				
Chloride		LE 250		LE 250
Sulphate		LE 500		LE 500
Total alkalinity		GE 30, LE 500	GE 20	GE 30, LE 500
pH	GE 6.5, LE 8.5	GE 6.5, LE 8.3	GE 6.5, LE 8.5	GE 6.5, LE 8.3
Carbonate				LE 38.5
Bicarbonate				NA
Total hardness				NA
Fluoride	LE 1.5			LE 1.5
Silica				NA
Conductance				NA
Threshold odour no.	LE 8	LE 4		LE 4
Colour				
Tannin & lignin				NA
Total filterable residue				NA
Total filterable residue fixed		LE 500		LE 500
Total non-filt. residue				NA
Total non-filt. residue fixed	LE 10			LE 10

continued ...

Table 8. Continued.

Parameter[d]	General Objective[a]	Additional criteria: acceptable for drinking water[b]	Additional criteria: protection of aquatic life[c]	Summary of tightest criteria
Turbidity (JTU)	LE 25	LE 5	Warm stream LE 50 Warm lakes LG 25	LE 5
Surfactants	LE 0.5			LE 0.5
Humic acids				NA
Total organic carbon				NA
Total inorganic carbon				NA
Total diss. organic carbon				NA
Nitrate + nitrite nitrogen		LT 10.0		LE 10
Ammonia nitrogen		LE 0.5		LE 0.5
Total Kjeldahl nitrogen	LE 1.0			LE 1.0
Total phosphorus	LE 0.15	LE 0.2		LE 0.15
Ortho-phosphorus				NA
Phenol	LE 0.005	LE 0.002	LE 0.001	LE 0.001
Oil & grease				NA
Sulphide	LE 0.05		LE 0.002	LE 0.002
Cyanide	LE 0.01	LE 0.01	LE 0.005	LE 0.004
Chlorophyll *a*				NA
Chemical oxygen demand				NA
Cadmium	LE 0.01	LT 0.01	LE 0.003	LE 0.003
Hexavalent chromium	LE 0.05		LE 0.05	LE 0.05
Copper	LE 0.02	LE 1.0	LE 0.005	LE 0.005
Iron	LE 0.3	LE 0.3	LE 0.3	LE 0.3

continued ...

Table 8. Concluded.

Parameter[d]	General Objective[a]	Additional criteria: acceptable for drinking water[b]	Additional criteria: protection of aquatic life[c]	Summary of tightest criteria
Lead	LE 0.05	LT 0.05	LE 0.03	LE 0.03
Manganese	LE 0.05	LE 0.05		LE 0.05
Silver	LE 0.05			LE 0.05
Zinc	LE 0.05	LE 5.0	LE 0.03	LE 0.03
Vanadium				NA
Selenium	LE 0.01	LT 0.01		LT 0.01
Mercury	LE 0.0001		LE 0.0002	LE 0.0001
Arsenic	LE 0.01	LE 0.01		LE 0.01
Nickel			LE 0.025	LE 0.025
Aluminum				NA
Cobalt				NA
Boron	LE 0.5	LT 5.0		LE 0.5

[a] Alberta Environment 1977; Saskatchewan Water Resources Commission 1970.

[b] National Health and Welfare 1969.

[c] Great Lakes Water Quality Board 1976; U.S. Environmental Protection Agency 1973; International Joint Commission 1976.

[d] Parameter values in ppm except for turbidity in Jackson Turbidity Units (JTU); LE-less than or equal to; GE-greater than or equal to; LT-less than.

human health and no water supply should be permitted to carry these substances at the indicated levels continuously. Acceptable levels concern substances which, at indicated limits, are objectionable to a significant number of people or are capable of producing deleterious health or other effects. Objective levels should be interpreted as long-term goals and water supplies that meet such levels are of very good quality and safe from health, aesthetic, and other viewpoints. Guidelines for acceptable levels of parameters are presented in Table 8.

Criteria related to the protection of the aquatic life are not easy to establish because of the complicated structure of the aquatic ecosystem. For example, fish can adapt to gradual changes in their environment on a short-term basis and can adapt on a longer term basis by genetic selection. The resultant feature is that populations of the same species in different habitats will tolerate different ranges in water chemistry parameters. Compounding the problem is the existence of a wide variety of life forms that are all trophically related. However, some guidelines have been published by a variety of sources and are shown in Table 8.

Criteria related to industrial application are very specific to the applications. As an extreme, high pressure steam generation generally requires very high quality feedstock. The total dissolved solids must be less than or equal to 0.5 mg/L (USEPA 1973). On the other hand, oil sands process water is already obtained from the Athabasca River by GCOS and Syncrude. Each individual venture will consider the character of available water and produce a suitable process design and thus no detailed consideration will be made here.

Criteria related to agricultural use concern either livestock watering or irrigation and guidelines have been published by both USEPA (1973) and the Australian Water Resources Council (1974). Presently, there is little agricultural utilization of water in the study area, so no detailed consideration of the application of guidelines to the AOSERP study area will be made. However, similarities can be drawn between large wildlife using the water and livestock watering and between periodic flooding of the Peace-Athabasca Delta and irrigation.

Criteria related to recreational use revolve around bacteriological and aesthetic considerations rather than the chemical constituents. Bacteriological parameters were measured at sites during most monthly sampling rounds in 1977. However, a detailed analysis of these parameters would have to await the generation of a larger sample suite.

Table 8 also contains a summary of the tightest criteria concluded from the general considerations and the drinking water and aquatic biota requirements. This summary will be used in the subsequent discussion on compliance.

2.2 NONCOMPLIANT WATER QUALITY DATA

The set of data for 1976 and 1977 for all sites listed in Tables 1, 2, and 3 was sorted into groups of compliance and noncompliance to the final criteria developed in Table 8. A summary of these groupings is given in Table 9. The purpose was not to evaluate the suitability of the water at each site for a particular purpose. Rather it was to identify possible parameters of concern regarding water surrounding oil sands developments. A summary of this grouping follows.

2.2.1 Calcium

There was only one occurrence of a noncompliant calcium level (above 200 ppm) throughout the entire set. It was at Eymundson Creek (Site DA0121) in February 1977, one of 11 measurements at that site. Natural calcium levels varied geographically and typically peaked during base flow (see Section 3.1).

Table 9. Compliance analysis of surface water in relation to the tightest criteria summarized in Table 8. Noncompliant to included values are displayed.

Site Code	Na	Cl	T. Alk.	pH	Odour	TFRF	TNFRF	Turb.	NH_3	TKN	Tp	Phenol	CN	Cd	Cr	Cu	Fe	Pb	Mn	Zn	Hg	Ni	B
Tributaries																							
CD0040 Hangingstone River	2/19			1/19	4/15	1/18	12/19	15/18		10/15	6/15	9/18	4/4	1/19		12/19	19/19	1/18	15/19	5/18	4/13	2/19	
CD0100 Saline Creek					3/7		6/8	6/7		3/7	4/7	8/8	4/4			5/8	8/8		6/8	3/8	1/5		
CC0030 Horse River				1/5	1/3		4/5	4/5			1/3	4/4	1/1			2/5	5/5			1/5	1/2		
CC0300 Horse River-mouth					1/4		2/4	2/4		2/4							4/4		2/4	1/4			
DA0060 Steepbank River				1/18	3/15		3/18	9/17		5/15	3/15	6/18	3/3			6/18	18/18		5/18	3/18	2/13		
DA0080 Muskeg River					5/18			6/15	2/18	12/18		6/18	6/6			3/18	18/18		10/18	3/18	2/16		
DA0090 Hartley Creek					6/17		1/17	4/15		8/17	1/17	7/16	5/5			7/17	17/17		5/17	4/16	3/14		
DB0040 Thickwood Creek					3/13			5/10		9/13	2/13	4/9	3/3			5/13	11/13		5/13	1/13	2/13		
DB0020 Dover River	3/13			2/13	4/13	1/13	5/13	7/11		9/13	2/13	4/13	3/3			4/13	13/13		5/13	1/13	3/13		1/13
DB0030 Dunkirk River				1/16	7/14		3/16	8/13		10/15	4/15	7/12	4/4			5/16	16/16		9/16	4/16	3/13		
DB0011 MacKay River	4/18		1/18	2/18	3/15	3/17	6/18	11/17	1/15	9/15	2/15	5/16	5/5			7/18	18/18	1/18	5/18		3/13	1/18	2/17
DA0100 Upper Ells River					4/13		1/13	1/11		1/13		2/9	3/3			5/13	7/13		3/13	1/13	1/12		
DA0170 Lower Ells River				1/14	3/14		2/14	4/12		2/14	1/14	3/14	3/3	1/14		4/14	14/14		1/14	1/14	3/14		
DA0160 Joslyn Creek					3/9		8/9	6/7		5/9	5/9	1/9	2/2	1/9		7/9	9/9		5/9	2/9	1/9		
DA0098 Ells River-mouth							2/2	1/2				2/2				1/2	2/2		1/2				
DA0099 Ells River-mouth					1/1		1/1	1/1		1/1		1/1	1/1				1/1		1/1		1/1		
DA0190 Upper Tar River					3/11			3/9		3/11	1/11	4/11	3/3			2/11	11/11		10/11	3/11	2/11		
DA0150 Lower Tar River				1/13	3/13		5/13	8/11	3/13	8/13	5/13	7/13	3/3			7/13	13/13	1/13	10/13	1/13	1/12	1/13	
DA0151 Tar River-mouth				1/4			1/3	3/3				3/3	1/1				3/3		1/3		1/1		
DA0140 Calumet River	3/11		2/11	1/11	3/11	3/11		2/10	3/11	10/11	3/11	3/11	1/1			4/11	11/11		6/11	1/11	4/11		2/11
DA0141 Calumet River-mouth	1/6				1/2		2/6	3/5		1/2	2/2	5/6	2/2			2/6	6/6	1/5	5/6		2/2		1/2
DA0130 Pierre River					3/10		1/10	3/8		4/10	2/10	4/10	2/2			2/10	10/10		9/10		1/9		
DA0131 Pierre River-mouth					1/1		2/4	4/4		1/1		4/4	1/1	1/4		1/4	4/4	1/4	4/4		1/1	1/4	
DA0120 Asphalt Creek					3/10		9/10	7/8		5/11	4/10	1/10	2/2			7/10	9/10	1/9	10/10	5/10	1/10	3/10	
DA0121 Eymundson Creek	1/11		1/11	1/11	3/8	3/11	7/11	10/11		7/8	4/8	5/11	1/1			7/11	10/11	1/9	11/11	3/10	2/8	3/11	1/11
DA0122 Eymundson Creek-mouth							1/1				1/1	1/1	1/1			1/1	1/1		1/1	1/1		1/1	
DA0110 Unnamed Creek				1/10	3/10		2/10	5/9		6/10		4/10	2/2			1/10	10/10		10/10		2/10		1/10
DA0111 Unnamed Creek													1/1	1/1		1/1	1/1	1/1	1/1		1/1		
DA0115 Unnamed Creek-mouth								2/2				2/2				1/2	2/2		2/2				
DC0010 Firebag River				2/17	4/14		2/17	1/15		4/13		5/16	4/4	1/16		7/16	16/16		3/16	2/16	1/14		
DC0011 Firebag River-mouth					2/3		1/3	1/3		1/3							3/3				1/3		
DC0020 Lost Creek				1/8	2/8					4/8		4/5	1/1			2/8	7/8		1/8		1/5		
DD0020 Richardson River					1/5		1/5	1/5		1/5						1/4	4/4			1/4	1/5		
DA0070 Poplar Creek	3/15	1/15		1/15	2/12	1/15	7/15	10/14		10/12	1/12	4/14	3/3	2/14	3/12	5/15	14/15	1/14	14/15	5/14	5/11		
DA0180 Beaver River	3/14			1/14	2/14	1/14	4/14	9/12		8/14	4/14	6/14	4/4	1/14		3/14	13/14		7/14	2/14	3/14		3/14
DA0179 Beaver River	2/2	2/2	2/2		1/2	2/2	2/2	1/1	2/2	1/2		2/2	2/2	1/2		2/2	2/2		2/2		2/2	1/2	1/2
DA0181 Beaver River	4/15	2/15		2/15	4/15	3/15	5/14	8/12	2/15	11/15	2/15	3/13	6/6		1/15	5/15	15/15		15/15	6/15	2/13		1/15
DA0182 Bridge Creek					6/12		8/12	8/10		10/12	1/12	6/11	4/4		1/12	2/12	12/12		11/12	3/12	4/11		

continued ...

Table 9. Concluded.

Site Code	Na	Cl	T. Alk.	pH	Odour	TFRF	TNFRF	Turb.	NH_3	TKN	Tp	Phenol	CN	Cd	Cr	Cu	Fe	Pb	Mn	Zn	Hg	Ni	B
Lakes																							
DE0011 Gregoire Lake					7/12			2/11		4/13		2/13	3/3			3/12	3/12		4/12	1/12	2/12	1/2	
CE0010 Gregoire Lake										1/1			1/1			1/1					1/1		
CD3000 Lake East of Fort McMurray												1/1				1/1			1/1				
DA0300 McClelland Lake												1/1				1/1							
DB0035 Birch Lake				1/1						1/1		1/1											
DA0220 Eaglenest Lake					6/12		2/12	5/12		11/12	5/12	3/8	1/1			6/12	12/12		9/12	1/12			
DA0200 Upper Gardiner Lake					6/11		1/11	1/11		3/11	3/11	3/8	1/1		1/11	4/11	2/11		4/11	1/11	2/11		
DA0210 Namur Lake					2/11		1/11	1/11		1/11		3/8	1/1			5/11	3/11						
DA2000 Lower Gardiner Lake					1/4			1/4	1/4	2/4	2/4	2/4	1/1			2/4	1/4		1/4				
DD0090 Jackfish Creek					2/5		3/5	3/5		2/5						1/5	5/5		1/5	2/4	1/5		
DD0080 Richardson Lake					1/5		2/6	3/5		4/5						2/6	5/6		2/6	1/5			
MD2000 Lake Athabasca					2/4			1/4		1/4						1/4	1/4			1/3			
KF0200 Lake Claire					1/4		4/4	4/4		4/4	1/4					4/4	4/4		2/4	1/3	3/3		
KF0201 Lake Claire					3/5		5/5	5/5		5/5	2/5					4/5	5/5		3/5	2/4	2/4		
KF0140 Prairie River					1/5		3/5	5/5		5/5	3/5					3/5	5/5		3/5	2/4			
KF0100 Mamawi Lake Channel					3/5		3/5	5/5		3/5	1/5					3/5	5/5		3/5	2/4	1/5		
KF0101 Chenal Des Quatre Fourchers					2/5		5/5	5/5		3/5	1/5					2/5	5/5		2/5	1/4	1/5		
NA0030 Riviere Des Rochers					2/4		3/4	4/4		4/4						2/5	5/5		2/5	1/4	2/4		
NA0031 Riviere Des Rochers					1/1		1/1	1/1		1/1	1/1					1/1	1/1		1/1	1/1			
Mainstem																							
CD2300 Clearwater River					4/11		10/17	11/15	1/12	5/12	2/12	9/14	5/5	1/16		8/17	17/17	1/16	8/17	2/16	6/8	1/16	
CC0012 Athabasca River					5/12		15/20	16/19	1/12	5/12	1/12	10/18	5/5			9/20	18/20		8/20	4/20	1/7		
DA0200 Athabasca River					7/15		14/15	9/9		8/15	8/16	6/14	15/15			12/15	15/15		15/15	8/15	1/1	2/15	1/15
DA0201 Athabasca River					3/7		5/7	4/6	2/7	3/7	4/7	2/7	5/5			5/7	6/7	1/7	3/7	1/7	4/7		
DA0203 Athabasca River				1/7	3/7		4/7	3/6	1/7	3/7	3/7	3/7	5/5			4/7	7/7		3/7		2/3		
DA0202 Athabasca River							4/8	6/8								3/8	8/8		4/8				
DA0204 Athabasca River					5/11		5/11	3/9	1/11	3/11	2/11	3/11	7/7			7/11	11/11	1/11	3/11	2/11	8/8		
DA0205 Athabasca River					2/6		4/7	3/6	1/7	3/7	2/7	3/6	5/5			6/7	7/7		2/7	3/7	3/3	1/7	1/7
DA0206 Athabasca River					3/5		5/7	4/6	2/6	3/6	1/6	4/6	3/3		1/5	5/7	7/7		4/7	2/7	2/2	1/7	
DA0207 Athabasca River					2/6		6/12	9/12		3/6	1/6	6/10				4/10	11/11		4/11	1/9	3/6		
DA0208 Athabasca River					2/7		4/7	4/6		2/7	3/7	3/7	5/5			5/7	7/7		3/7	2/7	2/3		
DA0209 Athabasca River					2/5		9/11	9/11		3/5	2/5	7/10	3/3			6/11	11/11	1/9	7/11	2/11	2/2		1/8
DA0210 Athabasca River					3/7		4/7	4/6		5/7	3/7	3/6	6/6		1/7	6/7	7/7	1/7	4/7	2/7	3/3		
DD0010 Athabasca River					3/4		3/4	3/4		4/4	1/4					2/4	4/4		3/4	2/4	1/4		
DD0212 Athabasca River					2/5		5/5	5/5		1/5	1/5					2/7	7/7		5/7	3/7	1/5		
DD0213 Athabasca River																	1/1		1/1				
DD0214 Athabasca River																	1/1		1/1				
DA0211 Athabasca River					1/1		1/1	1/1		1/1	1/1					1/2	2/2		2/2				

2.2.2 Magnesium

Noncompliant (greater than 150 ppm) magnesium values did not occur in the set. Natural magnesium levels showed considerable geographical variance and typically peaked during base flow (see Section 3.1).

2.2.3 Sodium

Noncompliant (greater than 75 ppm) sodium values did not occur in the lakes or the mainstem. However, a number of noncompliant values occurred in some tributaries. A notable cluster of noncompliance occurred in Zone 7 where current surface mining activity has necessitated the discharge of mine depressurization groundwater into the Beaver River and the Poplar Creek system (see Figures 3 and 4 and Table 10). However, the occurrence of noncompliant values in the adjacent Zone 3 (MacKay River ranged from 76 to 140 ppm from December 1976 to March 1977 and Dover River ranged from 87 to 92 ppm from January to March 1977) indicate natural saline discharge in winter as there have been no mining impacts in this zone. Thus, seasonal highs for sodium in Poplar Creek and Beaver River above Syncrude may be ascribed to natural base flow (especially in the case of Beaver River where no correspondingly high chloride values were exhibited). Noncompliance at Beaver River inside Syncrude and below Syncrude, however, shows the effects of mine depressurization water as these measurements were made during pumping. The data indicate that discharge of large amounts of mine depressurization to Lower Beaver River was interrupted in December 1976.

2.2.4 Chloride

The only noncompliant chloride values (greater than 250 ppm) throughout the entire data set were from Zone 7 (Table 10). The pattern closely corresponds to that of sodium noncompliance in that the highest noncompliant sodium values paired with the noncompliant chlorides. This parameter is another reflection of the impact of mine depressurization water which yields typical chloride values

Table 10. Noncomplicant sodium values and associated chloride and total filterable residue fixed values for Zone 7 in 1976 and 1977.

Site Code (00AT07-)		Date	Na (ppm)	Cl (ppm)	TFRF (ppm)
DA0070	Poplar Creek	21-12-76	125	164[a]	458[a]
		24-02-77	102	125[a]	408[a]
		16-12-77	388	525	1190
DA0180	Beaver River above Syncrude	04-01-77	115	3[a]	450[a]
		04-03-77	150	3[a]	502
DA0179	Beaver River inside Syncrude	19-10-76	800	1010	2132
		18-11-76	1050	1320	2730
DA0181	Beaver River below Syncrude	11-08-76	412	575	1204
		10-09-76	98	124[a]	468[a]
		20-10-76	162	217[b]	645
		17-11-76	240	302	836
		21-12-76	22[a]	22[a]	210[a]

[a] in compliance

between 2000 and 10 000 ppm (Lake and Rogers 1979). At some locations, there were pronounced maxima of natural chloride levels during base flow (see Section 3.1).

2.2.5 Sulphate

Noncompliant (greater than 500 ppm) sulphate values did not occur. Natural sulphate levels showed considerable geographic variation and typically peaked during base flow, though some peaks occurred during the spring-summer season (see Section 3.1).

2.2.6 Total Alkalinity

Noncompliant (less than 30 ppm or greater than 500 ppm) total alkalinity values did not occur in lakes or the mainstem river system. However, a small number of noncompliant values occurred in tributaries in Zones 3, 5, and 7. The MacKay River (DB0011) exhibited total alkalinity of 577 ppm in February 1977; Eymundson Creek (DA0121), 1000 ppm in February 1977; Calumet River (DA0141), 702 and 676 ppm in February and March 1977, respectively; and Beaver River inside Syncrude (DA0179), 625 and 764 ppm in October and November 1976, respectively. High alkalinity values during base flow no doubt reflect natural groundwater discharge for occurrence in Zones 3 and 5 (see Section 3.1) but mine depressurization water discharge explains the noncompliance in Zone 7.

2.2.7 pH

All pH values in the lakes and mainstem were slightly alkaline and virtually all complied with the criteria by being 8.3 or lower. Only one lake value (Birch Lake, Site DB0035, at a pH of 8.8 in July 1977) failed to comply. However, noncompliant values occurred randomly scattered among the tributaries of every zone at all times of the year, although ranging only up to 8.6. A detailed study of the Muskeg River basin (Akena 1979; Froelich 1980) observed some occurrences of low pH ranging down to 6.5. Occurrence of pH below 7.0 in headwater streams could be expected due to muskeg water input.

2.2.8 Carbonate

Noncompliant values (greater than 38.5 ppm) for carbonate were not detected, which is a consequence of pH compliance.

2.2.9 Fluoride

Noncompliant (greater than 1.5 ppm) fluoride values virtually did not occur. Only one measurement did not comply: Site DD0212 on the Athabasca River exhibited 6.0 ppm fluoride in September 1976. Higher fluoride levels did not correlate well with base flow conditions (see Section 3.1.2).

2.2.10 Total Filterable Residue Fixed

Noncompliant (greater than 500 ppm) total filterable residue fixed values did not occur in the lakes and mainstem. However, numerous noncompliant values were observed in the tributaries, notably Eymundson and Calumet creeks and in Zone 7. Mine depressurization water made available to the water course of Zone 7 ranged from 9300 to 19 000 ppm. Total filterable residue fixed compliance and occurrences of noncompliance corresponded closely with noncompliant sodium and chloride (Table 10). All other occurrences were during winter base flow, with Calumet River ranging up to 983 ppm and Eymundson up to 1630 ppm.

2.2.11 Threshold Odour Number

There was only partial compliance with threshold odour numbers throughout the entire region. The high organic content arising from muskeg and forest input, along with weathering of oil sands deposits, is no doubt responsible for elevated levels of odour.

2.2.12 Total Nonfilterable Residue Fixed

Only partial compliance of less than or equal to 10 ppm was noted at most of the sites, reflecting the sedimentary effects in the water courses described in Section 3.2. The best compliances were observed in Lake Athabasca and Birch Mountain Lakes; some smaller headwater streams like Thickwood Creek, Upper Tar River, and Lost Creek; and a few larger rivers such as the Firebag, Richardson, and Ells rivers. The worst example was the Athabasca River where typical ranges of up to 300 to 400 ppm caused a 67% noncompliance; the Hangingstone River, where 63% were noncompliant (ranging typically up to 600 ppm); Joslyn Creek, where 89% were noncompliant (ranging up to 100 ppm); and Asphalt Creek, where 90% were noncompliant (ranging up to 1000 ppm). Bridge Creek Diversion was also typically noncompliant (usually 10 to 40 ppm and above 2000 ppm on occasion), possibly a reflection of runoff from construction activities around Syncrude in 1976 and 1977.

2.2.13 Turbidity

The lack of turbidity compliance corresponded closely to the pattern of total nonfilterable residue fixed compliance (Table 9) and the characteristics outlined in Section 3.2.1.

2.2.14 Surfactants

There was only one occurrence of a noncompliant surfactants level (greater than 0.5 ppm) in the entire set. It was 0.80 ppm at Site DA0207 on the Athabasca River in October 1977, one of six measurements at that site.

2.2.15 Nitrate Plus Nitrite

Noncompliant values (greater than 10 ppm) for nitrate plus nitrite did not occur in the data set.

2.2.16 Ammonia

Only scattered noncompliance (greater than 0.5 ppm) was noted for ammonia throughout the region. The one occurrence of lake noncompliance and most of the Athabasca River noncompliances all happened during one sampling round in late July 1976, raising the question of contamination for these values. However, the noncompliance scattered throughout the tributary streams appears genuine, always occurring during ice-cover months when anaerobic processes become more significant. Ranges for the Lower Tar noncompliant values were 0.64 to 0.80 ppm which are typical for the region.

Noncompliance was also noted for sites receiving mine depressurization water in Zone 7. Such occurrences were in winter and ranged from 0.62 to 1.10 ppm for Beaver River inside Syncrude, and from 0.50 to 0.68 ppm for Beaver River at Hwy 63. However, no occurrences were noted in Poplar Creek.

2.2.17 Total Kjeldahl Nitrogen

Noncompliance (greater than 1.0 ppm) for total Kjeldahl nitrogen occurred in a majority of data throughout the region with the exception of sites in Zones 4 and 6 which were receive relatively low organic loadings. Seasonal patterns were not readily identifiable (see Section 4.3.3). Noncompliant values from sites receiving mine depressurization water ranged up to 3.06 ppm, not much different from normal noncompliant ranges up to 1.60 ppm (Muskeg River), 3.20 ppm (Beaver River above Syncrude), and 5.10 ppm (Eymundson Creek).

2.2.18 Total Phosphorus

A general tendency toward 20 to 50% noncompliance (greater than 0.15 ppm) was evident throughout the region except for the complete compliance of Gregoire Lake, Lake Athabasca, Namur Lake, the Muskeg River, and the relatively soft water tributary streams of Zones 4 and 6 (Table 9). In contrast to neighbouring Namur Lake, Eaglenest Lake showed a number of noncompliant values evident before spring break-up (up to 0.58 ppm on 1 March 1977) and in late summer (0.243 ppm on 23 August 1977).

The mainstem Athabasca River tended to show phosphorus peaks in spring-summer with clusters of noncompliance occurring in June and September. The June high values corresponded with peak particulate loadings and the September highs reflected full freshet conditions. Some noncompliance was noted also in January. Winter noncompliance values ranged only up to 0.45 ppm whereas summer noncompliance typically showed a slightly wider range. Two unusually high values were recorded: on 22 July 1977 at site DA0207 (Athabasca River at Fort MacKay), the total phosphorus was 1.05 ppm, and on 30 August 1976 at Site DA0205, the total phosphorus was 1.85 ppm.

Noncompliance in the tributaries tended to show a major cluster in April and a lesser one in October. The spring cluster tended to contain the highest values: Lower Tar River showed 1.4 ppm on 1 April 1977; Asphalt Creek, 0.63 ppm on 28 April 1977; Beaver River above Syncrude, 0.49 ppm on 18 May 1977; Hangingstone River, 0.41 ppm on 22 April 1977; and Beaver River at Hwy 63, 0.40 ppm on 27 April 1977. The autumn cluster of noncompliance contained only two values over 0.40 ppm, both in the Dunkirk River: 0.50 ppm on 7 February 1977 and 0.50 ppm on 7 November 1977.

Atypical of this seasonal pattern was an occurrence at Beaver River at Hwy 63 on 11 August 1976 of 0.60 ppm, probably reflecting the influence of mine depressurization water discharged from the Syncrude site.

2.2.19 Phenol

Noncompliance (greater than 0.001 ppm) occurred, generally, in at least 30% of the data from each sampling point throughout the region. Exceptions to this were data from the Upper Ells River where only 22% failed to comply, Asphalt Creek (only 10%), and Joslyn Creek (only 11%). Noncompliances in the lakes were scattered randomly throughout the seasons at levels below 0.010 ppm. Noncompliance in the mainstem Athabasca River also showed no seasonal preference, with the majority of values occurring below 0.010 ppm. However, a definite seasonal trend in many tributaries could be noted: most of the noncompliant occurrences clustered in the ice-covered months (see Figure 5). Also, ice-covered months in the tributaries contained the highest phenol values: spring and summer typically were limited to values below 0.005 ppm, whereas winter values ranged up to 0.030 ppm. This would seem to indicate that assimilation of naturally supplied phenol derivations is limited during ice-cover conditions.

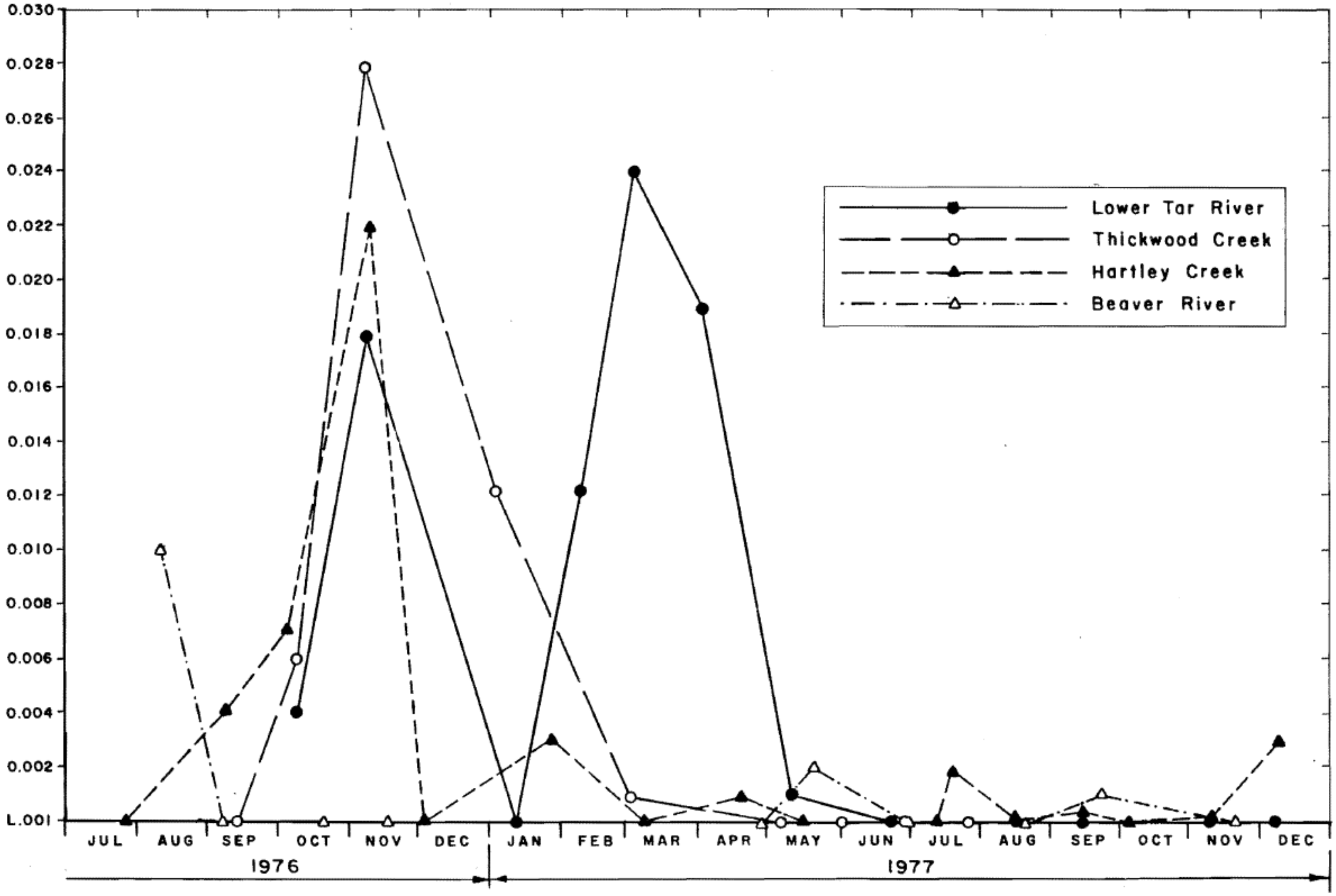

Figure 5. Phenol levels in selected small tributaries.

Noncompliance could not be ascribed definitely to an effect of mine depressurization water. However, noncompliance at Beaver River below Syncrude, at low levels during the summers of 1976 and 1977, appears to be out of phase of natural phenomena (see Figure 5) and thus anthropogenic. Noncompliance in the Athabasca River appears to increase slightly through the region of current surface mining activity (see Figure 6). However, a clear effect outside of normal variance of the data set was not discernable.

2.2.20 Sulphide

A limited number of sulphide determinations were conducted on 1976 samples from throughout the region. Noncompliance (greater than 0.002 ppm) did not occur in the set.

2.2.21 Cyanide

A limited number of cyanide determinations were run on 1976 samples from throughout the region and all were found not to comply with the criteria (greater than 0.004 ppm). However, due to the small size of the data set, no further consideration is given.

2.2.22 Trace Metals and Elements

Noncompliant silver values did not occur in the data set and only one noncompliant selenium value was noted. A small number (2 to 5) of noncompliant levels occurred for cadmium, chromium, lead, arsenic, and nickel. Some occurrences of noncompliant cadmium and chromium centred on the current oil sands development area (Zone 7). Large noncompliance was noted for copper, zinc, and mercury, and general noncompliance occurred throughout the area for iron and manganese. The details of occurrences of higher levels of these elements are covered in Section 3.4.

2.2.23 Boron

Noncompliant boron levels (greater than 0.5 ppm) occasionally occurred in the data set at scattered tributaries in Zones 3, 5,

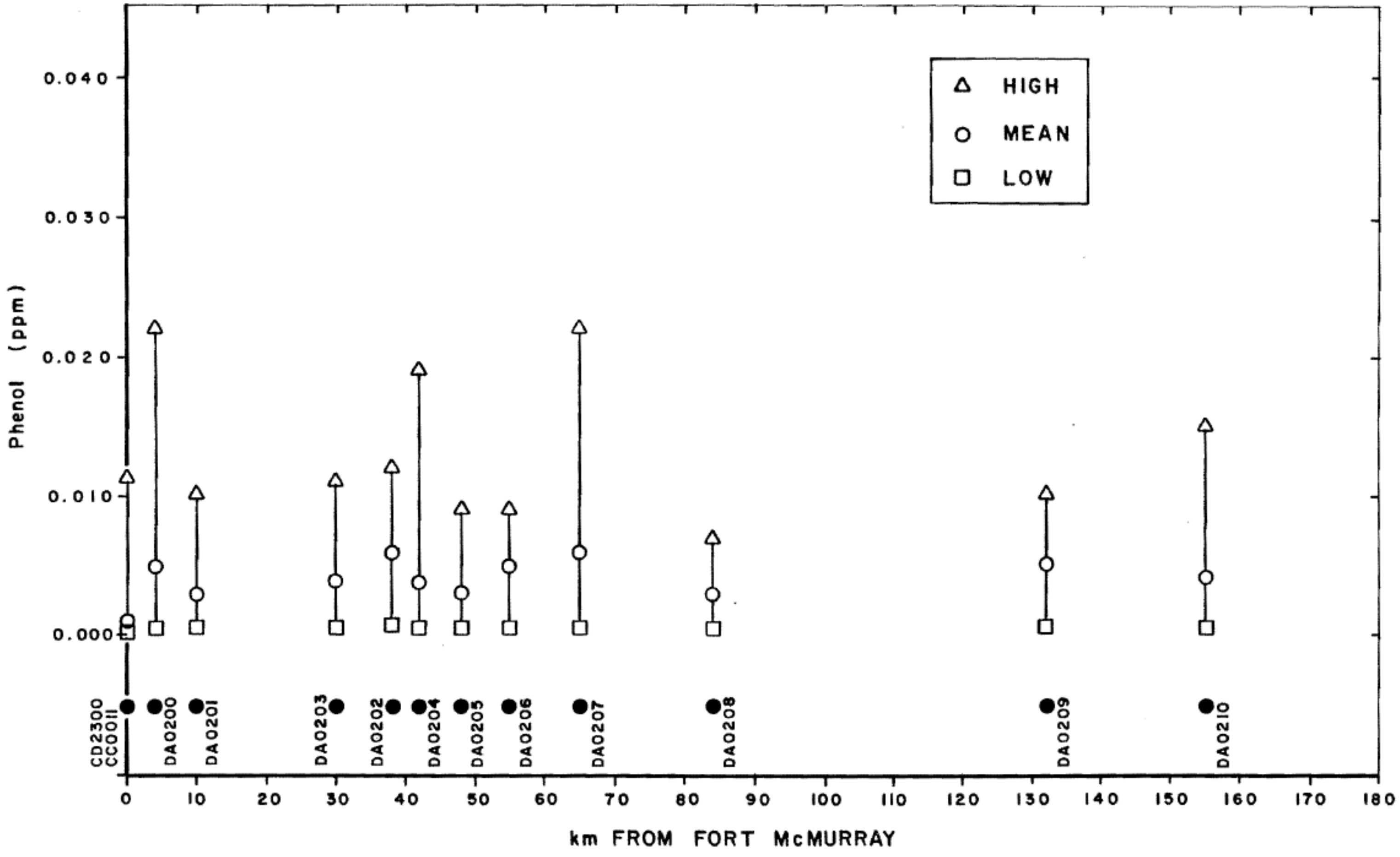

Figure 6. Phenol ranges and means for sites on Athabasca River.

and 7 and in the mainstem (Zone 8) but not in the lakes. The tributaries exhibited higher boron values during base flow conditions when scattered noncompliance levels between 0.5 and 1.0 ppm occurred (Table 11). Mine depressurization water contained elevated boron levels between 0.48 and 7.08 ppm (Lake and Rogers 1979) and evaporitic salts in other areas were notably high in boron (Hem 1970). Thus, there is nothing unusual about boron contributions during base flow. On the other hand, the three occurrences of noncompliant boron in the mainstem were during high flow conditions. This may indicate precipitation of borate complexes onto sediments provided to the mainstem and subsequent availability either as re-suspended particulate or as released dissolved species.

2.3 SUMMARY OF NONCOMPLIANCE ANALYSIS

The analysis of the data set for compliance to the tighest criteria in Table 8 indicates a number of parameters of interest regarding the management of the quality of the surface water in the oil sands area.

From a region-wide perspective, noncompliance occurred in a majority of cases for levels of total odour number, total nonfilterable residue fixed, turbidity, total Kjeldahl nitrogen, iron, and manganese. Additionally, there were a large number of occurrences of noncompliant levels of phenol, total phosphorus, copper, zinc, and mercury. The high frequency of noncompliance for these parameters reflects background "noise" of natural inputs. Thus, such parameters would appear inappropriate to detect chronic oil sands impacts. However, a toxicological analysis of these high frequency noncompliance parameters (along with those of low frequency) might indicate situations that could easily be stressed by additional anthropogenic loadings even at a relatively low level.

From the perspective of oil sands impacts, occurrences of noncompliant chloride, sodium, and total filterable residue fixed in tributaries adjacent to mining operations could be readily attributable to discharge of mine depressurization water. Additionally, noncompliant values of ammonia, total phosphorus, boron, and phenol

Table 11. Noncompliant boron levels (levels greater than 0.5 ppm).

Site	Date	B (ppm)
MacKay River	21-12-76	0.59
	25-02-77	0.58
Beaver River above Syncrude	04-01-77	0.93
	04-03-77	1.08
	06-12-77	0.58
Beaver River inside Syncrude	18-11-76	0.69
Calumet River	09-10-76	0.76
Eymundson Creek	02-03-77	0.90
Unnamed Creek	07-11-77	0.90
Athabasca River - Site DA0200	30-08-76	1.51
Site DA0205	30-08-76	1.51
Site DA0209	30-07-76	0.67

appeared to be associated with the same type of discharge. The few occurrences of noncompliant values of cadmium and chromium centred in the region of current oil sands development but could not be directly attributable to particular effluent. A slight tendency for phenol levels in the Athabasca River to increase throughout the reach north of Fort McMurray could be a reflection of the weathering of exposed oil sands deposits.

3. INTERPARAMETER RELATIONSHIPS

The surface water at any point can be visualized as stemming from differing components of upstream sources, such as direct runoff, including a subsurface part, shallow groundwater discharge, and deep groundwater discharge. The ultimate composition of a sample of water is determined by whatever physical, chemical, and biological processes that have operated previously on these components. Examples of such processes are the various chemical equilibria between the percolating water and the surface or subsurface materials, the storage and mixing caused by lakes and muskegs, and the utilization of dissolved and particulate matter by microorganisms. Thus, many values for parameters can exhibit relationships with each other and with time (McNeely and Neimanis 1978).

Where the processes involved are mainly chemical equilibria and physical discharge, well-defined relationships tend to hold true. Where the operating processes are physical transport mechanisms, although relationships can be drawn, the definition becomes less direct and more statistical. And where the operating processes are biological, relationships tend to be much less predictable. As with hydrometric analysis, data over a full range of environmental conditions are desirable to fully define the various relationships, and so the extent of definition of operating processes is reflected in the amount of data available.

The ensuing discussion has been grouped to coincide with the kinds of relationships operating: (1) the direct relationships that can be derived for the major ion parameters; (2) the regular but not quantitative seasonal variations associated with clastic loads; (3) the much less predictive relationships of compounds of carbon, nitrogen, and phosphorus as subjects of biological activity; and (4) the less predictive relationships of metals which are highly variable subjects of chemical transformations, particulate loading, and also biological activity. Irregularities in the regional patterns occurring adjacent to current oil sands operations are discussed in terms of impacts.

3.1 MAJOR IONS

An inspection of data summaries for the entire region (Appendix 5.2) reveals the general order of dominance of the major ions for the surface water as:

cations: calcium > magnesium > sodium
anions: bicarbonate > sulphate > chloride

a typical catena for glacial till watershed overlaying sedimentary formations. It should be noted, though, that most of the surface water in the area is highly variable, both geographically and temporally, and, at higher concentrations corresponding to base flow, sodium dominates magnesium and even calcium at many sites and chloride occassionally dominate sulphate and even bicarbonate.

To describe the ionic character of each tributary, as well as the variability in character, Stiff patterns (Hem 1970) were modified to include the equivalent ion concentration at minimum and maximum total dissolved solids and these are shown in Figure 7. Such patterns for each tributary illustrate the wide variety of differences among the tributaries, mainstem rivers, and lakes. Points at minimum and maximum concentrations tend to represent two types of loading to the surface water: maximum concentration coincides with winter base flow and is representative of deeper groundwater sources connected with such flow, whereas minimum concentration coincides with spring or summer freshets representing surface or much shallower groundwater sources.

For the cations, one noticeably common thread among all the sites was the presence of calcium and magnesium in a ratio generally between 3:1 and 4:1. Supply of these major ions, particularly during base flow, is provided by Upper Devonian formations of limestone, dolomites, and anhydrites. This ratio generally did not show much seasonal variation, indicating the similarity in cationic structure of eroded surface materials. Exceptions to the generalization were Hartley Creek, Bridge Creek Diversion, and Mamawi Lake Channel, which all showed relatively elevated calcium over magnesium during base flow conditions, and Joslyn Creek, Muskeg River, Unnamed Creek, and Lake Claire, which maintained a higher calcium content

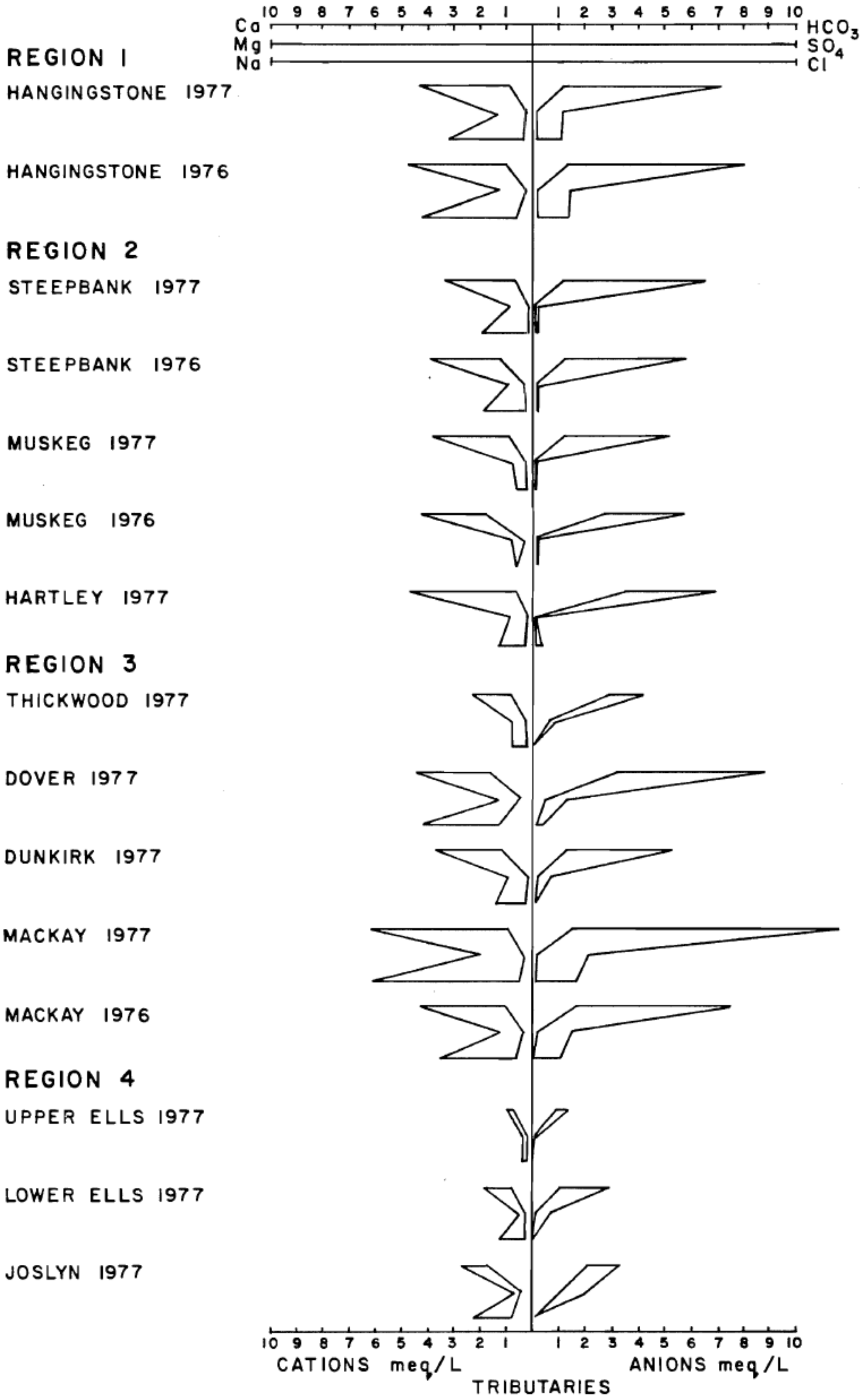

Figure 7. Modified Stiff patterns showing minimum and maximum equivalent concentrations of the major ions.

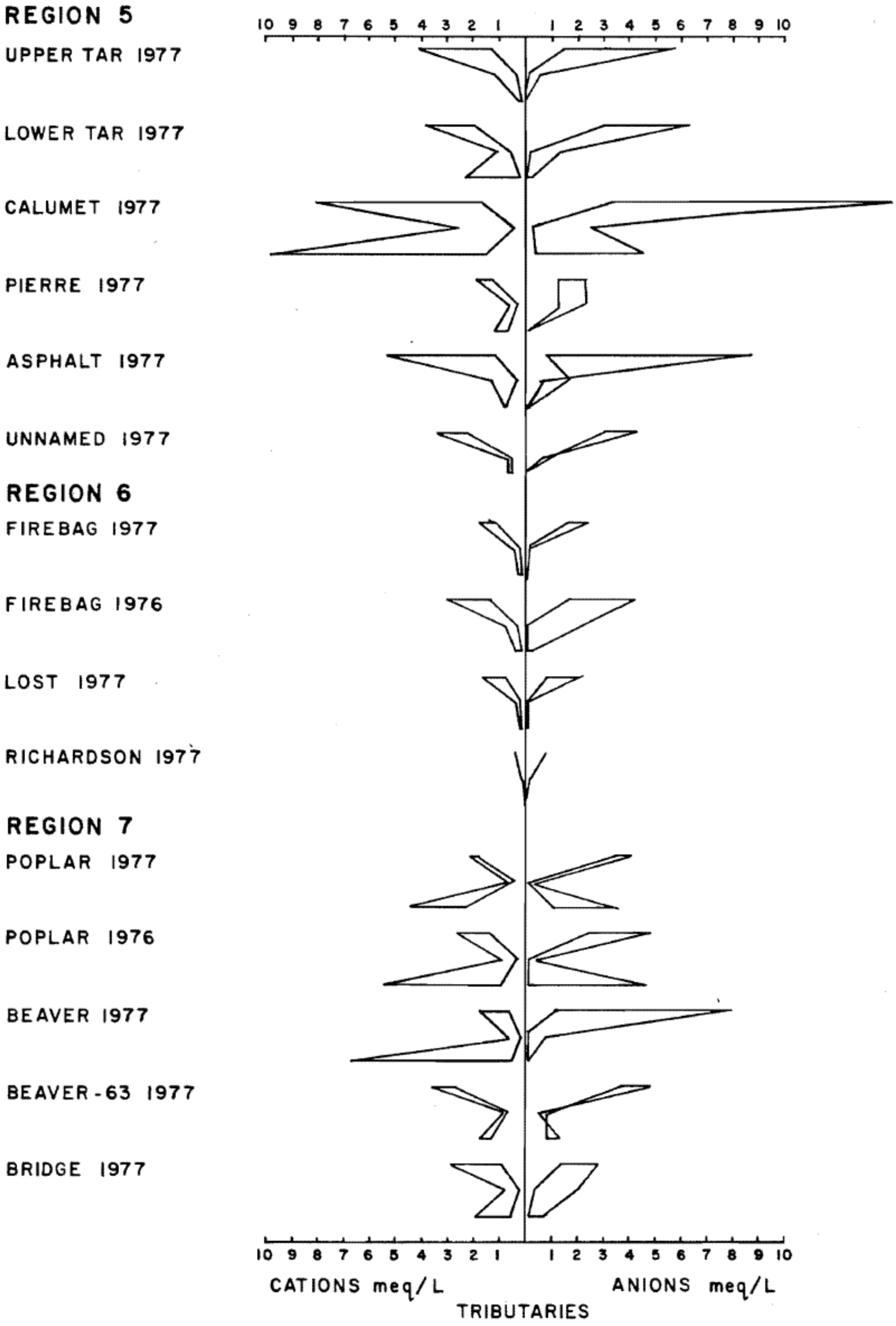

Figure 7. Continued.

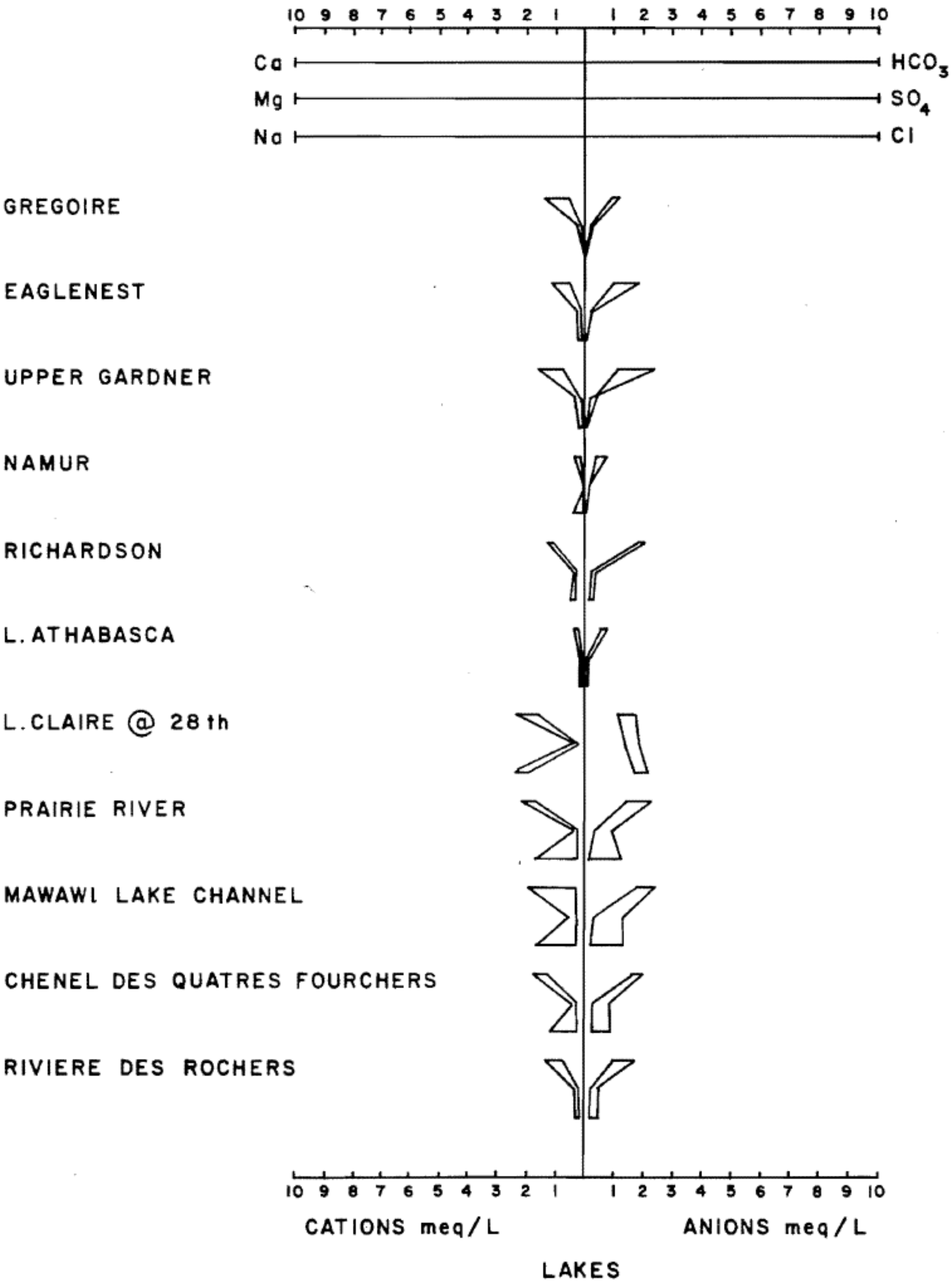

Figure 7. Continued.

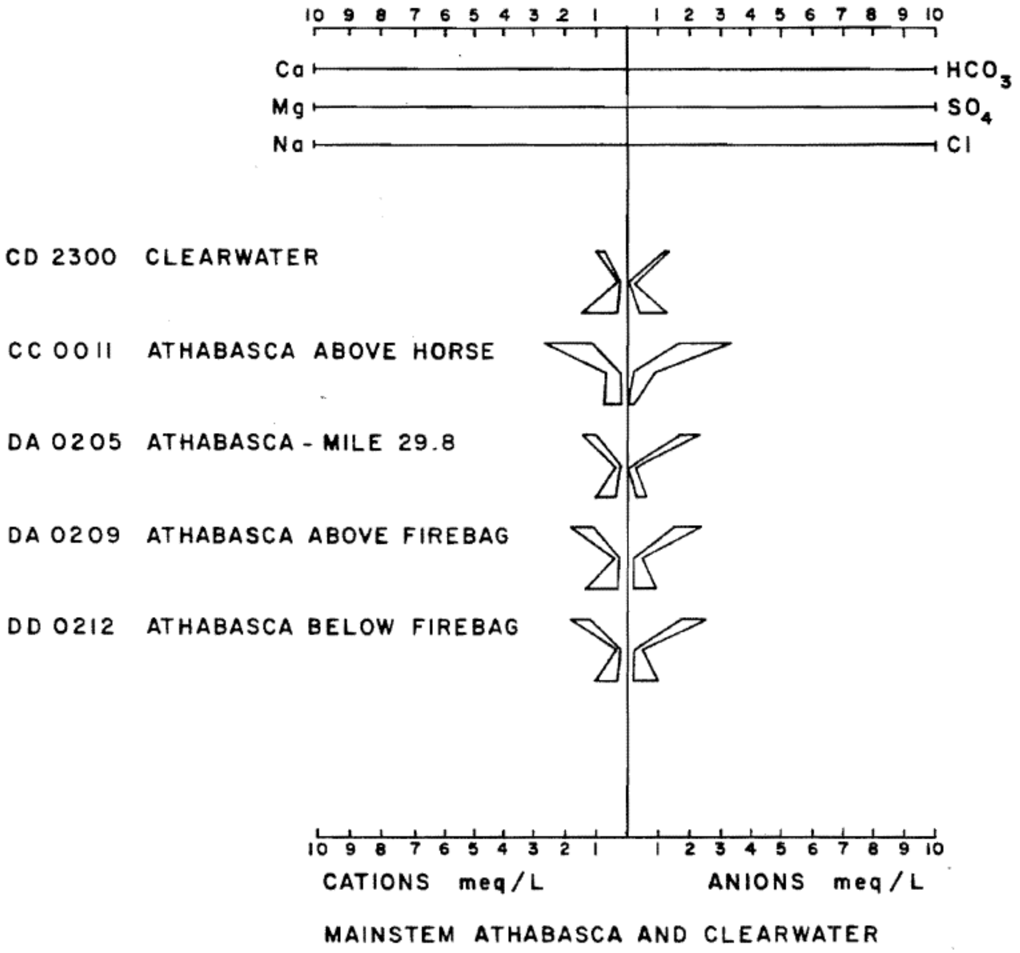

Figure 7. Concluded.

throughout the year (ratios ranged from 4.8:1 to 5.9:1). Sodium was a major cation in a number of tributaries, notably Poplar Creek, Beaver River, Calumet River, MacKay River, Dover River, Hangingstone River, Clearwater River, and Lake Claire, where it exceeded or rivaled calcium as the major cation. Water from Middle Devonian formations ranges up to 100 000 ppm chloride due to evaporitic halites (Gorrell 1974). Thus, in some cases, sodium appears to provide an indicator of a deeper groundwater component. However, shallower sources might be operating in the case of the Beaver and Dover rivers, where no corresponding high chlorides are evident.

Bicarbonate was the major anion in every case, except for Pierre River, where sulphate was the major anion, especially at base flow, and Lake Claire, where both sulphate and chloride exceeded bicarbonate. High sulphate concentrations were also evident at Bridge Creek Diversion, Joslyn Creek, and MacKay River. At Poplar Creek and the Clearwater River, chloride rivaled bicarbonate at base flow and it was a substantial component in Calumet River, Mamawi Lake Channel, and Prairie River. La Saline Spring, along the east bank of the Athabasca River (Figure 3), contained over 39 000 ppm chloride. Both sulphate and chloride can stem from Middle Devonian halites and anhydrites and indicate communications with deep sources at these sampling points. Mine depressurization water from the Syncrude operation ranged up to 10 500 ppm chloride and 78 ppm sulphate (Lake and Rogers 1974).

A variety of methods of analyzing interparameter relationships of major ionic species in natural surface water can be carried out to define and quantify the kinds of variations taking place. For flowing water, one approach that relates the variations to natural processes stems from the concept of dilution relationships. The relationship of specific conductance with discharge is first demonstrated, then the specific conductance is related to the individual ionic components of the natural water.

3.1.1 Specific Conductance-Discharge Relationship in Tributaries

Reviews of various dissolved solids-discharge relationships are available (Hall 1971; Liken et al. 1969). In the following discussion, the relationship between the specific conductance of stream water and the discharge of the stream for most surface waters in the form of a power curve (Steele 1973) was adopted:

$$SC = K\ Q^n \tag{1}$$

where: SC = specific conductance

Q = discharge

K = loading factor

n = dilution factor ranging between 0 and -1

Thus, for each stream, the actual specific conductance and corresponding discharge can be related to two factors: a loading factor which is proportional to the amounts of ionic material supplied by the watershed; and a dilution factor which is proportional to the variability of ionic concentrations. Where the variation in flow has no effect on changing the concentration of ionic substances, the diluting factor would be 0.0 and, where the diluting forces comprise no ionic species, the diluting factor would be -1.0. The range in between represents the typical situation where increased flows tend to accompany concentrations of solutes higher than anticipated by strict dilution.

This relationship is very useful not only from the physical understanding gained but also from the fact that specific conductance and discharge can be measured easily. Specific conductance can be further related to individual ionic species present as it represents the composite of cations and anions present.

By taking the log of the dilution equation (1), the equation takes the form:

$$\log SC = \log K + n \log Q \tag{2}$$

and thus, the relationship between the specific conductivity and discharge can be expressed graphically. Figure 8 shows such a graphical representation for data obtained from two rivers from similarly sized but different kinds of watersheds: the MacKay

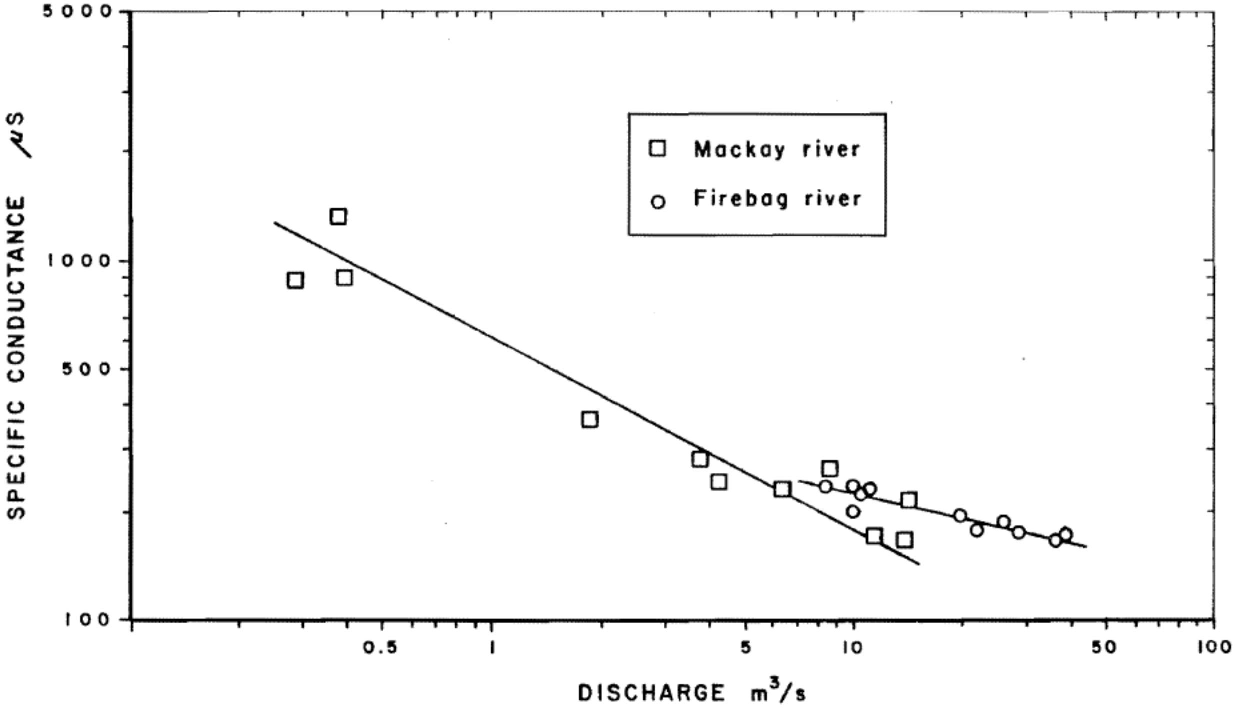

Figure 8. Specific conductance - discharge relationship of the Firebag and Mackay rivers in 1977.

(5230 km^2) and the Firebag (6030 km^2) rivers. It is evident that the dilution equation displays a very good fit to both groups of data. Also discernable in Figure 8 are characteristic differences between the two watersheds. The MacKay River relationship has a steeper slope (-n) depicting a greater dilution effect. The MacKay River relationship also has a higher elevation on the specific conductance axis showing the higher net loading (K) carried by that river.

The values for n and K, calculated by linear regression of all 1976 and 1977 specific conductance data collected at gauged tributaries in the study area, are shown in Table 12 along with the coefficients of determination. Data for most of the tributaries showed a good fit to the power curve as evidenced by their high coefficient of determination over the range of the data. However, data for Joslyn Creek, Pierre River, and Poplar Creek produced a poor fit. From a comparison of the results from sites where two years of data are available, one can tentatively conclude there is a yearly variation in this relationship that is more pronounced in the highly variable (high -n) sites, such as the MacKay River, than in the sites of low variability, such as the Firebag River. It is also notable that this yearly variation is particularly evident in the dilution factor whereas the loading factor between the two years is not as affected.

A plot of the loading factors versus dilution factors for each tributary for 1977 data portrays the types of tributaries in the study area (Figure 9). From the distribution presented by Figure 9, the types of tributaries range from a group of highly loaded and highly variable tributaries (the MacKay, Hangingstone, and Steepbank rivers) to a group of two relatively unloaded and stable tributaries (the Upper Ells and the Richardson rivers). The MacKay, Hangingstone, and Steepbank rivers all drain basins comprising mainly clayey and silty till (Griffiths 1978). The sampling point was low on the stream profiles (relatively close to the confluence with the mainstem) so that groundwater influence accounts for the

Table 12. Results of linear regression on 1976 and 1977 specific conductance (SC) and discharge (Q) data for the relationship $SC = KQ^n$. The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		K	n	r^2	K	n	r^2
CD0040	Hangingstone River	413	-0.43	0.97	441	-0.32	0.87
DA0060	Steepbank River	356	-0.46	0.96	383	-0.37	0.94
DA0080	Muskeg River	366	-0.30	0.79	364	-0.19	0.92
DA0090	Hartley Creek	194	-0.24	0.79	242	-0.21	0.75
DB0040	Thickwood Creek	75	-0.29	0.69			
DB0020	Dover River	421	-0.19	0.59			
DB0030	Dunkirk River	282	-0.35	0.90			
DB0011	MacKay River	584	-0.46	0.91	530	-0.31	0.89
DA0100	Upper Ells River	137	-0.13	0.82			
DA0170	Lower Ells River	265	-0.28	0.85			
DA0160	Joslyn Creek	364	-0.08	0.19			
DA0190	Upper Tar River	168	-0.19	0.71			
DA0150	Lower Tar River	263	-0.13	0.83			
DA0140	Calumet River	153	-0.35	0.84			
DA0130	Pierre River	301	-0.05	0.05			
DA0120	Asphalt Creek	310	-0.14	0.53			
DA0110	Unnamed Creek	299	-0.13	0.77			
DC0010	Firebag River	347	-0.22	0.83	403	-0.23	0.77
DC0020	Lost Creek	86	-0.28	0.86			
DD0020	Richardson River	124	-0.16	0.83			
DA0070	Poplar Creek	323	-0.04	0.06	347	-0.19	0.84
DA0180	Beaver River	238	-0.20	0.83			

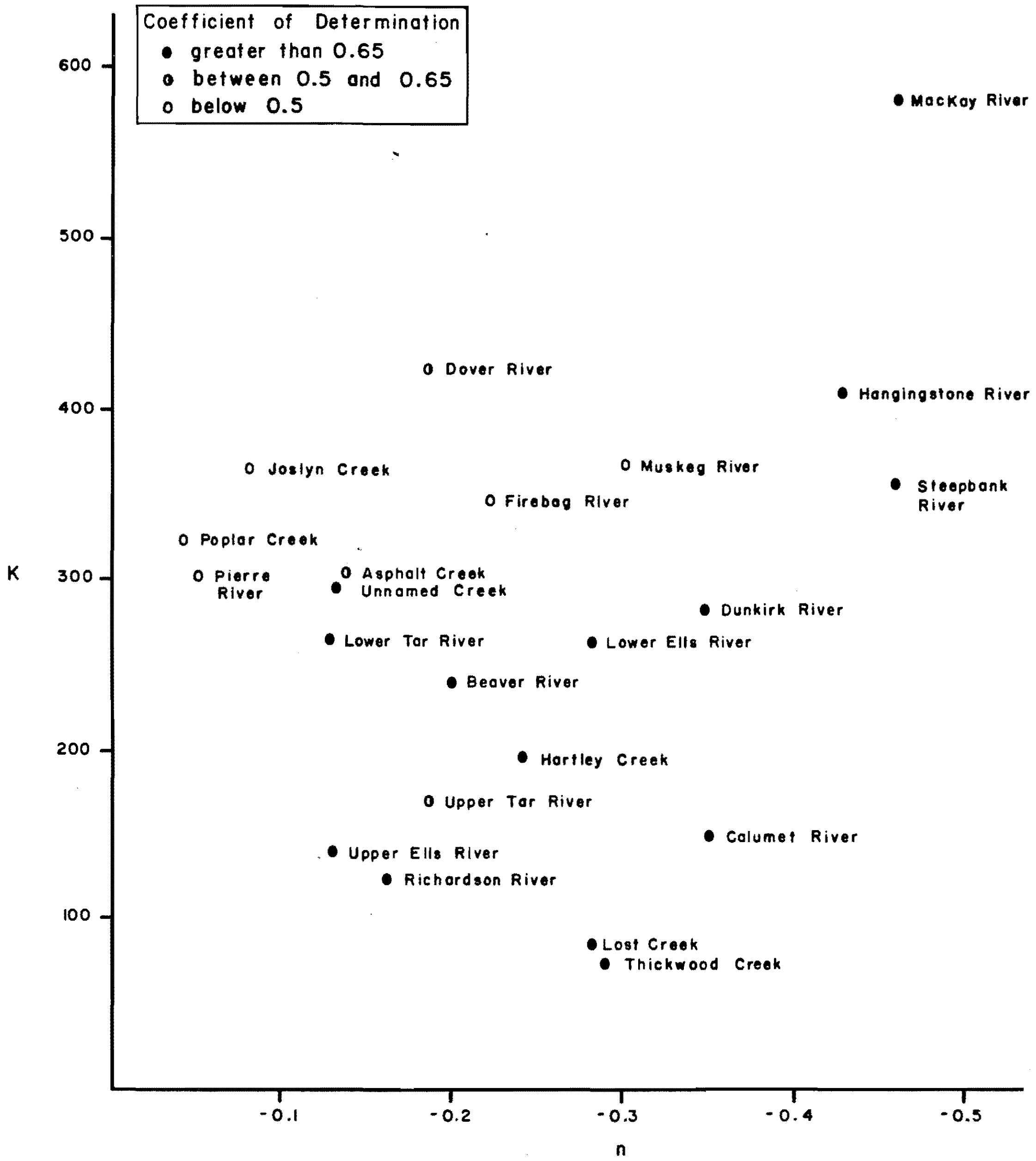

Figure 9. Distribution of loading factors (K) and dilution factors (n) for guaged tributaries in 1977 (equation (1)).

loading and variability (difference between runoff and groundwater). For both the Upper Ells and Richardson rivers, their low -n and K characters are determined chiefly by the large holdings of soft water in headwater lakes for both basins.

A noticeable cluster of points appears for sites of low variability yet high loading. This includes all lower sites for streams draining the east slopes of the Birch Mountains along with Poplar Creek (for 1977). This would seem to indicate a proportionally high groundwater influence. Possibly, the common low coefficients of determination for these data may indicate that another relationship would better describe their behaviour.

In the case of Poplar Creek, however, its inclusion in this grouping seems to be an artifact of the diversion of Beaver Creek into this watershed by Syncrude. Figure 3 shows the structure of Beaver River and Poplar Creek before Syncrude development and Figure 4 shows their resulting structure after development of the plant and mine. The increase in level of the Ruth Lake diversion complex, resulting in intermittent discharges into the Poplar Creek, appears to have disrupted the normal ionic regime of Poplar Creek, causing the low coefficient of determination and displacing its position in Figure 9 for 1977 data. In fact, the dilution relationship of Poplar Creek (Figure 10) indicates sporadic changes in its regime for 1977.

Another noticeable clustering of points in Figure 9 occurs with Lost Creek and Thickwood Creek. Both are small headwater tributaries (60 km^2 and 170 km^2, respectively) but they drain completely different terrain. Lost Creek drains mainly a jack pine community on hummocky morraine, whereas Thickwood Creek drains mainly muskeg, and yet their dilution factors and loading factors were almost identical for 1977.

3.1.2 Specific Conductance-Ion Relationships in Tributaries

The concentrations and subsequent ionic activity of each of the ionic species together determine the electrolytic character of

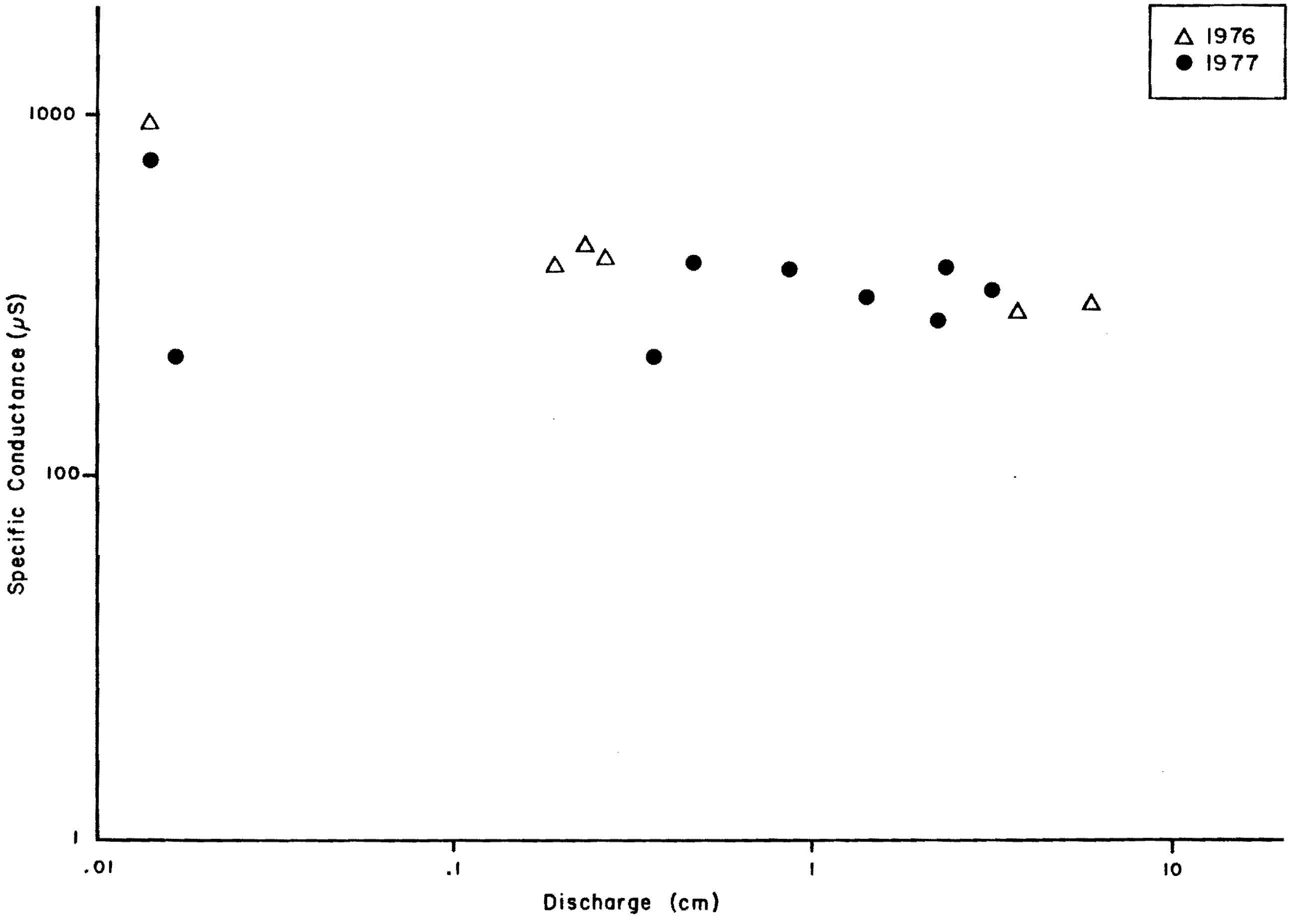

Figure 10. Specific conductance - discharge relationship of Poplar Creek from 1976 and 1977 data.

water. The electrical conductance of a water sample, then, is a composite of the ionic conductivities of both the cationic and anionic species present, such that:

$$\frac{1}{R} = K\ (C_a\lambda_a + C_b\lambda_b + \ldots.\ C_z\lambda_z) \qquad (3)$$

where: $\frac{1}{R}$ is reciprocal resistance, or conductance

C_i is concentration of ion i (equivalent/litre)

λ_i is constant characteristic of ion i

K is a proportionality constant that equals 1 under the standard conditions that defined $\frac{1}{R}$ = specific conductance

In case of a constant proportion of the various ionic components, as would be supplied by a common source to the base flow and diluting flow, one expects a linear relationship between the total dissolved solids and specific conductance (where λ_i would not vary appreciably in the range in question). In the case of varying proportions of the various ionic components, one expects an extent of non-linearity in the relationship of total dissolved solids and specific conductance that would reflect a shift in λ contributions. The λ_o (λ values at infinite dilution) values for typical ions in surface waters are shown in Table 13. A consideration of the significant ions from the standpoint of naturally occurring concentrations (calcium, magnesium, sodium, bicarbonate, chloride, and sulphate) indicates that not much deviation from linearity would be expected by varying the proportion of cations; however, one would expect a shift to higher specific conductance per total amount of ionic solids by increasing the proportion of either chloride or sulphate at the expense of bicarbonate. The total dissolved ionizable material is measured by the parameter filterable residue fixed.

Assuming a measure of linearity over the range of interest, an approximation of equation (3) can be made in the following form:

$$SC = K\ (FRF) + SC_o \qquad (4)$$

Table 13. Ionic equivalent conductivities at infinite dilution at 25°C (λ_o) for the main surface water ions.[a]

	Ion	λ_o mho-cm^2/g equivalent
Anions	HCO_3^-	44.48
	F^-	55.0
	$\frac{1}{2}CO_3^=$	69.3
	Cl^-	76.34
	$\frac{1}{2}SO_4^=$	80.0
	OH^-	198.0
Cations	Na^+	50.11
	$\frac{1}{2}Mg^{++}$	53.06
	$\frac{1}{2}Ca^{++}$	59.50
	K^+	73.52
	H^+	349.82

[a] From Meites and Thomas (1958).

where: SC is the specific conductance

FRF is the parameter filterable residue fixed

K is the proportionality factor

SC_o is a measure of non-linearity

The proportionality factor (K) relates to the amount of ionic activity per total amount of ionizable material. The higher the K, the higher the specific conductivity per ionizable material which reflects on the amount of ions provided by the solids and their λ_i. The SC_o is related to the non-linearity of fit. In actuality SC_o approaches 0 where concentrations approach zero but, in the range of interest, a positive SC_o indicates a decreasing contribution to specific conductivity at higher concentrations.

The relationship expressed by equation (4) is shown in Figure 11 for the MacKay and Firebag rivers for 1977. The more highly variable MacKay River displays a better fit and shows more specific conductance per dissolved material (probably as a result of a higher proportion of sulphate and chloride). It also has a slightly smaller non-linearity factor indicating that at higher concentrations the sulphate or chloride ions play an even more dominant role.

Values for SC_o and K, calculated by linear regression of 1976 and 1977 data for all tributaries, are shown in Table 14 along with the coefficient of determination. Data for most tributaries show a good fit to the approximation as evidenced by their high coefficient of determination over the range of the data. However, 1977 data for Poplar Creek obviously did not fit and 1977 data for Richardson River, Joslyn Creek, and Bridge Creek Diversion displayed a poor fit.

A plot of the proportionality factor versus non-linearity factors portrays the types of electrical character of the tributaries (Figure 12). Three groupings are apparent:

1. A group of the majority of tributary sites forming a generally smooth transition in K from lower activity per solid with a concurrent increase in this activity at higher loading (lower SC_o), likely caused by chloride

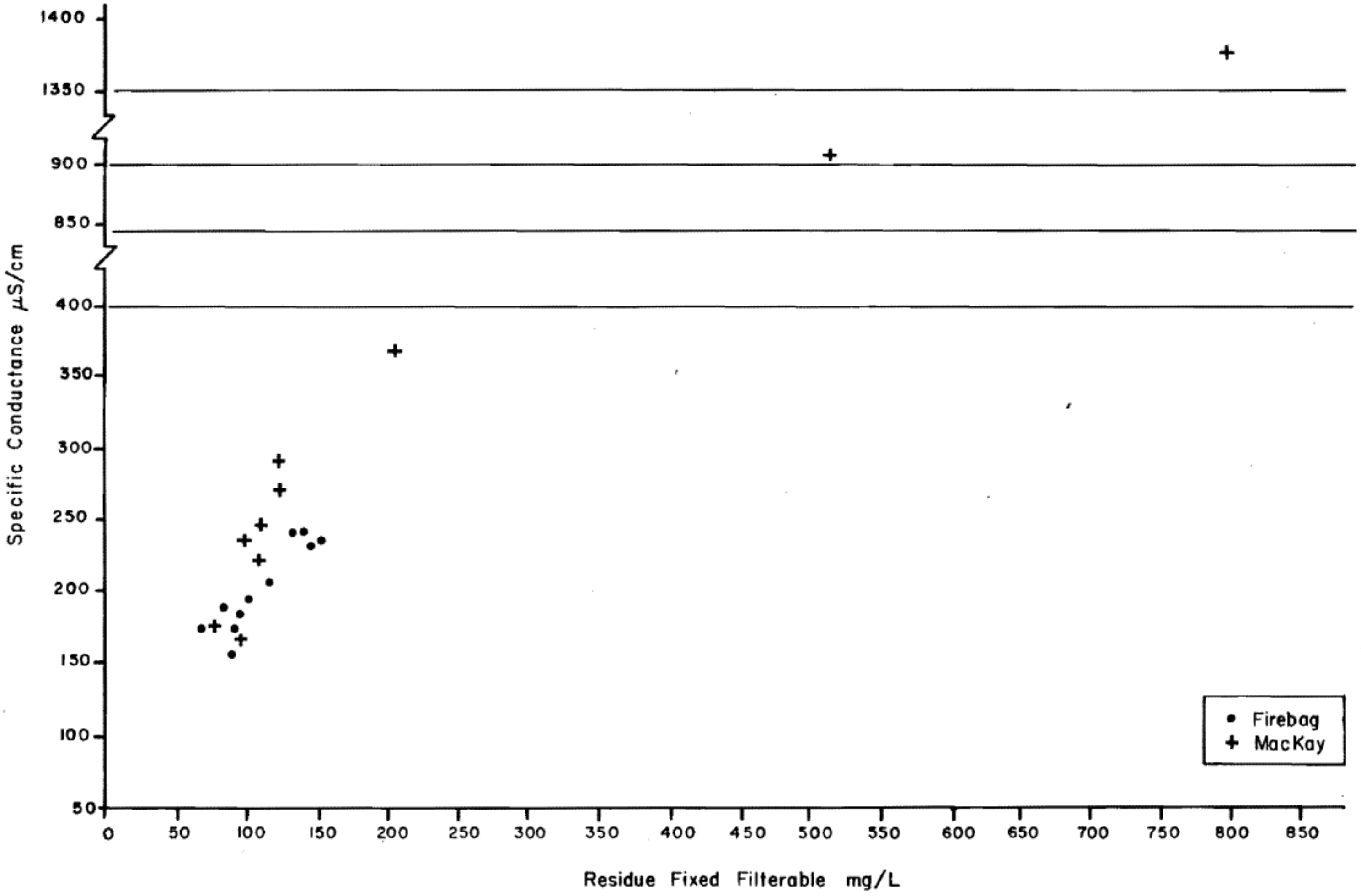

Figure 11. Specific conductance-filterable residue fixed relationship for the Firebag and MacKay rivers in 1977.

Table 14. Results of linear regression on 1976 and 1977 specific conductance (SC) and filterable residue fixed (FRF) data for the relationship SC = K(FRF) + SC_o. The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K	r^2	SC_o	K	r^2
CD0040	Hangingstone River	41	1.66	1.00	-12	1.99	0.88
DA0060	Steepbank River	55	1.66	0.99	98	1.10	0.89
DA0080	Muskeg River	64	1.59	0.92	146	1.19	0.66
DB0090	Hartley Creek	64	1.59	0.99			
DB0040	Thickwood Creek	36	1.90	0.92			
DB0020	Dover River	64.1	1.67	0.98			
DB0030	Dunkirk River	39	1.96	0.98			
DB0011	MacKay River	56	1.68	1.00	-9	1.91	0.98
DA0100	Upper Ells River	63	1.04	0.91			
DA0170	Lower Ells River	30	1.73	0.92			
DA0160	Joslyn Creek	190	0.98	0.65			
DA0190	Upper Tar River	29	1.72	0.99			
DA0150	Lower Tar River	58	1.58	0.96			
DA0140	Calumet River	57	1.78	0.98			
DA0130	Pierre River	3	1.78	0.83			
DA0120	Asphalt Creek	-9	1.76	0.98			
DA0110	Unnamed Creek	143	1.14	0.83			
DC0010	Firebag River	96	0.98	0.83	123	0.77	0.61
DC0020	Lost Creek	-1	2.02	0.89			
DD0020	Richardson River	56	50.00	0.52			
DA0070	Poplar Creek	380	-0.06	0.02	17	2.06	0.99
DA0180	Beaver River	72	1.44	0.97			
DA0181	Beaver River at Hwy 63	165	1.22	0.91			
DA0182	Bridge Creek Diversion	154	1.24	0.71			

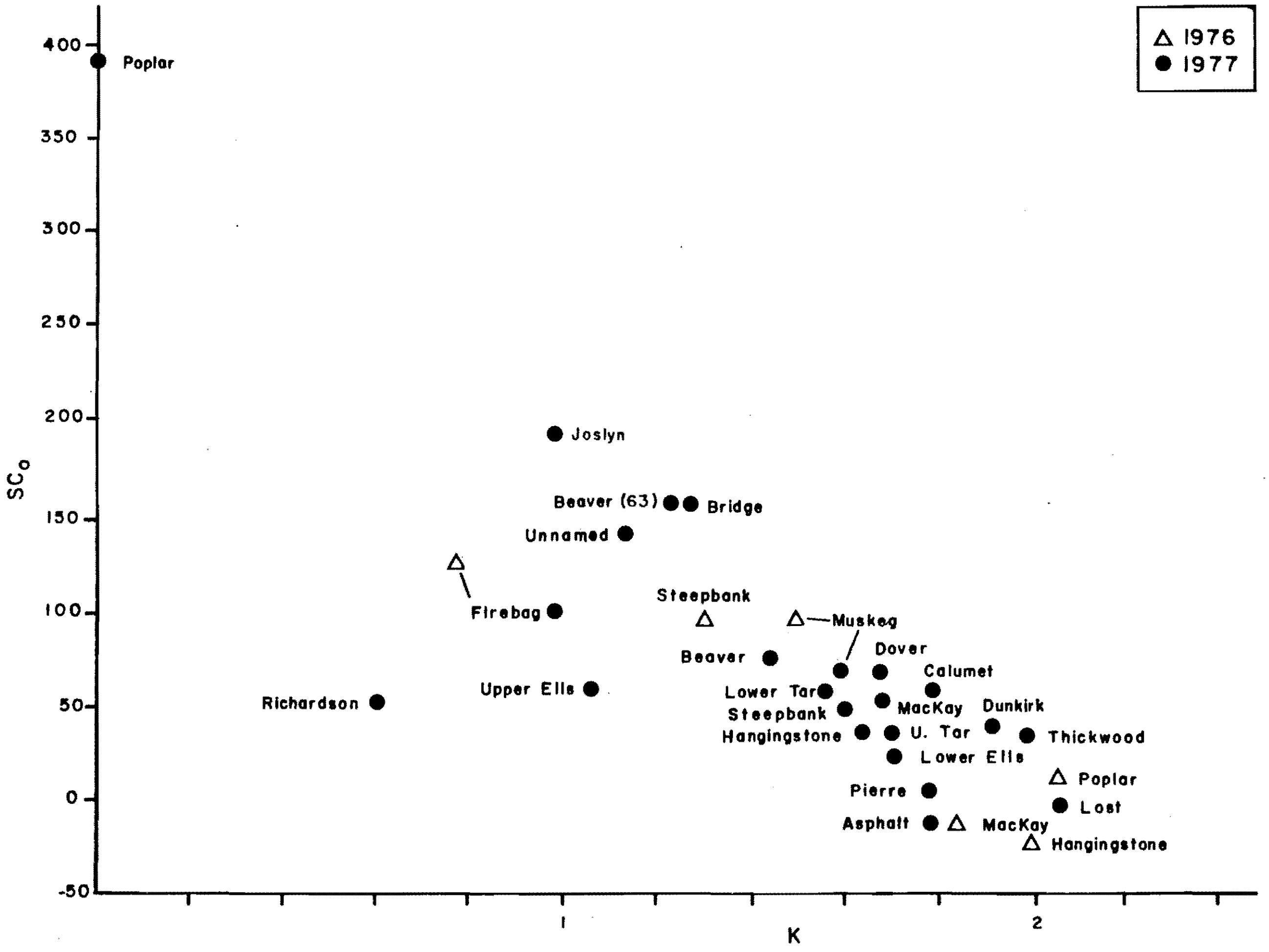

Figure 12. Relationship of proportionality of ionic activity per total dissolved solids (K) and non-linearity factor (SC$_o$) for equation (4).

and sulphate. Such a grouping appears indicative of similar kinds of base flow and of dilution operating at these sites;

2. A grouping of the Firebag, Upper Ells, and Richardson rivers out of line of the other tributaries. Lower ionic activity per solid reflects water from the Precambrian Shield, in the case of the eastern tributaries, and water from the high elevation soft water lakes, in the case of the Upper Ells River; and
3. Poplar Creek for 1977. Data for this year do not group with the rest of the region which probably reflects the disruptive effect of diversion.

The same relationship expressed by equation (4) can be explored for each individual ion concentration such that:

$$SC = K_i \ (I_i) + SC_o \qquad (5)$$

where: SC is the specific conductance

(I_i) is the parameter producing ion i

K_i is the proportionality factor for ion i

SC_o is a measure of non-linearity for ion i

The fact that the two factors deal with comparing an individual ion effect to a total effect preclude the kind of analysis conducted for equation (3). However, in general, one would expect good correlations for the major contributors to specific conductance. The relationship of equation (5) for major ionic species in the Firebag River is depicted in Figure 13.

Values for SC_o and (I_i) for equation (5), calculated by linear regression of 1976 and 1977 data for all tributaries, are shown in Tables 15 to 23 for the following ions: calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, fluoride, and silica. Good correlations are demonstrated for many cases, especially the major ions. Where a particular ion has the major effect on the conductivity, or is released to the surface water by the same processes releasing the ion with the predominant effect, one would expect a good correlation.

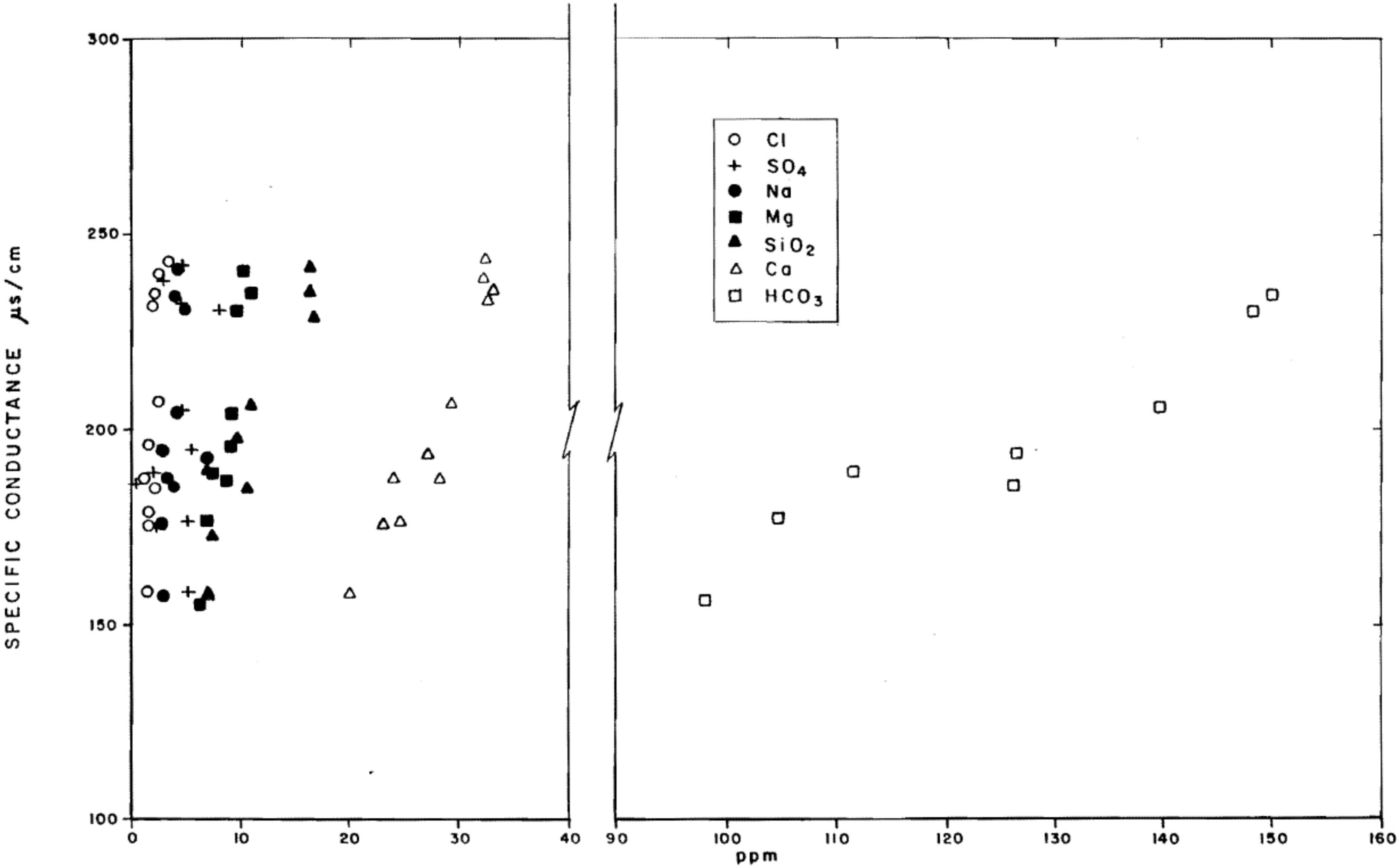

Figure 13. Relationship of major ion concentrations with specific conductance for the Firebag River in 1977.

Table 15. Results of linear regression on 1976 and 1977 specific conductance (SC) and calcium data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_{Ca}	r^2	SC_o	K_{Ca}	r^2
CD0040	Hangingstone River	-30.05	10.63	0.99	-32.10	9.33	0.97
DA0060	Steepbank River	-28.98	9.26	0.99	-34.13	9.05	0.99
DA0080	Muskeg River	62.52	6.00	0.91	79.96	5.35	0.97
DB0090	Hartley Creek	23.65	7.07	0.98			
DB0040	Thickwood Creek	3.62	7.44	0.91			
DB0020	Dover River	21.97	10.52	0.97			
DB0030	Dunkirk River	-3.79	7.92	0.99			
DB0011	MacKay River	-70.31	11.94	0.99	-44.13	10.78	1.00
DA0100	Upper Ells River	-4.56	8.11	0.79			
DA0170	Lower Ells River	-51.3	10.8	0.97			
DA0160	Joslyn Creek	219.33	4.18	0.43			
DA0190	Upper Tar River	-31.84	8.35	0.89			
DA0150	Lower Tar River	-3.59	8.87	0.95			
DA0140	Calumet River	-63.14	12.67	1.00			
DA0130	Pierre River	-86.60	13.13	0.83			
DA0120	Asphalt Creek	130.77	6.63	0.95			
DA0110	Unnamed Creek	175.31	4.01	0.52			
DC0010	Firebag River	25.00	6.31	0.89	-17.29	7.50	0.99
DC0020	Lost Creek	68.98	3.62	0.73			
DD0020	Richardson River	55.84	2.37	0.11			
DA0070	Poplar Creek	406.20	-1.30	0.01	-474.78	27.59	0.95
DA0180	Beaver River	-242.86	23.65	0.68			
DA0181	Beaver River at Hwy 63	280.92	4.34	0.13			
DA0182	Bridge Creek Diversion	16.42	9.40	0.96			

Table 16. Results of linear regression on 1976 and 1977 specific conductance (SC) and magnesium data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_{Mg}	r^2	SC_o	K_{Mg}	r^2
CD0040	Hangingstone River	-29.73	34.84	0.99	-48.75	36.31	0.96
DA0060	Steepbank River	-37.78	30.58	0.98	-45.15	29.64	0.95
DA0080	Muskeg River	4.59	28.48	0.93	-13.56	28.75	0.91
DB0090	Hartley Creek	-24.87	30.26	0.97			
DB0040	Thickwood Creek	2.99	20.85	0.90			
DB0020	Dover River	35.25	27.10	0.94			
DB0030	Dunkirk River	-11.71	27.22	1.00			
DB0011	MacKay River	-21.76	29.81	0.99	-50.28	31.79	0.98
DA0100	Upper Ells River	5.34	24.36	0.64			
DA0170	Lower Ells River	-80.22	39.97	0.92			
DA0160	Joslyn Creek	171.26	18.88	0.66			
DA0190	Upper Tar River	0.36	23.89	0.91			
DA0150	Lower Tar River	7.37	26.93	0.93			
DA0140	Calumet River	-9.18	33.05	0.99			
DA0130	Pierre River	-12.98	32.35	0.62			
DA0120	Asphalt Creek	84.06	22.36	0.97			
DA0110	Unnamed Creek	32.78	25.73	0.73			
DC0010	Firebag River	12.51	21.63	0.90	-6.66	22.82	0.96
DC0020	Lost Creek	10.82	21.30	0.90			
DD0020	Richardson River	63.79	4.58	0.07			
DA0070	Poplar Creek	399.98	-3.07	0.02	-337.81	64.00	0.93
DA0180	Beaver River	-189.74	58.05	0.83			
DA0181	Beaver River at Hwy 63	107.40	26.33	0.33			
DA0182	Bridge Creek Diversion	-40.69	34.22	0.92			

Table 17. Results of linear regression on 1976 and 1977 specific conductance (SC) and sodium data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_{Na}	r^a	SC_o	K_{Na}	r^2
CD0040	Hangingstone River	24.37	11.38	0.99	42.19	9.95	0.97
DA0060	Steepbank River	65.14	12.27	0.99	84.84	11.25	0.99
DA0080	Muskeg River	247.62	6.35	0.21	332.98	0.88	0.001
DB0090	Hartley Creek	-65.53	21.92	0.94			
DB0040	Thickwood Creek	90.60	9.33	0.36			
DB0020	Dover River	71.11	9.00	0.98			
DB0030	Dunkirk River	33.76	18.37	0.98			
DB0011	MacKay River	74.20	9.30	0.98	56.09	10.15	1.00
DA0100	Upper Ells River	89.67	9.06	0.49			
DA0170	Lower Ells River	75.90	11.49	0.97			
DA0160	Joslyn Creek	233.25	6.39	0.85			
DA0190	Upper Tar River	232.86	6.42	0.51			
DA0150	Lower Tar River	134.01	12.23	0.94			
DA0140	Calumet River	99.43	7.90	1.00			
DA0130	Pierre River	74.71	12.29	0.61			
DA0120	Asphalt Creek	40.83	19.32	0.24			
DA0110	Unnamed Creek	325.48	3.29	0.06			
DC0010	Firebag River	74.5	36.21	0.75	31.13	44.70	0.98
DC0020	Lost Creek	13.70	69.11	0.62			
DD0020	Richardson River	63.62	8.46	0.25			
DA0070	Poplar Creek	336.4	-0.10	0.004	125.62	6.70	0.99
DA0180	Beaver River	126.23	4.74	0.98			
DA0181	Beaver River at Hwy 63	333.06	5.55	0.61			
DA0182	Bridge Creek Diversion	6.16	11.50	0.92			

Table 18. Results of linear regression on 1976 and 1977 specific conductance (SC) and potassium data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_k	r^2	SC_o	K_k	r^2
CD0040	Hangingstone River	-13.62	174.5	0.88	-14.33	209.73	0.85
DA0060	Steepbank River	85.28	176.71	0.53	50.36	252.86	0.76
DA0080	Muskeg River	319.85	17.15	0.01	122.33	248.33	0.81
DB0090	Hartley Creek	296.56	8.47	0.70			
DB0040	Thickwood Creek	72.35	91.22	0.66			
DB0020	Dover River	-253.12	236.86	0.71			
DB0030	Dunkirk River	6.69	170.41	0.88			
DB0011	MacKay River	-61.16	219.54	0.87	-51.78	266.71	0.85
DA0100	Upper Ells River	49.78	75.23	0.62			
DA0170	Lower Ells River	-65.17	203.63	0.85			
DA0160	Joslyn Creek	214.00	65.36	0.73			
DA0190	Upper Tar River	83.46	148.37	0.86			
DA0150	Lower Tar River	46.46	162.54	0.83			
DA0140	Calumet River	-71.51	181.42	0.96			
DA0130	Pierre River	395.98	-11.15	0.01			
DA0120	Asphalt Creek	-39.33	167.24	0.63			
DA0110	Unnamed Creek	695.06	-113.83	0.51			
DC0010	Firebag River	135.78	83.04	0.75	96.29	155.68	0.84
DC0020	Lost Creek	167.6	-86.84	0.08			
DD0020	Richardson River	84.4	-5.38	0.04			
DA0070	Poplar Creek	-260.33	219.57	0.51	-251.32	311.46	0.56
DA0180	Beaver River	119.28	129.68	0.20			
DA0181	Beaver River at Hwy 63	497.36	15.07	0.01			
DA0182	Bridge Creek Diversion	397.12	-25.13	0.01			

Table 19. Results of linear regression on 1976 and 1977 specific conductance (SC) and bicarbonate data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_{HCO_3}	r^2	SC_o	K_{HCO_3}	r^2
CD0040	Hangingstone River	-7.27	2.02	1.00	5.08	1.85	0.94
DA0060	Steepbank River	10.66	1.48	1.00	14.97	1.49	0.99
DA0080	Muskeg River	15.94	1.47	0.96	42.30	1.32	0.95
DB0090	Hartley Creek	2.96	1.51	0.98			
DB0040	Thickwood Creek	9.81	1.54	0.92			
DB0020	Dover River	-18.63	1.73	0.96			
DB0030	Dunkirk River	6.65	1.68	0.99			
DB0011	MacKay River	141.58	1.54	0.59	-17.28	2.00	0.99
DA0100	Upper Ells River	-3.55	1.79	0.83			
DA0170	Lower Ells River	-34.58	2.18	0.96			
DA0160	Joslyn Creek	291.04	0.68	0.31			
DA0190	Upper Tar River	-11.32	1.69	0.99			
DA0150	Lower Tar River	82.45	1.37	0.93			
DA0140	Calumet River	-127.52	2.34	1.00			
DA0130	Pierre River	363.74	-0.09	0.001			
DA0120	Asphalt Creek	307.66	0.95	0.79			
DA0110	Unnamed Creek	278.19	0.48	0.19			
DC0010	Firebag River	28.70	1.33	0.93	-8.70	1.65	1.00
DC0020	Lost Creek	14.90	1.28	0.94			
DD0020	Richardson River	49.12	0.63	0.12			
DA0070	Poplar Creek	430.75	-0.32	0.03	-496.86	5.07	0.92
DA0180	Beaver River	1.17	1.57	0.99			
DA0181	Beaver River at Hwy 63	282.37	1.17	0.22			
DA0182	Bridge Creek Diversion	30.77	1.89	0.54			

Table 20. Results of linear regression on 1976 and 1977 specific conductance (SC) and sulphate data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_{SO_4}	r^2	SC_o	K_{SO_4}	r^2
CD0040	Hangingstone River	42.25	15.12	0.96	9.98	13.64	0.99
DA0060	Steepbank River	82.11	35.08	0.34	-32.69	44.99	0.60
DA0080	Muskeg River	360.65	-3.55	0.01	288.70	21.29	0.68
DB0090	Hartley Creek	187.96	20.52	0.05			
DB0040	Thickwood Creek	-54.49	26.49	0.40			
DB0020	Dover River	331.42	7.85	0.86			
DB0030	Dunkirk River	-47.74	16.27	0.95			
DB0011	MacKay River	72.42	11.84	0.97	74.71	10.58	0.96
DA0100	Upper Ells River	82.32	6.30	0.13			
DA0170	Lower Ells River	42.51	10.78	0.92			
DA0160	Joslyn Creek	331.60	1.02	0.25			
DA0190	Upper Tar River	85.72	16.49	0.85			
DA0150	Lower Tar River	365.34	1.91	0.03			
DA0140	Calumet River	232.47	13.56	0.95			
DA0130	Pierre River	194.31	1.80	0.66			
DA0120	Asphalt Creek	523.46	-0.85	0.06			
DA0110	Unnamed Creek	346.59	0.53	0.07			
DC0010	Firebag River	188.11	3.08	0.05	122.11	28.05	0.66
DC0020	Lost Creek	173.36	-8.86	0.16			
DD0020	Richardson River	82.60	-0.73	0.05			
DA0070	Poplar Creek	355.07	0.52	0.00008	140.56	21.97	0.98
DA0180	Beaver River	143.30	14.48	0.84			
DA0181	Beaver River at Hwy 63	527.72	0.32	0.02			
DA0182	Bridge Creek Diversion	252.76	2.73	0.49			

Table 21. Results of linear regression on 1976 and 1977 specific conductance (SC) and chloride data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_{Cl}	r^2	SC_o	K_{Cl}	r^2
CD0040	Hangingstone River	-56.63	23.76	0.95	49.88	18.67	0.79
DA0060	Steepbank River	-14.00	99.51	0.97	60.86	73.64	0.99
DA0080	Muskeg River	314.79	4.22	0.08	316.18	5.20	0.05
DB0090	Hartley Creek	152.16	24.73	0.80			
DB0040	Thickwood Creek	52.99	69.86	0.70			
DB0020	Dover River	119.50	50.73	0.82			
DB0030	Dunkirk River	34.93	234.72	0.67			
DB0011	MacKay River	143.77	23.15	0.98	148.96	19.04	0.81
DA0100	Upper Ells River	108.75	22.88	0.36			
DA0170	Lower Ells River	102.25	53.21	0.93			
DA0160	Joslyn Creek	372.11	18.24	0.10			
DA0190	Upper Tar River	256.49	12.85	0.39			
DA0150	Lower Tar River	192.83	62.86	0.91			
DA0140	Calumet River	264.83	10.21	1.00			
DA0130	Pierre River	412.60	-15.78	0.10			
DA0120	Asphalt Creek	322.86	31.72	0.05			
DA0110	Unnamed Creek	337.89	25.51	0.04			
DC0010	Firebag River	93.65	59.54	0.78	102.23	46.62	0.98
DC0020	Lost Creek	140.31	9.94	0.01			
DD0020	Richardson River	69.85	8.92	0.31			
DA0070	Poplar Creek	372.63	-0.15	0.02	263.75	4.27	0.99
DA0180	Beaver River	-195.52	315.12	0.71			
DA0181	Beaver River at Hwy 63	442.38	2.98	0.55			
DA0182	Bridge Creek Diversion	206.90	9.45	0.60			

Table 22. Results of linear regression on 1976 and 1977 specific conductance (SC) and fluoride data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_F	r^2	SC_o	K_F	r^2
CD0040	Hangingstone River	-32.18	2714.91	0.42	-44.78	2950.19	0.45
DA0060	Steepbank River	32.51	2511.97	0.44	228.47	424.43	0.02
DA0080	Muskeg River	-9.32	2888.23	0.54	89.59	2479.73	0.66
DB0090	Hartley Creek	-87.03	3073.07	0.72			
DB0040	Thickwood Creek	-21.07	2233.86	0.61			
DB0020	Dover River	-14.97	2661.27	0.80			
DB0030	Dunkirk River	236.69	700.43	0.04			
DB0011	MacKay River	148.33	2102.05	0.13	-32.11	3455.70	0.42
DA0100	Upper Ells River	119.53	28.16	0.001			
DA0170	Lower Ells River	50.00	1425.00	0.28			
DA0160	Joslyn Creek	423.38	-66.68	0.01			
DA0190	Upper Tar River	-237.62	3577.38	0.70			
DA0150	Lower Tar River	51.42	1664.34	0.50			
DA0140	Calumet River	19.44	3631.63	0.18			
DA0130	Pierre River	258.54	273.66	0.06			
DA0120	Asphalt Creek	3.00	1263.67	0.13			
DA0110	Unnamed Creek	321.45	186.35	0.10			
DC0010	Firebag River	206.75	-47.17	0.001	380.10	-1434.88	0.20
DC0020	Lost Creek	134.84	136.78	0.01			
DD0020	Richardson River	104.20	-300.00	0.20			
DA0070	Poplar Creek	530.81	-1402.97	0.06	-507.07	8362.96	0.28
DA0180	Beaver River	-54.61	2983.51	0.91			
DA0181	Beaver River at Hwy 63	66.52	2184.87	0.41			
DA0182	Bridge Creek Diversion	-87.03	3073.07	0.72			

Table 23. Results of linear regression on 1976 and 1977 specific conductance (SC) and silica data for equation (5). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Name	1977			1976		
		SC_o	K_{SiO_2}	r^2	SC_o	K_{SiO_2}	r^2
CD0040	Hangingstone River	-91.17	48.93	0.97	-76.74	42.93	0.71
DA0060	Steepbank River	12.14	41.88	0.95	67.83	24.95	0.43
DA0080	Muskeg River	121.52	26.47	0.76	237.59	7.92	0.24
DB0090	Hartley Creek	57.54	33.20	0.82			
DB0040	Thickwood Creek	50.48	15.97	0.80			
DB0020	Dover River	273.13	38.87	0.98			
DB0030	Dunkirk River	39.26	40.38	0.92			
DB0011	MacKay River	57.41	60.71	0.94	-50.29	50.17	0.59
DA0100	Upper Ells River	104.18	4.56	0.79			
DA0170	Lower Ells River	146.01	16.31	0.81			
DA0160	Joslyn Creek	540.97	-21.86	0.10			
DA0190	Upper Tar River	-48.10	42.91	0.94			
DA0150	Lower Tar River	74.64	31.96	0.86			
DA0140	Calumet River	-154.00	80.44	0.92			
DA0130	Pierre River	298.75	7.35	0.07			
DA0120	Asphalt Creek	57.67	35.47	0.96			
DA0110	Unnamed Creek	260.14	9.71	0.19			
DC0010	Firebag River	122.29	6.87	0.93	47.38	12.59	0.96
DC0020	Lost Creek	28.77	20.24	0.72			
DD0020	Richardson River	69.94	0.77	0.20			
DA0070	Poplar Creek	456.46	-16.78	0.03	399.43	8.89	0.01
DA0180	Beaver River	-90.21	63.79	0.95			
DA0181	Beaver River at Hwy 63	512.29	7.01	0.05			
DA0182	Bridge Creek Diversion	42.69	66.35	0.50			

For each ion, a comparison of the different proportionality factor K_i displayed by each site gives a quantitative distribution of the effect of the ions on the total electrical character of water from each site. The higher the K_i, the less the relative contribution that ion has to the total specific conductance. These values for each tributary correspond well with what is indicated by Figure 7 for the six major ions. In addition to the major contributors to the electrical character of the water, the relationships exhibited by the minor contributing parameters of potassium, fluoride, and silica deserve mention.

Fluoride concentrations generally showed a very poor fit (Table 22). Only in Beaver River did there seem to be a good relationship with nonfilterable residue fixed and to a lesser extent in the Dover River, Upper Tar River, and Hartley Creek. Thus, the release of fluoride is not simple and it may be that complexing, with metals such as aluminum and iron, may be complicating the fluoride discharge relationship.

Potassium also showed a generally poor fit to equation (5), but appeared to fit well for the Calumet, MacKay, Dunkirk, Upper Tar, Hangingstone, Lower Tar, and Lower Ells rivers (Table 18). For the sites on the lower portions of the profiles of the tributaries (in particular the Calumet, Hangingstone, and MacKay rivers), this correlation would appear to indicate a groundwater source of potassium along with sodium. The discharge relationship of potassium in surface water of the Muskeg basin has been shown to be a hysteresis which was interpreted to indicate leaching of leaf fall as a primary source (Schwartz 1978).

It is notable that silica can be correlated well with specific conductivity in most cases. As the silicate ion itself constitutes no more than 10% of total dissolved silica species between pH 8.4 and 8.9 (Hem 1970), its correlation is coincidental and would seem to indicate similar kinetics of release from the watershed as that of the major electrolytes. Silica is associated more with water that seeps through the soil (subsurface flow) than with overland flow or groundwater. Normally, during a rising stage, silica decreases initially while overland flow comprises the greater component, then increases as the subsurface component increases in dominance, and finally decreases as the groundwater component dominates (Kennedy 1971). The dilution behaviour implied by the correlations in Table 23 is contrary to this general behaviour of silica and may indicate the major source of silica from a component deeper than just subsurface.

3.1.3 Specific Conductance Relationships in the Mainstem Rivers

Two types of sampling program were conducted on the mainstem river system (Table 4). The program, starting in June 1977 involved only a part of that year, therefore, the following analysis deals only with the data collected from February 1976 to February 1977.

The specific conductance-discharge relationships of three sites is shown in Figure 14 for the time period of February 1976 to February 1977. The specific conductance-discharge relationships of these sites along the Athabasca-Clearwater river mainstem follow the same kind of pattern as the tributaries. However, it must be noted that a sparsity of data points during medium discharge periods makes for less confidence in the fit of this relationship to the power curve equation (1) than was attainable in the case of the tributaries.

Values for the dilution factors and loading factors calculated by linear regression of group for 1976-77 data are shown in Table 24 along with the coefficients of determination. A plot of the loading factors versus dilution factors for these data graphically portrays differences between sites (Figure 15) and, from the display of points, it is apparent that the sites differ more in loading as expressed by K than in variability as expressed by n. As expected, the Clearwater River, which drains some Precambrian Shield headwaters in Saskatchewan, has the lowest loading factor. However, the distribution of the other points indicates a complicated situation. Loading increases from Site CC0012 to Sites DA0201 and DA0203, despite what would be expected from the diluting influence of the Clearwater River. Samples were collected mid-stream, so the diluting influence of the Clearwater River depends upon the mixing characteristics of this particular section. Investigations of mixing characteristics, near the confluence of the Clearwater River and the Athabasca River and

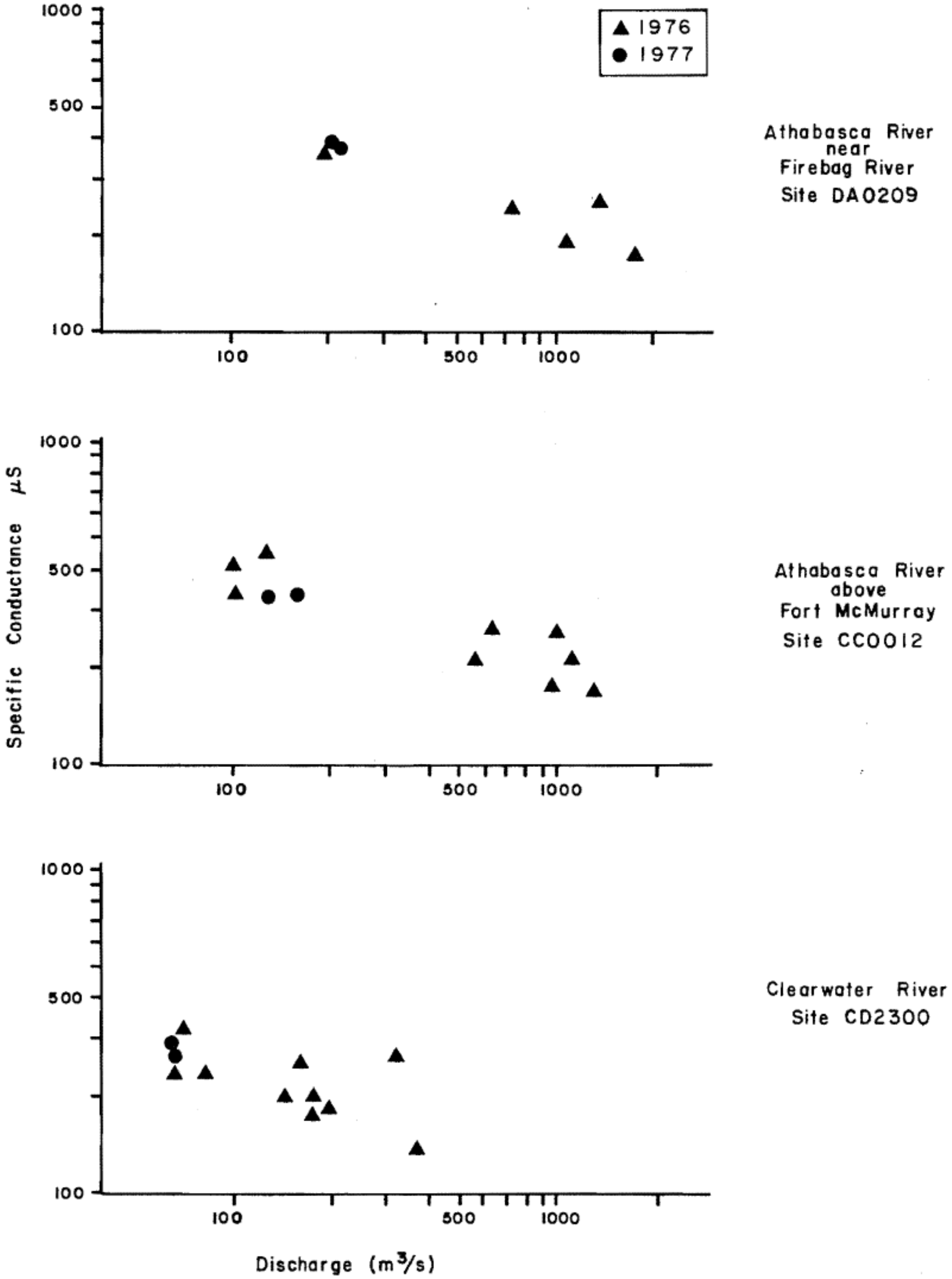

Figure 14. Specific conductance - discharge relationships of sites on the mainstem river system from February 1976 to February 1977.

Table 24. Results of linear regression on 1976 and 1977 specific conductance and discharge mainstem river data for equation (1). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Description	$SC = KQ^n$		
		K	n	r^2
CD2300	Clearwater River	746	-0.25	0.41
CC0012	Athabasca River above Horse River	1307	-0.27	0.83
DA0201	Athabasca River at km 10	1457	-0.29	0.83
DA0203	Athabasca River at km 30	1699	-0.31	0.84
DA0204	Athabasca River at km 42	1401	-0.27	0.71
DA0205	Athabasca River at km 48	848	-0.19	0.81
DA0206	Athabasca River at km 55	885	-0.19	0.54
DA0208	Athabasca River at km 84	1348	-0.26	0.83
DA0209	Athabasca River at km 132	2100	-0.32	0.90
DA0210	Athabasca River below Firebag River	1846	-0.30	0.87

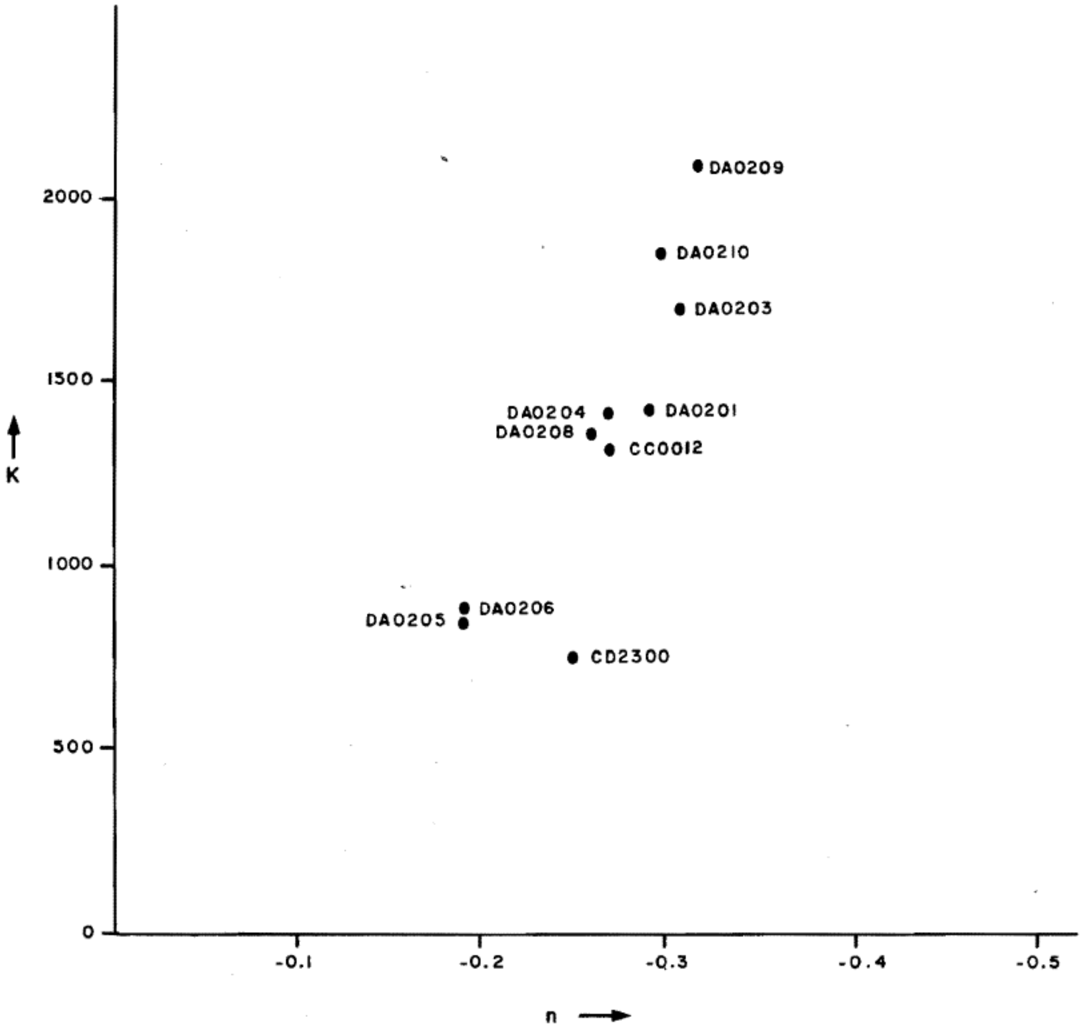

Figure 15. Distribution of loading factors (K) and dilution factors (n) for mainstem sites from February 1976 to February 1977.

for the Athabasca River under ice conditions downstream of Fort McMurray (Lipsett and Beltaos 1978; Beltaos 1979), have indicated slow transverse mixing in this relatively straight stretch of the Athabasca River and that 30 km may be necessary for the averaging effect of water quality parameters to take effect on the left side of the Athabasca River. Compounding this situation is a change in the suspended sediment regime that occurs at Fort McMurray which at times provides supersaturated conditions immediately below Fort McMurray (Doyle 1977; see Section 3.2). It could be that the interaction between the suspended solids and dissolved solids mimics this supersaturation so that the loading factors decrease after settling out of the solids. A decrease in loading factors occurs in the region of current oil sands activities between Sites DA0203 and DA0206 (about 30 to 50 km below the confluence). Following this, there is again an evident increase in loading.

A comparison of Figure 15 with the corresponding plot for the tributaries (Figure 9) proves worthwhile. The variability, as expressed by the dilution factor, is within what appears to be the average for the tributaries. On the other hand, the loading factors all greatly exceed the factors for the tributaries which is an indication that the loading effect of the tributaries on the mainstem is minimal. Even the diluting effect may be regarded as negligible in most cases. On the average, all study area tributaries amount to only about 9% contribution to the main flow (Neill 1979); however, it should be noted that, in the spring, the lag in runoff from upstream regions of the Athabasca River enhances the influence of the tributaries for short durations. For example, the MacKay River alone can contribute up to 10% of the total daily discharge briefly in the spring (Doyle 1977).

The specific conductance-filterable residue fixed relationships are of a similar kind to the tributary relationships albeit at a poorer fit to equation (4). Linear regression of 1976-77 data for the mainstem to fit equation (4) provides the proportionality and nonlinearity factors shown in Table 25 along with their coefficients of determination. The values are similar to what was observed for the tributaries (Table 14) although generally lower coefficients of determination prevailed. The values are plotted in Figure 16.

Table 25. Results of linear regression on 1976 and 1977 specific conductance and filterable residue fixed mainstem river data for equation (4). The coefficient of determination is shown as r^2.

Site Code (Figure 2)	Description	$SC = K\ (FRF) + SC_o$		
		SC_o	K	r^2
CD2300	Clearwater River	131	0.75	0.42
CC0012	Athabasca River above Horse River	75	1.33	0.67
DA0201	Athabasca River at km 10	114	1.04	0.66
DA0203	Athabasca River at km 30	101	1.12	0.73
DA0204	Athabasca River at km 42	175	0.58	0.19
DA0205	Athabasca River at km 48	150	0.83	0.65
DA0206	Athabasca River at km 55	225	0.39	0.18
DA0208	Athabasca River at km 84	93	1.21	0.87
DA0209	Athabasca River at km 132	76	1.48	0.89
DA0210	Athabasca River below Firebag	64	1.45	0.93

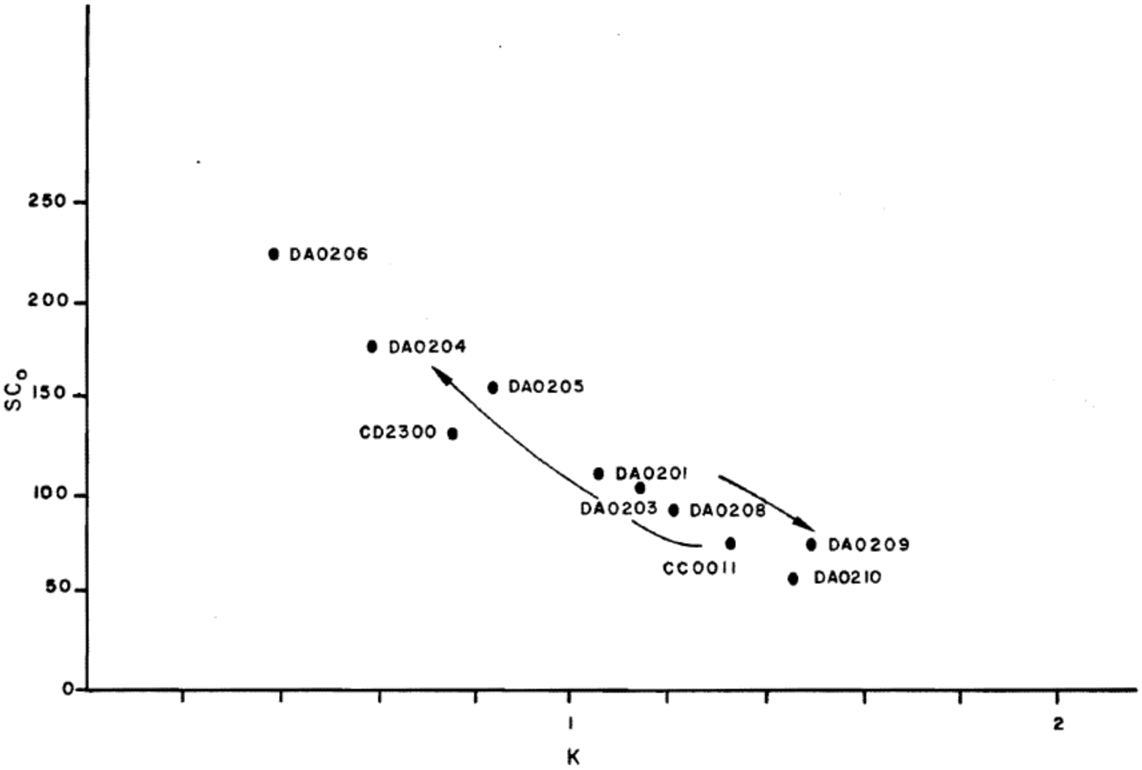

Figure 16. Distribution of proportionality and non-linearity factors for mainstem sites from February 1976 to February 1977.

A comparison of values for tributaries (Figure 12) shows that lower ionic activity per nonfilterable residue fixed factors is displayed by the mainstem than by most of the tributaries. A pattern of decreasing electrical activity per dissolved material downstream of the Clearwater River confluence to about 50 km (Sites DA0204, DA0205, DA0206) and then a subsequent increase with downstream distance is evident. This would indicate that the kind of loading of the downstream portion (from Site DA0206 to Sites DA0209 and DA0210 as shown in Figure 16) might be due to proportional increases in concentrations of active ions such as chloride or sulphate during high ionic activity periods (base flow conditions).

3.1.4 Variation of Major Ion Loadings in the Mainstem

Loadings for the major ions at each site were calculated from determined parameters and daily average discharge. The discharge values at each sampling point were deducted from that of the Athabasca River below Fort McMurray and whatever gauged tributaries (Loeppky and Spitzer 1977) were necessary to subtract from or add to this value. Such calculated loadings are shown in Table 26. Plots of the loadings for a selection of seasonal times are shown in Figure 17 for the cations and Figure 18 for the anions.

All the major cation loadings exhibited similar behaviour of a somewhat complicated variation throughout a 50 km stretch north of Fort McMurray, which includes the zone of current surface mining activity. This complex behaviour may be caused by a number of factors such as the mixing characteristics of the Clearwater River input, groundwater discharge-recharge phenomena, effluent discharge from Fort McMurray and/or oil sands mining operations, and absorption-desorption effects in the change in suspended sediment regime taking place at Fort McMurray (see Section 3.2). Downstream from this stretch, only gradual steady increases in cationic loadings were evident. By projecting this increase back to Fort McMurray, one can see that the net loading on the stretch immediately north of Fort McMurray does not appear to be substantially augmented by mining activity. Thus, the notable

Table 26. Loadings of major ions on mainstem sites from February 1976 to February 1977.

Dates	Site Code	Loadings (kg/s)					
		Ca	Mg	Na	HCO_3	SO_4	Cl
7-9 February 1976	CD2300	1.34	0.44	2.41	6.02	0.64	3.04
	CC0012	6.64	2.02	2.24	25.50	5.70	1.11
	DA0209	7.53	2.12	4.90	28.56	5.15	5.15
	DA0210	41.48	11.11	14.07	165.91	38.66	9.18
28 June to 1 July 1976	CD2300	2.94	1.04	3.42	14.04	0.09	4.42
	CC0012	30.80	8.01	6.78	118.08	29.26	3.08
	DA0201	28.66	7.72	18.07	115.89	16.57	17.45
	DA0203	31.16	8.47	14.96	124.62	10.59	13.71
	DA0204	33.01	9.24	13.87	132.05	29.58	11.49
	DA0205	35.65	9.51	11.88	138.65	35.52	7.62
	DA0206	38.29	10.30	9.24	145.26	43.31	3.57
	DA0208	36.71	9.88	12.71	159.56	5.64	7.20
	DA0209	40.95	10.59	13.41	170.85	10.87	7.76
	DA0210	41.48	11.11	14.07	165.91	38.66	9.18
27-30 July 1976	CD2300	2.63	0.91	2.98	15.63	0.02	3.95
	CC0012	21.71	6.41	4.72	100.07	11.52	1.89
	DA0201	20.45	6.46	15.60	114.07	0.65	18.19
	DA0203	24.77	7.54	5.38	120.62	6.25	3.12
	DA0204	24.84	7.34	5.40	116.64	12.53	3.24
	DA0205	23.90	7.40	10.81	127.46	0.23	9.33
	DA0206	26.17	7.40	6.26	132.01	8.76	3.64
	DA0208	29.01	7.48	7.14	119.40	21.87	5.47
	DA0209	29.01	7.48	8.93	114.94	25.67	8.26
	DA0210	28.66	7.79	9.17	124.94	21.78	8.48
27-30 August 1976	CD2300	7.75	3.03	7.85	31.96	6.13	7.75
	CC0012	32.23	10.40	7.32	124.59	20.57	1.14
	DA0205	41.61	11.29	14.66	210.01	21.79	2.77

continued ...

Table 26. Continued.

Dates	Site Code	Loadings (kg/s) Ca	Mg	Na	HCO_3	SO_4	Cl
2-3 September 1976	CD2300	5.75	1.93	4.08	27.08	0.78	4.53
	CC0012	34.97	9.87	7.54	142.61	19.47	2.19
	DA0201	28.97	9.72	19.63	140.18		21.68
	DA0203	36.64	10.90	16.35	161.61	15.03	12.60
	DA0208	42.55	12.31	13.58	172.02	21.73	7.97
	DA0209	42.55	11.95	15.39	168.39	20.82	10.32
	DA0210	46.33	13.34	17.05	198.29	29.28	10.56
27 September to 2 October 1976	CD2300	2.80	0.88	3.15	11.90	1.17	4.17
	CC0012	17.34	4.55	3.69	65.37	10.69	0.80
	DA0203	16.57	4.73	10.33	69.44	7.10	11.68
	DA0204	22.31	6.00	7.06	89.25	13.71	4.14
	DA0205	24.34	6.33	6.09	95.74	14.44	4.71
	DA0206	23.30	5.89	7.36	94.83	13.08	4.50
	DA0208	19.33	5.50	7.81	75.08	11.00	5.87
	DA0210	20.59	5.64	10.14	80.09	11.82	9.46
21 November 1976	CD2300	1.39	0.48	1.82	5.89	0.57	2.26
	CC0012	4.45	1.26	1.19	17.14	2.99	0.41
10-12 December 1976	CD2300	1.07	0.36	1.68	5.04	0.42	2.38
	CC0012	5.55	1.54	1.56	21.27	4.13	0.50
	DA0201	5.95	1.70	3.48	24.30	3.96	3.19
	DA0203	8.07	2.21	3.17	31.18	5.71	2.32
	DA0204	7.72	2.16	3.45	29.62	5.18	2.91
	DA0205	5.97	1.76	3.87	24.30	3.66	3.75
	DA0208	6.96	1.98	3.92	26.04	6.19	3.71
	DA0210	6.66	1.90	6.18	25.68	4.19	7.00

continued ...

Table 26. Concluded.

Dates	Site Code	Loadings (kg/s)					
		Ca	Mg	Na	HCO_3	SO_4	Cl
21-23 January 1977	CD2300	1.07	0.34	2.20	5.23	0.41	3.12
	CC0012	5.61	1.44	1.65	23.24	3.59	0.46
	DA0201	8.52	2.22	2.71	32.48	5.71	1.00
	DA0203	8.56	2.24	2.72	34.83	5.74	1.01
	DA0204	7.66	2.02	3.93		4.94	3.19
	DA0205	6.35	1.77	4.44	28.04	3.49	4.44
	DA0206	7.26	1.94	4.03	30.46	4.24	3.49
	DA0208	7.07	1.88	4.45	29.71	4.51	4.45
	DA0209	7.28	1.94	6.06	29.93	4.99	7.22
	DA0210	8.14	2.20	4.95	33.65	5.30	7.37
25-26 February 1977	CD2300	0.98	0.34	1.86	4.49	0.40	2.67
	CC0012	6.58	1.81	2.01	24.30	5.20	0.74
	DA0201	9.39	2.58	2.87	35.34	7.07	1.26
	DA0203	8.73	2.47	3.42	33.58	6.96	2.03
	DA0204	6.42	1.90	5.09	27.44	4.32	5.84
	DA0205	6.86	2.02	4.79	26.77	5.29	5.11
	DA0206	7.07	2.09	4.57	28.07	5.38	4.79
	DA0208	7.67	2.19	4.60	30.03	5.55	4.43
	DA0209	7.67	2.19	5.59	32.00	5.92	6.27
	DA0210	8.27	2.37	5.97	30.78	6.84	7.00

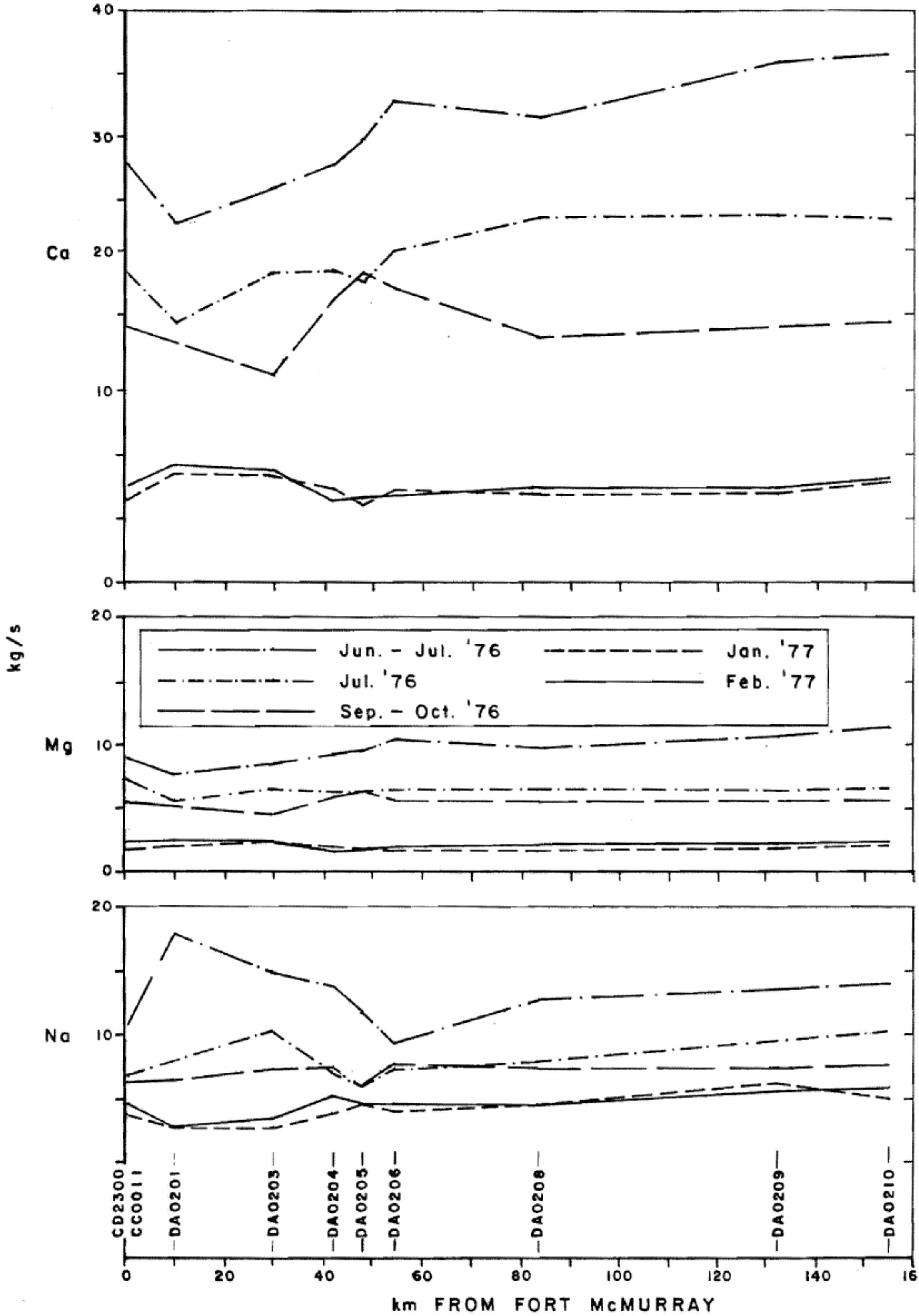

Figure 17. Loadings of the major cations in the Athabasca River during selected seasonal dates.

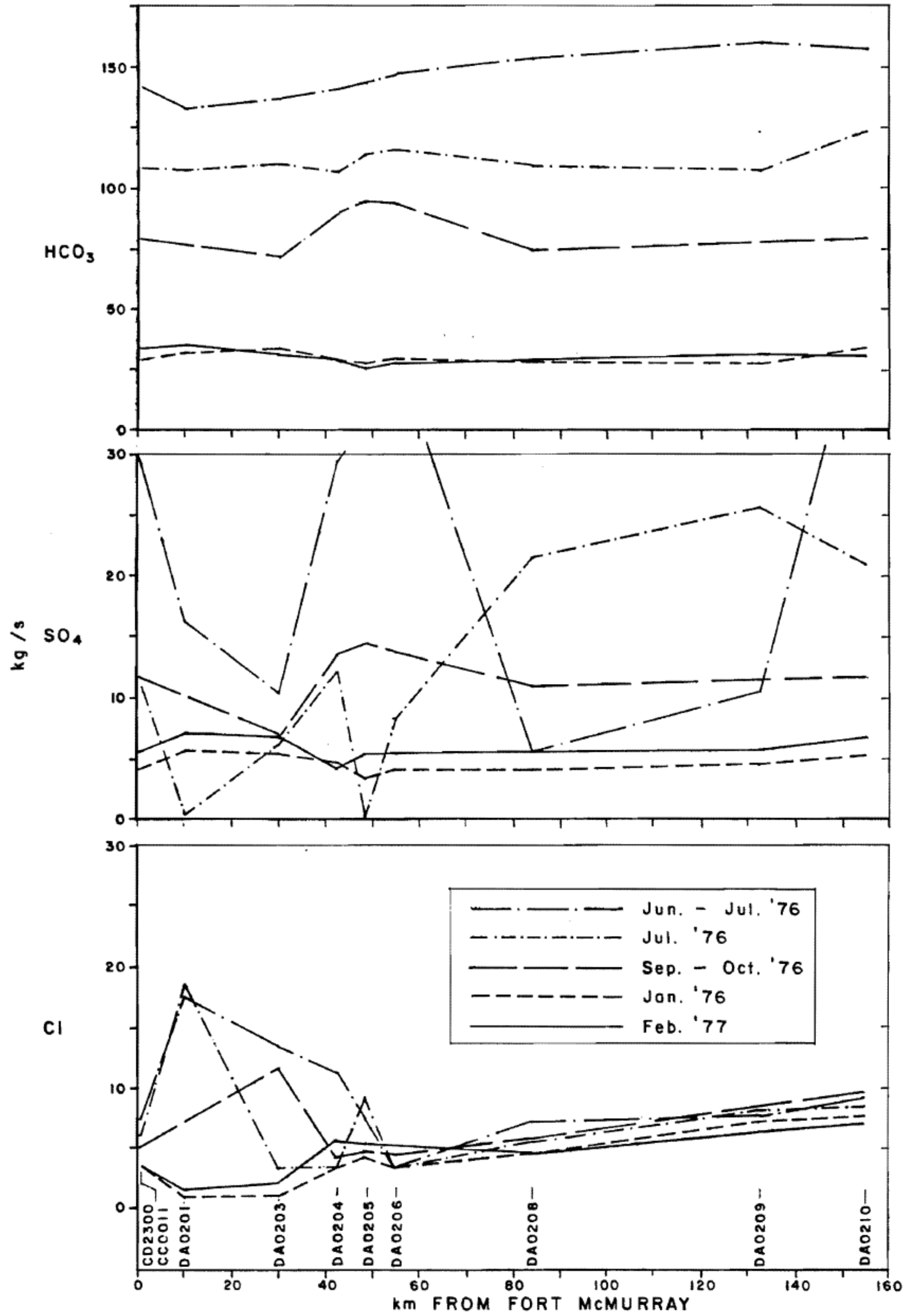

Figure 18. Loadings of the major anions in the Athabasca River during selected seasonal dates.

complicated loading charges appear to be caused by mixing, groundwater discharge-recharge, or absorption-desorption on the sediments. Seasonal variation of calcium and magnesium was larger than sodium which reflects relatively constant sodium loading by the Clearwater River, augmented by further relatively constant loading as perhaps by groundwater discharge.

The three major anions exhibit markedly differing behaviour. Bicarbonate loading shows a fairly regular, gradual increase north of Fort McMurray and wide seasonal swings that reflect control by upstream sources, modified only slightly by perturbations just north of Fort McMurray. Sulphate loadings swing widely and erratically which may be inherent primarily in the parameter itself as it has a tendency to be non-conservative (Schwartz 1978; McNeely and Neimanis 1978). Chloride loadings show temporal and special variations in the 50 km stretch north of Fort McMurray, then settle into a constant pattern of gradual increase with amazingly little seasonal variation. Projection of this constant pattern of gradual increase back to Fort McMurray indicates little if any augmentation of loading by man's activities just north of Fort McMurray. Levels of chloride are affected by the adsorption effect on sediments (Hem 1970). Control of this loading is also unaffected by the hydrological cycle and thus appears to be the relatively constant supply from the Clearwater River augmented by groundwater discharge.

3.1.5 Spacial Specific Conductance Variation in Lake Athabasca

Two different kinds of drainage basins meet directly in Lake Athabasca: (1) the rivers of the Western Canadian Sedimentary Basin that drain from the south and west as far as the Rocky Mountains; and (2) the rivers and lakes to the east of the Peace-Athabasca Delta within the Precambrian Shield. The character of water from these two drainage basins is distinct. Water draining from the Western Canadian Sedimentary Basin is highly variable in both filterable and nonfilterable residues and can be characterized as moderately hard and moderately to highly turbid of filterable residues. The predominant characteristics of water draining from the Canadian Shield are its soft nature and clarity due to consistently low amounts of both filterable and nonfilterable residues.

During winter months, minimal mixing of the two water types occurs under ice conditions within Lake Athabasca (PAD 1972). However, no knowledge of mixing during open-water periods has been gathered. A measurement of the mixing effect in the autumn of 1977 was carried out. On 26 and 27 October 1977, the variation in temerature, specific conductance, and dissolved oxygen were measured on three courses across Lake Athabasca north of the outlet channels of the Athabasca River. An in situ water quality analyzer, the Hydrolab Model 6D, coupled to a Hydrolab data scanner and recorder, was operated from a boat cruising at a steady rate of 6 km/h. Readings were taken at a depth of 0.5 m.

Water temperature varied from 2.5 to 4°C with colder temperatures encountered in the shallow southern portion of the lake. Dissolved oxygen was at saturation, varying only slightly from 12.8 to 13.3 ppm because of the temperature differences. Specific conductance measurements varied dramatically and provided a good marker for the relative positions of the two water sources.

Figure 19 illustrates specific conductance values recorded during the field measurements. Although some evidence of swirling of the two water types can be detected near Old Fort Point, the major characteristic detected is very little mixing of the two types in the autumn. Laboratory analysis for water samples collected 25 October 1977 for three sites, shown in Table 27, correspond well with field data.

This feature of minimum mixing during an open-water period may be significant in terms of oil sands development in that the extent of this effect limits the diluting of impacts on Athabasca River water by the relatively pure Precambrian Shield waters flowing west from Lake Athabasca. In addition, if the effect occurs in the spring, the Athabasca River water quality would have a primary effect on Mamawi Lake and Lake Claire during spring reversals where those lakes are flooded from the east.

3.1.6 Temporal Variation of Alkalinity and Hardness in Lakes

Nearly all of the classic lake types (oligotrophic, eutrophic, mesotrophic, and dystrophic) are represented in the AOSERP study area as the area is located primarily in the transition zone between the

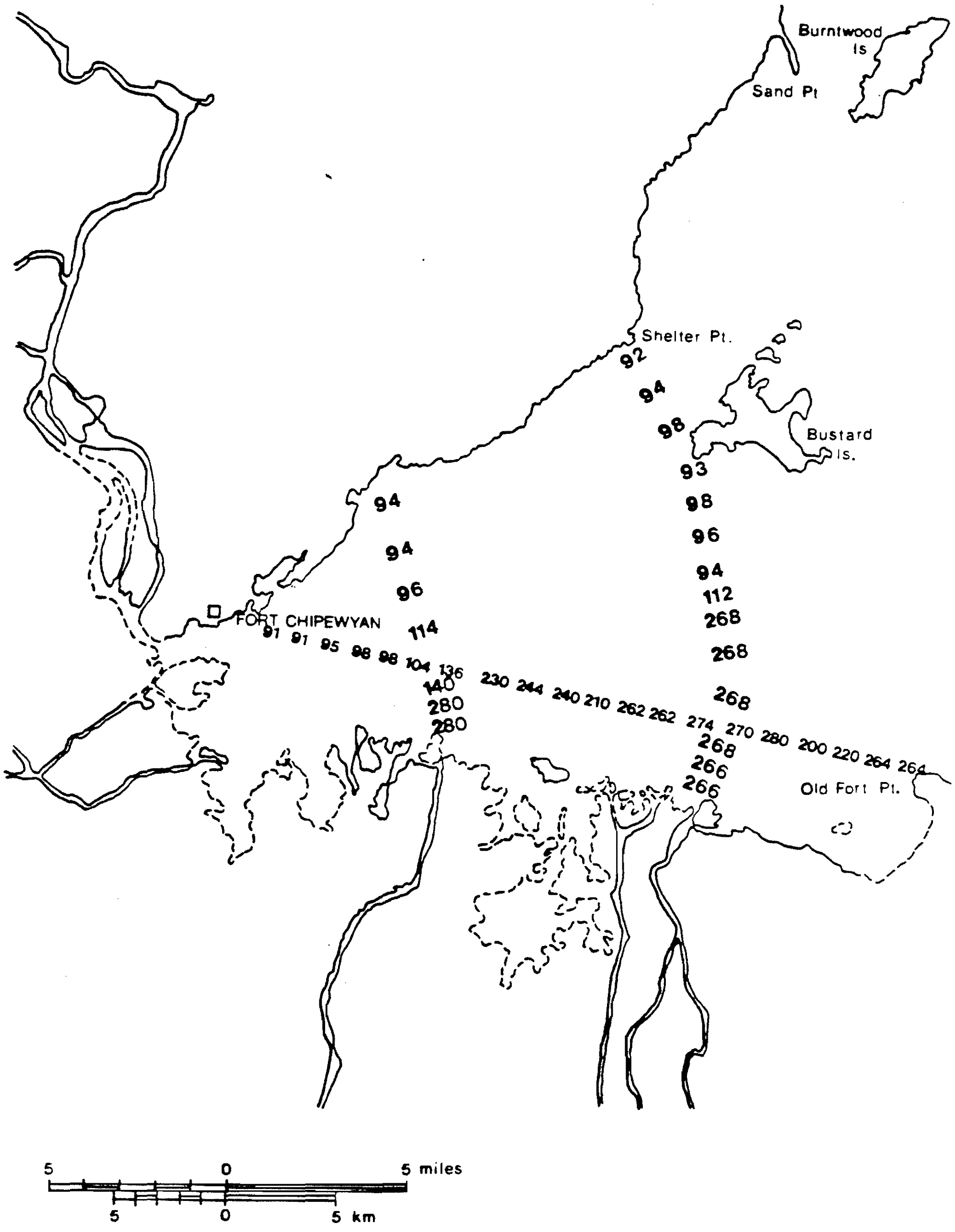

Figure 19. Spacial variance of specific conductance in Lake Athabasca on 25 October 1977.

Table 27. Laboratory analyses of water sampled 25 October 1977.

Location	Laboratory pH	Laboratory Specific Conductance (µs/cm)
Lake Athabasca at Sand Point	7.48	75
Athabasca River at Big Point Channel	7.92	232
Riviere des Rochers	7.6	104

mineral lakes of the prairies and the mineral-poor lakes of the north (Jantzie 1977). Large numbers of lakes are present in the northern portion of the study area north and south of Lake Athabasca and some large and important lakes are within 60 km of the current oil sands developments. However, few lakes are located within the current area of oil sands development; only Ruth Lake and Mildred Lake have been directly impacted by oil sands operations (Figures 3 and 4).

A key function provided by some of the dissolved ionic species and also by clays and silicates on the lake bottom is the capacity to buffer the lake ecosystem against acidification (Schindler 1978). Acid can be introduced into a lake by a number of physical and biological processes, the main one being by precipitation. Precipitation is naturally acidic from its content of carbon dioxide and nitrogen oxides. Such acid content can be augmented considerably by industrial emissions and lake acidification has become a worldwide concern (Wright and Gjessing 1976). The buffering capacity of many of the lakes in the study area has been assessed on the basis of the calcite saturation index which takes into account the lake's alkalinity, pH, and calcium concentrations (Hesslein 1979). It was found that generally the mineralized lakes in the study area were highly buffered due to high input of calcium-magnesium-bicarbonate type water but that some of the less mineralized lakes in the Namur-Gardiner group were less protected.

The temporal variation in total alkalinity for 1977 is shown in Figure 20 for a number of lakes. Typical seasonal patterns are displayed. Relatively high alkalinity builds up during periods of ice-cover when areal precipitation is unavailable to the lakes. During this period, plant respiration of dissolved carbon dioxide and groundwater discharge of anions would be operating to cause this increase. For some shallow lakes (e.g., Lake Claire), ice formation would be an important mechanism causing such a buildup. Spring break-up sees a steep reduction in alkalinity affected by the diluting and neutralizing effects of precipitation and surface runoff that are available to the lake. The stable period of relatively low alkalinity during the spring

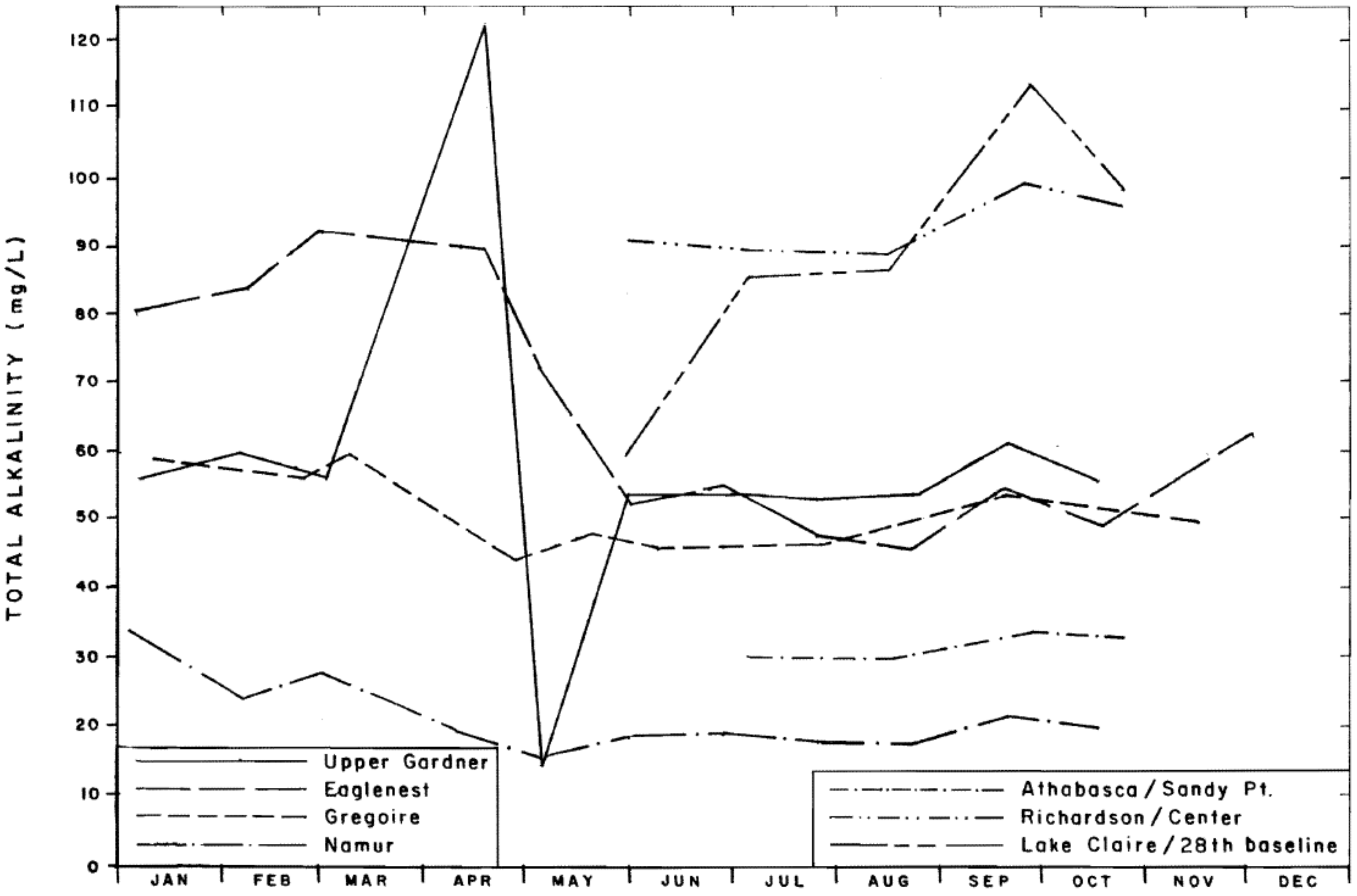

Figure 20. Temporal variation in total alkalinity in lakes in 1977.

and summer is followed by a brief increase during autumn lake turnover, when deeper water rich in buffering ions mixes with the surface water. Also, evident from Figure 18 is the comparatively low alkalinity of soft water lakes, Namur Lake, and Lake Athabasca.

Another indicator of the electrolytic character of a lake is total hardness. Because total hardness measures the sum of calcium and magnesium concentrations, it is generally representative of the cationic structure of most of the lakes in the area. Total hardness is of significance when considering the handling qualities of water and also toxicity (Sprague 1978). Temporal variation in total hardness is shown in Figure 21. Patterns very close to temporal variation in total alkalinity are apparent which indicates that generally the same kinds of controls operate in both cases (i.e., supply of calcium-magnesium-bicarbonate type water and lake mixing at turnover times).

3.1.7 Major Ion Changes in the Peace-Athabasca Delta

As referred to in Section 3.1.5, soft water from Precambrian Shield sources mixes with hard water passing through the AOSERP study area in Lake Athabasca near Fort Chipewyan. The western section of the Peace-Athabasca Delta also receives water from the study area which eventually mixes with the water from Lake Athabasca.

Figure 22 shows ranges of each of the major ion parameters at sites in the Peace-Athabasca Delta in 1977 (June to December). Also depicted is the general water flow direction. Of course, reverse flow phenomenon occurs for brief periods in the spring where, for example, water at Site NA0030 in Riviere des Rochers is moving from the Peace River and not from Lake Athabasca. Also, reverse flow in Chenal des Quartre Forches (Site KF0101) can occur, bringing water into Lake Claire (Sites KF0201 and KF0200) from the Peace River and Lake Athabasca (PAD 1972).

The pattern of all the major ion ranges in the eastern part of the delta reflect the behaviour outlined in Section 3.1.5 where the composition of the outflow of Lake Athabasca at Riviere des Rochers (Site NA0030) reflects a mixture of water from eastern Lake Athabasca (Site MD2000) and the Athabasca River (Site DD0212). All parameter

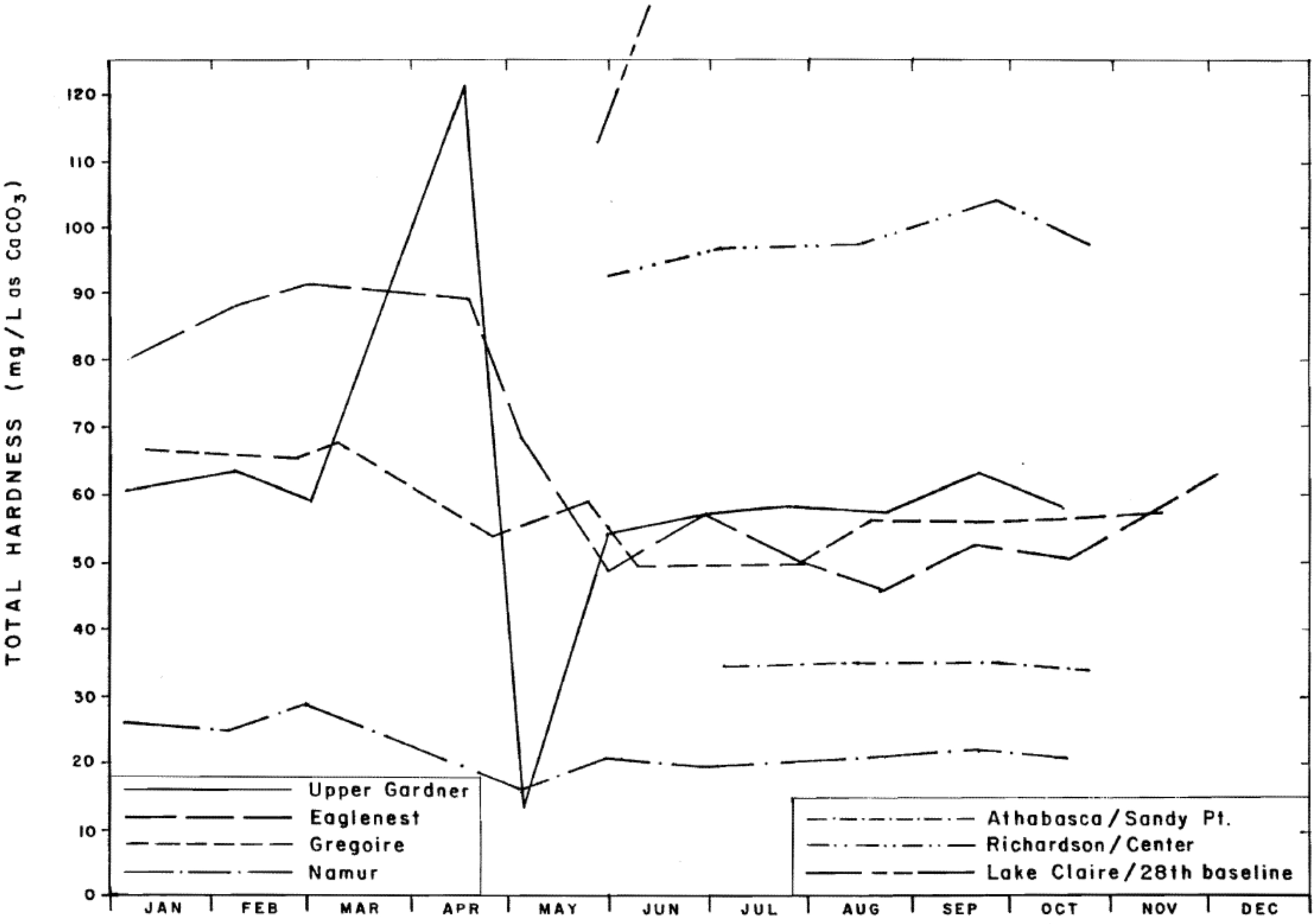

Figure 21. Temporal variation in total hardness in lakes in 1977.

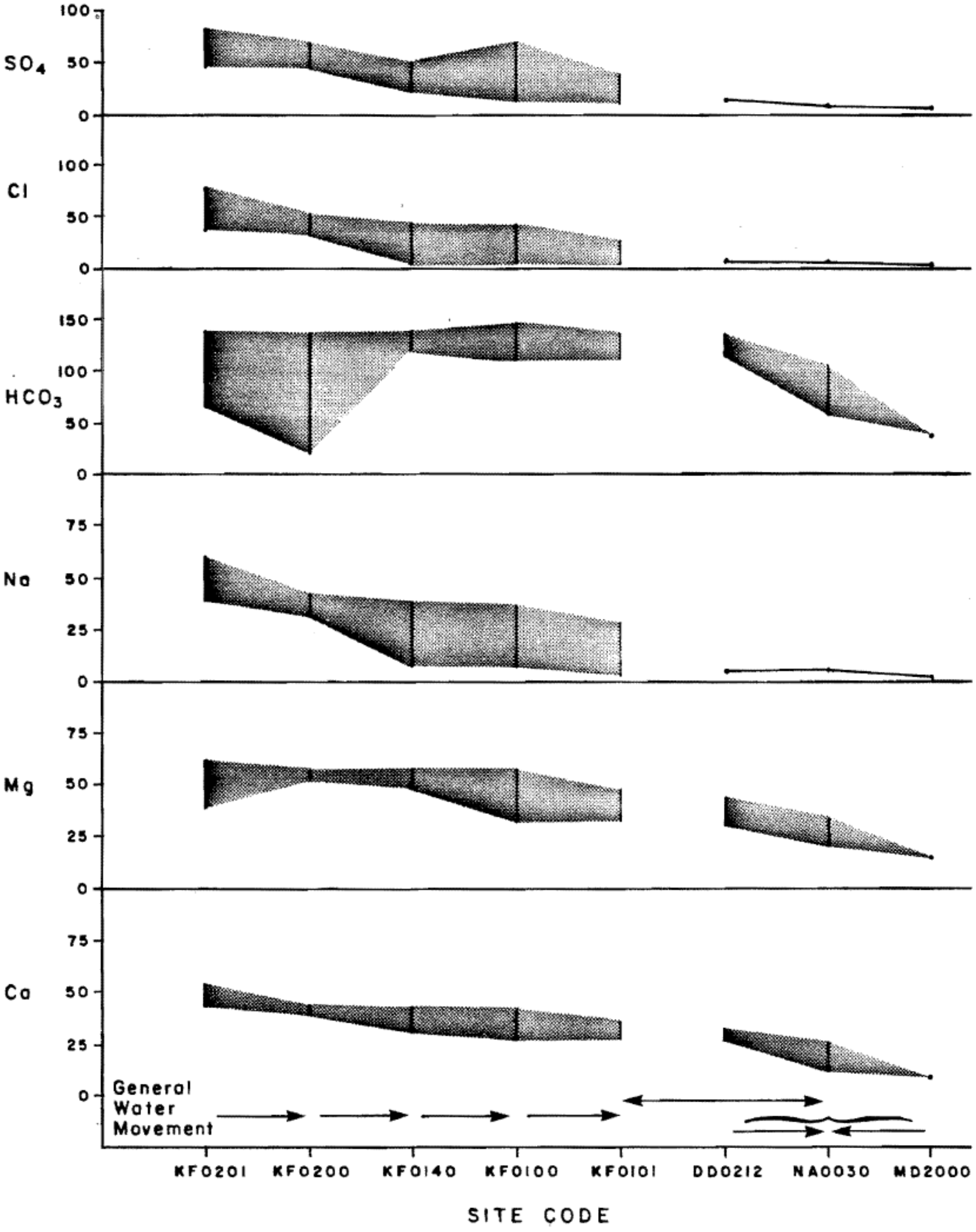

Figure 22. Concentration ranges for the major ions at sites in the Peace – Athabasca Delta.

ranges at Riviere des Rochers are intermediate between ranges at Site MD2000 and Site DD0212. The range at Site NA0030 is greater for all ions, showing the variation in contribution from the two starting sources.

The pattern of the major ion ranges in the western part of the delta reflects a general dilution effect as the water moves east to its outlet through the Peace-Slave River system. In the case of the sodium and chloride ranges, a diluting effect is even evident in Lake Claire where the southern site (KF0201) shows higher ranges than the northern site (KF0200). Such an effect would indicate groundwater discharge at the southern end of the lake possibly, in part, arising from the northern or northeastern slopes of the Birch Mountains. It is interesting to note, though, that bicarbonate and magnesium levels generally are maintained until dilution at Site KF0101, showing the hard nature of the water arising from the north and west.

3.2 SUSPENDED MATERIAL

Suspended materials in rivers and streams also follow a seasonally cyclic pattern. Instead of being diluted to lower concentrations by high flows as are the inorganic ions, concentrations of suspended materials are generally high during high flows as the events that cause high flow also wash these materials into the surface water system. The nature and occurrences of suspended and deposited sediments in rivers and streams of the AOSERP study area have been reported on by a number of investigators.

An analysis of the suspended and deposited sediment regime of parts of the Muskeg River basin was carried out (Froelich 1980; Akena 1979) using both standard water quality data and hydrometric and suspended sediment data collected by Water Survey of Canada (Warner and Spitzer 1978). The pattern of low loading with the brief occurrence of sharp peaks of loading corresponding to high discharges generally prevails in the area.

The suspended sediment regime of the Athabasca River has been described by Doyle (1977). The differing processes operating in the three distinct reaches, the turbulent meandering upstream of Fort

McMurray, the placid straight channel below Fort McMurray, and the Athabasca River Delta, were deduced from the suspended sediment rating curves (see Figure 23). These curves indicate that, at higher flows, the upstream section has a higher capacity to transport sediments whereas, at lower flow rates, the carrying capacity of the downstream section becomes more important. During high flow periods, a heavily loaded condition of the upstream section causes supersaturation of the downstream section and the sediments are deposited in the reach downstream of Fort McMurray. However, during low flows, the upstream loading is not at a saturation point relative to the downstream section and any deposited sediments are resuspended. Eventually, the greater amount of suspended material is deposited in the next reach, the Athabasca River Delta formation. In terms of loading, the various tributaries do not alter this picture appreciably.

The metal content of deposited sediments in the mainstem has been investigated by Allan and Jackson (1978). They correlated the metal content with fluvial and geochemical processes. Associated with larger amounts of metals, such as vanadium and nickel, were finer textured sediments which were related to larger surface areas, amorphous inorganic-organic coatings, layer silicate concentrations, and organic content. A general progression from lower to higher concentrations of metals was detected from downstream of Fort McMurray, to the Athabasca River Delta, to Lake Athabasca. The highest concentrations were found in the fine-textured sediments of Lake Athabasca.

The organic content of deposited sediments in the mainstem Athabasca River under winter conditions has been investigated by Strosher and Peake (1978). The total organic content of these deposited sediments was largely not extractable with organic solvents; of the extractable portion, the largest component was an asphaltene fraction.

The sedimentation characteristics of tributary basins in the area have been compiled (Griffiths and Walton 1978). Areas having high erosion potential in relation to development activities were determined to be the Lower Ells River basin and the adjacent eastern slopes of Birch Mountains (exemplified by Zone 5), the tributaries immediately

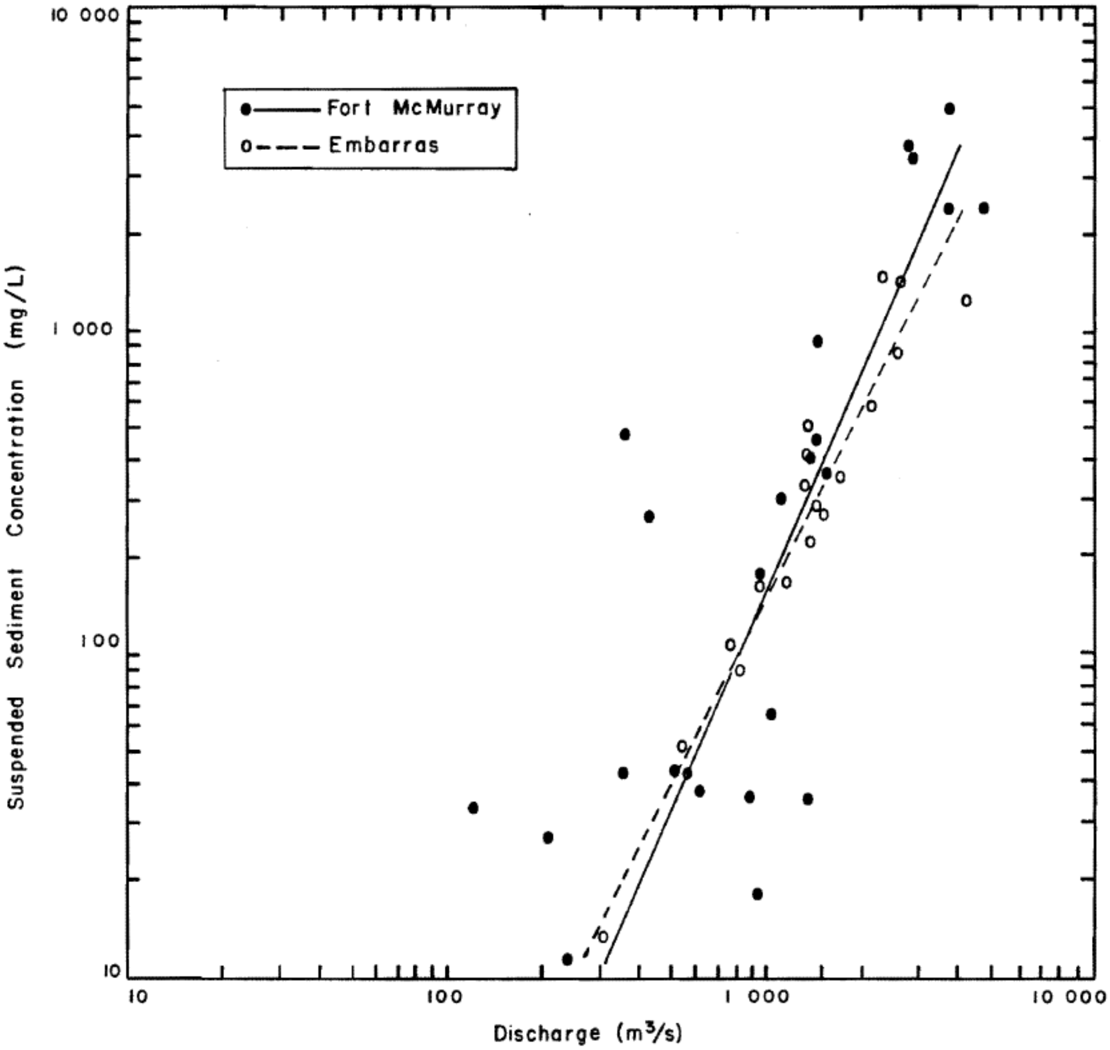

Figure 23. Suspended sediment rating curves at the WSC guages below Fort McMurray and at Embarras (from Doyle 1977).

north of Fort McMurray (including Zone 7), the Christina basin, the Hangingstone and Horse basins (in Zone 1), the Mackay and Dunkirk basins (Zone 3), and the Upper Ells basin (Zone 4).

Three water quality parameters commonly employed relate to the concentration of suspended materials: turbidity, nonfilterable residue (total suspended solids), and nonfilterable residue fixed (total inorganic suspended solids). Although these parameters relate directly to the amounts of solids carried by the surface water bodies, it should be emphasized that depth gradients produced by particle sizes complicate the picture (Guy and Norman 1970) and that standard methods employed by Water Survey of Canada (Warner and Spitzer 1978) are meant to provide the most accurate picture of clastic loading. Nevertheless, the water quality parameters can provide an understanding of the processes in operation.

3.2.1 Turbidity Frequency in Tributaries

Plots of 1977 turbidity frequency for larger tributaries (watersheds greater than 900 km^2), as calculated by the NAQUADAT Water Quality Summary Program, are presented in Figure 24. Three general observations are evident from these plots:

1. One group of sites, comprising the Upper Ells, Firebag, and Muskeg rivers, has a very low turbidity regime. The turbidity is less than 6 JTU for 90% of the time and even the detected peaks are very low, less than 12 JTU. The effect of the headwater lakes as a settling area likely causes this kind of regime for the Firebag and Upper Ells rivers.
2. All the other major tributaries, except for the Hangingstone, fall into another group of sites where peak times of high turbidity occur but they are of short duration. In this group, low turbidity generally prevails most of the time, with 75% of the turbidity measurements being less than 10 JTU (except for the Dover and Dunkirk rivers which were slightly higher).

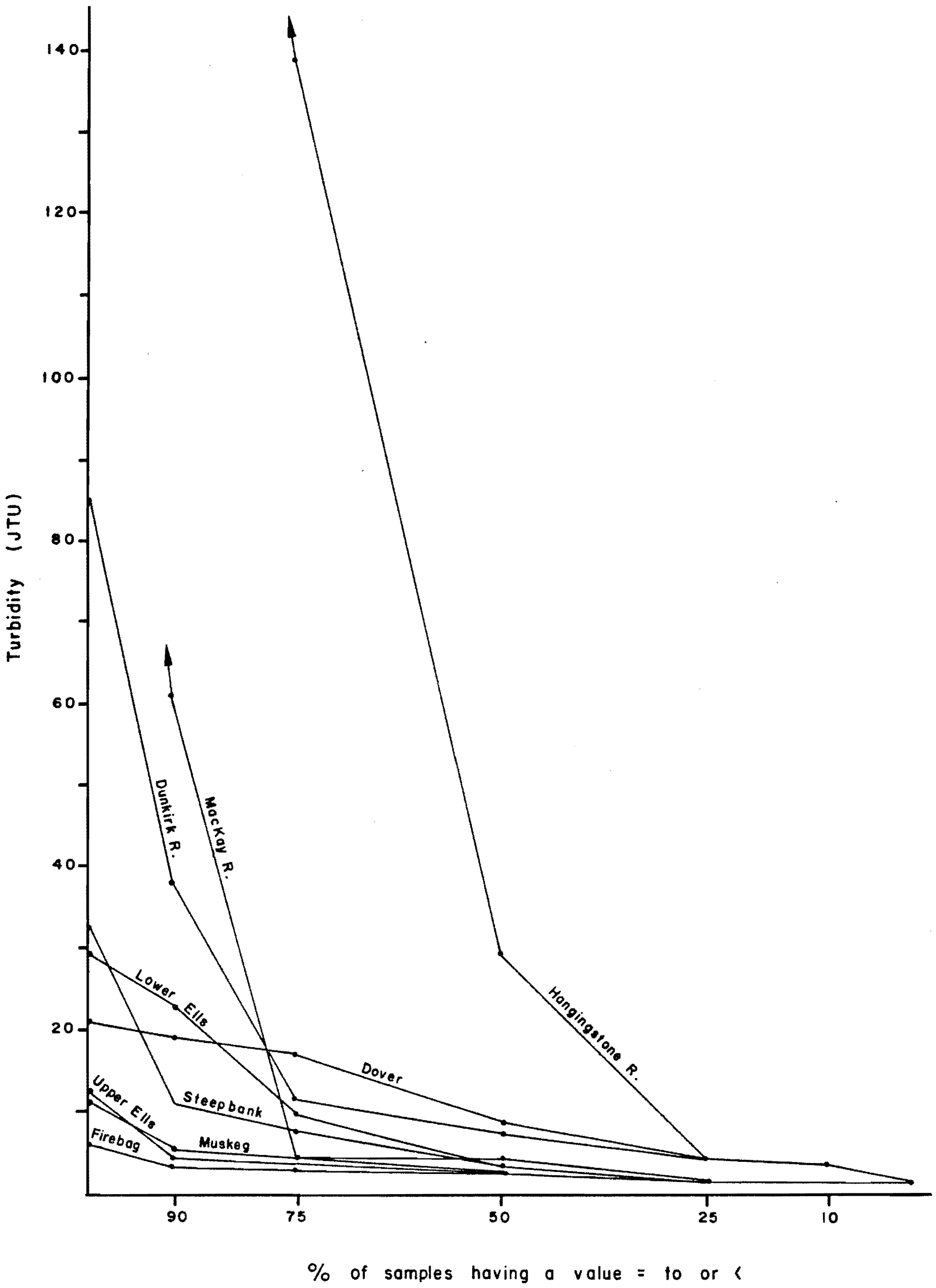

Figure 24. Turbidity frequency for major watersheds in 1977.

3. Two anomalies can be noted. The Hangingstone River site showed a prevailing regime of high turbidity. According to Griffiths (1978), the banks and lower reaches of the Hangingstone River are reasonably stable, so this high regime may be caused by the steep slopes of Stoney Mountain in the upper reaches. Also, a noticeable difference is the shape of the Dover River curve. It is somewhat anomalous in its convex pattern (showing a higher duration of intermediate values), as the typical concave curve limited the duration of higher values.

Plots of 1977 turbidity frequency for the smaller tributaries are presented in Figure 25. A much wider variation in turbidity regimes than in the larger tributaries reflects site-specific effects. Four general observations can be made from these plots:

1. None of the smaller tributaries fits in with the grouping of larger tributaries showing very low total turbidity regime. However, Thickwood Creek, Pierre River, and Upper Tar River have a similar kind of constant regime, albeit at a generally higher level. It may be that colloidal, organic material, relatively constantly supplied by extensive muskegs in these small watersheds, is responsible for this.
2. A general grouping of Hartley Creek, Calumet River, Poplar Creek, Unnamed Creek, Beaver River above Syncrude, and Beaver River at Hwy 63 can be made for tributaries showing turbidity of less than 10 JTU for half of the samples. This corresponds to a similar grouping for the larger tributaries but the recession of turbidity is not as steep as in the case of the larger rivers.
3. Asphalt Creek, Bridge Creek Diversion, Lower Tar River, and Eymundson River all have an enduring high turbidity comparable to that exhibited by the Hangingstone River. In the case of Asphalt Creek, Lower Tar Creek, and Eymundson Creek, steep slopes and erosion of Birch Mountains may be responsible.

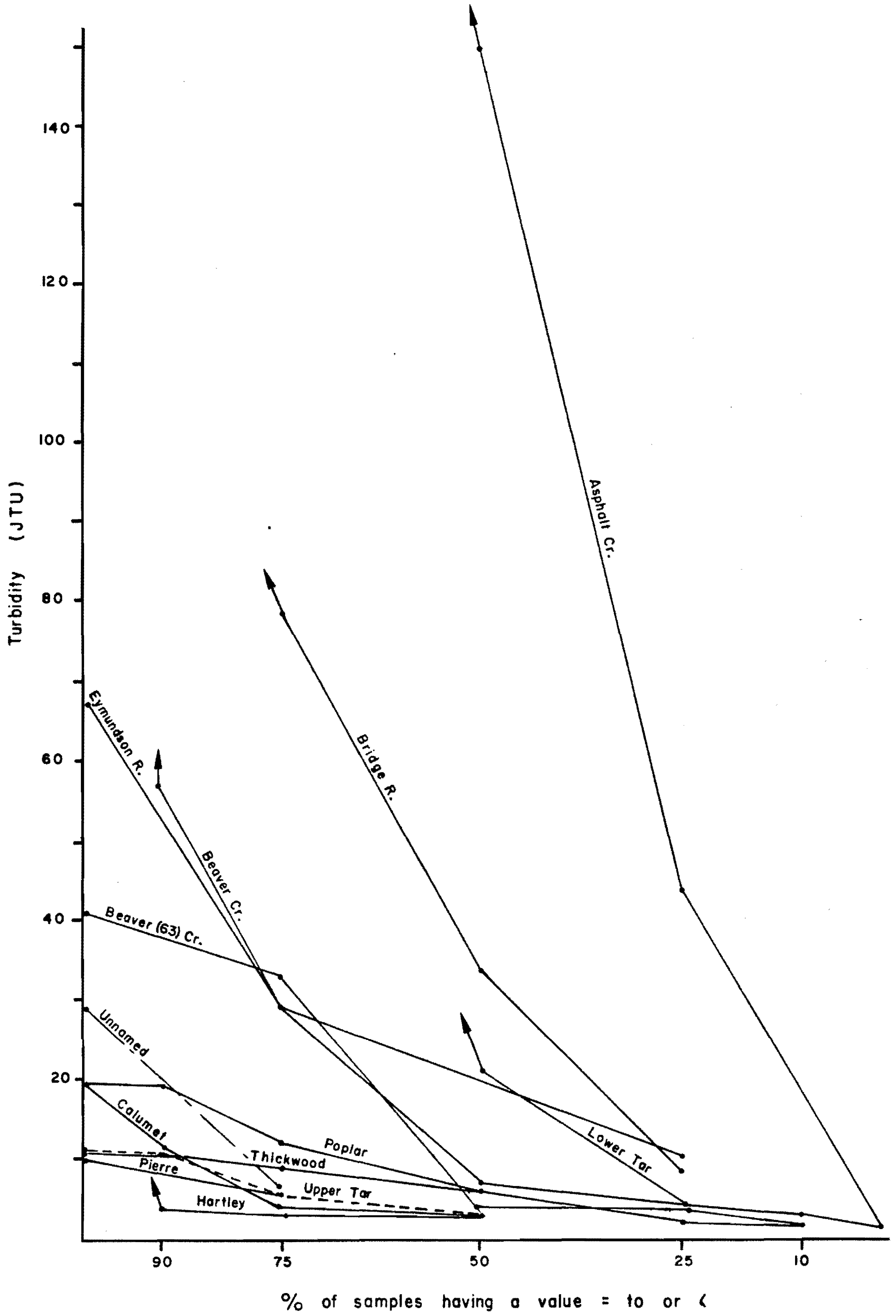

Figure 25. Turbidity frequency for smaller watersheds in 1977.

4. Notable as a typical behaviour is the convex pattern of the curves for Beaver River at Hwy 63 and Poplar Creek showing long duration of intermediate turbidity.

Oil sands developments have directly affected the drainage pattern of Bridge Creek, Beaver River, and Poplar Creek (Figures 3 and 4). This appears to have affected the turbidity regime somewhat by a typical pattern of enduring intermediate turbidity in Poplar Creek and Beaver River and by a heavy regime for Bridge Creek Diversion. However, the effects are not outside the range of regional behaviour.

3.2.2 Temporal Variation in Suspended Solids in Tributaries

Suspended solids can be divided into two components, the organic and the inorganic part. For purposes of analysis, these parts are categorized as two parameters: nonfilterable residue, which measures total inorganic and organic suspended solids, and nonfilterable residue fixed, which measures only the inorganic suspended solids.

The progressional relationship of these parameters with discharge for some selected representative tributaries is shown in Figures 26 to 34. Opposite to the discharge relationship in the conservative parameters (Figure 8), higher levels of particulates relate to higher discharges. Several trends are discernable:

1. For the larger tributaries (Figures 26 to 29), except the Hangingstone, a fairly stable regime of 10 ppm or less total suspended materials prevails throughout most of the year. The substantial organic component of the regime (nonfilterable residue minus nonfilterable residue fixed) varies somewhat throughout this period, usually reaching a maximum during base flow conditions. At such a time, the organic component of the particles can reach up to 90%.
2. For the larger tributaries, a brief episode of high suspended materials can occur during peak flow events. For sedimentary basins, such episodes can be 100 to 1000 ppm total nonfilterable residue, of which only 5% is typically the organic component. For the more stable sites, such as

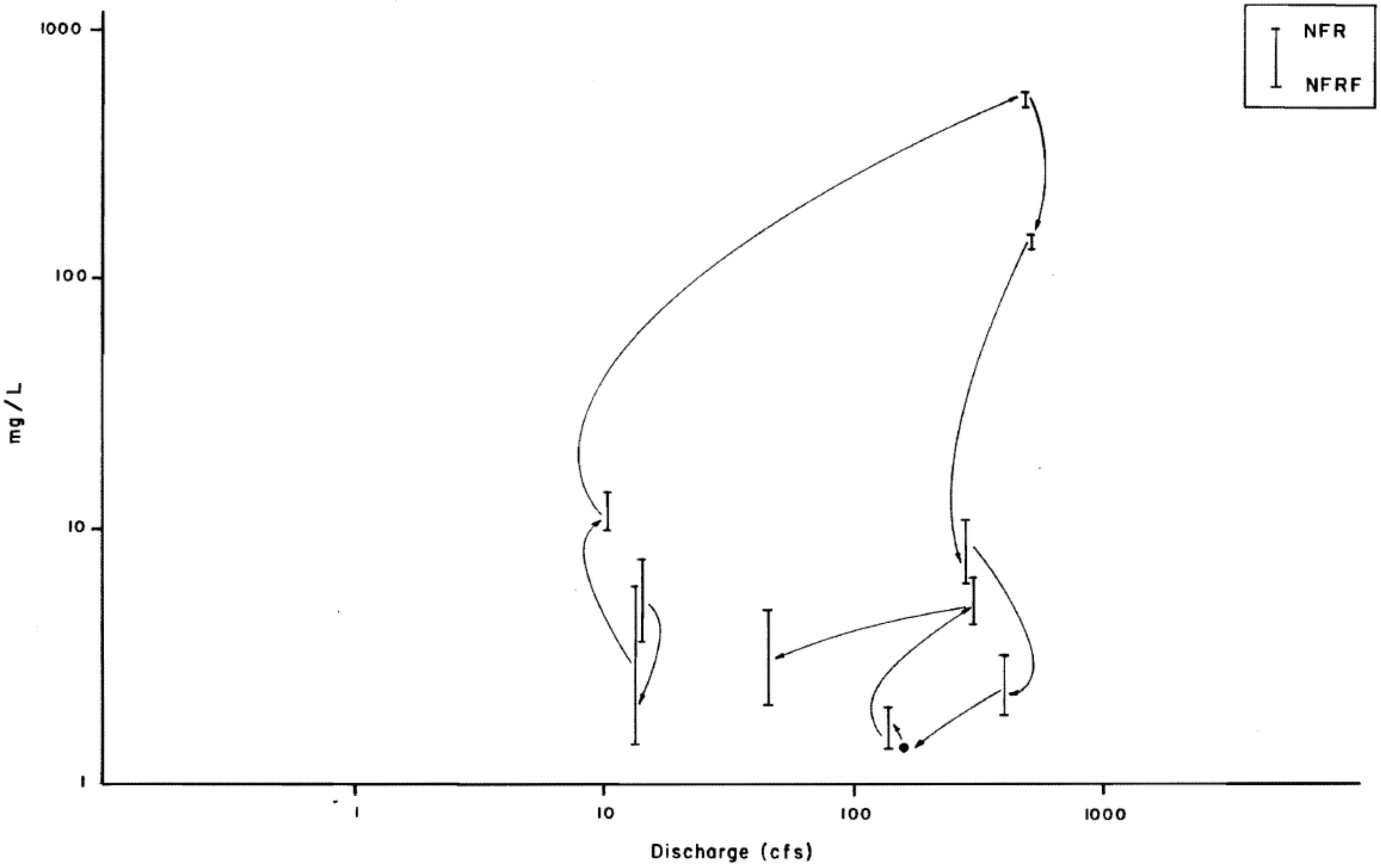

Figure 26. Progression of nonfilterable residue- and nonfilterable residue fixed-discharge relationships for the MacKay River (Site DB0011) in 1977.

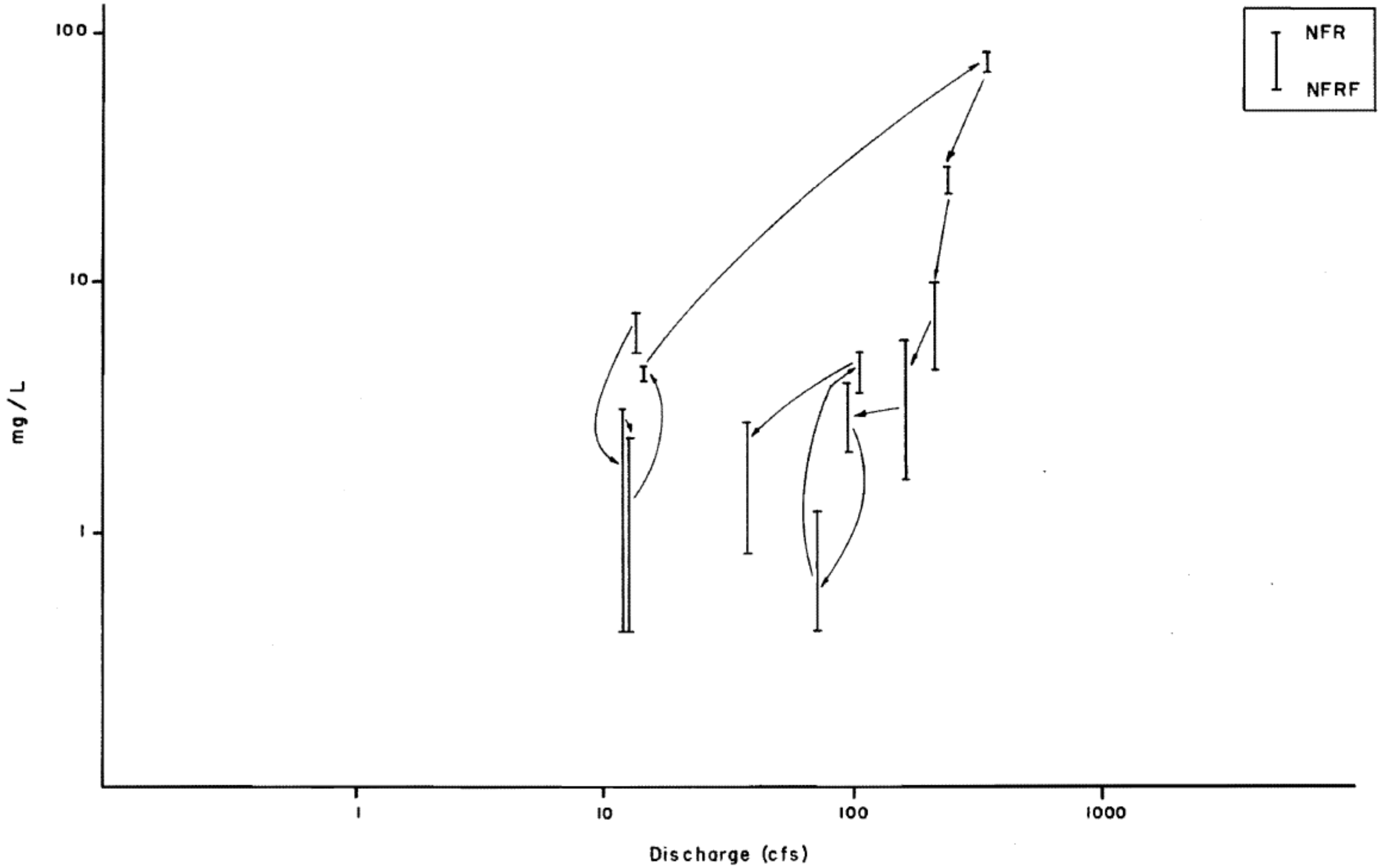

Figure 27. Progression of nonfilterable residue- and nonfilterable residue fixed-discharge relationships for the Steepbank River (Site DA0060) in 1977.

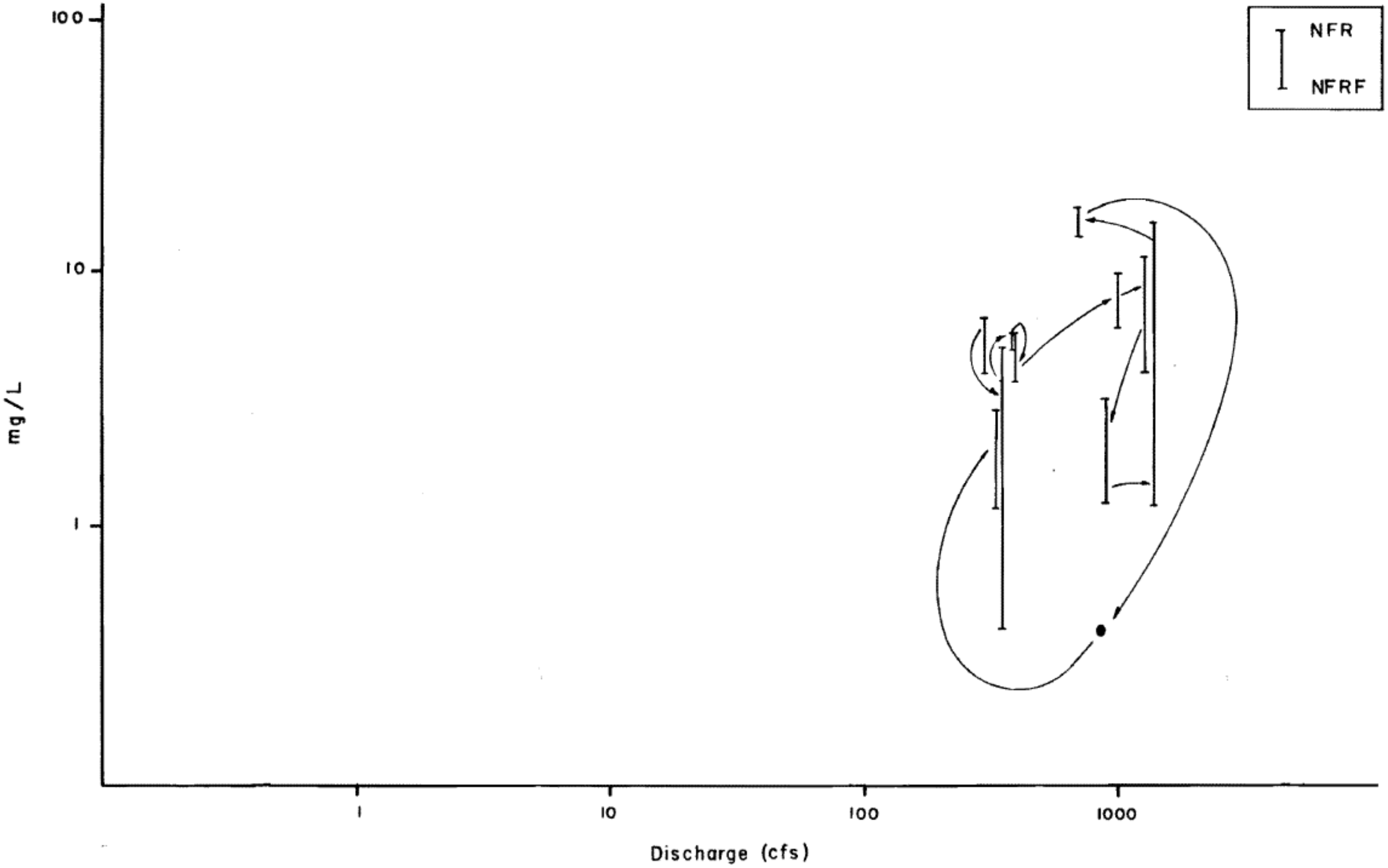

Figure 28. Progression of nonfilterable residue- and nonfilterable residue fixed-discharge relationships for the Firebag River (Site DC0010) in 1977.

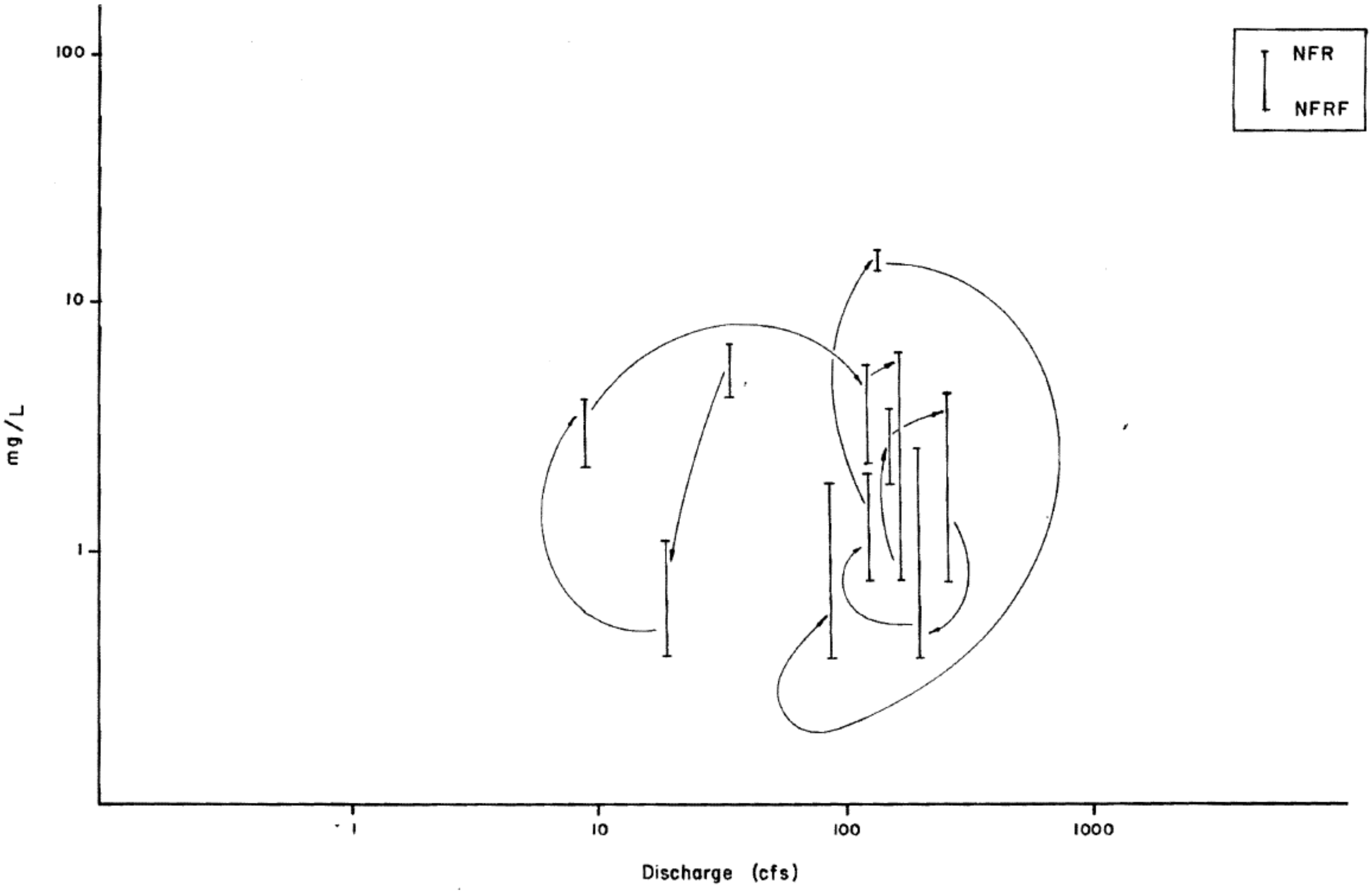

Figure 29. Progression of nonfilterable residue- and nonfilterable residue fixed-discharge relationships for the Upper Ells River (Site DA0100) in 1977.

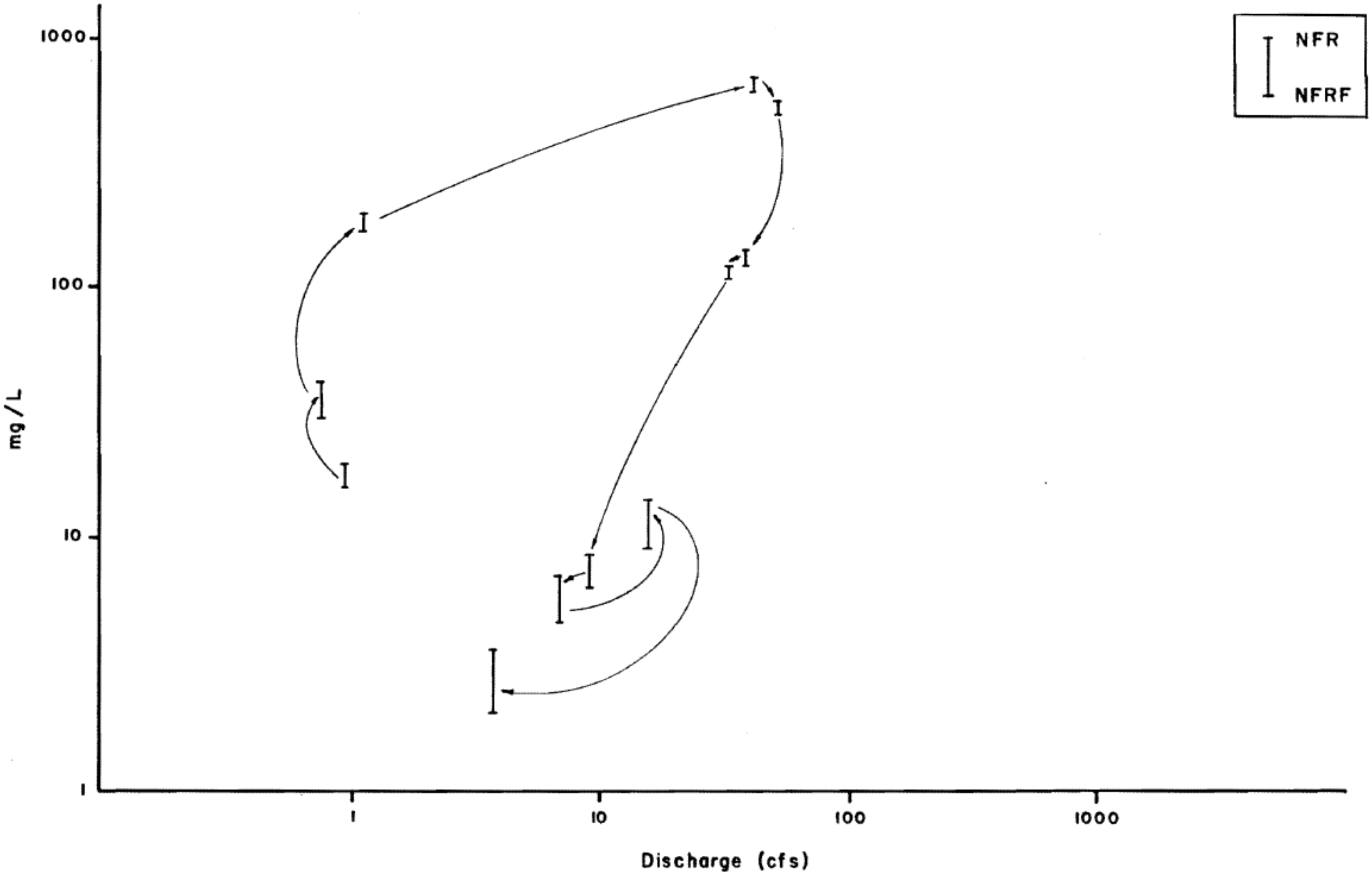

Figure 30. Progression of nonfilterable residue – and nonfilterable residue fixed - discharge relationships for the Hangingstone River (Site CD0040) in 1977.

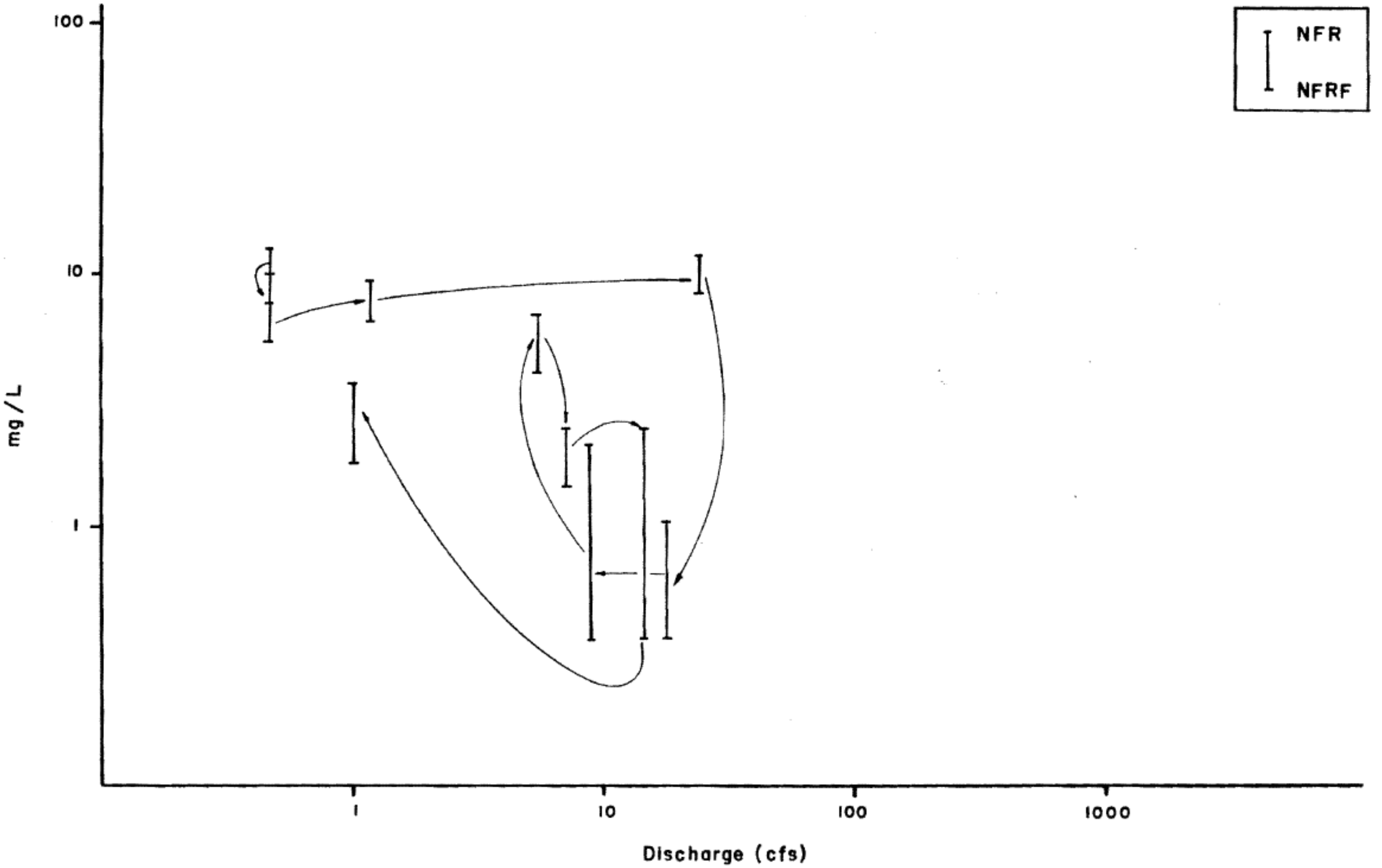

Figure 31. Progression of nonfilterable residue- and nonfilterable residue fixed - discharge relationships for Thickwood Creek (Site DB0040) in 1977.

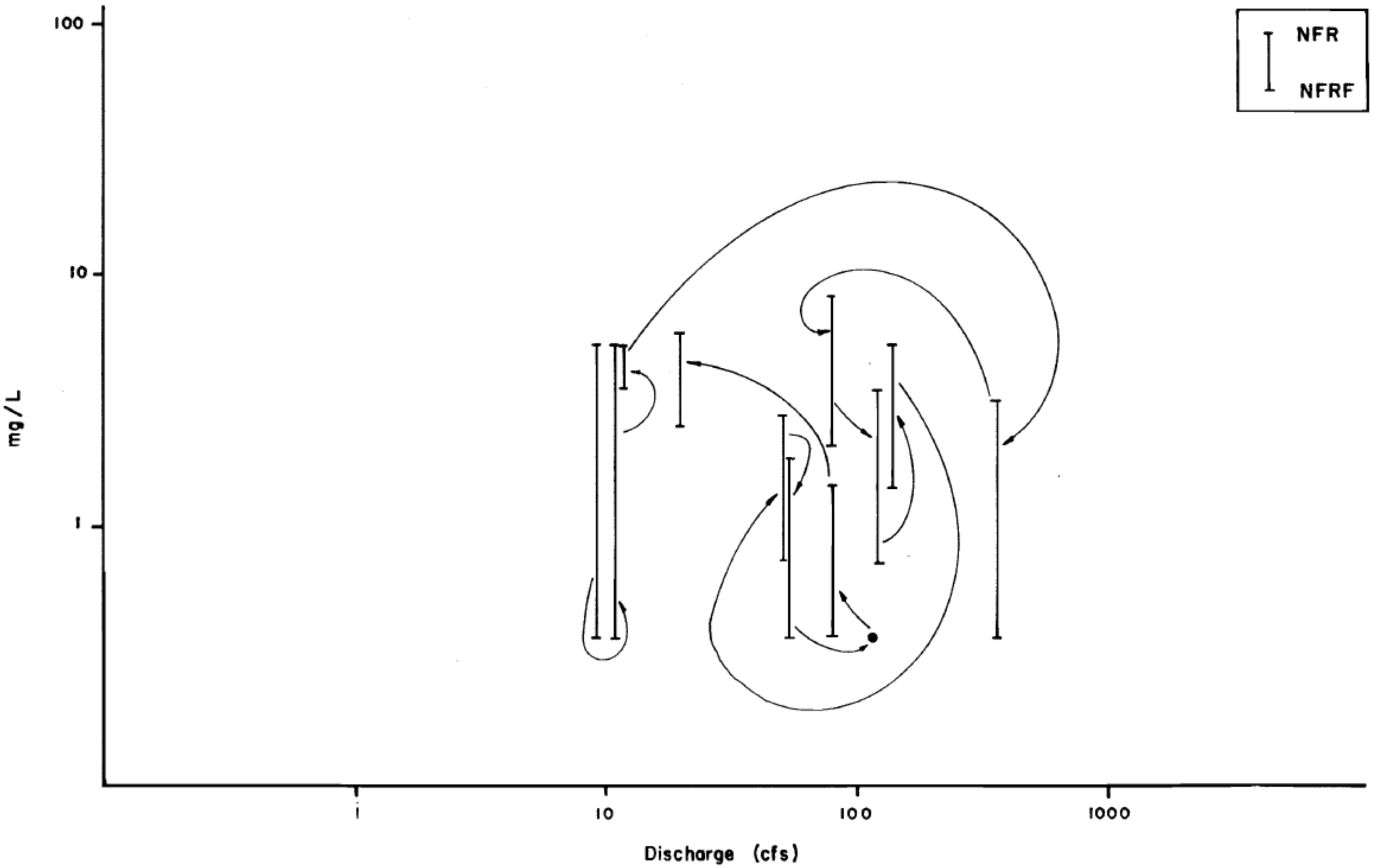

Figure 32. Progression of nonfilterable residue- and nonfilterable residue fixed-discharge relationships for the Muskeg River (Site DA0080) in 1977.

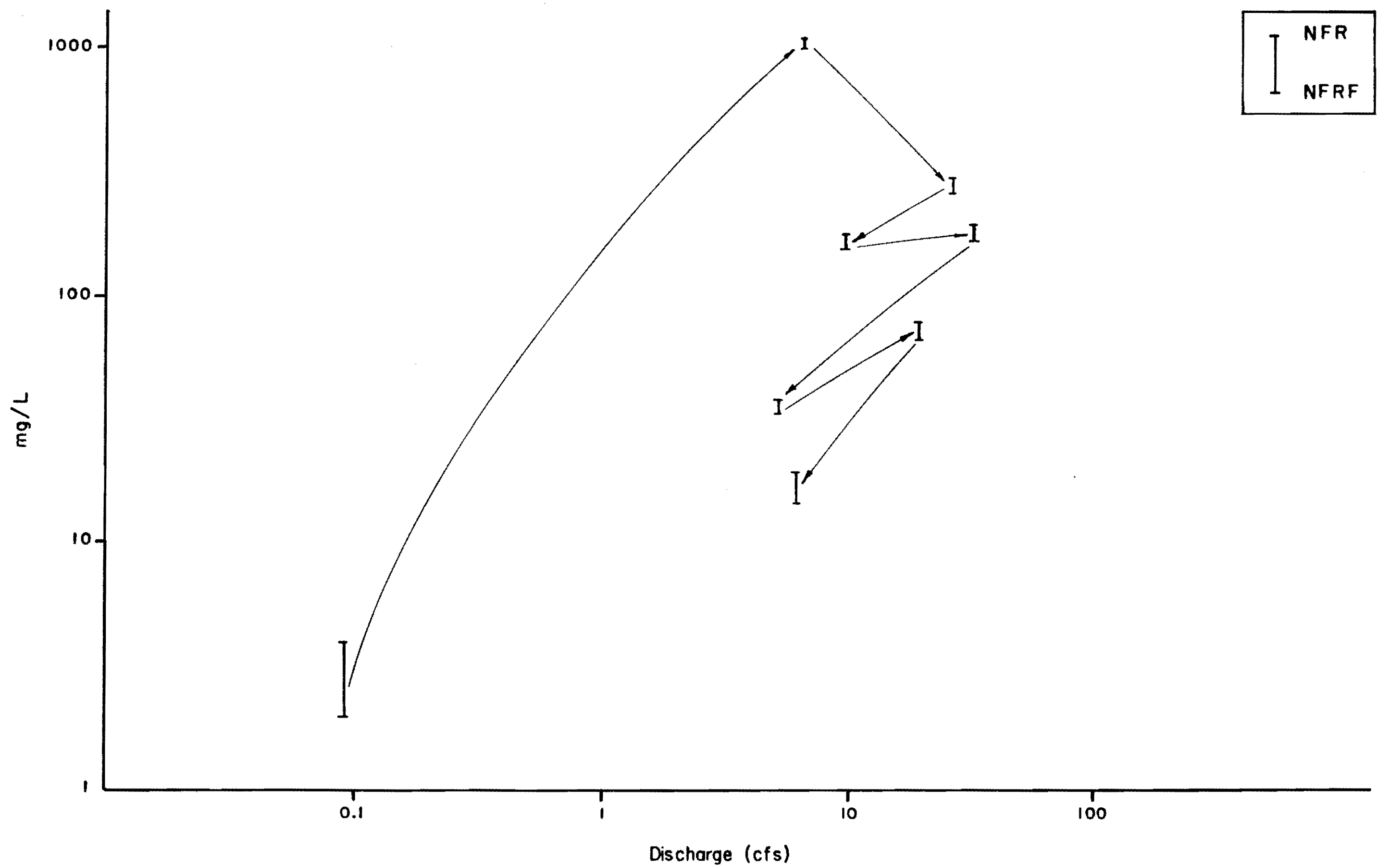

Figure 33. Progression of nonfilterable residue – and nonfilterable residue fixed – discharge relationships for Asphalt Creek (Site DA0080) in 1977.

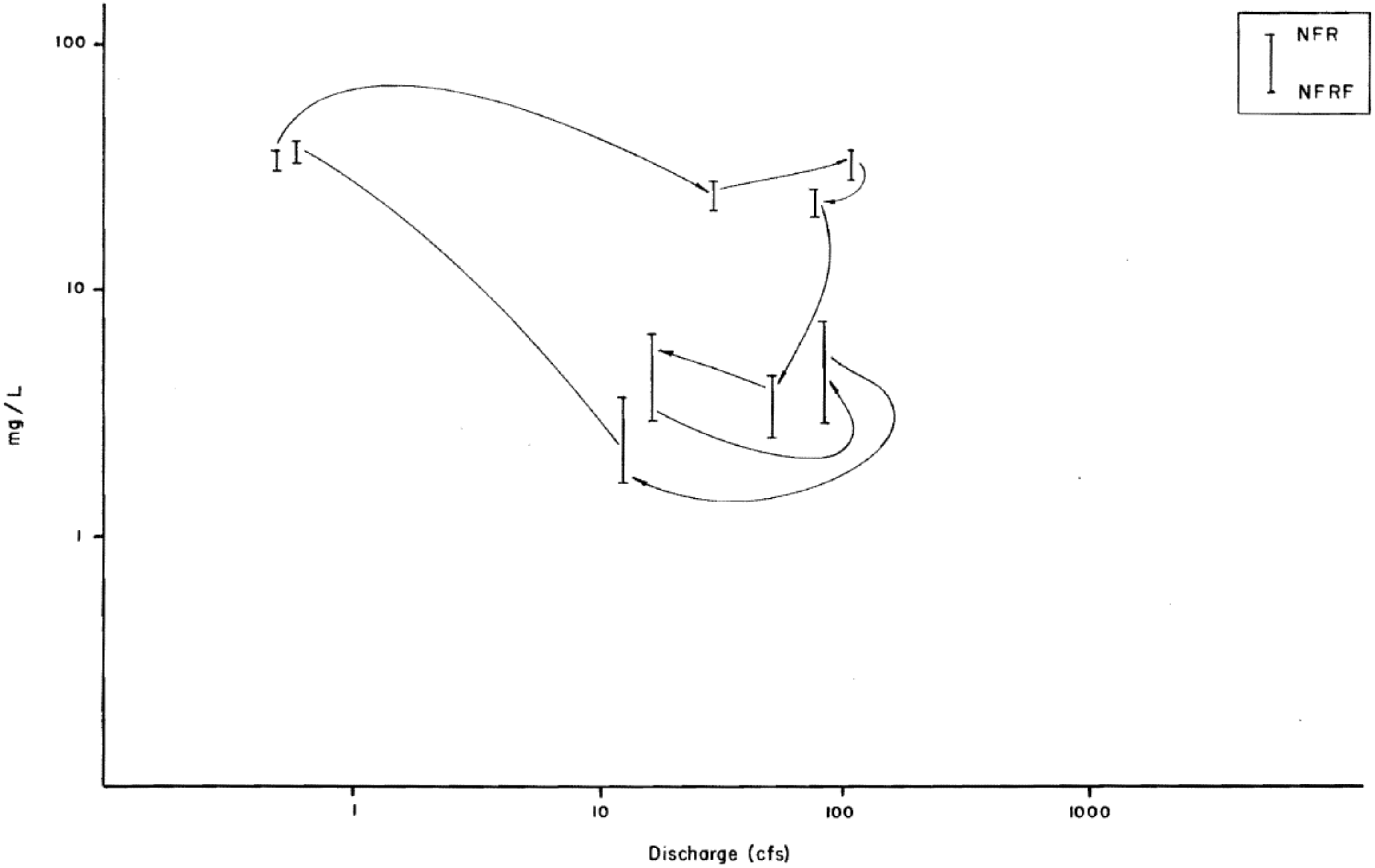

Figure 34. Progression of nonfilterable residue – and nonfilterable residue fixed – discharge relationships for Poplar Creek (Site DA0070) in 1977.

the Firebag and Upper Ells rivers (Figures 28 and 29), such episodes are not very pronounced and the general measured regime is maintained at less than 14 ppm throughout the year.

3. A general phenomenon can be noted in that the rising stage increases the inorganic component of the suspended materials and the falling stage increases the organic component. A consistent example of this is the Steepbank River (Figure 27).
4. For both Thickwood Creek and Muskeg River (Figures 31 and 32), a high duration of the organic component of suspended substances is evident. Such an effect likely is attributable to the dissolved and colloidal organic compounds provided by base flow from the extensive muskeg areas in these basins. Figure 31 shows the result of such organics of Thickwood Creek in winter.
5. Hangingstone River (Figure 30) and Asphalt Creek (Figure 33), which are two examples of very high turbidity regimes (see Figures 24 and 25), have suspended materials-discharge relationships unlike the other tributaries. Sustaining duration of solids with a high organic component did not occur. Wildly fluctuating values were of primarily inorganic composition at both sites indicating possibly slump or bank sources. The steep upper reaches of both these watersheds (Griffiths 1978) may be the prime contributing factor. Such inorganic contribution overshadows any organic effects.
6. Poplar Creek has a regime similar to that of the Hangingstone River in that there is high duration of elevated levels. However, the elevation of inorganic loading during winter base flow is much more pronounced which might reflect the recently effected diversionary measures in the watersheds.

The supply of organic particulate matter is of prime importance to microbial and invertebrate production. It appears that flow from muskegs sustains this supply in most basins in the area. Typically, a peak of organic detritus would be expected in early autumn corresponding to leaf fall. However, the organic particulate content remains high throughout late winter suggesting a groundwater supply. The organic plant derivatives could be supplied from shallow groundwater systems in muskegs in colloidal form or a dissolved material which later consolidates in the surface water course.

3.3 NUTRIENTS

The term nutrients can be very encompassing involving not only the major compounds utilized by the biota but also dissolved forms of many metal ions, compounds of sulphur and silicon, plus particulate forms of most of these compounds. But from the standpoint of being components of biomass uptake by plants and animals, compounds of carbon, nitrogen, and phosphorous are the major nutrients.

The relative proportions of these elements in the environment are given in Table 28 (Kramer et al. 1972). Evident from this summary are differing ratios of the various components relative to their ratios in the average organism. Nitrogen and phosphorus are selectively taken up by the organisms but, upon death, decay, burial, and/or diagenesis, phosphorus is selectively released before release of nitrogen. Thus, levels of such compounds are inseparably woven into the life cycles of the aquatic flora and fauna. A detailed interpretive discussion should be conducted from an organism standpoint (uptake) and a large amount of data points of the non-conservative parameters are desirable. A biologically oriented study of nutrient control by microorganisms in the Muskeg River basin has been conducted (Lock and Wallace 1978, 1979) and an investigation into microbial population and processes dealing mainly with compounds of carbon in the Athabasca River has been carried out (Costerton and Geesy 1978; Nix et al. 1979).

Table 28. Relative atom proportions of carbon, nitrogen, and phosphorus occurring in nature (Kramer et al. 1972).

Occurrence	Phosphorus	Carbon	Nitrogen
Earth (total)	1	0.7	0.002
Average sediment	1	96	2
Ocean (maxima)	1	780	16
Average river (soluable)	1	610	11
Average river (particulate)	1	300	26
Average organism	1	106	16

The following sections are meant only to explore general trends due to the limited number of data points so far. Four parameters are discussed: total dissolved organic carbon (TDOC), total phosphorus (TP) ammonia, and total Kjeldahl nitrogen (TKN).

3.3.1 Temporal Variation in Total Dissolved Organic Carbon in Tributaries

Plots of TDOC levels measured for six of the larger tributary rivers are presented in Figure 35. Common maxima are exhibited both in the spring and the autumn at almost all sites. Two different groups of TDOC regimes are evident:

1. The Firebag and Ells rivers display TDOC values at relatively stable levels, generally below 15 ppm. This behaviour no doubt reflects the stable hydrological regime prevailing in both the Firebag and Ells watersheds. Precambrian Shield lakes supply water free of organic materials to the Firebag River and the relatively high altitude, large headwater lakes in the Birch Mountain appear to serve the same function to the Ells River.
2. The other major rivers display TDOC levels that fluctuate between 10 and 40 ppm. The other larger tributaries (Dunkirk, Dover, and Steepbank rivers) fit into this category. A common tendency in this group is a downward trend during winter ice conditions to levels displayed by the Firebag and Ells rivers. Spring break-up causes a sharp rise that maintains the levels above those of the Firebag and Ells rivers throughout the open-water months. The autumn peaks are about the same order of magnitude above prevailing summer levels at all sites.

Control of TDOC levels thus appears to be mainly allochthonous associated with overland and subsurface flow involving plant materials. Spring runoff provides the main supply and autumn leaf fall provides a second maxima. However, a late winter peak in the Firebag and Hangingstone (and also the Dunkirk) rivers, and a tendency for

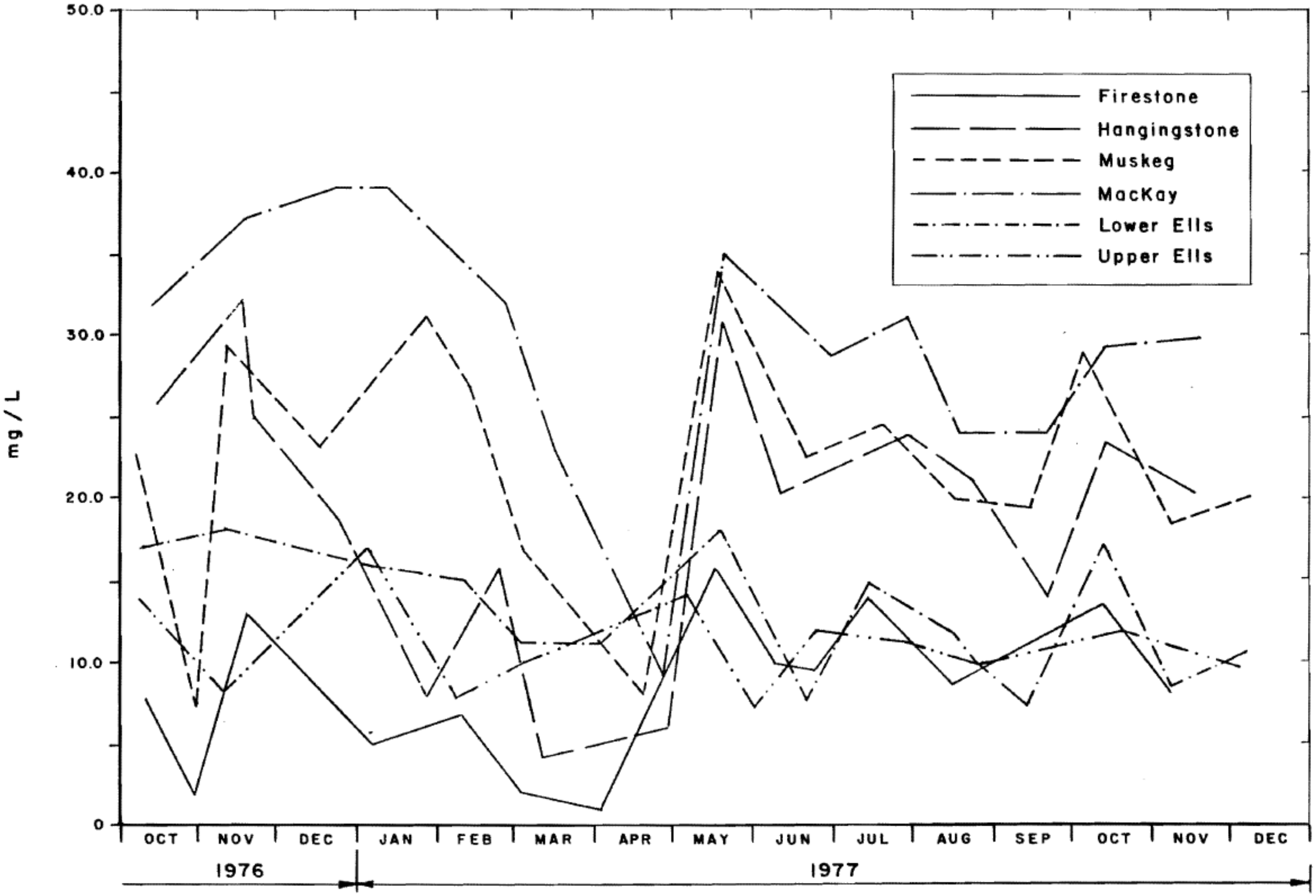

Figure 35. Total organic carbon dissolved in major rivers.

levels not to recess smoothly in late winter in the Muskeg and Lower Ells river, may indicate a deeper source of TDOC such as would be supplied by leachate of oil sands deposits.

Plots of TDOC levels for a selected number of smaller tributaries are presented in Figure 36. Most of these small tributaries show wide variations between 10 and 40 ppm, the extremes exhibited by the larger tributaries. However, there is no clear division into groupings of ranges as could be discerned in the case of larger tributaries. Noticeable trends were:

1. Most of the small tributaries showed a decline in TDOC levels during ice-cover conditions with a subsequent sharp increase at spring break-up typified by Hartley Creek in Figure 36. Such a regime no doubt reflects the typical inputs of allochthonous carbon in the spring and autumn as were displayed by the large rivers. However, Thickwood Creek and Calumet River did not behave in such a manner. Thickwood Creek maintained a relatively stable TDOC level at about 25 ppm, probably due to the large muskeg coverage of its catchment. The large muskeg storage would cause an influential subsurface component high in organic derivatives throughout the year. Long duration of elevated particulate carbon is evident from Figure 31. Figure 24 shows evidence of enduring high levels of carbon compounds in late winter. Calumet River maintained a similar high TDOC regime.
2. Watersheds, where development activities were occurring, showed irregular behaviour compared to the others. Noticeable in Bridge Creek Diversion was an unusually low minimum in TDOC in the autumn. Noticeable in Poplar Creek was a late minimum in May long after ice-out. The regime in Poplar Creek no doubt reflects sporadic inputs from Beaver Creek Diversion (Figure 10).

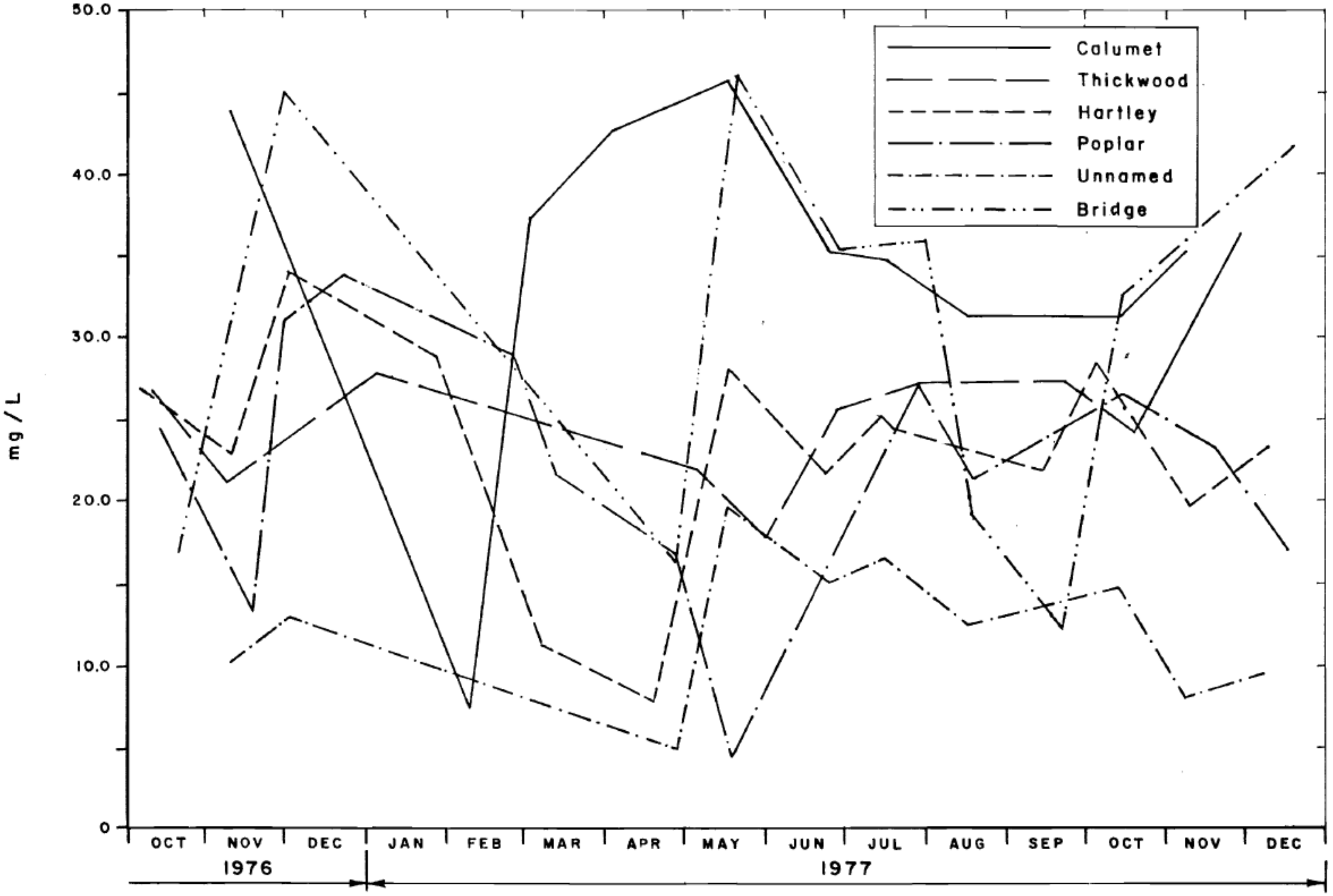

Figure 36. Total organic carbon dissolved in small tributaries.

3.3.2 Termporal Variation in Total Phosphorus in Tributaries

Plots of TP levels measured at six of the larger tributaries are shown in Figure 37. A general trend is seen in common, low stable periods from June to October when it appears that control of phosphorus levels is exercised by uptake by growing biota. At other times of the year, levels are much less predictable. Similar to TDOC regimes, two different groups of behaviour are evident:

1. The Firebag, Ells, and Muskeg rivers maintain relatively stable levels below 0.10 ppm throughout the year; and
2. In the other rivers, there are sporadic occurrences of levels between 0.15 and 0.50 ppm, with the Hangingstone River providing the highest level. The Dover, Dunkirk, and Steepbank rivers also showed this trend, the Dunkirk showing a very pronounced maxima. However, no common temporal cycles like those shown by TDOC regimes were discernable.

If maxima occurred in late winter, groundwater discharge could be the controlling factor; in early winter, algal die-off could be a major source; or in spring runoff, leaf litter leaching could be flagged as a major source. But without significant temporal cyclical trends evident in these plots of the large tributaries, no single factor is indicated as a predominate control of phosphorus levels.

Plots of TP levels measured at a selected number of small tributaries are shown in Figure 38. As with the larger tributaries, there occurred a common period of low TP from June to October. In all of the samll tributaries, maxima TP levels (over 0.10 ppm) were measured during the December to May period. The timing of maxima varies widely. A number of tributaries not shown in Figure 38, such as Asphalt Creek and Beaver River, had pronounced maxima occurring in late April and May. Noticeable trends included:

1. Streams that exhibited early maxima (January to March) tended to have a lower and more stable TP regime. Hartley and Thickwood creeks are notable examples of this and it may be that muskeg headwaters hold phosphorus released by spring runoff so that a winter release (possibly by winter die-off) provides the maxima.

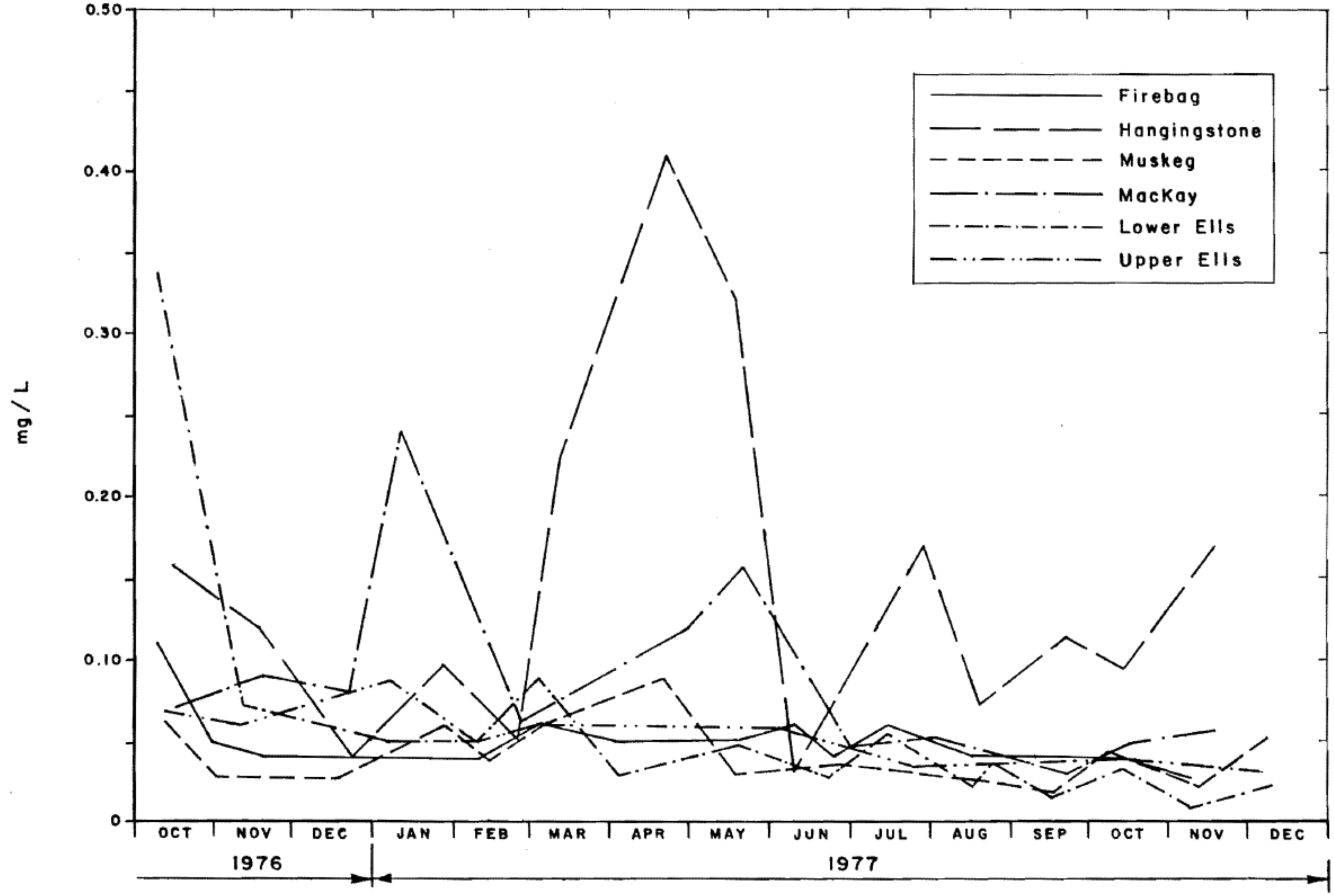

Figure 37. Total phosphorus in major rivers.

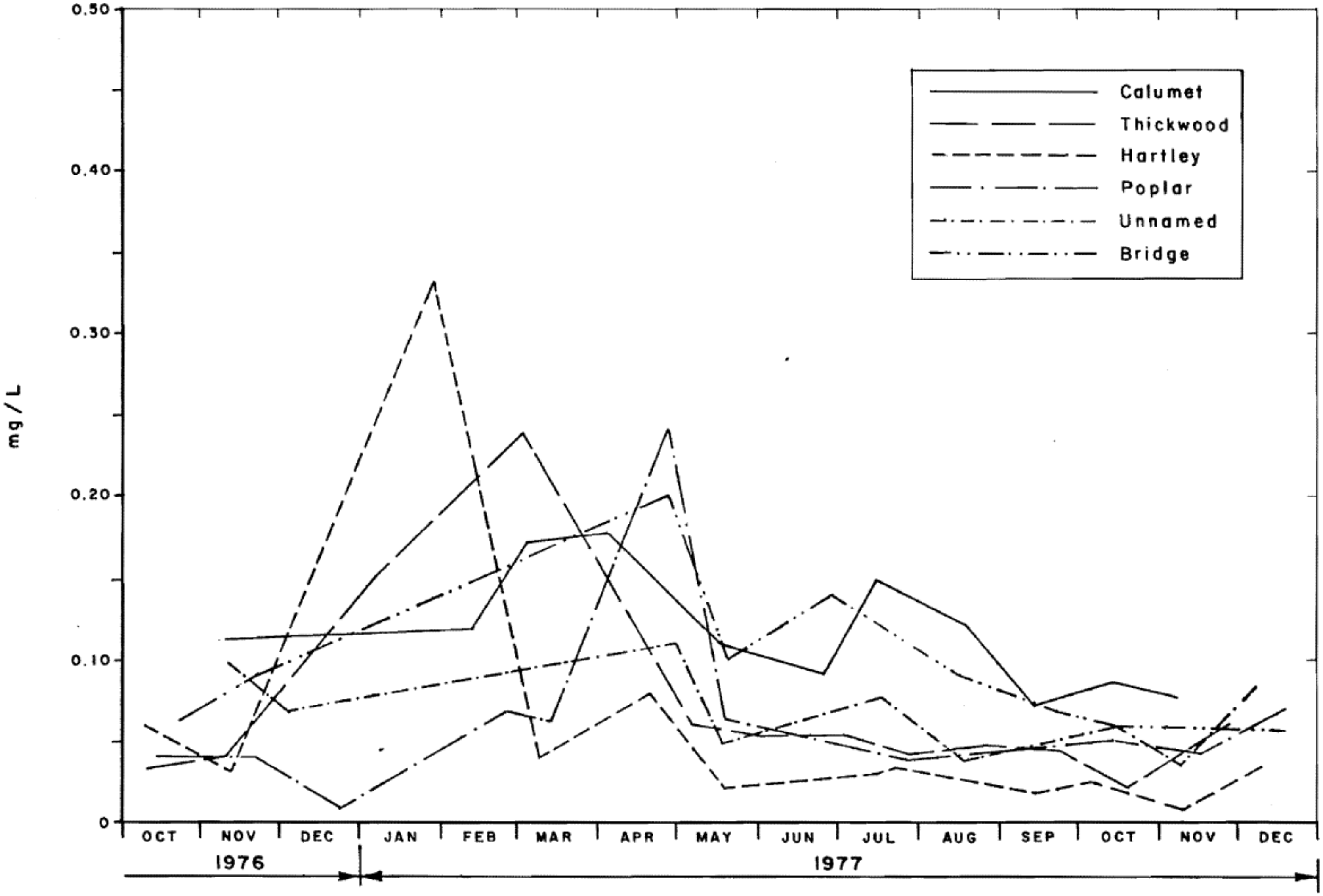

Figure 38. Total phosphorus in small tributaries.

2. A number of streams showed very pronounced maxima in measured TP that corresponded to spring breakup. Poplar Creek show this behaviour. Asphalt Creek and Beaver River are notable examples of this in that their maxima were very pronounced.

3.3.3 Temporal Variation in Ammonia in Tributaries

Plots of ammonia levels measured at six of the larger tributaries are shown in Figure 39. A general trend is seen in a common, brief period of low levels from mid-April to mid-June. Also common to all rivers are two maxima--one in early winter and one in late summer. In a pattern similar to TDOC regimes, two different groups of behaviour are evident:

1. The Firebag and Ells rivers maintain relatively stable levels below 0.10 ppm throughout the year; and
2. In the other rivers, relatively high peaks between 0.3 and 0.6 ppm occur for both winter and summer highs, with the Muskeg River providing the highest level.

The temporal trends common to all the large rivers indicate reductive processes predominating, both under ice conditions and in late summer, and oxidation processes being of particular significance immediately following spring ice-out. Oxidation and reduction of natural aqueous nitrogen species are allied closely with biological activity. Thus, the wide swings in the sedimentary rivers indicate their higher level nitrogen nutrient status and subsequent biological activity.

Plots of ammonia levels measured at a selected number of small tributaries are shown in Figure 40. As with the larger tributaries, there occurs a common period of low ammonia immediately following ice-out. However, the duration of this period is shorter than for the large rivers, reflecting the responsiveness of the smaller streams. Ranges were much wider than the large rivers and, typically, for the small tributaries, maxima ammonia measured at levels over 0.20 ppm under ice conditions. There were no clear divisions of tributaries into groups as was the case of the larger rivers.

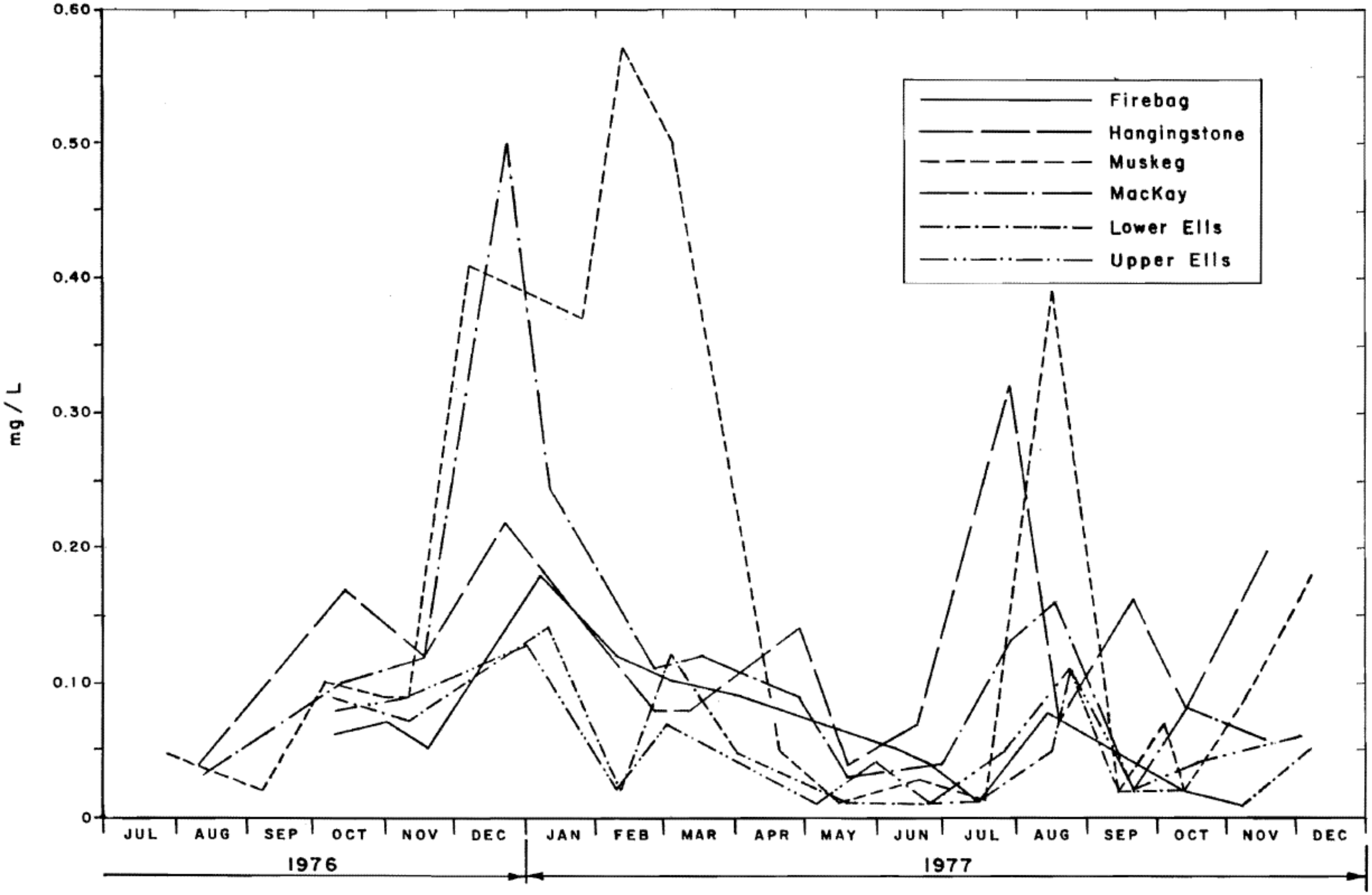

Figure 39. Ammonia in major rivers.

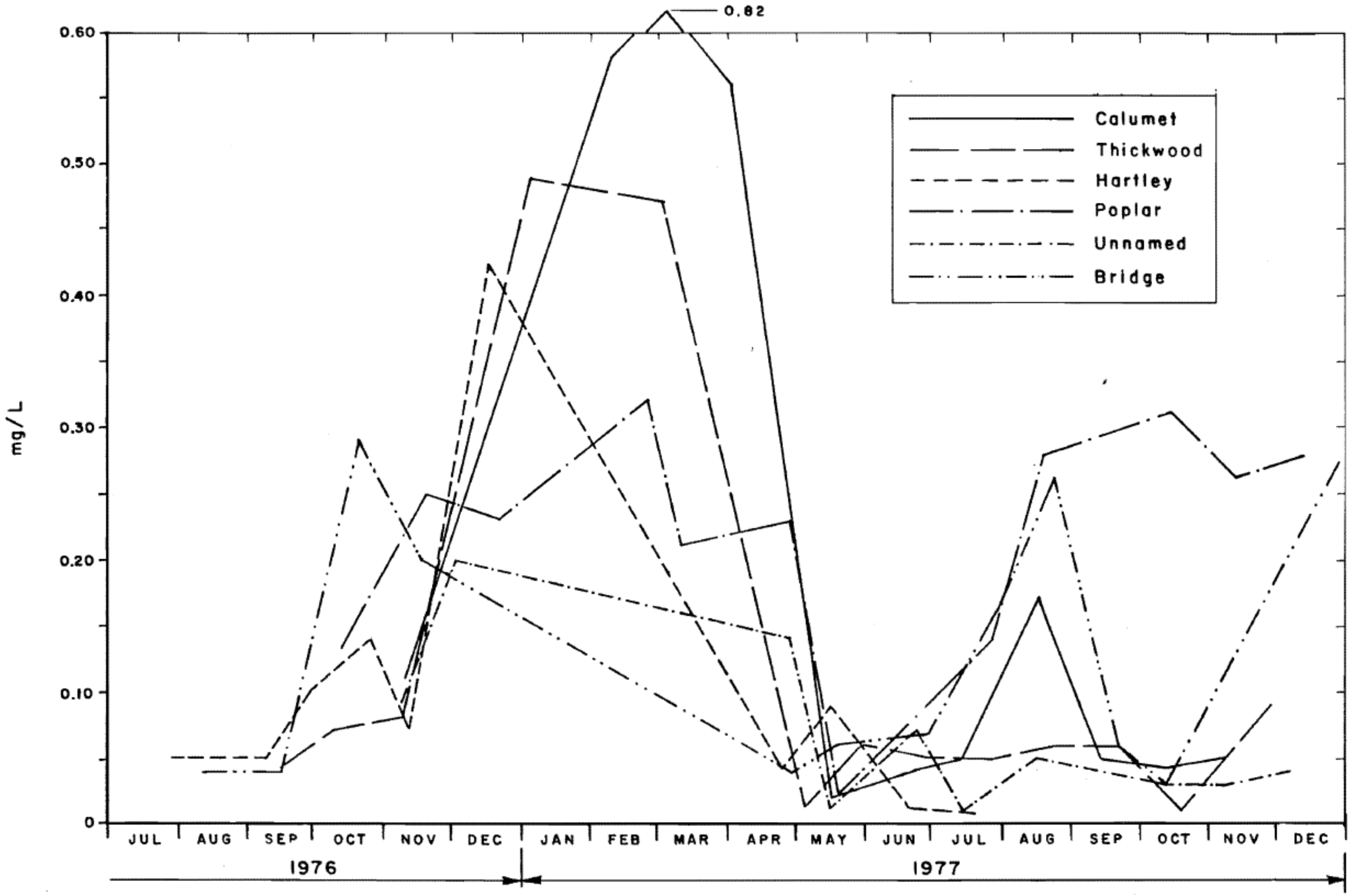

Figure 40. Ammonia in small tributaries.

However, noticeable trends were:

1. Some small streams exhibited a winter maximum earlier than the rest and these corresponded to those exhibiting earlier maximum TP regime. Hartley and Thickwood creeks are notable examples of this.
2. Watersheds, where development activities were occurring, showed somewhat irregular behaviour compared to the undisturbed sites. Bridge Creek had a very early ice-cover maximum; Poplar Creek had an enduringly high late summer maximum.
3. Both Thickwood Creek and Calumet River had exceptionally high late winter ammonia levels. These levels likely reflected reducing conditions operating on the nitrogen regime.

3.3.4 Temporal Variation in Total Kjeldahl Nitrogen in Tributaries

Plots of the TKN levels measured at the larger tributaries are shown in Figure 41. In contrast to the other nutrient parameters, no significant temporal trends are evident from the plots. In general, the values ranged randomly between 0.3 and 2.0 ppm, with the Firebag and Ells rivers displaying a lower regime than the others.

Plots of the TKN levels measured at some smaller tributaries are shown in Figure 42. Almost all sites showed a maximum in June 1977. This may have been related to late spring conditions and was also evident in data from the larger rivers. However, no similar effects were noted in the behaviour of either TDOC or TP levels.

3.3.5 Nutrient Ranges in the Peace-Athabasca Delta

Ranges of TKN, TDOC, and TP, measured during 1977, at points in the Peace-Athabasca Delta are shown in Figure 43.

The patterns of levels of these nutrient parameters in the eastern part of the delta are somewhat different than the patterns of inorganic parameters which are controlled mainly by dilution. Although TDOC and TP levels at the outflow of Lake Athabasca (Riviere des Rochers, Site NA0030) are intermediate between eastern Lake Athabasca water,

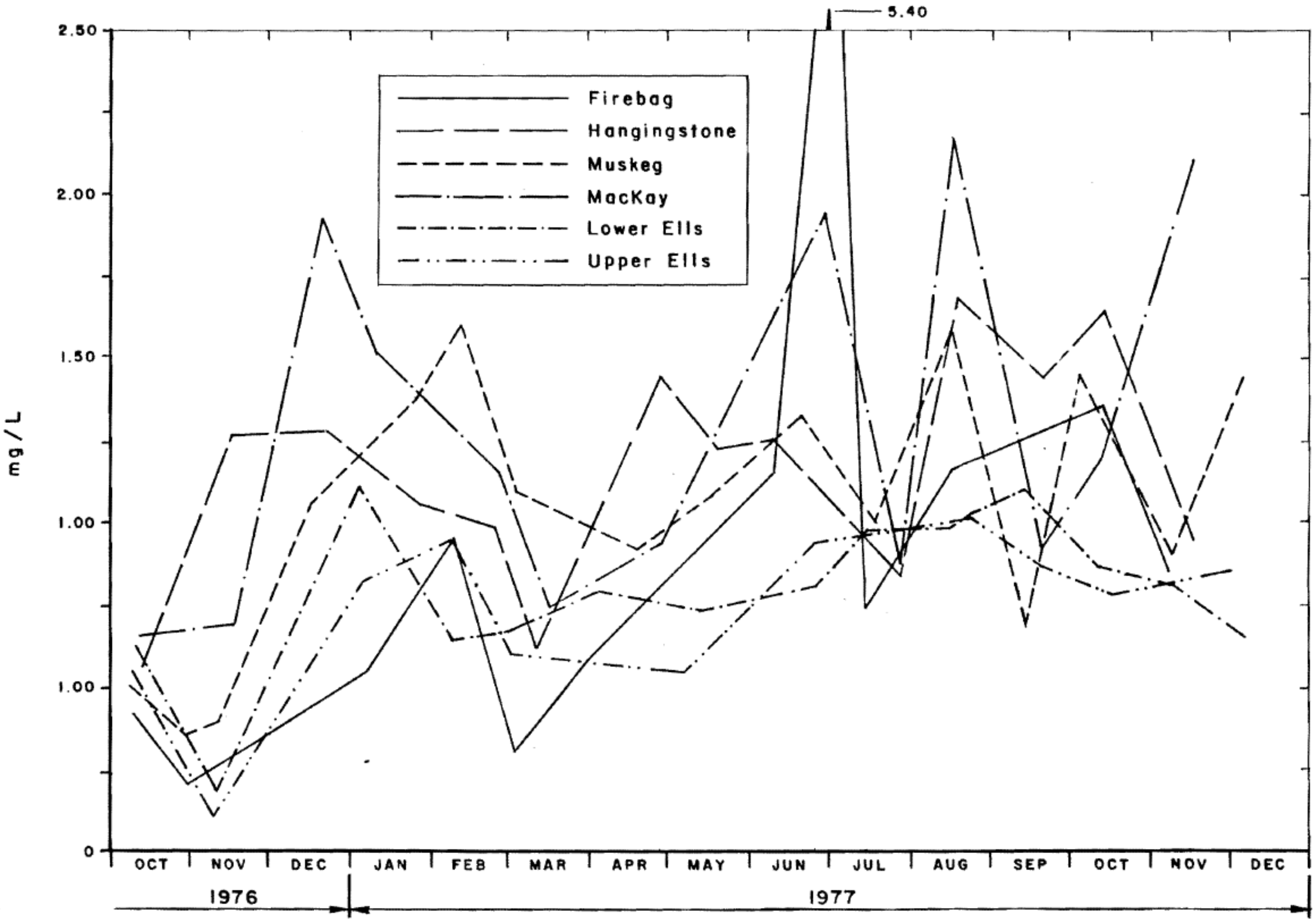

Figure 41. Total kjeldahl nitrogen in major rivers.

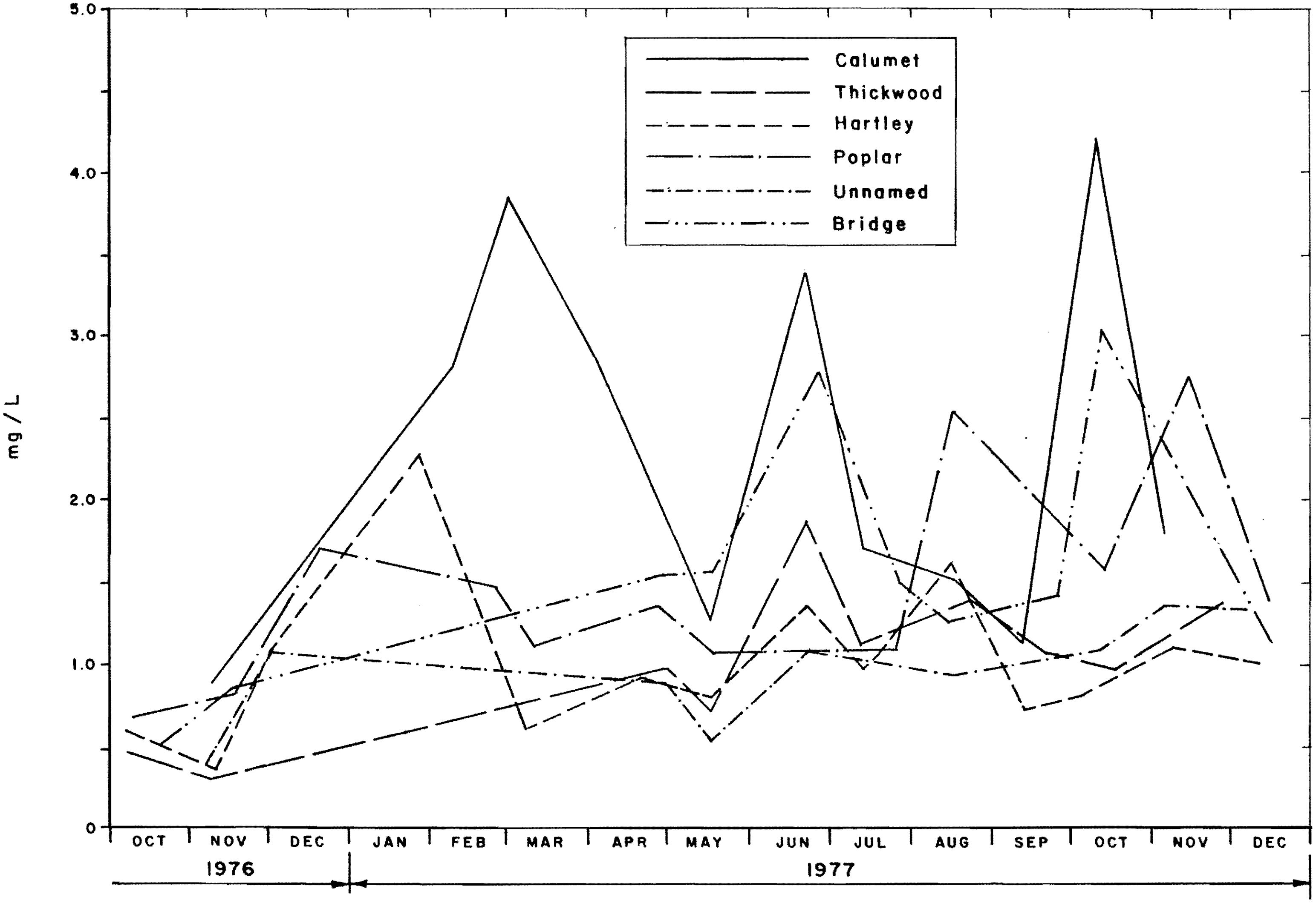

Figure 42. Total kjendahl nitrogen in small tributaries.

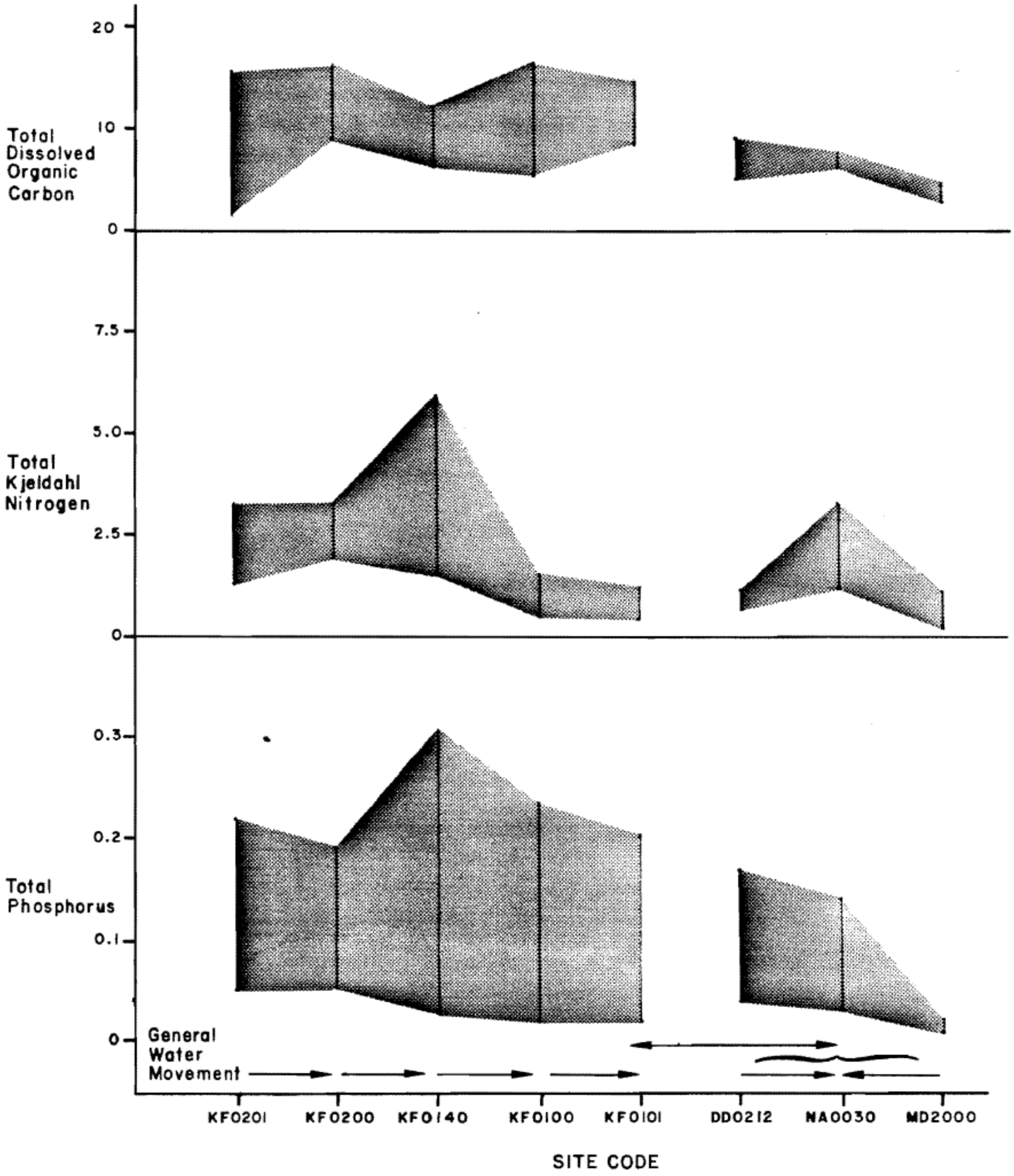

Figure 43. Ranges of total dissolved organic carbon, total Kjeldahl nitrogen and total phosphorus measured in the Peace - Athabasca Delta in 1977.

as represented by Site MD2000, and Athabasca River water (Site DD0212), a general tendency to exhibit a higher resultant regime at Site NA0030 than exhibited by the inorganic parameters (Figure 22) can be seen. In the case of TKN, there is an obviously higher regime than would be accounted for by dilution. Thus, nutrient levels in western Lake Athabasca appear to be highly augmented by discharge from the Athabasca River Delta directly but not through main channels, as represented by Big Point Channel (Site DD0212).

The patterns of levels of these nutrient parameters in the eastern part of the delta also contrast with behaviour of inorganic parameters which are controlled mainly by groundwater-surface water relationships (Section 3.1.7). As water moves from the southern part of Lake Claire (Site KF0201) through to Quatre Fourches (Site KF0101, there is an increase in TDOC levels all the way and an increase and subsequent decrease in TP and TKN levels, with maxima generally occurring at the exit of Lake Claire (Site KF0140). Thus, it appears that the supply-demand relationships of the biota in the main water courses, as well as the adjacent marshes, have a major control on nutrient levels.

3.4 METALS AND TRACE ELEMENTS IN LOTIC WATERS

Metals in surface waters can be in the form of dissolved ion species, particulates, or organic complexes. The amount of metal in each form represents a steady state of processes involving dissolution and complexing. Studies by Allan and Jackson (1978) and Korchinski (in prep.) have explored some aspects of the dynamics of these interactions in the AOSERP study area.

Allan and Jackson traced the concentrations of metals in sediments of the Athabasca River, its delta, and Lake Athabasca, and related them to fluvial processes and to the texture, organic content, carbonate content, and ferrous mineral content of the sediments. They found the finer textured sediments associated with higher amounts of precipitated heavy metals, which in turn related to increases in surface area, amorphous inorganic-organic coatings, layer silicate concentrations, and organic content. Generally, there is a progression from lower to higher concentrations of metals in sediments downstream from

Fort McMurray to the delta and into Lake Athabasca. The highest concentrations were found in fine-textured sediments taken from Lake Athabasca. They correlated the sediment concentrations of vanadium and nickel with each other as well as with organic carbon. Thus, it was concluded that these metals were present in an organic form that may be similar to that which occurs naturally in the oil sands deposits. As such, they would have undergone relatively little chemical or bacteriological alterations between the source and the site of deposition in bottom sediments.

Korchinski (in prep.) related the complexing capacity of surface water in the AOSERP study to the total organic content. Considering levels of both the organic content and complexing ability in surface waters, complexing would appear to be an important process operating in the oil sands area. However, from analysis of bank materials, he suggested erosional factors to be the major control of most metals in the surface water.

Metals are made available to surface waters by weathering processes and by groundwater discharge. Of particular interest are the metals associated with oil sands deposits which could be provided to surface water systems by weathering of exposed deposits, groundwater leaching and discharge, or by oil sands mining operations. Oil sands contain a variety of trace metals (Table 29), notably enriched in vanadium and nickel, as are many other oils (Hodgson 1954). It has been established that vanadium, in oil sands, occurs as porphyrin and related complexes (Cotton and Wilkenson 1972; Yen 1978) and nickel probably has a similar form. Important sources of other metals to the surface waters in the oil sands region may be underlying Devonian bedrock formations.

Total concentrations of many metals and trace elements were measured at each site in 1976 and 1977. Total concentrations include not only the dissolved ionic form but also whatever is dissolved from suspended particulates and whatever can be dissociated from the organic

Table 29. Typical elemental analyses of oil sands.

Element	Concentration (ppm) in bitumen	 in oil sands
V	210-290[a], 200[e]	32-117[c]
Fe	142[b], 254[b], 75[a]	800-13 800[d]
Ni	80-100[a], 72[b], 74[b], 60[e]	12-20[c]
Ti	110[e]	
Zn		61-2222[c], 5-2600[d]
Mn	3.9[b]	12-180[d]
Pb		6-52[c], 5-180[d]
Cu	2-5[a]	3-16[c]
Co	1.9, 1.3	1-13[c]
Cr	1.7[b], 1.0[b]	7-30[c]
Be	0.5-2.1	
Ru	0.72[b], 0.38[b]	
As	0.32[b], 0.40[b]	
Se	0.52[b], 0.29[b]	
Ga	0.27[b], 0.31[b]	
Sc	0.19[b], 0.20[b]	
Hg	0.082[b]	
Ce	0.069[b], 0.026[b]	
Sb	0.028[b], 0.031[b]	
Eu	0.023[b], 0.009[b]	
Au	0.001[b]	

[a] Puttagunta et al. 1977.

[b] Hitcon et al. Unpublished.

[c] Jonasson *in* Allan and Jackson 1978.

[d] Jonasson Unpublished.

[e] Walker et al. 1976.

complexes by the preservative employed (Table 5). The general order of dominance for total metals and trace elements in rivers and streams was concluded to be:

Fe>Al>Mn>Zn>Cu>Ni>Pb>Cr>Co>Ag>V>Cd>As>Se>Hg

The following sections detail the occurrences of levels of each of these elements.

3.4.1 Iron

Frequency distributions for total iron levels in streams and rivers by zones are shown in Figure 44. Virtually all occurrences were noncompliant (greater than 0.3 ppm) with the water quality criteria (see Table 9). In fact, levels above 1 ppm generally prevail throughout in all zones except for the Ells River (Zone 4) and the Firebag and Richardson rivers (Zone 6). In view of the markedly low suspended sediment regime in these two zones (see Figure 21), such a pattern seems to indicate a major role for erosional processes in providing total iron to the surface waters. In line with such a conclusion is the observation that for Zone 4 the majority of occurrences below 0.4 ppm were for the Upper Ells River (Site DA0100) and between 0.4 and 1.0 ppm were for the Lower Ells River (Site DA0170), and all above 1.0 ppm were for Joslyn Creek (Site DA0160).

The timing of occurrences of the highest levels of total iron (greater than 10 ppm) also indicates the importance of erosional factors (Table 30). Almost all very high values occurred during high suspended material (spring and summer). Sites where these kinds of levels occurred in winter were ones of highly enduring turbidity, like Lower Tar River and Asphalt Creek (see Figures 25 and 33). An exception to this rule was the total iron of Beaver River above Syncrude (16 ppm) in January 1977.

For the mainstem Athabasca system, major contributions to the total iron regime were not significant in the months October through March. For example, there were no occurrences in the upper 25 percentile during the autumn and winter (Table 31). However, the situation for some tributaries was different, notably in Zones 2, 3, and 6 (Table 31) where a major contribution to the upper 25 percentile was during the

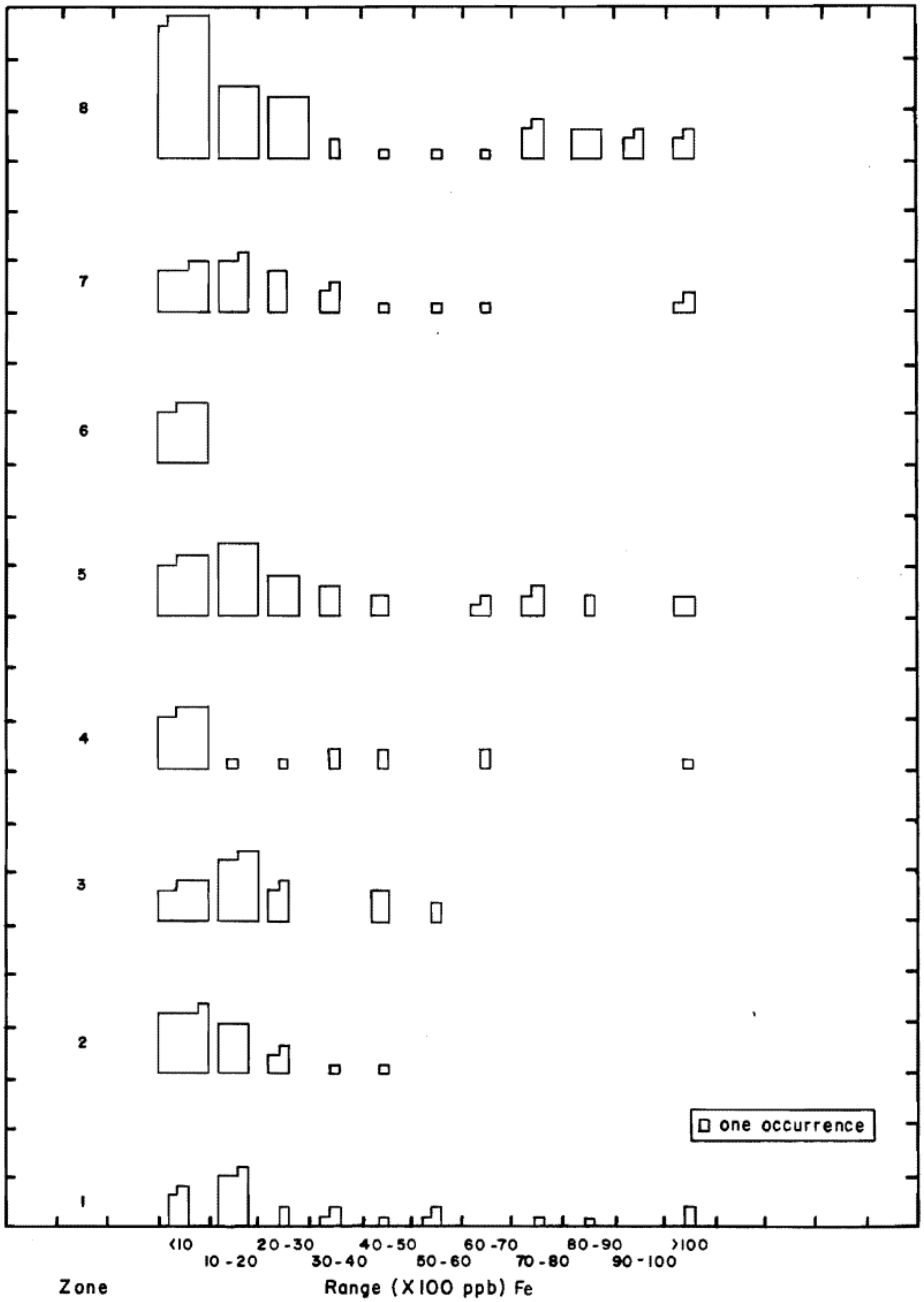

Figure 44. Frequency distribution for total iron in rivers and tributaries by zones from 1976 and 1977 data.

Table 30. Occurrences of levels of total iron greater than 10 ppm in 1976 and 1977 in rivers and streams.

Level (ppm)	Site Code		Date
63	DA0200	Athabasca River	30-08-76
63	DA0205	Athabasca River	30-08-76
52.5	DA0150	Lower Tar River	01-04-77
49	CD0040	Hangingstone River	29-08-76
27.7	DA0120	Asphalt Creek	28-04-77
24	CD2300	Clearwater River	28-08-76
19.9	DA0150	Lower Tar River	02-03-77
19	CD0040	Hangingstone River	27-04-77
17	DA0150	Lower Tar River	08-02-77
16	DA0180	Beaver River	04-01-77
15.5	DD0010	Athabasca River	07-06-77
14	DA0160	Joslyn Creek	09-11-76
14	DA0181	Beaver River-Hwy 63	11-08-76
10.9	DA0181	Beaver River-Hwy 63	27-04-77
10.2	DA0200	Athabasca River	02-09-76

Table 31. Upper 25 percentile levels occurring during autumn-winter of total iron, aluminum, manganese, and zinc for rivers and streams. Ranges and occurrences for October through March, 1976 and 1977.

	Percent Occurrence				Ranges			
Zone	Fe	Al	Mn	Zn	Fe	Al	Mn	Zn
1	22	22	44	11	3.65-49	1.90-10.0	0.130-1.4	0.035-0.20
2	67	33	69	46	1.30- 4.95	0.08- 0.70	0.10 -0.97	0.018-0.091
3	80	33	60	43	2.35- 5.60	0.23- 1.90	0.079-0.52	0.014-0.068
4	44	44	33	56	2.00-14.0	0.29- 6.20	0.050-0.525	0.018-0.088
5	43	35	70	55	3.25-52.5	0.27-11.2	0.405-6.40	0.024-0.155
6	71	20	86	29	0.68- 0.89	0.10- 0.48	0.039-0.79	0.010-0.043
7	29	29	71	47	2.60-16.0	0.54- 7.7	0.242-0.510	0.031-0.109
8	0	0	8	18	2.70-63.0	0.82-23.7	0.11 -1.70	0.029-0.331

autumn-winter period, indicating a subsurface component of dissolved or complexed iron. Ranges for winter occurrences in these three zones were relatively low compared to other zones but were still higher than would be accounted for by iron solubility under normal redox conditions of surface waters (Hem 1970), which suggests a significant complexing role by organic derivatives supplied from muskeg.

3.4.2 Aluminum

Frequency distributions for total aluminum levels in running waters by zones are shown in Figure 45. Levels generally clustered around 0.1 ppm throughout the region except for relatively clear water in Zone 6 (the Firebag and Richardson basins) where the levels were much lower. Also, the majority of occurrences in the upper 25 percentile were in the spring-summer period (Table 31). All indications imply levels controlled by sedimentary aluminum provided by clays which is typical for aluminum (Hem 1970).

3.4.3 Manganese

Frequency distributions for total manganese levels by zones are shown in Figure 46. The majority of occurrences were noncompliant (greater than 0.05 ppm) with the water quality criteria (see Table 9). Levels generally centred about 0.1 ppm (except for Zones 4 and 6) in a pattern strikingly similar to iron (Figure 44). The upper 25 percentile occurrences for manganese were also seasonally similar (Table 31) but then also showed substantial autumn and winter contributions in Zones 5 and 7.

Occurrences of the highest levels of total manganese (above 1 ppm) also indicate substantial autumn-winter contributions, especially in Zone 5, where they invariably occurred in the autumn-winter period (Table 32). Dissolved organic compounds (see Figure 34 for Calumut River and Unnamed Creek) thus appear to complex with manganese to maintain levels above what would be expected by solubility in oxygenated alkaline water (Hem 1970). Groundwater discharge (see Loeppky and

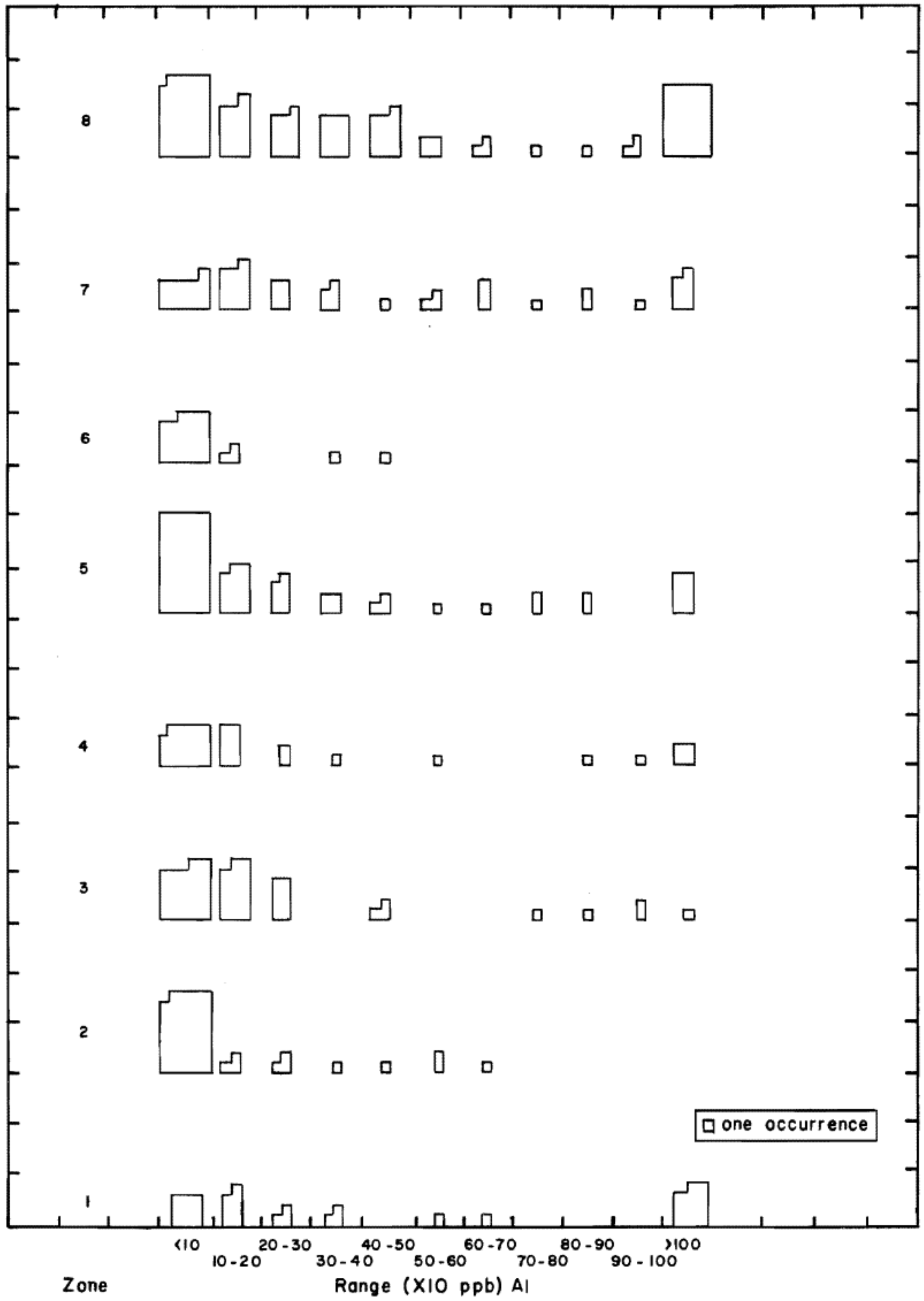

Figure 45. Frequency distribution for total aluminum in rivers and tributaries by zones from 1976 and 1977 data.

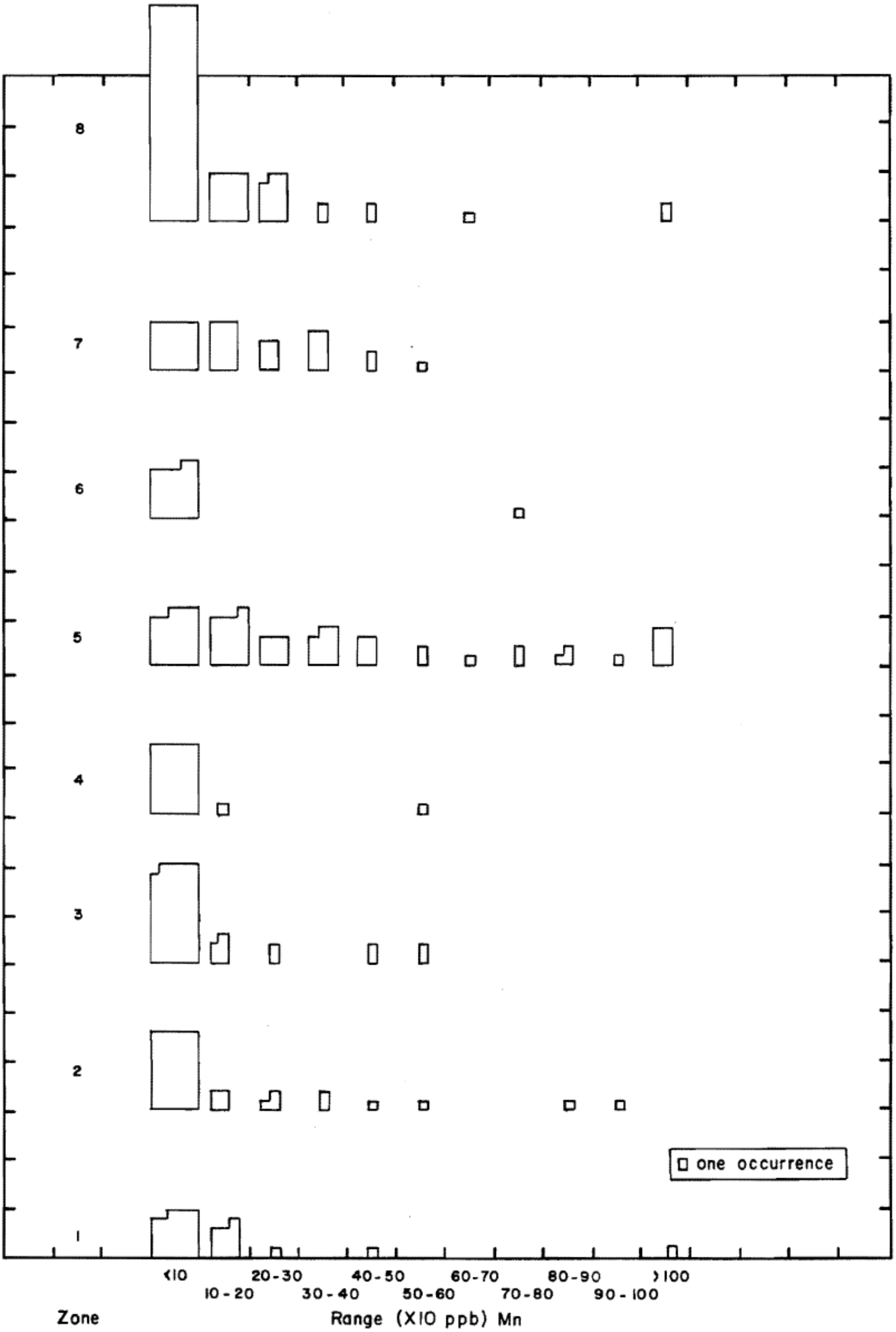

Figure 46. Frequency distribution for total manganese in rivers and tributaries by zones from 1976 and 1977 data.

Table 32. Occurrences of levels of total manganese greater than 1.0 ppm in 1976 and 1977 in rivers and streams.

Level (ppm)	Site Code		Date
6.4	DA0150	Lower Tar River	01-04-77
4.7	DA0150	Lower Tar River	09-02-77
3.5	DA0150	Lower Tar River	02-03-77
2.0	DA0121	Eymundson Creek	02-12-76
1.82	DA0121	Eymundson Creek	02-03-77
1.7	DA0200	Athabasca River	30-08-77
1.7	DA0205	Athabasca River	30-08-77
1.65	DA0140	Calumet River	09-02-77
1.65	DA0140	Calumet River	02-03-77
1.4	CD0040	Hangingstone River	29-08-76
1.17	DA0121	Eymundson Creek	15-11-77
1.0	DA0110	Unnamed Creek	11-02-76

Spitzer 1977 for evidence of substantial groundwater input into Unnamed Creek) may be responsible for the initial supply of manganese in this region. The high levels measured in the Athabasca and Hangingstone rivers relate better to particulate loadings.

3.4.4 Zinc

Frequency distributions for total zinc levels by zones are shown in Figure 47. Noncompliance with water quality criteria (greater than 0.03 ppm) ranged from 0 to 50% for the tributaries and typically ran about 30% for the mainstem (see Table 9). Asphalt Creek, with its enduring turbidity (Figures 25 and 33), showed the highest noncompliance at 50%. Levels centred about 0.01 ppm for the region and appeared to follow the same general pattern throughout. No marked differences between zones in ranges of the upper 25 percentile were detected (Table 31). Also, the seasonal occurrences of high levels were similar for all zones, except Zone 1, where the spring-summer predominates. Thus, it appears that undissolved and dissolved contributions are similary important to the total regime in all zones, except Zone 1, where high values appear to be related only to particulate loadings.

3.4.5 Copper

Frequency distributions for total copper levels by zones are shown in Figure 48. Noncompliance with water quality criteria (greater than 0.005 ppm) typically ranged from 30 to 60% throughout the entire region (see Table 9). The majority of occurrences were below 0.01 ppm, with generally higher levels prevailing in the mainstem (Zone 8) and in the Birch Mountain tributaries (Zone 5), although striking differences among zones were not evident.

Occurrences of the highest levels of total copper (above 40 ppb) are shown in Table 33, where the prevalence of high values (in the Athabasca River) can be noted. Very high values occurred during winter conditions, corresponding to dissolved loading, but a number of high values also occurred in the summer period, corresponding to particulate loadings. The solubility of hydroxy-carbonate mineralized copper in aerated water has been indicated to have a limit in the range from

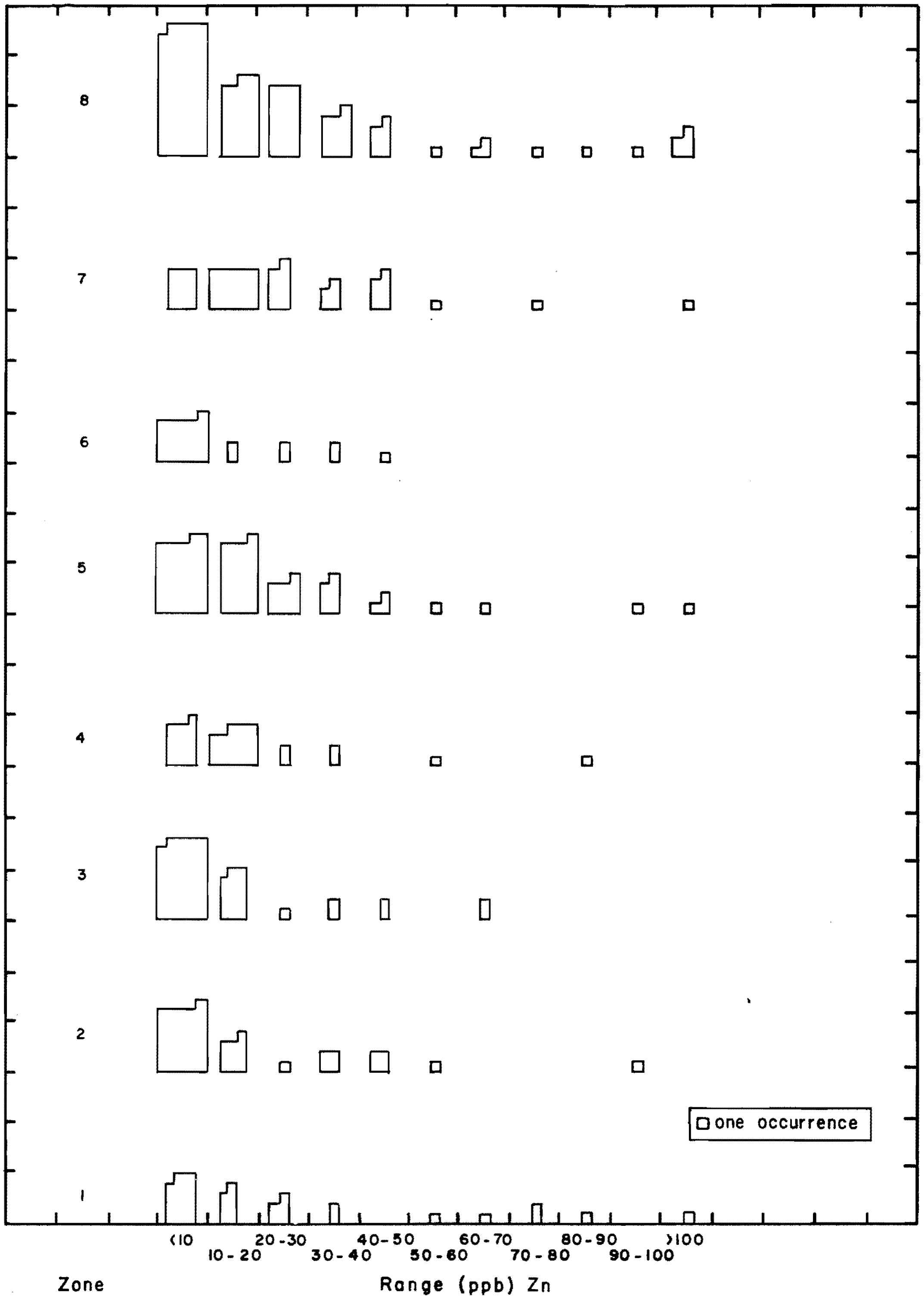

Figure 47. Frequency distribution for total zinc in rivers and tributaries by zones from 1976 and 1977 data.

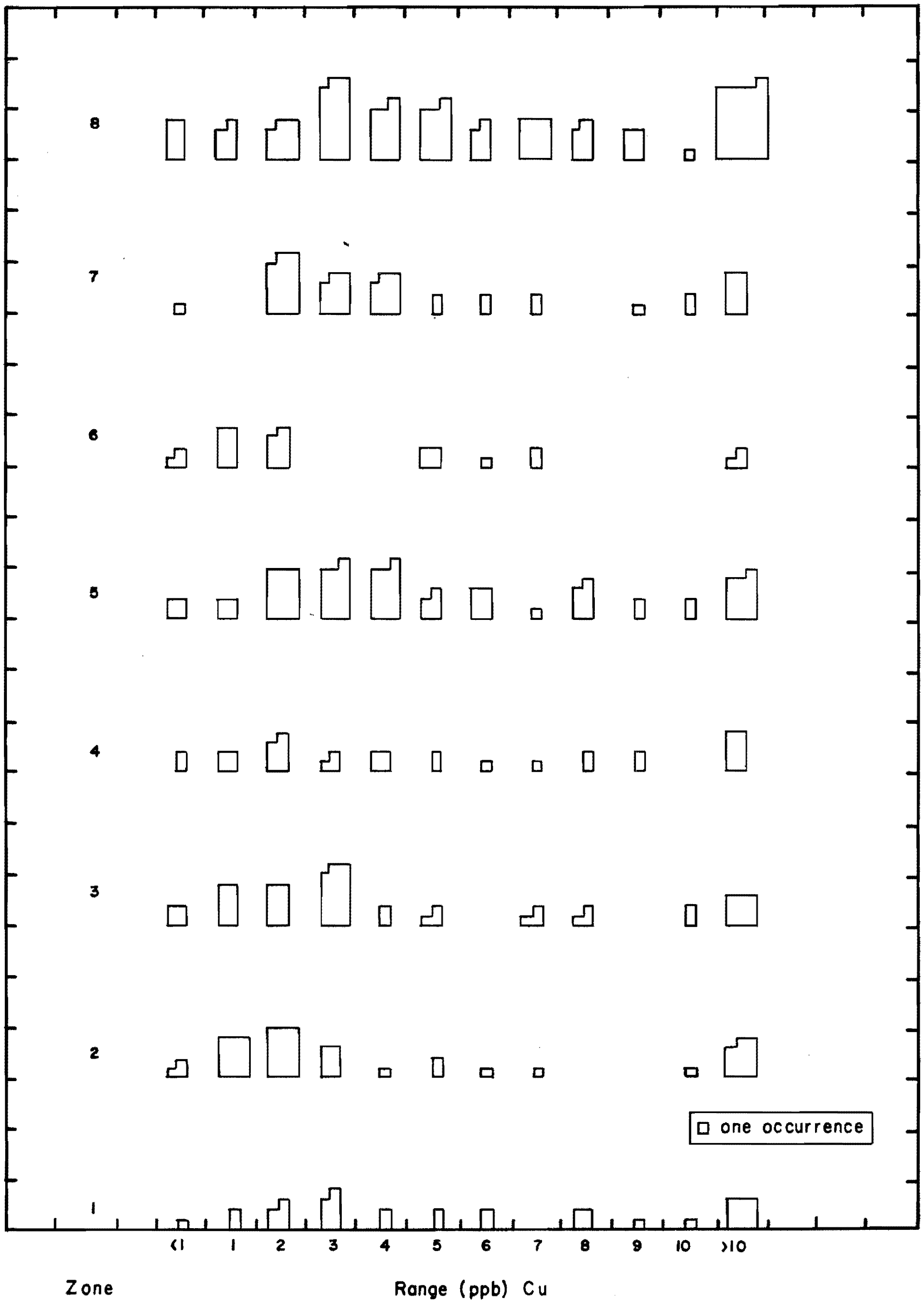

Figure 48. Frequency distribution for total copper in rivers and tributaries by zones from 1976 and 1977 data.

Table 33. Occurrences of levels of total copper greater than 0.04 ppm in 1976 and 1977 in rivers and tributaries.

Level (ppm)	Site Code		Date
0.180	DB0011	MacKay River	10-01-77
0.114	DA0150	Lower Tar River	02-03-77
0.093	DA0205	Athabasca River	25-02-77
0.077	DA0208	Athabasca River	11-12-76
0.059	DA0200	Athabasca River	30-08-76
0.059	DA0205	Athabasca River	30-08-76
0.053	DA0200	Athabasca River	28-07-76
0.049	DA0201	Athabasca River	26-02-77
0.048	CD0040	Hangingstone River	29-08-76
0.046	DA0206	Athabasca River	27-07-76
0.045	DA0213	Athabasca River	25-02-77

0.064 ppm at pH 7.0 to 0.0064 ppm at pH 8.0 (Hem 1970). Thus, solubility enhancement by organic ligands or other complexing agents appears to be operating during winter conditions for these high values.

3.4.6 Nickel

Frequency distributions for total nickel by zones are shown in Figure 49. Sporadic noncompliance with the water quality criteria (greater than 0.025 ppm) occurred in some tributaries and in the mainstem river (Table 9). The regimes in most zones were less than 10 ppb, with the exceptions of Zones 5 and 8, where substantial occurrences above 10 ppm can be noted which is remarkably similar to the pattern of the total copper occurrences.

Occurrences of the highest levels of total nickel (greater than 30 ppb) are shown in Table 34. It can be noted that these high occurrences in the mainstem (Zone 8) prevailed during the spring-summer season, whereas occurrences in the Birch Mountain tributaries prevailed during autumn-winter conditions. Nickel is one of the elements present in substantial amounts in oil sands (Table 16) and, thus, oil sands weathering or leaching may be implicated as a nickel source in Zone 5. The high occurrence at Beaver River inside Syncrude was almost certainly a result of discharge of mine depressurization water pumped out from beneath the McMurray formation.

3.4.7 Lead

Frequency distributions for total levels by zones are shown in Figure 50. Only sporadic noncompliance (greater than 0.030 ppm) was noted in some tributaries and the mainstem river system (Table 9). The majority of occurrences were below 2 ppb, a similar pattern throughout the region, with the exception of very low regimes in Zones 2, 4, and 6.

Occurrences of the highest levels of total lead (greater than 30 ppb) are shown in Table 35. The majority of high values occurred in the autumn-winter category. As the question of contamination from paint on the ice auger was raised in the midst of the project and steps were taken in the summer of 1977 to eliminate the possibility of contamination, future data will be necessary to tell if these high values are authentic.

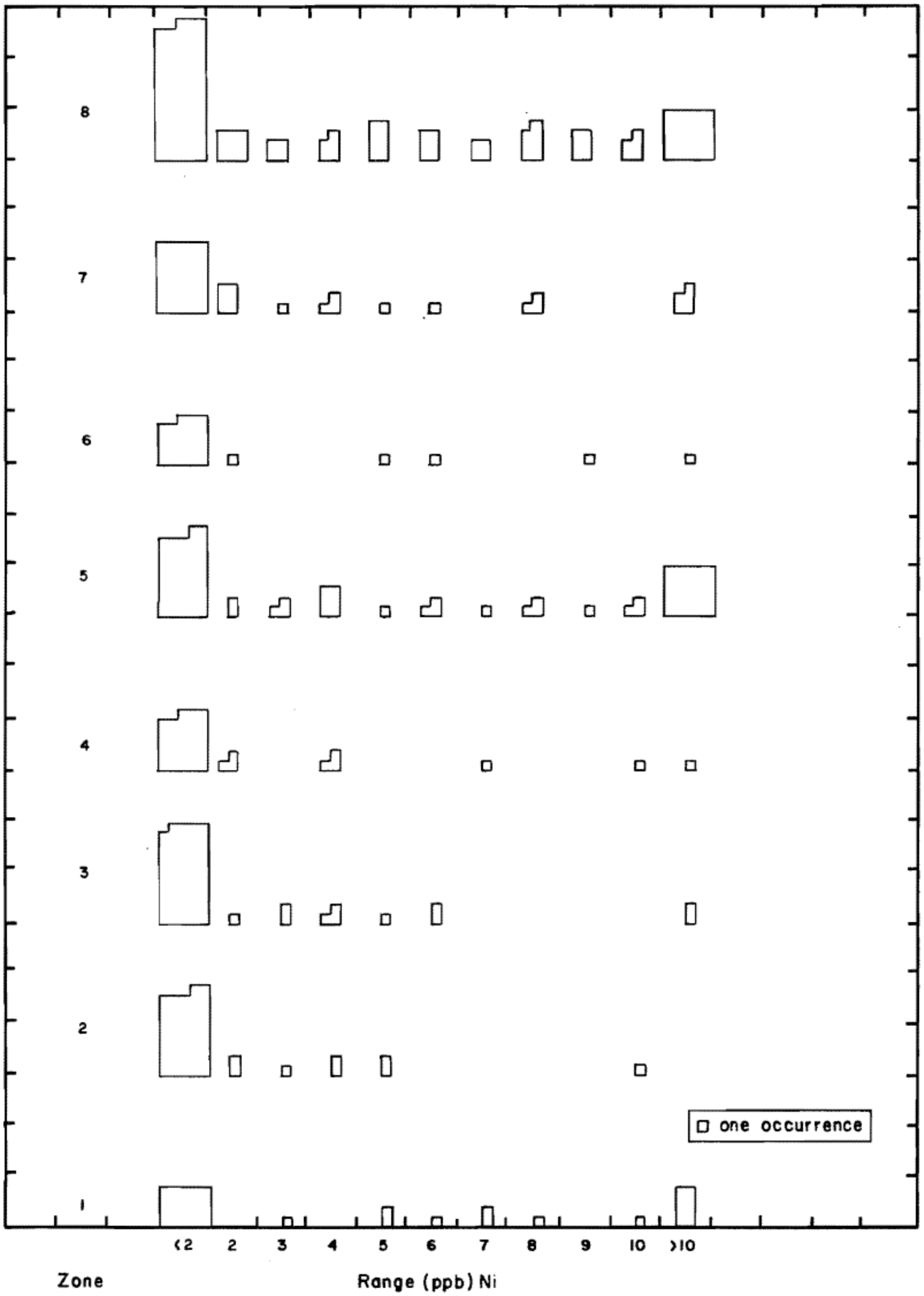

Figure 49. Frequency distribution for total nickel in rivers and tributaries by zones from 1976 and 1977 data.

Table 34. Occurrences of levels of total nickel greater than 0.03 ppm in 1976 and 1977 in rivers and tirbutaries.

Level (ppm)	Site Code		Date
0.130	DA0206	Athabasca River	27-07-76
0.080	DA0200	Athabasca River	09-08-76
0.072	CD0040	Hangingstone River	29-08-76
0.071	DA0200	Athabasca River	30-08-76
0.071	DA0205	Athabasca River	28-08-76
0.058	DA0122	Eymundson Creek (mouth)	09-11-76
0.051	DA0173	Beaver River inside Syncrude	19-10-76
0.046	DA0120	Asphalt Creek	09-10-76
0.046	DA0121	Eymundson Creek	02-03-77
0.044	DA0121	Eymundson Creek	02-12-76
0.042	CD2300	Clearwater River	28-08-76
0.034	CD0040	Hangingstone River	24-02-77
0.032	DA0121	Eymundson Creek	13-05-76

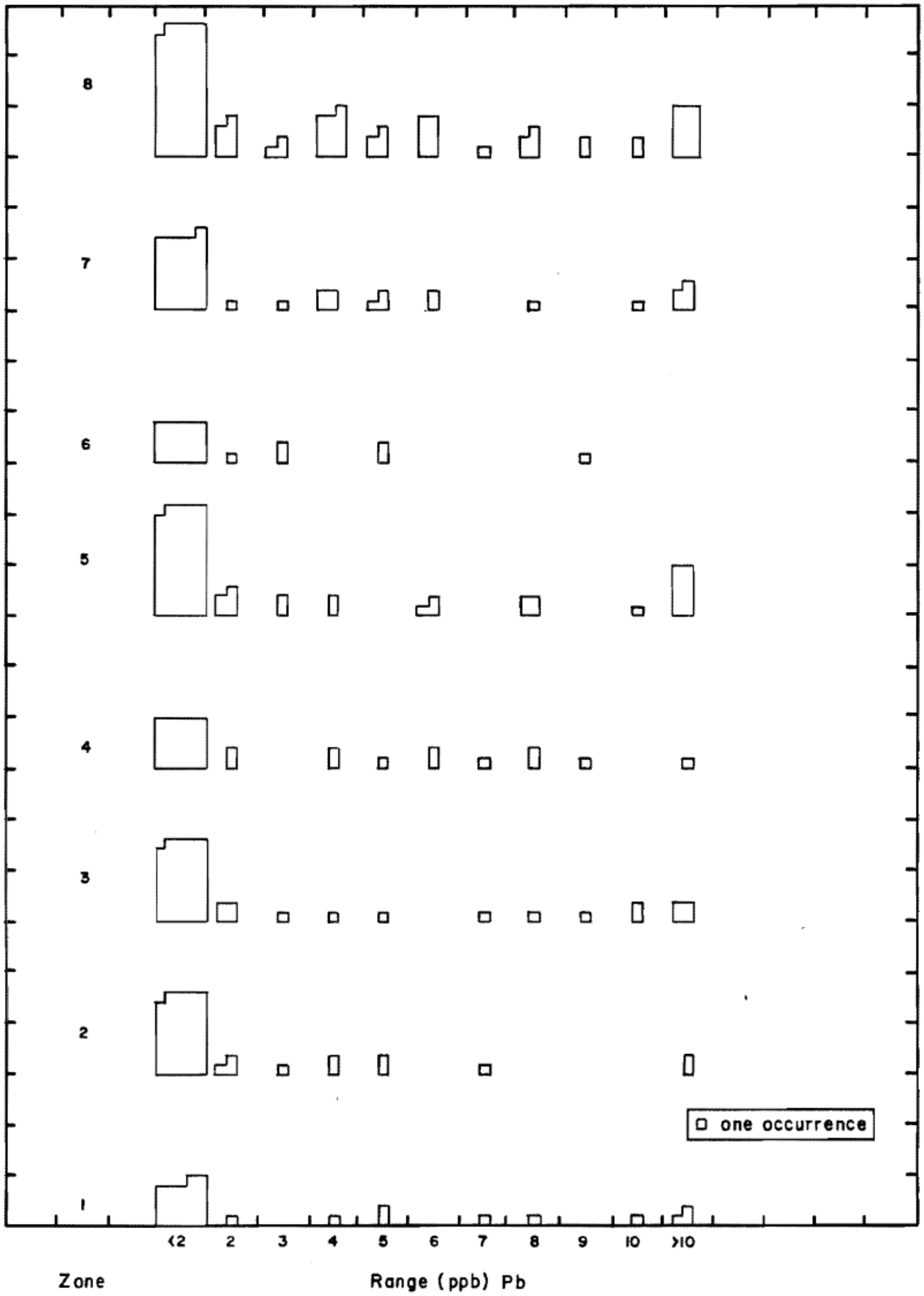

Figure 50. Frequency distribution for total lead in rivers and tributaries by zones from 1976 and 1977 data.

Table 35. Occurrences of levels total lead greater than 0.03 ppm in 1976 and 1977 in rivers and tributaries.

Level (ppm)	Site Code		Date
0.175	DA0070	Poplar Creek	27-04-77
0.052	CD0040	Hangingstone River	24-02-77
0.049	DA0131	Pierre River (mouth)	12-08-76
0.048	DA0204	Athabasca River	26-02-77
0.048	DA0111	Unnamed Creek (mouth)	09-10-76
0.048	DB0011	MacKay River	25-02-77
0.042	DA0209	Athabasca River	25-02-77
0.040	DA0210	Athabasca River	25-02-77
0.038	DA0150	Lower Tar River	09-10-76
0.036	CD2300	Clearwater River	26-02-77
0.035	DA0120	Asphalt Creek	09-10-76
0.035	DA0110	Unnamed Creek	12-08-76
0.033	DA0121	Eymundson Creek	02-03-77

3.4.8 Chromium

Frequency distributions for hexavalent chromium are shown in Figure 51. The number of noncompliant (greater than 0.050 ppm) values were minimal with such occurrences predominating in Zones 1, 5, 7, and 8.

Occurrences of the highest levels of hexavalent chromium (above 20 ppb) are shown in Table 36. There was a preponderance of high values in Zone 7 where current surface mining activity is being conducted. These particular occurrences showed no seasonal preferences even though high occurrences in other zones showed a definite trend to fall in the spring-summer season. Thus, industrial or related activity appears to be associated with these sporadic occurrences.

3.4.9 Cobalt

Frequency distributions for total cobalt levels by zones are shown in Figure 52. There were very few occurrences above 2 ppb, with Zones 1, 5, 7, and 8 accounting for just about all high occurrences.

Occurrences of the highest levels of total cobalt (above 10 ppb) are shown in Table 37. Every occurrence happened in the spring-summer period with the exception of one winter value in a Birch Mountain tributary (Zone 5) which implicates particulate loading with these high values.

3.4.10 Silver

Frequency distributions for total silver levels by zones are shown in Figure 53. Noncompliance with water quality criteria (greater than 0.05 ppm) did not occur at any site. The low number of occurrences above 1 ppb is notable and the silver regime is remarkably similar to that of cobalt, albeit at a lower level.

Occurrences of the highest levels of total silver (greater than 5 ppm) are shown in Table 38. Occurrences in the tributaries of Zones 5 and 7 fell mostly in the spring-summer period, corresponding to an erosional supply for the high silver levels. However, the high levels in the mainstem occurred during autumn-winter, which would correspond to either groundwater loading or a release from sediments

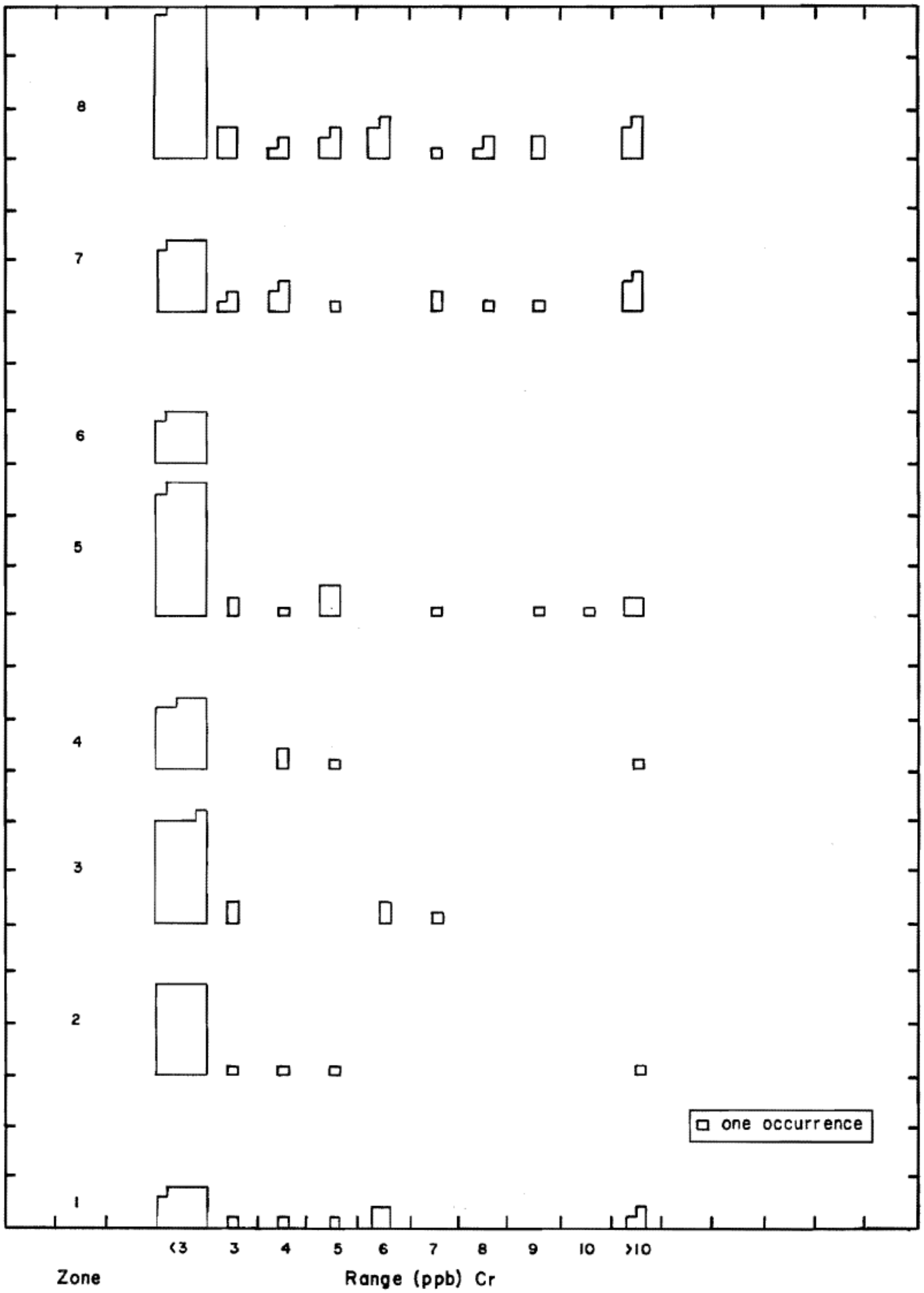

Figure 51. Frequency distribution for total hexavalent chromium in rivers and tributaries by zones from 1976 and 1977 data.

Table 36. Occurrences of levels of hexavalent chromium greater than 0.02 ppm in 1976 and 1977 in rivers and tributaries.

Level (ppm)	Site Code		Date
0.205	DA0181	Beaver River (Hwy 63)	18-12-77
0.177	DA0182	Bridge Creek Diversion (Hwy 63)	18-12-77
0.13	DA0210	Athabasca River	30-07-76
0.086	DA0206	Athabasca River	27-07-76
0.075	DA0070	Poplar Creek	27-04-77
0.075	DA0070	Poplar Creek	18-05-77
0.065	DA0070	Poplar Creek	14-10-77
0.033	DA0131	Pierre River (mouth)	12-08-76
0.032	DA0010	Athabasca River	07-06-77
0.031	DA0120	Asphalt Creek	28-04-77

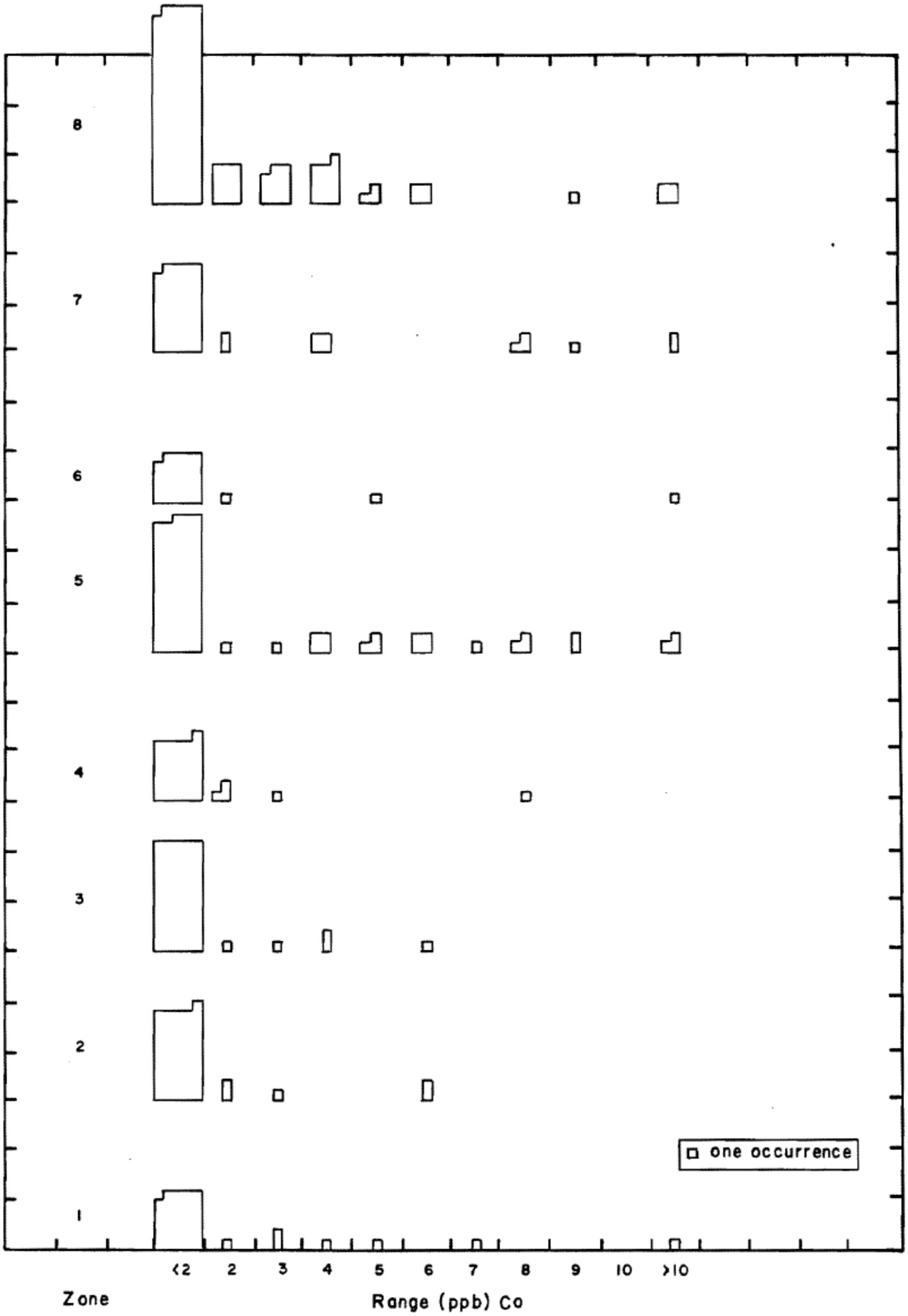

Figure 52. Frequency distribution for total cobalt in rivers and tributaries by zones from 1976 and 1977 data.

Table 37. Occurrences of total cobalt greater than 0.01 ppm in 1976 and 1977 in rivers and tributaries.

Level (ppm)	Site Code		Date
0.043	DA0205	Athabasca River	30-08-76
0.043	DA0200	Athabasca River	30-08-76
0.035	DA0206	Athabasca River	27-07-76
0.033	CD0040	Hangingstone River	29-08-76
0.031	DA0070	Poplar Creek	27-04-77
0.028	DA0120	Asphalt Creek	28-04-77
0.019	CD2300	Clearwater River	28-08-76
0.014	DA0121	Eymundson Creek	02-03-77
0.011	DA0121	Eymundson Creek	13-05-76
0.011	DA0181	Beaver River (Hwy 63)	11-08-76

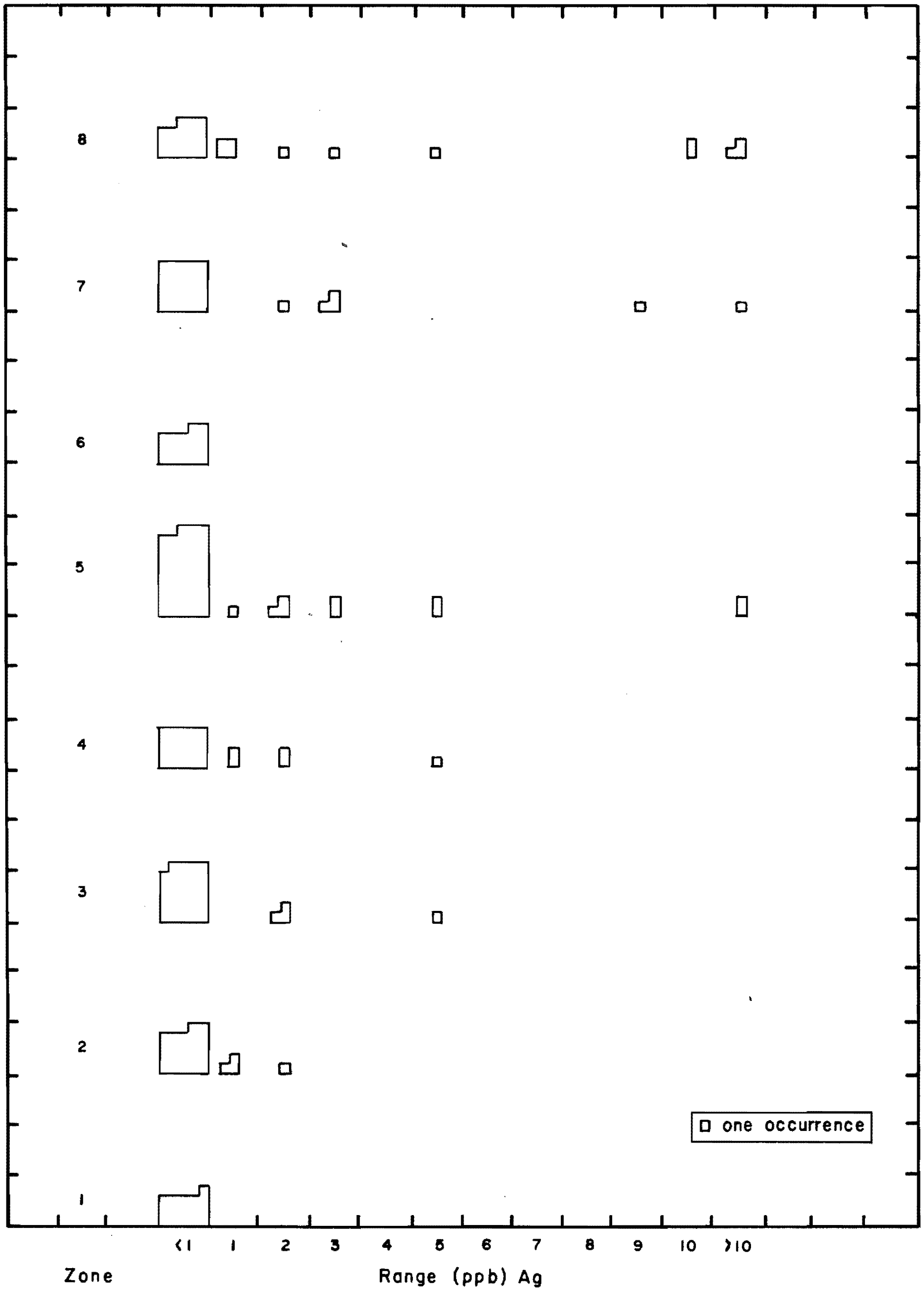

Figure 53. Frequency distribution for total silver in rivers and tributaries by zones from 1976 and 1977 data.

Table 38. Occurrences of levels of total silver greater than 0.005 ppm in 1976 and 1977 in rivers and tributaries.

Level (ppm)	Site Code		Date
0.070	DA0150	Lower Tar River	16-08-77
0.028	DA0070	Poplar Creek	27-04-77
0.015	DA0131	Pierre River (mouth)	12-08-76
0.015	DA0204	Athabasca River	25-02-77
0.015	DA0208	Athabasca River	26-02-77
0.013	CD2300	Clearwater River	15-12-77
0.010	DA0210	Athabasca River	25-02-77
0.010	DA0205	Athabasca River	25-02-77
0.009	DA0180	Beaver River above Syncrude	07-11-77

of what was previously made available as bound silver. The occurrence of high silver levels in Beaver River above Syncrude suggests that occurrences in lower reaches (now Poplar Creek) may not be due to mine depressurization water available through the Beaver River diversion.

3.4.11 Vanadium

Frequency distributions for total vanadium by zones are shown in Figure 54. A very low regime is noticeable and scattered occurrences above 3 ppb are mostly in Zones 1, 4, 5, 7, and 8.

Occurrences of the highest levels of total vanadium (greater than 3 ppb) are shown in Table 39. Most occurrences fell during the spring-summer period indicating association with particulate loading. A sediment-vanadium link has been suggested by Jackson and Allan (1978), where levels of vanadium have been correlated with fine sediments in the mainstem Athabasca River system. However, some autumn-winter values were also evident at scattered locations.

3.4.12 Cadmium

Frequency distributions for total cadmium by zones are shown in Figure 55. Sporadic occasions of noncompliance with water quality criteria (greater than 0.003 ppm) were noted in some of the tributaries (see Table 9). The cadmium regimes of only sporadic points above 2 ppb were very similar throughout the region. However, the area of current surface mining activity showed the highest range.

Occurrences of the highest levels of total cadmium (above 2 ppb) are shown in Table 40. The occurrences are scattered throughout the seasons as well as representing many zones. All high cadmium occurrences in Zone 7 cannot be blamed on surface mining effluent because one high occurrence in Beaver River was above Syncrude, but it is noted that Poplar Creek showed sporadic high values after receiving diverted water (Figure 4).

3.4.13 Arsenic

Frequency distributions for arsenic levels by zones are shown in Figure 56. Only three occasions of noncompliance with water quality

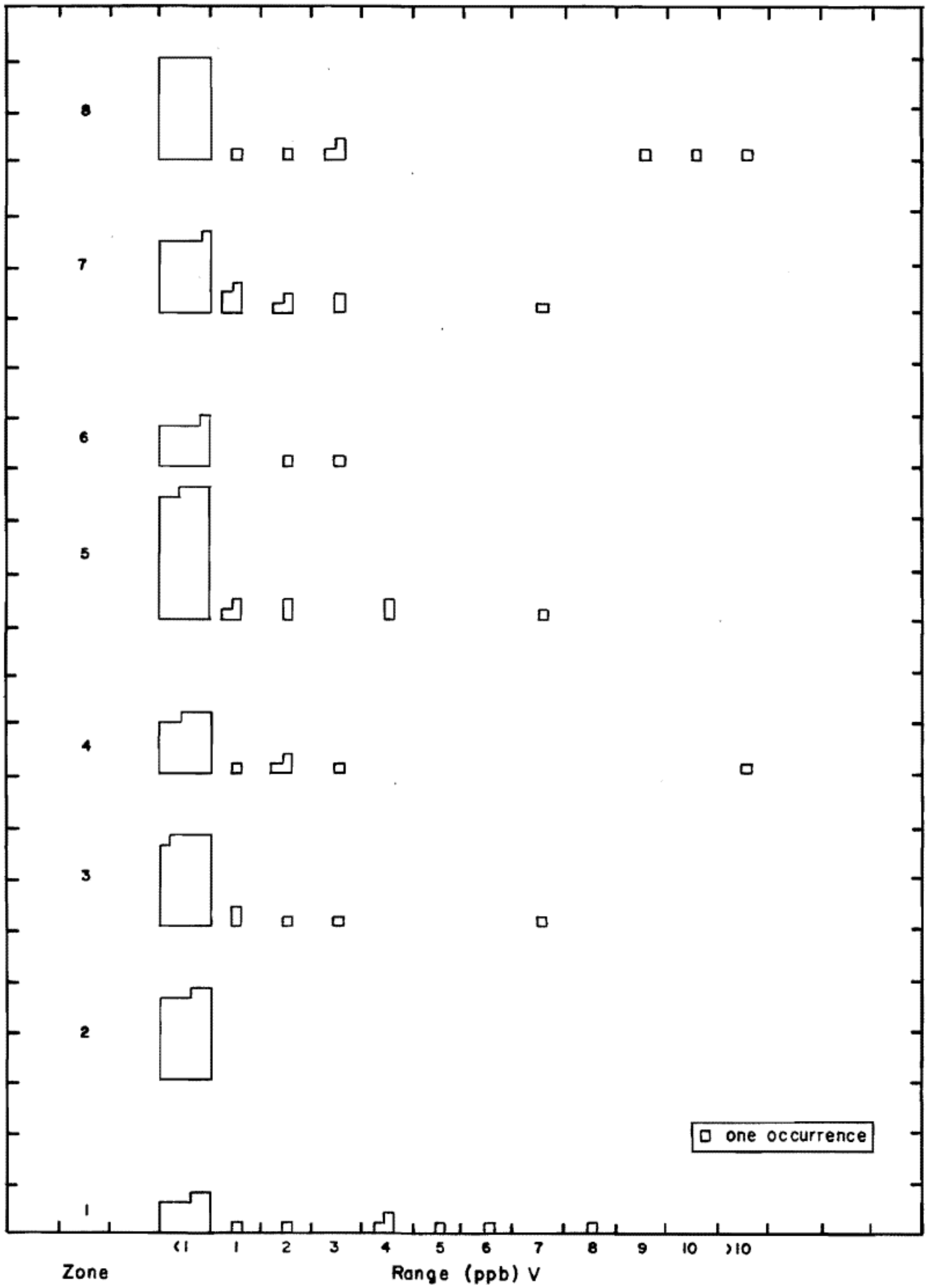

Figure 54. Frequency distribution for total vanadium in rivers and tributaries by zones from 1976 and 1977 data.

Table 39. Occurrences of levels of total vanadium greater than 0.003 ppm in 1976 and 1977 in rivers and streams.

Level (ppm)	Site Code		Date
0.013	DA0160	Joslyn Creek	18-05-77
0.011	DA0204	Athabasca River	22-01-77
0.010	DA0204	Athabasca River	26-02-77
0.009	DA0211	Athabasca River	31-05-77
0.008	CD0040	Hangingstone River	28-07-77
0.007	DA0182	Bridge Creek Diversion	27-04-77
0.007	DA0150	Lower Tar River	01-04-77
0.007	DB0011	MacKay River	19-05-77
0.006	CD0100	Saline Creek	27-04-77
0.005	CD0040	Hangingstone River	11-03-77
0.004	CD0040	Hangingstone River	27-04-77
0.004	CD0040	Hangingstone River	18-05-77
0.004	CD0100	Saline Creek	16-05-76
0.004	DA0120	Asphalt Creek	28-04-77
0.004	DA0150	Lower Tar River	08-02-77

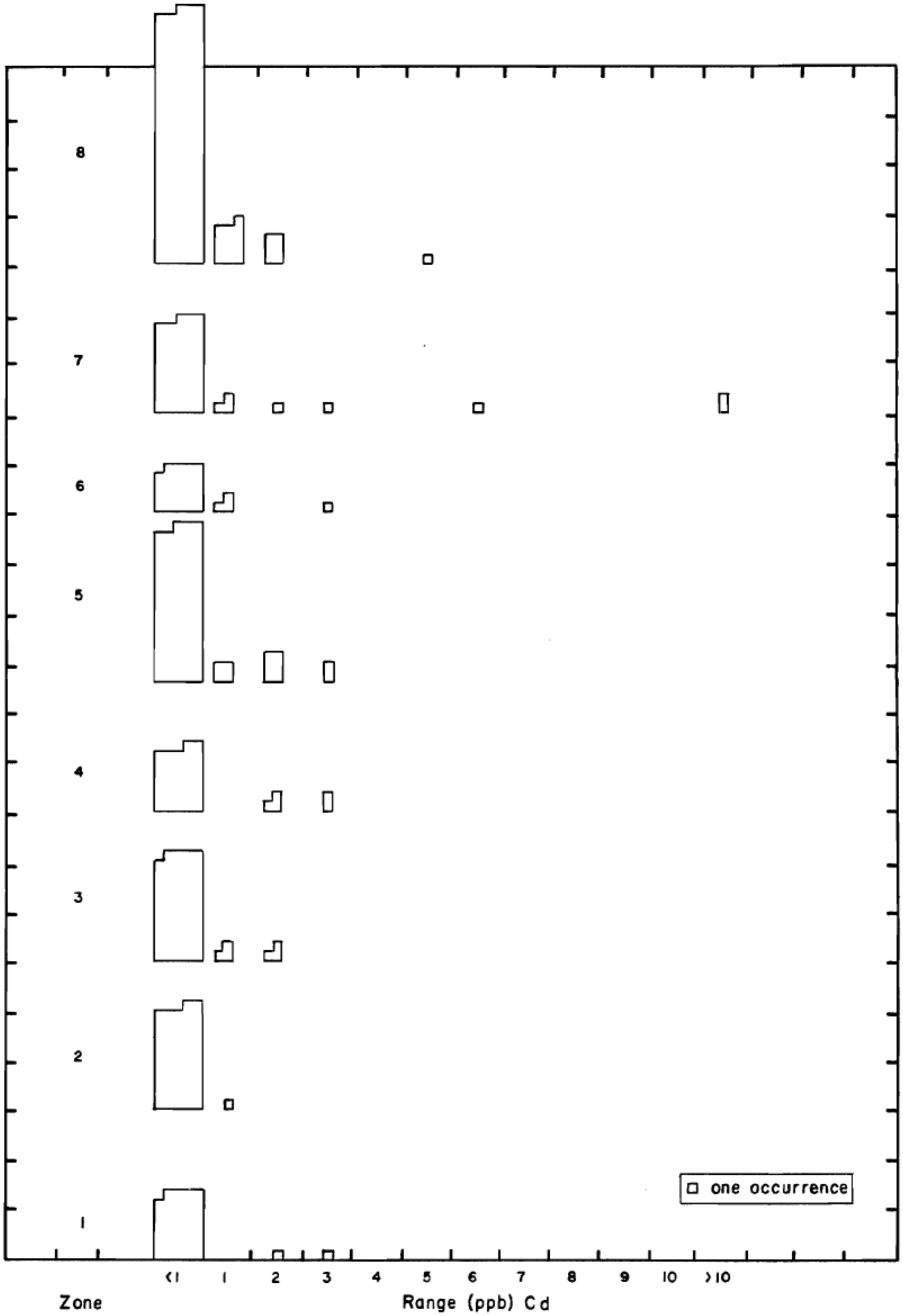

Figure 55. Frequency distribution for total cadmium in rivers and tributaries by zones from 1976 and 1977 data.

Table 40. Occurrences of levels of total cadmium greater than 0.002 ppm in 1976 and 1977 in rivers and tributaries.

Level (ppm)	Site Code		Date
0.016	DA0070	Poplar Creek	27-04-77
0.016	DA0070	Poplar Creek	18-05-77
0.006	DA0180	Beaver River Above Syncrude	07-11-77
0.005	CD2300	Clearwater River	10-12-76
0.003	CD0040	Hangingstone River	24-02-77
0.003	DA0170	Lower Ells River	18-05-77
0.003	DA0160	Joslyn Creek	09-11-76
0.003	DA0130	Pierre River (mouth)	12-08-76
0.003	DA0111	Tributary to Unnamed Creek	09-10-76
0.003	DC0010	Firebag River	15-08-77
0.003	DA0070	Poplar Creek	18-11-77

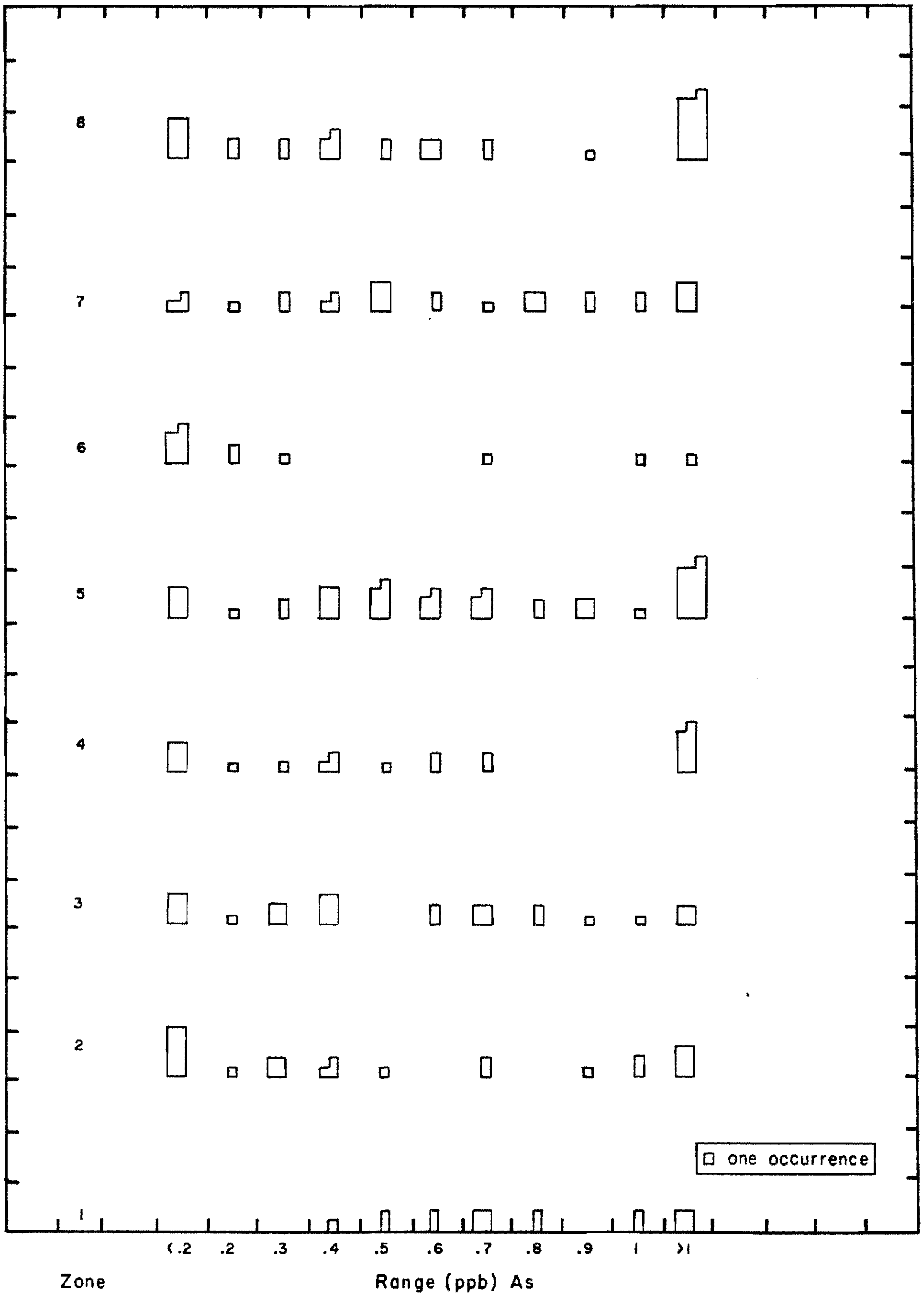

Figure 56. Frequency distribution for total arsenic in rivers and tributaries by zones from 1976 and 1977 data.

criteria (greater than 0.010 ppm) were observed (Lower Tar River and Athabasca River). Levels centred around 0.001 ppm in a similar pattern amongst the zones, except for Zone 1 (south of Fort McMurray), which tended toward high values, and Zone 6 (the Firebag and Richardson rivers), which tended toward low values.

Occurrences of the highest levels of arsenic (above 0.005 ppm), shown in Table 41, indicate that practically all high occurrences happen in the autumn-winter period. Groundwater is a typical source of arsenate (Hem 1970), corresponding to base flow occurrences. However, high occurrences in the Athabasca River are notable in the spring-summer period. Thus, much of the arsenate supplied to the mainstem may co-precipitate with metals such as iron (Hem 1970) into the sediments in the mainstem, which would explain detection of high levels during times of high turbidity.

3.4.14 Selenium

Frequency distributions for selenium levels by zone are shown in Figure 57. Noncompliance with water quality criteria (greater than or equal to 0.010 ppm) only occurred one time, at the Clearwater River site. Levels were generally below 0.001 ppm, with Zones 4 (Ells River basin) and 6 (Firebag and Richardson rivers) displaying relatively low regimes and Zones 2 (Muskeg and Steepbank rivers) and 8 (mainstem) displaying relatively high regimes.

Occurrences of the highest levels of selenium (greater than 0.0008 ppm; Table 42) show a preponderance of high levels during the autumn-winter period. The high occurrences within Zone 7 are likely due to mine depressurization water. The occurrence at Beaver River (Hwy 63) was out of step with seasonal trends, thus indicating anthropogenic influence, and the high occurrence in the sample from Beaver River within Syncrude corresponds in timing to influence of mine depressurization water (see Section 4.2.3).

Table 41. Occurrences of levels of total arsenic greater than 0.005 ppb in 1976 and 1977 in rivers and tributaries.

Level (ppb)	Site Code		Date
20	DA0080	Muskeg River	16-12-76
17.3	DA0150	Lower Tar River	10-05-77
15	DA0205	Athabasca River	30-08-76
12	DA0080	Muskeg River	29-10-76
10	DA0203	Athabasca River	02-09-76
10	DA0203	Athabasca River	28-09-76
9	DA0170	Lower Ells River	10-11-78
8	DA0205	Athabasca River	28-09-76
7	DB0011	MacKay River	21-12-76
7	DB0020	Dover River	04-01-77
7	DA0150	Lower Tar River	08-02-77
6	DA0204	Athabasca River	26-02-77
6	DA0140	Calumet River	02-03-77

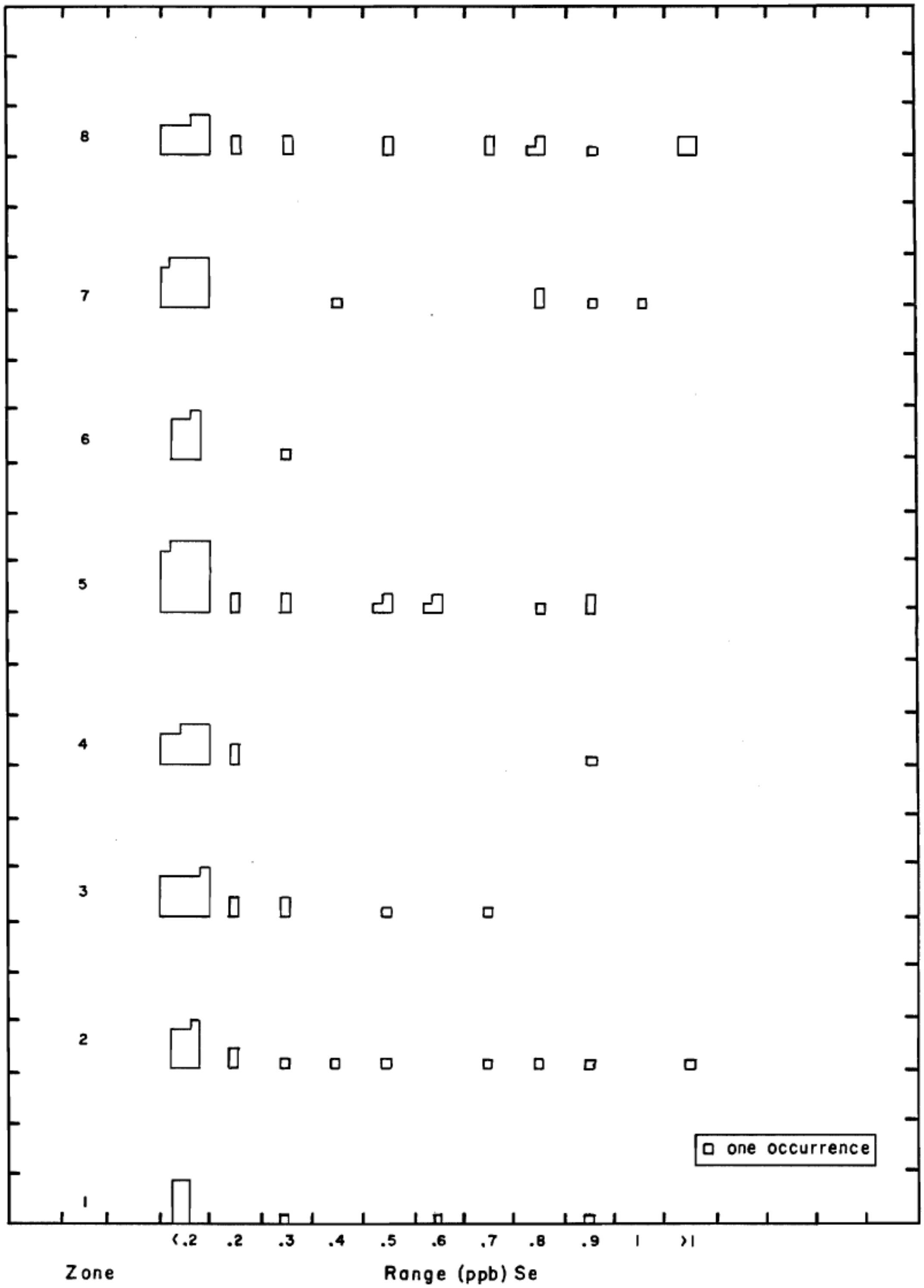

Figure 57. Frequency distribution for total selenium in rivers and tributaries by zones from 1976 and 1977 data.

Table 42. Occurrences of levels of total selenium greater than 0.8 ppb in 1976 and 1977 in rivers and tributaries.

Level (ppb)	Site Code		Date
35.0	CD2300	Clearwater River	21-11-76
6.0	DA0205	Athabasca River	11-12-76
4.0	CD2300	Clearwater River	15-12-77
3.4	DA0206	Athabasca River	19-12-77
1.4	DA0060	Steepbank River	04-01-77
1.0	DA0181	Beaver River (Hwy 63)	18-05-77
0.9	DA0060	Muskeg River	25-01-77
0.9	DA0100	Upper Ells River	09-11-76
0.9	DA0130	Pierre River	08-11-76
0.9	DA0150	Lower Tar River	01-04-77
0.9	DA0179	Beaver River inside Syncrude	18-11-76
0.9	DA0210	Athabasca River	02-10-76

3.4.15 Mercury

Frequency distributions for total mercury levels by zones are shown in Figure 58. Noncompliance with water quality criteria (greater than 0.0001 ppm) was evident on occasion at most sites (Table 9). Levels were typically below 0.0001 ppm, with most of the high levels occurring in the mainstem (Zone 8), the region of current surface mining activity (Zone 7), and the Birch Mountain tributary streams (Zone 5).

Occurrences of the highest levels of mercury (greater than 0.001 ppm) are shown in Table 43. A large number of occurrences are notable in the period 24 February to 2 March 1977 which raises a question of contamination for these data. Even by ignoring these data, winter occurrences predominate for these high levels, suggesting either strong groundwater contribution or mobilization of erosionally supplied mercury. One sampling of Beaver River inside Syncrude, which carries mine depressurization water, provided a high occurrence of mercury.

3.5 SUMMARY OF INTERPARAMETER RELATIONSHIPS

3.5.1 Major Ions

Definite relationships of discharge with filterable residue fixed were demonstrated for most of the tributaries in the region. The relationship at each site, attributable to the geology and physiography of the basins, ranged in character from the highly variable hard waters of the MacKay and Hangingstone rivers to the relatively stable soft waters of the Firebag and Richardson rivers emanating from the Precambrian Shield. Proportional variation of the ionic components at most sites tended to show the regular pattern of relatively elevated chlorides and/or sulphates at the higher levels of filterable residue fixed. Disruptions in these patterns could be discerned in the data set for Poplar Creek which had been subject to diversion influence.

In the stretch of the Athabasca River flowing through the oil sands development area, dilution behaviour typical of the tributaries was noted. Variations in either loading or dilution factors may be attributable either to mixing characteristics downstream of the

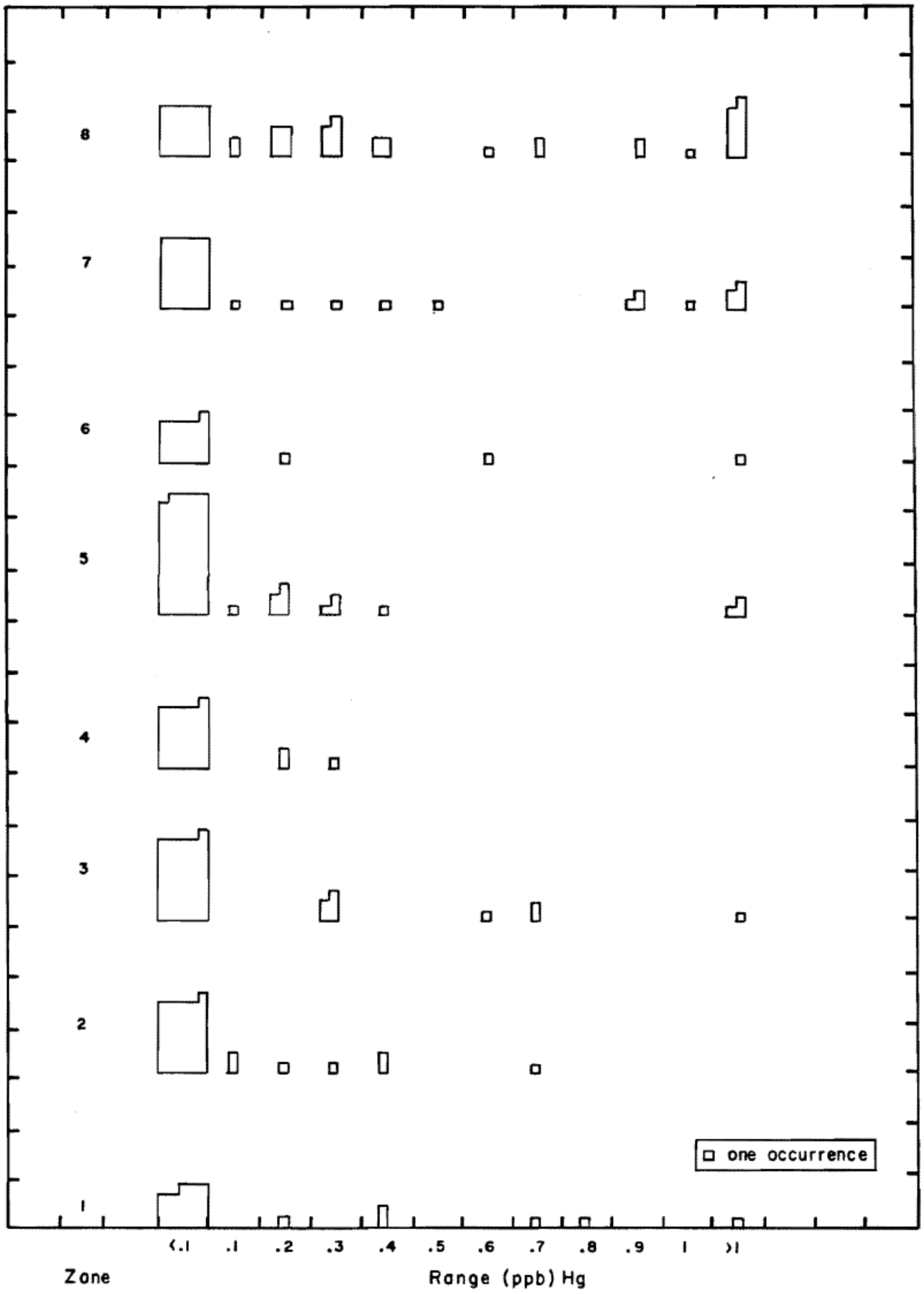

Figure 58. Frequency distribution for total mercury in rivers and tributaries by zones from 1976 and 1977 data.

Table 43. Occurrences of levels of total mercury greater than 1.0 ppb in 1976 and 1977 in rivers and tributaries.

Level (ppb)	Site Code		Date
60.0	CD2300	Clearwater River	09-02-76
48.0	DA0207	Athabasca River	19-09-77
6.4	DA0182	Bridge Creek Diversion	16-09-76
4.6	DA0140	Calumet River	09-02-77
4.4	DA0200	Athabasca River	08-09-76
4.2	DA0179	Beaver River inside Syncrude	18-11-76
2.7	DA0121	Eymundson Creek	02-03-77[a]
2.1	DB0011	MacKay River	25-02-77[a]
1.7	CD0040	Hangingstone River	24-02-77[a]
1.6	DA0070	Poplar Creek	24-02-77[a]
1.5	DA0208	Athabasca River	25-02-77[a]
1.4	CD2300	Clearwater River	26-02-77[a]
1.4	DA0210	Athabasca River	25-02-77[a]
1.3	DA0204	Athabasca River	12-12-76[a]
1.3	DA0209	Athabasca River	25-02-77[a]
1.3	DA0122	Eymundson Creek (mouth)	08-11/76
1.3	DC0010	Firebag River	09-10-76
1.2	DA0070	Poplar Creek	21-12-76
1.2	DA0204	Athabasca River	12-12-76
1.2	DA0204	Athabasca River	21-01-77
1.1	DA0070	Poplar Creek	18-11-76
1.1	DA0206	Athabasca River	19-12-77

[a] Possible contamination.

confluence of the Athabasca and Clearwater rivers or to interchange effects involving sediments north of Fort McMurray. Calculated loadings of the major ions, particularly the anions, displayed a complex behaviour north of Fort McMurray possibly reflecting groundwater discharge-recharge or adsorption-desorption phenomenon. Manmade inputs north of Fort McMurray were not detectable.

3.5.2 Suspended Solids

There was a high variation in the turbidity regimes of the tributaries throughout the area. The large tributaries varied, from the highly enduring turbidity of the Hangingstone River to the consistently clear Firebag River. The smaller tributaries showed a similar variation, the highest turbidity shown by Asphalt Creek and the lowest by Thickwood Creek. In most streams and rivers, there were at least brief episodes of high suspended solids as measured by both nonfilterable residue and nonfilterable residue fixed. Many smaller tributaries showed high duration of an organic component of the nonfilterable residue, likely caused by muskeg input. The above average suspended materials regimes of tributaries adjacent to oil sands activities were not above the range for the region.

3.5.3 Nutrients

Throughout the region, the maximum total dissolved organic carbon levels varied between 10 and 45 ppm. Occurrences of maxima typically corresponded to allochthonous inputs during spring and autumn, but anomalous behaviours were exhibited by a relatively constant regime in Poplar Creek and an irregular pattern in Bridge Creek Diversion which appear to be a consequence of development activities. Calumet River also was atypical in displaying pre-ice-out elevated levels which could possibly be caused by high loadings from groundwater discharge.

Maximum total phosphorus levels ranged from 0.1 to 0.5 ppm throughout the region. No single controlling factor was discernible from the data and tributaries affected by mining activity showed no significant departure from the regional pattern.

Maximum ammonia values ranged from 0.1 to 0.6 ppm, typically occurring in late summer and in mid-winter. Bridge Creek Diversion was somewhat different by displaying an early mid-winter maximum and Poplar Creek had an unusual, enduringly high, late summer-autumn regime.

Maximum total Kjeldahl nitrogen levels ranged randomly between 0.3 and 2.0 ppm. Total Kjeldahl nitrogen regimes, in tributaries impacted by oil sands activities, were not out of step with the undisturbed tributaries.

3.5.4 Trace Elements

The general order of dominance for each of the trace elements was concluded to be:

Fe>Al>Mn>Zn>Cu>Ni>Pb>Cr>Co>Ag>V>Cd>As>Se>Hg

Generally, the levels of most of the elements included particulate, ionic, and complexed forms and control of the levels appeared to be through natural geochemical processes. However, slightly higher occurrences of chromium, cadmium, and selenium were discerned in the region of current oil sands activity, which appears to reflect anthropogenic inputs. A larger data set would be necessary to confirm this.

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5. APPENDIX

5.1 REPORTING AND QUALITY CONTROL SECTION OF CONTRACT FOR ANALYTICAL SERVICES

5.1.1 Analytical Quality Control

(1) The Consultant will provide full documentation of its services, equipment, expertise, experience and fee schedule.

(2) The Consultant will demonstrate an acceptable internal quality control program and will submit documentation of it with monthly invoices to Environmental Protection Services. Such a program will include replicate analyses of at least one sample per twenty which will be reported to Environmental Protection Services. All costs of this program will be borne by the Consultant.

(3) The Consultant will participate in external quality control program administered by the Alberta Pollution Control Laboratory. It is anticipated that many other laboratories in Alberta including Syncrude Canada Ltd., and Great Canadian Oil Sands Ltd. will participate in the quality control program. All costs for this participation will be borne by the Consultant.

(4) CONSISTENCY OF ANALYTICAL DATA: An acceptable report will contain an ion balance (NAQUADAT method 00103 L) within the range 0.90 to 1.10. In the case of a smaller amount of sample being available for analysis an analytical report containing an ion balance within the range 0.85 to 1.15 will be acceptable if there is insufficient sample to recheck some of the ion analyses.

(5) PRECISION QUALITY CONTROL: From time to time agents of AOSERP may submit to the Consultant, without prior notification or identification as such, two or more samples of identical composition but differing in composition by a known factor established by volumetric dilution in the field. The Consultant will be informed of all results of duplicate analysis. If there occurs a deviation greater than 10% of the mean value on any particular analysis that results in a mean value greater than ten times the detection limit, the Consultant will make every effort

to discover the source of error and correct the situation. A consecutive occurrence of such unsatisfactory deviation in the same particular analysis may be cause of non-payment of that particular analysis on the duplicate run.

Furthermore, for those results that are less than ten times the detection limit (as for example, trace metal analysis), the company will demonstrate an improvement of its precision where such improvement is indicated as desirable and necessary to agents of AOSERP by the results of the duplicate analysis.

(6) ACCURACY QUALITY CONTROL: From time to time, agents of AOSERP may submit for analysis to two other laboratories (probably the Pollution Control Laboratory and Inland Waters Quality Laboratory in Calgary), water samples from the field identical to the water samples submitted to the Consultant for analysis. The results might indicate areas where an improvement in accuracy is desirable. The Consultant will respond to suggestions by striving to improve accuracy in the areas of concern.

From time to time, agents of AOSERP may prepare and submit for analysis to the Consultant without prior notification or identification as such, solutions or other materials of precise known composition or solutions or other materials to which precise amounts of chemicals have been added ("spiked" samples). The comparisons of the analytical results with the design concentrations will subsequently be made available to the Consultant. If these comparisons indicate areas where the Consultant should improve the accuracy of the analysis, the Consultant will endeavour to improve.

For persistent gross errors (deviations greater than 25% from a design concentration or from a valid mean) in a particular analysis as indicated by any quality control procedure, the Consultant will not be paid for that particular analysis until such time as the faulty analysis procedure is rectified as demonstrated by acceptable accuracy quality control analysis.

(7) DETECTION LIMITS: Payment for any analytical result that does not achieve the detection limits specified in Appendix 1 or as might be adjusted by negotiation with the Minister, will not be made.

5.1.2 Reporting

(1) Analytical data reports will be edited and forwarded to designated Alberta Environment personnel within fifteen working days of receipt of samples. The standard NAQUADAT form will be used for data reporting. Codes will be provided by agents of AOSERP. The Consultant may hold back data on individual samples if required for analytical verification.

(2) If the Consultant does not maintain a timely schedule of analysis and reports as set out in clause (1) of this part, the Consultant's invoices may be discounted by the Minister for each week or portion thereof elapsing after the due date, by an amount of 10% of the total payable under the invoices concerned.

(3) Results from quality control work will be reported on a monthly basis. These dated monthly reports will detail any areas of concern indicated by internal and/or external quality control programs. They will also specify how the Consultant is handling problems in these areas.

(4) Written interim progress reports are required at three-month intervals after commencement of work. The reports will contain a summary of the problems encountered in the receipt of samples and sample analysis, analytical methods and modifications thereof, a summary of the data collected, and an historical documentation from the start of contract of changes in analytical procedure and detection limits.

(5) Invoices will be sub-totalled according to the project number which is specified on the sample submission form to the Consultant.

5.2 DATA SUMMARIES FOR ALL SAMPLE SITES

STATION: CC0012 Athabasca River above Horse River
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	23.0	55.0	37.0
magnesium	6.8	16.3	10.0
sodium	4.3	18.1	9.1
potassium	0.5	2.4	1.5
chloride	1.0	9.0	3.0
sulphate	11.8	46.0	24.0
total alkalinity	85.6	195.0	120.0
pH	7.4	8.21	7.9
carbonate	-	-	-
bicarbonate	104.0	238.0	146.0
total hardness	85.4	203.0	135.0
fluoride	0.05	0.19	0.09
silica	4.0	9.0	5.3
conductance	171	440	275
threshold odour number	2	4	3
colour	5	80	30
tannin and lignin	0.08	1.40	0.7
turbidity	1.5	255.0	52.0
TFR	109.0	251.0	162.0
TFRF	86.0	216.0	133.0
TNFR	0.8	433.0	71.0
TNFRF	L.4	397.0	61.0
surfactants	L.02	0.09	0.04
humic acids	L1.0	18.0	3.0
total organic carbon	4.0	144.0	19.0
total inorg. carbon	15.5	41.0	26.0
total diss. org. carbon	2.5	12.0	9.0
nitrate and nitrite N	0.003	0.66	0.09
ammonia nitrogen	L.01	1.40	0.16
total Kjeldahl N	0.51	1.05	3.19
total phosphorus	0.018	0.35	0.08
ortho-phosphorus	0.003	0.01	0.01
phenol	L.001	0.011	0.00
oil and grease	L.1	3.0	0.8
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	15.0	123.0	48.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.008	0.004
copper[a]	L.001	0.015	0.006
iron[a]	0.20	9.20	1.80
lead[a]	L.002	0.008	0.004
manganese[a]	0.008	0.290	0.06
silver[a]	L.001	L.005	L.004
zinc[a]	L.001	0.047	0.02
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	0.0011	0.0004
mercury[b]	L.0001	0.0003	0.0002
arsenic[c]	0.0002	0.0015	0.0010
nickel[a]	L.002	0.002	0.005
aluminum[a]	0.033	4.15	0.7
cobalt[a]	L.001	0.006	0.002
boron[c]	0.02	0.17	0.07

[a] extractable
[b] total
[c] dissolved

STATION: CC0030 Horse River at Abasands Park

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	18.5	65.9	47.6
magnesium	5.5	19.3	14.0
sodium	12.0	47.0	32.0
potassium	0.8	3.2	2.0
chloride	2.0	15.8	9.9
sulphate	9.7	40.0	25.0
total alkalinity	75.5	271.0	195.0
pH	7.0	8.3	7.7
carbonate	0.0	0.0	0.0
bicarbonate	92.0	330.0	237.0
total hardness	68.8	229.7	159.4
fluoride	0.09	0.23	0.15
silica	2.8	16.4	11.4
conductance	155	590	428
threshold odour number	2	4	3
colour	25	140	67
tannin and lignin	0.8	2.95	1.7
turbidity	4.7	41.0	13.8
TFR	120.0	390.0	275.0
TFRF	98.0	361.0	208.0
TNFR	6.4	23.6	14.0
TNFRF	4.0	20.0	12.0
surfactants	L.02	0.10	0.05
humic acid	L1.0	9.0	3.0
total organic carbon	2.0	31.0	19.0
total inorg. carbon	14.5	66.0	40.0
total diss. org. carbon	2.0	27.0	16.0
nitrate and nitrite N	0.01	0.37	0.19
ammonia nitrogen	0.04	0.12	0.07
total Kjeldahl N	0.39	0.81	0.67
total phosphorus	0.05	0.18	0.11
ortho-phosphorus	0.03	0.04	0.03
phenol	0.001	0.005	0.004
oil and grease	L.1	L.1	L.1
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	-	-	-
chemical oxygen demand	27.0	87.3	61.0
cadmium[a]	0.001	0.002	0.001
hexavalent chromium[a]	L.003	0.003	0.003
copper[a]	0.001	0.021	0.007
iron[a]	0.86	1.85	1.3
lead[a]	L.002	0.005	0.003
manganese[a]	0.03	0.045	0.04
silver[a]	L.004	L.005	L.005
zinc[a]	0.002	0.037	0.012
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0005	L.0005	L.0005
mercury[b]	L.0001	0.0004	0.0002
arsenic[c]	0.0007	0.006	0.003
nickel[a]	L.002	0.007	0.003
aluminum[a]	0.05	0.30	0.13
cobalt[a]	L.002	0.003	0.002
boron[c]	0.01	0.36	0.22

[a] extractable

[b] total

[c] dissolved

STATION: CD0040 Hangingstone Creek at Hwy 63
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	15.5	95.0	40.1
magnesium	4.7	27.5	12.0
sodium	9.5	93.0	33.0
potassium	0.5	5.3	2.1
chloride	5.2	45.8	18.0
sulphate	8.8	71.0	25.1
total alkalinity	61.0	406.8	159.0
pH	7.2	8.4	7.7
carbonate	0.0	5.0	0.0
bicarbonate	74.0	496.0	194.0
total hardness	9.3	344.3	146.0
fluoride	0.08	0.32	0.15
silica	4.0	21.2	10.1
conductance	125	960	382
threshold odour number	2	4	3
colour	15	300	108
tannin and lignin	0.40	2.5	1.6
turbidity	2.2	656.0	114.0
TFR	102.0	665.0	246.0
TFRF	57.5	513.0	196.0
TNFR	2.0	656.0	131.0
TNFRF	L1.0	588.0	114.0
surfactants	L.02	0.24	0.06
humic acids	0.0	54.0	5.0
total organic carbon	9.0	39.0	22.0
total inorg. carbon	10.0	72.0	31.0
total diss. org. carbon	4.0	32.0	20.0
nitrate and nitrite N	L.003	0.45	0.09
ammonia nitrogen	0.04	0.32	0.13
total Kjeldahl N	0.56	1.69	1.15
total phosphorus	0.03	0.41	0.14
ortho-phosphorus	0.01	0.05	0.02
phenol	L.001	0.020	0.003
oil and grease	L.1	2.2	0.7
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.001	0.001
chemical oxygen demand	28.0	101.0	61.0
cadmium[a]	L.001	0.003	0.001
hexavalent chromium[a]	L.003	0.036	0.006
copper[a]	L.001	0.048	0.010
iron[a]	0.58	49.0	6.0
lead[a]	L.002	0.052	0.008
manganese[a]	0.024	1.4	0.2
silver[a]	L.001	L.005	L.003
zinc[a]	0.002	0.20	0.03
vanadium[b]	L.001	0.008	0.002
selenium[c]	L.0002	0.0005	0.0004
mercury[b]	L.0001	0.0017	0.0003
arsenic[c]	0.001	0.005	0.003
nickel[a]	L.002	0.072	0.011
aluminum[a]	0.03	10.0	1.6
cobalt[a]	L.002	0.033	0.004
boron[c]	0.08	0.40	0.21

[a] extractable
[b] total
[c] dissolved

STATION: CC0300 Horse River near Fort McMurray

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	14.5	28.0	21.1
magnesium	4.2	8.5	6.6
sodium	6.4	17.5	12.2
potassium	0.5	1.28	0.91
chloride	2.0	5.0	3.6
sulphate	8.7	18.0	11.5
total alkalinity	54.0	115.0	86.0
pH	7.53	8.11	7.8
carbonate	-	-	-
bicarbonate	66.0	141.0	105.0
total hardness	53.5	104.9	79.7
fluoride	0.09	0.13	0.11
silica	4.7	6.5	5.5
conductance	106	214	165
threshold odour number	2	4	3
colour	180	200	195
tannin and lignin	2.0	2.5	2.3
turbidity	2.30	82.0	26.0
TFR	75.4	141.0	109.0
TFRF	37.0	90.0	69.0
TNFR	8.8	102.4	35.2
TNFRF	6.0	89.2	29.2
surfactants	0.025	0.15	0.09
humic acids	2.5	54.0	13.0
total organic carbon	25.0	34.0	29.0
total inorg. carbon	9.0	22.0	17.0
total diss. org. carbon	23.0	27.5	25.3
nitrate and nitrite N	L.003	0.150	0.043
ammonia nitrogen	L.01	0.07	0.04
total Kjeldahl N	0.78	1.65	1.07
total phosphorus	0.054	0.14	0.08
ortho-phosphorus	0.009	0.024	0.016
phenol	L.001	L.001	L.001
oil and grease	0.3	1.6	1.0
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	66.0	98.0	78.0
cadmium^a	L.001	L.001	L.001
hexavalent chromium^a	L.003	L.003	L.003
copper^a	0.002	0.003	0.003
iron^a	1.10	3.55	1.95
lead^a	L.002	L.002	L.002
manganese^a	0.027	0.134	0.062
silver^a	L.001	L.001	L.001
zinc^a	0.003	0.073	0.023
vanadium^b	L.001	L.001	L.001
selenium^c	L.0002	L.0002	L.0002
mercury^b	L.0001	L.0001	L.0001
arsenic^c	0.0004	0.0008	0.0006
nickel^a	L.002	L.002	L.002
aluminum^a	0.12	0.69	0.31
cobalt^a	L.002	L.002	L.002
boron^c	L.05	0.21	0.16

^{a} extractable

^{b} total

^{c} dissolved

STATION: CD0100 Saline Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	14.0	91.0	30.2
magnesium	5.0	31.0	10.5
sodium	11.5	36.5	17.3
potassium	0.2	2.0	1.0
chloride	1.5	10.1	6.4
sulphate	3.8	65.5	15.8
total alkalinity	62.8	348.0	123.0
pH	7.0	8.0	7.7
carbonate	-	-	-
bicarbonate	77.0	424.0	150.0
total hardness	55.5	354.9	118.6
fluoride	0.07	0.16	0.10
silica	2.0	11.4	5.8
conductance	149	720	261
threshold odour number	2	4	3
colour	50	170	114
tannin and lignin	0.65	2.5	1.8
turbidity	3.5	280.0	144.0
TFR	95.0	522.5	185.0
TFRF	61.0	327.5	123.0
TNFR	6.4	454.0	158.0
TNFRF	3.6	415.0	144.0
surfactants	L.02	L.02	L.02
humic acids	L.01	7.0	4.0
total organic carbon	14.0	42.0	30.0
total inorg. carbon	11.0	67.0	32.0
total diss. org. carbon	14.0	38.0	27.0
nitrate and nitrite N	L.01	0.01	0.01
ammonia nitrogen	0.05	0.25	0.13
total Kjeldahl N	0.68	1.50	1.11
total phosphorus	0.03	0.33	0.18
ortho-phosphorus	L.01	0.22	0.04
phenol	0.002	0.016	0.006
oil and grease	L.1	0.8	0.4
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	59.0	180.0	93.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.012	0.006
copper[a]	0.002	0.016	0.008
iron[a]	0.74	7.6	3.6
lead[a]	L.002	0.008	0.003
manganese[a]	0.045	0.190	0.09
silver[a]	L.001	L.005	L.003
zinc[a]	0.006	0.061	0.025
vanadium[b]	L.001	0.006	0.003
selenium[c]	L.0005	0.0009	0.0006
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	0.006	0.020	0.013
nickel[a]	L.002	0.012	0.005
aluminum[a]	0.04	7.60	2.23
cobalt[a]	L.002	0.003	0.002
boron[c]	0.03	0.30	0.15

[a] extractable

[b] total

[c] dissolved

STATION: CD2300 Clearwater River above Waterways

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	11.5	30.4	16.0
magnesium	3.7	9.4	5.0
sodium	10.0	34.0	21.0
potassium	0.5	1.8	1.0
chloride	9.8	45.3	27.0
sulphate	0.1	19.0	7.0
total alkalinity	45.0	94.9	61.0
pH	7.1	8.0	7.5
carbonate	-	-	-
bicarbonate	55.0	116.0	75.0
total hardness	43.9	109.0	63.0
fluoride	L.05	0.9	0.1
silica	5.0	112.0	15.0
conductance	129	309	208
threshold odour number	2	4	3
colour	15	180	49
tannin and lignin	0.40	1.85	0.8
turbidity	1.1	450.0	52.0
TFR	77.4	223.0	139.0
TFRF	52.5	171.0	107.0
TNFR	2.0	1751.0	139.0
TNFRF	0.4	1608.0	118.0
surfactants	L.02	L.2	L.1
humic acids	1.0	2.0	2.0
total organic carbon	5.0	83.0	16.0
total inorg. carbon	8.0	22.0	13.0
total diss. org. carbon	4.0	20.0	10.0
nitrate and nitrite N	0.003	1.20	0.13
ammonia nitrogen	L.01	0.73	0.13
total Kjeldahl N	0.48	2.61	1.1
total phosphorus	0.03	0.32	0.09
ortho-phosphorus	L.005	0.047	0.01
phenol	L.001	0.011	0.004
oil and grease	L.1	0.9	3.0
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	11.0	101.0	42.0
cadmium[a]	L.001	0.005	0.001
hexavalent chromium[a]	L.003	0.004	0.003
copper[a]	L.001	0.032	0.006
iron[a]	0.69	24.0	3.0
lead[a]	L.002	0.036	0.006
manganese[a]	0.022	0.69	0.10
silver[a]	L.001	0.013	0.004
zinc[a]	L.001	0.087	0.016
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	0.035	0.004
mercury[b]	L.0001	0.06	0.00
arsenic[c]	L.0005	L.0005	L.0005
nickel[a]	L.002	0.042	0.01
aluminum[a]	0.02	4.3	0.5
cobalt[a]	L.002	0.019	0.004
boron[c]	L.01	0.38	0.11

[a] extractable

[b] total

[c] dissolved

STATION: CE0011 Gregoire Lake at Weir

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	13.5	18.5	15.8
magnesium	3.7	5.2	4.4
sodium	1.7	2.8	2.2
potassium	0.7	1.3	1.0
chloride	0.5	1.1	0.8
sulphate	4.3	9.5	7.1
total alkalinity	44.0	59.0	51.4
pH	7.2	8.0	7.5
carbonate	-	-	-
bicarbonate	54.0	73.0	63.0
total hardness	48.9	67.6	57.4
fluoride	0.04	0.12	0.09
silica	0.07	2.2	1.5
conductance	95	138	115
threshold odour number	1	8	3
colour	15	35	27
tannin and lignin	0.3	1.8	0.7
turbidity	0.2	13.7	3.6
TFR	56.7	82.2	70.0
TFRF	39.0	66.0	50.0
TNFR	0.8	21.2	7.2
TNFRF	L.4	15.4	3.7
surfactants	L.02	0.11	0.05
humic acids	L1.0	1.0	1.0
total organic carbon	4.0	16.0	12.0
total inorg. carbon	8.0	12.0	10.0
total diss. org. carbon	4.0	16.0	11.0
nitrate and nitrite N	0.006	0.22	0.03
ammonia nitrogen	L.01	0.14	0.06
total Kjeldahl N	L.1	1.18	0.9
total phosphorus	0.02	0.07	0.03
ortho-phosphorus	L.003	0.01	0.01
phenol	L.001	0.002	0.001
oil and grease	L.1	2.1	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.019	0.006
chemical oxygen demand	19.0	80.0	41.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	0.001	0.014	0.004
iron[a]	0.11	0.93	0.28
lead[a]	L.002	0.013	0.003
manganese[a]	0.008	0.064	0.03
silver[a]	L.001	L.005	L.003
zinc[a]	L.001	0.030	0.011
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0011	L.0005
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	L.0002	0.007	0.002
nickel[a]	L.002	0.025	0.004
aluminum[a]	L.01	0.10	0.39
cobalt[a]	L.002	0.009	0.003
boron[c]	0.03	0.12	0.07

[a] extractable

[b] total

[c] dissolved

STATION: DA0060 Steepbank River

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	13.0	68.0	37.0
magnesium	4.2	21.0	12.0
sodium	4.4	45.5	20.0
potassium	0.2	2.4	1.0
chloride	1.3	7.0	3.2
sulphate	1.9	15.5	7.0
total alkalinity	50.0	329.0	164.0
pH	7.0	8.3	7.8
carbonate	-	-	-
bicarbonate	61.0	401.0	200.0
total hardness	49.8	252.1	139.5
fluoride	0.05	0.23	0.1
silica	2.0	13.7	8.0
conductance	110	610	308
threshold odour number	2	8	3
colour	10	120	77
tannin and lignin	0.5	2.0	1.3
turbidity	1.1	42.0	10.0
TFR	0.4	391.0	167.0
TFRF	40.0	364.0	150.0
TNFR	1.2	171.0	20.0
TNFRF	L.4	151.0	16.0
surfactants	L.02	0.11	0.04
humic acids	L.1	L.1	L.1
total organic carbon	9.0	33.0	20.0
total inorg. carbon	7.0	70.0	32.0
total diss. org. carbon	9.0	28.0	18.0
nitrate and nitrite N	0.003	0.34	0.07
ammonia nitrogen	0.01	0.17	0.06
total Kjeldahl N	0.56	2.10	1.0
total phosphorus	0.024	0.22	0.08
ortho-phosphorus	L.001	0.15	0.03
phenol	L.001	0.010	0.002
oil and grease	0.0	2.4	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.007	0.003
chemical oxygen demand	23.0	112.0	57.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	L.001	0.030	0.008
iron[a]	0.6	2.5	1.1
lead[a]	L.002	0.028	0.004
manganese[a]	0.021	0.39	0.07
silver[a]	L.001	L.005	L.003
zinc[a]	L.001	0.058	0.013
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	0.0014	0.0004
mercury[b]	L.0001	0.0004	0.0001
arsenic[c]	L.0002	0.003	0.001
nickel[a]	L.002	0.005	0.003
aluminum[a]	L.01	0.7	0.2
cobalt[a]	L.002	0.006	0.002
boron[c]	0.06	0.48	0.21

[a] extractable

[b] total

[c] dissolved

STATION: DA0070 Poplar Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	25.0	70.0	35.1
magnesium	6.5	33.0	12.9
sodium	23.0	388.0	70.0
potassium	1.4	3.8	2.6
chloride	5.5	525.0	73.0
sulphate	4.4	37.5	10.7
total alkalinity	124.0	347.0	170.0
pH	7.5	8.4	7.9
carbonate	0.0	0.3	0.0
bicarbonate	151.0	423.0	207.0
total hardness	97.0	310.0	140.8
fluoride	0.08	0.17	0.12
silica	1.8	11.6	6.0
conductance	216	970	397
threshold odour number	2	4	2
colour	55	140	87
tannin and lignin	0.45	2.1	1.5
turbidity	3.35	60.0	12.0
TFR	156.0	130.0	344.0
TFRF	122.0	1190.0	274.0
TNFR	2.0	323.0	37.0
TNFRF	1.0	287.0	31.0
surfactants	L.02	0.361	0.08
humic acids	3.0	3.0	3.0
total organic carbon	13.0	45.0	28.0
total inorg. carbon	0.21	43.0	31.0
total diss. org. carbon	13.0	41.0	25.0
nitrate and nitrite N	L.01	0.51	0.09
ammonia nitrogen	0.02	0.32	0.22
total Kjeldahl N	0.69	2.75	1.46
total phosphorus	L.01	0.24	0.06
ortho-phosphorus	L.003	0.02	0.01
phenol	L.001	0.007	0.007
oil and grease	0.1	3.3	0.7
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	46.0	205.0	87.0
cadmium[a]	L.001	0.016	0.003
hexavalent chromium[a]	L.003	0.075	0.021
copper[a]	L.001	0.018	0.005
iron[a]	0.12	4.70	1.3
lead[a]	L.002	0.175	0.015
manganese[a]	0.022	0.47	0.18
silver[a]	L.001	0.028	0.005
zinc[a]	L.001	0.08	0.02
vanadium[b]	L.001	0.001	0.001
selenium[c]	L.0002	0.0008	0.0004
mercury[b]	L.0001	0.0016	0.0005
arsenic[c]	L.0002	0.004	0.001
nickel[a]	L.002	0.024	0.005
aluminum[a]	L.01	1.0	0.2
cobalt[a]	L.002	0.031	0.005
boron[c]	0.10	0.33	0.22

[a] extractable
[b] total
[c] dissolved

STATION: DA0080 Muskeg River, 2.2 mi N.E. of Fort MacKay
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	16.5	82.0	47.6
magnesium	4.5	18.5	12.1
sodium	4.9	38.5	14.8
potassium	0.5	2.6	1.2
chloride	1.7	29.7	6.2
sulphate	0.1	9.5	4.4
total alkalinity	64.6	289.0	184.2
pH	7.28	8.2	7.7
carbonate	-	-	-
bicarbonate	79.0	352.0	225.0
total hardness	59.0	280.9	168.6
fluoride	0.06	0.16	0.12
silica	2.2	25.0	10.1
conductance	126	520	343
threshold odour number	2	16	3
colour	20	110	68
tannin and lignin	0.08	1.75	1.2
turbidity	0.65	17.0	6.0
TFR	80.0	365.0	218.0
TFRF	68.0	308.0	172.0
TNFR	L.4	10.0	4.3
TNFRF	L.4	6.0	1.5
surfactants	L.02	0.14	0.05
humic acids	L1.0	9.0	2.2
total organic carbon	8.0	35.0	24.0
total inorg. carbon	10.0	61.0	37.0
total diss. org. carbon	7.0	34.0	22.0
nitrate and nitrite N	0.003	0.31	0.04
ammonia nitrogen	L.01	0.57	0.17
total Kjeldahl N	0.35	1.66	1.10
total phosphorus	L.005	0.09	0.04
ortho-phosphorus	L.003	0.02	0.01
phenol	L.001	0.018	0.003
oil and grease	L.0	3.5	0.8
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.003	0.001
chemical oxygen demand	34.0	88.4	56.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.016	0.004
copper[a]	L.001	0.026	0.004
iron[a]	0.45	3.85	1.42
lead[a]	L.002	0.021	0.003
manganese[a]	0.015	0.97	0.21
silver[a]	L.001	L.005	L.003
zinc[a]	0.002	0.091	0.016
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	0.0009	0.0004
mercury[b]	L.0001	0.0004	0.0001
arsenic[c]	L.0002	0.020	0.003
nickel[a]	L.001	0.010	0.002
aluminum[a]	L.01	0.22	0.04
cobalt[a]	L.002	0.006	0.002
boron[c]	L.05	0.26	0.15

[a] extractable

[b] total

[c] dissolved

STATION: DA0090 Hartley Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	11.5	91.0	38.1
magnesium	3.5	21.8	10.6
sodium	5.5	30.0	16.4
potassium	0.2	2.5	0.9
chloride	1.0	17.0	5.4
sulphate	0.1	12.5	5.1
total alkalinity	46.4	348.2	158.2
pH	7.2	8.2	7.7
carbonate	-	-	-
bicarbonate	57.0	424.0	193.0
total hardness	43.1	317.0	138.5
fluoride	0.005	0.24	0.12
silica	1.7	16.8	8.1
conductance	105	660	293
threshold odour number	2	4	3
colour	30	130	88
tannin and lignin	0.85	2.40	1.4
turbidity	0.9	320.0	27.0
TFR	67.0	420.0	184.0
TFRF	49.0	383.0	145.0
TNFR	L.4	459.0	32.0
TNFRF	L.4	400.0	26.0
surfactants	L.02	0.13	0.05
humic acids	L1.0	18.0	3.3
total organic carbon	9.0	36.0	25.0
total inorg. carbon	9.0	73.0	33.0
total diss. org. carbon	8.0	34.0	23.0
nitrate and nitrite N	0.003	0.07	0.02
ammonia nitrogen	0.01	0.21	0.09
total Kjeldahl N	0.35	2.25	1.04
total phosphorus	L.005	0.33	0.06
ortho-phosphorus	0.004	0.06	0.01
phenol	L.001	0.022	0.003
oil and grease	L.1	1.9	0.5
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	40.0	111.0	70.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.005	0.003
copper[a]	L.001	0.028	0.007
iron[a]	0.43	4.95	1.1
lead[a]	L.002	L.002	L.002
manganese[a]	0.009	0.42	0.07
silver[a]	L.001	L.005	L.003
zinc[a]	0.001	0.048	0.015
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0001	0.0007	0.0003
mercury[b]	L.0001	0.0007	0.0002
arsenic[c]	L.0002	0.0026	0.001
nickel[a]	L.001	0.004	0.002
aluminum[a]	L.01	0.36	0.07
cobalt[a]	L.001	L.002	L.002
boron[c]	0.01	0.48	0.14

[a] extractable
[b] total
[c] dissolved

STATION: DA0100 Upper Ells River

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	13.0	19.5	15.8
magnesium	3.7	5.8	4.8
sodium	2.4	8.0	3.6
potassium	0.4	1.3	0.9
chloride	0.3	2.1	0.6
sulphate	4.2	8.1	6.4
total alkalinity	48.8	70.3	58.0
pH	7.1	8.1	7.4
carbonate	-	-	-
bicarbonate	59.0	86.0	71.0
total hardness	47.7	72.6	59.0
fluoride	0.07	0.14	0.10
silica	0.37	9.9	4.3
conductance	96	123	152
threshold odour number	2	8	3
colour	5	40	28
tannin and lignin	0.30	1.85	0.7
turbidity	0.50	11.35	3.0
TFR	59.6	106.0	79.0
TFRF	37.0	91.0	58.0
TNFR	1.2	16.8	5.7
TNFRF	L.4	14.9	3.0
surfactants	L.02	0.11	0.05
humic acids	L1.0	L2.5	L1.1
total organic carbon	7.0	17.0	12.0
total inorg. carbon	9.0	16.0	11.0
total diss. org. carbon	7.0	17.0	7.0
nitrate and nitrite N	L.003	0.011	0.007
ammonia nitrogen	0.01	0.13	0.006
total Kjeldahl N	0.1	1.02	0.8
total phosphorus	0.031	0.09	0.05
ortho-phosphorus	0.003	0.04	0.02
phenol	L.001	0.020	0.004
oil and grease	L.1	0.5	0.2
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.002	0.001
chemical oxygen demand	20.0	54.0	37.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	0.001	0.021	0.006
iron[a]	0.18	0.58	0.31
lead[a]	L.002	0.002	0.002
manganese[a]	0.013	0.090	0.04
silver[a]	L.001	L.005	0.003
zinc[a]	0.002	0.088	0.016
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	0.0009	0.0004
mercury[b]	L.0001	0.0002	0.00001
arsenic[c]	L.0002	0.005	0.001
nickel[a]	L.002	L.002	L.002
aluminum[a]	L.01	0.25	0.07
cobalt[a]	L.002	0.002	0.002
boron[c]	0.02	0.19	0.08

[a] extractable

[b] total

[c] dissolved

STATION: DA0110 Unnamed Creek

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	39.0	79.0	51.7
magnesium	11.5	20.0	13.8
sodium	8.5	21.5	14.0
potassium	2.5	3.4	2.9
chloride	0.6	1.9	1.3
sulphate	9.3	170.0	52.2
total alkalinity	112.2	211.6	158.2
pH	7.4	8.4	7.8
carbonate	0.0	2.0	0.0
bicarbonate	137.0	258.0	193.0
total hardness	146.3	279.6	185.8
fluoride	0.11	0.40	0.26
silica	8.3	15.8	12.0
conductance	316	600	391
threshold odour number	2	8	3
colour	10	40	28
tannin and lignin	0.25	1.10	0.7
turbidity	2.0	28.0	7.2
TFR	194.0	452.0	251.0
TFRF	161.0	388.0	215.0
TNFR	1.6	74.0	14.3
TNFRF	L.4	51.2	9.4
surfactants	L.02	0.13	0.05
humic acids	L.01	2.0	1.0
total organic carbon	9.5	23.0	15.0
total inorg. carbon	23.5	50.5	33.0
total diss. org. carbon	5.0	20.0	12.0
nitrate and nitrite N	0.009	0.140	0.05
ammonia nitrogen	0.01	0.20	0.08
total Kjeldahl N	0.35	1.35	0.96
total phosphorus	0.037	0.11	0.07
ortho-phosphorus	0.006	0.026	0.02
phenol	L.001	0.022	0.003
oil and grease	L.1	2.2	0.5
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	11.0	82.0	45.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	L.001	0.006	0.003
iron[a]	0.57	1.70	1.03
lead[a]	L.002	0.008	0.003
manganese[a]	0.091	0.44	0.22
silver[a]	L.001	L.005	L.002
zinc[a]	0.001	0.024	0.008
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	0.0002	L.001	L.001
nickel[a]	L.002	0.002	0.002
aluminum[a]	0.02	0.35	0.08
cobalt[a]	L.002	L.002	L.002
boron[c]	0.02	0.9	0.2

[a] extractable

[b] total

[c] dissolved

STATION: DA0120 Asphalt Creek

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	21.5	105.0	45.6
magnesium	7.5	33.0	15.7
sodium	13.5	30.0	21.5
potassium	1.9	4.5	2.7
chloride	1.9	4.9	3.4
sulphate	28.5	185.0	122.8
total alkalinity	37.2	435.2	98.3
pH	7.2	8.0	7.6
carbonate	0.0	0.0	0.0
bicarbonate	45.0	531.0	120.0
total hardness	84.6	398.0	178.3
fluoride	0.28	0.45	0.35
silica	5.2	21.0	10.7
conductance	221	810	440
threshold odour number	2	4	3
colour	20	60	37
tannin and lignin	0.45	1.3	1.1
turbidity	1.4	890.0	220.0
TFR	150.0	502.0	278.0
TFRF	129.0	460.0	246.0
TNFR	4.0	1058.0	189.0
TNFRF	2.0	966.0	168.0
surfactants	L.02	0.14	0.05
humic acids	L1.0	3.0	1.2
total organic carbon	8.0	21.0	13.0
total inorg. carbon	9.0	61.0	17.0
total diss. org. carbon	5.0	14.0	10.0
nitrate and nitrite N	0.005	0.033	0.02
ammonia nitrogen	0.01	0.16	0.07
total Kjeldahl N	0.43	5.60	1.55
total phosphorus	0.02	0.63	0.18
ortho-phosphorus	0.003	0.04	0.01
phenol	L.001	0.020	0.003
oil and grease	L.1	1.7	0.5
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	29.0	90.0	54.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.031	0.009
copper[a]	0.003	0.033	0.009
iron[a]	0.16	27.7	6.8
lead[a]	L.002	0.035	0.008
manganese[a]	0.135	0.54	0.32
silver[a]	L.001	L.005	L.003
zinc[a]	0.018	0.155	0.042
vanadium[b]	L.001	0.004	0.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	L.0002	L.0001
arsenic[c]	L.0002	0.0023	0.0010
nickel[a]	L.0002	0.046	0.017
aluminum[a]	L.01	11.20	3.53
cobalt[a]	L.002	0.028	0.006
boron[c]	0.13	0.27	0.19

[a] extractable

[b] total

[c] dissolved

STATION: DA0121 Eymundson Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	8.5	210.0	61.0
magnesium	3.7	146.0	28.6
sodium	9.7	128.0	35.0
potassium	2.4	26.5	6.3
chloride	2.2	24.5	6.3
sulphate	17.8	466.0	140.0
total alkalinity	36.0	1000.0	198.0
pH	6.6	8.1	7.4
carbonate	0.0	0.0	0.0
bicarbonate	44.0	1219.0	241.0
total hardness	36.5	1125.5	269.0
fluoride	0.09	0.60	0.34
silica	1.5	104.0	19.0
conductance	119	2800	659
threshold odour number	2	8	3
colour	25	250	89
tannin and lignin	0.70	2.30	1.5
turbidity	3.6	440.0	74.0
TFR	77.0	1750.0	443.0
TFRF	49.0	1630.0	379.0
TNFR	8.0	696.0	109.0
TNFRF	2.4	626.0	95.0
surfactants	L.02	0.31	0.09
humic acids	L1.0	7.0	2.0
total organic carbon	7.0	50.0	27.0
total inorg. carbon	7.0	150.0	34.0
total diss. org. carbon	5.0	43.0	20.0
nitrate and nitrite N	L.003	0.14	0.04
ammonia nitrogen	0.03	0.25	0.12
total Kjeldahl N	0.75	5.10	2.16
total phosphorus	0.08	6.25	2.21
ortho-phosphorus	0.008	0.08	0.02
phenol	L.001	0.007	0.002
oil and grease	L.01	2.0	0.7
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	40.0	207.0	101.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.010	0.005
copper[a]	0.002	0.020	0.007
iron[a]	0.09	0.22	0.14
lead[a]	L.002	0.033	0.007
manganese[a]	0.12	2.00	0.74
silver[a]	L.001	L.005	L.003
zinc[a]	0.010	0.066	0.026
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	0.0006	0.0004
mercury[b]	L.0001	0.0027	0.0005
arsenic[c]	L.0002	0.0015	0.001
nickel[a]	L.002	0.046	0.018
aluminum[a]	0.04	4.25	0.8
cobalt[a]	L.002	0.014	0.005
boron[c]	0.10	0.90	0.26

[a] extractable
[b] total
[c] dissolved

STATION: DA0130 Pierre River
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	25.0	42.5	34.8
magnesium	8.5	14.3	11.7
sodium	14.5	25.5	22.8
potassium	2.2	4.6	3.5
chloride	1.9	6.4	4.0
sulphate	50.0	123.5	85.1
total alkalinity	58.4	130.0	88.1
pH	7.2	7.9	7.7
carbonate	0.0	0.0	0.0
bicarbonate	71.0	158.0	107.0
total hardness	97.0	165.0	135.0
fluoride	0.06	0.43	0.32
silica	4.3	14.3	8.6
conductance	248	442	359
threshold odour number	2	4	3
colour	40	60	54
tannin and lignin	0.5	1.2	0.9
turbidity	2.45	10.0	4.8
TFR	165.0	260.0	226.0
TFRF	153.0	239.0	198.0
TNFR	2.8	38.4	9.1
TNFRF	L.4	31.2	5.7
surfactants	L.02	0.22	0.09
humic acids	L1.0	3.0	1.2
total organic carbon	7.0	34.0	20.0
total inorg. carbon	10.0	28.0	17.0
total diss. org. carbon	6.5	33.0	18.0
nitrate and nitrite N	0.007	0.08	0.02
ammonia nitrogen	L.01	0.13	0.05
total Kjeldahl N	0.30	1.86	0.99
total phosphorus	0.047	0.23	0.23
ortho-phosphorus	0.006	0.020	0.01
phenol	L.001	0.029	0.006
oil and grease	L.1	1.0	0.4
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	31.0	96.0	58.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.005	0.003
copper[a]	0.0021	0.16	0.005
iron[a]	0.40	3.25	1.46
lead[a]	L.002	0.029	0.005
manganese[a]	0.046	0.88	0.28
silver[a]	L.001	L.005	L.002
zinc[a]	0.005	0.019	0.013
vanadium[b]	L.001	0.001	0.001
selenium[c]	L.0002	0.0009	0.0004
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	L.0002	L.001	L.001
nickel[a]	L.002	0.010	0.004
aluminum[a]	0.015	0.47	0.12
cobalt[a]	L.002	0.004	0.002
boron[c]	0.04	0.28	0.16

[a] extractable
[b] total
[c] dissolved

STATION: DA0140 Calumet River
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	32.5	160.0	62.7
magnesium	10.7	61.0	22.4
sodium	35.0	225.0	80.0
potassium	2.0	10.5	4.4
chloride	12.0	165.0	45.3
sulphate	3.8	118.0	38.3
total alkalinity	161.0	702.0	199.7
pH	7.6	8.3	7.9
carbonate	0.0	0.0	0.0
bicarbonate	196.0	856.0	365.0
total hardness	125.2	650.7	248.7
fluoride	0.12	0.35	0.20
silica	4.75	23.2	11.2
conductance	372	1920	729
threshold odour number	2	8	3
colour	110	170	132
tannin and lignin	1.3	2.7	2.0
turbidity	0.5	18.9	4.2
TFR	227.0	1178.0	461.0
TFRF	168.0	983.0	375.0
TNFR	L.4	13.2	4.1
TNFRF	L.4	8.0	1.9
surfactants	L.02	0.20	0.08
humic acids	1.0	6.0	3.2
total organic carbon	7.3	46.0	36.0
total inorg. carbon	10.8	112.0	44.0
total diss. org. carbon	7.2	46.0	34.0
nitrate and nitrite N	0.003	0.08	0.02
ammonia nitrogen	0.02	0.82	0.23
total Kjeldahl N	0.85	4.23	2.30
total phosphorus	0.072	0.18	0.12
ortho-phosphorus	0.13	0.172	0.05
phenol	L.001	0.026	0.004
oil and grease	L.1	1.4	0.5
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	41.0	355.0	130.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.005	0.003
copper[a]	0.001	0.017	0.005
iron[a]	0.6	3.45	1.3
lead[a]	L.002	0.008	0.003
manganese[a]	0.02	1.65	0.40
silver[a]	L.001	L.005	L.003
zinc[a]	0.005	0.096	0.019
vanadium[b]	L.001	0.001	0.001
selenium[c]	L.0002	0.0005	0.0003
mercury[b]	L.0001	0.0046	0.0006
arsenic[c]	0.003	0.0062	0.001
nickel[a]	L.002	0.020	0.004
aluminum[a]	L.01	0.11	0.05
cobalt[a]	L.002	L.002	L.002
boron[c]	0.04	0.69	0.27

[a] extractable
[b] total
[c] dissolved

STATION: DA0150 Lower Tar River

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	29.5	80.0	46.6
magnesium	9.2	27.5	15.0
sodium	4.4	50.0	23.2
potassium	1.1	4.5	2.1
chloride	0.8	9.2	3.5
sulphate	8.6	62.5	27.8
total alkalinity	108.0	392.0	193.7
pH	7.0	8.3	7.7
carbonate	0.0	0.0	0.0
bicarbonate	132.0	478.0	236.0
total hardness	11.5	313.0	178.0
fluoride	0.10	0.38	0.21
silica	5.0	18.8	10.6
conductance	267	710	411
threshold odour number	2	8	3
colour	15	100	59
tannin and lignin	0.45	2.10	1.1
turbidity	1.45	570.0	89.0
TFR	162.0	508.0	262.0
TFRF	126.0	438.0	219.0
TNFR	3.6	986.0	122.0
TNFRF	1.2	883.0	101.0
surfactants	L.02	0.20 2	0.05
humic acids	L1.0	5.0	1.6
total organic carbon	10.0	30.0	19.0
total inorg. carbon	19.0	65.0	37.0
total diss. org. carbon	9.0	26.0	17.0
nitrate and nitrite N	L.003	0.100	0.02
ammonia nitrogen	L.01	0.80	0.22
total Kjeldahl N	0.3	4.40	1.7
total phosphorus	0.063	1.4	0.3
ortho-phosphorus	0.009	0.05	0.02
phenol	L.001	0.024	0.006
oil and grease	L.1	1.6	0.4
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	24.0	151.0	80.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	0.009	0.004
copper[a]	0.002	0.114	0.017
iron[a]	1.20	52.5	8.7
lead[a]	L.002	0.038	0.005
manganese[a]	0.002	6.40	1.24
silver[a]	L.001	0.070	0.008
zinc[a]	L.001	0.041	0.014
vanadium[b]	L.001	0.007	0.002
selenium[c]	L.0002	0.0009	0.0004
mercury[b]	L.0001	0.0003	0.0001
arsenic[c]	L.0002	0.0173	0.003
nickel[a]	L.002	0.026	0.007
aluminum[a]	0.02	1.39	0.33
cobalt[a]	L.002	0.008	0.003
boron[c]	0.07	0.31	0.16

[a] extractable

[b] total

[c] dissolved

STATION: DA0160 Joslyn Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	37.5	56.5	46.2
magnesium	10.0	16.7	13.0
sodium	17.5	36.0	28.3
potassium	2.2	3.6	2.8
chloride	1.5	4.2	2.2
sulphate	52.5	100.0	72.1
total alkalinity	102.5	186.0	148.7
pH	7.4	8.14	7.9
carbonate	0.0	0.0	0.0
bicarbonate	125.0	227.0	181.0
total hardness	134.8	209.8	168.9
fluoride	0.11	0.33	0.24
silica	5.6	10.0	6.8
conductance	348	500	422
threshold odour number	2	4	3
colour	30	110	72
tannin and lignin	0.60	2.15	1.4
turbidity	0.9	216.0	68.0
TFR	210.0	315.0	265.0
TFRF	172.0	274.0	224.0
TNFR	2.0	142.4	42.9
TNFRF	L.4	121.2	35.4
surfactants	L.02	0.18	0.07
humic acids	L1.0	6.0	2.0
total organic carbon	18.0	33.0	24.0
total inorg. carbon	13.0	35.5	28.0
total diss. org. carbon	15.5	30.0	22.0
nitrate and nitrite N	0.006	0.09	0.03
ammonia nitrogen	0.02	0.36	0.10
total Kjeldahl N	0.58	1.54	1.08
total phosphorus	0.089	0.32	0.18
ortho-phosphorus	0.007	0.04	0.02
phenol	L.001	0.023	0.003
oil and grease	L.1	1.5	0.7
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	50.0	133.0	75.0
cadmium[a]	L.001	0.003	0.001
hexavalent chromium[a]	L.003	0.011	0.004
copper[a]	0.003	0.019	0.009
iron[a]	2.00	14.0	5.4
lead[a]	L.002	0.009	0.004
manganese[a]	0.026	0.525	0.106
silver[a]	L.001	L.005	L.002
zinc[a]	0.008	0.039	0.021
vanadium[b]	L.001	0.013	0.003
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	L.0002	L.0001
arsenic[c]	L.0005	0.0015	0.0010
nickel[a]	L.002	0.020	0.005
aluminum[a]	0.19	6.20	2.08
cobalt[a]	L.002	0.008	0.003
boron[c]	0.16	0.28	0.21

[a] extractable
[b] total
[c] dissolved

STATION: DA0170 Lower Ells River
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	17.5	38.0	25.3
magnesium	5.5	11.0	7.6
sodium	5.0	26.0	12.1
potassium	0.8	2.2	1.3
chloride	0.6	5.4	2.3
sulphate	9.3	30.2	16.5
total alkalinity	61.8	150.4	96.2
pH	7.3	8.3	7.7
carbonate	0.0	0.0	0.0
bicarbonate	75.0	183.0	117.0
total hardness	66.3	140.2	94.5
fluoride	0.08	0.16	0.11
silica	0.35	9.9	4.1
conductance	133	270	219
threshold odour number	2	8	3
colour	20	50	34
tannin and lignin	0.4	1.2	0.7
turbidity	1.1	20.0	7.6
TFR	79.8	235.0	138.0
TFRF	57.0	179.0	107.0
TNFR	2.0	39.0	9.0
TNFRF	L.4	32.4	5.5
surfactants	L.02	0.19	0.06
humic acids	L1.0	2.0	1.1
total organic carbon	7.5	21.5	15.0
total inorg. carbon	7.5	25.0	18.0
total diss. org. carbon	7.5	18.0	13.0
nitrate and nitrite N	0.003	0.43	0.11
ammonia nitrogen	L.01	0.14	0.05
total Kjeldahl N	0.20	1.11	0.78
total phosphorus	0.009	0.34	0.06
ortho-phosphorus	L.003	0.06	0.01
phenol	L.001	0.024	0.003
oil and grease	L.1	8.2	0.9
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	17.0	108.0	45.0
cadmium[a]	L.001	0.003	0.001
hexavalent chromium[a]	L.003	0.005	0.003
copper[a]	L.001	0.033	0.007
iron[a]	0.30	0.97	0.61
lead[a]	L.002	0.012	0.004
manganese[a]	0.012	0.057	0.02
silver[a]	L.001	0.005	0.003
zinc[a]	0.003	0.054	0.014
vanadium[b]	L.001	0.003	0.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0003	0.0001
arsenic[c]	L.0002	0.009	0.001
nickel[a]	L.002	0.007	0.003
aluminum[a]	0.02	0.88	0.17
cobalt[a]	L.001	0.003	0.002
boron[c]	0.05	0.30	0.15

[a] extractable
[b] total
[c] dissolved

STATION: DA0180 Beaver River above Syncrude

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	12.0	34.5	26.1
magnesium	4.2	14.8	9.7
sodium	13.5	150.0	50.0
potassium	0.7	3.2	1.8
chloride	0.8	3.3	1.9
sulphate	3.7	42.0	15.5
total alkalinity	63.8	422.0	189.0
pH	7.0	8.3	7.8
carbonate	0.0	0.0	0.0
bicarbonate	78.0	514.0	219.0
total hardness	47.3	147.1	105.1
fluoride	0.07	0.29	0.14
silica	4.4	13.6	8.0
conductance	136	810	360
threshold odour number	2	4	2
colour	15	150	97
tannin and lignin	0.50	2.60	1.5
turbidity	3.9	1800.0	167.0
TFR	88.0	530.0	232.0
TFRF	69.0	502.0	195.0
TNFR	2.0	1364.0	119.0
TNFRF	L.4	1198.0	102.0
surfactants	L.02	0.14	0.06
humic acids	L1.0	12.5	3.0
total organic carbon	10.0	147.0	31.0
total inorg. carbon	11.0	79.0	35.0
total diss. org. carbon	9.5	34.0	19.0
nitrate and nitrite N	L.003	0.31	0.07
ammonia nitrogen	0.01	0.25	0.06
total Kjeldahl N	0.3	3.2	1.2
total phosphorus	0.079	0.49	0.16
ortho-phosphorus	L.01	0.04	0.02
phenol	L.001	0.023	0.005
oil and grease	L.1	2.2	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.003	0.002
chemical oxygen demand	20.0	125.0	69.0
cadmium[a]	L.001	0.006	0.001
hexavalent chromium[a]	L.003	0.007	0.003
copper[a]	0.002	0.027	0.006
iron[a]	0.04	16.0	3.0
lead[a]	L.002	0.014	0.003
manganese[a]	0.025	0.39	0.09
silver[a]	L.001	0.009	0.003
zinc[a]	0.004	0.045	0.016
vanadium[b]	L.001	0.003	0.001
selenium[c]	L.0002	0.0008	0.0004
mercury[b]	L.0001	0.0009	0.0002
arsenic[c]	L.0002	0.003	0.001
nickel[a]	0.001	0.012	0.003
aluminum[a]	L.01	1.70	0.35
cobalt[a]	L.002	0.008	0.003
boron[c]	0.14	1.08	0.41

[a] extractable

[b] total

[c] dissolved

STATION: DA0181 Beaver River at Hwy 63
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	48.0	77.5	62.7
magnesium	13.5	32.5	18.7
sodium	22.5	412.5	88.1
potassium	2.4	8.0	3.7
chloride	17.8	575.0	106.2
sulphate	28.0	120.0	60.0
total alkalinity	162.0	328.0	210.0
pH	7.40	8.54	7.8
carbonate	0.0	0.0	0.0
bicarbonate	197.0	400.0	246.0
total hardness	175.4	308.8	233.3
fluoride	0.11	0.24	0.16
silica	1.6	8.9	6.0
conductance	460	2100	791
threshold odour number	2	8	3
colour	L5	70	33
tannin and lignin	0.20	2.60	1.0
turbidity	1.65	41.0	13.0
TFR	288.0	1452.0	494.0
TFRF	210.0	1204.0	434.0
TNFR	3.2	55.0	21.0
TNFRF	L.4	45.0	15.0
surfactants	L.02	0.21	0.08
humic acids	L1.0	8.5	1.9
total organic carbon	13.5	85.0	27.0
total inorg. carbon	24.0	95.0	39.0
total diss. org. carbon	7.0	35.0	18.0
nitrate and nitrite N	L.01	0.48	0.16
ammonia nitrogen	0.01	0.68	0.25
total Kjeldahl N	0.65	1.70	1.24
total phosphorus	0.025	0.60	0.12
ortho-phosphorus	L.003	0.046	0.01
phenol	L.001	0.010	0.002
oil and grease	L.1	1.8	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	22.0	326.0	72.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	0.205	0.018
copper[a]	0.002	0.014	0.005
iron[a]	0.3	14.0	2.5
lead[a]	L.002	0.027	0.005
manganese[a]	0.076	0.51	0.22
silver[a]	L.001	L.005	L.003
zinc[a]	0.014	0.109	0.031
vanadium[b]	L.001	0.002	0.001
selenium[c]	L.0002	0.001	0.0
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	L.0002	0.0014	0.001
nickel[a]	L.002	0.022	0.00 4
aluminum[a]	0.01	7.70	0.83
cobalt[a]	L.002	0.011	0.003
boron[c]	L.01	0.71	0.16

[a] extractable
[b] total
[c] dissolved

STATION: DA0182 Bridge Creek at Hwy 63
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	18.5	54.0	36.0
magnesium	6.3	17.5	11.4
sodium	14.0	47.0	30.1
potassium	1.2	2.9	2.1
chloride	4.4	38.0	15.8
sulphate	14.7	102.0	33.4
total alkalinity	73.8	186.0	133.8
pH	7.2	8.1	7.6
carbonate	0.0	0.0	0.0
bicarbonate	90.0	227.0	163.0
total hardness	72.1	206.9	135.9
fluoride	0.07	0.20	0.13
silica	2.7	9.9	5.5
conductance	180	560	351
threshold odour number	2	4	3
colour	15	300	140
tannin and lignin	0.15	3.90	2.2
turbidity	4.35	185.0	49.0
TFR	121.0	336.0	223.0
TFRF	86.0	308.0	174.0
TNFR	3.2	264.0	50.0
TNFRF	0.4	235.0	40.0
surfactants	L.02	0.21	0.06
humic acids	L1.0	21.5	5.3
total organic carbon	15.0	55.0	38.0
total inorg. carbon	12.0	53.5	27.0
total diss. org. carbon	12.0	46.0	30.0
nitrate and nitrite N	L.003	0.30	0.04
ammonia nitrogen	0.03	0.29	0.13
total Kjeldahl N	0.50	3.06	1.50
total phosphorus	0.056	0.20	0.01
ortho-phosphorus	0.005	0.060	0.02
phenol	L.001	0.013	0.004
oil and grease	L.1	1.8	0.7
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.003	0.002
chemical oxygen demand	36.0	1186.0	248.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.177	0.19
copper[a]	L.002	0.016	0.005
iron[a]	0.94	6.90	2.5
lead[a]	L.002	0.010	0.004
manganese[a]	0.049	0.280	0.12
silver[a]	L.001	L.005	L.003
zinc[a]	0.009	0.053	0.025
vanadium[b]	L.001	0.007	0.002
selenium[c]	L.0002	0.0005	0.0003
mercury[b]	L.0001	0.0064	0.0008
arsenic[c]	0.0004	0.005	0.001
nickel[a]	L.002	0.004	0.002
aluminum[a]	0.10	2.70	0.80
cobalt[a]	L.002	0.004	0.002
boron[c]	0.01	0.31	0.15

[a] extractable

[b] total

[c] dissolved

STATION: DA0190 Upper Tar River

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	22.5	81.5	39.0
magnesium	6.7	27.5	12.4
sodium	2.0	62.5	9.6
potassium	0.5	3.9	1.3
chloride	0.3	26.3	3.0
sulphate	3.9	34.5	12.4
total alkalinity	83.0	298.2	149.8
pH	7.3	8.2	7.7
carbonate	0.0	0.0	0.0
bicarbonate	101.0	364.0	183.0
total hardness	83.8	316.7	150.5
fluoride	0.09	0.22	0.15
silica	4.8	16.2	8.2
conductance	171	595	198
threshold odour number	1	4	2
colour	1	120	49
tannin and lignin	0.35	1.7	0.8
turbidity	1.35	10.5	3.9
TFR	104.0	389.0	183.0
TFRF	81.0	331.0	155.0
TNFR	2.4	19.6	6.8
TNFRF	L.4	6.0	2.6
surfactants	L.02	0.20	0.06
humic acids	L1.0	2.0	1.1
total organic carbon	9.0	36.0	17.0
total inorg. carbon	15.0	70.0	30.0
total diss. org. carbon	7.0	36.0	16.0
nitrate and nitrite N	L.003	0.24	0.06
ammonia nitrogen	L.01	0.21	0.06
total Kjeldahl N	L.1	3.2	1.0
total phosphorus	0.040	0.243	0.09
ortho-phosphorus	0.005	0.05	0.02
phenol	L.001	0.019	0.004
oil and grease	L.1	2.2	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	20.0	141.0	50.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	0.001	0.015	0.005
iron[a]	0.63	3.95	1.54
lead[a]	L.002	0.003	0.002
manganese[a]	0.047	0.50	0.19
silver[a]	L.001	0.005	0.002
zinc[a]	0.001	0.047	0.015
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0004	0.0001
arsenic[c]	L.0002	0.003	0.001
nickel[a]	L.002	L.002	L.002
aluminum[a]	L.01	0.24	0.08
cobalt[a]	L.002	L.002	L.002
boron[c]	0.01	0.28	0.12

[a] extractable

[b] total

[c] dissolved

STATION: DA0201 Athabasca River at km 10
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	15.5	42.5	29.6
magnesium	5.2	11.7	8.3
sodium	6.5	20.5	13.3
potassium	0.5	2.1	1.3
chloride	2.0	18.8	10.6
sulphate	0.6	32.0	19.5
total alkalinity	61.5	133.0	100.2
pH	7.3	8.0	7.7
carbonate	0.0	0.0	0.0
bicarbonate	75.0	162.0	122.0
total hardness	60.1	154.3	108.2
fluoride	0.07	0.90	0.22
silica	4.8	9.2	7.3
conductance	140	320	247
threshold odour number	2	4	3
colour	15	80	37
tannin and lignin	0.50	1.80	0.89
turbidity	1.6	168.0	59.0
TFR	88.0	210.0	159.0
TFRF	56.0	192.0	129.0
TNFR	1.6	237.0	81.0
TNFRF	L.4	211.0	70.0
surfactants	L.02	L.02	L.02
humic acids	L1.0	19.0	5.9
total organic carbon	11.0	61.0	21.0
total inorg. carbon	15.5	28.0	22.0
total diss. org. carbon	7.0	14.0	10.0
nitrate and nitrite N	L.01	0.62	0.12
ammonia nitrogen	0.03	0.82	0.24
total Kjeldahl N	0.64	4.17	1.59
total phosphorus	0.03	0.43	0.19
ortho-phosphorus	L.005	0.17	0.04
phenol	L.001	0.010	0.003
oil and grease	L.1	7.0	1.9
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.002	L.001
chemical oxygen demand	19.7	91.0	60.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.009	0.004
copper[a]	L.001	0.049	0.012
iron[a]	0.29	9.0	2.9
lead[a]	L.002	0.050	0.009
manganese[a]	0.008	0.280	0.09
silver[a]	L.005	0.005	0.005
zinc[a]	0.002	0.047	0.016
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0005	0.0008	0.006
mercury[b]	L.0001	L.0002	L.0002
arsenic[c]	L.001	L.005	L.003
nickel[a]	L.002	0.023	0.007
aluminum[a]	L.01	2.00	0.66
cobalt[a]	L.002	0.006	0.003
boron[c]	0.06	0.32	0.13

[a] extractable
[b] total
[c] dissolved

STATION: DA0203 Athabasca River at km 30
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	19.5	44.5	30.7
magnesium	5.8	12.2	8.6
sodium	5.0	17.5	12.2
potassium	0.4	2.1	1.3
chloride	2.9	14.8	8.9
sulphate	5.8	31.5	17.5
total alkalinity	70.4	141.6	103.5
pH	7.4	8.3	7.7
carbonate	0.0	0.0	0.0
bicarbonate	86.0	173.0	126.0
total hardness	72.6	161.3	112.0
fluoride	0.07	0.15	0.09
silica	6.1	7.8	7.0
conductance	150	350	255
threshold odour number	2	4	3
colour	15	100	38
tannin and lignin	0.06	1.65	0.78
turbidity	1.6	218.0	72.0
TFR	110.0	236.0	165.0
TFRF	64.0	216.0	137.0
TNFR	1.6	314.0	88.0
TNFRF	L.4	278.0	77.0
surfactants	L.02	L.02	L.02
humic acids	L1.0	14.0	5.6
total organic carbon	9.5	22.0	14.0
total inorg. carbon	11.0	35.0	22.0
total diss. org. carbon	10.0	14.0	12.0
nitrate and nitrite N	L.01	0.65	0.14
ammonia nitrogen	0.02	0.86	0.17
total Kjeldahl N	0.54	3.7	1.24
total phosphorus	0.03	0.43	0.19
ortho-phosphorus	1.005	0.26	0.06
phenol	L.001	0.011	0.004
oil and grease	L.1	2.0	0.4
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.005	L.002
chemical oxygen demand	28.4	154.0	77.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.009	0.004
copper[a]	0.001	0.035	0.010
iron[a]	0.31	8.60	2.9
lead[a]	L.002	0.009	0.003
manganese[a]	0.012	0.230	0.09
silver[a]	L.005	L.005	L.005
zinc[a]	0.005	0.029	0.011
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0005	0.0020	0.0010
mercury[b]	L.0001	0.0009	0.0003
arsenic[c]	L.001	0.010	0.005
nickel[a]	L.002	0.014	0.005
aluminum[a]	L.01	2.20	0.61
cobalt[a]	L.001	0.005	0.003
boron[c]	0.02	0.24	0.09

[a] extractable

[b] total

[c] dissolved

STATION: DA0204 Athabasca River at km 42

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	23.0	42.5	32.4
magnesium	6.8	11.9	9.0
sodium	5.0	23.0	14.5
potassium	0.5	2.1	1.4
chloride	2.2	26.4	11.6
sulphate	11.6	33.6	22.7
total alkalinity	82.0	134.0	107.9
pH	7.3	8.0	7.7
carbonate	0.0	0.0	0.0
bicarbonate	100.0	163.0	132.0
total hardness	85.4	155.1	117.9
fluoride	0.06	0.16	0.09
silica	4.5	9.7	6.8
conductance	160	360	284
threshold odour number	2	4	3
colour	10	40	27
tannin and lignin	0.06	0.95	0.59
turbidity	1.8	270.0	63.0
TFR	125.0	238.0	181.0
TFRF	80.0	224.0	155.0
TNFR	2.8	442.0	87.0
TNFRF	L.4	406.0	78.0
surfactants	L.02	L.02	L.02
humic acids	L1.0	16.0	4.0
total organic carbon	7.0	30.0	13.0
total inorg. carbon	15.0	80.0	28.0
total diss. org. carbon	7.0	12.0	9.0
nitrate and nitrite N	L.01	0.61	0.17
ammonia nitrogen	0.03	0.97	0.17
total Kjeldahl N	0.38	3.19	1.21
total phosphorus	0.03	0.197	0.07
ortho-phosphorus	L.005	0.02	0.01
phenol	L.001	0.019	0.004
oil and grease	L.1	4.4	0.7
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.013	0.005
chemical oxygen demand	30.0	96.5	55.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.008	0.004
copper[a]	L.001	0.016	0.006
iron[a]	0.43	8.9	2.2
lead[a]	L.002	0.048	0.008
manganese[a]	0.016	0.280	0.08
silver[a]	L.005	0.015	0.006
zinc[a]	0.004	0.046	0.014
vanadium[b]	L.001	0.011	0.004
selenium[c]	L.0005	L.0005	L.0005
mercury[b]	0.0001	0.0013	0.0006
arsenic[c]	L.005	0.010	0.006
nickel[a]	L.002	0.021	0.005
aluminum[a]	0.04	1.60	0.5
cobalt[a]	L.002	0.004	0.002
boron[c]	0.02	0.14	0.08

[a] extractable

[b] total

[c] dissolved

STATION: DA0205 Athabasca River at km 48

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	21.0	34.0	28.0
magnesium	5.7	10.01	7.9
sodium	7.4	22.0	14.2
potassium	0.5	1.7	1.3
chloride	1.4	23.5	12.5
sulphate	0.2	26.9	16.9
total alkalinity	86.0	114.0	98.4
pH	7.4	7.9	7.7
carbonate	0.0	0.0	0.0
bicarbonate	105.0	139.0	120.0
total hardness	75.9	126.1	102.4
fluoride	0.07	0.16	0.09
silica	5.7	9.5	7.3
conductance	190	310	255
threshold odour number	2	4	3
colour	10	120	42
tannin and lignin	0.07	2.60	0.86
turbidity	2.4	675.0	160.0
TFR	110.0	195.0	157.0
TFRF	60.0	180.0	126.0
TNFR	3.6	2602.0	435.0
TNFRF	0.8	2456.0	406.0
surfactants	L.02	0.04	0.02
humic acids	L1.0	11.5	5.0
total organic carbon	9.0	57.0	21.0
total inorg. carbon	18.0	26.0	22.0
total diss. org. carbon	9.0	19.0	14.0
nitrate and nitrite N	L.01	0.60	0.14
ammonia nitrogen	0.04	0.71	0.17
total Kjeldahl N	0.68	3.20	1.43
total phosphorus	0.04	1.85	0.34
ortho-phosphorus	L.005	0.03	0.02
phenol	L.001	0.009	0.003
oil and grease	L.1	0.9	0.3
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.005	L.003
chemical oxygen demand	27.9	267.0	97.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	0.018	0.006
copper[a]	L.001	0.093	0.026
iron[a]	0.36	63.0	10.8
lead[a]	L.002	0.019	0.006
manganese[a]	0.12	1.70	0.30
silver[a]	L.005	0.01	0.01
zinc[a]	0.004	0.331	0.065
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0005	0.006	0.002
mercury[b]	L.0002	0.0009	0.0003
arsenic[c]	L.001	0.015	0.006
nickel[a]	L.002	0.071	0.015
aluminum[a]	0.040	10.6	1.9
cobalt[a]	L.002	0.043	0.008
boron[c]	0.04	1.51	0.30

[a] extractable

[b] total

[c] dissolved

STATION: DA0206 Athabasca River at km 55

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	23.0	36.0	30.3
magnesium	6.5	9.6	8.0
sodium	5.5	21.0	12.1
potassium	0.5	1.9	1.3
chloride	2.7	22.0	9.5
sulphate	7.7	32.8	20.0
total alkalinity	90.0	124.0	101.0
pH	7.4	8.1	7.8
carbonate	0.0	0.0	0.0
bicarbonate	110.0	151.0	123.0
total hardness	84.2	129.4	106.6
fluoride	0.07	0.10	0.08
silica	4.6	8.7	6.1
conductance	186	330	267
threshold odour number	2	4	3
colour	20	50	31
tannin and lignin	0.06	0.75	0.50
turbidity	1.4	270.0	62.0
TFR	124.0	216.0	158.0
TFRF	48.0	188.0	116.0
TNFR	3.2	417.0	94.0
TNFRF	L.4	374.0	83.0
surfactants	L.02	L.02	L.02
humic acids	1.0	2.0	2.0
total organic carbon	7.0	14.5	11.0
total inorg. carbon	13.0	24.0	20.0
total diss. org. carbon	7.0	12.0	9.0
nitrate and nitrite N	L.01	0.60	0.12
ammonia nitrogen	0.055	1.02	0.37
total Kjeldahl N	0.72	2.75	1.38
total phosphorus	L.005	0.23	0.07
ortho-phosphorus	L.005	0.17	0.06
phenol	L.001	0.009	0.005
oil and grease	L.1	L.2	L.1
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.005	L.002
chemical oxygen demand	24.0	43.0	36.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.086	0.20
copper[a]	0.003	0.046	0.013
iron[a]	0.45	9.85	3.2
lead[a]	L.002	0.011	0.004
manganese[a]	0.02	0.46	0.13
silver[a]	L.005	L.005	L.005
zinc[a]	0.004	0.046	0.020
vanadium[b]	L.001	0.003	0.002
selenium[c]	L.0005	0.0034	0.0011
mercury[b]	L.0002	0.0011	0.0004
arsenic[c]	0.004	0.012	0.007
nickel[a]	L.002	0.130	0.026
aluminum[a]	L.01	1.25	0.39
cobalt[a]	L.002	0.035	0.007
boron[c]	0.06	0.18	0.09

[a] extractable

[b] total

[c] dissolved

STATION: DA0207 Athabasca River at Fort MacKay

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	26.5	52.5	33.7
magnesium	6.7	15.0	9.7
sodium	4.9	23.5	14.0
potassium	0.8	1.7	1.3
chloride	1.4	24.0	10.0
sulphate	10.3	32.0	19.0
total alkalinity	89.0	177.0	115.0
pH	7.5	8.1	7.9
carbonate	0.0	0.0	0.0
bicarbonate	108.0	216.0	140.0
total hardness	93.8	192.8	126.0
fluoride	L.05	0.12	0.09
silica	4.8	9.2	6.5
conductance	170	422	280
threshold odour number	2	8	3
colour	10	65	37
tannin and lignin	0.25	0.9	0.6
turbidity	1.8	102.0	23.0
TFR	114.0	260.0	161.0
TFRF	66.0	227.0	121.0
TNFR	2.4	180.4	40.0
TNFRF	0.8	162.8	35.0
surfactants	L.02	0.80	0.20
humic acids	L1.0	2.0	1.0
total organic carbon	6.5	27.0	13.0
total inorg. carbon	16.0	31.5	25.0
total diss. org. carbon	6.0	18.0	12.0
nitrate and nitrite N	0.012	0.13	0.05
ammonia nitrogen	L.01	0.12	0.06
total Kjeldahl N	0.50	1.20	0.88
total phosphorus	0.012	0.166	0.06
ortho-phosphorus	0.004	0.013	0.008
phenol	L.001	0.022	0.006
oil and grease	0.2	1.1	1.0
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	11.0	87.0	41.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	0.004	0.003
copper[a]	0.002	0.008	0.005
iron[a]	0.34	2.5	0.9
lead[a]	L.002	L.004	L.003
manganese[a]	0.015	0.147	0.05
silver[a]	L.001	L.004	L.002
zinc[a]	L.001	0.034	0.011
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.048	0.008
arsenic[c]	L.0002	0.0007	0.0004
nickel[a]	L.002	0.011	0.003
aluminum[a]	0.022	1.3	0.3
cobalt[a]	L.002	0.003	0..2
boron[c]	0.02	0.16	0.10

[a] extractable

[b] total

[c] dissolved

STATION: DA0208 Athabasca River at km 84

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	23.5	39.0	30.1
magnesium	6.7	11.2	8.3
sodium	6.4	22.0	14.1
potassium	0.5	1.9	1.3
chloride	4.4	11.0	12.2
sulphate	4.0	34.7	19.0
total alkalinity	77.6	120.4	99.0
pH	7.3	7.9	7.6
carbonate	0.0	0.0	0.0
bicarbonate	95.0	147.0	121.0
total hardness	86.7	143.5	109.4
fluoride	0.06	0.16	0.09
silica	4.6	8.2	6.9
conductance	175	350	262
threshold odour number	2	4	3
colour	15	50	29
tannin and lignin	0.40	1.55	0.78
turbidity	1.8	218.0	84.0
TFR	107.0	238.0	164.0
TFRF	84.0	206.0	139.0
TNFR	3.2	330.0	108.0
TNFRF	L.4	302.0	97.0
surfactants	L.02	L.02	L.02
humic acids	L1.0	22.0	5.1
total organic carbon	5.0	23.0	12.0
total inorg. carbon	15.5	33.0	21.0
total diss. org. carbon	5.0	10.5	7.0
nitrate and nitrite N	L.001	0.59	0.12
ammonia nitrogen	0.01	0.13	0.07
total Kjeldahl N	0.51	2.75	1.05
total phosphorus	0.02	0.67	0.18
ortho-phosphorus	L.005	0.07	0.02
phenol	L.001	0.007	0.003
oil and grease	L.1	0.4	0.2
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.008	0.003
chemical oxygen demand	24.8	79.0	54.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	0.006	0.004
copper[a]	0.003	0.077	0.017
iron[a]	0.38	8.0	3.0
lead[a]	L.002	0.016	0.006
manganese[a]	0.014	0.265	0.09
silver[a]	L.005	0.015	0.006
zinc[a]	0.011	0.098	0.033
vanadium[b]	L.001	0.002	0.001
selenium[c]	L.0005	0.0007	0.0006
mercury[b]	L.0001	0.0015	0.0004
arsenic[c]	L.001	0.005	0.003
nickel[a]	L.001	0.019	0.007
aluminum[a]	L.01	2.40	0.84
cobalt[a]	L.002	0.004	0.002
boron[c]	0.01	0.14	0.08

[a] extractable

[b] total

[c] dissolved

STATION: DA0209 Athabasca River at km 132

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	23.5	38.1	32.3
magnesium	6.6	10.7	8.7
sodium	8.0	30.0	18.0
potassium	0.8	1.9	1.5
chloride	5.5	35.7	17.0
sulphate	7.7	27.0	21.0
total alkalinity	76.0	121.6	104.0
pH	7.5	8.0	7.7
carbonate	0.0	0.0	0.0
bicarbonate	93.0	148.0	126.0
total hardness	85.9	139.0	117.0
fluoride	L.05	0.09	0.07
silica	4.6	8.3	6.5
conductance	170	390	292
threshold odour number	2	4	3
colour	10	70	28
tannin and lignin	0.40	1.40	0.72
turbidity	2.1	230.0	56.0
TFR	105.0	251.0	165.0
TFRF	66.0	211.0	120.0
TNFR	4.4	334.0	92.0
TNFRF	L.4	310.0	83.0
surfactants	L.02	L.02	0.02
humic acids	L1.0	11.0	4.0
total organic carbon	5.0	23.0	12.0
total inorg. carbon	17.0	40.0	25.0
total diss. org. carbon	6.0	12.0	10.0
nitrate and nitrite N	L.01	0.60	0.18
ammonia nitrogen	0.03	0.12	0.06
total Kjeldahl N	0.61	2.89	1.40
total phosphorus	0.03	0.36	0.15
ortho-phosphorus	L.01	0.02	0.01
phenol	L.001	0.010	0.005
oil and grease	L.1	L1.0	L.4
suphide	L.05	6.0	15.0
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.005	L.002
chemical oxygen demand	19.4	110.0	53.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.006	0.004
copper[a]	0.001	0.014	0.004
iron[a]	0.15	0.22	0.18
lead[a]	L.002	0.042	0.010
manganese[a]	0.019	0.49	0.12
silver[a]	L.004	L.005	L..05
zinc[a]	L.001	0.103	0.019
vanadium[b]	L.001	0.003	0.002
selenium[c]	L.0005	L.0005	L.0005
mercury[b]	L.0002	0.0013	0.0005
arsenic[c]	L.0005	0.005	0.002
nickel[a]	L.002	0.020	0.008
aluminum[a]	0.005	2.85	0.69
cobalt[a]	L.002	0.004	0.002
boron[c]	0.04	0.67	0.19

[a] extractable

[b] total

[c] dissolved

STATION: DA0210 Athabasca River - 21 km below Firebag River confluence
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	25.0	37.0	30.4
magnesium	6.8	10.3	8.5
sodium	8.0	32.5	17.3
potassium	0.6	1.9	1.4
chloride	5.7	36.8	18.9
sulphate	15.5	29.8	21.8
total alkalinity	86.0	125.6	100.3
pH	7.4	8.0	7.7
carbonate	0.0	0.0	0.0
bicarbonate	105.0	153.0	122.0
total hardness	90.4	133.6	110.8
fluoride	0.08	0.18	0.10
silica	4.9	9.3	7.0
conductance	200	390	293
threshold odour number	2	4	3
colour	10	60	29
tannin and lignin	0.45	2.30	0.89
turbidity	2.6	270.0	96.0
TFR	119.0	245.0	181.0
TFRF	98.0	224.0	158.0
TNFR	6.4	469.0	110.0
TNFRF	1.2	427.0	96.0
surfactants	L.02	L.02	L.02
humic acids	-	-	-
total organic carbon	9.5	22.5	14.0
total inorg. carbon	12.5	24.5	21.0
total diss. org. carbon	9.0	13.0	11.0
nitrate and nitrite N	L.01	0.59	0.12
ammonia nitrogen	L.02	0.24	0.07
total Kjeldahl N	0.70	2.89	1.37
total phosphorus	0.03	0.37	0.15
ortho-phosphorus	L.01	0.18	0.04
phenol	L.001	0.015	0.004
oil and grease	L.1	0.7	0.2
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.005	L.002
chemical oxygen demand	40.3	142.0	70.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.13	0.02
copper[a]	0.003	0.045	0.013
iron[a]	0.57	9.10	3.2
lead[a]	L.002	0.040	0.010
manganese[a]	0.027	0.255	0.10
silver[a]	L.005	0.01	0.01
zinc[a]	0.002	0.160	0.042
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0005	0.0009	0.0006
mercury[b]	L.0002	0.0014	0.0004
arsenic[c]	L.005	0.010	0.006
nickel[a]	L.002	0.021	0.009
aluminum[a]	0.07	2.60	0.93
cobalt[a]	L.002	0.005	0.003
boron[c]	0.02	0.17	0.09

[a] extractable
[b] total
[c] dissolved

STATION: DA0211 Athabasca River at Embarras Channel
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	25.1	25.5	25.3
magnesium	6.5	6.5	6.5
sodium	8.0	8.5	8.3
potassium	0.8	1.0	0.9
chloride	5.1	7.0	6.1
sulphate	12.0	12.0	12.0
total alkalinity	78.7	90.0	84.4
pH	7.6	7.9	7.8
carbonate	0.0	0.0	0.0
bicarbonate	96.0	110.0	103.0
total hardness	89.4	90.4	89.9
fluoride	0.09	0.09	0.09
silica	6.3	7.0	6.7
conductance	197	210	204
threshold odour number	4	4	4
colour	60	60	60
tannin and lignin	1.2	1.2	1.2
turbidity	76.9	76.9	76.9
TFR	137.0	137.0	137.0
TFRF	124.0	124.0	124.0
TNFR	498.0	498.0	498.0
TNFRF	87.6	87.6	87.6
surfactants	L.02	L.02	L.02
humic acids	L1.0	L1.0	L1.0
total organic carbon	13.5	17.0	15.0
total inorg. carbon	8.0	16.0	12.0
total diss. org. carbon	8.0	8.0	8.0
nitrate and nitrite N	0.03	0.03	0.03
ammonia nitrogen	0.05	0.05	0.05
total Kjeldahl N	1.25	1.25	1.25
total phosphorus	0.15	0.15	0.15
ortho-phosphorus	L.01	L.01	L.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	52.0	52.0	52.0
cadmium[a]	0.001	0.001	0.001
hexavalent chromium[a]	0.014	0.014	0.014
copper[a]	0.003	0.024	0.014
iron[a]	2.8	7.85	5.3
lead[a]	L.002	0.004	0.003
manganese[a]	0.10	0.125	0.11
silver[a]	0.001	0.003	0.002
zinc[a]	0.009	0.023	0.006
vanadium[b]	0.009	0.009	0.009
selenium[c]	L.0005	0.0007	0.0006
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	L.0005	0.0014	0.0010
nickel[a]	L.002	0.006	0.004
aluminum[a]	8.10	8.10	8.10
cobalt[a]	L.002	0.003	0.003
boron[c]	0.09	0.09	0.09

[a] extractable

[b] total

[c] dissolved

STATION: DB0011 MacKay River at Hwy 63

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	17.0	120.0	43.0
magnesium	5.7	47.0	15.3
sodium	12.0	140.0	38.3
potassium	0.5	6.2	2.1
chloride	2.4	57.0	13.0
sulphate	5.1	100.0	32.0
total alkalinity	13.4	577.0	170.0
pH	6.9	8.5	7.8
carbonate	0.0	0.0	0.0
bicarbonate	16.0	703.0	207.0
total hardness	65.9	493.1	170.0
fluoride	0.07	0.29	0.14
silica	1.0	20.0	7.5
conductance	166	1370	434
threshold odour number	2	8	3
colour	70	180	118
tannin and lignin	0.7	3.0	1.9
turbidity	0.9	370.0	35.0
TFR	113.0	862.0	276.0
TFRF	73.0	781.0	222.0
TNFR	0.4	547.0	58.0
TNFRF	L.4	463.0	48.0
surfactants	L.02	0.26	0.07
humic acids	L1.0	7.0	3.0
total organic carbon	9.0	45.0	32.0
total inorg. carbon	11.0	88.0	37.0
total diss. org. carbon	9.0	39.0	30.0
nitrate and nitrite N	L.003	0.32	0.07
ammonia nitrogen	0.02	0.50	0.12
total Kjeldahl N	0.67	2.17	1.32
total phosphorus	0.029	0.24	0.08
ortho-phosphorus	L.003	0.08	0.02
phenol	L.001	0.009	0.003
oil and grease	L.1	2.3	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	34.0	127.0	81.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	0.006	0.003
copper[a]	L.001	0.180	0.015
iron[a]	0.59	4.4	1.7
lead[a]	L.002	0.048	0.006
manganese[a]	0.015	0.29	0.06
silver[a]	L.001	0.005	0.003
zinc[a]	L.002	0.020	0.009
vanadium[b]	L.001	0.007	0.001
selenium[c]	L.0002	0.0007	0.0004
mercury[b]	L.0001	0.0021	0.0003
arsenic[c]	0.0003	0.007	0.001
nickel[a]	L.002	0.030	0.004
aluminum[a]	0.01	1.9	0.3
cobalt[a]	L.002	0.006	0.002
boron[c]	0.05	0.59	0.25

[a] extractable

[b] total

[c] dissolved

STATION: DB0020 Dover River
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	31.5	84.0	51.2
magnesium	11.2	31.5	19.3
sodium	32.0	92.5	53.5
potassium	1.4	5.0	3.3
chloride	3.7	14.5	8.8
sulphate	7.8	83.0	29.1
total alkalinity	161.0	436.0	272.2
pH	7.5	8.4	8.0
carbonate	0.0	0.0	0.0
bicarbonate	196.0	531.0	330.0
total hardness	124.8	339.4	207.2
fluoride	0.08	0.35	0.21
silica	2.1	15.7	7.8
conductance	370	920	554
threshold odour number	2	8	3
colour	25	160	89
tannin and lignin	0.6	2.3	1.5
turbidity	1.65	21.0	10.6
TFR	220.0	575.0	342.0
TFRF	122.5	505.0	285.0
TNFR	4.4	52.0	15.8
TNFRF	2.4	24.8	9.1
surfactants	L.02	0.19	0.07
humic acids	L1.0	7.0	1.9
total organic carbon	14.0	47.0	27.0
total inorg. carbon	30.0	87.0	53.0
total diss. org. carbon	12.0	43.0	26.0
nitrate and nitrite N	L.003	0.37	0.07
ammonia nitrogen	L.01	0.25	0.08
total Kjeldahl N	0.50	1.76	1.17
total phosphorus	0.03	0.30	0.10
ortho-phosphorus	0.005	0.03	0.02
phenol	L.001	0.23	0.003
oil and grease	L.1	1.7	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	36.0	137.0	85.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.006	0.003
copper[a]	0.001	0.020	0.006
iron[a]	0.65	2.70	1.49
lead[a]	L.002	0.024	0.005
manganese[a]	0.022	0.115	0.05
silver[a]	L.001	L.005	L.003
zinc[a]	0.002	0.067	0.013
vanadium[b]	L.001	0.001	0.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0003	0.0001
arsenic[c]	L.0002	0.007	0.001
nickel[a]	L.002	0.012	0.003
aluminum[a]	0.07	0.96	0.23
cobalt[a]	L.002	0.004	0.002
boron[c]	0.10	0.61	0.32

[a] extractable
[b] total
[c] dissolved

STATION: DB0030 Dunkirk River - near Fort MacKay
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	17.0	72.0	41.4
magnesium	5.5	21.2	12.2
sodium	5.7	30.0	15.5
potassium	0.5	3.5	1.7
chloride	0.3	4.4	1.4
sulphate	9.2	45.0	23.0
total alkalinity	62.9	273.0	153.0
pH	7.3	8.3	7.6
carbonate	0.0	0.0	0.0
bicarbonate	77.0	333.0	186.0
total hardness	65.1	276.1	154.0
fluoride	0.06	0.23	0.12
silica	2.7	12.6	7.4
conductance	141	580	320
threshold odour number	2	8	4
colour	50	180	106
tannin and lignin	0.85	2.55	1.6
turbidity	2.1	86.0	15.0
TFR	84.0	364.0	194.0
TFRF	49.0	284.0	142.0
TNFR	2.8	124.0	25.0
TNFRF	L.4	104.8	18.0
surfactants	L.02	0.20	0.07
humic acids	L1.0	11.5	3.0
total organic carbon	17.0	44.0	29.0
total inorg. carbon	10.0	58.0	28.0
total diss. org. carbon	15.0	42.0	27.0
nitrate and nitrite N	L.003	0.35	0.09
ammonia nitrogen	L.01	0.41	0.12
total Kjeldahl N	0.58	2.22	1.17
total phosphorus	0.06	0.50	0.16
ortho-phosphorus	0.013	0.18	0.04
phenol	L.001	0.014	0.004
oil and grease	L.1	0.9	0.3
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	51.0	97.8	78.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.007	0.003
copper[a]	0.001	0.017	0.0015
iron[a]	1.10	5.60	2.5
lead[a]	L.001	0.009	0.003
manganese[a]	0.03	0.52	0.13
silver[a]	L.001	L.005	L.003
zinc[a]	L.001	0.045	0.015
vanadium[b]	L.001	0.002	0.001
selenium[c]	L.0002	L.0005	L.0004
mercury[b]	L.0001	0.0003	0.0002
arsenic[c]	L.0002	0.001	0.001
nickel[a]	L.002	0.006	0.002
aluminum[a]	0.035	0.81	0.19
cobalt[a]	L.002	L.002	L.002
boron[c]	0.07	0.39	0.19

[a] extractable
[b] total
[c] dissolved

STATION: DB0035 Birch Lake near Snipe Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	26.5	26.5	26.5
magnesium	8.0	8.0	8.0
sodium	10.5	10.5	10.5
potassium	1.6	1.6	1.6
chloride	0.8	0.8	0.8
sulphate	13.0	13.0	13.0
total alkalinity	100.0	100.0	100.0
pH	8.8	8.8	8.8
carbonate	0.0	0.0	0.0
bicarbonate	122.0	122.0	122.0
total hardness	99.1	99.1	99.1
fluoride	0.15	0.15	0.15
silica	3.6	3.6	3.6
conductance	219	219	219
threshold odour number	2	2	2
colour	70	70	70
tannin and lignin	1.0	1.0	1.0
turbidity	3.3	3.3	3.3
TFR	133.0	133.0	133.0
TFRF	103.0	103.0	103.3
TNFR	3.2	3.2	3.2
TNFRF	L.4	L.4	L.4
surfactants	0.135	0.135	0.135
humic acids	L1.0	L1.0	L1.0
total organic carbon	25.5	25.5	25.5
total inorg. carbon	14.5	14.5	14.5
total diss. org. carbon	24.5	24.5	24.5
nitrate and nitrite N	L.003	L.003	L.003
ammonia nitrogen	0.05	0.05	0.05
total Kjeldahl N	2.43	2.43	2.43
total phosphorus	0.11	0.11	0.11
ortho-phosphorus	0.026	0.026	0.026
phenol	0.002	0.002	0.002
oil and grease	1.6	1.6	1.6
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	26.0	26.0	26.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	L.001	L.001	L.001
iron[a]	0.19	0.19	0.19
lead[a]	L.002	L.002	L.002
manganese[a]	0.026	0.026	0.026
silver[a]	L.001	L.001	L.001
zinc[a]	0.010	0.010	0.010
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0002	L.0002
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	0.0004	0.0004	0.0004
nickel[a]	L.002	L.002	L.002
aluminum[a]	0.05	0.05	0.05
cobalt[a]	L.002	L.002	L.002
boron[c]	0.19	0.19	0.19

[a] extractable
[b] total
[c] dissolved

STATION: DB0040 Thickwood Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	9.5	46.0	18.7
magnesium	3.4	16.2	6.6
sodium	2.0	14.0	4.0
potassium	0.1	2.9	0.7
chloride	0.2	4.3	1.2
sulphate	0.8	10.3	6.8
total alkalinity	35.2	182.0	70.0
pH	6.8	7.8	7.2
carbonate	0.0	0.0	0.0
bicarbonate	43.0	222.0	85.0
total hardness	37.7	181.6	73.8
fluoride	0.03	0.15	0.07
silica	1.0	16.0	6.1
conductance	83	360	139
threshold odour number	2	8	3
colour	85	180	148
tannin and lignin	1.2	2.75	2.2
turbidity	1.3	11.6	6.1
TFR	48.4	232.0	86.0
TFRF	L.4	173.0	54.0
TNFR	1.2	15.2	6.7
TNFRF	L.4	9.6	3.7
surfactants	L.02	0.15	0.07
humic acids	1.0	14.0	4.3
total organic carbon	18.0	36.5	27.0
total inorg. carbon	5.0	36.0	15.0
total diss. org. carbon	18.0	36.5	26.0
nitrate and nitrite N	L.001	1.0	0.1
ammonia nitrogen	L.01	0.49	0.12
total Kjeldahl N	0.3	2.05	1.2
total phosphorus	0.022	0.24	0.07
ortho-phosphorus	0.01	0.04	0.02
phenol	L.001	0.028	0.006
oil and grease	L.1	4.4	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	46.0	214.0	94.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	L.001	0.017	0.004
iron[a]	0.08	4.40	1.33
lead[a]	L.002	0.012	0.003
manganese[a]	0.019	0.46	0.10
silver[a]	L.001	L.005	L.003
zinc[a]	0.004	0.068	0.014
vanadium[b]	L.001	0.003	0.001
selenium[c]	L.0002	0.0005	0.0003
mercury[b]	L.0001	0.0007	0.0002
arsenic[c]	L.0002	0.003	0.001
nickel[a]	L.002	0.003	0.002
aluminum[a]	L.01	0.26	0.11
cobalt[a]	L.002	L.002	L.002
boron[c]	0.03	0.33	0.13

[a] extractable
[b] total
[c] dissolved

STATION: DC0010 Firebag River
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	20.0	59.9	30.2
magnesium	6.7	18.8	9.5
sodium	2.5	9.0	3.9
potassium	0.3	2.0	0.8
chloride	1.2	7.0	2.2
sulphate	0.1	8.6	4.4
total alkalinity	80.4	219.0	113.0
pH	7.2	8.4	7.8
carbonate	0.0	1.0	0.0
bicarbonate	98.0	267.0	137.0
total hardness	77.5	227.0	114.0
fluoride	0.06	0.15	0.10
silica	7.0	29.6	12.9
conductance	158	433	215
threshold odour number	2	8	3
colour	L5	80	34
tannin and lignin	0.3	1.7	0.8
turbidity	1.1	5.5	2.8
TFR	101.0	166.0	128.0
TFRF	69.0	149.0	105.0
TNFR	L.4	17.6	7.0
TNFRF	L.1	13.6	4.0
surfactants	L.02	0.14	0.04
humic acids	L1.0	3.5	1.3
total organic carbon	L1.0	18.0	11.0
total inorg. carbon	14.0	53.0	22.0
total diss. org. carbon	L1.0	16.0	9.0
nitrate and nitrite N	0.005	0.33	0.05
ammonia nitrogen	L.01	0.18	0.06
total Kjeldahl N	0.20	5.40	1.07
total phosphorus	0.026	0.11	0.05
ortho-phosphorus	0.005	0.03	0.02
phenol	L.001	0.010	0.002
oil and grease	L.1	0.9	0.4
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	12.0	106.0	44.0
cadmium[a]	L.001	0.003	0.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	L.001	0.026	0.005
iron[a]	0.36	0.89	0.61
lead[a]	L.002	0.009	0.003
manganese[a]	0.024	0.79	0.08
silver[a]	L.001	L.005	L.003
zinc[a]	L.001	0.043	0.009
vanadium[b]	L.001	0.003	0.001
selenium[c]	L.0002	0.0005	0.0004
mercury[b]	L.0001	0.0013	0.0002
arsenic[c]	L.0002	0.003	0.001
nickel[a]	L.002	0.013	0.003
aluminum[a]	0.009	0.48	0.08
cobalt[a]	L.001	0.03	0.00
boron[c]	0.02	0.18	0.07

[a] extractable
[b] total
[c] dissolved

STATION: DC0011 Firebag River near Mouth

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	24.0	32.0	28.3
magnesium	8.3	10.7	9.2
sodium	3.3	4.6	4.0
potassium	0.65	0.88	0.78
chloride	2.0	2.5	2.2
sulphate	0.1	5.0	3.0
total alkalinity	100.2	129.2	111.7
pH	7.68	7.89	7.77
carbonate	0.0	0.0	0.0
bicarbonate	122.0	157.0	136.0
total hardness	94.1	124.0	108.5
fluoride	0.09	0.13	0.11
silica	9.7	16.0	11.8
conductance	171	231	198
threshold odour number	2	8	5
colour	25	35	32
tannin and lignin	0.5	0.7	0.6
turbidity	2.0	10.4	5.6
TFR	114.0	155.0	129.0
TFRF	100.0	130.0	110.0
TNFR	4.0	17.2	10.3
TNFRF	L.4	12.8	6.4
surfactants	0.06	0.09	0.07
humic acids	L1.0	L1.0	L1.0
total organic carbon	7.0	11.0	9.2
total inorg. carbon	19.0	32.0	24.5
total diss. org. carbon	6.5	11.0	9.0
nitrate and nitrite N	L.003	0.090	0.046
ammonia nitrogen	L.01	0.06	0.04
total Kjeldahl N	0.82	1.07	0.95
total phosphorus	0.034	0.051	0.044
ortho-phosphorus	0.010	0.016	0.013
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	25.0	87.0	47.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	0.001	0.001	0.001
iron[a]	0.65	0.79	0.74
lead[a]	L.002	0.004	0.003
manganese[a]	0.024	0.049	0.037
silver[a]	L.001	0.001	0.001
zinc[a]	0.003	0.009	0.007
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0002	L.0002
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	L.0002	L.0002	L.0002
nickel[a]	L.002	L.002	L.002
aluminum[a]	0.05	0.12	0.09
cobalt[a]	L.002	L.002	L.002
boron[c]	-	-	-

[a] extractable

[b] total

[c] dissolved

STATION: DC0020 Lost Creek
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	13.0	30.5	22.6
magnesium	3.7	8.3	6.3
sodium	1.4	2.5	2.0
potassium	0.04	0.4	0.2
chloride	0.2	1.2	0.4
sulphate	0.1	4.9	2.9
total alkalinity	46.4	112.9	83.2
pH	7.4	8.3	7.8
carbonate	0.0	0.0	0.0
bicarbonate	57.0	138.0	102.0
total hardness	47.7	110.3	82.2
fluoride	L.05	0.13	0.07
silica	2.7	7.5	6.0
conductance	88	198	150
threshold odour number	2	4	3
colour	40	80	54
tannin and lignin	0.6	1.6	0.9
turbidity	0.6	2.2	1.4
TFR	55.0	120.0	93.0
TFRF	46.0	101.0	74.0
TNFR	L.4	6.8	2.3
TNFRF	L.4	4.0	0.9
surfactants	L.02	0.09	0.05
humic acids	L1.0	2.5	1.2
total organic carbon	6.0	15.5	11.0
total inorg. carbon	8.0	27.0	17.0
total diss. org. carbon	6.0	15.0	11.0
nitrate and nitrite N	0.003	0.049	0.01
ammonia nitrogen	L.01	0.12	0.04
total Kjeldahl N	0.48	5.98	1.59
total phosphorus	0.03	0.051	0.04
ortho-phosphorus	0.01	0.03	0.02
phenol	L.001	0.011	0.004
oil and grease	L.1	0.5	0.2
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	25.0	85.0	42.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	L.001	0.005	0.002
iron[a]	0.25	0.74	0.56
lead[a]	L.002	L.002	L.002
manganese[a]	0.013	0.51	0.26
silver[a]	L.001	L.005	L.002
zinc[a]	L.001	0.023	0.009
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0006	0.0002
arsenic[c]	L.0002	L.0005	L.0003
nickel[a]	L.002	0.005	0.002
aluminum[a]	L.01	0.10	0.03
cobalt[a]	L.000	L.002	L.002
boron[c]	0.04	0.15	0.10

[a] extractable
[b] total
[c] dissolved

STATION: DD0010 Athabasca River at Embarras
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	26.0	40.0	32.3
magnesium	6.0	11.7	8.8
sodium	6.8	26.1	14.4
potassium	1.15	2.0	1.5
chloride	6.0	26.4	12.8
sulphate	8.6	27.2	14.9
total alkalinity	91.8	144.0	114.5
pH	7.7	8.01	7.9
carbonate	0.0	0.0	0.0
bicarbonate	112.0	176.0	140.0
total hardness	89.6	148.0	116.9
fluoride	0.09	0.18	0.12
silica	5.2	7.9	6.4
conductance	190	285	261
threshold odour number	1	4	3
colour	25	50	35
tannin and lignin	0.3	0.8	0.6
turbidity	1.5	290.0	93.0
TFR	125.0	252.0	171.0
TFRF	91.0	221.0	143.0
TNFR	3.2	592.0	173.0
TNFRF	1.2	548.0	158.0
surfactants	L.02	0.07	0.05
humic acids	L1.0	1.0	1.0
total organic carbon	10.0	25.0	15.0
total inorg. carbon	15.5	31.5	21.6
total diss. org. carbon	6.0	24.5	13.1
nitrate and nitrite N	0.005	0.083	0.04
ammonia nitrogen	L.01	0.07	0.04
total Kjeldahl N	1.06	1.45	1.26
total phosphorus	0.032	0.36	0.13
ortho-phosphorus	0.005	0.01	0.01
phenol	L.001	L.001	L.001
oil and grease	0.1	0.1	0.1
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	36.0	55.0	49.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.032	0.010
copper[a]	0.003	0.031	0.011
iron[a]	0.85	15.5	4.9
lead[a]	L.002	L.002	L.002
manganese[a]	0.048	0.290	0.119
silver[a]	L.001	0.001	0.001
zinc[a]	0.011	0.074	0.033
vanadium[b]	L.000	0.003	0.002
selenium[c]	L.0002	0.0005	0.0003
mercury[b]	L.0001	0.0004	0.0002
arsenic[c]	L.0002	0.0016	0.0007
nickel[a]	L.002	0.008	0.004
aluminum[a]	0.17	23.7	6.3
cobalt[a]	L.002	0.003	0.002
boron[c]	0.05	0.08	0.07

[a] extractable
[b] total
[c] dissolved

STATION: DD0020 Richardson River
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	9.3	10.5	9.7
magnesium	3.3	3.9	3.6
sodium	1.7	2.3	2.0
potassium	0.5	0.95	0.8
chloride	0.9	1.6	1.2
sulphate	1.8	4.5	3.5
total alkalinity	36.5	42.0	39.3
pH	7.06	7.56	7.3
carbonate	0.0	0.0	0.0
bicarbonate	44.0	51.0	48.0
total hardness	36.8	42.3	39.3
fluoride	0.07	0.09	0.08
silica	10.9	17.9	13.3
conductance	74	86	80
threshold odour number	2	4	2
colour	15	30	24
tannin and lignin	0.4	1.05	0.6
turbidity	1.65	18.7	6.1
TFR	53.8	66.0	58.0
TFRF	39.0	58.0	48.0
TNFR	5.6	37.6	14.6
TNFRF	2.8	26.4	9.4
surfactants	0.025	0.14	0.07
humic acids	L1.0	L1.0	L1.0
total organic carbon	2.5	9.0	4.6
total inorg. carbon	6.0	12.5	10.0
total diss. org. carbon	2.5	7.0	4.0
nitrate and nitrite N	0.006	0.083	0.03
ammonia nitrogen	L.01	0.10	0.03
total Kjeldahl N	0.35	1.58	0.85
total phosphorus	0.03	0.06	0.04
ortho-phosphorus	0.008	0.02	0.01
phenol	L.001	L.001	L.001
oil and grease	L.1	0.7	0.4
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	7.0	25.0	17.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	L.003	L.003
copper[a]	L.001	0.017	0.005
iron[a]	0.54	0.82	0.65
lead[a]	L.002	0.003	0.002
manganese[a]	0.030	0.032	0.031
silver[a]	L.001	L.001	L.001
zinc[a]	0.006	0.034	0.014
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	L.0002	L.0005	L.0003
nickel[a]	L.002	L.002	L.002
aluminum[a]	0.05	0.39	0.15
cobalt[a]	L.002	L.002	L.002
boron[c]	0.02	0.08	0.04

[a] extractable
[b] total
[c] dissolved

STATION: DD0090 Jackfish Creek

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	16.0	27.5	20.8
magnesium	4.7	7.7	6.0
sodium	4.0	8.0	6.0
potassium	0.88	1.70	1.2
chloride	2.8	5.6	4.1
sulphate	1.6	12.5	7.0
total alkalinity	60.0	93.0	75.7
pH	7.2	7.77	7.6
carbonate	0.0	0.0	0.0
bicarbonate	73.0	113.0	92.0
total hardness	59.3	100.4	76.5
fluoride	0.07	0.08	0.08
silica	5.1	7.9	6.5
conductance	119	209	166
threshold odour number	2	16	6
colour	L5	25	14
tannin and lignin	0.4	0.95	0.5
turbidity	2.7	86.0	25.0
TFR	78.4	125.0	104.0
TFRF	63.0	191.0	85.0
TNFR	2.4	69.2	24.0
TNFRF	L.4	56.4	17.0
surfactants	L.02	0.05	0.03
humic acids	-	-	-
total organic carbon	4.5	11.0	8.0
total inorg. carbon	13.0	22.0	17.0
total diss. org. carbon	4.0	10.0	7.0
nitrate and nitrite N	0.004	0.267	0.06
ammonia nitrogen	L.01	0.08	0.03
total Kjeldahl N	0.82	1.06	0.95
total phosphorus	0.020	0.093	0.05
ortho-phosphorus	0.006	L.01	L.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	23.0	60.0	36.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.005	0.004
copper[a]	0.002	0.006	0.003
iron[a]	0.41	4.50	1.45
lead[a]	L.002	0.006	0.003
manganese[a]	0.030	0.080	0.045
silver[a]	L.001	L.001	L.001
zinc[a]	0.008	0.310	0.093
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0003	0.0001
arsenic[c]	0.0003	0.0010	0.0006
nickel[a]	L.002	0.009	0.004
aluminum[a]	0.09	1.40	0.62
cobalt[a]	L.002	L.002	L.002
boron[c]	0.02	0.05	0.04

[a] extractable

[b] total

[c] dissolved

STATION: DD0212 Athabasca River at Big Point Channel

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	24.2	33.0	27.3
magnesium	6.3	8.7	7.4
sodium	7.5	13.0	9.2
potassium	0.9	1.3	1.1
chloride	5.4	11.0	7.1
sulphate	10.0	15.0	12.9
total alkalinity	78.2	110.5	92.6
pH	7.6	8.0	7.8
carbonate	0.0	0.0	0.0
bicarbonate	95.0	135.0	113.0
total hardness	87.4	118.2	98.6
fluoride	0.09	6.0	1.6
silica	4.0	7.5	5.6
conductance	196	237	217
threshold odour number	2	4	3
colour	20	50	31
tannin and lignin	0.3	1.3	0.6
turbidity	18.3	97.0	44.0
TFR	124.0	153.0	139.0
TFRF	103.0	132.0	120.0
TNFR	22.8	169.0	66.3
TNFRF	18.8	144.0	55.2
surfactants	L.02	0.07	0.04
humic acids	-	-	-
total organic carbon	6.5	18.0	11.0
total inorg. carbon	15.5	26.0	20.0
total diss. org. carbon	5.0	9.0	7.0
nitrate and nitrite N	0.006	0.267	0.06
ammonia nitrogen	L.01	0.08	0.05
total Kjeldahl N	0.58	1.22	0.89
total phosphorus	0.036	0.17	0.07
ortho-phosphorus	0.003	0.010	0.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	15.0	76.0	34.0
cadmium[a]	L.001	0.001	0.001
hexavalent chromium[a]	L.003	0.013	0.006
copper[a]	0.002	0.021	0.006
iron[a]	0.75	6.8	2.7
lead[a]	L.002	0.010	0.005
manganese[a]	0.035	0.13	0.08
silver[a]	L.001	L.001	L.001
zinc[a]	0.0-8	0.215	0.060
vanadium[b]	L.001	0.001	0.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0002	0.0001
arsenic[c]	0.0004	0.0014	0.0006
nickel[a]	L.002	0.006	0.004
aluminum[a]	0.47	0.54	0.50
cobalt[a]	L.002	0.004	0.003
boron[c]	0.02	0.14	0.06

[a] extractable

[b] total

[c] dissolved

STATION: KF0140 Prairie River

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	32.5	41.0	36.9
magnesium	7.7	11,5	9.7
sodium	7.5	38.5	23.9
potassium	1.8	3.3	2.5
chloride	5.3	46.0	26.9
sulphate	19.7	51.0	35.0
total alkalinity	95.8	112.6	106.2
pH	7.6	8.02	7.8
carbonate	0.0	0.0	0.0
bicarbonate	117.0	137.0	130.0
total hardness	112.9	149.7	132.0
fluoride	0.15	0.16	0.16
silica	2.1	4.3	3.3
conductance	255	453	357
threshold odour number	2	4	4
colour	20	35	26
tannin and lignin	0.4	0.9	0.7
turbidity	12.6	425.0	212.0
TFR	153.0	287.0	215.0
TFRF	117.0	239.0	181.0
TNFR	10.4	410.0	192.0
TNFRF	8.0	367.0	170.0
surfactants	L.02	0.11	0.07
humic acids	-	-	-
total organic carbon	6.0	17.5	13.1
total inorg. carbon	16.0	34.0	24.0
total diss. org. carbon	6.0	12.5	10.2
nitrate and nitrite N	L.01	0.056	0.3
ammonia nitrogen	0.015	0.07	0.05
total Kjeldahl N	1.50	6.04	2.72
total phosphorus	0.028	0.31	0.15
ortho-phosphorus	0.003	0.01	0.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	18.0	78.0	45.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.025	0.010
copper[a]	0.003	0.013	0.009
iron[a]	0.52	15.1	7.9
lead[a]	L.002	0.003	0.002
manganese[a]	0.015	0.285	0.139
silver[a]	L.001	L.001	L.001
zinc[a]	0.021	0.044	0.032
vanadium[b]	L.001	0.007	0.003
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	0.0003	0.0033	0.0010
nickel[a]	L.002	0.004	0.003
aluminum[a]	0.31	30.0	11.4
cobalt[a]	L.002	0.002	0.002
boron[c]	0.05	0.13	0.09

[a] extractable
[b] total
[c] dissolved

STATION: DA0200 Upper Gardner Lake in Birch Mountains
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	3.8	32.0	16.2
magnesium	0.9	10.0	4.9
sodium	0.5	3.5	2.8
potassium	0.2	2.0	1.0
chloride	0.2	2.1	0.6
sulphate	0.5	7.1	5.4
total alkalinity	14.4	122.0	58.1
pH	7.1	8.1	7.5
carbonate	0.0	0.0	0.0
bicarbonate	18.0	149.0	71.0
total hardness	13.2	121.1	60.5
fluoride	0.07	0.27	0.12
silica	0.5	9.3	4.9
conductance	34	223	121
threshold odour number	2	8	3
colour	L5	80	32
tannin and lignin	0.30	2.40	0.9
turbidity	1.1	5.3	2.5
TFR	22.1	150.0	77.0
TFRF	19.0	126.0	57.0
TNFR	0.8	22.8	5.5
TNFRF	L.4	12.8	2.3
surfactants	L.02	0.10	0.05
humic acids	L1.0	1.0	1.0
total organic carbon	2.0	17.0	11.0
total inorg. carbon	3.0	20.0	10.0
total diss. org. carbon	2.0	16.0	10.0
nitrate and nitrite N	L.003	0.24	0.06
ammonia nitrogen	L.01	0.12	0.04
total Kjeldahl N	0.58	1.70	0.96
total phosphorus	0.2	0.22	0.08
ortho-phosphorus	0.003	0.18	0.03
phenol	L.001	0.003	0.002
oil and grease	L.1	1.9	0.6
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	0.001	0.001
chemical oxygen demand	13.0	111.0	48.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.94	0.09
copper[a]	L.001	0.037	0.007
iron[a]	0.15	2.25	0.41
lead[a]	L.002	0.006	0.003
manganese[a]	0.003	0.4	0.1
silver[a]	L.001	L.005	L.002
zinc[a]	L.001	0.133	0.020
vanadium[b]	L.001	0.001	0.001
selenium[c]	L.0002	L.0005	L.0004
mercury[b]	L.0001	0.0001	0.0001
arsenic[c]	L.0002	0.0022	0.001
nickel[a]	L.002	0.007	0.003
aluminum[a]	L.01	0.59	9.11
cobalt[a]	L.002	L.002	L.002
boron[c]	0.01	0.24	0.10

[a] extractable

[b] total

[c] dissolved

STATION: DA0210 Namur Lake at Birch Mountain Lodge
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	4.5	7.8	5.7
magnesium	1.2	2.2	1.8
sodium	1.5	7.5	2.6
potassium	0.6	1.4	1.0
chloride	0.2	1.5	0.5
sulphate	4.0	6.8	5.2
total alkalinity	15.8	34.0	21.5
pH	6.8	7.8	7.1
carbonate	0.0	0.0	0.0
bicarbonate	19.0	41.0	26.0
total hardness	16.2	28.5	21.7
fluoride	0.03	0.08	0.06
silica	0.21	1.1	0.6
conductance	43	89	55
threshold odour number	2	8	3
colour	L5	15	7
tannin and lignin	L.10	0.60	0.4
turbidity	0.4	6.8	1.8
TFR	25.5	45.0	32.5
TFRF	16.0	33.0	22.0
TNFR	L.4	15.6	3.7
TNFRF	L.4	10.0	1.8
surfactants	L.02	0.07	0.04
humic acids	L1.0	L1.0	L1.0
total organic carbon	5.0	15.5	8.0
total inorg. carbon	3.0	6.0	4.0
total diss. org. carbon	4.5	14.0	7.0
nitrate and nitrite N	L.003	0.05	0.02
ammonia nitrogen	L.01	0.15	0.06
total Kjeldahl N	0.39	1.0	0.72
total phosphorus	0.02	0.10	0.04
ortho-phosphorus	L.003	0.08	0.02
phenol	L.001	0.008	0.002
oil and grease	L.1	2.1	0.5
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	0.002	0.002	0.002
chemical oxygen demand	8.0	96.0	37.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.004	0.003
copper[a]	0.001	0.036	0.009
iron[a]	0.07	0.44	0.21
lead[a]	L.002	0.006	0.002
manganese[a]	0.003	0.023	0.01
silver[a]	L.001	L.005	L.002
zinc[a]	0.003	0.025	0.011
vanadium[b]	L.001	0.001	0.001
selenium[c]	L.0002	L.0005	L.0004
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	L.0002	0.003	0.001
nickel[a]	L.002	0.006	0.002
aluminum[a]	L.01	0.83	0.24
cobalt[a]	L.002	L.002	L.002
boron[c]	0.01	0.09	0.05

[a] extractable
[b] total
[c] dissolved

STATION: DA0220 Eaglenest Lake
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	12.0	24.0	16.8
magnesium	3.8	7.8	5.7
sodium	2.4	5.4	3.6
potassium	0.6	1.3	0.9
chloride	0.2	2.2	0.6
sulphate	2.5	6.6	4.9
total alkalinity	46.2	92.0	65.4
pH	6.8	7.6	7.3
carbonate	0.0	0.0	0.0
bicarbonate	56.0	112.0	80.0
total hardness	45.6	91.2	65.4
fluoride	0.09	0.19	0.13
silica	0.3	5.5	2.6
conductance	90	191	133
threshold odour number	2	8	4
colour	25	55	39
tannin and lignin	0.30	3.35	1.0
turbidity	2.3	453.0	42.1
TFR	54.0	121.0	82.0
TFRF	30.0	100.0	58.0
TNFR	3.2	352.0	38.0
TNFRF	L.4	232.0	23.0
surfactants	L.02	0.16	0.06
humic acids	L1.0	1.0	1.0
total organic carbon	8.0	21.5	15.0
total inorg. carbon	9.0	17.5	13.0
total diss. org. carbon	7.0	17.0	13.0
nitrate and nitrite N	0.005	0.380	0.09
ammonia nitrogen	0.01	0.45	0.16
total Kjeldahl N	0.67	6.55	1.97
total phosphorus	0.09	0.58	0.18
ortho-phosphorus	0.03	0.15	0.06
phenol	L.001	0.003	0.002
oil and grease	L.1	3.3	1.0
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	L.001	L.001	L.001
chemical oxygen demand	28.0	235.0	62.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.004	0.003
copper[a]	0.001	0.122	0.024
iron[a]	0.43	9.60	1.59
lead[a]	L.002	0.003	L.002
manganese[a]	0.032	0.41	0.13
silver[a]	L.001	L.005	L.002
zinc[a]	0.003	0.051	0.014
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	0.0005	0.0004
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	L.0002	0.005	0.001
nickel[a]	L.002	0.020	0.004
aluminum[a]	0.02	1.13	0.20
cobalt[a]	L.002	L.002	L.002
boron[c]	0.02	0.25	0.09

[a] extractable
[b] total
[c] dissolved

STATION: DA2000 Gardiner Lake - Lower Site

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	4.5	32.5	17.9
magnesium	1.5	10.0	5.5
sodium	1.9	3.5	3.0
potassium	0.8	1.5	1.1
chloride	0.4	2.0	0.9
sulphate	5.5	7.1	6.3
total alkalinity	17.0	121.6	64.3
pH	6.9	7.4	7.1
carbonate	0.0	0.0	0.0
bicarbonate	21.0	148.0	79.0
total hardness	17.4	122.3	67.3
fluoride	0.05	0.16	0.10
silica	0.4	12.5	7.8
conductance	44	250	142
threshold odour number	2	8	4
colour	5	90	40
tannin and lignin	0.5	3.15	1.3
turbidity	0.6	5.3	2.8
TFR	28.5	150.0	88.1
TFRF	21.0	82.5	60.0
TNFR	2.0	8.0	3.8
TNFRF	L.4	4.4	1.9
surfactants	L.02	L.02	L.02
humic acids	-	-	-
total organic carbon	5.0	21.0	12.0
total inorg. carbon	8.5	32.0	16.0
total diss. org. carbon	5.0	21.0	11.0
nitrate and nitrite N	0.05	0.31	0.14
ammonia nitrogen	L.01	1.04	0.27
total Kjeldahl N	0.64	4.51	1.73
total phosphorus	0.05	0.28	0.18
ortho-phosphorus	0.01	0.19	0.06
phenol	L.001	0.007	0.003
oil and grease	L.1	1.4	0.7
suphide	L.05	L.05	L.05
cyanide	L.01	L.01	L.01
chlorophyll a	0.002	0.033	0.018
chemical oxygen demand	32.0	103.0	63.0
cadmium[a]	L.001	L.002	L.001
hexavalent chromium[a]	L.002	0.005	0.003
copper[a]	0.002	0.011	0.006
iron[a]	0.07	0.27	0.11
lead[a]	L.002	L.002	L.002
manganese[a]	0.003	6.90	1.74
silver[a]	L.001	L.005	L.004
zinc[a]	0.002	0.023	0.009
vanadium[b]	L.001	0.002	0.001
selenium[c]	L.0005	L.0005	L.0005
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	L.0005	0.005	0.002
nickel[a]	0.001	L.002	L.001
aluminum[a]	0.01	0.21	0.07
cobalt[a]	L.002	L.002	L.002
boron[c]	0.02	0.27	0.11

[a] extractable

[b] total

[c] dissolved

STATION: DD0080 Richardson Lake - centre
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	25.5	29.0	27.2
magnesium	6.7	7.5	7.2
sodium	7.6	10.3	8.3
potassium	1.2	1.8	1.6
chloride	4.9	7.7	5.7
sulphate	8.2	16.0	12.7
total alkalinity	86.8	99.5	91.8
pH	7.3	7.9	7.7
carbonate	0.0	0.0	0.0
bicarbonate	106.0	121.0	112.0
total hardness	92.5	103.3	97.4
fluoride	0.10	0.10	0.10
silica	4.1	8.2	5.9
conductance	191	230	213
threshold odour number	2	4	2
colour	L5	20	12
tannin and lignin	0.3	0.85	0.5
turbidity	1.0	120.0	43.0
TFR	122.0	140.0	132.0
TFRF	101.0	122.0	109.0
TNFR	0.8	126.0	46.0
TNFRF	0.0	106.0	31.0
surfactants	L.02	0.06	0.04
humic acids	-	-	-
total organic carbon	8.5	13.5	11.0
total inorg. carbon	14.5	22.0	18.0
total diss. org. carbon	4.5	10.5	8.0
nitrate and nitrite N	0.003	0.097	0.03
ammonia nitrogen	L.01	0.10	0.05
total Kjeldahl N	0.94	1.74	1.28
total phosphorus	0.022	0.138	0.07
ortho-phosphorus	0.005	0.01	0.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	7.0	58.0	32.0
cadmium[a]	L.001	0.002	0.001
hexavalent chromium[a]	L.003	0.009	0.005
copper[a]	0.002	0.021	0.006
iron[a]	0.17	4.75	2.2
lead[a]	0.002	0.006	0.003
manganese[a]	0.002	0.135	0.049
silver[a]	L.001	L.001	L.001
zinc[a]	0.008	0.053	0.021
vanadium[b]	L.001	0.003	0.002
selenium[c]	L.0002	L.0005	L.003
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	L.0002	0.0009	0.0004
nickel[a]	L.002	0.005	0.003
aluminum[a]	0.06	7.2	2.2
cobalt[a]	L.002	0.003	0.002
boron[c]	0.04	0.12	0.07

[a] extractable
[b] total
[c] dissolved

STATION: KF0100 Mamawi Lake Channel
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	26.0	40.0	31.8
magnesium	6.7	11.4	8.5
sodium	7.5	38.0	14.9
potassium	1.10	3.20	1.8
chloride	5.3	43.0	13.8
sulphate	9.9	57.5	30.7
total alkalinity	88.4	118.4	102.3
pH	7.5	7.98	7.8
carbonate	0.0	0.0	0.0
bicarbonate	108.0	144.0	125.0
total hardness	92.5	146.8	114.4
fluoride	0.09	0.17	0.13
silica	2.0	6.1	3.7
conductance	210	438	272
threshold odour number	2	8	4
colour	15	60	31
tannin and lignin	0.3	1.20	0.6
turbidity	7.7	350.0	105.0
TFR	126.0	276.0	169.0
TFRF	97.0	249.0	143.0
TNFR	10.0	96.8	48.7
TNFRF	7.2	302.0	96.0
surfactants	L.02	0.11	0.05
humic acids	-	-	-
total organic carbon	9.0	18.5	14.0
total inorg. carbon	17.0	24.0	20.0
total diss. org. carbon	5.5	17.0	10.5
nitrate and nitrite N	0.005	0.059	0.02
ammonia nitrogen	0.01	0.05	0.03
total Kjeldahl N	0.48	1.60	1.09
total phosphorus	0.018	0.236	0.09
ortho-phosphorus	L.003	L.01	L.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	18.0	84.0	55.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.006	0.004
copper[a]	0.003	0.014	0.006
iron[a]	0.39	12.50	3.39
lead[a]	L.002	0.004	0.002
manganese[a]	0.017	0.26	0.09
silver[a]	L.001	L.001	L.001
zinc[a]	0.014	0.081	0.039
vanadium[b]	L.001	0.002	0.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0003	0.0001
arsenic[c]	0.0003	0.0023	0.0008
nickel[a]	L.002	L.02	L.01
aluminum[a]	0.25	3.90	2.12
cobalt[a]	L.002	L.002	L.002
boron[c]	0.06	0.07	0.07

[a] extractable
[b] total
[c] dissolved

STATION: KF0101 Chenal des Quatre Fourchers
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	26.0	34.5	30.2
magnesium	6.7	9.5	8.0
sodium	7.5	8.5	3.1
potassium	1.20	2.65	1.6
chloride	5.5	31.2	11.9
sulphate	11.0	39.3	17.2
total alkalinity	90.0	110.0	97.9
pH	7.7	8.09	7.9
carbonate	0.0	0.0	0.0
bicarbonate	110.0	134.0	119.0
total hardness	92.5	125.3	108.3
fluoride	0.09	0.14	0.11
silica	3.0	6.0	4.1
conductance	210	350	252
threshold odour number	2	8	4
colour	15	50	30
tannin and lignin	0.4	1.3	0.6
turbidity	6.65	280.0	91.0
TFR	130.0	220.0	159.0
TFRF	104.0	196.0	133.0
TNFR	14.0	310.0	118.0
TNFRF	11.6	274.0	104.0
surfactants	L.02	0.08	0.04
humic acids	-	-	-
total organic carbon	10.0	15.0	12.0
total inorg. carbon	16.0	24.0	20.0
total diss. org. carbon	5.5	15.0	9.0
nitrate and nitrite N	L.003	0.21	0.06
ammonia nitrogen	L.01	0.07	0.04
total Kjeldahl N	0.42	1.25	0.95
total phosphorus	0.020	0.208	0.10
ortho-phosphorus	0.003	L.01	L.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	12.0	55.0	36.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.006	0.004
copper[a]	0.00	0.014	0.006
iron[a]	0.54	8.00	2.92
lead[a]	L.002	L.002	L.002
manganese[a]	0.020	0.245	0.083
silver[a]	L.001	L.001	L.001
zinc[a]	0.002	0.243	0.017
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0001	0.0001
arsenic[c]	L.0002	0.0019	0.0006
nickel[a]	L.002	0.007	0.003
aluminum[a]	0.05	3.85	1.94
cobalt[a]	L.002	0.002	0.002
boron[c]	0.03	0.09	0.06

[a] extractable
[b] total
[c] dissolved

STATION: KF0200 Lake Claire, N. end of Birch River

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	37.5	44.0	40.8
magnesium	10.7	11.2	11.0
sodium	33.0	42.0	36.8
potassium	3.0	3.4	3.2
chloride	38.0	54.5	46.5
sulphate	42.2	70.5	57.2
total alkalinity	17.5	107.8	80.4
pH	7.7	8.11	7.9
carbonate	0.0	0.0	0.0
bicarbonate	21.0	131.0	98.0
total hardness	138.9	153.9	146.9
fluoride	0.15	0.19	0.17
silica	1.7	3.3	2.4
conductance	420	480	448
threshold odour number	2	4	3
colour	15	30	21
tannin and lignin	0.55	0.7	0.6
turbidity	27.8	262.0	141.0
TFR	252.0	304.0	283.0
TFRF	233.0	268.0	246.0
TNFR	28.8	219.0	104.0
TNFRF	24.8	190.0	90.0
surfactants	L.02	0.11	0.08
humic acids	-	-	-
total organic carbon	10.0	27.0	17.0
total inorg. carbon	16.0	28.0	22.0
total diss. org. carbon	9.0	17.0	4.0
nitrate and nitrite N	0.007	0.051	0.024
ammonia nitrogen	0.01	0.15	0.07
total Kjeldahl N	1.96	3.33	2.83
total phosphorus	0.050	0.198	0.12
ortho-phosphorus	0.007	0.015	0.011
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	28.0	70.0	43.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.011	0.006
copper[a]	0.005	0.011	0.007
iron[a]	0.87	8.0	4.22
lead[a]	L.002	0.002	0.002
manganese[a]	0.028	0.245	0.108
silver[a]	L.001	L.001	L.001
zinc[a]	0.009	0.033	0.021
vanadium[b]	L.001	0.004	0.002
selenium[c]	L.0002	0.002	0.001
mercury[b]	0.0001	0.0002	0.0002
arsenic[c]	0.0003	0.0022	0.0010
nickel[a]	0.003	0.004	0.004
aluminum[a]	0.67	2.85	1.51
cobalt[a]	L.002	0.002	0.002
boron[c]	0.09	0.09	0.09

[a] extractable

[b] total

[c] dissolved

STATION: KF0201 Lake Claire at 28th Baseline
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	32.5	55.0	45.3
magnesium	7.7	11.8	10.6
sodium	37.5	60.0	50.0
potassium	2.5	3.6	3.2
chloride	44.0	76.0	64.1
sulphate	47.5	90.0	75.0
total alkalinity	59.2	113.4	88.5
pH	7.3	8.06	7.7
carbonate	0.0	0.0	0.0
bicarbonate	72.0	138.0	108.0
total hardness	112.9	185.9	156.8
fluoride	0.16	0.20	0.18
silica	1.3	3.1	2.2
conductance	430	610	523
threshold odour number	2	8	4
colour	15	30	24
tannin and lignin	0.65	1.3	0.8
turbidity	21.7	475.0	189.0
TFR	258.0	370.0	324.0
TFRF	239.0	341.0	295.0
TNFR	17.2	432.0	159.0
TNFRF	12.8	386.0	140.0
surfactants	L.02	0.14	0.07
humic acids	-	-	-
total organic carbon	5.0	17.0	13.0
total inorg. carbon	14.0	19.0	17.0
total diss. org. carbon	2.0	17.0	11.0
nitrate and nitrite N	L.001	0.112	0.043
ammonia nitrogen	L.01	0.08	0.05
total Kjeldahl N	1.19	3.35	1.98
total phosphorus	0.036	0.22	0.12
ortho-phosphorus	0.005	0.012	0.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	47.0	95.0	66.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.026	0.013
copper[a]	0.004	0.011	0.008
iron[a]	0.67	14.7	6.5
lead[a]	L.002	0.002	0.002
manganese[a]	0.020	0.295	0.12
silver[a]	L.001	L.001	L.00
zinc[a]	0.16	0.464	0.136
vanadium[b]	L.001	0.003	0.002
selenium[c]	L.0002	L.0005	L.003
mercury[b]	L.0001	0.0008	0.0003
arsenic[c]	0.0004	0.0018	0.0008
nickel[a]	L.002	0.015	0.005
aluminum[a]	0.44	6.9	3.1
cobalt[a]	L.002	0.004	0.003
boron[c]	0.03	0.12	0.08

[a] extractable
[b] total
[c] dissolved

STATION: MD2000 Lake Athabasca at Sandy Point
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	8.8	9.5	9.3
magnesium	2.7	2.9	2.8
sodium	2.8	3.5	3.2
potassium	0.96	1.10	1.0
chloride	3.4	3.5	3.5
sulphate	2.4	6.9	4.5
total alkalinity	30.0	33.8	31.8
pH	7.48	7.62	7.6
carbonate	0.0	0.0	0.0
bicarbonate	37.0	41.0	39.0
total hardness	33.9	34.8	34.6
fluoride	0.08	0.08	0.08
silica	2.5	3.0	2.9
conductance	75	85	79
threshold odour number	2	8	4
colour	L5	L5	L5
tannin and lignin	0.1	0.3	0.2
turbidity	1.3	5.0	2.4
TFR	47.1	51.5	49.6
TFRF	36.0	44.0	40.5
TNFR	0.4	12.0	4.0
TNFRF	L.4	6.4	1.9
surfactants	L.02	0.02	0.02
humic acids	-	-	-
total organic carbon	3.5	5.0	4.0
total inorg. carbon	6.5	10.0	8.4
total diss. org. carbon	2.5	4.5	3.3
nitrate and nitrite N	0.007	0.082	0.032
ammonia nitrogen	L.01	0.07	0.04
total Kjeldahl N	0.19	1.12	0.44
total phosphorus	0.005	0.016	0.012
ortho-phosphorus	L.003	0.005	0.004
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	12.0	72.0	29.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.003	0.003
copper[a]	0.001	0.013	0.005
iron[a]	0.09	0.35	0.17
lead[a]	L.002	L.002	L.002
manganese[a]	0.003	0.013	0.007
silver[a]	L.001	L.001	L.001
zinc[a]	0.004	0.195	0.068
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0002	L.0002
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	L.0002	0.0009	0.0004
nickel[a]	L.002	L.002	L.002
aluminum[a]	0.05	0.31	0.15
cobalt[a]	L.002	L.002	L.002
boron[c]	0.01	L.05	L.03

[a] extractable
[b] total
[c] dissolved

STATION: NA0030 Riviere des Rochers
DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	13.0	26.0	20.7
magnesium	3.9	6.5	5.5
sodium	4.7	7.0	6.2
potassium	0.9	1.4	1.1
chloride	4.5	5.9	5.2
sulphate	5.0	12.0	9.0
total alkalinity	47.0	84.3	68.1
pH	7.6	8.0	7.8
carbonate	0.0	0.0	0.0
bicarbonate	57.0	103.0	83.0
total hardness	48.5	91.7	74.5
fluoride	0.08	0.09	0.09
silica	3.5	5.4	4.4
conductance	104	205	161
threshold odour number	2	8	4
colour	L5	114	36
tannin and lignin	0.2	0.7	0.5
turbidity 13.6	13.6	160.0	78.0
TFR	69.0	125.0	99.0
TFRF	51.0	101.0	81.0
TNFR	11.6	200.0	93.0
TNFRF	8.0	182.0	82.0
surfactants	L.02	0.03	0.02
humic acids	-	-	-
total organic carbon	6.0	17.0	9.0
total inorg. carbon	9.5	17.0	15.0
total diss. org. carbon	6.0	8.0	7.0
nitrate and nitrite N	0.006	0.050	0.023
ammonia nitrogen	L.01	0.11	0.05
total Kjeldahl N	1.17	3.33	2.14
total phosphorus	0.021	0.146	0.08
ortho-phosphorus	0.004	0.007	0.006
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	7.0	60.0	25.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	L.003	0.008	0.005
copper[a]	0.002	0.007	0.004
iron[a]	0.48	9.65	3.5
lead[a]	L.002	L.004	L.002
manganese[a]	0.015	0.155	0.068
silver[a]	L.001	L.001	L.001
zinc[a]	0.005	0.031	0.016
vanadium[b]	L.001	L.001	L.001
selenium[c]	L.0002	L.0005	L.0003
mercury[b]	L.0001	0.0009	0.0004
arsenic[c]	0.0004	0.0012	0.0006
nickel[a]	L.002	0.004	0.003
aluminum[a]	0.26	3.85	2.24
cobalt[a]	L.002	0.004	0.003
boron[c]	L.01	0.08	0.05

[a] extractable
[b] total
[c] dissolved

STATION: NA0031 Riviere des Rochers at mile 217.5

DATES: 1976 and 1977

Parameter	Minimum	Maximum	Mean
calcium	23.5	23.5	23.5
magnesium	5.7	5.7	5.7
sodium	7.6	7.6	7.6
potassium	1.3	1.3	1.3
chloride	5.9	5.9	5.9
sulphate	10.0	10.0	10.0
total alkalinity	80.0	80.0	80.0
pH	7.7	7.7	7.7
carbonate	0.0	0.0	0.0
bicarbonate	98.0	98.0	98.0
total hardness	82.1	82.1	82.1
fluoride	0.09	0.09	0.09
silica	5.3	5.3	5.3
conductance	187	187	187
threshold odour number	4	4	4
colour	30	30	30
tannin and lignin	0.85	0.85	0.85
turbidity	195.0	195.0	195.0
TFR	123.0	123.0	123.0
TFRF	113.0	113.0	113.0
TNFR	269.0	269.0	269.0
TNFRF	241.0	241.0	241.0
surfactants	L.02	L.02	L.02
humic acids	-	-	-
total organic carbon	8.5	8.5	8.5
total inorg. carbon	15.0	15.0	15.0
total diss. org. carbon	5.0	5.0	5.0
nitrate and nitrite N	0.04	0.04	0.04
ammonia nitrogen	0.04	0.04	0.04
total Kjeldahl N	1.27	1.27	1.27
total phosphorus	0.15	0.15	0.15
ortho-phosphorus	L.01	L.01	L.01
phenol	-	-	-
oil and grease	-	-	-
suphide	-	-	-
cyanide	-	-	-
chlorophyll a	-	-	-
chemical oxygen demand	68.0	68.0	68.0
cadmium[a]	L.001	L.001	L.001
hexavalent chromium[a]	0.016	0.016	0.016
copper[a]	0.009	0.009	0.009
iron[a]	10.1	10.1	10.1
lead[a]	L.002	L.002	L.002
manganese[a]	0.200	0.200	0.200
silver[a]	L.001	L.001	L.001
zinc[a]	0.031	0.031	0.031
vanadium[b]	0.010	0.010	0.010
selenium[c]	0.0008	0.0008	0.0008
mercury[b]	L.0001	L.0001	L.0001
arsenic[c]	0.0011	0.0011	0.0011
nickel[a]	0.004	0.004	0.004
aluminum[a]	9.10	9.10	9.10
cobalt[a]	L.002	L.002	L.002
boron[c]	0.07	0.07	0.07

[a] extractable

[b] total

[c] dissolved

6. LIST OF AOSERP RESEARCH REPORTS

1.		AOSERP First Annual Report, 1975
2.	AF 4.1.1	Walleye and Goldeye Fisheries Investigations in the Peace-Athabasca Delta--1975
3.	HE 1.1.1	Structure of a Traditional Baseline Data System
4.	VE 2.2	A Preliminary Vegetation Survey of the Alberta Oil Sands Environmental Research Program Study Area
5.	HY 3.1	The Evaluation of Wastewaters from an Oil Sand Extraction Plant
6.		Housing for the North--The Stackwall System
7.	AF 3.1.1	A Synopsis of the Physical and Biological Limnology and Fisheries Programs within the Alberta Oil Sands Area
8.	AF 1.2.1	The Impact of Saline Waters upon Freshwater Biota (A Literature Review and Bibliography)
9.	ME 3.3	Preliminary Investigations into the Magnitude of Fog Occurrence and Associated Problems in the Oil Sands Area
10.	HE 2.1	Development of a Research Design Related to Archaeological Studies in the Athabasca Oil Sands Area
11.	AF 2.2.1	Life Cycles of Some Common Aquatic Insects of the Athabasca River, Alberta
12.	ME 1.7	Very High Resolution Meteorological Satellite Study of Oil Sands Weather: "A Feasibility Study"
13.	ME 2.3.1	Plume Dispersion Measurements from an Oil Sands Extraction Plant, March 1976
14.		
15.	ME 3.4	A Climatology of Low Level Air Trajectories in the Alberta Oil Sands Area
16.	ME 1.6	The Feasibility of a Weather Radar near Fort McMurray, Alberta
17.	AF 2.1.1	A Survey of Baseline Levels of Contaminants in Aquatic Biota of the AOSERP Study Area
18.	HY 1.1	Interim Compilation of Stream Gauging Data to December 1976 for the Alberta Oil Sands Environmental Research Program
19.	ME 4.1	Calculations of Annual Averaged Sulphur Dioxide Concentrations at Ground Level in the AOSERP Study Area
20.	HY 3.1.1	Characterization of Organic Constituents in Waters and Wastewaters of the Athabasca Oil Sands Mining Area
21.		AOSERP Second Annual Report, 1976-77
22.		Alberta Oil Sands Environmental Research Program Interim Report to 1978 covering the period April 1975 to November 1978
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 1.5.2	Air System Winter Field Study in the AOSERP Study Area, February 1977.
25.	ME 3.5.1	Review of Pollutant Transformation Processes Relevant to the Alberta Oil Sands Area

26.	AF 4.5.1	Interim Report on an Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
27.	ME 1.5.1	Meteorology and Air Quality Winter Field Study in the AOSERP Study Area, March 1976
28.	VE 2.1	Interim Report on a Soils Inventory in the Athabasca Oil Sands Area
29.	ME 2.2	An Inventory System for Atmospheric Emissions in the AOSERP Study Area
30.	ME 2.1	Ambient Air Quality in the AOSERP Study Area, 1977
31.	VE 2.3	Ecological Habitat Mapping of the AOSERP Study Area: Phase I
32.		AOSERP Third Annual Report, 1977-78
33.	TF 1.2	Relationships Between Habitats, Forages, and Carrying Capacity of Moose Range in northern Alberta. Part I: Moose Preferences for Habitat Strata and Forages.
34.	HY 2.4	Heavy Metals in Bottom Sediments of the Mainstem Athabasca River System in the AOSERP Study Area
35.	AF 4.9.1	The Effects of Sedimentation on the Aquatic Biota
36.	AF 4.8.1	Fall Fisheries Investigations in the Athabasca and Clearwater Rivers Upstream of Fort McMurray: Volume I
37.	HE 2.2.2	Community Studies: Fort McMurray, Anzac, Fort MacKay
38.	VE 7.1.1	Techniques for the Control of Small Mammals: A Review
39.	ME 1.0	The Climatology of the Alberta Oil Sands Environmental Research Program Study Area
40.	WS 3.3	Mixing Characteristics of the Athabasca River below Fort McMurray - Winter Conditions
41.	AF 3.5.1	Acute and Chronic Toxicity of Vanadium to Fish
42.	TF 1.1.4	Analysis of Fur Production Records for Registered Traplines in the AOSERP Study Area, 1970-75
43.	TF 6.1	A Socioeconomic Evaluation of the Recreational Fish and Wildlife Resources in Alberta, with Particular Reference to the AOSERP Study Area. Volume I: Summary and Conclusions
44.	VE 3.1	Interim Report on Symptomology and Threshold Levels of Air Pollutant Injury to Vegetation, 1975 to 1978
45.	VE 3.3	Interim Report on Physiology and Mechanisms of Air-Borne Pollutant Injury to Vegetation, 1975 to 1978
46.	VE 3.4	Interim Report on Ecological Benchmarking and Biomonitoring for Detection of Air-Borne Pollutant Effects on Vegetation and Soils, 1975 to 1978.
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys for Moose on the AOSERP Study Area
48.	HG 1.1	Interim Report on a Hydrogeological Investigation of the Muskeg River Basin, Alberta
49.	WS 1.3.3	The Ecology of Macrobenthic Invertebrate Communities in Hartley Creek, Northeastern Alberta
50.	ME 3.6	Literature Review on Pollution Deposition Processes
51.	HY 1.3	Interim Compilation of 1976 Suspended Sediment Date in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plan, June 1977

53.	HY 3.1.2	Baseline States of Organic Constituents in the Athabasca River System Upstream of Fort McMurray
54.	WS 2.3	A Preliminary Study of Chemical and Microbial Characteristics of the Athabasca River in the Athabasca Oil Sands Area of Northeastern Alberta
55.	HY 2.6	Microbial Populations in the Athabasca River
56.	AF 3.2.1	The Acute Toxicity of Saline Groundwater and of Vanadium to Fish and Aquatic Invertebrates
57.	LS 2.3.1	Ecological Habitat Mapping of the AOSERP Study Area (Supplement): Phase I
58.	AF 2.0.2	Interim Report on Ecological Studies on the Lower Trophic Levels of Muskeg Rivers Within the Alberta Oil Sands Environmental Research Program Study Area
59.	TF 3.1	Semi-Aquatic Mammals: Annotated Bibliography
60.	WS 1.1.1	Synthesis of Surface Water Hydrology
61.	AF 4.5.2	An Intensive Study of the Fish Fauna of the Steepbank River Watershed of Northeastern Alberta
62.	TF 5.1	Amphibians and Reptiles in the AOSERP Study Area
63.	ME 3.8.3	Analysis of AOSERP Plume Sigma Data
64.	LS 21.6.1	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Large Mammals in the AOSERP Study Area
65.	LS 21.6.2	A Review and Assessment of the Baseline Data Relevant to the Impacts of Oil Sands Development on Black Bears in the AOSERP Study Area
66.	AS 4.3.2	An Assessment of the Models LIRAQ and ADPIC for Application to the Athabasca Oil Sands Area
67.	WS 1.3.2	Aquatic Biological Investigations of the Muskeg River Watershed
68.	AS 1.5.3 AS 3.5.2	Air System Summer Field Study in the AOSERP Study Area, June 1977
69.	HS 40.1	Native Employment Patterns in Alberta's Athabasca Oil Sands Region
70.	LS 28.1.2	An Interim Report on the Insectivorous Animals in the AOSERP Study Area
71.	HY 2.2	Lake Acidification Potential in the Alberta Oil Sands Environmental Research Program Study Area
72.	LS 7.1.2	The Ecology of Five Major Species of Small Mammals in the AOSERP Study Area: A Review
73.	LS 23.2	Distribution, Abundance and Habitat Associations of Beavers, Muskrats, Mink and River Otters in the AOSERP Study Area, Northeastern Alberta
74.	AS 4.5	Air Quality Modelling and User Needs
75.	WS 1.3.4	Interim Report on a Comparative Study of Benthic Algal Primary Productivity in the AOSERP Study Area
76.	AF 4.5.1	An Intensive Study of the Fish Fauna of the Muskeg River Watershed of Northeastern Alberta
77.	HS 20.1	Overview of Local Economic Development in the Athabasca Oil Sands Region Since 1961.
78.	LS 22.1.1	Habitat Relationships and Management of Terrestrial Birds in Northeastern Alberta

79.	AF 3.6.1	The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.
80.	HS 10.2 & HS 10.1	History of the Athabasca Oil Sands Region, 1980 to 1960's. Volumes I and II.
81.	LS 22.1.2	Species Distribution and Habitat Relationships of Waterfowl in Northeastern Alberta.
82.	LS 22.2	Breeding Distribution and Behaviour of the White Pelican in the Athabasca Oil Sands Area.
83.	LS 22.2	The Distribution, Foraging Behaviour, and Allied Activities of the White Pelican in the Athabasca Oil Sands Area.
84.	WS 1.6.1	Investigations of the Spring Spawning Fish Populations in the Athabasca and Clearwater Rivers Upstream from Fort McMurray; Volume I.
85.	HY 2.5	An intensive Surface Water Quality Study of the Muskeg River Watershed. Volume I: Water Chemistry.
86.	AS 3.7	An Observational Study of Fog in the AOSERP Study Area.
87.	WS 2.2	Hydrogeological Investigation of Muskeg River Basin, Alberta
88.	AF 2.0.1	Ecological Studies of the Aquatic Invertebrates of the Alberta Oil Sands Environmental Research Program Study Area of Northeastern Alberta
89.	AF 4.3.2	Fishery Resources of the Athabasca River Downstream of Fort McMurray, Alberta. Volume 1
90.	AS 3.2	A Wintertime Investigation of the Deposition of Pollutants around an Isolated Power Plant in Northern Alberta
91.	LS 5.2	Characterization of Stored Peat in the Alberta Oil Sands Area
92.	WS 1.6.2	Fisheries and Habitat Investigations of Tributary Streams in the Southern Portion of the AOSERP Study Area. Volume I: Summary and Conclusions
93.	WS 1.3.1	Fisheries and Aquatic Habitat Investigations in the MacKay River Watershed of Northeastern Alberta
94.	WS 1.4.1	A Fisheries and Water Quality Survey of Ten Lakes in the Richardson Tower Area, Northeastern Alberta. Volume I: Methodology, Summary, and Discussion.
95.	AS 4.2.6	Evaluation of the Effects of Convection on Plume Behaviour in the AOSERP Study Area
96.	HS 20.3	Service Delivery in the Athabasca Oil Sands Region Since 1961
97.	LS 3.4.1	Differences in the Composition of Soils Under Open and Canopy Conditions at Two Sites Close-in to the Great Canadian Oil Sands Operation, Fort McMurray, Alberta
98.	LS 3.4.2	Baseline Condition of Jack Pine Biomonitoring Plots in the Athabasca Oil Sands Area; 1976 and 1977
99.	LS 10.1	Synecology and Autecology of Boreal Forest Vegetation in the AOSERP Study Area
100.	LS 10.2	Baseline Inventory of Aquatic Macrophyte Species Distribution in the AOSERP Study Area
101.	LS 21.1.3	Woodland Caribou Population Dynamics in Northeastern Alberta
102.	LS 21.1.4	Wolf Population Dynamics and Prey Relationships in Northeastern Alberta