EVALUATION OF THE BASELINE HYDROMETRIC AND WATER QUALITY NETWORKS IN THE AOSERP STUDY AREA

by

E.K. YAREMKO

and

R.B. MURRAY

Northwest Hydraulic Consultants Ltd.

Chemical and Geological Laboratories Ltd.

for

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ABSTRACT

The Alberta Oil Sands Environmental Research Program continues to fund extensive streamflow, lake level, suspended sediment, and water quality networks in their study area for the purpose of collecting baseline information. The fiscal year 1977-78 marked the end of year three in the Program, and a stated objective in the Program was to complete this activity by this year before moving into activities of a more site specific or applied research orientated nature.

The purpose of the study reported herein was generally to assess these networks and the collected information, with a view to determining their sufficiency from a point of view of describing the areal and temporal variation of hydrological and water quality regimes in the study area. It was concluded that the data are insufficient at this time to provide even a gross appreciation of these parameters, and it has been recommended that the networks be operated for at least one more year, and possibly two (to end of 1979). Some definite trends in consistency of parameter values were observed within some derived zones, but further information and analyses are required to completely support these trends. The suggested zoning did indicate that some stations are likely superfluous, but the economies which would be gained by eliminating them for two more years may not be worthwhile.

Redirection of the network could consider movement into what has been termed Stage 2 networks; these would be activities which are specific in location or purpose. Several have been recommended. These activities would have the objective of developing a predictive capability in terms of impact due to oil sands development.

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1. INTRODUCTION

1.1 STATEMENT OF PROBLEM

The Alberta Oil Sands Environmental Research Program (AOSERP) presently (to end of March, 1978) supports a system of 27 streamflow, four lake-level, and 42 water quality stations within the area shown by Figure 1. These networks have the purpose of providing information "...which may be used to establish the baseline states for physical, chemical and biological constituents of aqueous systems in the study area..."; AOSERP Direction Document (1977). It has been AOSERP's objective to operate a broad based baseline network during the first three years of the Program, thereafter moving into refined networks and site-specific research studies that would attempt to bridge the gap between the known baseline states of the Water System and the need to predict the impact of oil sands development on this system. As March 1978 marks the end of the Program's first three years, it is necessary to review the adequacy of the networks, as well as the quantity and quality of the Water System information collected to date, to determine whether this information provides an adequate baseline data base within the Program's study area. The responsibility of this review was given to Northwest Hydraulic Consultants Ltd. (NHCL), and it is the purpose of this report to present their findings.

1.2 STUDY TERMS OF REFERENCE

Authorization for NHCL to proceed with the review was received from AOSERP's M. Falk on 6 December 1977. A copy of NHCL's terms of reference for the study, as established by AOSERP, is provided in Appendix 8.1. Generally, the "...objective is to evaluate the present streamflow, suspended sediment, lake level and water quality networks in the AOSERP study area on the basis of the current data base so as to provide the basis for continuation and or redirection..." AOSERP Direction Document (1977). Specifically, NHCL has been charged with:

1. Evaluating the present streamflow, lake level, suspended sediment, and water quality networks with respect to adequacy of the distribution of stations throughout the study area;
2. Evaluating the adequacy of existing data base as generated by these networks to date; of special concern is a need to have the temporal variations of the quantities being measured adequately defined;
3. Providing criteria that would be used to evaluate the networks on an ongoing basis;
4. Recommendation of streamflow, lake level, suspended sediment and water quality networks that would, with respect to environmental impact due to oil sands development, enable the program to achieve its objectives of having a predictive capability after five years of network operation;
5. Recommending the procedures by which various of the stations might be shut down or relocated; estimates of costs associated with station shutdown, and annual costs associated with maintaining a new network should be provided; and
6. Evaluating the existing suspended sediment network with respect to a need to define the natural sediment load balance of the Athabasca River and its tributaries.

It should be noted that a major item not included for consideration in the terms of reference was adequacy of the precipitation network in relation to its ability to properly monitor precipitation events within any of the primary tributary watersheds. The importance of this information to the hydrologist-engineer is well understood, but because AOSERP's needs are more orientated towards the environmental aspects of surface water, it has been assumed that they have no desire to define precipitation-runoff regimes in the study area at this time; more will be said about this later in the report.

1.3 STUDY APPROACH

Review of the streamflow, lake level and suspended sediment networks and their data, as well as overall co-ordination of the study were the responsibilty of NHCL. Assessment of the water quality network and data was the responsibility of Chemical and Geological Laboratories Ltd. (C and G); this firm was retained as a subconsultant in the study.

Several meetings were held with AOSERP's Water System manager to discuss progress of the study, and to have clarified some of the Programs' stated objectives. This latter point was important because various interpretations could be placed on some of the objectives, and it was important during the course of the study to arrive at some understanding as to which of the interpretations AOSERP had intended. A review of some of the more important points considered is presented below in order to properly establish the framework upon which the study was based:

1. The ten-year period in which AOSERP could operate imposes a limitation on the longevity of any network they are funding. For example, AOSERP considers that environmental information sufficient for its purposes can be collected from a baseline network in the first three years of operation. Thereafter, baseline networks would be reduced in favour of greatly increased activity in applied research. Because little environmental information is available in the study area for the period prior to AOSERP, the majority of baseline information collected to the end of 1977 essentially covers a period of only three years or less. These data may provide a broad-based measure of water quality, as well as a measure of the temporal variation of flow, suspended sediment and water quality, but they would not be sufficient to permit the prediction of extreme events, during which time a stressful condition could be imposed on the environment. From its definition of baseline states,

AOSERP appears to recognize this shortcoming, but has taken the approach that the initial set of baseline information need only be sufficient to enable the determination of a "gross appreciation" of hydrological and water quality characteristics anywhere in the study area. This ability would be important to the development of more meaningful site specific applied research programs. For this study, NHCL has taken the approach that collection of baseline information should continue over the long term, but that this will be accomplished with a different and likely reduced network of stations than presently exists. The structure of future networks will depend on development priorities and recognized gaps in the information base. Funding of these future networks may be partly covered by AOSERP, but in the long term it is expected that outside (permanent) agencies and private companies will be tasked with this responsibility. However, it is important for AOSERP to establish that the existing network has provided it with a sufficient set of streamflow, sediment and water quality information with which to conceive, plan and implement the required applied research programs. This in essence is what is requested in (1) and (2) of the "Study Terms of Reference".

2. It appears that information collected and applied research programs funded by AOSERP is intended to be environmental in nature; this would seem to imply that the collection of data for engineering purposes is only of secondary importance in the Program. For example, AOSERP requires a measure of streamflow for the purpose of computing loadings of various water quality parameters and suspended sediment, but it is not interested in providing sufficient streamflow data throughout the study area to enable rigorous

statistical analyses in deriving hydrological parameters such as flood and drought frequencies.

However, for this study, NHCL has taken the approach that, if the hydrometric and water quality networks have distributions of baseline stations which are acceptable to AOSERP, then they would also be networks which are acceptable to the engineer. Thus, if AOSERP is satisified that an adequate set of environmental data has been generated and wishes to pass on funding of these networks to outside (engineering-orientated) agencies for continued operation, these agencies would find little need to expand a network's structure, and would find the available information suitable for their needs.

3. In (4) of the "Study Terms of Reference", AOSERP expresses a desire to achieve a "predictive capability" during the fourth and fifth years of the Program. This term is in reference to the prediction of impact on the environment due to oil sand related development, and should be distinguished from prediction of baseline conditions in the study area. A necessary prelude to working toward this predictive capability is a need to define the potential problems that might occur because of development. At this stage of the Program such a list of problems would have to be tentative, being based more on conceptual impressions, personal opinions and gut-feeling, rather than on observed impact in the study area. A comparison of this list and the baseline conditions would form the basis upon which applied research programs are developed.

   The approach by NHCL in this study has been to perceive streamflow-water quality networks, different from the baseline (or Stage 1) networks, that would provide additional baseline environmental information. These (Stage 2) networks might be located in only one or two basins where such information would be utilized in the development of applied research programs for areas where there is considered to be a need for intense, impact orientated studies.

1.4 RELATIONSHIP BETWEEN AND THE NEED FOR STREAMFLOW SEDIMENT AND WATER QUALITY INFORMATION

Short definitions are provided below that outline what each kind of information may mean to the attainment of the Program objectives:

1. Streamflow: Water flowing along a channel acts as the median by which water-borne organic and inorganic elements are carried. Knowledge of the flow rate, in concert with measured concentrations of these elements, provides a measure of the loadings imposed by the surface water environment over a period of time. Supposedly, a comparison of loadings before and after development will provide a measure of impact;
2. Suspended Sediment: The fine inorganic particles being carried in suspension are derived from the products of land, gully, bank and bed erosion. Their concentrations generally increase with the rate of streamflow, and there can occur detrimental impacts on the aquatic biota when concentrations are too high. Any aspect of development that results in an increase in the suspended sediment concentrations over those naturally occurring would be of concern to the environmentalist; and
3. Water Quality: The chemical and mineral constituents of streamflow are a reflection of the upstream character of surface (via surface runoff) and subsurface material (via groundwater flow) within the basin

boundaries. It is important to establish the nature and quantity of any toxic substances, so that comparisons of their natural or background concentrations can be made with those which might be imposed as a result of development.

1.5 REPORT ORGANIZATION

Section 2 deals with assessment of the existing baseline hydrometric and water quality networks in terms of their areal extent and adequacy of available information. The criteria on which these assessments are based are discussed at the beginning of Section 2, and are then applied throughout the remainder of the section.

In Section 3 we discuss the merits of providing criteria to be used to assess the hydrometric and water quality networks and information on an ongoing basis; the approach has been to show why different sets of criteria may be required for Stage 1 and Stage 2 networks.

In Section 4 some suggestions are given with respect to what a Stage 2 hydrometric or water quality network might look like; reasons are provided as to why specific station locations have been recommended.

There will be a cost to AOSERP for dismantling some elements of the Stage 1 network and in turn, adding stations at other locations that are a part of the Stage 2 network. This cost, in addition to estimates of the annual cost for the operation of these stations, has been estimated in Section 5.

2. BASELINE NETWORKS

2.1 CRITERIA FOR ASSESSMENT OF BASELINE NETWORKS

The streamflow, suspended sediment and water quality networks were each assessed on the basis of: (1) station distribution within the study area; (2) the ability of available information to adequately define the water quality anywhere within the study area; and (3) the ability of streamflow information to provide a means of computing loadings using measured water quality parameter and suspended sediment concentrations. Network assessment has been carried out realizing that the purpose of the information being collected is to provide a gross appreciation of the water quality and streamflow characteristics anywhere in the study area. Because of the shortness of record available for most stations, the term "gross appreciation" or "adequacy" cannot be quantified or tied to any minimum limits of statistical confidence. Generally, it is assumed that three years of information will permit reasonable estimates to be made of average values associated with measured water quality parameters, while properly distributed network stations will ensure that estimates of these average values can be made for any streams within the study area.

Before embarking on a detailed analysis of networks, a short summary of the criteria used to assess each network is presented below:

1. Streamflow-Lake Level Networks: Areal distribution of stations; initially, the study area was segmented into what were considered to be hydrological zones; that is, it was assumed that the hydrology was similar in each zone. A full description of how these zones were established will be found in the next section.

   The distribution of active stations amongst the zones was assessed, with the view that at least one station should have been located within each one, provided that a high proportion (>50%) of a zone had the potential for oil sands development. More for interests sake than any other reason, the density of stations within the study area (stations per square kilometre) was compared with those in Alberta and Saskatchewan. From these comparisons and considerations, conclusions were drawn as to whether the existing network was adequately distributed.

The adequacy of the existing data base was assessed on the basis of quality, temporal distribution and length of record. In the case of quality, such things as method of monitoring water levels, frequency of and timing of discharge measurements, and stability of channel or stage-discharge curves were considered in relation to accepted standards. Measurement of the temporal distribution of streamflow was considered adequate if precipitation generated runoff events were being fully described with respect to stage and time; as well, a streamflow value should have been available with every suspended sediment and water quality sample. With respect to length of record, it has previously been stated that a minimum of three years of measurements would suffice for the needs of AOSERP, except that a streamflow station should operate as long as a water quality station is in operation. Thus, the aspect of collecting a long enough record to enable prediction of extreme streamflow events is not a consideration in these criteria.

2. Suspended Sediment Network: The distribution of sediment stations was assessed in relation to the previously proposed hydrological zones in order to determine whether too many stations had been established in areas that may be producing similar yields of sediment. As an aside, station density in the study area was compared to those existing in Alberta and Saskatchewan.

Conclusions were then made as to whether additional stations might be added to the baseline network or whether some stations were redundant.

With respect to the adequacy of available suspended sediment information, assessment was based on sampling techniques, frequency of sampling, and the ability to compute sediment loads over a period of time. Sufficient samples should be collected during periods of high flow to enable a complete definition of the sediment loads during any period of the hydrograph. A sediment station should continue operation until a satisfactory stage-sediment concentration relationship is established so that sediment concentrations between sampling points can be reasonably estimated from the discharge record. Although this relationship may be poorly defined for some stations, particulary those on small basins, even a rough approximation would be considered satisfactory for the purpose of computing sediment yields (tonnes per square kilometre).

3. Water Quality Network: Water quality stations must operate in conjunction with streamflow stations so that loadings of the various water quality parameters can be computed. Because the opposite is generally not the case, it was assumed that AOSERP required operation of their baseline streamflow network only as long as the water quality network was required. This point indicates the over-riding importance of collecting a satisfactory set of baseline water quality information as quickly as possible.

   The distribution of the water quality stations was also assessed in relation to the proposed hydrological zones. If a consistency in water quality parameters was evident within some zones, a reduction in the number of stations would be warranted. This is particularly true if more than one station has been located within a basin. Also, it was felt that of two basins, each much different in size but exhibiting similar water quality characteristics, and each having a station, the station monitoring the larger basin would be selected for continued operation.

Assessment of the adequacy of water quality information primarily considered sampling frequency and the ability of the information to adequately define the temporal variation of water quality.

2.2 PROPOSED HYDROLOGICAL ZONES

2.2.1. Basis for Zone Selections

An assessment was made of the study area to determine whether the area could be segmented into sub-areas that might each have unique hydrological and water quality characteristics. This assessment was based primarily on the following three considerations:

1. Physiography: A variance in topography should result in an associated variance in rates of runoff and sediment load;
2. Surficial Material: This term relates to that layer of material lying above bedrock, and is generally referred to as glacial drift. The composition of this material will influence rate of water percolation, runoff, and land erosion, as well as vegetative cover, quality and amount of groundwater stored in the drift zones (the latter also influences minimum or low flow rates), and the quality of water running off the surface into drainage courses; and
3. Oil Sands Development Potential: AOSERP has stated that research funded by it should be orientated toward potential oil sands development problems within the study area. In respect of this, stations

funded by AOSERP should be located in, and along basins that have potential for oil sands development, or have the potential of being influenced by the results of this development. Appendix 8.2 provides a summary of the above characteristics for the major basins in the study area, together with other factors such as basin aspect, length, slope and area. Table 1 was developed from this information, which groups together those basins having similar physiographic components; Table 2, which separates basins into groups that have a common array of surficial soils; and Table 3, which groups basins that have a similar potential for oil sands development. An assessment of this information resulted in the development of Table 4, which is a breakdown of the study area into proposed hydrological zones; the boundaries of these zones are shown on Figure 1.

2.2.2 Confirmation of Zone Boundaries

The available hydrological and water quality data were utilized in an attempt to show that the proposed zoned boundaries do indeed separate areas within which there are similar hydrological and water quality characteristics. Because of the over-riding importance of the water quality parameters in this study, use of existing water quality information to confirm zone boundaries has been left to Section 2.5.

Parameters that are used herein to characterize the hydrological regime of a watershed include consideration of peak flow, basin yield (or total annual runoff per unit area) and base flow (annual minimum discharge). The following comparisons were made on a short-term basis (1976 and 1977) for all active stations; as well, comparisons were made over a longer term for those hydrometric stations that provide a longer period of record:

1. Peak flow: Comparisons of flood peaks based on short-term records were of limited value because of the

Table 1. Hydrological divisions in the AOSERP study area based on physiographic comparisons.[a]

Basin	Physiographic Distribution
Lower Ells Joslyn Tar Calumet Pierre Asphalt Unnamed Redclay	Birch Mtns. Upland Algar Plain Clearwater Lowland
McIvor Buckton	Birch Mtns. Upland Athabasca Delta
Eleanor Unnamed Richardson Maybelle Keane	Athabasca Delta Athabasca Plain
Firebag	Athabasca-Firebag Plain Clearwater Lowland
Muskeg Steepbank	Muskeg Mtn. Upland Clearwater Lowland
Dunkirk	Birch Mtns. Uplands Algar Plain
Upper Ells	Birch Mtns. Uplands

continued ....

Table 1. Concluded.

Basin	Physiographic Distribution
Unnamed Wood Unnamed Clarke Rainbow	Clearwater Lowland
Clearwater	
Christina	Methy Portage Plain
Saprae Saline Hangingstone House Algar	Algar Plain Stony Mtn. Upland
Little Fishery Conn Cache Poplar Beaver	Algar Plain Clearwater Upland
Loon Livock Buffalo Lower MacKay Dover	Algar Plain
McClelland	Clearwater Lowland

[a] Information base taken from Northeast Alberta Regional Commission (1976).

Table 2. Proposed hydrological divisions in the AOSERP study area based on surficial deposits.[a]

Basin	Material character
Lower Ells Joslyn Tar Pierre Asphalt Unnamed Redclay McIvor Buckton	Predominately clayey and silty till in upper regions; outwash sand deposits in lower regions
Eleanor Unnamed Richardson Maybelle Keane	Aeolian sands in the lower reaches; sands and gravels in the upper reaches
Firebag	Outwash sands and gravels
Muskeg	Outwash sand in lower region; clayey and silty till in the upper region
Steepbank Unnamed Wood Unnamed Clarke Rainbow Little Fishery Conn Cache Poplar Beaver	Clayey and silty till
Clearwater	

continued ....

Table 2. Concluded.

Basin	Material Character
Christina	Clayey and silty till in the lower regions; ground moraine composed predominately of sand
Saprae Saline Hangingstone House Algar	Clayey and silty till
Loon Livock Unnamed Buffalo Lower MacKay Dover	Predominately clayey and silty till
Dunkirk	Hummocky moraine; drift of sand, gravel and silt
Upper Ells	Hummocky moraine; drift of sand, gravel and silt
McClelland	Outwash sands and gravels

[a] Information base taken from Northeast Alberta Regional Commission (1976).

Table 3. Proposed hydrological divisions in the AOSERP study area based on oil sands potential.[a]

Basin	Potential
Little Fishery Conn Poplar Cache Beaver Lower Mackay Dover Lower Ells Joslyn Tar Pierre Asphalt Unnamed	100% (or near to) developable; similar proportions available for open pit or in situ mining
McIvor Buckton	<25% developable; in situ only
Eleanor Unnamed Richardson Maybelle Keane	0% developable
Firebag	<10% developable; open pit to in situ mining possible
Muskeg Steepbank Unnamed Wood Unnamed Clarke Rainbow	50 to 100% developable; negligible in situ mining potential

continued ....

Table 3. Concluded.

Basin	Potential
Clearwater	0% developable upstream of Christina confluence
Christina	<10% developable; open pit to in situ mining potential
Saprae Saline Hangingstone House Algar	100% (or near to) developable; predominately in situ mining potential
Upper MacKay	75% developable; 100% in situ mining potential
Upper Ells	100% developable; in situ mining potential only
McClelland	100% developable; predominately open pit mining potential

[a] Information base taken from Northeast Alberta Regional Commission (1976).

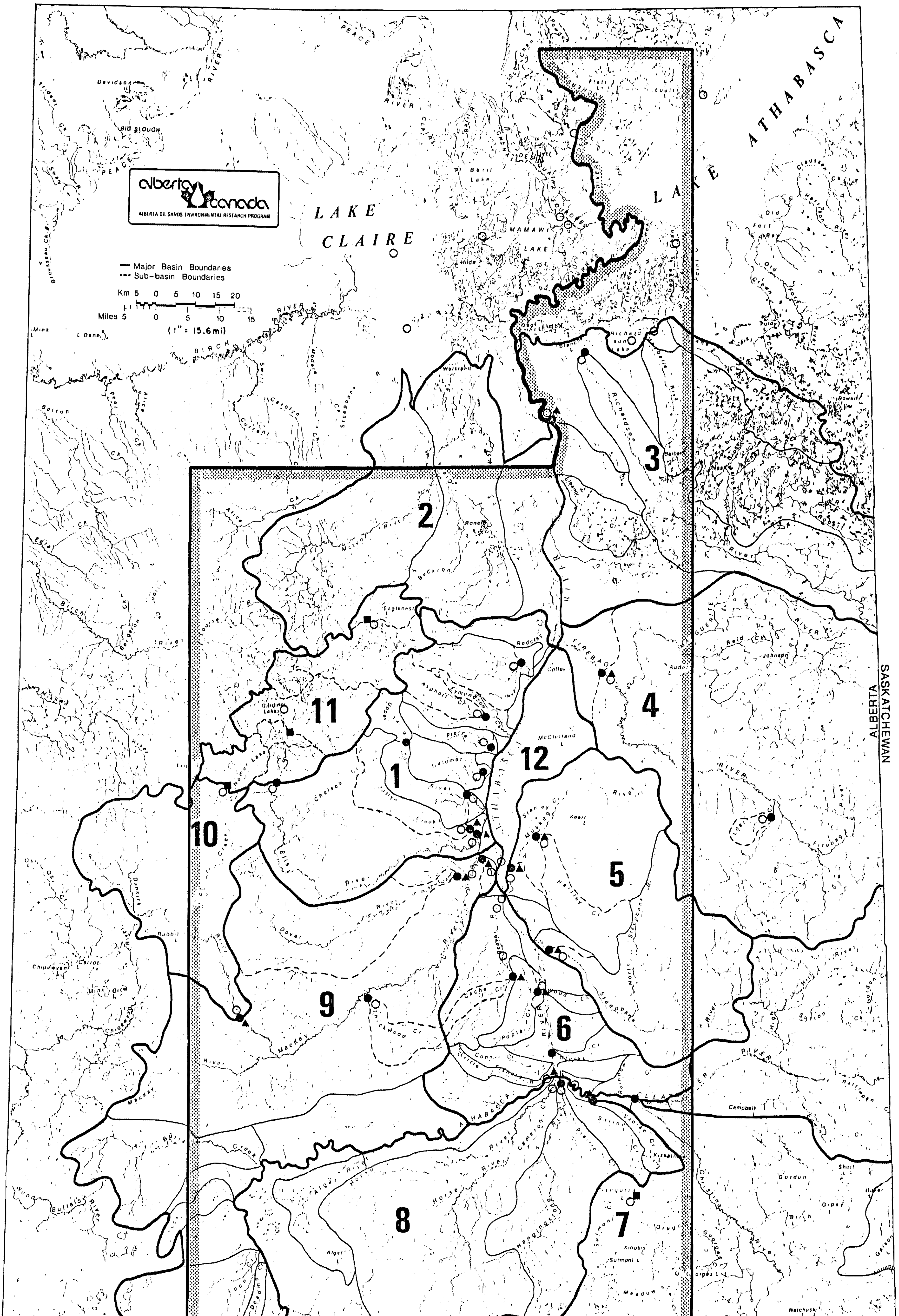
Table 4. Proposed hydrological zones within the AOSERP study area.

Hydrological Zone	Physiographic Distribution	Surficial Material	Oil Sands Development Potential
1	Birch Mtns Upland Algar Plain Clearwater Lowland	Predominately clayey & silty till in upper regions; outwash sand deposits in lower regions	Nearly 100% developable; similar proportions available for open pit and in situ mining
2	Birch Mtns Upland	"	<25% developable; in situ mining only
3	Athabasca Delta	Aeolian sands in the lower reaches; sands and gravels in upper reaches	0% developable
4	Athabasca-Firebag Plain Clearwater Lowland	Outwash sands and gravels	<10% developable open pit to in situ mining possible
5	Muskeg Mtns Upland	Outwash sands in lower regions; clayey and silty till in the upper regions	30 to 100% developable; negligible in situ mining potential
6	Algar Plain Clearwater Lowland	Clayey and silty material	100% developable; negligible in situ mining potential
7	Methy Portage Plain	Clayey and silty till in the lower region; ground moraine composed predominately of sand	<10% developable; open pit to in situ mining potential

continued........

Table 4. Concluded.

Hydrological Zone	Physiographic Distribution	Surficial Material	Oil Sands Development Potential
8	Algar Plain Stony Mtn Upland	Clayey and silty till	Nearly 100% developable; predominately in situ mining potential
9	Algar Plain	Predominately clayey and silty till	Nearly 100% developable; 80% potentially suited to in situ mining
10	Birch Mtns Upland Algar Plain	Hummocky moraine; drift of sand, gravel and silt	100% developable; in situ mining potential only
11	Birch Mtns Upland	Hummocky moraine	100% developable; in situ mining potential only
12	Clearwater Lowland	Outwash sands and gravels	90% developable; primarily open-pit mining potential



LEGEND

Stream flow measurement (W.S.C.) stn.........●
Lake level station.................................■
Suspended sediment station (W.S.C.)..........▲
Water quality station..............................○
Hydrological zone boundary
Hydrological zone number (see table 4)......4
A.O.S.E.R.P. study area
Basin boundary

NOTE: See table 5 for W.S.C. stn. numbers

The A.O.S.E.R.P. Study Area & Proposed Hydrological Zones

Figure 1

pronounced effects of individual runoff events and the spatial and temporal variation of precipitation within one storm event. However, longer term comparisons were hampered by the fact that approximately one half of the hydrometric stations had useable records only since 1976. Assuming that four years of record would provide a reasonable estimate of the mean annual flood peak, the values provided in Column 4 of Table 5 were used for purposes of comparison.

The mean annual flood values (Q) were plotted against gross drainage areas (A) in Figure 2, along with several lines drawn at a slope of 0.8. The various positions of these lines represent different values of "a", while 0.8 represents the value of "b" in the relationship log Q = a + b log A. Examination of these plotted points shows the Firebag, Muskeg and Richardson basins appear to have similar flood peak regimes, and all plot lower than the others. Similarly, the MacKay, Hangingstone, and Beaver points display similar flood peak regimes, and all plot higher than the others. The remaining two, Steepbank and Poplar, plot at an intermediate level.

2. Basin yield: Table 6 summarizes the yield values available for the years 1976 to 1977. In many cases only the 1976 data were available at the time of writing, so the comparisons were based on a rather small amount of information. Nevertheless some trends were apparent. For example:

- Zone 1 exhibited the lowest yield values, and appeared to be an area distinctly different from Zones 3, 4 5, 9 or 11 which surround this zone.
- Highest yield values occurred on the Hangingstone River (Zone 8) and Richardson River (Zone 3), located at the southern and northern extremities of the study

Table 5. Runoff estimates for streams with at least four years of record.[a]

Stream (1)	Hydrological Zone Number (2)	Total Drainage Area Above Station (km^2) (3)	Mean Annual Flood Peak (m^3/s) (4)	Annual Yield (m^3/km^2) (5)	Mean Minimum Daily Discharge (m^3/s) (6)
Richardson	3	2875	34.6 (6)[c]	175 505 (6)[c]	10.4 (6)[c]
Firebag	4	5853	70.4 (3)	142 243 (3)	9.0 (4)
Muskeg	5	1419	25.0 (4)	93 341 (4)	0.2 (4)
Steepbank	5	1401	36.8 (4)	137 309 (4)	0.4 (4)
Poplar[b] (natural)	6	142	4.7 (5)	133 251 (5)	0.003 (5)
Lower Beaver[b]	6	435	31.4 (6)	123 244 (6)	0.2 (5)
Hangingstone	8	907	59.5 (12)	180 800 (7)	0.4 (7)
MacKay	9,10	5232	183.0 (5)	113 920 (5)	0.3 (5)

[a] The exception is the Firebag River where only 3 years were available.

[b] Includes estimated data for 1976 and 1977.

[c] Number in parentheses is years of available record.

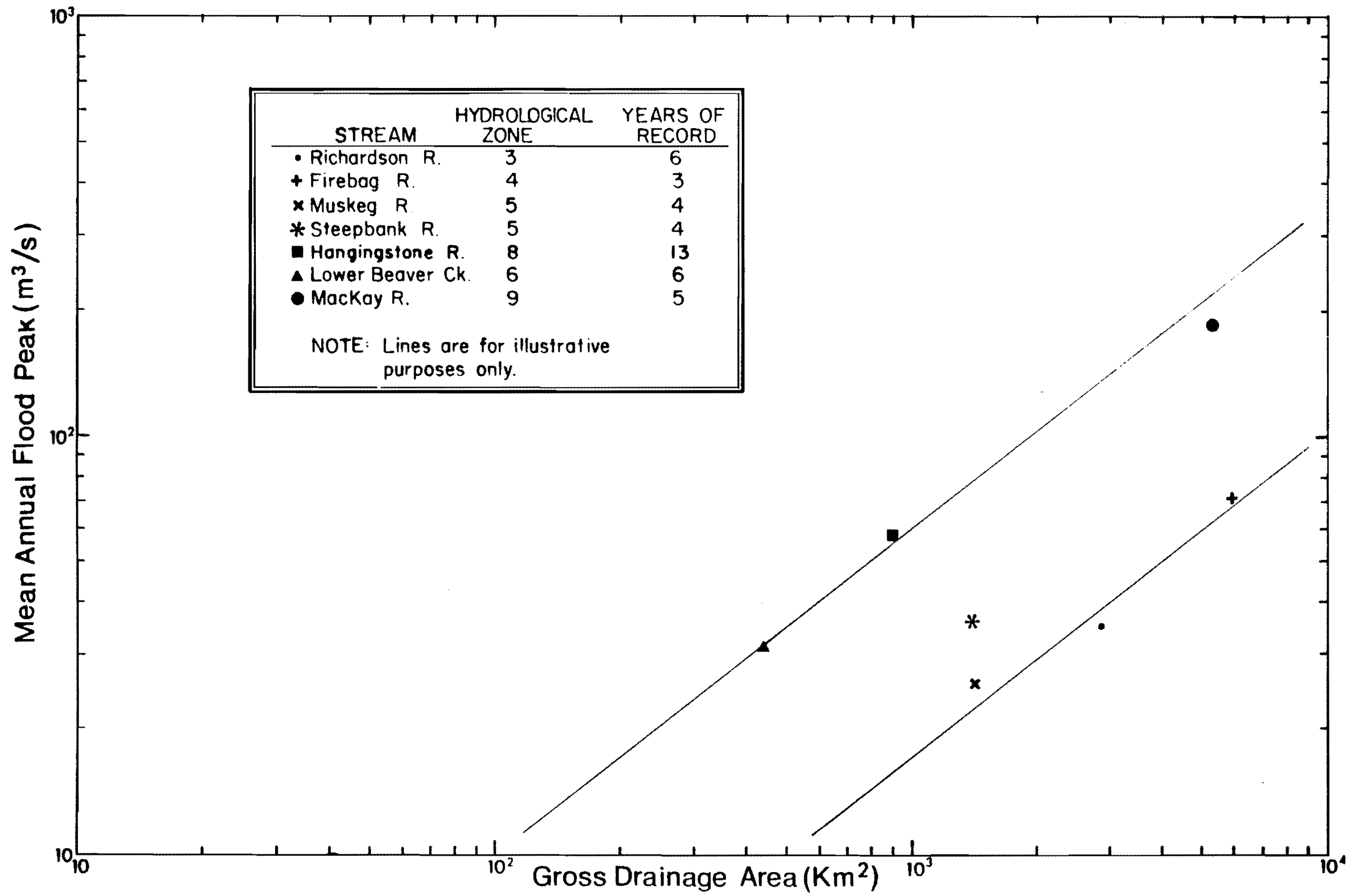


Figure 2. Mean annual flood peak vs. gross drainage area for hydrometric stations having at least three years of record.

Table 6. Annual basin yield within hydrological zones for streams having hydrometric stations during 1976-77.

Stream	Drainage Area Above Station (km^2)	Hydrological Zone No.	Mean Annual Runoff 1976 (m^3/km^2)	Mean Annual Runoff 1977 (m^3/km^2)	Average Runoff for 1976 & 1977 (m^3/km^2)
Lower Ells	2442	1	54 775	-	
Joslyn	243	1	77 637	-	
Lower Tar					
Upper Tar	98	1	-	-	
Calumet	181	1	30 960	-	
Pierre	135	1	-	-	
Asphalt	161	1	59 538	-	
Unnamed	303	1	29 531	-	
Richardson	2875	3	166 705	-	
Firebag	5853	4	117 884	119 408	118 599
Lost	60	4			
Muskeg	1419	5	46 439	51 536	49 059
Hartley	319	5	75 875	54 775	65 253
Steepbank	1400	5	92 450	69 064	80 971

continued.......

Table 6. Concluded.

Stream	Drainage Area Above Station (km^2)	Hydrological Zone No.	Mean Annual Runoff 1976 (m^3/km^2)	1977	Average Runoff for 1976 & 1977 (m^3/km^2)
			AVERAGE FOR ZONE		(65 253)
Upper Beaver	176	6	128 839	68 587	98 594
Poplar	142	6	83 829	126 220	104 786
			AVERAGE FOR ZONE		(101 928)
Christina[a]	13 390	7	115 741	-	
Hangingstone	907	8	185 043	-	
Horse		8	140 032	-	
MacKay	5 232	9	89 163	33 484	61 443
Dover	976	9	53 346	-	
Thickwood	171	9	-	-	
Dunkirk	1 567	10	65 729	-	
Upper Ells	1 378	11	79 542		

[a] Difference between Clearwater stations at Draper and above Christina River (7CD-1 and 7CD-5).

area, respectively.

- Zone 8 experienced much higher yields than neighbouring Zones 6 and 9.
- Based on two years of record, there was a reasonable consistency in yield values within Zones 5 and 6; the same was concluded for the one year of record for Zone 1.
- Yield for the Hangingstone River exceeded that from the Horse River (both in Zone 8) by about 25%. This difference may be due either to spatial variations in rainfall intensity during summer storms, or to a real hydrological difference between two basins (eg. the steeper terrain of the Hangingstone basin).

In referring to the longer term records provided by Table 5 the range of yields was much smaller. However, the Hangingstone and Richardson rivers both experienced much higher values than the others. Also, the Steepbank River again indicated it produced a much higher yield than the Muskeg or Hartley basins.

3. Minimum flows: The composition of the glacial drift is thought to be an important factor in the ability of a basin to sustain a high base flow during the winter months. Since this was one of the factors considered in deriving the zones, it follows that there should be a relation between these zones and measured minimum flows. Figure 3 is a plot of minimum discharges versus gross drainage area using only the 1976 data. Generally, it shows that the majority of measured streams had near-zero flow during the winter months. However, some trends are apparent:

- Points for basins to the east of the Athabasca River (Zones 3 to 8) plot higher relative to those to the

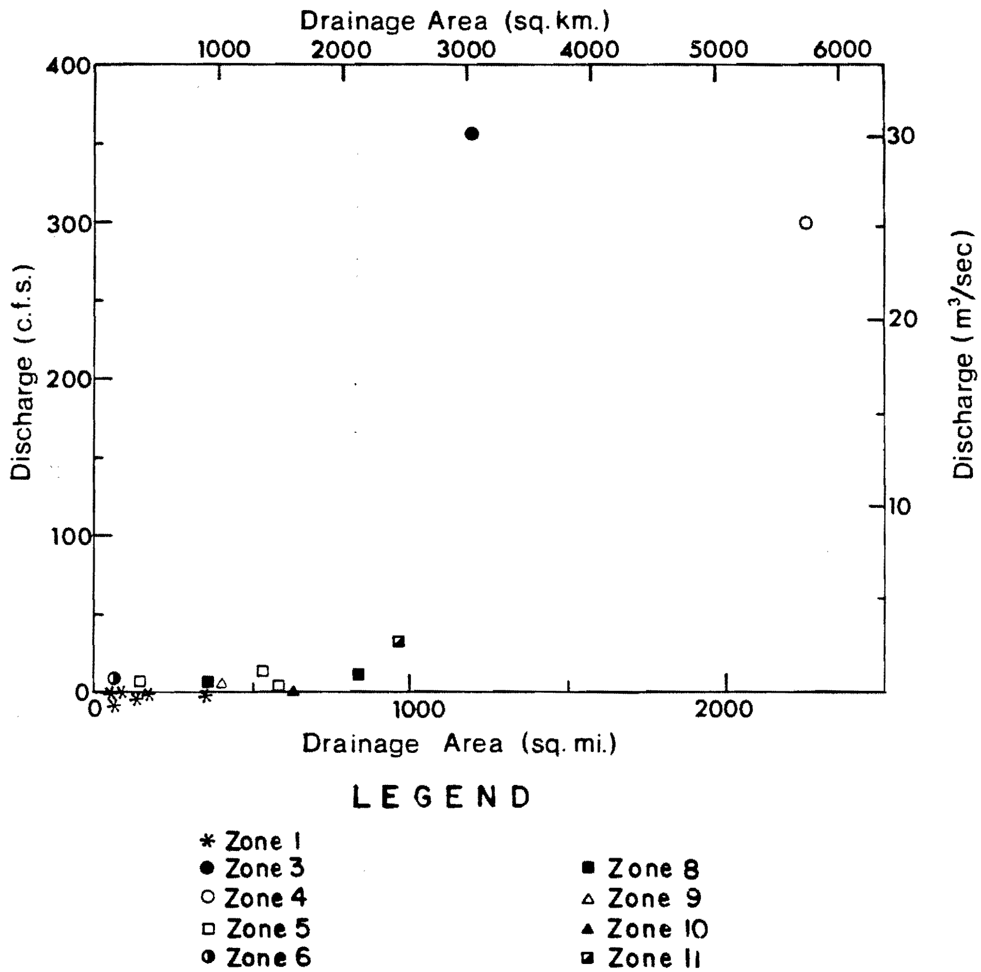


Figure 3. Minimum discharge (1976) vs. gross drainage area.

west; the exception is Zone 11 which has the advantage of lake storage in the Birch Mountain region.

- All basins in Zone 1 essentially reach zero discharge during the winter months.
- For the size of the basin, Dunkirk (Zone 10) and MacKay (Zone 9) appear to have a relatively low winter flow regime, which suggests rapid runoff during the open water season.
- The Firebag (Zone 4) and Richardson (Zone 3) have winter flows that are an order-of-magnitude greater than other basins in the study area, presumably because of the effects of surface storage and groundwater contributions.

The above analyses do not conclusively establish that the proposed hydrological zones are in fact confirmed. However, some established trends do suggest that the notion of hydrological zoning should be pursued as further hydrometric data are collected. Some of the more important conclusions derived are as follows:

1. There is a consistency of hydrological values within Zone 1, suggesting that the chosen boundary is valid.
2. Zone 11 should be unique by virtue of its large lake system, and one should anticipate relatively high base flows and low flood peaks, a situation which is similar to that of Zone 3 (Richardson River);
3. It will likely develop that Zones 3 and 5 have a similar hydrological character, except for the Steepbank basin, which appears to be hydrologically different than the Muskeg basin. The Steepbank likely has a greater similarity to Zone 6 (Beaver River and Poplar Creek);
4. There is some indication that the Horse River is hydrologically different than the Hangingstone River; and
5. There is a strong indication that base (minimum) flows for basins west of the Athabasca River are generally lower than those basins to the east of this river.

This trend lends some credence to the use of the character of the surficial drift zone to delineate hydrological zones.

2.3 STREAMFLOW AND LAKE LEVEL NETWORK

2.3.1 Evaluation of Areal Extent of Existing Baseline Network

2.3.1.1 Existing (1978) baseline network. AOSERP, after three years, has reached the stage where it is funding operation of 31 hydrometric stations, 27 of which monitor streamflow and four which monitor lake levels. Water Survey of Canada (WSC) was responsible for establishing these stations and are now responsible for their operation, as well as the processing and compilation of data for publication. All streamflow stations have been provided with continuous (bubbler-type) recorders; lake levels are measured manually.

Figure 1 shows the locations of these stations within the study area. The study area is generally bisected by the Athabasca River. Fifteen of the streamflow stations are to the west (left) of this river and eight to the east (right); two stations on each of the Athabasca and Clearwater rivers, together with the four lake level stations, make up the remainder of the total 31 active stations. The cost of operating these stations during the last fiscal year (March to February of 1977-78), was about $140 000, or $4500 per station. Generally, the cost included monthly servicing of each station, when discharge measurements were taken (more frequent visits during highwater periods), as well as data processing and publication. The above total amount includes operation of full scale and miscellaneous suspended sediment programs, so that a more realistic summary of per station operating costs is as follows:

1. Athabasca River (near Fort McMurray and Embarras stations) and the Clearwater River (near Draper) station; $6500, including complete sediment

sampling program and analysis of samples;

2. All remaining stations, except the lake level stations; \$4700, including a miscellaneous sediment programs at some stations; and
3. Lake level stations; \$1000.

2.3.1.2 Relationship of existing streamflow and lake level network to zones. Based on a comparison of the suggested hydrological zones and the active streamflow stations, the following points are made regarding the areal distribution of the hydrometric stations tributary to the Athabasca and Clearwater Rivers (see Table 7 in conjunction with these points):

1. Zone 1: This zone presently contains eight stations, all of which monitor streamflow, two of which are contained within the Ells basin (lower Ells River and Joslyn Creek), and two of which are contained within the Tar Basin (upper and lower Tar River). Drainage areas above these stations vary from 98 km^2 to 5853 km^2, with seven of them being less that 313 km^2. The upper Tar River station has been established for the specific purpose of monitoring streamflow from an area having runoff from a steep portion of the Birch Mountains. It should be noted that all of this zone has the potential for in situ oil sands development.

   Zone 1 has a high density of stations relative to what it is for the other zones; Table 7 indicates that very little of this zone is not monitored for surface water runoff. Considering the rather narrow range of basin areas, it is questionable whether all of the stations are required to provide a set of baseline information;
2. Zone 2: No stations are contained within this zone, but then less than 25% of the zone has potential for oil sands development (in situ);

Table 7. Relationship of hydrological zones to existing streamflow network.

Zone	Stream	Streamflow Stations (WSC)	Area Above Station (km^2)
1	Lower Ells	7DA-17	2442 (1064 km^2 to Upper Ells station)
	Joslyn	7DA-16	243
	Lower Tar	7DA-15	313
	Upper Tar	7DA-19	98
	Calumet	7DA-14	181
	Pierre	7DA-12	135
	Asphalt	7DA-12	161
	Unnamed	7DA-11	303
	Zone Area (approx) = 2979 km^2 (station density = 1 station per 373 km^2)		
	Total Area Monitored by WSC Stations = 2714 km^2		
2	No streamflow stations		
	Zone Area (approx) = 3367 km^2 (station density = 0)		
3	Richardson	7DD-2	2875
	Zone Area (approx) = 5439 km^2 (station density = 1 station per 2720 km^2)		
	Total Area Monitored by WSC Stations = 2875 km^2		
4	Firebag	7DC-1	5853
	Lost Creek	7DC-2	60
	Zone Area (approx) = 5957 km^2 (station density = 1 station per 2979 km^2)		
	Total Area Monitored by WSC Stations = 5853 km^2		

continued.......

Table 7. Continued.

Zone	Stream	Streamflow Stations (WSC)	Area Above Station (km²)
5	Muskeg	7DA-8	1419
	Hartley	7DA-9	548
	Steepbank	7DA-6	1400
	Zone Area (approx) = 2979 km² (station density = 1 station per 984 km²)		
	Total Area Monitored by WSC Stations = 2821 km²		
6	Beaver	7DA-18	176
	Poplar	7DA-7	142
	Zone Area (approx) = 2072 km² (station density = 1 station per 1036 km²)		
	Total Area Monitored by WSC Stations = 319 km²		
7	Gregoire Lake	7CE-1	298
	Zone Area (approx) = 13 235 km² (station density = 1 station per 13 235 km²)		
8	Hangingstone	7CD-4	907
	Horse	7CC-1	2098
	Zone Area (approx) = 4142 km² (station density = 1 station per 2072 km²)		
	Total Area Monitored by WSC Stations = 3004 km²		
9	Mackay	7DB-1	5232 (3665 km² without Dunkirk River)
	Dover	7DB-2	976
	Thickwood	7DB-4	171
	Zone Area (approx) = 3976 km² (station density = 1 station per 1295 km²)		
	Total Area Monitored by WSC Stations = 3665 km²		

continued......

Table 7. Concluded.

Zone	Stream	Streamflow Stations (WSC)	Area Above Station (km²)
10	Dunkirk	7DB-3	1567
	Zone Area (approx) = 1567 km^2 (station density = 1 station per 1567 km^2)		
	Total Area Monitored by WSC Stations = 1567 km^2		
11	Upper Ells	7DA-10	1378
	Eaglenest Lake	7DA-22	
	Gardiner Lake	7DA-20	
	Namur Lake	7DA-21	
	Zone Area (approx) = 1378 km^2 (station density = 1 station per 344 km^2)		
	Total Area Monitored by WSC Stations = 1378 km^2		
12	McClelland		
	Zone Area (approx) = 648 km^2 (station density = 0 stations per km^2)		

3. Zone 3: A station is present on the Richardson River, but this zone has no potential for oil sands development;
4. Zone 4: This zone contains two active stations, one of which (Lost Creek) has been established for the purpose of monitoring runoff from an area covered by jack pine. Only a small percentage of this zone has the potential for being developed (less than 10%);
5. Zone 5: Three streamflow stations are contained within this zone, with the Hartley Creek station providing a measure of runoff from equal portions of the Muskeg River Upland and Clearwater River Lowland areas. All of the Muskeg basin has the potential for development (about 70% of area has potential for open pit mining), as compared to the Steepbank basin's 30 to 40% potential (30% of which has potential for open pit mining);
6. Zone 6: This zone is comprised of small basins (259 km^2 or less) situated entirely within the Clearwater Lowland. The Beaver Creek station is located immediately upstream of the creek's diversion to Poplar Creek; the station on the latter creek monitors streamflow that includes the diverted Beaver Creek flow. Two streamflow stations are located within this zone, with 100% of the area having potential for development;
7. Zone 7: No streamflow stations in this zone, but there is a lake level station on Gregoire Lake. Less than 10% of the area lies within the study boundaries and only one half of this has the potential for development (in situ). Reasonable estimates of runoff from the Christina basin can be made by subtracting the Clearwater River at Draper streamflow values (Station 7CD-1) from the Clearwater above Christina River flow values (Station 7DC-5).

8. Zone 8: Two streamflow stations have been located in the two largest basins in this zone. Almost 100% of the area has the potential for in situ development;
9. Zone 9: Excepting most of the Dunkirk tributary basin, this zone is made up entirely of the MacKay River basin. One station is located near the mouth of the MacKay River, a second station monitors streamflow from the Dover River tributary, and a third station has been located at the mouth of Thickwood Creek; the latter installation is for the purpose of obtaining runoff information from an area covered by muskeg. Nearly 100% of the area is potentially developable, with about 80% of this likely to be developed by an in situ mining process;
10. Zone 10: One streamflow station is located near the mouth of the Dunkirk River, with all of this zone being comprised of the basin area upstream of this station. Only about 50% of this zone has development potential (in situ mining);
11. Zone 11: Three out of four stations in this zone are for the purpose of monitoring lake levels; the fourth station monitors runoff at the downstream end of an extensive lake system in the Birch Mountains. All of the area has the potential for in situ development; as well, all of the area is within the Birch Mountains Upland region; and
12. Zone 12: No streamflow stations are located in this zone. It appears that most of the area drains into McCelland Lake, which in turn does not appear to have a surface outlet to the Athabasca River. Most of the area has the potential for open pit mining.

2.3.1.3 Conclusions regarding areal distribution of streamflow network:

1. Main Stem Network: These are adequately located and sufficient in number; the Fort McMurray and Embarras stations on the Athabasca River can be compared to provide a measure of the tributary inflow from the majority of the study area, although the comments in Section 2.4 with respect to this matter should be considered. Similarly, the two Clearwater stations at Draper and above Christina River can be compared to provide a measure of flow entering the study area, as well as flow entering from the Christina basin.
2. Small Stream (Tributary) Network: Based on a comparison of hydrological zones and active station locations, it is concluded that stations have been adequately located, and certainly are more than sufficient in number. Although the majority of these stations are located near their confluences, and thus provide a measure of runoff from areas that have a combination of potential for both in situ and surface mining development, there are also sufficient stations in areas having only in situ potential (e.g. Dover, Dunkirk, Upper Ells, and Thickwood stations).

   However, it is felt that a less dense network is warranted because in some zones too many of the stations have been located in areas that should have common streamflow characteristics. If one were to consider what a less dense yet adequate streamflow network might consist of, the writer offers the recommendations summarized in Table 8. This table lists the minimum streamflow network that is considered the one that would likely satisfy AOSERP's baseline streamflow information needs. It is important to remember that this network is based strictly on hydrological considerations and not on environment impact or water

Table 8. Recommended distribution of a minimum streamflow lake level network.

Zone	Minimum Distribution Small Stream Network
1	Lower Ells; WSC 7DA-17
2	No streamflow stations
4	Firebag; WSC 7DC-1
5	Muskeg; WSC 7DA-8 Hartley; WSC 7DA-9 Steepbank; WSC 7DA-6
6	Poplar; WSC 7DA-7
7	No streamflow stations
8	Hangingstone; WSC 7CD-4 Horse; WSC 7CC-1
9	MacKay; WSC 7DB-1
10	Dunkirk; WSC 7DB-3
11	Upper Ells; WSC 7DA-10
12	No streamflow stations
sub-total	11

continued.....

Table 8. Concluded.

Zone	Minimum Distribution
	Main Stem
	Athabasca; 7DA-1
	Athabasca; 7DD-1
	Clearwater; 7CD-1
	Clearwater; 7DC-5
sub-total	4
	Lakes
2	Gardiner; WSC 7DA-20
7	Gregoire; WSC 7CE-1
sub-total	2
total	17

quality factors. For example the Richardson River station has been excluded strictly on the basis that none of Zone 3 has potential for oil sands development. This list should be treated as tentative only at this point, as in the final analysis it will be shown that consideration of these other factors dictated the recommendation of a slightly different network.

3. Lake Level Stations: The largest and most important lakes in the study area are presently having their levels monitored. However, consideration should be given to reducing to one the number of stations in the Birch Mountains region; this could be done if an adequate correlation exists between the Gardiner Lake elevations and those of the other two (Namur and Eaglenest Lakes). This was attempted with measured Gardiner and Eaglenest Lake elevations, and although data are skimpy, it appears from Figure 4 that an adequate correlation might be developed.

2.3.2 Evaluation of Existing Baseline Streamflow Data

2.3.2.1 Streamflow and lake level records available. Figure 5 is a bar graph which summarizes the period of streamflow record available to the end of 1977; Table 9 summarizes the record availability for the 31 stations of interest in this study. Of the 21 tributary stations, 16 streamflow records provide two years or less of continuous data, and another six provide seven years or less; only the Hangingstone River has more than 10 years of record. Several of the Zone 1 records are missing fall or early spring measurements for 1976 and 1977.

Of the main stem stations, the Clearwater River station near Draper and the Athabasca River station near Fort McMurray have 20 years of continuous record; 12 years are available for the Clearwater above Christina River station (open water only to the

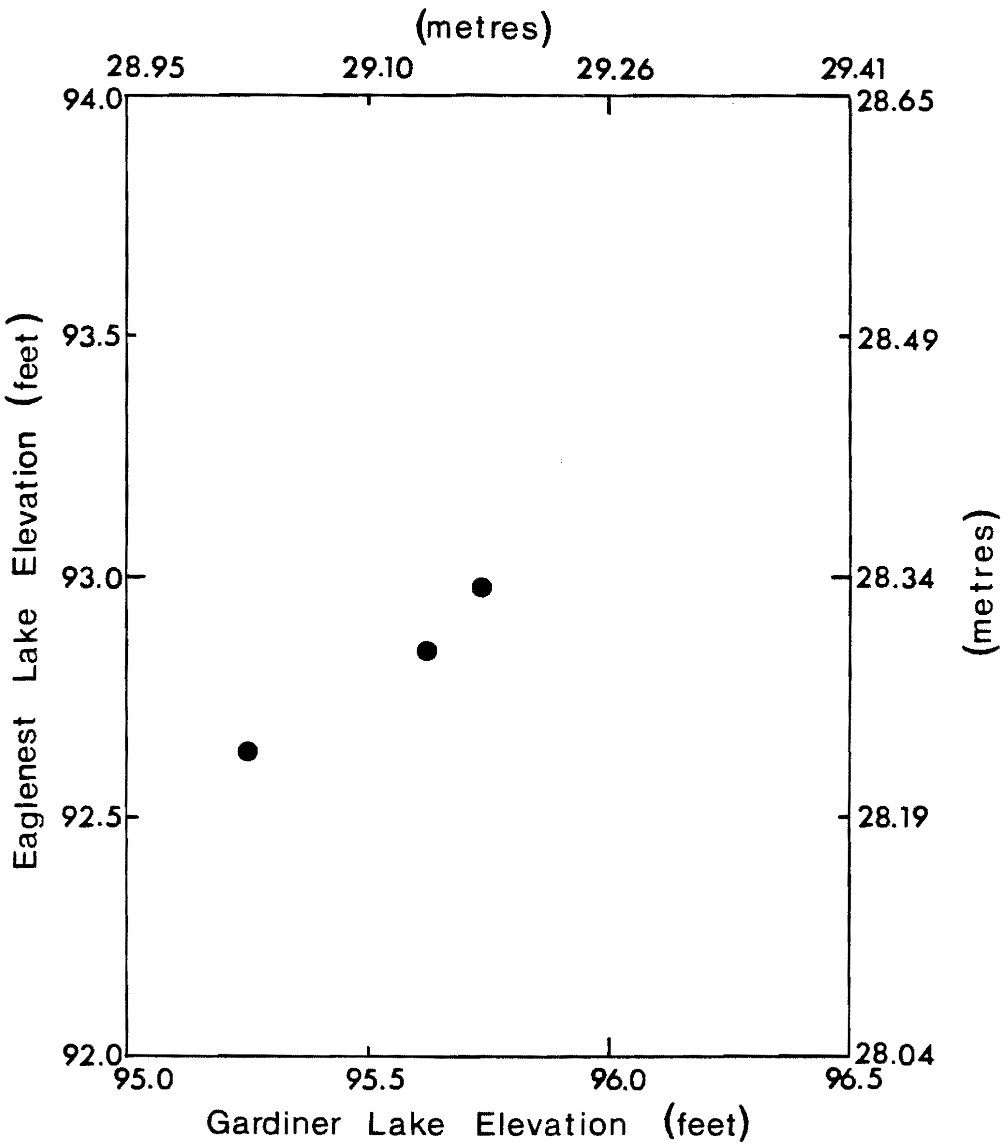


Figure 4. Correlation of Gardiner Lake and Eaglenest Lake elevations.

Table 9. Summary of available streamflow records (active stations).

River or Stream	WSC		Period of Record Available
Lost Ck.	7DB-4		1976 (Aug. to Sept. only)
Tar R. (upper)	7DA-19		1976 (July to Dec. only)
Thickwood Ck.	7DB-4	2 yrs	1976 (May to Dec. only)
Asphalt	7DA-12		1975 (miscellaneous)
Beaver R.	7DA-18		1975 (miscellaneous)
Calumet R.	7DA-14		1975 (Aug. to Dec. only)
Dover R.	7DB-2		1975 (Aug. to Dec. only)
Dunkirk	7DB-3		1975 (Sept. to Dec. only)
Ells R. (lower)	7DA-17		1975 (Aug. to Dec. only)
Ells R. (upper)	7DA-10		1975 (July to Dec. only)
Hartley Ck.	7DA-9		1975 (mid-June to Dec. only)
Horse R.	7CC-1	3 yrs	1975 (miscellaneous)
Joslyn Ck.	7DA-16		1975 (Aug. to Dec. only)
Pierre R.	7DA-13		1975 (Sept. to Dec. only)
Unnamed Ck.	7DA-11		1975 (Sept. to Dec. only)
Tar R. (lower)	7DA-15		1975 (Sept. to Dec. only)
Muskeg R.	7DA-8	4 yrs	Continuous
MacKay R.	7DB-1	6 yrs	1972 (July to Dec. only)
Poplar Ck.	7DA-7		1972 (miscellaneous)
Steepbank R.	7DA-6		1972 (mid-Sept. to Dec. only)
Firebag R.	7DC-1	7 yrs	1971 (mid-Oct. to Dec. only)
Richardson R.	7DD-2	8 yrs	1970 (June to Dec. only)
Hangingstone R.	7CD-4	13 yrs	1965 to 1969 (open water only)

continued.........

Table 9. Concluded.

River or Stream	WSC	Period of Record Available	
Clearwater R.	7CD-5	12 yrs	Open water only
Clearwater R.	7CD-1	20 yrs	Continuous since 1958; Sept. to Dec. in 1957
Athabasca R.	7DA-1	20 yrs	Continuous since 1958
Athabasca R.	7DD-1	7 yrs	1971 (May to Sept. only)
Eaglenest Lk.	7DA-22	2 yrs	Intermittent readings
Gardiner Lk.	7DA-20	2 yrs	Intermittent readings
Gregoire Lk.	7CE-1	9 yrs	Weekly to 2 d readings during open water
Namur Lk.	7DA-21	2 yrs	Weekly to 2 d readings

end of 1977), and only seven years are available for the Athabasca River station near Embarass.

2.3.2.2 Adequacy of existing streamflow and lake level information base. An assessment of the adequacy of existing baseline information should be carried out in association with a consideration of the needs for the information. Previously, the point has been made that AOSERP's needs are environmental in nature, that is, they need to know the chemical and biological nature of the water being carried in rivers and streams. However, aside from the water quality streamflow relationship aspects, adequacy of existing streamflow information is considered on the basis of quality, temporal distribution and length of record.

1. Quality of data: The procedures used by Water Survey of Canada in establishing and operating streamflow stations are well within any minimum equipment and operating standards. Considering the remoteness and difficult access to many of the stations, the availability to AOSERP of a continuous discharge record for so many streams provides a high level of information in relation to the information being gathered by the sediment and water quality networks. A study of the stage-discharge curves established for each station supports that the sections are reasonably stable, that is, not prone to shifting, and thus provide some assurance that the curves can be extrapolated into the higher range of flows using accepted procedures.

   Some areas which indicate minor inconsistencies are as follows:

   - The differences between the Athabasca streamflow at the Embarras and Fort McMurray stations should provide a measure of the tributary contribution between these stations. Available records since 1972 show that the 22 015 km^2 of tributary area provided 3.3, 8.7 and 13.3% of the total flow at the Embarras station in the years 1972, 1973, and 1975, respectively. These values could be checked by adding together the recorded tributary inflow, but 1976 is the only complete year available, and unfortunately the Embarras record is incomplete for this particular year. However, Table 10 was prepared using 1976 monthly mean flows for the summer months, and some observations deserve mention:

- A negative flow is indicated for August, whereas at least 52.5 m^3/s was contributed by the tributaries. The difference may be within the range of acceptable error for measurement of streamflow. For example, a 2% error in the August mean flow at Embarras would be about $\pm$ 27 m^3/s; it is suggested that the probable error range for the WSC type of operation is 2 to 5%. This points out the need for caution in assuming that the two Athabasca stations can be totally relied upon to provide a measure of tributary inflow.
- The tributaries presently being monitored account for about 80% of the total 22 015 km^2 of tributary drainage area between the Embarras and Fort McMurray stations. The proportion of measured inflow as compared to the total, as indicated, varied from 61 to 95%. This raises the question of whether the remaining 20% of tributary area contributed 30 to 40% of the tributary runoff during May and September, which seems unlikely, or only 5% during July, which again seems unlikely. This further illustrates a potential problem from trying to monitor with confidence any development impact on local runoff or local loadings (sediment, water quality parameters) using measurement from the much larger Athabasca River flows.

Table 10. Tributary flow vs. Athabasca River flows for 1976.

	Area km^2	May m^3/s	July m^3/s	Aug m^3/s	Sept m^3/s
Athabasca R. (at Embarras)	154 882	807	1382	1357	1376
Athabasca R. (below Ft. McMurray)	132 867	705	1311	1382	1232
(difference)	22 015	102	71	25	144
Tributary Inflow (meas)	17 514	68	68	53	88
(WSC station)[a]		66%	95%	-	61%

[a] Denotes percentage of measured tributary inflow as compared to tributary inflow given by the difference between the two Athabasca River stations.

- Preliminary assessment of data: It is important during the course of collecting streamflow data (or any other type of hydrometric data) to carry out some initial analysis of the data to ensure its consistency, and to establish trends in hydrological parameters. Errors or gaps may appear, and adjustments in the collection procedures may be implemented before the general users are given the information for their needs. This point does not relate to the quality control procedures of WSC, as they have an in-house system of checking data before it is published. It refers however to in-house activities that AOSERP should be pursuing. To the end of 1976, WSC personnel have plotted annual hydrographs, together with plots of stage-discharge, mean velocity, and flow-area relationships (see Loeppky and Spitzer 1977). As well, an annual yield (runoff) map has been plotted for 1976 (C.R. Froelich, personal communication). This is a commendable first step, but consideration should have been given to doing even more as part of quality control; for example:
  . Specific precipitation-runoff events should be analyzed and documented; this will provide some early and valuable insight into the hydrological water balance regime for the study area;
  . Annual or seasonal precipitation-runoff relationships should be established;
  . It should be established whether there is a consistency of precipitation-runoff relationships and water balance components within given regions as, for example, within the suggested hydrological zones shown in Figure 1; and
  . Water quality versus discharge relationships should be attempted in order to determine whether adequate data are available to develop such relationships, and

whether extrapolation can provide a means of predicting water quality parameters in the range of flows not measured. As well, loadings of these various parameters should be compared to physiographic and surficial aspects of each basin to see if some regionalized relationships can be developed.

2. Temporal Distribution: The continuous streamflow records provide a measure of how discharge varies throughout the year. For AOSERP's purposes, this information is important in assessing the time variation of chemical and mineral loadings carried by the streams. This aspect will be discussed more fully in the section concerning water quality but, from a hydrologist's point of view, the data adequately define the temporal distribution of streamflow. If flow records are missing, it usually occurred during low flow periods when the ungauged flow portion was insignificant to the total flow for the year.

3. Length of record: Stations on the mainstem rivers (Athabasca and Clearwater rivers) must continue to operate, irrespective of who funds their operation. They presently provide the longest period of record in the area, and it is a record base which should continue to expand, primarily because the Athabasca River and its delta have the highest priority in terms of minimizing impact due to development. On the other hand, the tributary stream records are inadequate in terms of having the ability to reliably predict extreme runoff (drought or flood) events. Thirty or more years of record should be available before standard statistical procedures can be applied with confidence. AOSERP personnel are likely aware of this factor, and the argument becomes rather academic when one realizes that they are constrained by a 10-year time limit and a desire to greatly reduce their

baseline streamflow network in the next year or two; recall it was previously suggested that three years of streamflow information would be sufficient to provide a gross appreciation of the baseline states. Based on a review of the available streamflow information, and assuming water quality and suspended sediment needs have been satisfied, it is recommended that AOSERP support operation of a hydrometric network to at least the end of 1979. At that time, outside agencies could then continue to support and operate the network on a long term basis as desired. The suggested reduced network in Table 8 might possibly be considered at that time.

2.4 SUSPENDED SEDIMENT NETWORK

2.4.1 Existing (1977) Baseline Network

At the end of 1977 there were 14 sites at which WSC had the responsibility of collecting and analyzing suspended sediment samples. Two of these were located on the Athabasca River, one on the Clearwater River, seven on tributaries to the west of the Athabasca River, and four on tributaries to the east; Figure 1 shows their locations. Each of these sites is associated with a WSC streamflow station. Table 11 summarizes the availability of information, and it can be seen that eight tributary stations have only two years of record and the remaining three have one year.

Suspended sediment samples were also collected during 1977 at various sites within the Muskeg basin, as well as at sites where water quality samples have been collected. This is part of a miscellaneous data collection program carried out by AOSERP. These data have been discarded from NHCL's network assessment, primarily because the frequency of sampling is considered to have been too low to provide meaningful results. As well, the purpose of the program appears more orientated toward site-specific research goals

Table 11. Active WSC suspended sediment stations in the AOSERP study area (to 1977).

River or Stream	WSC Station	Period of Record
Athabasca River (below Fort McMurray)	7DA-1	1969-72 (some winter months missing)
Athabasca River (at Fort McMurray)	7CC-2	1973-78 (no associated flows with published data)
Athabasca River (near Embarras airport)	7DD-1	1976-77
Clearwater (at Draper)	7CD-1	1969-77 (some winter months missing)
Beaver River	7DA-1B	1976-77
Dover River	7DB-2	1977
Dunkirk River	7DB-3	1977
Ells River	7DA-17	1976-77
Firebag River	7DC-1	1976-77
Hartley Ck.	7DA-9	1976-77
Joslyn Ck.	7DA-16	1976-77
MacKay River	7DB-1	1976-77
Muskeg River	7DA-8	1976-77
Poplar Ck.	7DA-7	1977
Steepbank River	7DA-6	1976-77

rather than the broad-based baseline network operated by W.S.C.

Of primary importance to AOSERP is the Peace-Athabasca River Delta and minimization of detrimental effects to this delta system because of oil sands development. Injection of "extra" sediment from the tributary basins into the Athabasca River as a consequence of massive land erosion in association with road construction and land clearing, or failure of settling pond containment dikes, are likely concerns held by many who feel this impact will have a severe detrimental impact on the downstream delta system. In response to this, Table 12 has been prepared to shed some light on the role played by the tributary basins in supplying sediment to the Athabasca River. Although the values in Table 12 are based on short term data, there is some justification to conclude that the 22 015 km^2 of tributary inflow between Fort McMurray and the Embarras station contributes only about 5% of the sediment entering the delta. It therefore seems inconceivable to believe that development in the tributary basins could produce increased sediment loads in the Athabasca River to the extent that the environmental nature of the aquatic habitat in the relatively larger river would change significantly. Likely of greater importance is consideration of:

1. The local impact: If local rivers are important fish habitats, then injection of extra sediment into the system may be detrimental to this local habitat; and
2. Water quality: Some metals attach themselves to a sediment grain and perhaps, by increasing the sediment concentration, there will be an associated increased capacity by the river to carry this type of pollutant.

In either case, some basic measurements of naturally occurring suspended sediment concentrations collected over a broad network should provide sufficient information with which to conceive site specific and impact prediction orientated research needs.

2.4.2 Areal Distribution of Suspended Sediment Stations

On a gross basis, the 14 sediment sampling stations within the study area provide a density of one station per 2072 km^2.

Table 12. Annual suspended sediment load for the Athabasca River.

	Drainage Area km^2	Average Annual Load (tonnes x 10^6)
Athabasca River (at Fort McMurray)	101 270	9.98
Clearwater River (at Fort McMurray)	31 600	0.82
Total	132 870	10.80
Athabasca River (near Embarras)	154 880	11.43 (estimated)[a]

[a] Estimate based on sediment yield for Clearwater basin.

A comparable value for all of Alberta in 1974, including all of those stations contained in research basins, was one station per 20 720 km^2. It might therefore seem that AOSERP has more than enough suspended sediment stations.

In relation to the proposed hydrological zones established in Section 2.2, one or more of the 11 tributary sediment stations have some measured sediment concentrations for six of the 12 zones. Zones 2, 3, 7, 8, 11, and 12 presently do not have sediment data being collected in them by WSC. The areas of concern are Zones 7 and 8 in which there are in-situ development projects being considered at this time. Sediment coming out of Zone 11 need not be a consideration because the extensive lake system within it should absorb and prevent any impact from extending downstream; the question of lake sedimentation (natural or impact related) is orientated more towards a site specific research effort and would require a much more extensive network than is presently available. Zones 2 and 3 essentially have no potential for development, and Zone 12 has a poorly defined surface drainage system in which sediment yields are likely insignificant.

Based solely on the distribution of stations within each suggested hydrological zone, consideration of areas of potential development, and personal opinion, the following is concluded regarding the areal distribution of sediment stations:

1. It is suggested that one station should be added in Zone 8 at either of the Hangingstone or Horse River streamflow station locations. This station would supplement the Dunkirk River station, the latter being the only present one which is monitoring sediment from an area having primarily in situ development potential;
2. The Dover River station is not required, as the MacKay River station in combination with the Dunkirk one should provide a sufficient measure of suspended sediment yield from Zone 9;

3. The Joslyn River station should be continued as it will provide a measure of sediment yield from an area that is experiencing extensive slumping (east slopes of Birch Mountains);
4. The Firebag River station is not required because little of its basin has development potential;
5. The Steepbank River station could be eliminated, as the Muskeg River station should provide sufficient suspended sediment information for Zone 5;
6. The Beaver River station could be eliminated and the Poplar Creek station used to provide suspended sediment data for both basins; and
7. The Athabasca and Clearwater rivers sediment stations should continue to be operated on a long term basis.

2.4.3 Adequacy of Existing Suspended Sediment Information

Of the 14 active (1977) sediment stations, only the two Athabasca River and Clearwater River stations are being operated at what might be termed a first order level. Sediment samples are being collected on a frequent basis, good sediment concentration-discharge relationships have been developed, and daily sediment loads can be estimated. Collection of samples at Fort McMurray, rather than at the downstream streamflow station, has removed the influence of sediment coming in from the Clearwater River. Also, the Embarras station is far enough downstream from any larger tributary to ensure that there is a reasonable chance that sediment concentrations are uniform across the channel. For these larger channels, WSC, as a matter of course, will take a number of samples across the channel to provide a measure of the sediment distribution.

The remaining sediment stations do not have the same level of operation. In fact the operation can more properly be defined as a miscellaneous sediment program, whereby single depth integrated mid-channel samples are obtained during those times when discharges are metred. One important assumption in this operation is that the concentration of suspended sediment across a section can be considered sufficiently representative of the concentration anywhere. The data for eight of the tributary stations were plotted on stage-discharge curves (see Appendix 8.3), with a distinction being made between spring (April to May) and summer values. After assessing these plots several observations bear mention:

1. In the majority of cases the sampled concentrations lie in the lower range of measured discharges; the Ells River is the exception;
2. There is a hysteresis effect during spring runoff for four of the stations; i.e., for the same discharge, suspended sediment concentrations are higher on the downside of a flood hydrograph than on the upside;
3. A reasonable attempt has been made to define the discharge versus sediment variation during spring runoff;
4. A seasonal difference in the sediment concentration versus discharge relationship is not obvious with the available data;
5. The sediment concentration versus discharge relationships are not sufficient to enable computation of loadings; and
6. The available data are not sufficient to define the sediment concentration regimes during summer floods.

If the purpose of the sediment program on the tributary streams is to obtain gross appreciation for the natural suspended sediment concentrations and sediment loadings over a broad range of flows, then it is concluded that the available data are insufficient. The policy of obtaining samples on a once per month basis when servicing the streamflow stations does not guarantee that high flow events will be sampled.

Factors which likely make it difficult to obtain sufficient high flow sediment data include size of basins and logistics problems. Many of the basins are relatively small and remote rainfall induced flood events may rapidly develop and pass before WSC personnel can properly respond. The cost of maintaining a helicopter on a standby basis so that high flow events can be responded to likely is prohibitive. In a practical sense, and on the basis of present operating procedures, it is doubtful whether meaningful stage-concentration curves can be developed, which in turn indicates that meaningful estimates of sediment loads will not be possible unless substantially more money is made available to WSC. On the other hand the present program will provide a measure of the range of sediment concentrations, as well as a measure of the sediment sizes being transported. If this is considered by AOSERP as being useful baseline information, then it is recommended that they continue to fund operations of the tributary sediment network to at least the end of 1979.

Previous discussion has indicated that, based on zonal considerations, sediment sampling at some stations could be eliminated. However, WSC have indicated that incremental costs of collecting and analyzing the relatively few samples for the tributary sediment network is insignificant as compared to the cost of operating the associated hydrometric gauge. Therefore, it is concluded that there would be no justification in terminating support of the miscellaneous sediment program until such time as AOSERP no longer supports a given gauge where sediment samples are being collected. In addition, however, it is recommended that the sediment network be expanded to include the Hangingstone River station (WSC No. 7CD4).

2.5 WATER QUALITY NETWORK

2.5.1 Objectives

The purpose of the water quality network is to provide information on the baseline regime, which in time will assist in the prediction of disturbed regimes as a result of oil sands development. The general objective of this section is to evaluate the present water quality network on the basis of the current data base so as to provide the foundation for continuation and/or redirection. The specific study objectives are outlined in Section 1.2, and a broadened declaration of the objectives for the water quality network, as stated by AOSERP, is provided here so that the evaluation that follows can be more meaningful. The network is required:

1. To provide regional baseline water quality data (including the Athabasca Delta area); this objective has been stated and discussed several times already, and is really the primary purpose of the water quality network;
2. To identify significant naturally occurring water quality parameters which should be included in procedures for predicting water quality; this objective will fall out of a properly distributed and operated network;
3. To provide a preliminary assessment of the contributions of water originating in or passing through the AOSERP study area on the water chemistry balance of the regions around Lake Athabasca; this established the concurrent need for streamflow information;
4. To provide data on the variation of water quality parameters over time at the mouths of important stream basins, which will be used by future studies to confirm the general accuracy of calibrated water quality models through a comparison of predicted and measured water quality levels; the writer prefers to assign this objective to a Stage 2 network, a matter which is discussed more fully in Sections 3 and 4; and
5. To provide water quality information for concurrent studies; it has been assumed that a concurrent study would not dictate the structure of the baseline network.

2.5.2 Existing Baseline Network

The water quality network has been assessed on the basis of there being 42 stations, including three on the Athabasca River (at Fort McMurray, Fort MacKay, and Embarras), one on the Clearwater River, 11 in the Athabasca Delta region, eight on tributaries east of the Athabasca River, and 19 west of the Athabasca; Figure 1 shows the locations of these stations. Other miscellaneous water quality data are available, but AOSERP has directed that they not be considered as part of the baseline network at this time.

Generally, water quality samples were collected monthly, with analysis being carried out by Chemex Labs (Alberta) Ltd.; a list in Table 13 shows parameters which were tested for. Typically a single sample was collected near the stream's edge and a homogeneous distribution of water quality was assumed along a section from that point. All stations, except those in the Athabasca Delta region, are associated with WSC streamflow stations. It has been assumed that discharges at the delta sites are being obtained in conjunction with the streamflow network established for the Peace-Athabasca Delta study, and thus is an area of data collection not being funded by AOSERP.

2.5.3 Areal Distribution of Water Quality Stations

The unbalanced hydrological zonal distribution of the 42 water quality stations is presented in Figure 1 and Table 14; criteria used to evaluate the adequacy of the areal coverage consisted of the following:

1. Stations should be representative of areas slated for development of oil sands and within the boundaries of the AOSERP study area;
2. Stations should be representative of as large an area as possible in order to be cost effective;
3. Present station data are assumed to be homogeneous (3-dimensional) and representative of upstream quality;
4. Stations must be located in areas where hydrometric gauges are located in order to quantify loadings to

Table 13. Parameters for regional and delta water quality study (from Seidner in prep.).

Parameter	NAQUADAT Code (specifying method and detection limit)
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	01603 L
Fluoride	09105 L
Silica	14101 L
Conductance	02041 L
Threshold Odor No.	02001 L
Color	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	06051 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-Phosphorous	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	26304 L, 26301 L 26101 L

Table 13. Concluded.

Parameter	NAQUADAT Code (specifying method and detection limit)
Lead	82302 L, 82301 L 82101 L
Manganese	25304 L, 25301 L 25101 L
Silver	47302 L, 47301 L
Zinc	30305 L, 33304 L 30301 L 23301 L
Vanadium	23003 L, 23301 L 23101 L
Selenium	34102 L, 34302 L 38101 L, 34302 L
Mercury	80011 L, 80301 L
Arsenic	33104 L, 33104 L 33101 L, 33301 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 14. Water quality sampling frequency and distribution (according to season[a]) amongst stations and temporal variation of data base.

Zone[b]	Station	Total Samples	Winter	Spring	Summer	Autumn
1	Upper Ells R.	12	2	3	3	4
	Lower Ells R.	12	2	2	2	4
	Joslyn Cr.	8	0	1	3	4
	Tar R.	11	2	3	3	3
	Calumet R.	6	0	1	3	2
	Pierre R.	9	0	2	3	4
	Asphalt Cr.	7	0	2	4	1
	Unnamed Cr.	5	2	0	2	1
2	Not Represented	0				
3	Richardson R.	2	0	0	1	1
4	Firebag R.	15	3	4	4	4
	Lost Cr.	6	0	0	4	2
5	Muskeg R.	15	3	3	3	6
	Hartley Cr.	15	2	3	5	5
	Steepbank R.	9	3	2	0	4
6	Beaver Cr. above Syncrude	11	0	3	4	4
	Beaver Cr. at hwy.	11	2	1	3	5
	Bridge Cr.	12	0	2	4	6
	Poplar Cr.	12	2	3	3	4

continued.......

Table 14. Continued.

Zone[b]	Station	Total Samples	Winter	Spring	Summer	Autumn
	Clearwater R.	15	4	2	4	5
7	Gregoire L.	12	3	3	3	3
8	Horse R.	5	1	0	2	2
	Hangingstone R.	15	4	4	3	4
9	Thickwood Cr.	12	1	3	3	5
	Dover R.	4	0	1	1	2
	MacKay R.	10	3	3	2	2
10	Dunkirk R.	10	1	3	3	3
11	Eaglenest L.	11	2	4	3	2
	Gardiner L.	11	2	4	3	2
	Namur L.	11	2	4	3	2
Athabasca River Sites	100 m u/s Horse R.	11	3	0	4	4
	at Fort MacKay	8	1	2	2	3
	at Embarras	1	0	0	0	1
Delta Sites	Richardson L.	5	0	1	2	2
	Jackfish Cr.	4	0	0	2	2
	Big Pt. Channel	6	0	1	2	2
	Lake Claire east of 28th	4	0	0	2	2
	Lake Claire center	2	0	0	0	2

continued.......

Table 14. Concluded.

Zone[b]	Station	Total Samples	Winter	Spring	Summer	Autumn
	Prairie R.	3	0	0	2	1
	Mamawi L. Channel	1	0	0	1	0
	Channel des Quatre Fourchers	5	0	0	3	2
	Riviere des Rochiers	5	0	0	2	3
	Sandy Point	4	0	0	2	2
	Totals	353	50	71	109	123

[a]Assuming:

Winter samples occur in the months of December, January, February, March.

Spring samples occur in the months of April, May, June.

Summer samples occur in the months of July, August.

Autumn samples occur in the months of September, October, November.

[b]See Figure 1 for zone description.

the Athabasca River, and eventually to the delta;

5. Multiple stations on any watercourse must be justified as representing specific local or unique characteristics from other stations, or be removed;
6. Discharge regime must be adequate to allow indigenous fish species to complete at least one aspect of their life cycle;
7. Streams are characteristic of natural states; and
8. Within a watershed a station must represent at least 10% of the total tributary streamflow at the Athabasca confluence.

Based on the unbalanced hydrological zonal distribution of the water quality stations, the following concepts emerged early on in the program:

1. Due to the small potential for oil sands development, present stations in Zone 3 could be eliminated; therefore, consideration of these sites was not warranted in the evaluation process;
2. Evaluation of watersheds in Zone 2 was not considered since no information was available;
3. Delta sites cannot be evaluated at present due to the obvious deficiency of the data base (see Section 2.5.4 for further discussion);
4. Consideration of additional stations in either/or both Zone 7 and Zone 8 was warranted; and
5. Statistical tests should be considered to ascertain whether a reduction in station density can be achieved in Zones 1, 4, 5, 6, 9, and 11.

As previously stated, the existing network is extensive in coverage (42 stations) and was basically designed as a broad screening program. It is conceived that such a program should yield a gross appreciation of the surficial water chemistry of the region, realizing at the same time, however, that it lacks the sampling intensity necessary to satisfy the requirement of a predictive correlation among parameters at the present time. Therefore, in a meeting with the Scientific Authority (R. Seidner) it was generally agreed that the primary direction of the evaluation process should be oriented towards assessing the adequacy of the present network coverage. That is, if a reduction in station density, hence funding, could be realized, then the program could be redirected in a cost efficient manner.

It was rationalized that the evaluation process should be designed to compare stations in close proximity to one another. If a redundance in water quality information is evident, then a reduction in the number of stations would be warranted. Also, it was felt that of two basins, each much different in size but exhibiting similar water quality characteristics, and each having a station, the station monitoring the larger basin would be selected for continued operation. This approach is also concurrent with the concept of hydrological zonation discussed previously in this report. This was by design because it was felt very early in the program that integrated hydrometric and water quality networks would yield the most cost effective benefits to the program due to a savings in logistical costs.

With this as a basis, the data were initially grouped by percent cumulative distribution in order to gain insight into any similarities between stations within a single watershed and, secondly, within a hydrological zone. Certain patterns or "apparent trends" were generally observed for dissolved ions of surficial or geological origin between stations located within the same basin and among stations located within the same or contiguous hydrological zones(s). On this basis, it was hypothesized for parameters of similar geological origin (conductivity, total hardness, total alkalinity, sodium, chloride, magnesium, calcium, potassium, flouride, reactive silica, and sulphate) that:

1. Upper Ells should be generally characteristic of Namur, Gardiner, and Eaglenest Lakes, but different in quality for Joslyn Creek, Tar River, Calumet Creek, Pierre River, Asphalt Creek, and Unnamed Creek;

2. Joslyn Creek should appear to be of different quality for the Lower Ells River and more characteristic of the northern watersheds in Zone 1;
3. Firebag River should appear to be of similar quality to Lost Creek;
4. Hartley Creek, Steepbank River, and the Muskeg River should be consistent in quality characteristics;
5. Upper Beaver Creek should be similar to the Poplar Creek station; and
6. MacKay River appears to be distinct from the Dover River and other upstream stations.

It was recognized that, in order to alleviate investigator bias and strengthen the confidence base for comparisons amongst stations, statistical reasoning was required. Statistical analysis of paired data would be ideal; however, this approach had to eventually be precluded due to the difference in sampling dates between stations for which comparisons were desired. Eventually, due to a desire to establish some statistical reasoning, the Wilcoxon non-parametric signed Rank two-sample test was chosen for comparing differences between two means since it requires no knowledge or assumptions of the pattern of distribution of concentrations over time. Significance was chosen at the 0.05 level; this test procedure is outlined in Sokal and Rohlf (1969).

Certain problems were encountered due to outliers in the frequency distribution. That is, at several stations outliers were consistent with the low flow, winter sampling period, thus yielding significant difference between periods of ice-cover to open water periods. These results, compounded by a paucity of winter sampling points, resulted in the application of a judgement factor to only compare open water data points.

Results of these comparisons are presented in Tables 15 to 75; graphical presentation of concentrations over the open water period are located in Figures 6 to 23.

Table 15. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

DISSOLVED CHLORIDE

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	0.38	1.3	0.30	0.46	0.37			
Upper Ells River	0.38		<	=	=	=			
Lower Ells River	1.3	>		>	>	>			
Namur Lake	0.30	=	<		<	=			
Gardiner Lake	0.46	=	<	>		=			
Eaglenest Lake	0.37	=	<	=	=				

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 16. Statistical comparisons[a] between mean value for tributaries and lakes located in Zone 11.

DISSOLVED FLUORIDE

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	0.10	0.10	0.06	0.09	0.12			
Upper Ells River	0.10		=	>	=	<			
Lower Ells River	0.10	=		>	=	=			
Namur Lake	0.06	<	<		<	<			
Gardiner Lake	0.09	=	=	>		=			
Eaglenest Lake	0.12	>	=	>	=				

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 17. Statistical comparisons[a] between mean value for tributaries and lakes located in Zone 11.

DISSOLVED MAGNESIUM

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	45	6.1	1.7	4.7	4.4			
Upper Ells River	4.5		<	>	<	=			
Lower Ells River	6.1	>		>	>	>			
Namur Lake	1.7	<	<		<	<			
Gardiner Lake	4.7	>	<	>		=			
Eaglenest Lake	4.4	=	<	>	=				

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 18. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

DISSOLVED POTASSIUM

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$		11.9	0.93	1.00	0.73			
Upper Ells River	0.87		<	=	=	=			
Lower Ells River	1.19	>		=	=	>			
Namur Lake	0.93	=	=		=	>			
Gardiner Lake	1.00	=	=	=		>			
Eaglenest Lake	0.73	=	<	<	<				

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 18. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

DISSOLVED POTASSIUM

	$\bar{X}$	Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
$\bar{X}$			11.9	0.93	1.00	0.73			
Upper Ells River	0.87		<	=	=	=			
Lower Ells River	1.19	>		=	=	>			
Namur Lake	0.93	=	=		=	>			
Gardiner Lake	1.00	=	=	=		>			
Eaglenest Lake	0.73	=	<	<	<				

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 19. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

CONDUCTANCE (µmhos/cm)

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	110.0	168	48.5	114.6	101.5			
Upper Ells River	110.0		<	>	=	=			
Lower Ells River	168.0	>		>	>	>			
Namur Lake	48.5	<	<		<	<			
Gardiner Lake	114.6	=	<	>		=			
Eaglenest Lake	101.5	=	<	>	=				

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 20. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

TOTAL ALKALINITY

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	53.2	77.0	19.4	55.1	50.8			
Upper Ells River	53.2		<	>	=	=			
Lower Ells River	77.0	>		>	>	>			
Namur Lake	19.4	<	<		<	<			
Gardiner Lake	55.1	=	<	>		=			
Eaglenest Lake	50.8	=	<	>	=				

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 21. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

TOTAL HARDNESS

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	54.8	76.4	20.6	57.9	50.6			
Upper Ells River	54.8		<	>	=	>			
Lower Ells River	76.4	>		>	>	>			
Namur Lake	20.6	<	<		<	<			
Gardiner Lake	57.9	=	<	>		>			
Eaglenest Lake	50.6	<	<	>	<				

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 22. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

DISSOLVED CALCIUM

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	14.5	20.2	5.4	15.5	13.0			
Upper Ells River	14.5		<	>	=	=			
Lower Ells River	20.2	>		>	>	>			
Namur Lake	5.4	<	<		<	<			
Gardiner Lake	15.5	=	<	>		>			
Eaglenest Lake	13.0	=	<	>	<				

[a] Level of Significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 23. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

REACTIVE SILICA

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	1.70	1.65	0.38	3.4	1.1			
Upper Ells River	1.70		=	>	=	=			
Lower Ells River	1.65	=		>	=	=			
Namur Lake	0.38	<	<		<	<			
Gardiner Lake	3.4	=	=	>		=			
Eaglenest Lake	1.1	=	=	>	=				

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 24. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

DISSOLVED SODIUM

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$	2.9	8.6	1.9	2.8	2.7			
Upper Ells River	2.9		<	>	=	>			
Lower Ells River	8.6	>		>	>	>			
Namur Lake	1.9	<	<		<	<			
Gardiner Lake	2.8	=	<	>		<			
Eaglenest Lake	2.7	<	<	>	=				

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 25. Statistical comparisons[a] between mean values for tributaries and lakes located in Zone 11.

DISSOLVED SULPHATE

		Upper Ells River	Lower Ells River	Namur Lake	Gardiner Lake	Eaglenest Lake			
	$\bar{X}$		12.1	5.2	5.8	4.3			
Upper Ells River	5.7		<	=	=	=			
Lower Ells River	12.1	>		>	>	>			
Namur Lake	5.2	=	<		=	=			
Gardiner Lake	5.8	=	<	=		=			
Eaglenest Lake	4.3	=	<	=	=				

a Level of significance at 0.05
= denotes no significant difference between means
< denotes significantly less than
> denotes significantly greater than

Table 26. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

DISSOLVED CHLORIDE

		Unnamed Creek	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{x}$	1.1	2.7	2.8	14.3	2.0	2.0	1.3	
Unnamed Creek	1.1		<	<	<	<	<	=	
Asphalt Creek	2.7	>		=	<	=	>	>	
Pierre River	2.8	>	=		<	=	>	>	
Calumet River	14.3	>	>	>		>	>	>	
Tar River	2.0	>	=	=	<		=	>	
Joslyn Creek	2.0	>	<	<	<	=		=	
Lower Ells River	1.3	=	<	<	<	<	=		

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 27. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

DISSOLVED FLUORIDE

		Unnamed Creek	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	0.32	0.32	0.37	0.17	0.20	0.25	0.10	
Unnamed Creek	0.32		=	=	>	>	=	>	
Asphalt Creek	0.32	=		=	>	>	=	>	
Pierre River	0.37	=	=		>	>	>	>	
Calumet River	0.17	<	<	<		=	=	>	
Tar River	0.20	<	<	<	=		=	>	
Joslyn Creek	0.25	=	=	<	=	=		>	
Lower Ells River	0.10	<	<	<	<	<	<		

[a] Level of significance at 0,05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 28. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

DISSOLVED MAGNESIUM

	$\bar{X}$	Unnamed Creek	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	12.4	11.8	11.6	12.7	10.6	12.5	6.1	
Unnamed Creek	12.4		=	=	=	=	=	>	
Asphalt Creek	11.8	=		=	=	=	=	>	
Pierre River	11.6	=	=		=	=	=	>	
Calumet River	12.7	=	=	=		>	=	>	
Tar River	10.6	=	=	=	<		=	>	
Joslyn Creek	12.5	=	=	=	=	=		>	
Lower Ells River	6.1	<	<	<	<	<	<		

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 29. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

DISSOLVED POTASSIUM

		Unnamed Creek	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	2.8	2.5	3.6	2.6	1.8	3.0	1.2	
Unnamed Creek	2.8		=	<	=	>	=	>	
Asphalt Creek	2.5	=		<	=	>	<	>	
Pierre River	3.6	>	>		>	>	=	>	
Calumet River	2.6	=	=	<		>	=	>	
Tar River	1.8	<	<	<	<		<	>	
Joslyn Creek	3.0	=	>	=	=	>		>	
Lower Ells River	1.2	<	<	<	<	<			

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 30. Statistical comparisons[a] between mean values for tributaries location in hydrological zone 1.

CONDUCTANCE (µmhos/cm)

	$\bar{X}$	Unnamed Creek	Asphalt Creek	Pierre River	Calumet River	Tar River	Creek	Lower Ells River	
Unnamed Creek	348		-	-	<	>	<	>	
Asphalt Creek	356	=		=	=	=	=	>	
Pierre River	371	=	=		=	>	=	>	
Calumet River	401	>	=	=		>	=	>	
Tar River	290	<	=	<	<		<	>	
Joslyn Creek	411	>	=	=	=	>		>	
Lower Ells River	168	<	<	<	<	<	<		

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 31. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

TOTAL ALKALINITY

		Unnamed Creek	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	348	356	371	401	290	411	168	
Unnamed River	348		=	=	<	>	<	>	
Asphalt Creek	356	=		=	=	=	=	>	
Pierre River	371	=	=		=	>	=	>	
Calumet River	401	>	=	=		>	=	>	
Tar River	290	<	=	<	<		<	>	
Joslyn Creek	411	>	=	=	=	>		>	
Lower Ells River	168	<	<	<	<	<	<		

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 32. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

TOTAL HARDNESS

		Unnamed River	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	157.6	128.6	134.8	144.5	124.7	163.2	76.4	
Unnamed River	157.6		=	>	=	>	=	>	
Asphalt Creek	128.6	=		=	=	=	=	>	
Pierre River	134.8	<	=		=	=	<	>	
Calumet River	144.5	=	=	=		>	=	>	
Tar River	124.7	<	=	=	<		<	>	
Joslyn Creek	163.2	=	=	>	=	>		>	
Lower Ells River	76.4	<	<	<	<	<	<		

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 33. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

DISSOLVED CALCIUM

		Unnamed River	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	42.7	32	34.8	37.0	32.5	44.8	20.2	
Unnamed River	42.7		>	>	>	>	=	>	
Asphalt Creek	32.0	<		=	=	=	<	>	
Pierre River	34.8	<	=		=	=	<	>	
Calumet River	37.0	<	=	=		>	<	>	
Tar River	32.5	<	=	=	<		<	>	
Joslyn Creek		=	>	>	>	>		>	
Lower Ells River	20.2	<	<	<	<	<	<		

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 34. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

REACTIVE SILICA

		Unnamed River	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	9.2	7.5	8.4	6.6	6.7	5.9	1.6	
Unnamed Creek	9.2		=	=	>	>	>	>	
Asphalt Creek	7.5	=		=	=	=	>	>	
Pierre River	8.4	=	=		>	>	>	>	
Calumet River	6.6	<	=	<		=	=	>	
Tar River	6.7	<	=	<	=		=	>	
Joslyn Creek	5.9	<	<	<	=	=		>	
Lower Ells River	1.6	<	<	<	<	<	<		

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 35. Statistical comparisons[a] between mean values for tributaries located in hydrological zone 1.

DISSOLVED SODIUM

		Unnamed River	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	15.0	20.4	23.8	38.2	15.9	27.3	8.6	
Unnamed Creek	15.0		<	<	<	=	<	>	
Asphalt Creek	20.4	>		<	<	>	=	>	
Pierre River	23.8	>	>		<	>	=	>	
Calumet River	38.2	>	>	>		>	>	>	
Tar River	15.9	=	<	<	<		<	>	
Joslyn Creek	27.3	>	=	=	<	>		>	
Lower Ells River	8.6	<	<	<	<	<	<		

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 36. Statistical comparinsons[a] between mean values for tributaries in hydrological zone 1.

DISSOLVED SULPHATE

		Unnamed River	Asphalt Creek	Pierre River	Calumet River	Tar River	Joslyn Creek	Lower Ells River	
	$\bar{X}$	44.6	118.4	91.0	10.2	28.3	74.5	12.1	
Unnamed Creek	44.6		<	<	=	=	=	=	
Asphalt Creek	118.4	>		=	>	>	>	>	
Pierre River	91.0	>	=		>	>	=	>	
Calumet River	10.2	=	<	<		<	<	=	
Tar River	28.3	=	<	<	>		<	>	
Joslyn Creek	74.5	=	<	=	>	>		>	
Lower Ells River	12.1	=	<	<	=	<	<		

a Level of significance at 0.05
= denotes no significant difference between means
< denotes significantly less than
> denotes significantly greater than

Table 37. Statistical comparisons[a] between mean values for tributaries located in Zone 4.

CONDUCTANCE (µmhos/cm)

	$\bar{X}$	Lost Creek	Firebag
$\bar{X}$		154	184
Lost Creek	154		<
Firebag	184	>	

TOTAL ALKALINITY

	$\bar{X}$	Lost Creek	Firebag
$\bar{X}$		89	96
Lost Creek			=
Firebag		=	

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 38. Statistical comparisons[a] between mean values for tributaries located in Zone 4.

TOTAL HARDNESS

	$\bar{X}$	Lost Creek	Firebag
		88	98
Lost Creek	88		=
Firebag	98	=	

DISSOLVED CALCIUM

	$\bar{X}$	Lost Creek	Firebag
		24.0	25.8
Lost Creek	24.0		=
Firebag	25.8	=	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 39. Statistical comparisons[a] between mean values for tributaries located in Zone 4.

DISSOLVED CHLORIDE

		Lost Creek	Firebag
	$\bar{X}$	0.47	1.6
Lost Creek	0.47		<
Firebag	1.6	>	

DISSOLVED FLUORIDE

		Lost Creek	Firebag
	$\bar{X}$	0.08	0.10
Lost Creek	0.08		=
Firebag	0.10	=	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 40. Statistical comparisons[a] between mean values for tributaries located in Zone 4.

DISSOLVED MAGNESIUM

	$\bar{X}$	Lost Creek	Firebag River
Lost Creek	6.7		=
Firebag River	8.0	=	

DISSOLVED POTASSIUM

	$\bar{X}$	Lost Creek	Firebag River
Lost Creek	0.15		<
Firebag River	0.62	>	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 41. Statistical comparisons[a] between mean values for tributaries located in Zone 4.

REACTIVE SILICA

		Lost Creek	Firebag River
	$\bar{X}$	6.2	8.6
Lost Creek	6.2		<
Firebag River	8.6	>	

DISSOLVED SODIUM

	Lost Creek	Firebag River
$\bar{X}$	2.0	4.0
Lost Creek		<
Firebag River	>	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 42. Statistical comparisons[a] between mean values for tributaries located in Zone 4.

DISSOLVED SULPHATE

		Lost Creek	Firebag River						
	$\bar{X}$	3.3	3.4						
Lost Creek	3.3		=						
Firebag River	3.4	=							

[a] Level of significance at 0.05

= denotes no significant difference

< denotes significantly less than

> denotes significantly greater than

Table 43. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

DISSOLVED CHLORIDE

		Hartley Creek	Muskeg River	Steepbank River
	$\bar{X}$	1.8	9.1	2.4
Harley Creek	1.8		<	=
Muskeg River	9.1	<		=
Steepbank River	2.4	=	=	

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 44. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

DISSOLVED FLUORIDE

	$\bar{X}$	Hartley Creek	Muskeg River	Steepbank River
$\bar{X}$		0.10	0.12	0.11
Harltey Creek	0.10		=	=
Muskeg River	0.12	=		=
Steepbank River	0.11	=	=	

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 45.i Statistical comparisons[a] between mean values for tributaries located in Zone 5.

DISSOLVED MAGNESIUM

		Hartley Creek	Muskeg River	Steepbank River					
	$\bar{X}$	7.4	10.3	8.5					
Hartley Creek	7.4		=	=					
Muskeg River	10.3	=		=					
Steepbank River	8.5	=	=						

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 46. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

DISSOLVED POTASSIUM

		Hartley Creek	Muskeg River	Steepbank River					
	$\bar{X}$	0.99	0.96	0.88					
Harltey Creek	0.99		=	=					
Muskeg River	0.96	=		=					
Steepbank River	0.88	=	=						

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 47. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

CONDUCTANCE (μmhos/cm)

	$\bar{X}$	Hartley Creek	Muskeg River	Steepbank River
$\bar{X}$		193	300	215
Hartley Creek	193		<	=
Muskeg River	300	>		>
Steepbank River	215	=	<	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 48. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

TOTAL ALKALINITY

		Hartley Creek	Muskeg River	Steepbank River
	$\bar{X}$	114	157	134
Hartley Creek	114		<	=
Muskeg River	157	>		=
Steepbank River	134	=	=	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 49. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

TOTAL HARDNESS

		Hartley Creek	Muskeg River	Steepbank River					
	$\bar{X}$	100	139	116					
Hartley Creek	100		<	=					
Muskeg River	139	>		=					
Steepbank River	116	=	=						

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 50. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

DISSOLVED CALCIUM

		Hartley Creek	Muskeg River	Steepbank River					
	$\bar{X}$	26.9	38.6	27.0					
Harley Creek	26.9		<	=					
Muskeg River	38.6	>		>					
Steepbank River	27.0	=	<						

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 51. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

REACTIVE SILICA

		Hartley Creek	Muskeg River	Steepbank River
	$\bar{X}$	4.7	5.8	5.4
Hartley Creek	4.7		=	=
Muskeg River	5.8	=	=	
Steepbank River	5.4	=	=	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 52. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

DISSOLVED SODIUM

		Hartley Creek	Muskeg River	Steepbank River					
	$\bar{X}$	11.3	17.5	13.0					
Hartley Creek	11.3		=	=					
Muskeg River	17.5	=		=					
Steepbank River	13.0	=	=						

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 53. Statistical comparisons[a] between mean values for tributaries located in Zone 5.

DISSOLVED SULPHATE

		Hartley Creek	Muskeg River	Steepbank River
	$\bar{X}$	4.1	5.9	3.8
Hartley Creek	4.1		=	=
Muskeg River	5.9	=		=
Steepbank River	3.8	=	=	

a Level of significance at 0.05

= denotes no significant difference

< denotes significantly less than

> denotes significantly greater than

Table 54. Statistical comparison[a] between mean values for tributaries located in Zone 6.

DISSOLVED CHLORIDE

		Beaver Creek	Lower Beaver Creek	Bridge Cr. Diversion	Lower Poplar Creek				
	$\bar{X}$	1.6	33.5	17.0	28.4				
Beaver Creek	1.6		<	<	<				
Lower Beaver Creek	33.5	>		=	=				
Bridge Cr. Diversion	17.0	>	=		=				
Lower Poplar Creek	28.4	>	=	=					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 55. Statistical comparison[a] between mean values for tributaries in Zone 6.

DISSOLVED FLUORIDE

	$\bar{X}$	Beaver Creek	Lower Beaver Creek	Bridge Cr. Diversion	Lower Poplar Creek
$\bar{X}$		0.13	0.18	0.14	0.11
Beaver Creek	0.13		=	=	=
Lower Beaver Creek	0.18	=		=	>
Bridge Ck. Diversion	0.14	=	=		>
Lower Poplar Creek	0.11	=	<	<	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 56. Statistical comparison[a] between mean values for tributaries located in Zone 6.

DISSOLVED MAGNESIUM

		Beaver Creek	Lower Beaver Creek	Bridge Cr. Diversion	Lower Poplar Creek
	$\bar{X}$	9.6	17.4	11.3	9.8
Beaver Creek	9.6		<	=	=
Lower Beaver Creek	17.4	>		>	>
Bridge Cr. Diversion	11.3	=	<		=
Lower Poplar Creek	9.8	=	<	=	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 57. Statistical comparison[a] between mean values for tributaries located in Zone 7.

DISSOLVED POTASSIUM

		Beaver Creek	Lower Beaver Creek	Bridge Cr. Diversion	Lower Poplar Creek				
	$\bar{X}$	1.55	3.64	2.12	2.73				
			<	<	<				
Beaver Creek	1.55	>		>	>				
Lower Beaver Creek	3.64	>		>	>				
Bridge Cr. Diversion	2.12	>	<		<				
Lower Poplar Creek	2.73	>	<	>					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 58. Statistical comparison[a] between mean values for tributaries located in Zone 7.

CONDUCTANCE (µmhos/cm)

		Beaver Creek	Lower Beaver Creek	Bridge Ck. Diversion	Lower Poplar Creek				
	$\bar{X}$	306	543	352	350				
Beaver Creek	306		<	=	=				
Lower Beaver Creek	543	>		>	>				
Bridge Ck. Diversion	352	=	<		=				
Lower Poplar Creek	350	=	<	=					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 59. Statistical comparison[a] between mean values for tributaries located in Zone 7.

TOTAL ALKALINITY

		Beaver Creek	Lower Beaver Creek	Bridge Ck. Diversion	Lower Poplar Creek				
	$\bar{X}$	154	197	154	153				
Beaver Creek	154		=	=	=				
Lower Beaver Creek	197	=		>	>				
Bridge Ck. Diversion	154	=	<		=				
Lower Poplar Creek	153	=	<	=					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 60. Statistical comparison[a] between mean values for tributaries located in Zone 7.

TOTAL HARDNESS

		Beaver Creek	Lower Beaver Creek	Bridge Ck. Diversion	Lower Poplar Creek
	$\bar{X}$	107	233	144	113
Beaver Creek	107		<	<	=
Lower Beaver Creek	233	>		>	>
Bridge Ck. Diversion	144	>	<		=
Lower Poplar Creek	113	=	<	=	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 61. Statistical comparison[a] between mean values for tributaries located in Zone 7.

DISSOLVED CALCIUM

		Beaver Creek	Lower Beaver Creek	Bridge Ck. Diversion	Lower Poplar Creek
	$\bar{X}$	27.0	64.8	37.9	29.1
Beaver Creek	27.0		<	=	=
Lower Beaver Creek	64.8	>		>	>
Bridge Ck. Diversion	37.9	=	<		=
Lower Poplar Creek	29.1	=	<	=	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 62. Statistical comparison[a] between mean values for tributaries located in Zone 7.

REACTIVE SILICA

		Beaver Creek	Lower Beaver Creek	Bridge Ck. Diversion	Lower Poplar Creek
	$\bar{X}$	6.0	3.5	4.8	4.9
Beaver Creek	6.0		>	=	=
Lower Beaver Creek	3.5	<		=	=
Bridge Ck. Diversion	4.8	=	=		=
Lower Poplar Creek	4.9	=	=	=	

[a] Level of significance at 0.05

= denotes no significant difference between mean values

< denotes significantly less than

> denotes significantly greater than

Table 63. Statistical comparison[a] between mean values for tributaries located in Zone 7.

DISSOLVED SODIUM

		Beaver Creek	Lower Beaver Creek	Bridge Ck. Diversion	Lower Poplar Creek				
	$\bar{X}$	35.8	35.7	31.0	40.5				
Beaver Creek	35.8		=	=	=				
Lower Beaver Creek	35.7	=		=	=				
Bridge Ck. Diversion	31.0	=	=		<				
Lower Poplar Creek	40.5	=	=	>					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 64. Statistical comparison[a] between mean values for tributaries location in Zone 7.

DISSOLVED SULPHATE

		Beaver Creek	Lower Beaver Creek	Bridge Ck. Diversion	Lower Poplar Creek				
	$\bar{X}$	8.9	52.2	21.4	5.6				
Beaver Creek	8.9		<	<	=				
Lower Beaver Creek	52.2	>		>	>				
Bridge Ck. Diversion	21.4	>	<	>	>				
Lower Poplar Creek	5.6	=	<						

[a] Level of Significance at 0.5

= denotes no significant difference

< denotes significantly less than

> denotes significantly greater than

Table 65. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

DISSOLVED CHLORIDE

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.				
	$\bar{X}$	0.9	0.9	5.5	7.7				
Dunkirk R.	0.9		=	<	<				
Thickwood Creek	0.9	=		<	<				
MacKay R.	5.5	>	>		=				
Dover R.	7.7	>	>	=					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 66. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

DISSOLVED FLUORIDE

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.				
	$\bar{X}$	0.12	0.06	0.13	0.17				
Dunkirk R.	0.12		>	=	<				
Thickwood Creek	0.06	<		<	<				
MacKay R.	0.13	=	>		=				
Dover R.	0.17	>	>	=					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 67. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

DISSOLVED MAGNESIUM

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.				
	$\bar{X}$	7.5	4.7	10.7	15.2				
Dunkirk R.	7.5		>	=	<				
Thickwood Creek	4.7	<		<	<				
MacKay R.	10.7	=	>		<				
Dover R.	15.2	>	>	=					

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 68. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

DISSOLVED SODIUM

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.
	$\bar{X}$	7.5	2.5	22.0	41.2
Dunkirk R.	7.5		>	<	<
Thickwood Creek	2.5	<		<	<
MacKay R.	22.0	>	>		<
Dover R.	41.2	>	>	>	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 69. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

CONDUCTANCE (μmhos/cm)

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.
	$\bar{X}$	193	117	280	429
Dunkirk R.	193		>	<	<
Thickwood Creek	117	>		<	
MacKay R.	280	>	>		<
Dover R.	429	<	>	>	

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 70. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

TOTAL ALKALINITY

	$\bar{X}$	Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.
	$\bar{X}$	91.5	48.5	131.4	219.5
Dunkirk R.	91.5		>	=	<
Thickwood Creek	48.5	<		<	<
MacKay R.	131.4	=	>		=
Dover R.	219.5	>	>	=	

a Level of significance at 0.05

= denotes no significant differennce between means

< denotes significantly less than

> denotes significantly greater than

Table 71. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

TOTAL HARDNESS

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.				
	$\bar{x}$	93.1	52.3	118.8	165.2				
Dunkirk R.	93.1		>	=	<				
Thickwood Creek	52.3	<		<	<				
MacKay R.	118.8	=	>		=				
Dover R.	165.2	>	>	=					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater tban

Table 72. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

DISSOLVED CALCIUM

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.
	$\bar{X}$	24.9	13.2	30.0	41.1
Dunkirk R.	24.9		>	=	=
Thickwood Creek	13.2	<		<	<
MacKay R.	30.0	=	>		=
Dover R.	41.1	=	>	=	

a Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 73. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

REACTIVE SILICA

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.				
	$\bar{X}$	3.9	3.1	5.6	3.9				
Dunkirk R.	3.9		=	=	=				
Thickwood Creek	3.1	=		=	=				
MacKay R.	5.6	=	=		=				
Dover R.	3.9	=	=	=					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 74. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

DISSOLVED POTASSIUM

		Dunkirk R.	Thickwood River	MacKay R.	Dover R.				
	$\bar{X}$	1.1	0.34	1.7	3.2				
Dunkirk R.	1.1		>	<	<				
Thickwood River	0.34	<		<	<				
MacKay R.	1.7	>	>		<				
Dover R.	3.2	>	>	>					

[a] Level of significance at 0.05

= denotes no significant difference between means

< denotes significantly less than

> denotes significantly greater than

Table 75. Statistical comparisons[a] between mean values for tributaries located in Zone 9.

DISSOLVED SULPHATE

		Dunkirk R.	Thickwood Creek	MacKay R.	Dover R.				
	$\bar{X}$	14.4	6.6	16.8	17.8				
Dunkirk R.	14.4		>	=	=				
Thickwood Creek	6.6	<		<	<				
MacKay R.	16.8	=	>		=				
Dover R.	17.8	=	>	=					

[a] Level of Significance at 0.5

= denotes no significant difference

< denotes significantly less than

> denotes significantly greater than

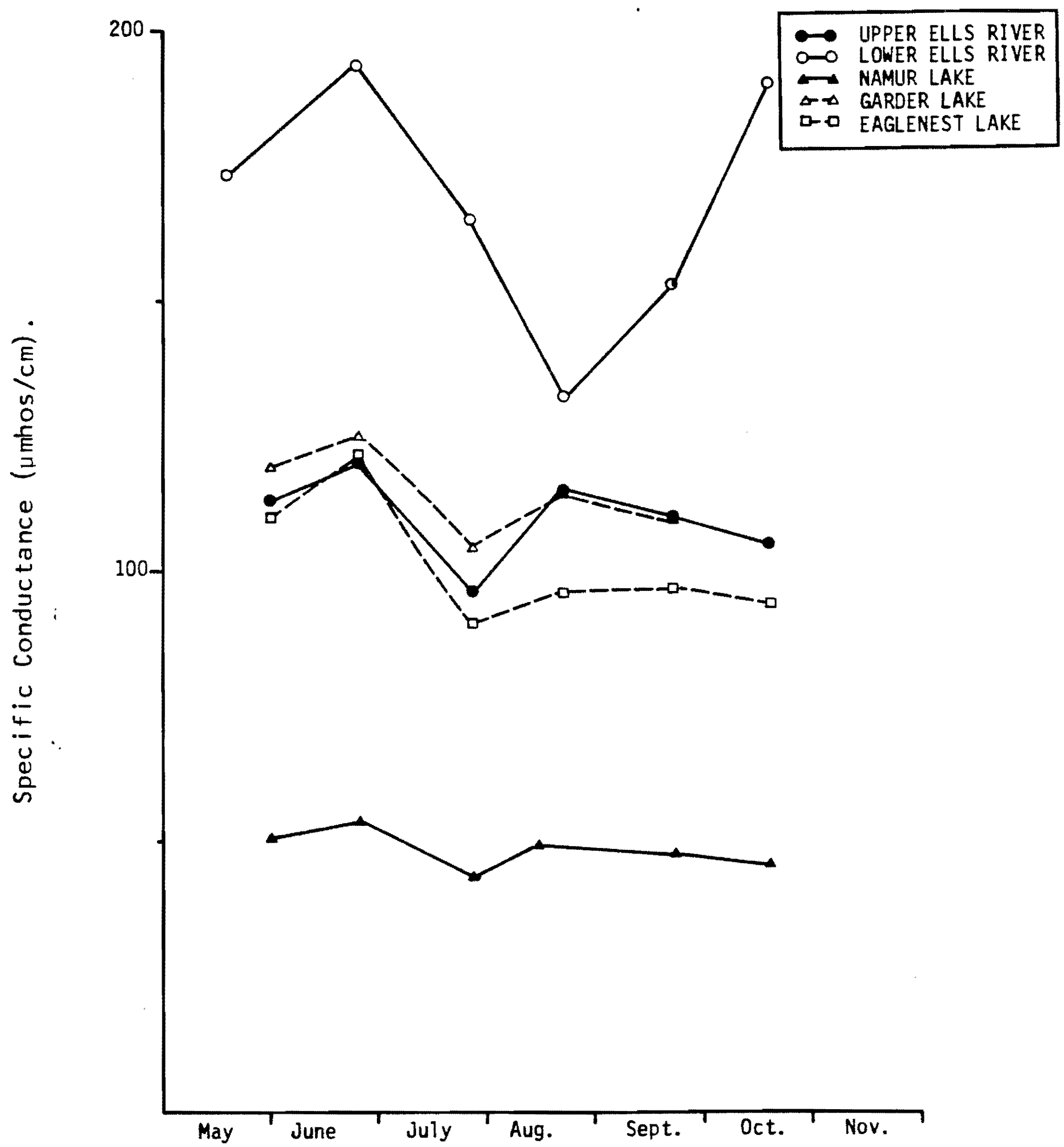


Figure 6. Fluctuations in specific conductance during open water months.

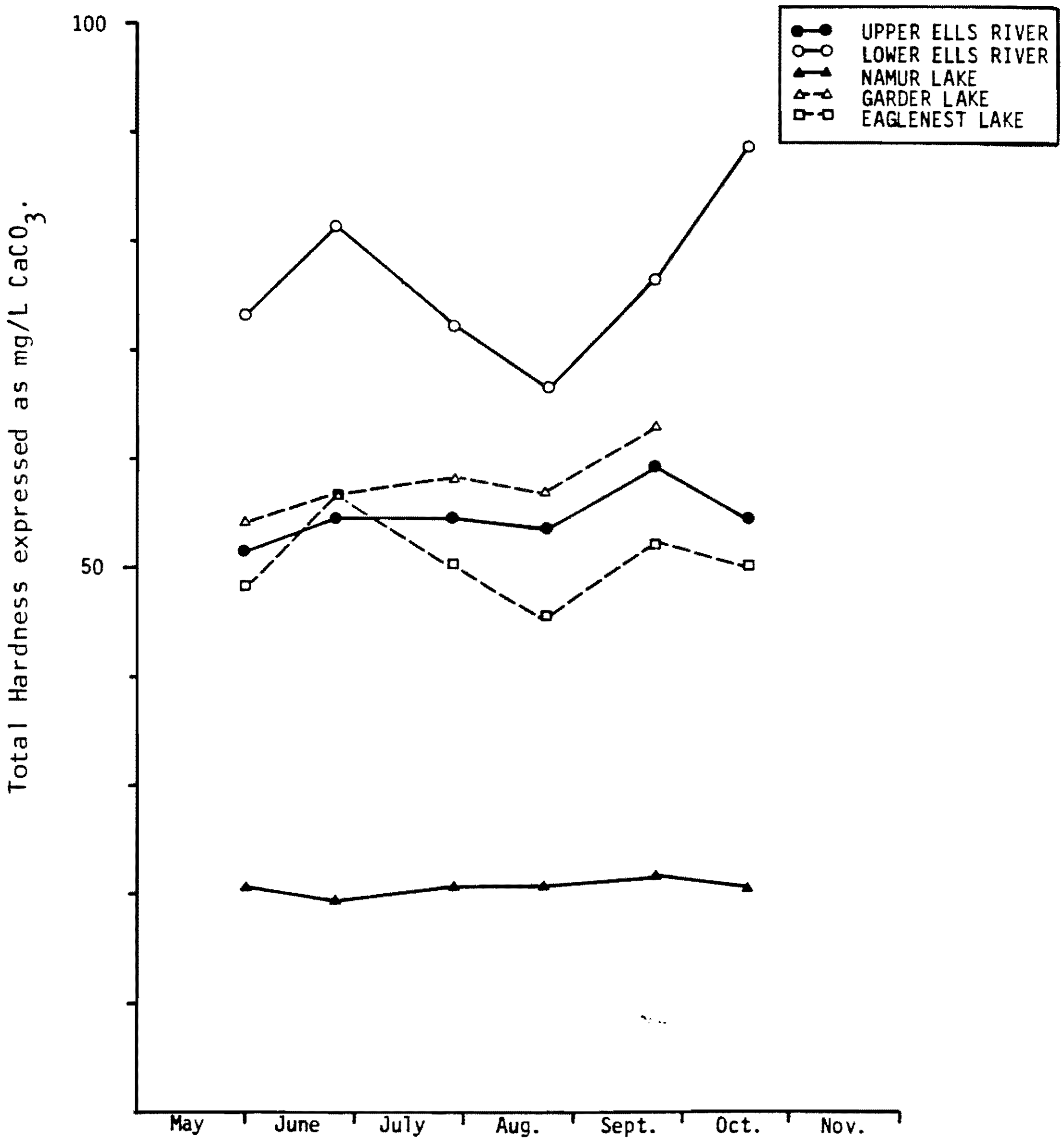


Figure 7. Fluctuations in total hardness during open water months.

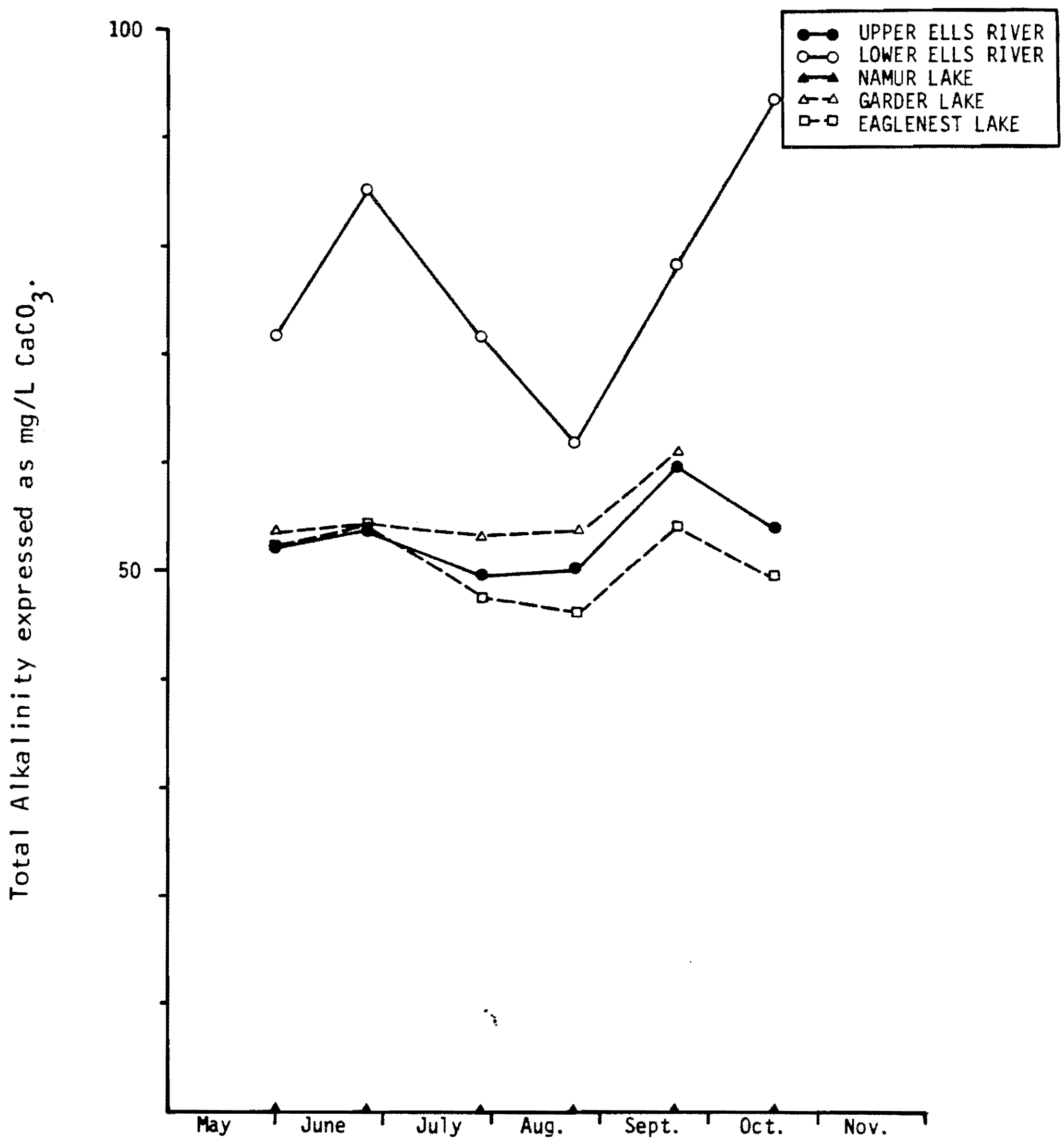


Figure 8. Fluctuations in total alkalinity during open water months.

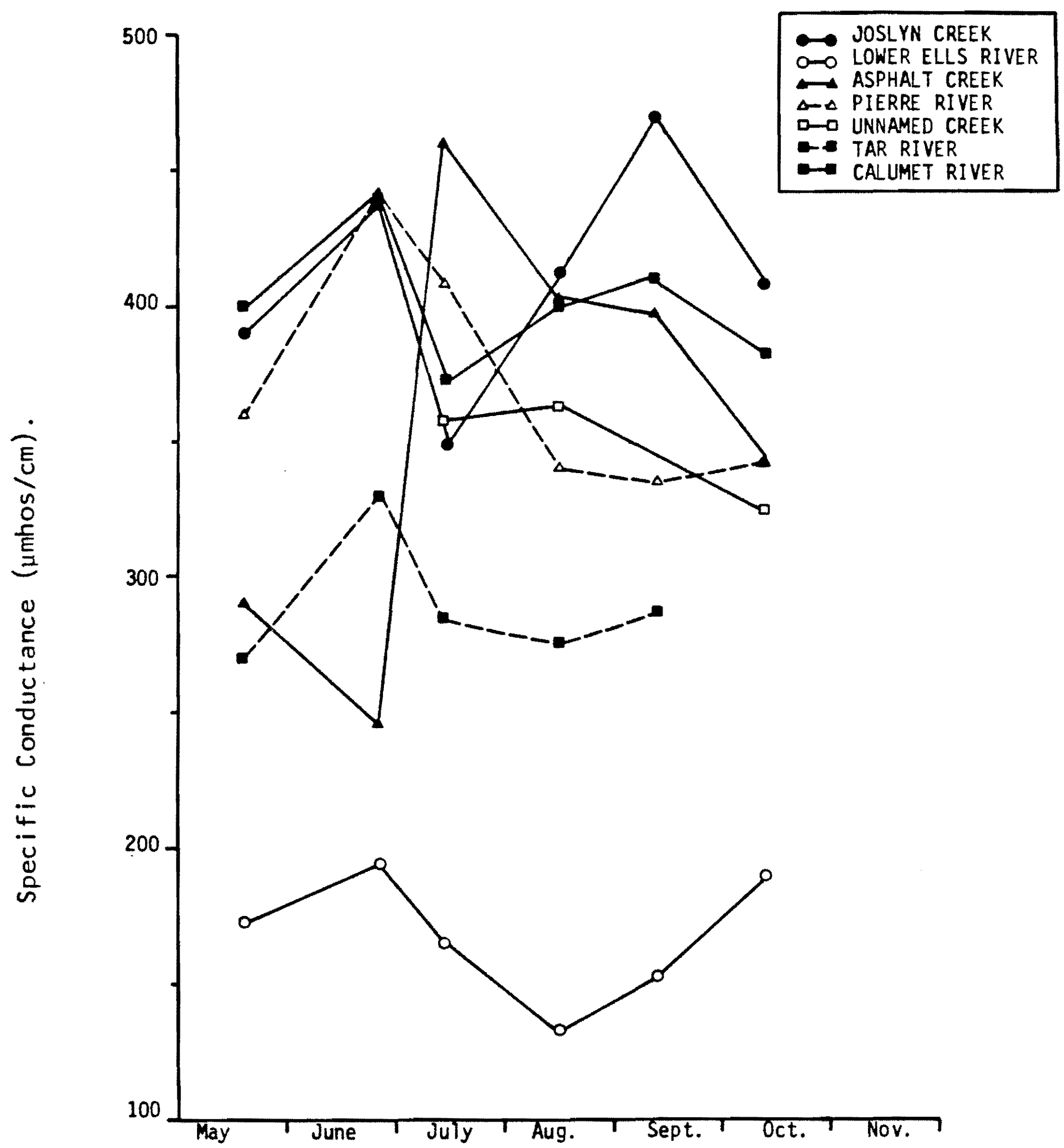


Figure 9. Fluctuations in specific conductance during open water months.

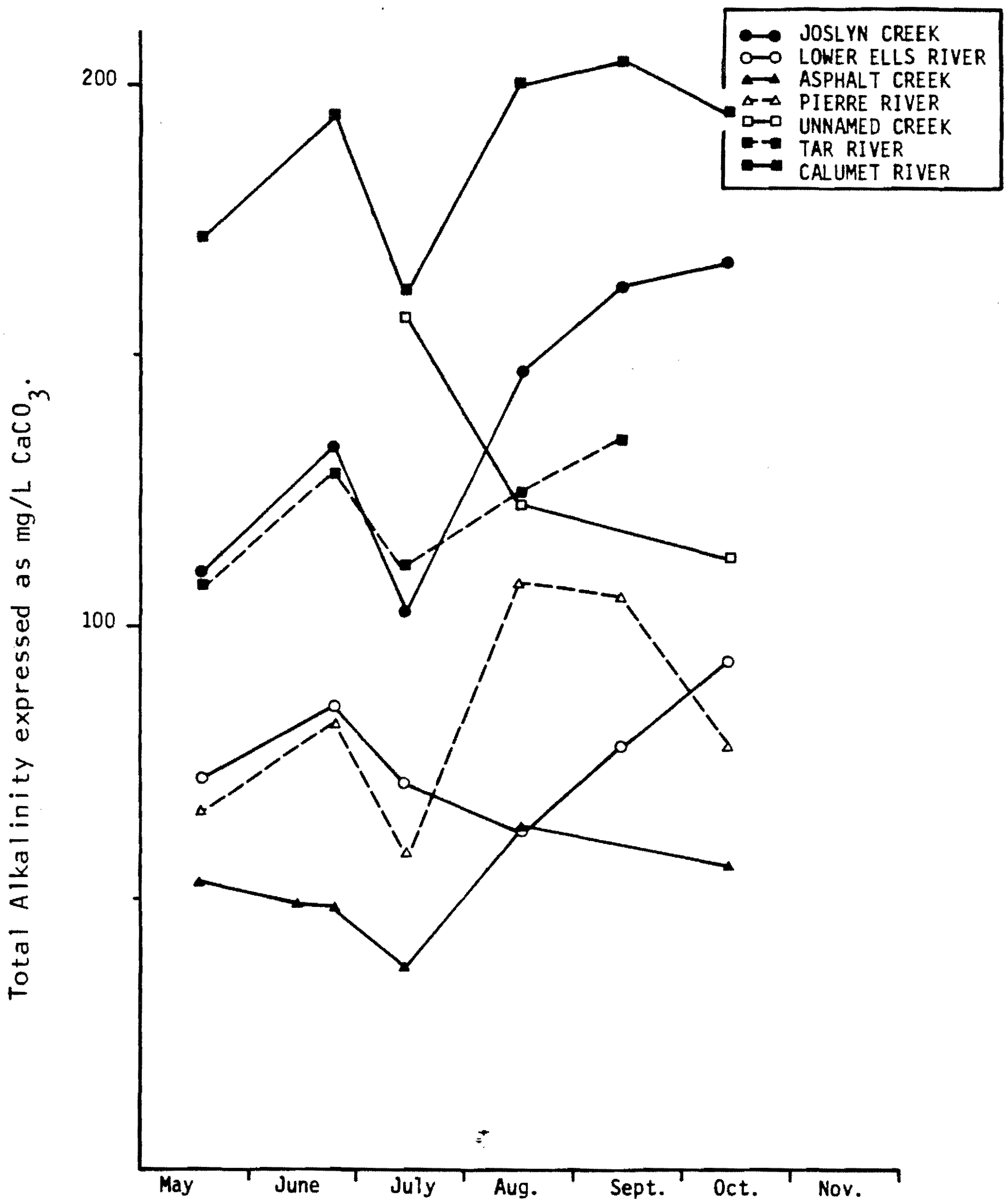


Figure 10. Fluctuations in total alkalinity during open water months.

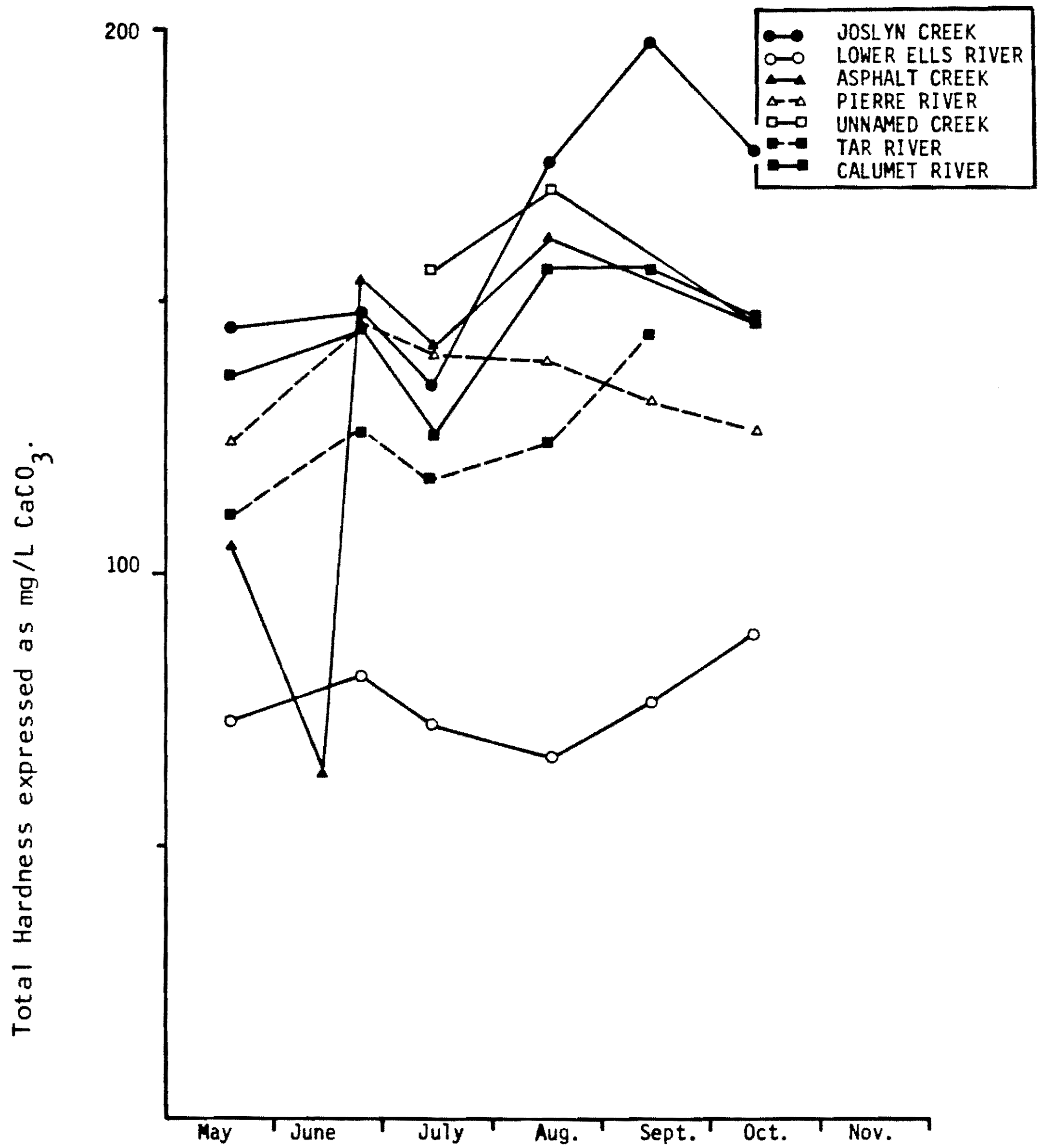


Figure 11. Fluctuations in total hardness during open water months.

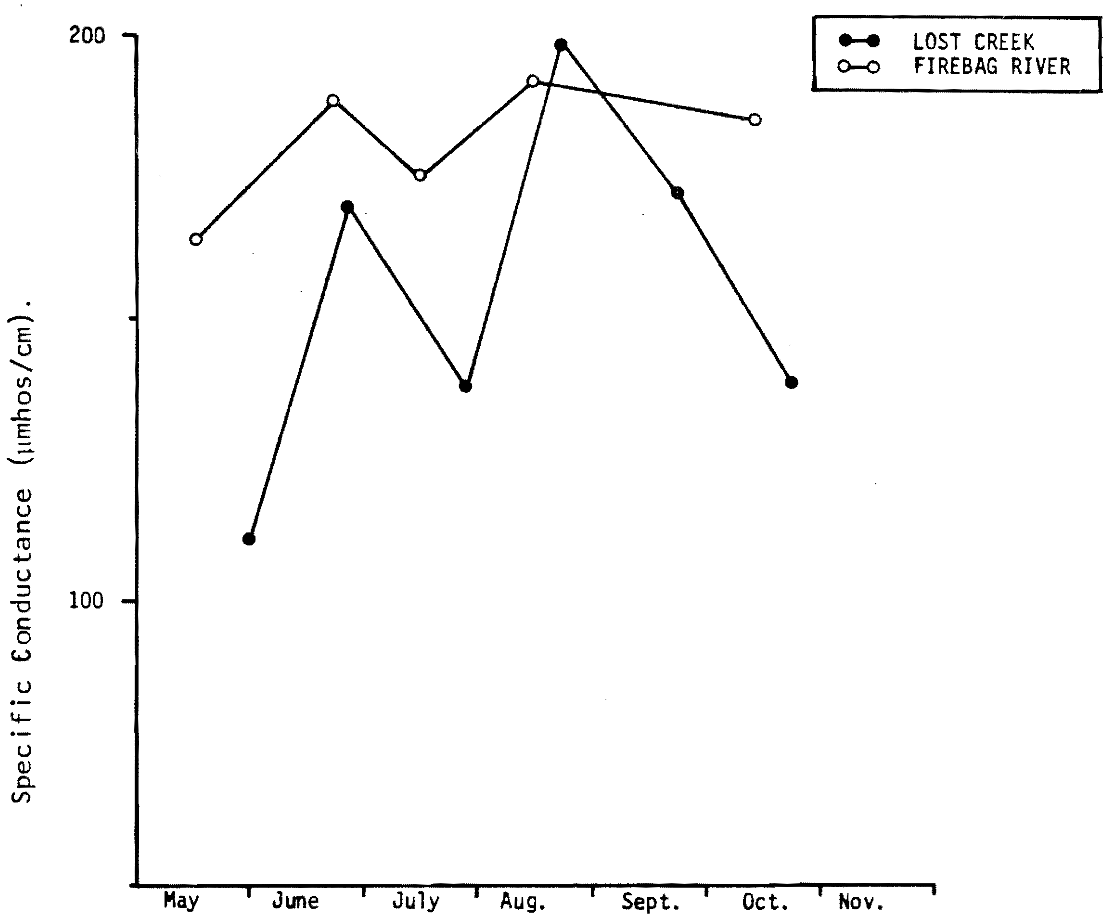


Figure 12. Fluctuations in specific conductance during open water months.

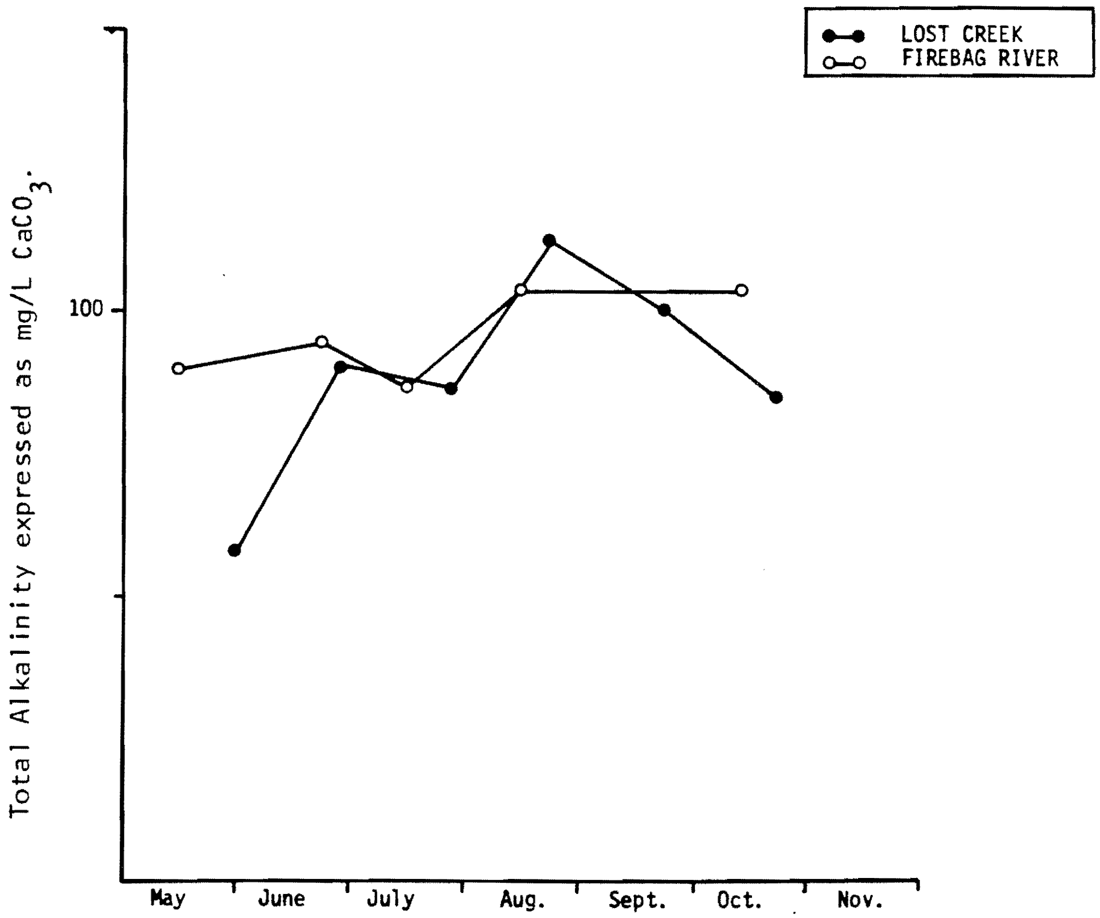


Figure 13. Fluctuations in total alkalinity during open water months.

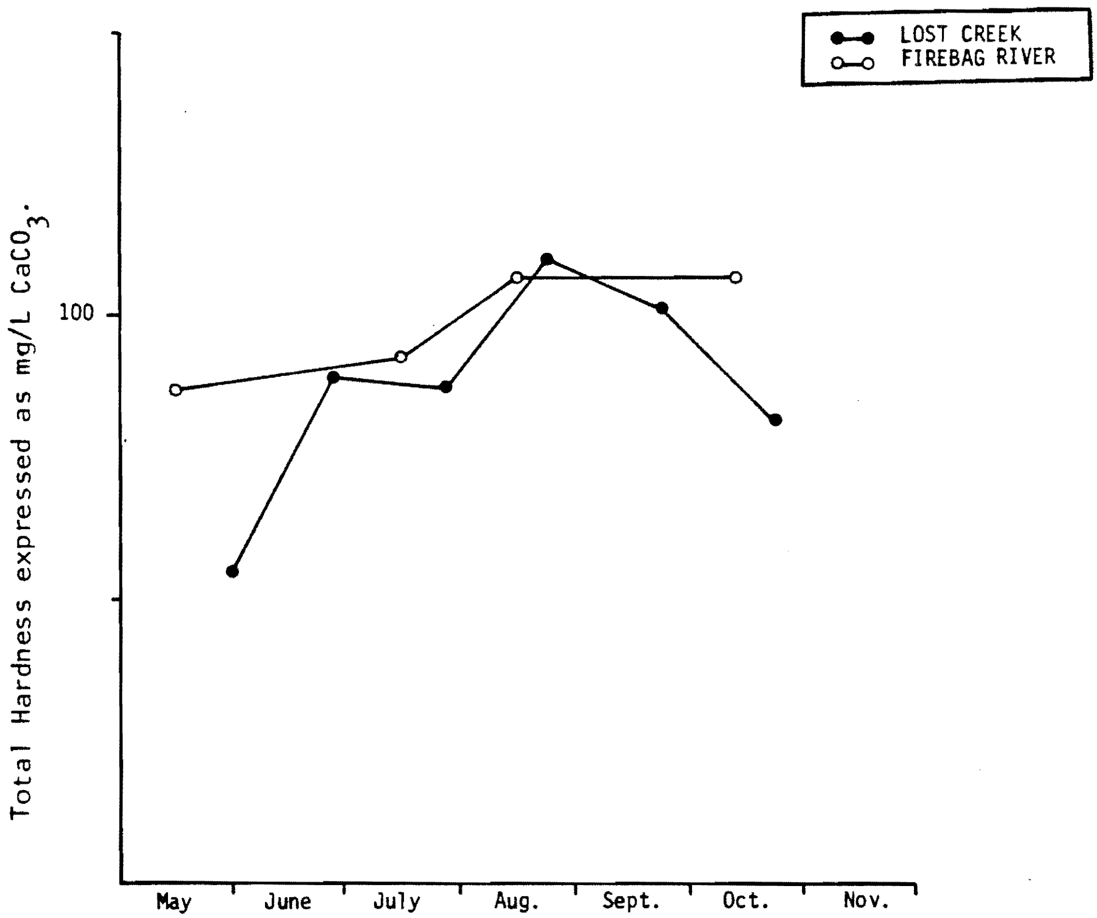


Figure 14. Fluctuations in total hardness during open water months.

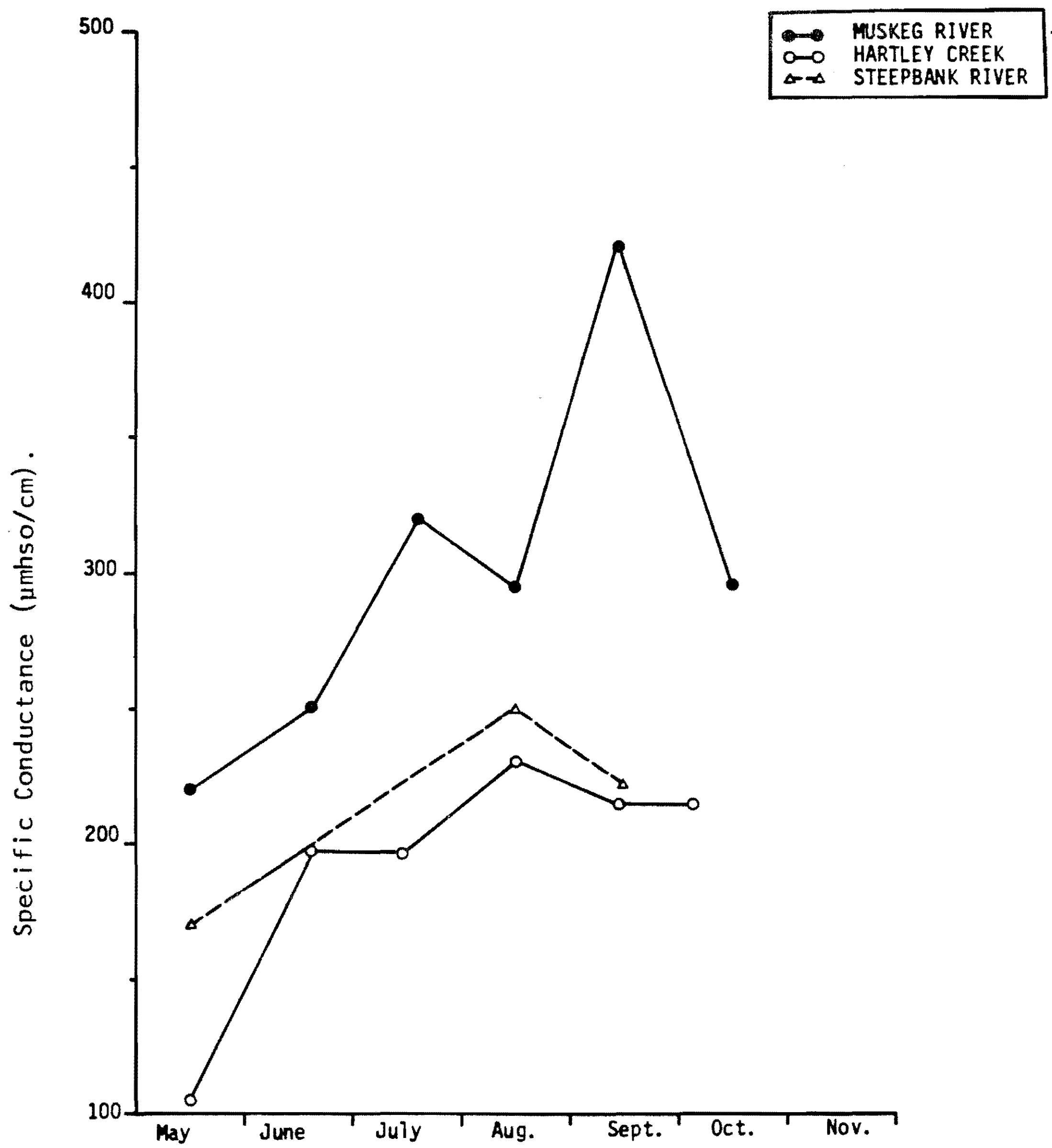


Figure 15. Fluctuations in specific conductance during open water months.

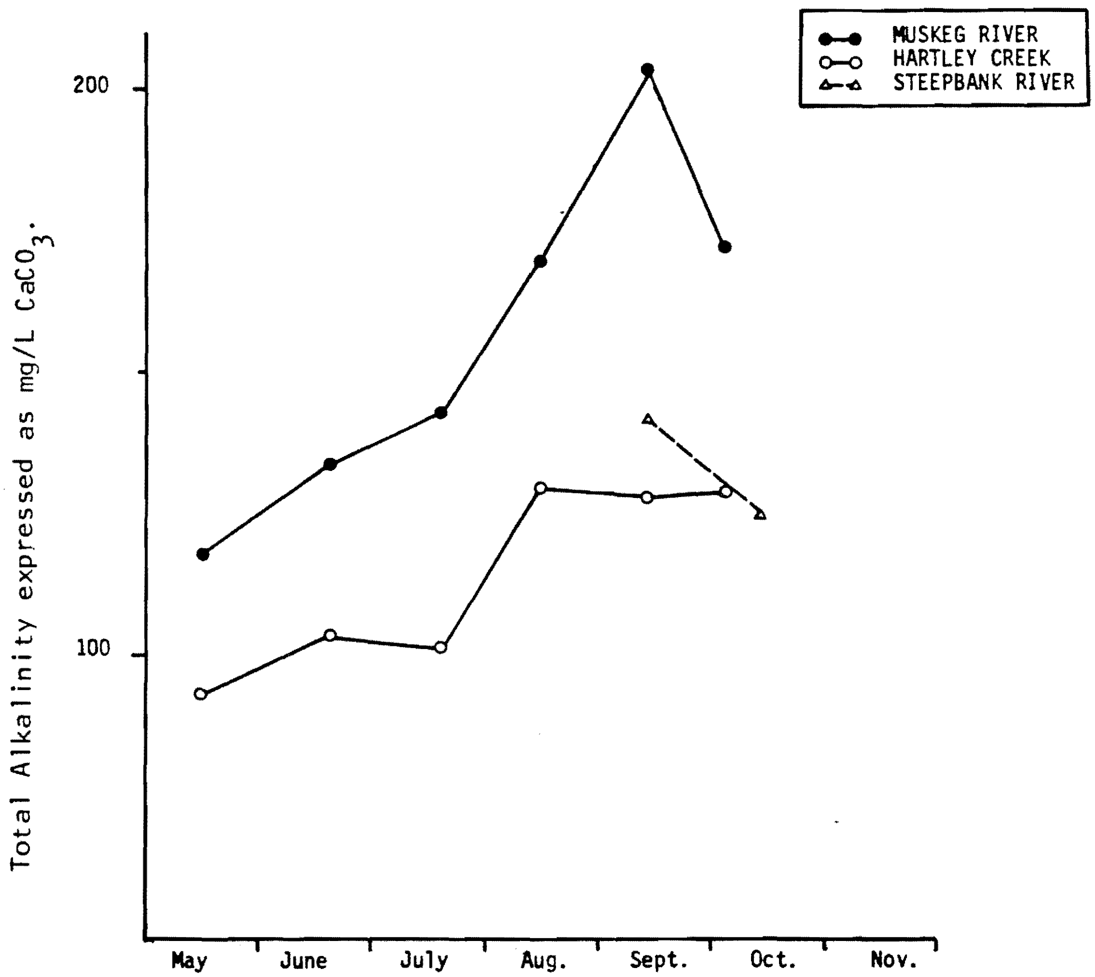


Figure 16. Fluctuations in total alkalinity during open water months.

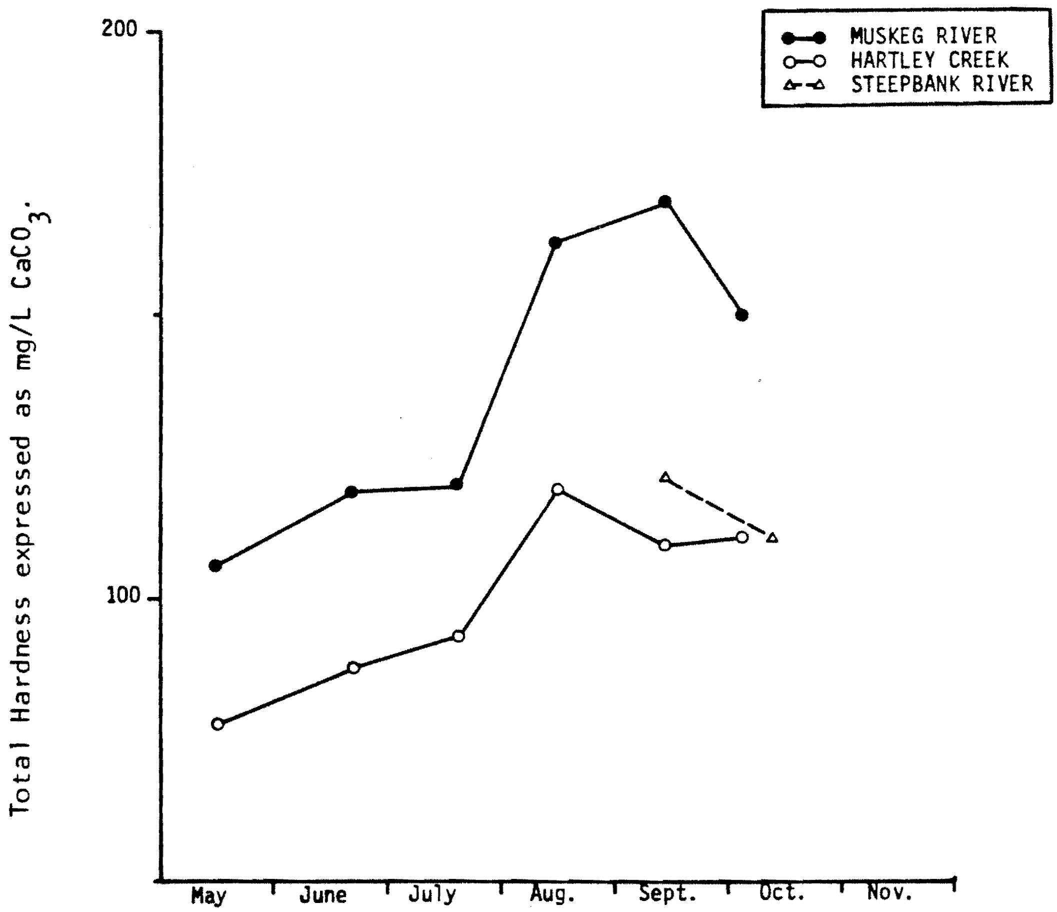


Figure 17. Fluctuations in total hardness during open water months.

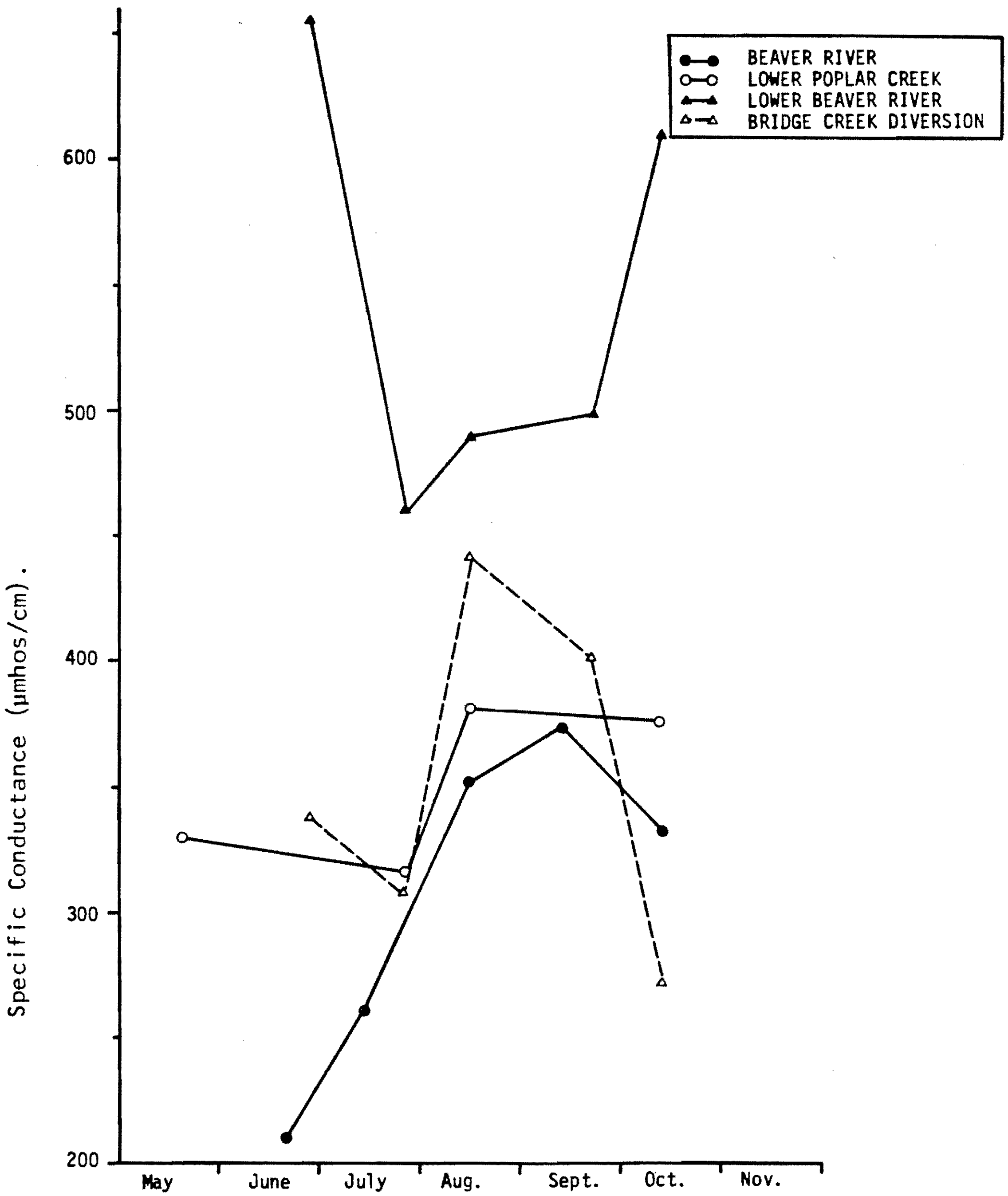


Figure 18. Fluctuations in specific conductance during open water months.

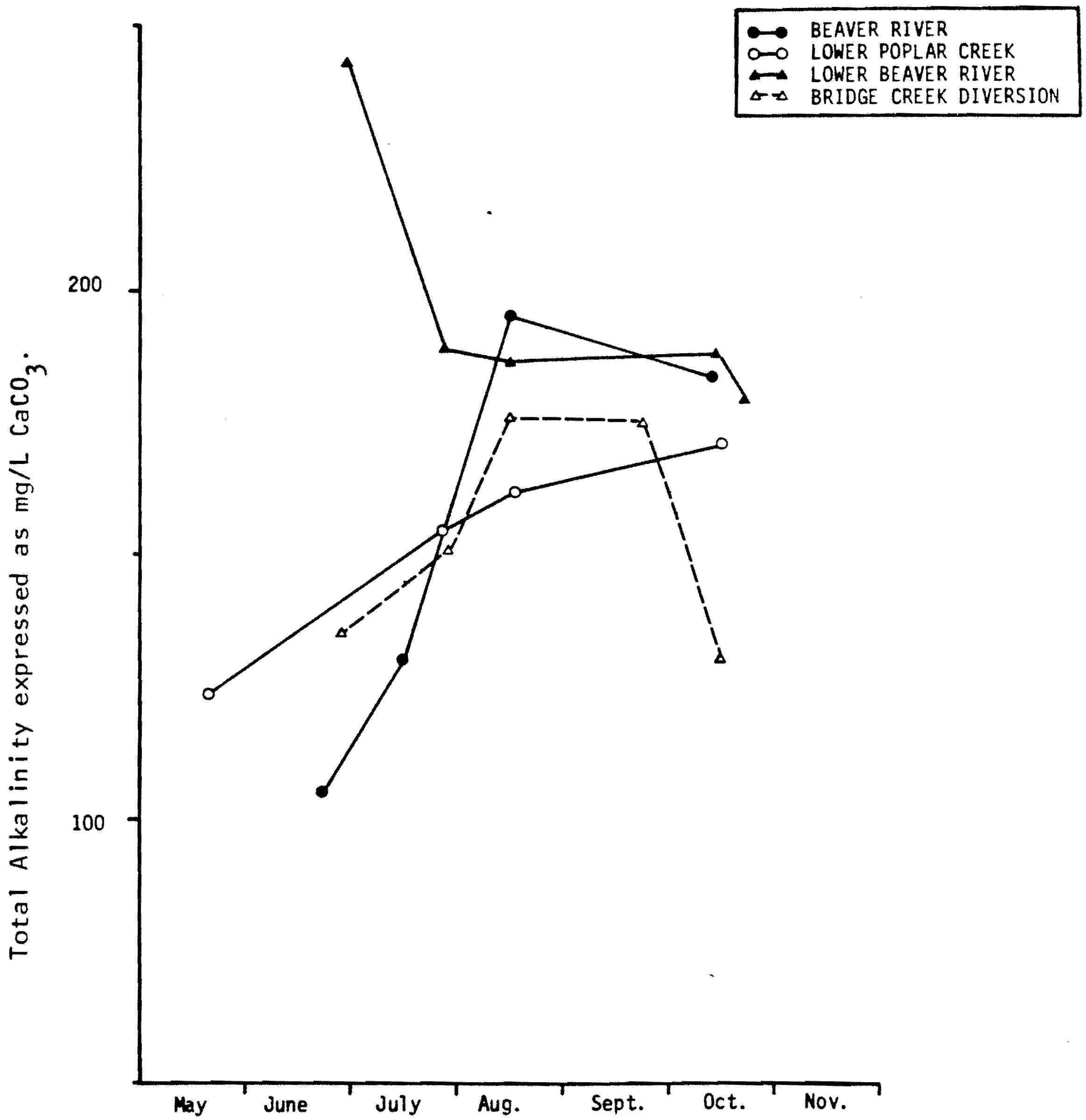


Figure 19. Fluctuations in total alkalinity during open water months.

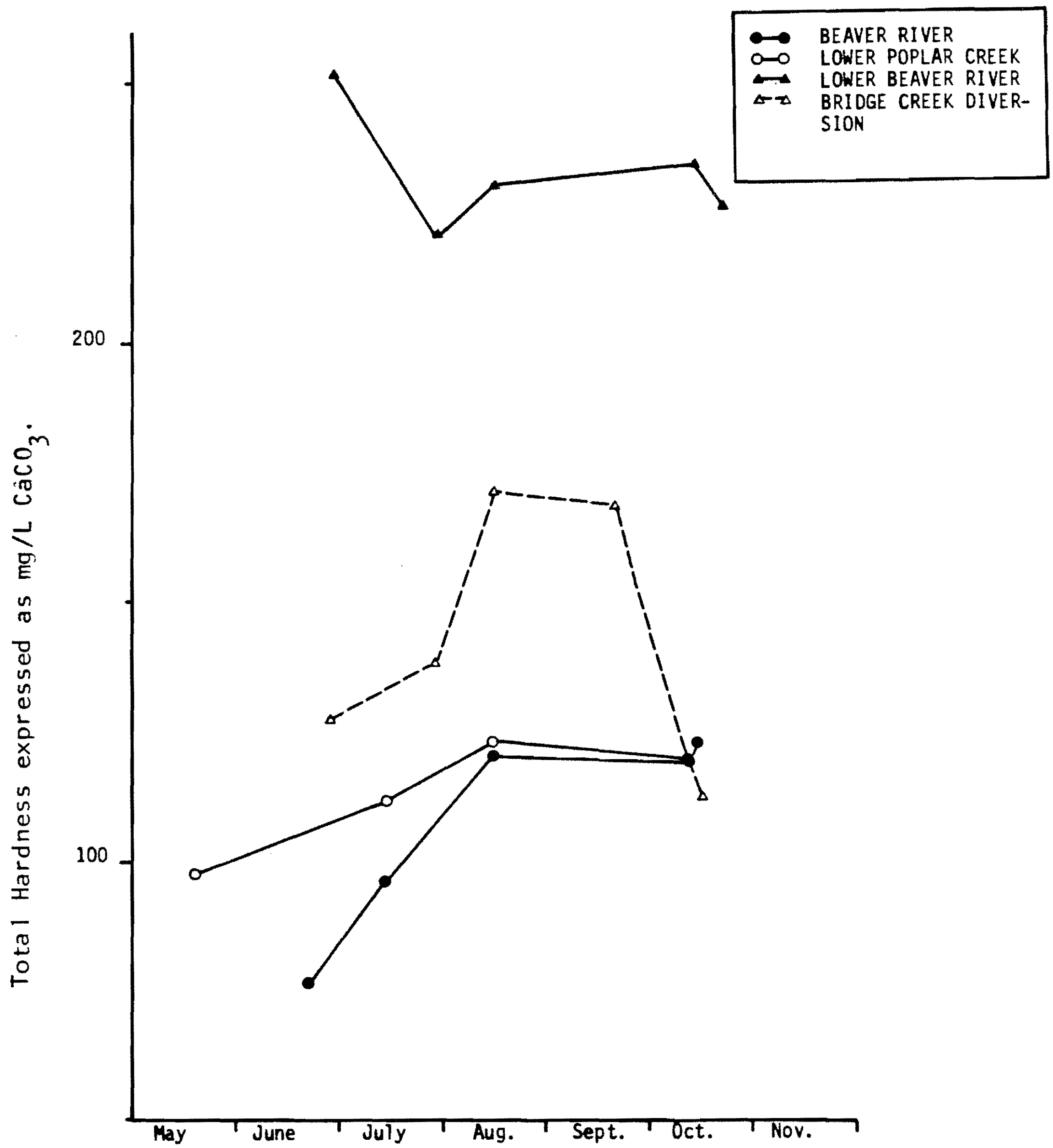


Figure 20. Fluctuations in total hardness during open water months.

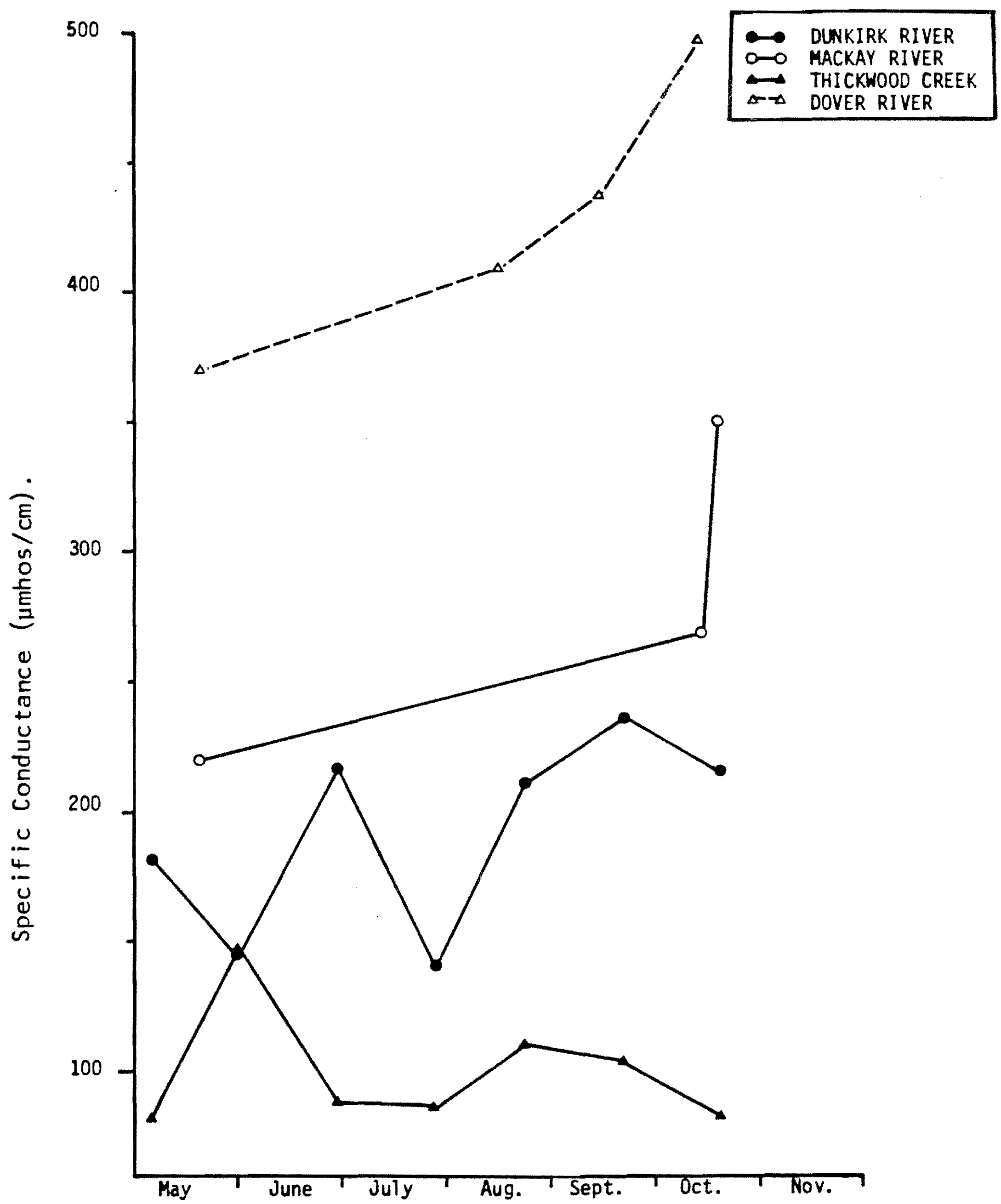


Figure 21. Fluctuations in specific conductance during open water months.

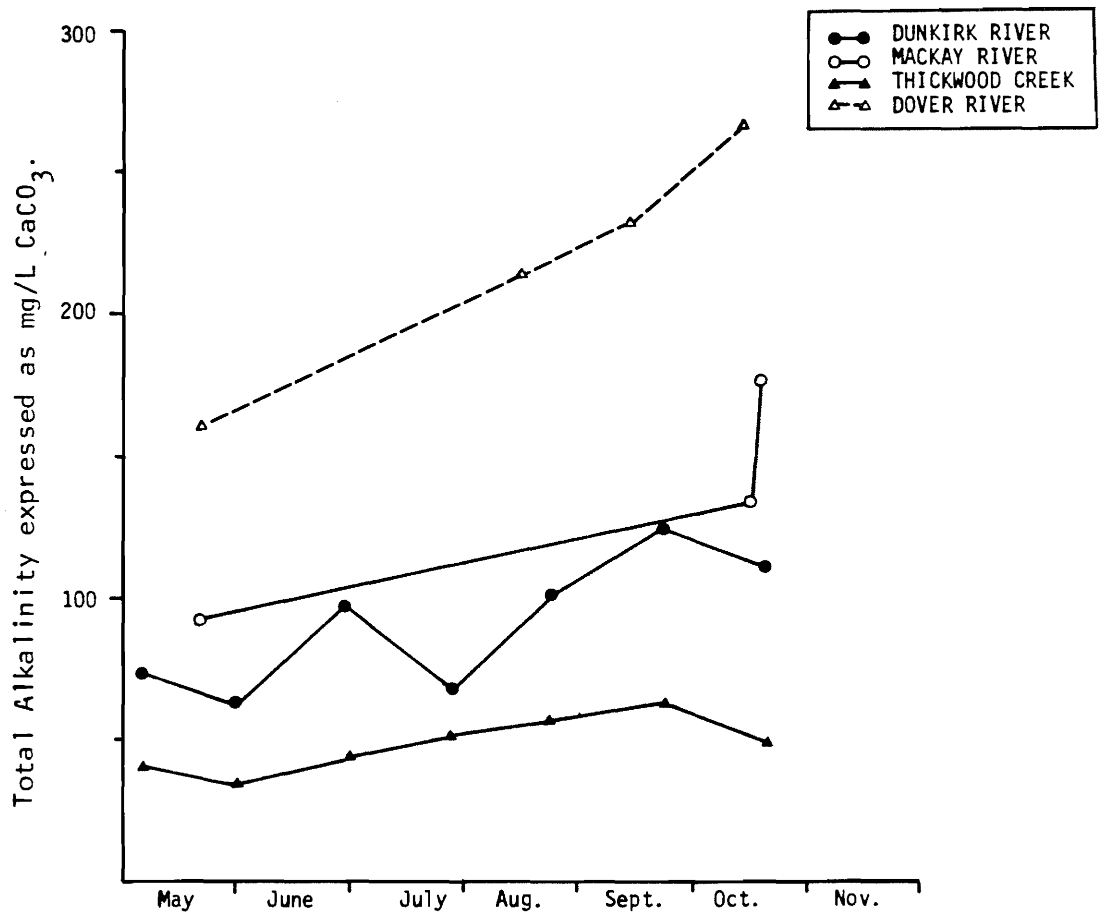


Figure 22. Fluctuations in total alkalinity during open water months.

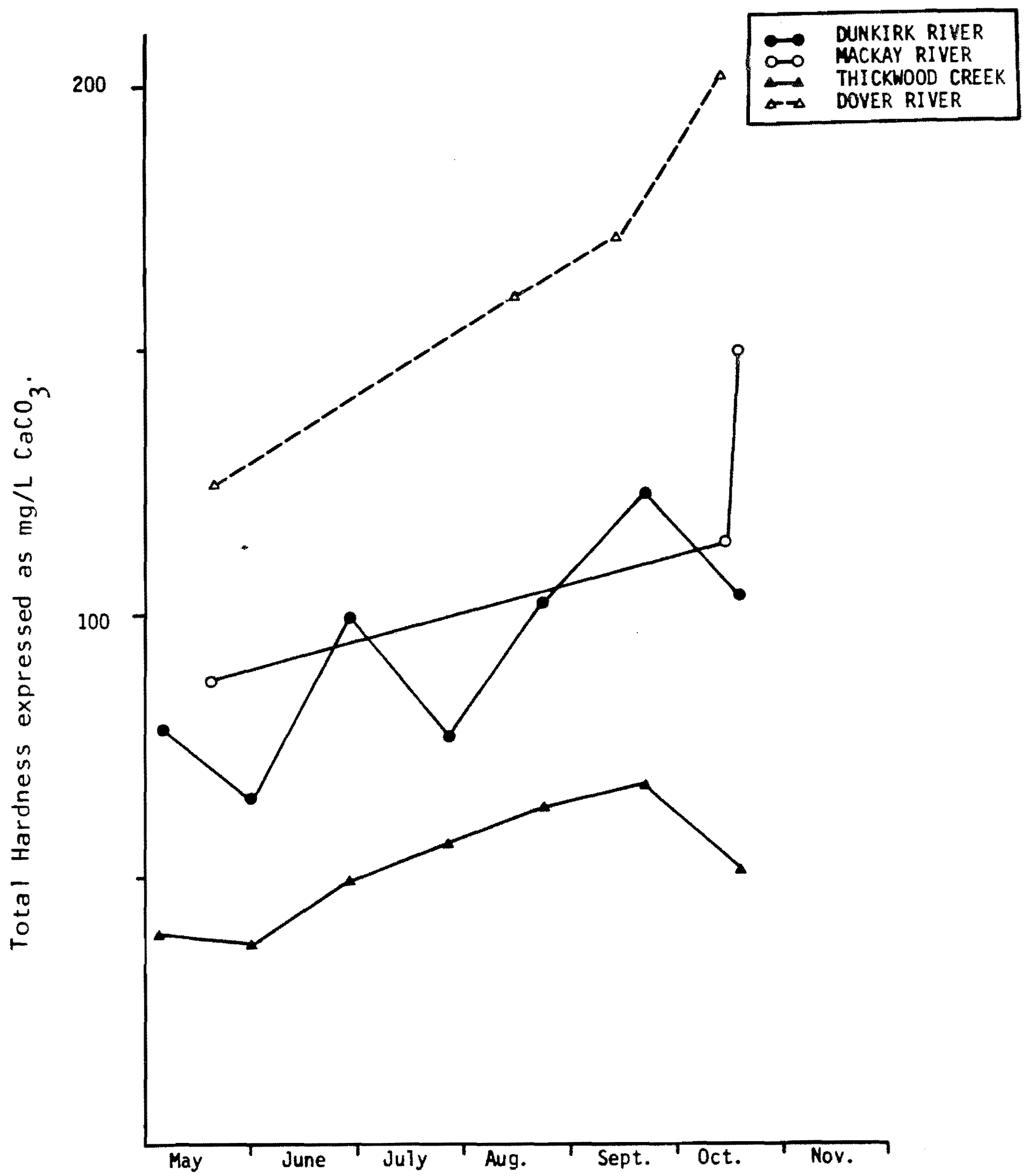


Figure 23. Fluctuations in total hardness during open water months.

In reviewing this information the following trends are apparent:

1. Zones 1 and 11: Since the discharge from Zone 11 to the Athabasca River is through Zone 1, these stations were grouped for comparison purposes. As illustrated in Figures 6 to 8, there appears to be a distinct trend developing for conductance, hardness and alkalinity among the Upper Ells, Lower Ells, Namur Lake, Gardiner Lake and Eaglenest Lake stations. That is, for all three parameters, Upper Ells appears to be consistent in quality with Gardiner Lake and Eaglenest Lake. Namur Lake is consistently better in quality, while Lower Ells River is consistently lower in quality. Statistical comparisons (Table 15) for these parameters, as well as others (dissolved calcium, chloride, fluoride, potassium, sodium, sulphate and reactive silica), reveals that for these determinations:
   - The Lower Ells River is significantly lower in quality than upstream stations except for reactive silica and fluoride;
   - The Upper Ells station is not significantly different from Eaglenest Lake, except total hardness, dissolved fluoride and sodium;
   - The Upper Ells station is not significantly different from Gardiner Lake except for dissolved magnesium; and
   - The Upper Ells station is significantly different in quality from Namur Lake, except for dissolved potassium, sodium and reactive silica.

   Each of these stated exceptions warrants limited attention in terms of environmental concerns. Therefore, on the basis of the stated criteria for redundancy, Gardiner and Eaglenest stations should be eliminated. Lower Ells and Upper Ells stations should be sustained for the present; as well, on the basis of the statistical evaluation, Namur Lake should be continued. Significance is attributed to Namur Lake's much superior quality compared to downstream stations. Namur Lake is a good indicator of change from acidic aerial emissions due to its relatively weak buffering capacity, even though it is the investigators' understanding that plume dispersal generally will be confined to the Athabasca River valley.

Figures 9 to 11 illustrate the trends for conductivity, alkalinity and hardness for the following stations: Lower Ells River, Joslyn Creek, Asphalt Creek, Pierre River, Unnamed Creek, Tar River and Calumet River. In particular, Figures 8 and 10 indicate that Joslyn Creek is similar in quality to the northern watersheds in Zone 1, although not comparable to the Lower Ells River as we originally hypothesized. However, this trend is not evident for total alkalinity (Figure 10).

Statistically, Tables 26 to 36 reveal a significant difference between the Lower Ells station and those to the north in Zone 1 (Joslyn Creek, Tar River, Calumet Creek, Pierre River, Asphalt Creek and Unnamed Creek) for the determinations: conductance, total alkalinity (with the exception of Pierre River), total hardness, reactive silica, dissolved sodium, fluoride, potassium, calcium and magnesium. Significance was maintained for dissolved chloride, with two exceptions (Joslyn Creek and Unnamed Creek), as well as dissolved sulphate, except for Unnamed Creek and Calumet River. Once again the exceptions are minor in nature. On this basis, Lower Ells stations should be maintained as hypothesized.

A review of Tables 26 to 36 reveals that our original hypothesis that Joslyn Creek is comparable to northern watersheds within Zone 1 must be rejected. Continuation of these stations for another year is advisable on the basis of this evaluation. Perhaps a sampling program designed to allow paired data analysis will yield results compatible to the hydrological zone concept.

2. Zone 4: Figures 12 to 14 present the similarity in trends developing between the Firebag River and Lost Creek stations. Comparison of means (Tables 37 to 42) reveals that there is no significant difference between these stations for the determinations: total alkalinity and hardness, dissolved calcium, fluoride, magnesium and sulphate. Slight significance did occur for the determinations: conductivity, chloride, potassium, silica and sodium. However, due to the extremely low concentrations represented (Tables 37 to 42), environmental concern is not warranted. The Lost Creek station was judged to be redundant and hence should be terminated.

3. Zone 5: Figures 15 to 17 illustrate similar trends between Hartley Creek and the Steepbank River. This is consistent with the hydrological zone concept since both streams originate in the Muskeg Mountain Uplands. Although the Muskeg River station is higher in terms of concentration, a similar trend to Hartley Creek and the Steepbank River is developing.

   There is no statistical difference (Tables 43 to 53) between these three stations during open water months for the dissolved ions sodium, sulphate, reactive silica, potassium, fluoride and magnesium. As well, no significant difference occurs between Hartley Creek and the Steepbank River for the determinations: conductivity, total alkalinity, hardness, calcium and chloride. Of the above-stated determinations, the only significant difference amongst mean concentrations occurred between Muskeg River and Hartley Creek (conductivity, total alkalinity, total hardness, calcium and chloride), and between the Muskeg River and the Steepbank River (conductivity and calcium only). In these instances the Muskeg River was significantly greater in concentration from Hartley Creek and the Steepbank River, as expected. These results verify our original hypothesis that the Hartley Creek and Steepbank River are similar and represent a redundancy in information. Since the Steepbank River drains a larger watershed, the Hartley Creek station can be terminated.

4. Zone 6: Figures 18 to 20 illustrate similar trends for Poplar Creek and Upper Beaver stations, as hypothesized. It is interesting to note that Lower Beaver Creek appears discrete from the other stations, indicating a possible effect from oil sands development activity. Statistical comparisons of means (Tables 54 to 64) reveal non-significance between Upper Beaver Creek and Poplar Creek stations for the following determinations: conductivity, total alkalinity and hardness, calcium, fluoride, magnesium, reactive silica, sodium and sulphate. Although chloride concentrations were significantly greater in Poplar Creek than Beaver Creek, the Beaver Creek station can be terminated on the basis of this evaluation. As well, the Bridge Creek diversion station can also be eliminated on the basis of non-significance with Upper Beaver Creek and Poplar Creek. However, the Lower Beaver Creek station should remain, as significant difference compared to Bridge Creek, Poplar Creek and Upper Beaver Creek implies that development activity is affecting Lower Beaver Creek to some degree.

5. Zone 9: Figures 21 to 23 show interesting correlations developing between the MacKay River and trib-

utary stations. It is evident that the MacKay River has a moderating effect on the quality of the Dover River. Statistical comparisons of means (Tables 65 to 75) for the determinations of conductance, total alkalinity and hardness, dissolved calcium, chloride, fluoride, magnesium, sodium, reactive silica, potassium, and sulphate reveal:

- The MacKay River is not significantly different from the Dover River (except for conductivity, sodium and potassium);
- There is no significance between the MacKay River and Dunkirk River (except for conductivity, chloride, sodium and potassium); and
- The MacKay River is significantly greater in all determinations, except reactive silica, when compared to the Thickwood Hills station.

The exceptions are not judged to be critical due to the small concentrations involved and the inherent moderating effect of the MacKay River. Therefore, on the basis of the statistical test and stated criteria, the Dunkirk and Dover stations should be eliminated. However, it may be desirable to maintain the Dunkirk station since it is the only station representing Hydrological Zone 10.

2.5.4 An Evaluation of Temporal Variation of Data Base

Problems associated with assessing temporal variation are basically two-fold:

1. Existing data base represents a period of time less than one year; and
2. No data were collected for many stations during the period of ice-cover; therefore, temporal variation for these sites cannot be assessed on a seasonal basis.

These limitations are apparent in a review of Table 14. However, in an effort to obtain an appreciation of temporal variation, several parameters were plotted (concentration versus time) for streams in which there were three or more data points for the period June to October and December to March, inclusive. Since the data base precluded comparing monthly sample points on an annual basis (i.e. 1976 data versus 1977 data) and since seasonal differentiation was difficult, temporal variation was assessed on the basis of comparing months with ice cover versus open water months. For comparison purposes it was assumed that ice cover months were December through March, and open water occurred from May or June through October. The months of April and/or May were treated separately due to severe variations occurring during these month(s).

On this basis, temporal variation was assessed for the following parameters:

1. Total Organic Carbon: With few exceptions, total organic carbon generally declined during months of ice-cover, with lowest concentrations occurring in April; this was followed by a sharp increase in concentration, usually during May. Subsequent fluctuations during the open water months were generally more stable, with concentrations of the same relative magnitude as during months with ice-cover. Therefore, with the exception of spring breakup, substantial variation over the rest of the year was not apparent.

   Comparisons of ranges between open water and ice-cover periods are presented in Table 76.
2. Total Phosphorus: Comparison of ranges between open water and ice-cover periods are presented in Table 77. Normally, concentrations during ice cover are greater than in summer, in response to biological activity. In all but two cases (Upper and Lower Ells River), severe fluctuation occurred during ice cover (usually peaking in February). A downward trend was generally

Table 76. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter total organic carbon.

Station Location	December to March	June to October
Namur Lake	6 - 14	5 - 15.5
Gardiner Lake	8 - 16	9.5 - 17
Eaglenest Lake	12.5 - 20	9.5 - 21.5
Upper Ells River	8 - 17	7 - 15
Lower Ells River	11.5 - 20	7.5 - 21.5
Lower Tar River	19.5 - 25	12 - 25
Firebag River	3 - 8	9.5 - 17
Muskeg River	24 - 32	20 - 35
Hartley Creek	12 - 36	23.5 - 28.5
Steepbank River	9 - 25	18 - 30.5
MacKay River	25 - 41	34 - 41
Lower Beaver Creek	17 - 24	13 - 25.5
Poplar Creek	24 - 35	23 - 45

Table 77. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter total phosphorus.

Station Location	December to March	June to October
Namur Lake	.05 - .10	.02 - .04
Gardiner Lake	.10 - .25	.02 - .05
Eaglenest Lake	.09 - .58	.11 - .24
Upper Ells River	.05 - .09	.03 - .06
Lower Ells River	.05 - .09	.01 - .06
Lower Tar River	.18 - 1.4	.012 - .075
Firebag River	.04 - .06	.039 - .057
Muskeg River	.03 - .06	.015 - .045
Hartley Creek	.04 - .30	.02 - .045
Steepbank River	.06 - .25	-
MacKay River	.06 - .24	.04 - .16
Thickwood River	.15 - .24	.025 - .05
Lower Beaver Creek	.03 - .05	.025 - .11
Poplar Creek	<.01 - .07	.04 - .06

observed during spring breakup (April, May), followed by an upward pulse in late May or early June. For the remainder of the summer months (June to August), total phosphorus generally declined in response to biological consumption. In most cases an upward pulse was observed in September or October. This is common, particularly in lakes, where this upward pulse is associated with overturn. This trend did not occur at the Upper and Lower Ells stations, where total phosphorus levels were fairly uniform for all sampling periods.

3. Total Kjeldahl Nitrogen: Although ranges are generally similar when comparing individual periods of ice cover to open water for some stations (Table 78), there was no observable trend amongst stations. Temporal variation was not substantial except for possibly Eaglenest Lake and the Lower Tar River.

4. Phenolic Compounds: Phenolic compounds were seldom observed in concentrations greater than the minimum detection limit (Table 79). However, at nine of the 14 stations, ascending fluctuation was observed during January to February period. In only two instances (Namur Lake, Muskeg River) variation was associated with spring breakup. In these events, Namur Lake reported a concentration of 0.008 mg/L (early May) and the Muskeg River a concentration of 0.005 mg/L (April). Due to the general paucity of phenolic compounds detected, temporal variation was not apparent except for a one month period during ice cover.

5. Oil and Grease: Temporal variation was not substantial (Table 80). Concentrations during ice-cover periods were generally less than the detection limit. In most cases, variation associated with spring breakup was not severe. The greatest fluctuation with spring breakup occurred at the Thickwood Creek station, where concentrations increased from a winter low of <0.1 to

Table 78. Comparison of ranges in concentration (mg/L) between periods of open water and ice cover for the parameter total kjeldahl nitrogen.

Station Location	December to March	June to October
Namur Lake	.85 - 1.0	.5 - 1.0
Gardiner Lake	.60 - 1.0	.6 - 1.7
Eaglenest Lake	1.05 - 6.55	.65 - 3.7
Upper Ells River	.8 - 1.0	.55 - 1.0
Lower Ells River	.65 - 1.1	.75 - 1.1
Lower Tar River	1.70 - 4.1	.6 - 4.4
Firebag River	.3 - .95	.75 - 5.4
Muskeg River	1.05 - 1.1	.65 - 1.6
Hartley Creek	.6 - 2.25	.65 - 1.6
Steepbank River	.75 - .95	-
MacKay River	.7 - 1.95	.7 - 1.25
Thickwood River	-	.95 - 1.90
Lower Beaver Creek	1.35 - 1.55	.70 - 1.50
Poplar Creek	1.15 - 170	1.05 - 1.80

Table 79. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter phenolic compounds.

Station Location	December to March	June to October
Namur Lake	<.001	<.001
Gardiner Lake	<.001	<.001
Eaglenest Lake	<.001 - .002	<.001
Upper Ells River	<.001 - .008	<.001
Lower Ells River	<.001 - .007	<.001
Lower Tar River	<.001 - .024	<.001
Firebag River	<.001	<.001
Muskeg River	<.001 - .003	<.001 - .002
Hartley Creek	<.001 - .003	<.001 - .002
Steepbank River	<.001 - .002	<.001
MacKay River	<.001 - .009	<.001
Thickwood River	<.001 - .012	<.001
Lower Beaver Creek	<.001	<.001
Poplar Creek	<.001	<.001

Table 80. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter Oil and Grease.

Station Location	December to March	June to October
Namur Lake	<.1	<.1 - .6
Gardiner Lake	-	-
Eaglenest Lake	<.1 - .5	.2 - 1.1
Upper Ells River	<.1	<.1 - .4
Lower Ells River	<.1	<.1 - .7
Lower Tar River	<.1	<.1 - 1.6
Firebag River	<.1	.2 - .9
Muskeg River	<.1 - 1.8	.4 - 1.2
Hartley Creek	<.1	<.1 - 1.9
Steepbank River	<.1	1.2 - 2.4
MacKay River	<.1	.7 - 2.3
Thickwood River	<.1	<.1 - .6
Lower Beaver Creek	<.1 - .8	.5 - 1.75
Poplar Creek	<.1 - 1.1	.2 - 1.2

<3.0 mg/L from June to October, inclusive.

6. Extractable Lead: Temporal variation was not considered substantial (Table 81). Only sporadic variation in concentration to levels greater than the detection limit was observed. During spring breakup (April), only three stations of those reported in Table 81 presented a deviation from the detection limit (0.002 mg/L). These were Poplar Creek (0.175 mg/L), Firebag River (0.009 mg/L) and Lower Ells River (0.012 mg/L).
7. Extractable Copper: Substantial temporal variation was evident. Review of Table 82 illustrates that concentrations during ice-cover were considerably greater than for the open-water period, in the majority of instances. However, similarities in the ranges during the open-water period amongst stations was apparent. Temporal variation was due to high winter peaks (January to February) in concentration for the Steepbank River, Hartley Creek, Lower Tar River, Lower Ells River and MacKay River, relative to the open water period. High concentrations associated with spring breakup (April) were observed for the Muskeg River, Firebag River, Poplar Creek and Lower Beaver Creek stations.
8. Extractable Cadmium: A review of the data (Table 83) indicates that extractable cadmium is generally sparse in concentrations greater than the detection limit. Variation associated with the spring breakup was limited to the Poplar Creek station (0.016 mg/L in April). On this basis, temporal variation is not considered significant.
9. Hexavalent Chromium: Comparisons of ranges in data between periods of open water and ice-cover are presented in Table 84. Due to the paucity of data greater than the detection limits, temporal variation of the data base is not considered significant. As

Table 81. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter extractable lead.

Station Location	December to March	June to October
Namur Lake	<.002 - .006	<.002
Gardiner Lake	<.002	<.002 - .006
Eaglenest Lake	<.002	<.002
Upper Ells River	<.002	<.002
Lower Ells River	<.002 - .012	<.002
Lower Tar River	<.002	<.002
Firebag River	<.002	<.002 - .005
Muskeg River	<.002	<.002 - .005
Hartley Creek	-	-
Steepbank River	<.002	<.002 - .005
MacKay River	<.002 - .048	<.002 - .005
Thickwood River	<.002	<.002 - .012
Lower Beaver Creek	<.002	<.002 - .004
Poplar Creek	<.002	<.002

Table 82. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter extractable copper.

Station Location	December to March	June to October
Namur Lake	.006 - .036	<.001 - .016
Gardiner Lake	.004 - .037	<.001 - .009
Eaglenest Lake	.008 - .122	<.001 - .014
Upper Ells River	.001 - .021	<.001 - .018
Lower Ells River	.004 - .033	<.001 - .016
Lower Tar River	.010 - .114	.002 - .014
Firebag River	<.001 - .007	<.001 - .014
Muskeg River	.002 - .003	<.001 - .006
Hartley Creek	.005 - .028	<.001 - .014
Steepbank River	.002 - .030	≤.001
MacKay River	<.005 - .180	<.001 - .010
Thickwood River	.001 - .005	<.001 - .020
Lower Beaver Creek	.002 - .003	.002 - .013
Poplar Creek	.001 - .018	.002 - .004

Table 83. Comparison of ranges in concentrations (mg/L) between periods of open water and ice-cover for the parameter extractable cadmium.

Station Location	December to March	June to October
Namur Lake	<.001	<.001 - .002
Gardiner Lake	<.001	<.001
Eaglenest Lake	<.001	<.001
Upper Ells River	<.001	<.001 - .002
Lower Ells River	<.001	<.001 - .003
Lower Tar River	<.001	<.001
Firebag River	<.001	<.001 - .003
Muskeg River	<.001	<.001
Hartley Creek	<.001	<.001
Steepbank River	<.001	<.001
MacKay River	<.001	<.001
Thickwood River	<.001	<.001
Lower Beaver Creek	-	<.001
Poplar Creek	<.001	<.001

Table 84. Comparison or ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter hexavalent chromium.

Station Location	December to March	June to October
Namur Lake	<.003	<.003 - .004
Gardiner Lake	<.003	<.003
Eaglenest Lake	<.003 - .004	<.003
Upper Ells River	<.003	<.003
Lower Ells River	<.003 - .005	<.003
Lower Tar River	<.003 - .009	<.003
Firebag River	<.003	<.003
Muskeg River	<.003	<.003
Hartley Creek	<.003 - .005	<.003
Steepbank River	<.003	<.003
MacKay River	<.003 - .006	<.003
Thickwood River	<.003	<.003
Lower Beaver Creek	<.003	<.003 - .005
Poplar Creek	<.003 - .008	<.003 - .065

well, substantial variation associated with spring breakup occurred at only two of the reported sites. These were Lower Beaver Creek (0.014 mg/L) and Poplar Creek (0.075 mg/L); this may be related to construction activity on the Syncrude lease.

10. Extractable Zinc: The salient feature regarding temporal distribution for zinc was the month to month variability as well as its significant temporal variation. Due to high variability during periods of ice-cover and open water, prominent fluctuations during spring breakup were not conspicuous; data are presented in Table 85.
11. Total Vanadium: Table 86 indicates no signifcant temporal variation for the parameter. At only one site (Lower Tar River) was there any variation associated with spring breakup (0.004 mg/L).
12. Dissolved Selenium: Temporal variation is not evident in review of Table 87. As well, only one site reported a concentration greater than the detection limit during the month of April (0.0009 mg/L at Lower Tar River). Less than 5% of the data had concentrations greater than the detection limit for this parameter.
13. Extractable Cobalt: Temporal variation of natural concentrations is not apparent in review of Table 88. Again, the Lower Tar River site is the only station where substantial deviation from the detection limit occurred during spring breakup (0.008 mg/L). In fact, less than 5% of the data are greater than the detection limit (0.002 mg/L).
14. Extractable Boron: A review of Table 89 reveals that natural concentrations during ice cover months were in a higher range than during the open water period. A fairly distinct trend is developing. During ice-cover, concentrations reach peak heights during

Table 85. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter extractable zinc.

Station Location	December to March	June to October
Namur Lake	.003 - .012	.008 - .025
Gardiner Lake	.001 - .019	.001 - .024
Eaglenest Lake	.008 - .023	.006 - .010
Upper Ells River	.004 - .088	.002 - .018
Lower Ells River	.004 - .054	.008 - .018
Lower Tar River	.016 - .041	.005 - .009
Firebag River	.004 - .007	.002 - .036
Muskeg River	.002 - .006	.004 - .091
Hartley Creek	.011 - .031	.003 - .048
Steepbank River	.003 - .047	.003 - .010
MacKay River	.005 - .020	.004 - .019
Thickwood River	.007 - .068	.004 - .027
Lower Beaver Creek	-	.014 - .024
Poplar Creek	.006 - .047	.006 - .044

Table 86. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter total vanadium.

Station Location	December to March	June to October
Namur Lake	<.001	<.001
Gardiner Lake	<.001	<.001
Eaglenest Lake	<.001	<.001
Upper Ells River	<.001	<.001
Lower Ells River	<.001	<.001 - .002
Lower Tar River	<.001 - .004	<.001 - .002
Firebag River	<.001	<.001 - .003
Muskeg River	<.001	<.001
Hartley Creek	<.001	<.001
Steepbank River	<.001	<.001
MacKay River	<.001	<.001 - .007
Thickwood River	-	<.001
Lower Beaver Creek	<.001	<.001
Poplar Creek	<.001	<.001

Table 87. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter dissolved selenium.

Station Location	December to March	June to October
Namur Lake	<.0005	<.0005
Gardiner Lake	<.0005	<.0005
Eaglenest Lake	<.0005	<.0005
Upper Ells River	<.0005	<.0005
Lower Ells River	<.0005	<.0005
Lower Tar River	<.0005 - .0008	<.0005
Firebag River	<.0005	<.0005
Muskeg River	<.0005 - .0009	<.0005
Hartley Creek	<.0005	<.0005 - .0007
Steepbank River	<.0005 - .0014	<.0005
MacKay River	.0005 - .0007	<.0005
Thickwood River	<.0005	<.0005
Lower Beaver Creek	<.0005	<.0005
Poplar Creek	<.0005 - .0008	<.0005

Table 88. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter extractable cobalt.

Station Location	December to March	June to October
Namur Lake	<.002	<.002
Gardiner Lake	<.002	<.002
Eaglenest Lake	<.002	<.002
Upper Ells River	<.002	<.002
Lower Ells River	<.002	<.002
Lower Tar River	<.002 - .006	<.002
Firebag River	<.002	<.002 - .030
Muskeg River	<.002	<.002
Hartley Creek	<.002	<.002
Steepbank River	<.002	<.002
MacKay River	<.002 - .006	<.002
Thickwood River	<.002	<.002
Lower Beaver Creek	<.002	<.002
Poplar Creek	<.002 - .008	<.002 - .003

Table 89. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter extractable boron.

Station Location	December to March	June to October
Namur Lake	.05 - .07	.02 - .09
Gardiner Lake	.05 - .24	.01 - .18
Eaglenest Lake	.04 - .25	.02 - .09
Upper Ells River	.02 - .19	.03 - .13
Lower Ells River	.13 - .30	.05 - .21
Lower Tar River	.22 - .32	.07 - .18
Firebag River	.02 - .18	.04 - .10
Muskeg River	.17 - .27	.14 - .22
Hartley Creek	.01 - .26	.06 - .18
Steepbank River	.18 - .48	-
MacKay River	.23 - .59	.10 - .14
Thickwood River	.04 - .33	.03 - .18
Lower Beaver Creek	-	.09 - .30
Poplar Creek	.10 - .28	.18 - .23

the first week in March. A sharp decline occurs through April and occasionally into May. Subsequently, concentrations tend to increase to peak heights in late summer. This is followed by a decline usually in September and October.

15. Extractable Aluminum: with the exception of Eaglenest Lake, Lower Tar River, Hartley Creek and Muskeg River, concentrations were generally low and uniform during ice cover, while open-water concentrations were greater and more variable (Table 90). In addition, there was a sharp increasing trend in concentration associated with spring breakup during April and early May. In regard to the exceptions above, Eaglenest Lake, Lower Tar River and Hartley Creek displayed irregularly high fluctuations during ice-cover as opposed to the other water bodies. The Muskeg River did not show appreciable temporal variation between open-water and ice-cover periods, except for a significant fluctuation in April (0.022 mg/L).

16. Total Mercury: Table 91 reveals no significant temporal variation between periods of ice cover to open water due to the apparent low levels of naturally occurring mercury in the area. Variation associated with spring breakup was only observed at Lower Ells River site where total mercury concentrations peaked at 0.003 mg/L during April. At all other sites reported in Table 91, April concentrations were less than the detection limit for mercury.

17. Extractable Nickel: Compared to the other sites, Lower Tar River site displays considerable variation in concentration, particularly during ice-cover. At all the other sites (Table 92), concentrations were normally less than the detection limit (0.002 mg/L), except for the occasional outlier. Variation associated with

Table 90. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter extractable aluminum.

Station Location	December to March	June to October
Namur Lake	<.01 - .09	.04 - .83
Gardiner Lake	<.01 - .04	<.01 - .31
Eaglenest Lake	<.01 - 1.13	.04 - .38
Upper Ells River	<.01 - .05	<.01 - .25
Lower Ells River	.07 - .10	.07 - .88
Lower Tar River	.05 - 1.39	.12 - .88
Firebag River	<.01 - .05	.06 - .48
Muskeg River	<.01 - .04	<.01 - .06
Hartley Creek	.03 - .22	.01 - .07
Steepbank River	<.01 - .05	-
MacKay River	<.01 - .12	.06 - 1.9
Thickwood River	.08 - .11	<.01 - .26
Lower Beaver Creek	.05 - .09	<.01 - .14
Poplar Creek	.01 - .8	<.01 - .38

Table 91. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter total mercury.

Station Location	December to March	June to October
Namur Lake	<.0001	<.0001
Gardiner Lake	<.0001	<.0001
Eaglenest Lake	<.0001	<.0001
Upper Ells River	<.0001	<.0001 - .0002
Lower Ells River	<.0001	<.0001
Lower Tar River	<.0001 - .0003	<.0001
Firebag River	<.0001	<.0001
Muskeg River	<.0001	<.0001
Hartley Creek	<.0001 - .0007	<.0001 - .0002
Steepbank River	<.0001 - .0004	<.0001
MacKay River	<.0001 - .0021	<.0001
Thickwood River	<.0001	<.0001
Lower Beaver Creek	<.0001 - .0002	<.0001
Poplar Creek	<.0001 - .0016	<.0001

Table 92. Comparison of ranges in concentration (mg/L) between periods of open water and ice-cover for the parameter extractable nickel.

Station Location	December to March	June to October
Namur Lake	<.002	<.002 - .006
Gardiner Lake	<.002	<.002 - .006
Eaglenest Lake	<.002	<.002
Upper Ells River	<.002	<.002
Lower Ells River	<.002 - .007	<.002
Lower Tar River	<.002 - .026	<.002 - .006
Firebag River	<.002 - .013	<.002 - .009
Muskeg River	<.002	<.002
Hartley Creek	<.002 - .004	<.002
Steepbank River	<.002 - .030	<.002
MacKay River	<.002 - .030	<.002
Thickwood River	<.002	<.002
Lower Beaver Creek	<.002	<.002
Poplar Creek	<.002 - .024	<.002 - .008

the spring event occurred only at the Lower Tar River, where the concentration erupted from the detection limit to 0.011 mg/L. Less than 10% of all data were greater than the detection limit for extractable nickel.

18. Conductivity: Temporal variation was generally observed for all stations. In all of these cases ice-cover concentrations were greater than open-water concentrations, with peak activity usually associated with the spring event. In this regard, there tends to be an inverse correlation between conductivity and discharge. It is worthy to note that the percent increase in concentrations during ice-cover, compared to the open water period, varied considerably amongst stations. For example, the percent increase at the Firebag River site was 29.5%, while it was greater than 200% at the Thickwood Creek site. Conductivity is a function of total ionic concentration in the water. Therefore, as temporal variation increases, the more likely this trend will be reflected in the independent ionic parameters present. A review of the data base indicated that at the high range for conductivity (i.e. percent increase greater than 100%), dissolved calcium, magnesium, sodium, potassium, sulphate, bicarbonate and flouride, also displayed temporal variation in varying degrees. However, at the lower range (less than 50% increase) only calcium and bicarbonate consistently displayed similar temporal variation between periods of ice cover and open water.

19. Tannins and Lignins, Surfactants and Humic Acids: These organics were seldom present in concentrations greater than their respective detection limits during ice cover. Occasionally they were present in greater concentrations, but these events are restricted to periods of open water.

2.5.5 Loadings

As with suspended sediment, the collection of water quality samples provides a gross appreciation of the range of concentrations that the many water quality parameters considered might have. If, however, AOSERP requires a measure of the loadings that each of these parameters would produce over some period of time, then it becomes necessary to have the means of estimating concentrations between sampling times; that is, a concentration versus stream discharge relationship must be developed for each parameter. Several possibilities exist for the form that these relationships might take:

1. There may an inverse relationship, whereby concentrations during low flow (winter) periods are higher than during the higher summer flows (examples are calcium, phosphorous and copper) so that, although the loadings may be higher during open water, the quality of water is poorer in the winter;
2. There may be a direct relationship between concentrations and stream discharge, so that loadings could be relatively high during summer and low in winter;
3. Concentrations may vary little with stream discharge, so that loadings would vary directly with flow; and
4. A wide scatter of points might occur, indicating a poor correlation of concentrations and stream discharge; in this case other factors must be brought into the relationship via multiple correlation techniques.

Because of the large number of water quality parameters and stations involved, NHCL was not able to consider all possible relationships of stream discharge versus parameter concentrations. As an example, however, concentrations of calcium and discharge are shown plotted on Figure 24, for various stations. The results show a general inverse trend, with some relatively good correlations occurring for the Muskeg, Lower Ells, Steepbank and MacKay rivers data; a poor correlation is apparent for Beaver Creek, while calcium concentrations don't appear to vary much with discharge for the Firebag and Hartley Creek data.

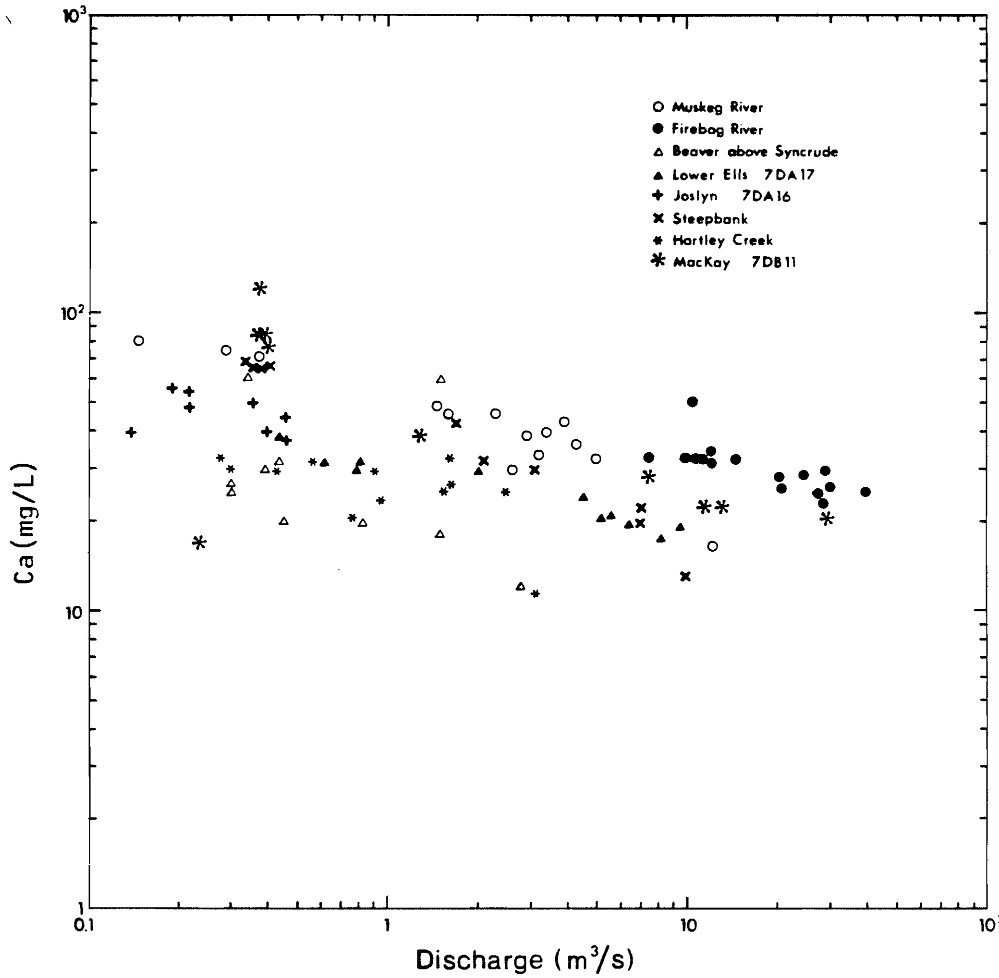


Figure 24. Plot of calcium concentration vs. discharge.

2.6 RESOLUTION OF BASELINE ANALYSIS (REDIRECTION)

The water quality, suspended sediment, and streamflow-lake level baseline networks have been dealt with in this section more or less independently. As a result, there are conflicting or overlapping recommendations, particularly with respect to the question of network redirection. Table 93 provides a resolution of the different points of view, specifically outlining the recommended baseline networks which should operate for the next two years.

One of the primary mandates of the AOSERP program is to achieve a predictive capability within five years. This involves development of machinery and of criteria to assess the program on an ongoing basis. This necessitates development of a data storage and retrieval system in order to achieve the required rapid data integration, development and/or evaluation of correlations between selected parameters at successive sampling sites as well as the development and evaluation of statistical tests and procedures to analyze the validity of integrated data from all sources. At the present time the program objectives are limited by:

1. Lack of proper data storage and retrieval system which will select and organize data (eg. by means range, standard deviation, and coefficient); and
2. Small sample size which limits the selection and applicability of strong statistical evaluation techniques as well as selecting multivariate, linear equations to verify certain assumptions and evaluate the significance of individual independent variables.

In an earlier section we have identified trends or relationships statistically. However, this was established on the basis of a rather weak statistical test. Since we cannot verify statistical normality of data (due to small sample size), a better non-parametric test would involve Wilcoxon non-parametric signed rank test for paired data. To satisfy the conditions to use this test, field sampling must be conducted on the same day at stations for which comparisons are required.

Table 93. Recommended baseline network for the period 1978-79.

Station	Streamflow/ Lake Level	Suspended Sediment	Water Quality
Ells (Lower)	✓	✓	✓
Joslyn	✓	✓	✓
Tar (Lower)	✓	X	✓
Tar (Upper)	X	X	X
Calumet	✓	X	✓
Pierre	✓	X	✓
Asphalt	✓	X	✓
Unnamed	✓	X	✓
Richardson	X	X	X
Firebag	✓	✓	✓
Lost	X	X	X
Muskeg	✓	✓	✓
Hartley	X	X	X
Steepbank	✓	✓	✓
Beaver (Upper)	X	X	X
Poplar	✓	✓	✓
Gregoire Lake	✓	X	✓
Hangingstone	✓	✓[a]	✓
Horse	✓	X	✓
MacKay	✓	✓	✓
Dover	✓	X	X
Thickwood	X	X	
Dunkirk	✓	✓	✓
Ells (Upper)	✓	X	✓
Eaglenest Lake	X	X	X
Gardiner Lake	✓	X	X
Namur Lake	X	X	✓

continued........

Table 93. Concluded.

Station	Streamflow/ Lake Level	Suspended Sediment	Water Quality
Delta Sites	X	X	X
Athabasca (Fort McMurray)	√	√	√
Athabasca (McKay)	X	X	X
Athabasca (Embarras)	√	√	√
Clearwater (Draper)	√	√	√
Clearwater (Above Christina)	√	X	√
Total	23	12	22
Present	31	12	42

X - Denotes No

√ - Denotes yes

[a] Indicates new station or added activity

3. CRITERIA TO EVALUATE NETWORK AND DATA BASE ON ON-GOING BASIS

3.1 GENERAL

It is suggested that there are two types of network to be considered: (1) the existing baseline (or Stage 1) network; and (2) Stage 2 network which would be geared to collect additional hydrometric and water quality baseline information, but for streams or specific regions that require a more concentrated (spatially and temporally) set of information. The purpose or objective of each type will differ, so that criteria to evaluate their performance could also differ in some aspects.

3.2 STAGE ONE NETWORK

3.2.1 Streamflow-Lake Level Network

We have already indicated that the baseline network should operate only until the end of 1979 insofar as AOSERP's needs are concerned. It has been assumed that other agencies could choose to continue to operate all or part of the network to provide long term information, so that extremes may be predicted. If the above is the case, then on-going evaluation of the network should be based on the ability of the information to provide a gross appreciation of streamflow in the study area. This means that AOSERP must undertake analyses of the available information (to a degree greater than was done for this study) to the end of 1977, with further analyses at the end of 1978 and 1979. The primary objective would be to develop averaged values for various hydrological factors such as annual runoff and minimum flows; as well, consideration should be given to the character of basin response to precipitation events.

3.2.2 Suspended Sediment Network

If AOSERP require a means of computing sediment loadings from the tributary streams, then on-going evaluation of this network over the next two years should be based primarily on the ability of the data to define sediment concentration-discharge relationships through the whole range of measured streamflow. The relationships may not necessarily be well defined, but their present definition is generally inadequate. Particular attention should be paid to establishing seasonal differences in the relationships. Responsibility for this activity should be with AOSERP, although WSC likely plot these relationships as a matter of course.

3.2.3 Water Quality Network

Keeping in mind that the primary objective is being able to predict the baseline water quality parameters anywhere in the study area that might be influenced by oil sands development, then on-going analyses should work toward regionalizing these parameters. It has previously been suggested that several of the parameters (heavy metals) are consistent over a major portion of the study area, while others (conductivity related or dissolved parameters) tend to follow the suggested zones. The strength of these trends should be evaluated as further information becomes available.

Possibly of greater importance to AOSERP is the matter of loads, a subject which was briefly dealt with in Section 2.5.5. On-going evaluation of the water quality network should include a program to evaluate parameter concentrations versus stream discharge relationshiops if it is AOSERP's desire to derive a means of computing loadings from tributary streams. This analysis would have the added benefit of providing a means of defining the temporal variation of water quality.

3.3 STAGE TWO NETWORK

Criteria to assess the performance of these networks will have to be established on the basis of the purpose for a given network. For example, the miscellaneous information collection program operated in the Muskeg River basin during 1977 would qualify as a Stage 2 network. The purpose of this particular program is not known to the writer, so it is difficult to consider whether it has been a success. In this case AOSERP should have a clear statement of the program's objectives; this would serve as the criteria with which to assess the results; any such statement should include the following:

1. The reasons why stations have been located where they are;
2. A description of the equipment and sampling procedures to be used;
3. The agency who would be responsible for collection of samples or raw data, as well as the agency who would process this data and analyze the information;
4. A statement as to what would be considered a successful conclusion to the program; and
5. An estimate of how long a network might be required to operate.

4. REQUIRED HYDROMETRIC-WATER QUALITY NETWORKS VERSUS OBJECTIVE OF A PREDICTIVE CAPABILITY

4.1 GENERAL

This section deals with the question raised in Section 1.2, Point 4 (Study Terms of Reference), and that is: What networks should AOSERP consider having in order to help it achieve a predictive capability in terms of impact of oil sands development on the surface water environment? They already have existing hydrometric-water quality networks which have been designated as being part of a Stage 1 baseline network, while the possibilities for a Stage 2 network have yet to be considered and defined. In the previous section we have defined a Stage 2 network as being an extension or supplement to the Stage 1 baseline network. Information gathered by both levels of network will play an important role when order-of-magnitude impact predictions are attempted, or when research programs are implemented to monitor impact; in the last case, a Stage 2 network would be a necessary prelude to such a research program.

4.2 NETWORKS FOR PREDICTIVE CAPABILITY

1. Utilizing Stage 1 Network: Immediately undertake a study to apply streamflow data to a selected and available mathematical runoff (or watershed) model. Watershed modelling is important to AOSERP in terms of development impact. In this case, AOSERP would terminate support of the tributary streamflow network at the end of 1979, except that a few key basins might continue to be monitored in order to improve the modelling capability. Key basins would be selected on the basis of having common hydrological characteristics within a broad region (eg. regions established as hydrological zones in Figure 1), and having some priority with respect to oil sands development; possibilities are the Ells, MacKay and Steepbank

basins. Before discontinuing operation of some stations, existing streamflow information should have been used to establish that the key basins are representative of all possible runoff conditions in the study area.

In order to properly adapt a given runoff model there should be several distinct recorded runoff events which could be reconstituted by the model using recorded precipitation values. This benchmarking is necessary in order to gain a proper understanding of how given basins react to precipitation events; of particular importance is the ability to develop an understanding of the ratio between infiltration capacity of the soil and direct runoff for given amounts of precipitation. Because of the importance of a proper precipitation record in watershed modelling, assessment of sufficiency of streamflow information should be carried out in conjunction with assessment of availability of the precipitation record. In particular, because many of the basins being considered are small, there should be a proper mix of recording and non-recording precipitation stations. This aspect is not part of the terms of reference for this study, so a detailed assessment of the precipitation record was not made. A cursory look indicated that the areal distribution of these stations appear satisfactory, and as a recording station is known to exist at Fort McMurray, there is some hope that the precipitation record is adequate. However, it is recommended that liaison be established between streamflow and meteorological information groups within AOSERP in order to ensure that adequate precipitation data are being collected for the purpose of watershed modelling.

Streamflow records for the tributary streams were reviewed to determine whether a sufficient number of high runoff events have been recorded; the results are presented in Table 94. Not all of the 1977 records were available at the time of review, but generally low runoff was experienced in the study area during 1977. The review indicated the following:

- Those stations having only four or less years of streamflow information do not have sufficient number of "events" for the purpose of watershed modelling.
- There appear to be sufficient "events" only for the MacKay and Hangingstone rivers.

2. Water Quality Modelling: Immediately undertake an evaluation of existing water quality models with a view toward establishing one or possibly two which might be adapted for use initially on the Athabasca River between Fort McMurray and Embarras. Preliminary runs could be made using existing water quality and channel hydraulic information, but it can be expected that an upgrading of information will likely be required during 1979. Proving homogeneity of information across a section, and assessment of dispersion characteristics from point (tributary) sources, will be important considerations.
3. Lower Poplar River: As part of a Stage 2 network, expand the water quality program at this station to include analysis of organics by broad groups, as well as sediment-heavy metal chemistry.
4. Lower Beaver River: This area provides an opportunity to measure impact due to the Syncrude Canada Ltd. development. It is recommended that consideration be given to re-establishing a station at its previous location for the purpose of measuring streamflow, suspended sediment and water quality. Operation of this station should be for a duration of not less than five years.

Table 94. Availability of flood hydrograph events for rivers and creeks tributary to the Athabasca River.

River or Stream	WSC	Hydrograph Event
Lost Ck.	7DC-2	None
Tar R.(upper)	7DA-19	None
Thickwood Ck.	7DB-4	None
Asphalt Ck.	7DA-13	None
Beaver R. (upper)	7DA-18	None (1977)
Calumet R.	7DA-14	April 1976 (snowmelt)
Dover R.	tDB-2	April 1976 (snowmelt)
Dunkirk R.	7DB-3	April 1976 (snowmelt)
Ells R. (upper)	7DA-10	April 1976 (snowmelt)
Ells R. (lower)	7DA-17	April 1976 (snowmelt)
Hartley Ck.	7DA-9	April 1976 (snowmelt)
Horse R.	7CC-1	Aug. 1976 (rainfall)
Joslyn Ck.	7DA-16	April 1976 (snowmelt)
Pierre R.	7DA-13	None
Tar R. (lower)	7DA-15	April 1976 (snowmelt)
Unnamed R.	7DA-11	None
Muskeg R.	7DA-8	None (1977)
MacKay R.	7DB-1	June 1973 (rainfall) 1977 April 1974 (snowmelt) April 1976
Poplar Ck.	7DA-7	Aug. 1976 (rainfall) 1977
Steepbank R.	7DA-6	April 1974 (snowmelt) 1977
Firebag R.	7DC-1	Aug. 1973 (rainfall)
Richardson R.	7DD-2	None

continued............

Table 94. Concluded.

River or Stream	WSC	Hydrograph Event
Hangingstone	7CD-4	Aug. 1973 (rainfall) June 1973 (rainfall) Aug. 1976
Clearwater R.	7CD-1	Several events since 1958

5. Muskeg Basin: The structure and purpose of the miscellaneous network operated in 1977 is not known to the writer, but it is recommended that it be continued for at least two more years as part of a Stage 2 network. Affirmation of the network's objectives should be carried out as soon as possible to determine whether the original program was sufficient.
6. Ells River-MacKay River: These are considered priority streams in terms of their importance as a fishery. Therefore, consideration should be given to operating the existing stations (streamflow and water quality) on these rivers beyond 1979. Analysis of the water quality samples should expand to include organic and sediment-heavy metal chemistry.
7. Surmont Creek-Gregoire Lake: An in situ pilot plant (AMOCO) south of Gregoire Lake suggests that AOSERP should consider establishment of Stage 2 network stations. This basin has not been observed at close hand but, tentatively, consideration should be given to maintaining a lake level and water quality station at the outlet of Gregoire Lake beyond 1979, as well as measurement of suspended sediment and water quality at the inlet.
8. Athabasca Delta: The baseline water quality information base has been judged inadequate. However, rather than recommending continuation of the present program and because of the complexity and extreme importance of the area, it is recommended that a Stage 2 network be established. This suggests that a much denser network of water quality stations be established in the reach from Embarras to the Rivière des Rochers in order to more precisely define the baseline water quality states in the delta.

5. COST OF NETWORK REDIRECTION

Recommendations have been given in previous sections as to what Stage 1 hydrometric and water quality stations AOSERP should fund to the end of 1979. As the recommended network would require fewer stations than operated previously, there should accrue a savings in operating costs. However, there could also be a cost associated with removal of a station and/or installation of an additional station.

Table 95 has been prepared in order to provide an estimate of what annual budget would be required to operate the recommended hydrometric and water quality Stage 1 network. Estimates have been based on the following unit costs:

1. Operation:	
Major streamflow Station (Athabasca and Clearwater Rivers)	= $ 6500/yr
Tributary streamflow station	= $ 4700/yr
Lake Level station	= $ 1000/yr
Water quality station	= $ 3000/yr
2. Installation:	
Streamflow station	= $10000
3. Removal:	
Streamflow station	= $ 3600

Costs for major and tributary streams include collection and analysis of suspended sediment samples.

Table 95. Estimated annual budget (1978) for Stage 1 hydrometric and water quality networks.[a]

Station[b]		Number Recommended	Total Cost ($)
Main streams		4	26,000
Tributary streams		19	89,300
Lake Level		2	2,000
Water Quality		22	66,000
	Subtotal		183,300
Installation: Hangingstone[c]		sediment only	nil
	Subtotal		-
Removal: Streaflow Stations		8	28,800
	Subtotal		28,800
Estimated 1978 Budget			212,100

[a] Includes sampling, laboratory analysis and data publication.

[b] Stations considered are those listed in Table 8.

[c] Additional costs to collect and analyze suspended sediment samples assumed small.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 STREAMFLOW-LAKE LEVEL NETWORK:

1. On the basis of developing a gross appreciation of surface water hydrology, the AOSERP network must be sufficient to enable definition of the surface water regime throughout the study area. In order to ascertain whether some stations in the network are redundant or superfluous on an areal basis, it was conceived that there are 12 unique hydrological zones in the study area. Whether or not these zones prove to be unique, or whether other kinds of criteria would show there to be additional characteristics, it is concluded that the existing network is adequate in areal extent, and in fact, it has been suggested that eight of the stations might ultimately be eliminated [see Table 93 and comments in (2)].

   It is recommended that available surface water data be further analyzed to further confirm the existance of hydrological zones.

2. The existing data base for the tributary streams is not adequate to enable development of a proper gross appreciation of the surface water hydrology. It is recommended that the network be funded by AOSERP until the end of 1979. Whether or not AOSERP should include funding of the stations suggested as being redundant (on an areal basis) is a matter for further consideration. Having an additional one year's (1978) data to confirm the character and boundaries of hydrological zones may show that the final year (1979) is not warranted (aside from water quality considerations).

3. Two kinds of criteria should be considered in on-going evaluation of the streamflow network: (1) those for the existing one (Stage 1), and (2) criteria required for more site specific networks (Stage 2). In the former case the adequacy of the data base should be evaluated in relation to its ability to provide a gross appreciation of the surface water hydrology, as well as its need to support computation of loadings (water quality parameters).
   In this case it is recommended that AOSERP immediately undertake detailed analyses of the data, along with updated analyses at the end of 1979.
   Stage 2 networks would have unique sets of criteria based on their specific terms of reference or objectives; a set of requirements has been recommended in Section 3.3 in establishing evaluation of criteria for these networks.
4. Assessment of the network required to develop a predictive capability (after five years of the Program) has taken the approach that various methods of prediction should be pursued for example, by studying various predictive watershed (mathematical) models and selecting those considered most appropriate; in testing these models, use would be made of baseline data (Stage 1) and/or data collected at selected points (Stage 2). Section 4.2 provides several recommendations of what programs might be instituted in working toward a predictive capability.
5. Recommendations regarding re-direction of the streamflow network have been limited to the possibility of eliminating some streamflow-lake level stations because they might be redundant; estimates of costs to operate the smaller network, as well as station removal,

have been provided in Section 5. However, the writer would prefer to see the existing network operated for at least one more year, and possibly two.

6.2 SUSPENDED SEDIMENT NETWORK

Satisfactory estimates of sediment concentrations and loadings can be made for the two Athabasca and one Clearwater River stations.

The mode of operation for the tributary sediment stations is more in the realm of a miscellaneous data network, and as such, information collected will be useful in providing a gross appreciation of sediment concentrations (areal and temporal variations) from tributary basins. However, it is doubtful whether adequate estimates of loadings could be made because of the generally inadequate sediment concentration versus discharge curves available. Continued operation may not necessarily improve this situation.

It is recommended that the existing suspended sediment network be operated until the end of 1979; hopefully by that time adequate sediment versus discharge relationships will have been developed for the purpose of estimating loadings.

6.3 WATER QUALITY NETWORK

1. The areal distribution of the 42 water quality stations in the network initially utilized the hydrological zones conceived in Section 2.2. Some significant trends toward similarity of water quality parameters are apparent within these zones, particularly when parameters of similar geological origin are considered. However, these trends were based on a statistical comparison of means where the data base is generally inadequate in length. It is therefore recommended that the baseline water quality network be operated until the end of 1979 to provide a better data base.

The density of stations is considered more than adequate, and in fact, based on the preliminary statistical comparisons, some reductions are possible; a possible recommended network is provided in Table 18. However, it may be prudent to consider such a reduced network only after 1978 data have been assessed.

2. The data base is not sufficient to adequately assess temporal variation of water quality; there is a particular paucity of data during the winter months (December through March, inclusive). However, some significant trends were apparent when using whatever information is available to at least compare several differences in water quality. These trends do not preclude the need for additional collection of data, but attempts should be made to collect paired samples; that is, all samples should be collected more or less at the same time.
3. Criteria with which to evaluate the baseline water quality network on an ongoing basis have basically been provided in the manner by which the network was assessed in this study. That is, future analyses should move toward strengthening the trends established herein.

   Data collection programs not part of the baseline network (considered as being part of a Stage 2 network) should establish evaluation criteria on a site specific basis; refer to Section 3.3.
4. Several (Stage 2) programs have been recommended in Section 4.2 for the purpose of developing a predictive capability in conjunction with oil sands development.
5. Redirection of the baseline water quality network is not necessarily advantageous at this time. Further operation of the network has been recommended until the end of 1979, although a reduction of the network might be achieved at the end of 1978 (see Table 93).

7. REFERENCES CITED

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8. APPENDICES

8.1 NHCL STUDY TERMS OF REFERENCE

The following is a copy of the original terms of reference as issued to Northwest Hydraulic Consultants by AOSERP.

M. Falk
15.9.77

TERMS OF REFERENCE

TO

EVALUATION OF STREAM FLOW, SUSPENDED SEDIMENT QUALITY NETWORKS IN THE AOSERP STUDY AREA

1. BACKGROUND:

At the present time the AOSERP study area supports a network of ca.30 streamflow and lake-level stations and ca.40 water quality stations. Streamflow and lake-level stations were installed and are maintained by Water Survey of Canada. Water Quality Stations were established upon recommendations of the Hydrology Committe and are monitored by Pollution Control Division of Alberta Environment. Sample analysis is being done by Chemex Labs (Alberta) Ltd.

The purpose of these networks was to provide information on the baseline regime of streamflow, lake-level and water quality for the AOSERP study area and to assist in the prediction of distrubed regimes. This is in keeping with the purpose of AOSERP as well as the three-year objectives. As 1977-78 is the third year of the Program, it is necessary to evaluate the water quantity and water quality networks in relation to Program needs as the emphasis changes from a phase of Baseline States to that of Applied Research.

2. OBJECTIVES

The general objective is to evaluate the present streamflow suspended sediment and lake level and water quality networks in the AOSERP study area on the basis of the current data basis so as to provide the basis for continuation and/or redirection.

3. OUTLINE OF WORK:

3.1 STREAMFLOW - LAKE LEVEL NETWORK:

1. Evaluate the adequacy of the present streamflow - lake level network as to coverage in the AOSERP study area with respect to predicting streamflow suspended sediment, channel and water quality regimes.

2. Evaluate the adequacy of the data base generated through the streamflow - lake level network in the AOSERP study area. Historical information has been provided to the Program in the form of an Interim Report.

3. Develop criteria that could be used to evaluate the network and the data based on an ongoing basis. Criteria are to include but not be limited to priority streams within the surface mining area, number of stations per stream, period of record, validity of rating curves, confidence limits, flow extremes, water yields, etc.

4. Based upon the above evaluations, and defined needs, recommend a streamflow - lake level network appropriate to the needs of the Program in achieving its five-year objective of a predictive capability.

5. Provide recommendations on the means by which the existing network is redirected, the cost

of station shutdown and the annual maintenance budget required.

3.2 WATER QUALITY NETWORK:

1. Evaluate the adequacy of the present water quality network coverage in the AOSERP study area with respect to defining the natural concentrations and loadings throughout the region.

2. Evaluate the adequacy of the data base generated through the water quality network in the AOSERP study area, with respect to temporal variations. Historical information is available through R. Seidner, Pollution Control Division.

3. Develop criteria that could be used to evaluate the water quality network and the data base on an ongoing basis.

4. Based on the above evaluations and defined needs recommend a water quality network appropriate to the needs of the Program in achieving its five-year objective of a predictive capability.

5. Provide recommendations on the means by which the existing network is redirected, and the annual maintenance budget.

3.3 SUSPENDED SEDIMENT NETWORK:

1. Evaluate the adequacy of the present suspended sediment network for the purpose of determining the natural sediment regime of the Athabasca

River and tributaries in the study area.

TIMING AND DURATION:

The work described under these terms of reference will commence 1 October 1977 and will terminate 1 December 1978.

REPORTING:

The Contractor will submit to the Program Director a monthly written progress report on 1 November 1977 of not more than three pages in length. The progress report will describe the research performed, the expenditures and commitments during the previous month, and the research proposed to be performed during the ensuing month.

A draft final report is to be submitted to the Program Director on or before 1 December 1977. The final report will be submitted on or before 15 December 1977.

EQUIPMENT AND FACILITIES:

The Contractor will provide all necessary support to the personnel listed under these terms of reference.

8.2 TABLE OF HYDROLOGICAL ZONING CHARACTERISTICS

The following table (Table 96) provides a breakdown of physiographic and surficial factors for various basins in the AOSERP study area. As well, hydrological and oil sands development potential factors are given for these basins.

8.3 SUSPENDED SEDIMENT PLOTS

Available suspended sediment measurements (1974 to 1976) have been superimposed on the stage-discharge plots for a number of the active hydrometric stations in the study area (Figures 25 to 32). It should be noted that a distinction has been made between spring and summer measurements.

8.3.1 Graphs Showing Suspended Sediment Concentrations vs. Discharge

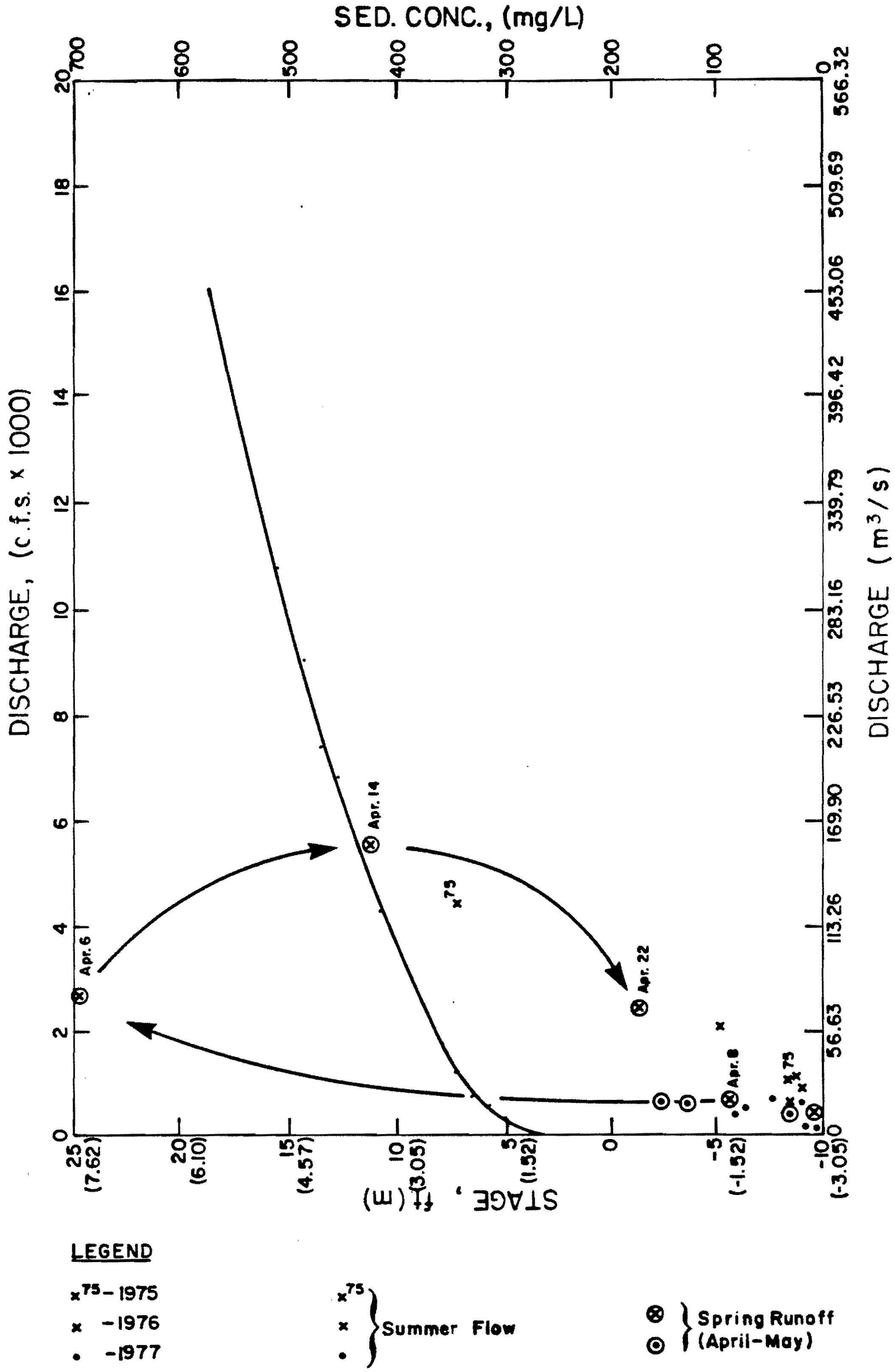

Figure 25. MacKay River near Fort MacKay.

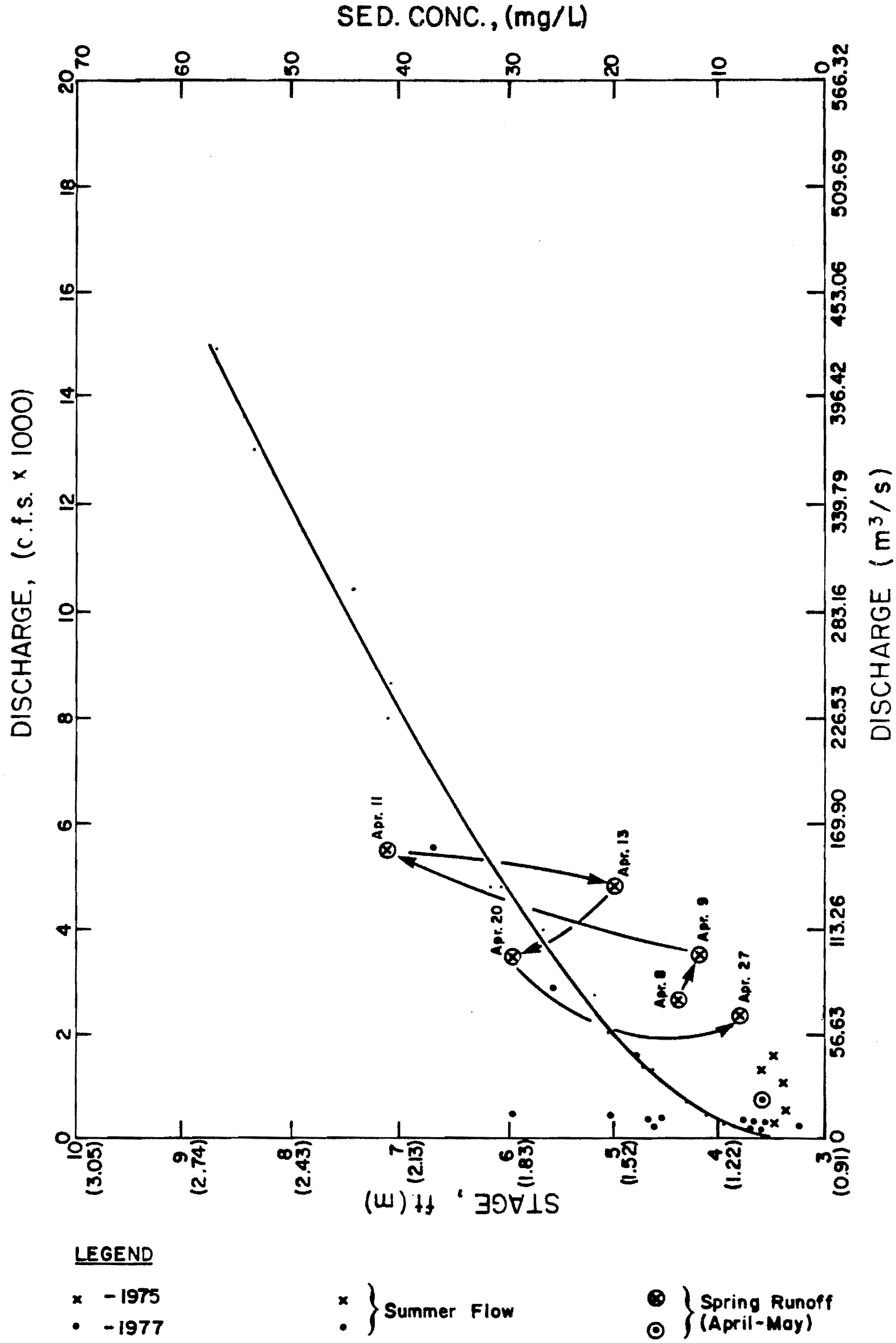

Figure 26. Muskeg River near Fort MacKay.

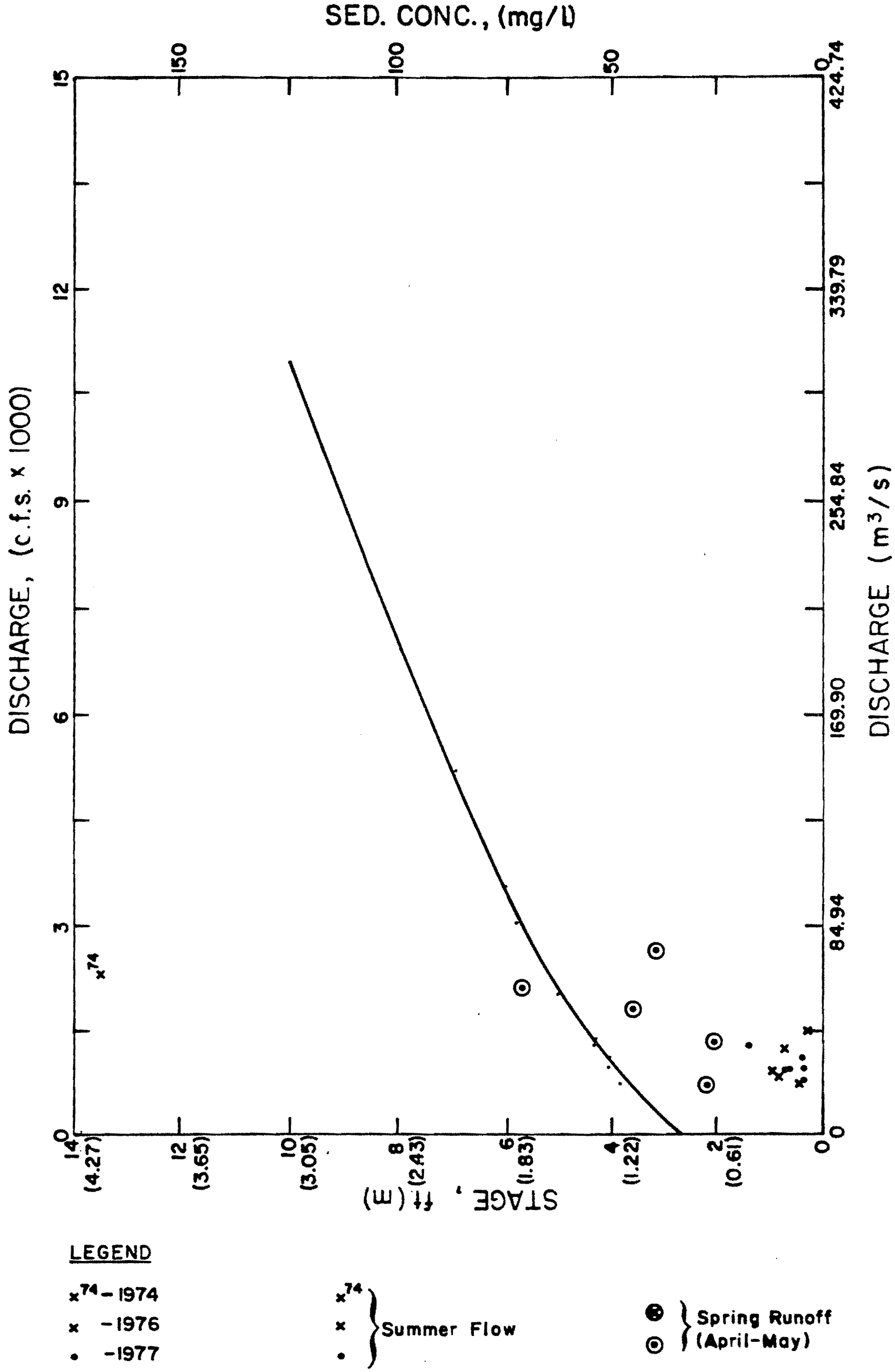

Figure 27. Firebag River near the mouth.

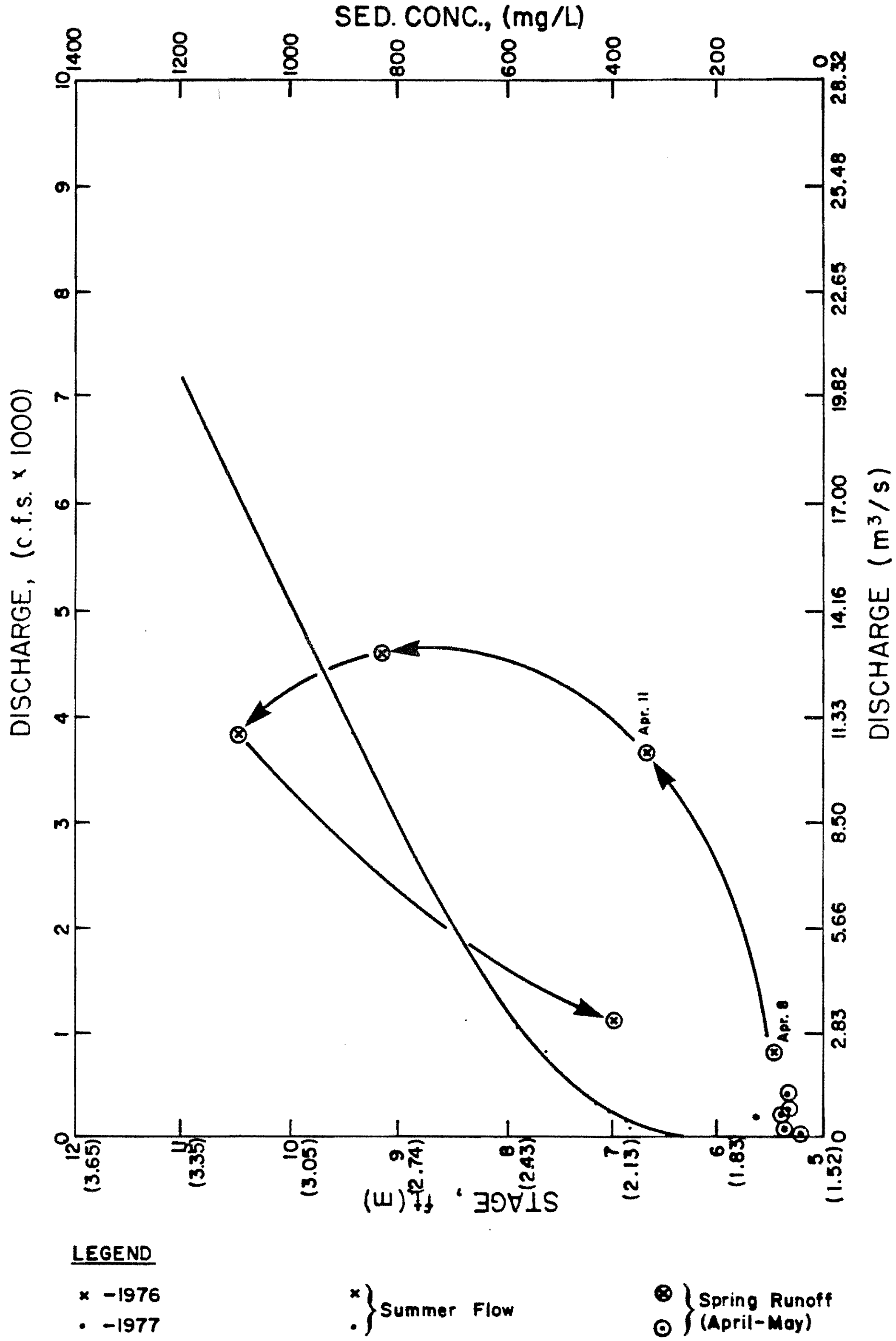

Figure 28. Joslyn Creek near Fort MacKay.

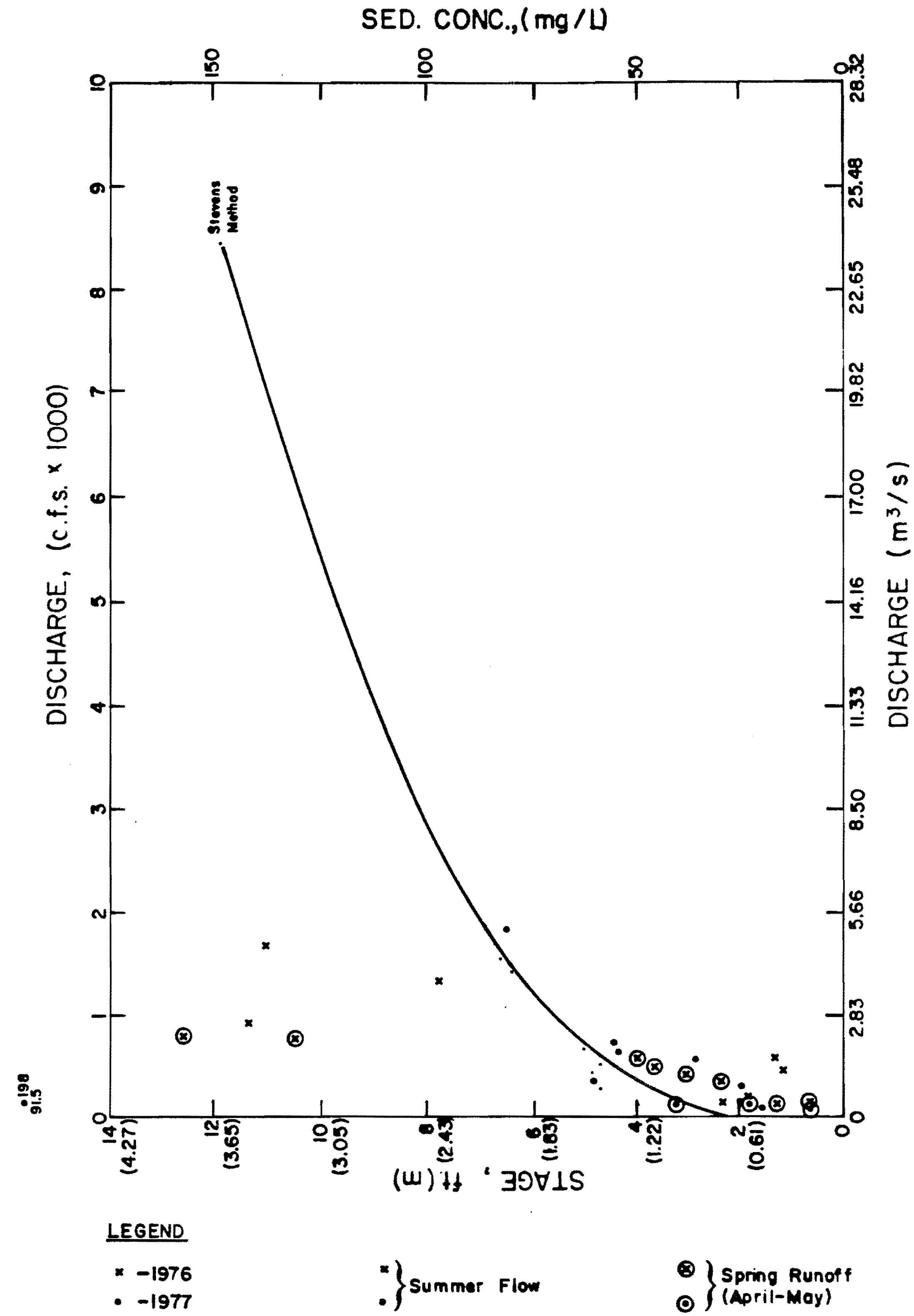

Figure 29. Beaver River above Syncrude.

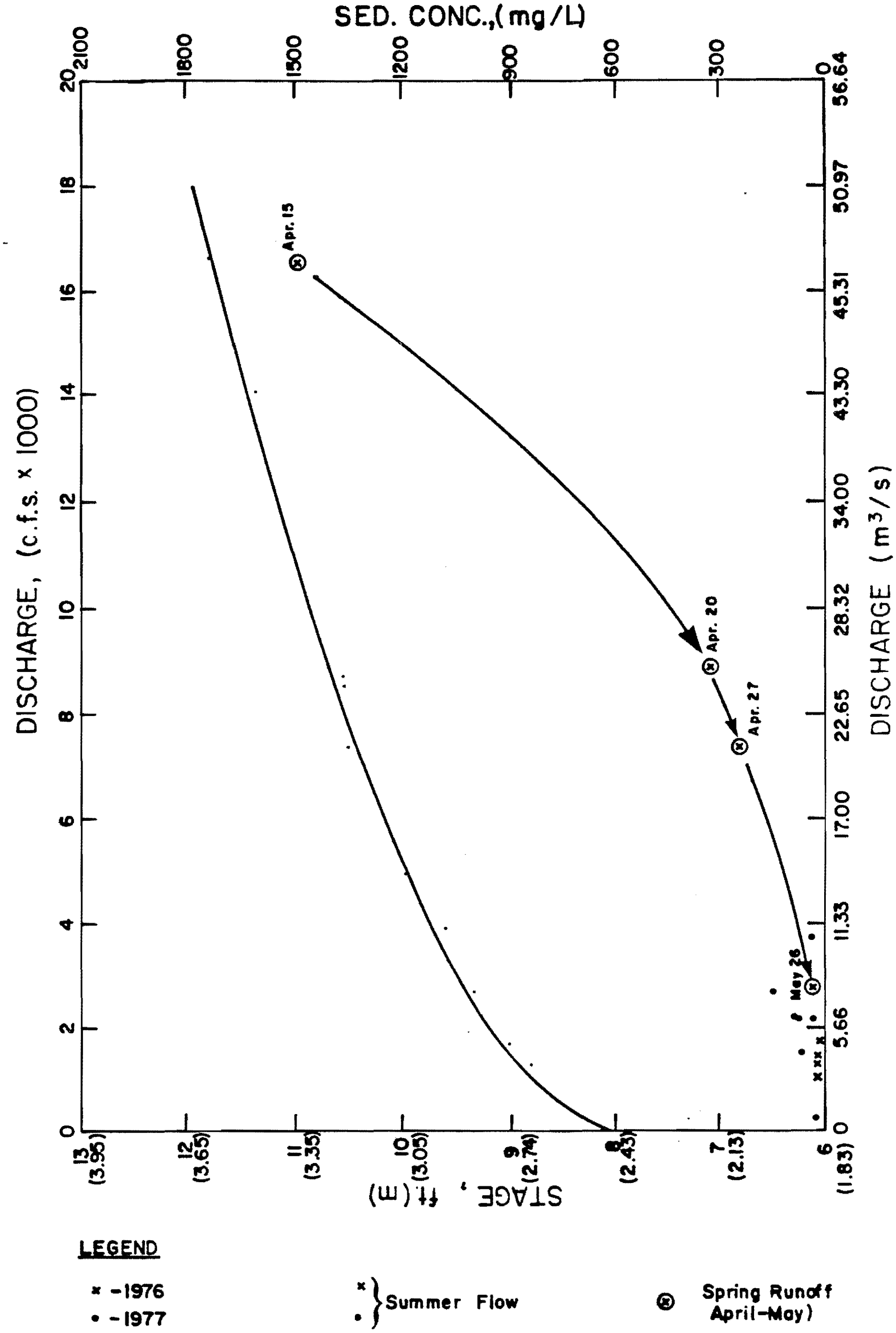

Figure 30. Ells River near the mouth.

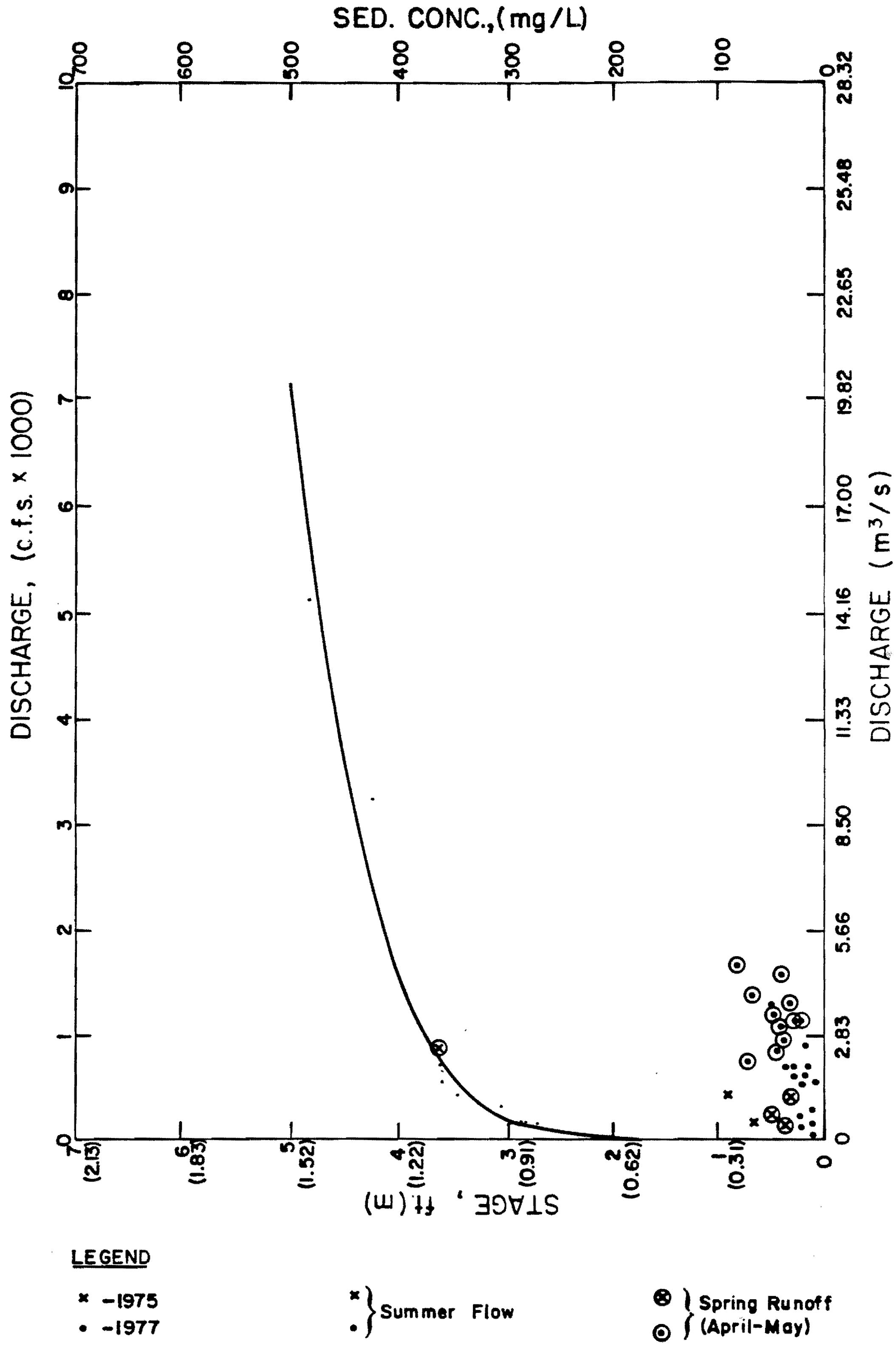

Figure 31. Poplar Creek near Fort McMurray.

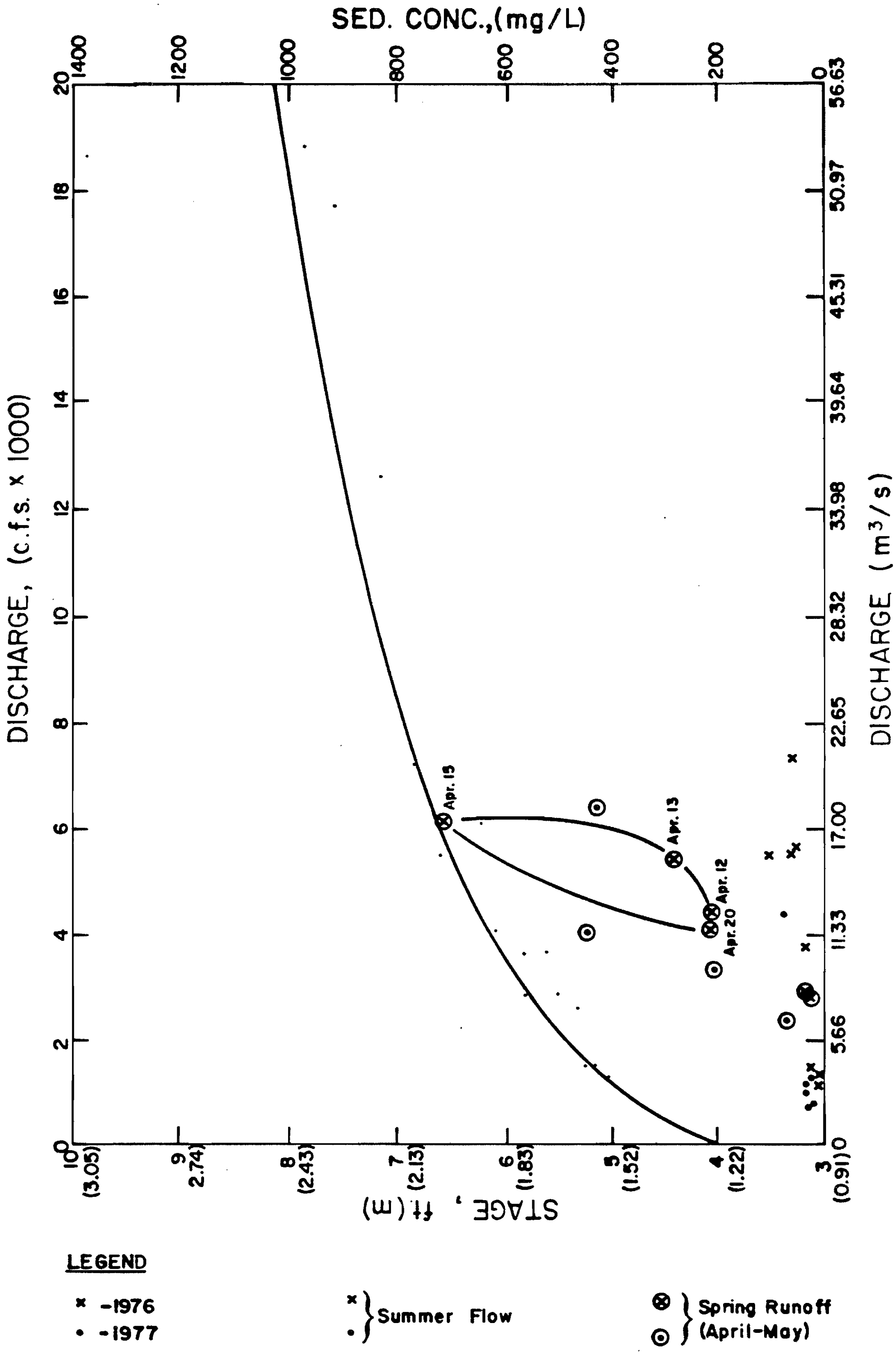

Figure 32. Steepbank River near Fort McMurray.

9. 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
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.	HE 2.3	Maximization of Technical Training and Involvement of Area Manpower
23.	AF 1.1.2	Acute Lethality of Mine Depressurization Water on Trout Perch and Rainbow Trout
24.	ME 4.2.1	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
41.	AF 3.5.1	Acute and Chronic Toxicity of Vanadium to Fish
42.	TF 1.1.4	Analysis of Fish 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
47.	TF 1.1.1	A Visibility Bias Model for Aerial Surveys of 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 Data in the AOSERP Study Area
52.	ME 2.3.2	Plume Dispersion Measurements from an Oil Sands Extraction Plant, 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

These reports are not available upon request. For further information about availability and location of depositories, please contact:

Alberta Oil Sands Environmental Research Program
15th Floor, Oxbridge Place
9820 - 106 Street
Edmonton, Alberta T5K 2J6