HYDROGEOLOGICAL INVESTIGATION OF MUSKEG RIVER BASIN, ALBERTA

by

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for

ALBERTA OIL SANDS ENVIRONMENTAL
RESEARCH PROGRAM

WS 2.2

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The Hon. J.W. (Jack) Cookson
Minister of the Environment
222 Legislative Building
Edmonton, Alberta

and

The Hon. John Fraser
Minister of the Environment
Environment Canada
Ottawa, Ontario

Sirs:

Enclosed is the report "Hydrogeological Investigation of Muskeg River Basin, Alberta".

This report was prepared for the Alberta Oil Sands Environmental Research Program, through its Water System, under the Canada-Alberta Agreement of February 1975 (amended September 1977).

Respectfully,

W. Solodzuk, P.Eng.
Chairman, Steering Committee, AOSERP
Deputy Minister, Alberta Environment

A.H. Macpherson, Ph.D
Member, Steering Committee, AOSERP
Regional Director-General
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HYDROGEOLOGICAL INVESTIGATION OF THE MUSKEG RIVER BASIN, ALBERTA

DESCRIPTIVE SUMMARY

BACKGROUND

Muskeg terrain covers a major portion of the Athabasca Oil Sands deposit of northeastern Alberta. The water associated with the muskeg plays an important role in sustaining the rivers and streams in the area. Further, the handling of muskeg overburden poses special problems for the mining companies. The goal of this investigation was to define more clearly muskeg shallow groundwater conditions in order to foresee effects of surface disturbance caused by oil sands mining. Detailed objectives are found in the Introduction.

This investigation involved a two-year field program in the Muskeg River basin. This particular basin was chosen because it typified muskeg conditions throughout the region and because it appeared to be a candidate for immediate development. It contained at least three active leases, including that of the Alsands Group. The interested reader is referred to the interim report (AOSERP Report 48) for further background information.

ASSESSMENT

The draft of the report has been reviewed by a number of professionals from Alberta Environment, the consulting industry, and the University of Saskatchewan, and the author responded to input from their review. Various conclusions have been drawn by the author regarding effects of oil sands development. The Alberta Oil Sands Environmental Research Program is pleased with the efforts put forth by the researchers in this project and accepts their report, "Hydrogeological Investigation of the Muskeg River Basin, Alberta" as an important and valid document suitable for wide distribution.

S.B. Smith, Ph.D
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ABSTRACT

Detailed studies of groundwater-surface water systems in Hartley Creek basin show the creek to be at baseflow for only a few months in the winter when other contributions to streamflow are negligible. Following spring snowmelt, drainage of muskeg is the major contributor to streamflow along with groundwater inflow. Similar patterns of streamflow generation were observed for Firebag, Steepbank, and Muskeg rivers as well as Thickwood Creek. Quantitative hydrograph separations for these basins show that the main differences result from variable amounts of inflow from muskeg during winter. Muskeg River like Hartley Creek is close to baseflow in winter. However, in Firebag River and Thickwood Creek, drainage from muskeg may comprise as much as 40 to 50% of the streamflow in winter.

Streamflow in all basins will be influenced by the disturbance of muskeg. For the particular case where muskeg is removed and replaced by mineral soils, stream discharge will tend to decrease during summer and to increase during spring runoff and stormflow periods. In cases where the local disturbance of muskeg is considerable, marked variation in streamwater chemistry can be anticipated.

ACKNOWLEDGEMENTS

This research project WS 2.2 was funded by the Alberta Oil Sands Environmental Research Program, a joint Alberta-Canada research program established to fund, direct, and co-ordinate environmental research in the Athabasca Oil Sands area of northeastern Alberta.

The contributions to this study of those associated with AOSERP are gratefully acknowledged. R. Seidner, C.R. Froelich, A.M. Akena, and A. Mann provided various data necessary for the study and gave freely of their time to discuss various aspects of this project.

Students, technical assistants, and academic staff at the University of Alberta contributed to this study. W.A. Milne-Home, P. Dettlaff, and their assistants capably executed the field programme. G.L. McClymont and D.W. Chorley helped with the laboratory work, data synthesis, and preparation of the report.

1. INTRODUCTION

1.1 OBJECTIVES AND SCOPE

The main objective of this program is to study the role that shallow groundwater and muskeg systems play in determining the quantity and quality of surface water. More specific objectives are:

1. To collect and interpret existing hydrogeological data for Muskeg River basin;
2. To collect and interpret hydrogeochemical data which are easily obtainable for the watershed;
3. To evaluate the role of muskeg in the groundwater regime and relate it to other muskeg-type watersheds in the area;
4. To develop models for use in the evaluation of shallow groundwater systems along the streams; and
5. To assess potential impacts of mining on the groundwater and surface water systems.

All of these aspects have been addressed in a three-year study of the Muskeg River basin with particular emphasis on the Hartley Creek sub-basin. This research programme has concentrated on the development of methods of investigation involving water chemistry. This strategy was designed to overcome the practical problems of excessive costs and difficulties in access involved with drilling equipment or other tools used in conventional hydrogeological studies.

Sufficient hydrologic and chemical data are available to apply these methods to other watersheds. The Steepbank, Firebag, and Thickwood basins have been selected for analysis in order to test of the usefulness and generality of the approach.

1.2 RESUME OF CURRENT KNOWLEDGE

The main applications of the chemical techniques to watershed studies are reviewed in this section. These can involve regional characterization of groundwater conditions, development of workable hydrologic models, and hydrograph separation.

The chemical techniques are all based on the observation that various sources of water contributing to a stream usually are chemically unique. Groundwater is a major component of streamflow. Often, groundwater is the only contributor to streamflow. This condition is termed baseflow. During these times, the stream chemistry may be closely related to that of the groundwater.

Associated with periods of rainfall or snowmelt are contributions to a stream other than groundwater. The most important are surface runoff, interflow, and direct precipitation (Schwartz 1979). Following these respective pathways water reaches a stream by flow across the ground surface, by lateral flow in the soil zone, and by rain or snow falling on the stream. These waters are thus the product of unique sets of chemical environments. As a result, they usually have different chemical compositions. Other components of streamflow, such as delayed drainage of muskeg, outflow from lakes, or glacial melting, may be important in some situations (Schwartz 1979).

The application of geochemical techniques to regional water resource studies is not new. Durum (1953) established a relationship between stream discharge and chemical quality. Some of the earliest work by Hendrickson and Krieger (1960) and by Zekster (1963) exploited this relationship in order to explain features of watershed and groundwater systems. Since that time, there has been a variety of studies designed to determine the origin of chemical variations in surface waters and to develop chemical methods to evaluate conventional engineering hydrology problems.

Recent work in Canada (Schwartz 1970, 1974) has demonstrated how studies of stream baseflow chemistry can give a good indication of the regional groundwater chemistry and can identify those geological units mainly responsible for streamflow. Preliminary application of this technique to the Athabasca Oil Sands area (Schwartz 1979) has indicated its considerable potential for evaluating near-surface groundwater conditions.

Under conditions of baseflow, detailed sampling of a surface water system should yield an integrated sample of total groundwater inflow upstream from the sampling point. While the concept is straightforward, there are several serious problems that may arise. Probably most important is the problem of determining whether or not the stream is a baseflow.

During long periods without precipitation, streamflow may consist not only of groundwater but other chemically unique components. For example, streamflow could originate in part from prolonged drainage of upstream lakes, reservoirs, or muskeg areas. Preliminary indications are that these components are important in the Muskeg River basin (Schwartz 1979).

Thus, only when it can be demonstrated with certainty that a stream is at baseflow and that its chemical composition has not been completely altered by evaporation or other processes will detailed chemical analysis of the water yield true information about regional groundwater chemistry. The similarity of groundwater and surface water during winter in the Hartley Creek sub-basin demonstrated that baseflow conditions are achieved. Thus, it should be possible to describe other streams in the region that exhibit a similar behaviour.

The interpretation of baseflow chemistry may also be complicated by the changing conditions of groundwater inflow along the stream channel. Groundwater discharge to surface water systems in the upland portion of a basin probably comes from shallow flow systems. As the stream becomes more deeply entrenched in downstream reaches, progressively deeper flow systems are intersected. If chemical differences exist between the shallow and deeper units, the net result will be a baseflow chemistry that changes progressively in a downstream direction and that requires more comprehensive data to interpret.

Finally, problems can arise from physical, chemical, and biological processes that may alter certain features of the surface water chemistry. For example, when groundwaters become exposed to the atmosphere, carbon dioxide is released, with the possibility that some carbonate minerals are precipitated. Thus, care must be exercised when evaluating particular ions in terms of their relationship to actual groundwater chemistry.

A second possibility for the application of methodologies based on chemistry is in the development of watershed response models. In the absence of conventional watershed simulation models, this type of model may be helpful in assessing the influence of various developmental activities within the watershed.

There are several important studies which have demonstrated the feasibility of this approach. A comprehensive study of water systems in the Hubbard Brook Experimental Forest (Johnson et al. 1968, 1969; Likens et al. 1967) has documented the pathways of dissolved mineral matter movement in a small New Hampshire (USA) basin. The simple conceptual model developed in this case (Johnson et al. 1969) showed how the chemistry of surface water outflow from this basin could be explained simply as the mixing of rainwater or surface water with deeper soil water. Other studies have evaluated the contribution that groundwater makes to high runoff events in the streams (Sklash 1978; Sklash et al. 1976). These works showed that groundwater comprised a very significant proportion of the streamflow and that groundwater flow from near the stream was responsible for the increased contributions. Thus, fundamental work on the hydrology of small drainage basins has reinforced the awareness of the importance of groundwater as a contributor to stream runoff during storms (Pinder and Jones 1969; Dincer et al. 1970; Martinec 1975).

Reliable prediction of the response of surface water systems to change within a watershed requires a clear understanding of how the watershed functions. The chemically based methodologies appear to offer advantages in this respect over more traditional graphical or other semi-empirical techniques favored by hydrologists. One specific application of chemical methods involves the use of mass balance techniques to separate a composite streamflow hydrograph. This method is basically an extension of the concepts discussed in the previous paragraphs. It is an approach to hydrograph separation that can be related to actual physical processes operating in the basin. Readers interested in learning more about this technique should refer to the following studies: Kunkle (1965), Pinder and

Jones (1969), Newbury et al. (1969), Schwartz (1970), Sklash et al. (1976), and Sklash (1978).

Preliminary work completed in the Muskeg River basin (Schwartz 1979) has been concerned mainly with the characterization of the major ion chemistry of water systems. This report, in addition to synthesizing and interpreting the complete record of chemical and physical data, will focus on the practical applications of the chemical results.

1.3 STUDY AREA

The Muskeg River basin was chosen for detailed study because of the variety of muskeg terrain and because this basin will probably be the site of the next major surface mining project in the Athabasca Oil Sands area. The Muskeg River basin has an areal extent of 1460 km^2 and is typical of the large basins draining the upland areas east of the Athabasca River (Figure 1). Of the several tributaries to Muskeg River only two have received formal names. Hartley Creek, with an areal extent of 368 km^2, is the largest. Most of the present programme of studies was conducted in this sub-basin. Stanley Creek is a smaller sub-basin draining upland areas north-northwest of the main stem of Muskeg River (Figure 2).

The only large surface water body in the basin is Kearl Lake. Extensive muskeg areas are located along the main stem of Muskeg River and in the uppermost reaches of the basin.

Maximum basin relief is approximately 350 m. Locally, the topography is smooth to slightly rolling. The uppermost reaches of the watershed are poorly drained and covered with muskeg. Relatively steep slopes in the middle reaches of the watersheds have enabled a moderately well defined but only slightly entrenched channel system to develop. Along steeper and better drained portions of this slope, there is a mixed deciduous-coniferous forest with scattered muskeg. The flatlands along the main stem of Muskeg River are poorly drained and covered by extensive muskeg.

A discussion of the bedrock and surficial geology and an extensive review of existing hydrogeological studies relevant to the

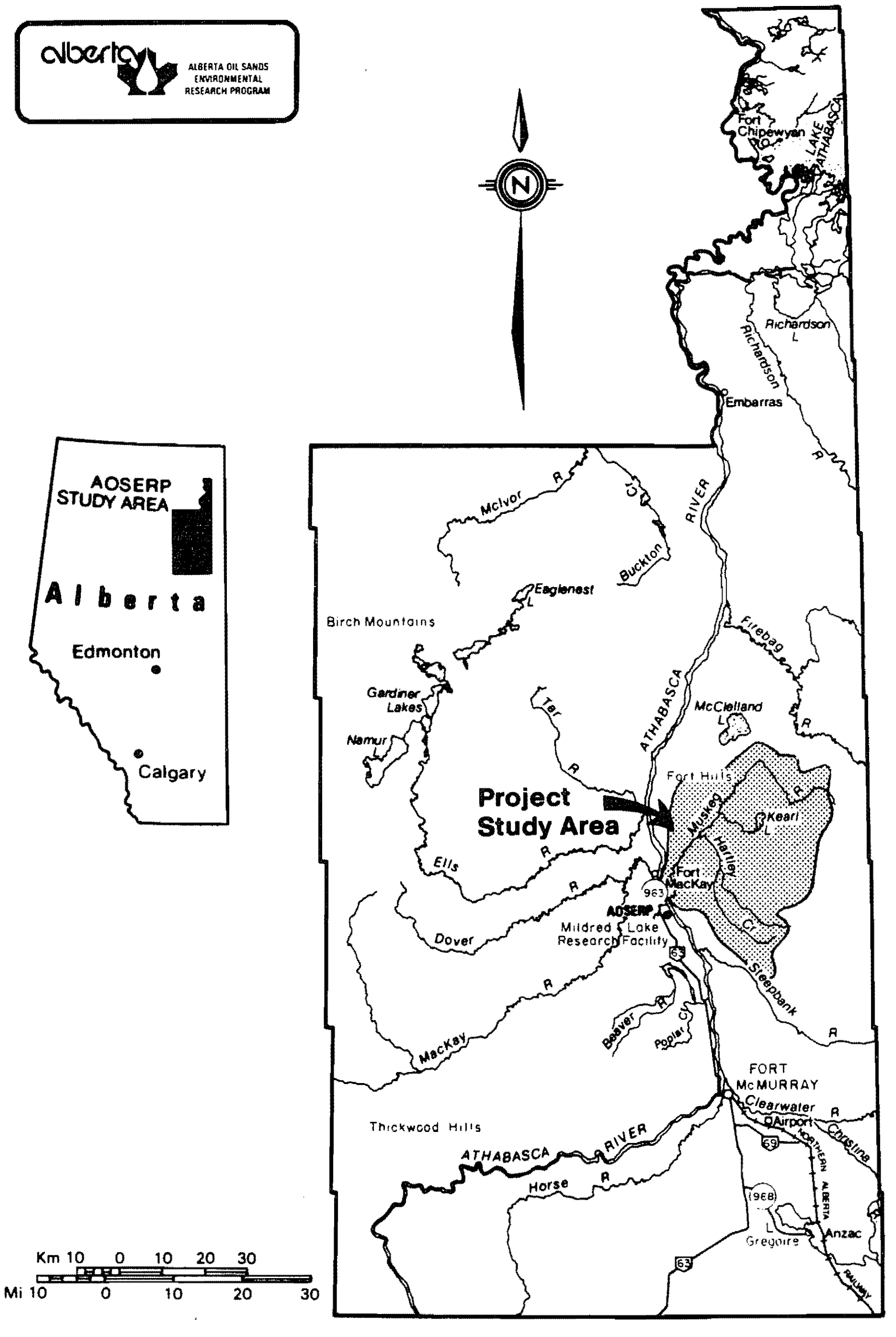

Figure 1. The Alberta Oil Sands Environmental Research Program study area.

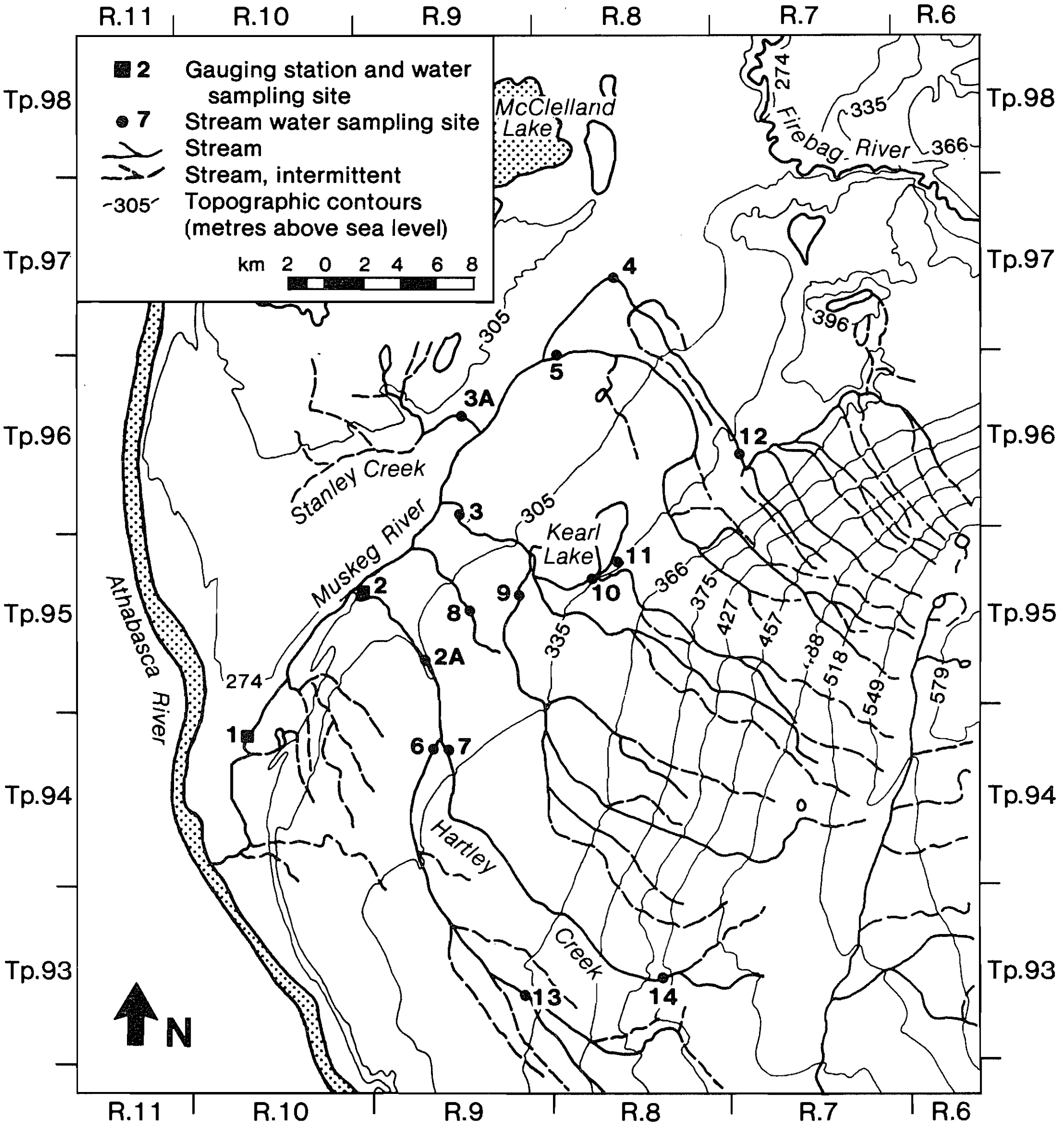

Figure 2. Topography, drainage, and surface water sampling sites.

project study have been presented elsewhere (Schwartz 1979). However, for reference, a detailed fence diagram of the geology has been included (Figure 3).

The Steepbank and Firebag rivers drain large areas. 1420 km^2 and 6320 km^2, respectively, east of Athabasca River (Figure 1). Thickwood Creek, a tributary of the MacKay River, is a much smaller basin with an areal extent of 170 km^2.

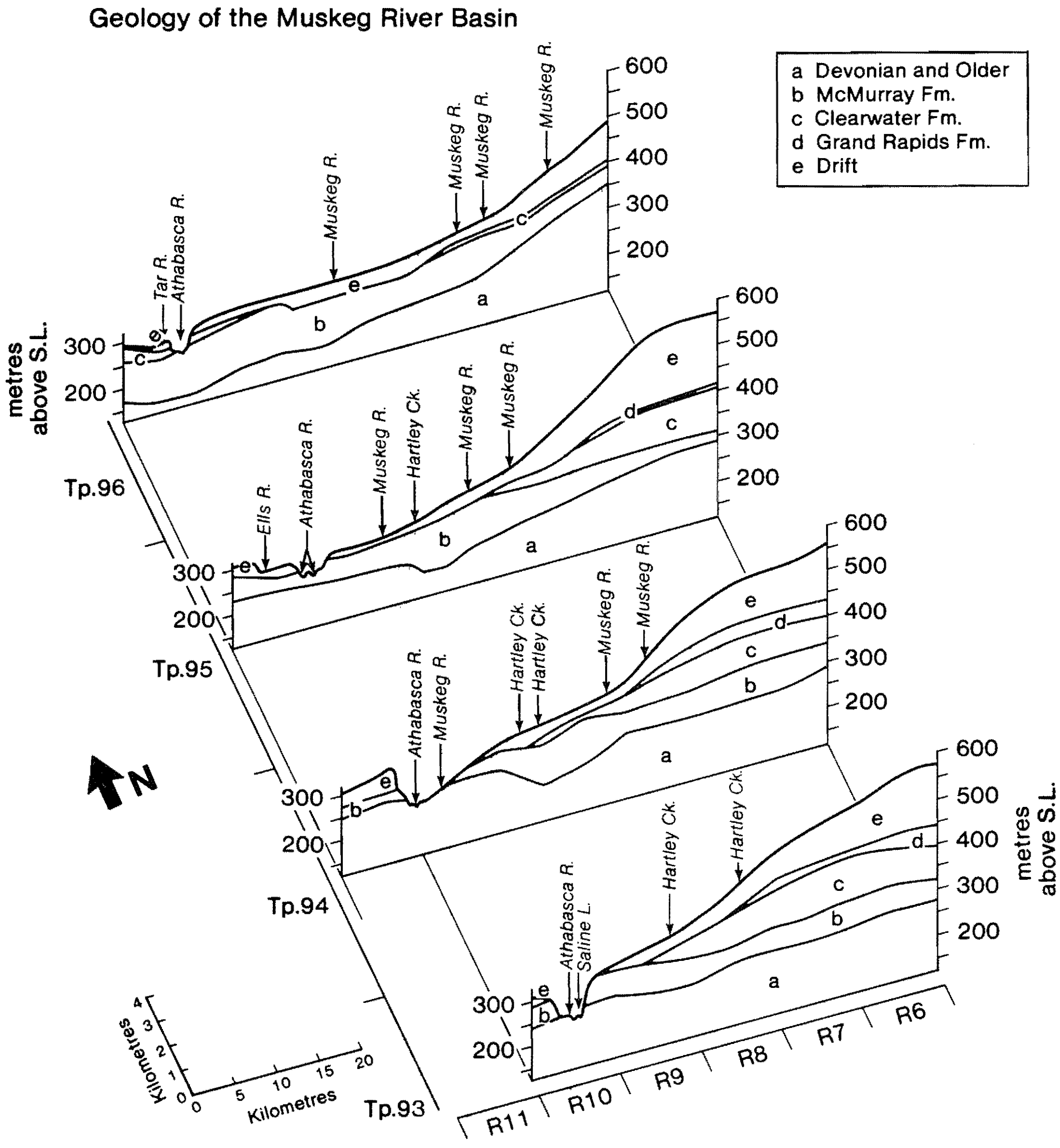

Figure 3. Three-dimensional representation of the near-surface geology.

2. SOURCES OF DATA

2.1 CLIMATOLOGICAL AND SURFACE WATER DATA

The chemical methodologies depend on stream discharge and stream chemistry measurements. Baseline data collected in other studies of the Alberta Oil Sands Environmental Research Program (AOSERP) are used extensively in this research. Estimates of mean daily discharge for 1976, 1977, and most of 1978 are available from the two permanent gauging sites in the project study area and sites on the Firebag and Steepbank rivers (Figure 1). Discharge for Thickwood Creek was determined only for 1977 and part of 1976. The spatial variability of streamflow at high, medium, and low flows in the Muskeg River basin and the temporal variability in suspended sediment concentration at Site 2 have been characterized by Froelich (in prep.).

Major ion, minor ion, and nutrient concentrations are monitored on a continuing basis at sites within the Muskeg, Firebag, and Steepbank river basins. Data for Thickwood Creek are only available for 1977 and part of 1976 and 1978. In addition, an intensive one-year study of surface water chemistry was completed in the Muskeg River basin. During 1977 and 1978, samples were collected usually monthly or bimonthly at 14 sites as part of an AOSERP project (Figure 2) (Akena in prep.). A preliminary interpretation of the hydrogeological significance of these data has been presented by Schwartz (1979).

To supplement this information, additional samples were collected at Site 2 during the 1977 and 1978 field season. All samples, with the exception of a few collected in 1977, were analyzed by Chemex Labs (Alberta) Ltd. using standard methods. The remainder were analyzed in the Department of Geology, University of Alberta, using procedures discussed by Schwartz (1979). The resulting chemical data for Muskeg River and Hartley Creek are summarized in Appendix 7, Table 8.

2.2 MUSKEG WATERS

Vegetation maps prepared by Intera Environmental Consultants Ltd. included portions of Hartley Creek sub-basin. The compilation map presented here shows the extent of muskeg terrain over much of the sub-basin (Figure 4). Before this study began, little data were available on the chemical character of water in muskeg in the AOSERP study area. During the summer of 1977, eight diverse muskeg areas were investigated in detail (Figure 5). Standing water at the sites was sampled and piezometers were placed in the muskeg. Methods of installation and features of the piezometer design are discussed by Schwartz (1979).

During the summer of 1978, routine sampling at several of these sites was continued and another eight sites were established (Figure 5). In total, approximately 140 major ion analyses are now available for surface and subsurface waters in the muskeg. These data are summarized in Appendix 7, Table 9.

2.3 GROUNDWATER

The network of shallow piezometers and observation wells at 28 sites in the Hartley Creek basin in 1977 provides a basis for evaluating the groundwater system (Schwartz 1979). These wells were sampled periodically in 1977 and 1978 in order to characterize the major ion chemistry of the groundwater. Details of the sampling procedure and methods for treating the samples in the field are described elsewhere (Schwartz 1979).

In total, 100 shallow groundwater samples from the project study area have been analyzed. A complete summary of the results is presented in Appendix 7, Table 7.

In addition to the chemical sampling programme, water levels in the well network were measured approximately every three weeks in spring and summer 1978. For individual wells, usually from one to six waterlevel measurements for spring and summer periods of 1977 and 1978 are available (Appendix 7, Table 10).

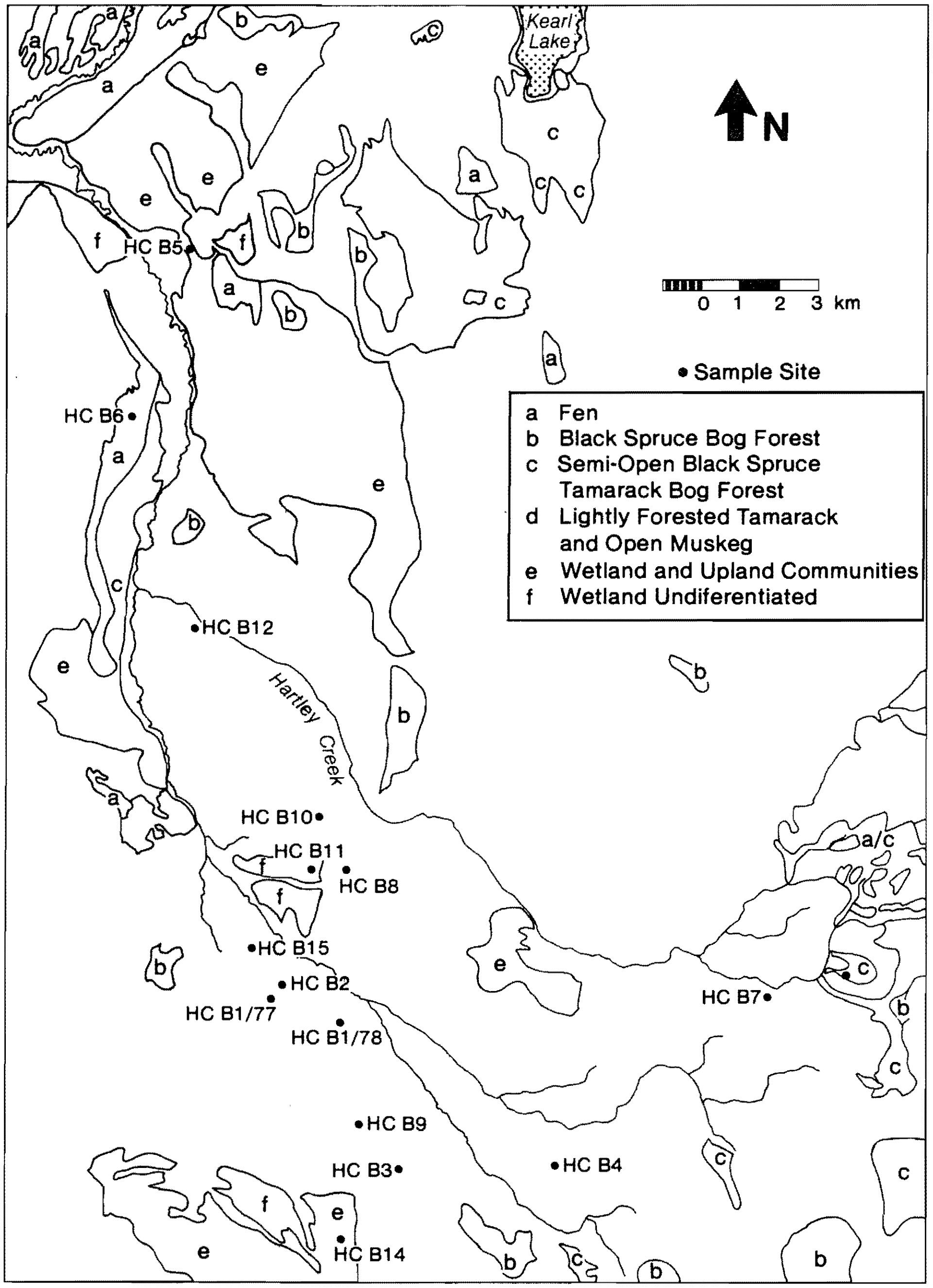

Figure 4. Distribution of muskeg in the Hartley Creek sub-basin.

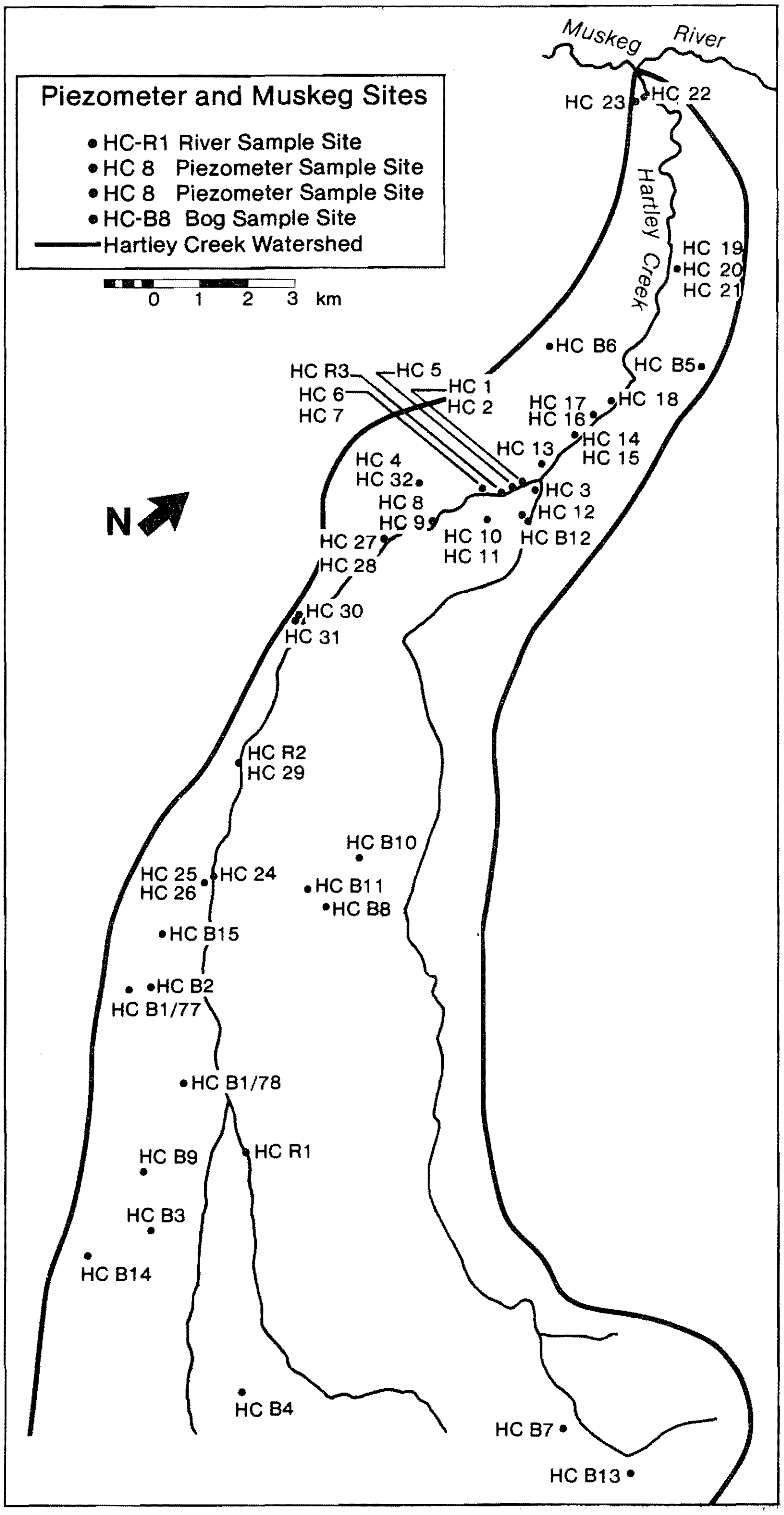

Figure 5. Piezometer and muskeg sampling sites.

3. RESULTS

3.1 SURFACE WATER

3.1.1 Geochemical Hydrographs

More than two years of chemical data on surface water at Sites 1 and 2 in the Muskeg River basin make it possible to evaluate the time variability of major ions (Figures 6 and 7). The generalized patterns of response discussed previously by Schwartz (1979) for these sites are evident for the entire period of record. Highest concentrations of nearly all ions, except K^+ and SO_4^{2-}, are observed during winter (Figures 6 and 7). Lowest values for all ions, except K^+ and SO_4^{2-}, were observed consistently during the period of snowmelt runoff. Results for summer and autumn months lie between these two extremes.

The Na^+ and Cl^- ion concentrations for Muskeg River at Site 1 occasionally increase to uncharacteristically high values during summer (Figure 6). These increases are caused by periodic discharges of groundwater from the Shell test pit (Akena in prep.). Typically, these waters have relatively high concentrations of Na^+ and Cl^- ions. Hartley Creek, which is located upstream of the discharge point, does not exhibit a similar pattern of changing concentrations (Figure 7).

Concentration variation of SO_4^{2-} and K^+ ions has been discussed by Schwartz (1979). It subsequently has been reported that SO_4^{2-} behaviour could be best explained as a problem of sample deterioration before analysis (Akena in prep.). Lack of consistency among the SO_4^{2-} data in this case is not explainable as a natural phenomenon. Schwartz (1970) found that in small watersheds in the Prairie Parkland, the dilution behaviour of SO_4^{2-} ion in streamwater was similar to other major ions.

Concentrations of K^+ ions continued to exhibit the unique behaviour observed in 1977. However, the simple cyclical behaviour previously described by Schwartz (1979) appears to be more complex during years, such as 1978, that are characterized by several episodes

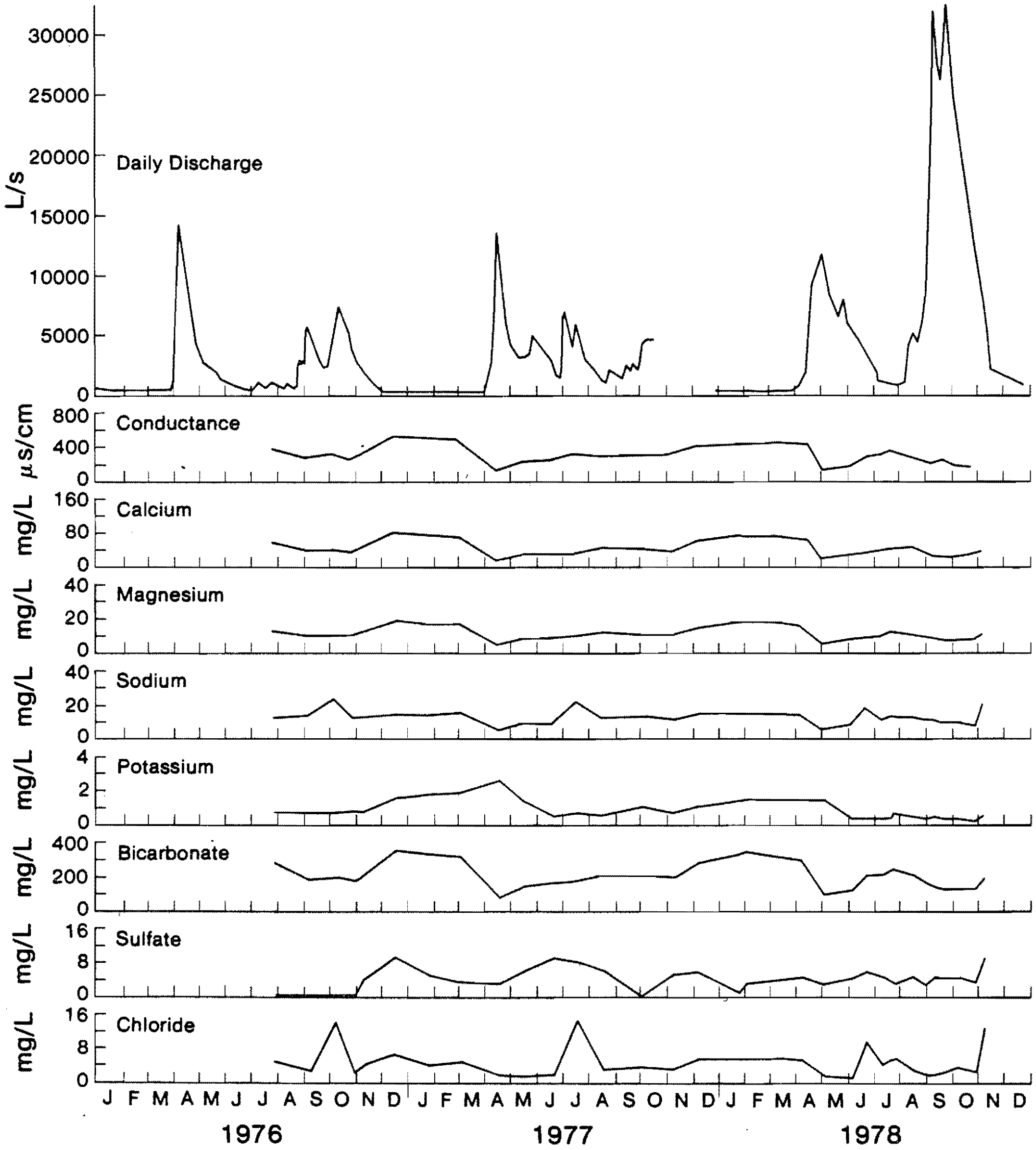

Figure 6. Geochemical and discharge hydrographs for Muskeg River.

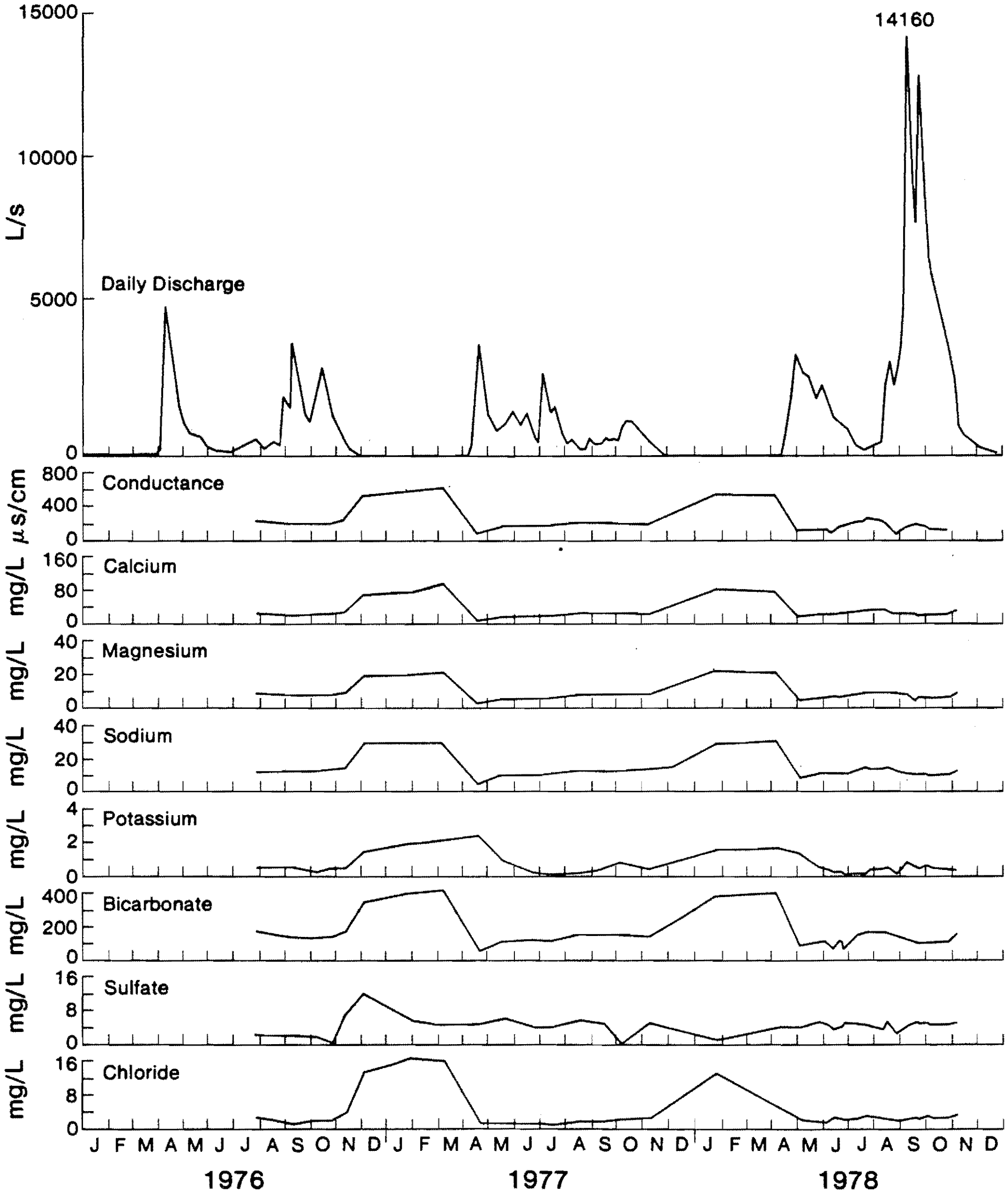

Figure 7. Geochemical and discharge hydrographs for Hartley Creek.

of high streamflow. During the spring runoff period, concentrations of K^+ ions are approximately equal to or greater than the concentrations during winter flow (Figure 8). Lowest concentrations usually are observed during the lower flow periods from June to August. Concentrations are typically higher during summer and fall runoff but never reach the snowmelt maxima (Figure 8). The highest concentration of K^+ ions in the streamwater probably coincides with periods of surface runoff.

Studies were not sufficiently detailed to explain the K^+ ion concentrations. However, it is suspected that waters moving over the ground surface dissolve K^+ ions present in the soil litter. A high concentration of K^+ ion in surface runoff in areas of the Prairie Parkland has been documented by Schwartz and Gallup (1978).

3.1.2 Relationships Between Ion Concentration and Discharge

The relationships between ion concentration and discharge for Sites 1 and 2 in 1976 and 1977, and 1978 are depicted in Figures 9 to 12. Inspection of these figures shows that the main features of the 1976 and 1977 data set (Figures 9 and 11) generally hold for 1978 (Figures 10 and 12). The most important relationships are the tendencies for the concentrations of the major ions, except Na^+ and SO_4^{2-}, to decrease with increasing discharge. However, at discharges greater than 5000 L/s and 3000 L/s for Sites 1 and 2, respectively, there is a large scattering of the data. In other words, for a given value of high discharge, a wide range of ion concentrations was observed. Typically, most ions, except K^+ and SO_4^{2-}, are diluted more during spring runoff period than during storm flow periods with equivalent discharges. This response is particularly evident for the 1978 data (Figures 10 and 12) which include a major storm runoff period. For convenience of comparison, spring runoff value corresponding to a discharge maximum and concentration minimum is circled (Figures 10 and 12).

Because of the scatter of the concentration-discharge data, it is inappropriate to develop a general statistical predictor

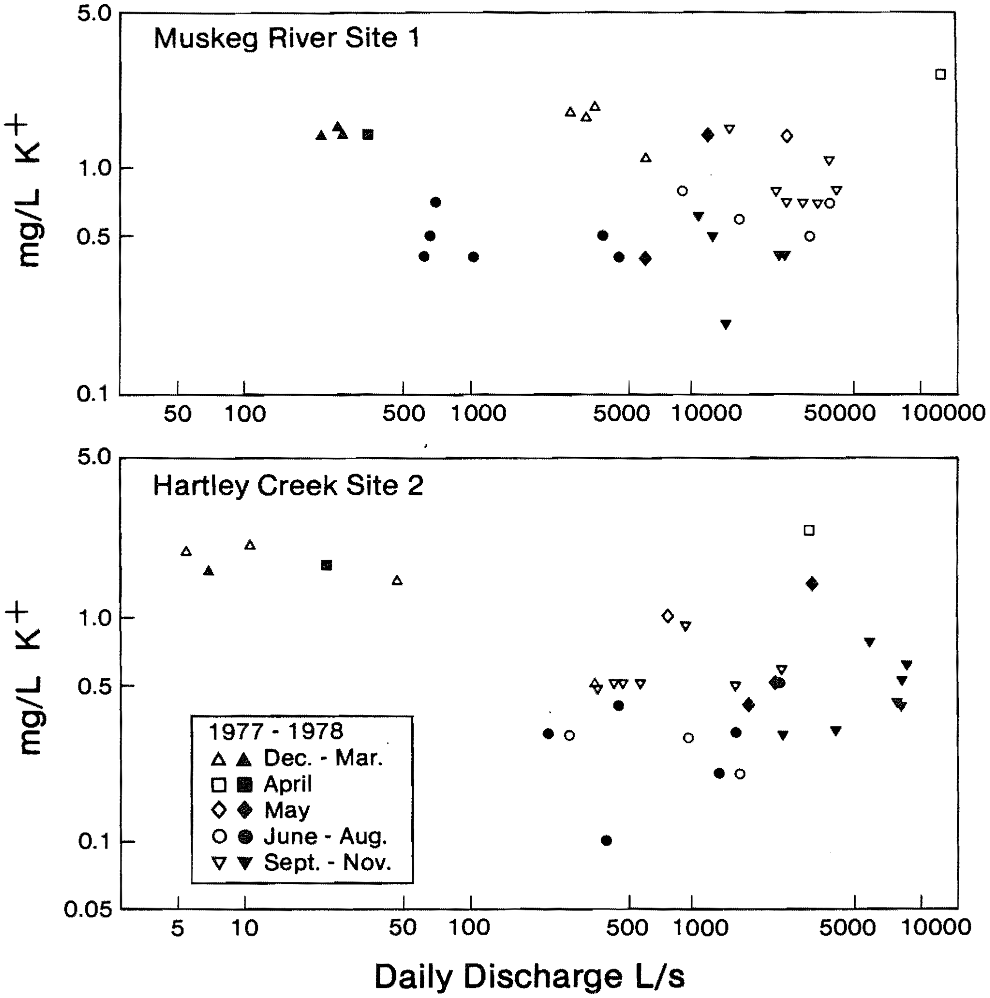

Figure 8. Scatter diagram of discharge versus K^+ ion concentration.

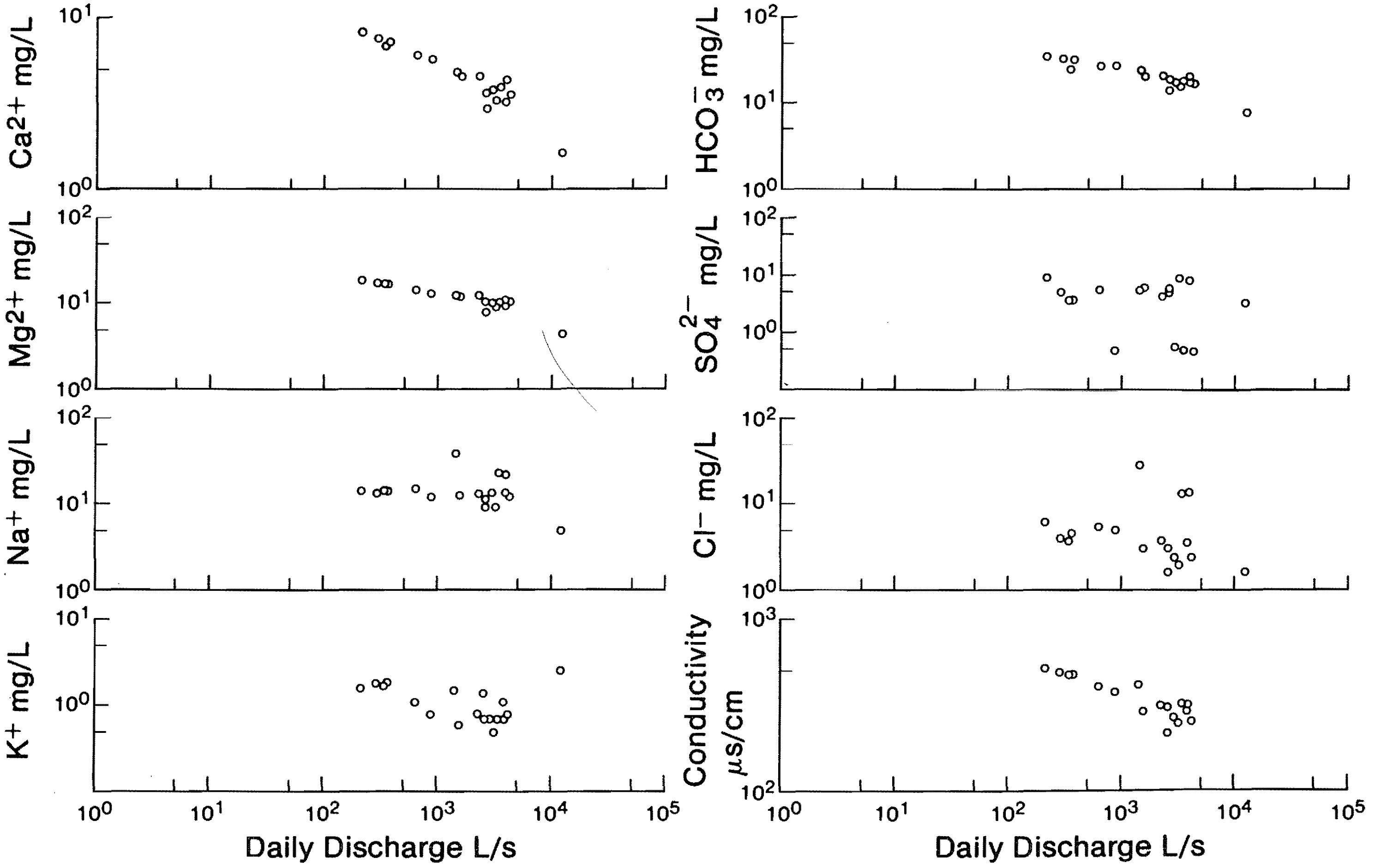

Figure 9. Ion concentration or specific conductance versus discharge for Muskeg River, 1976-77.

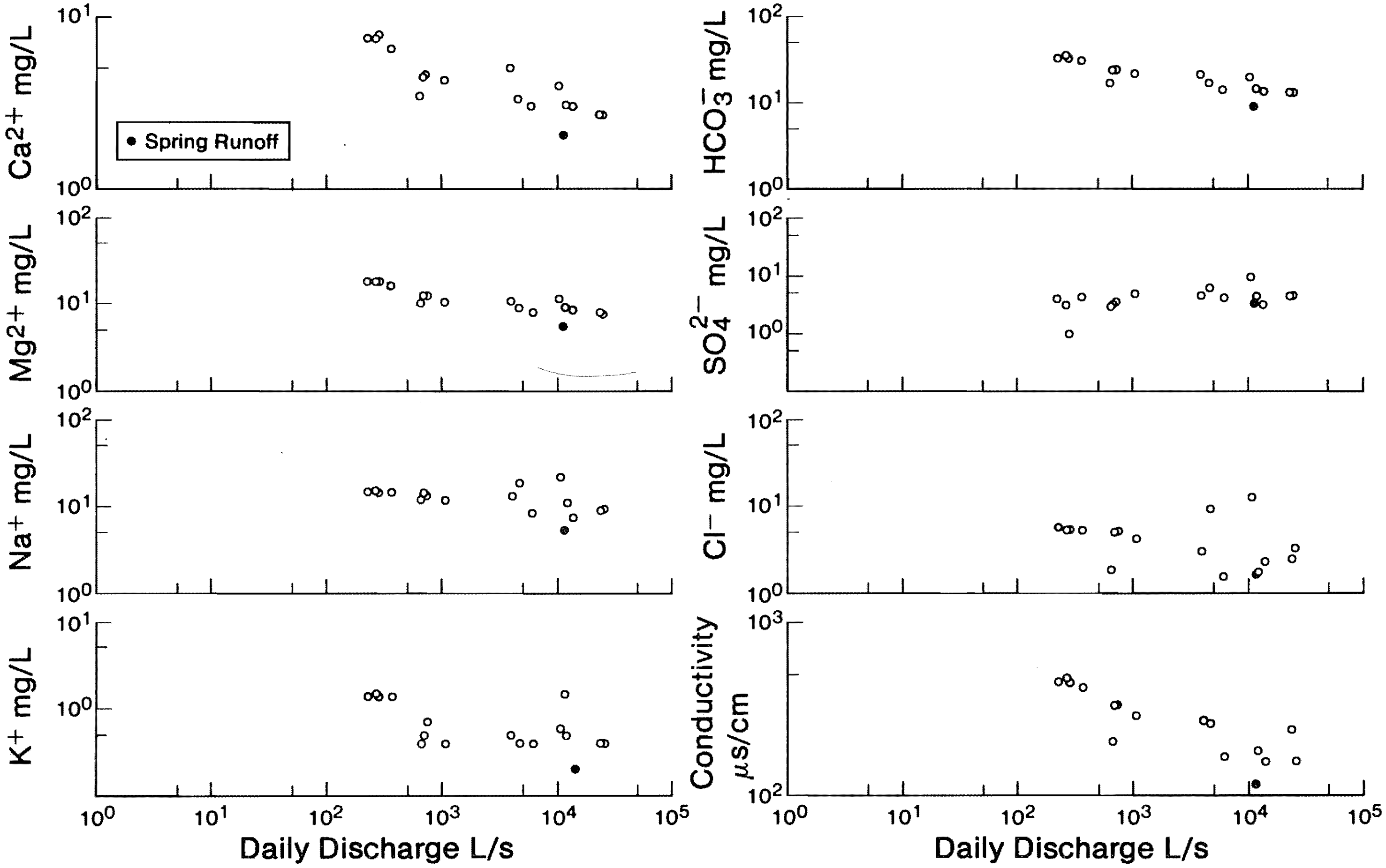

Figure 10. Ion concentration or specific conductance versus discharge for Muskeg River, 1978.

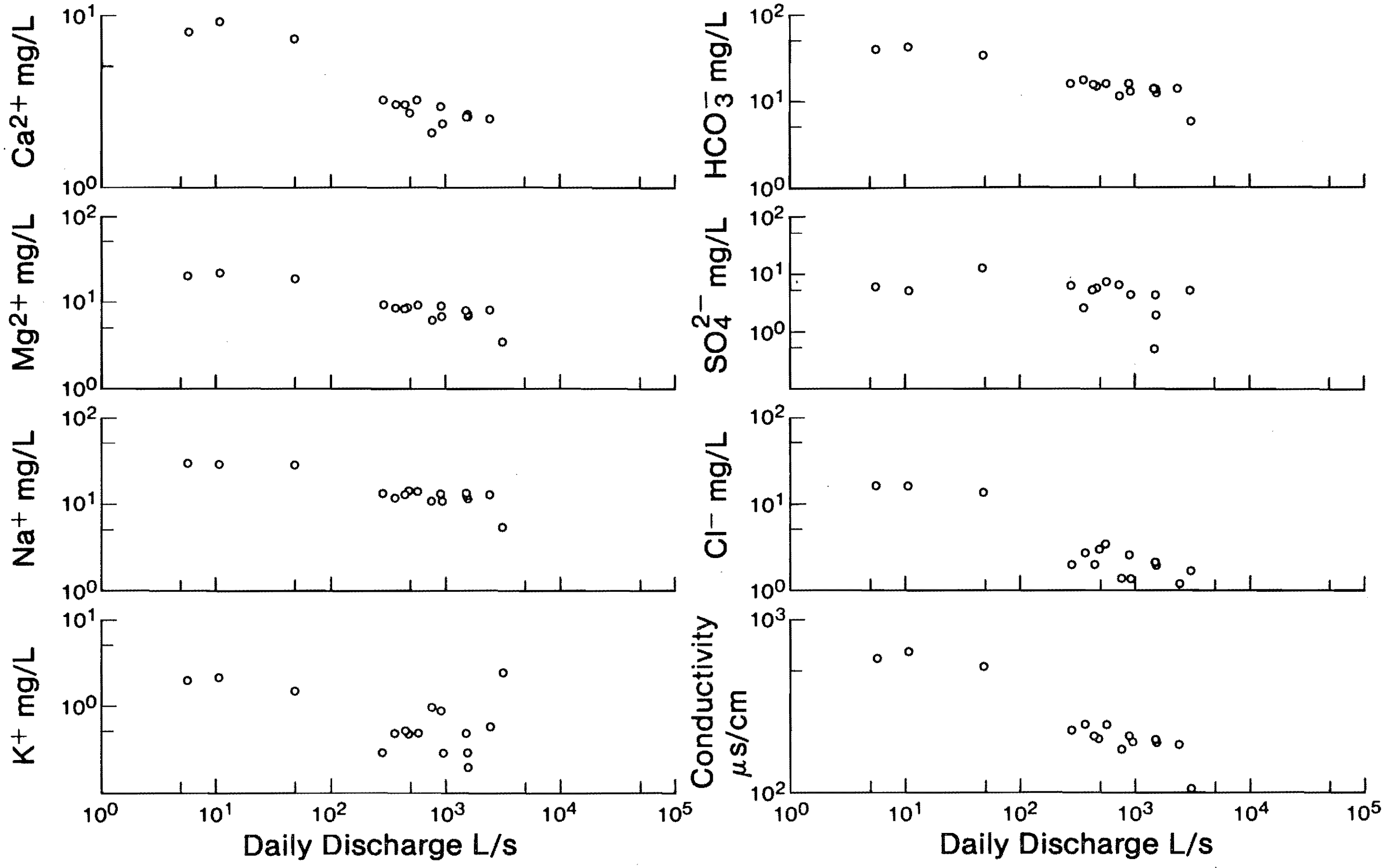

Figure 11. Ion concentration or specific conductance versus discharge for Hartley Creek, 1976-77.

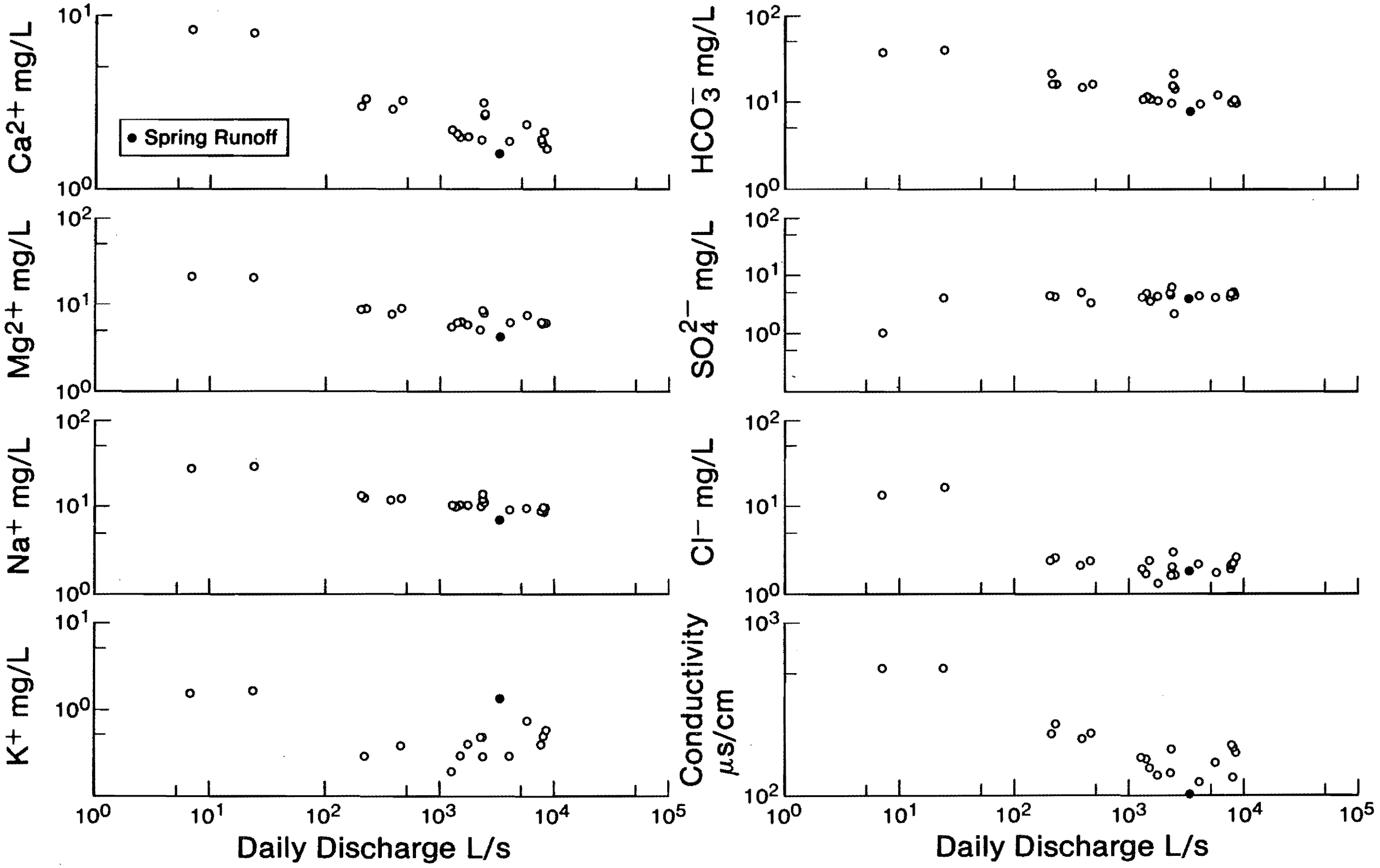

Figure 12. Ion concentration or specific conductance versus discharge for Hartley Creek, 1978.

of concentration or conductivity from discharge measurements. For years such as 1977, with only minor summer and fall storm runoff, an accurate curvilinear statistical predictor may be developed as was previously shown (Schwartz 1979).

3.1.3 Dilution Behaviour

Examination of the dilution of individual ions and conductivity can provide important information about a stream system. The geochemical hydrographs reveal that the concentration change of ions in a storm runoff or snowmelt period may vary considerably. In the following analysis, a dimensionless concentration and conductivity ratio was calculated by dividing individual values by the day 350 values at Site 1 and the day 432 values at Site 2 (Figures 13 and 14). The chemical analyses for these two days generally represent the highest concentrations and specific conductances. Thus, except for K^+ and SO_4^{2-} ion concentrations, all concentration and specific conductance ratios are less than 1 (Figures 13 and 14). The only apparent anomalies are the Na^+ and Cl^- ratios at Site 1. These are caused by pumping at the Shell pit. Because of the slight lack of consistency in the data from Site 1, the following descriptions will be concerned with information related to Site 2 (Figure 14).

The obvious similarity in the dilution behaviour among the ions and specific conductance is evident from Figure 15. Typically, the dilution ratios for Ca^{2+}, Mg^{2+}, Na^+, HCO_3^- , and specific conductance on any given day lie within a range of 10 to 15%. The degree of dilution appears relatively consistent with $Ca^{2+} > HCO_3^-$ and specific conductance $> Mg^{2+} > Na^+$. Figure 15 shows that dilution ratios for Cl^- are often less than one-half the Ca^{2+} ratios (the lowest of the other major ions).

A second component of the dilution analysis involves detailed examination of dilution behaviour of Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, and Cl^- ions and specific conductance through the important storm flow period in the fall of 1978. In this case, the dilution ratios (Figures 15 and 16) are based on pre-storm values of concentration

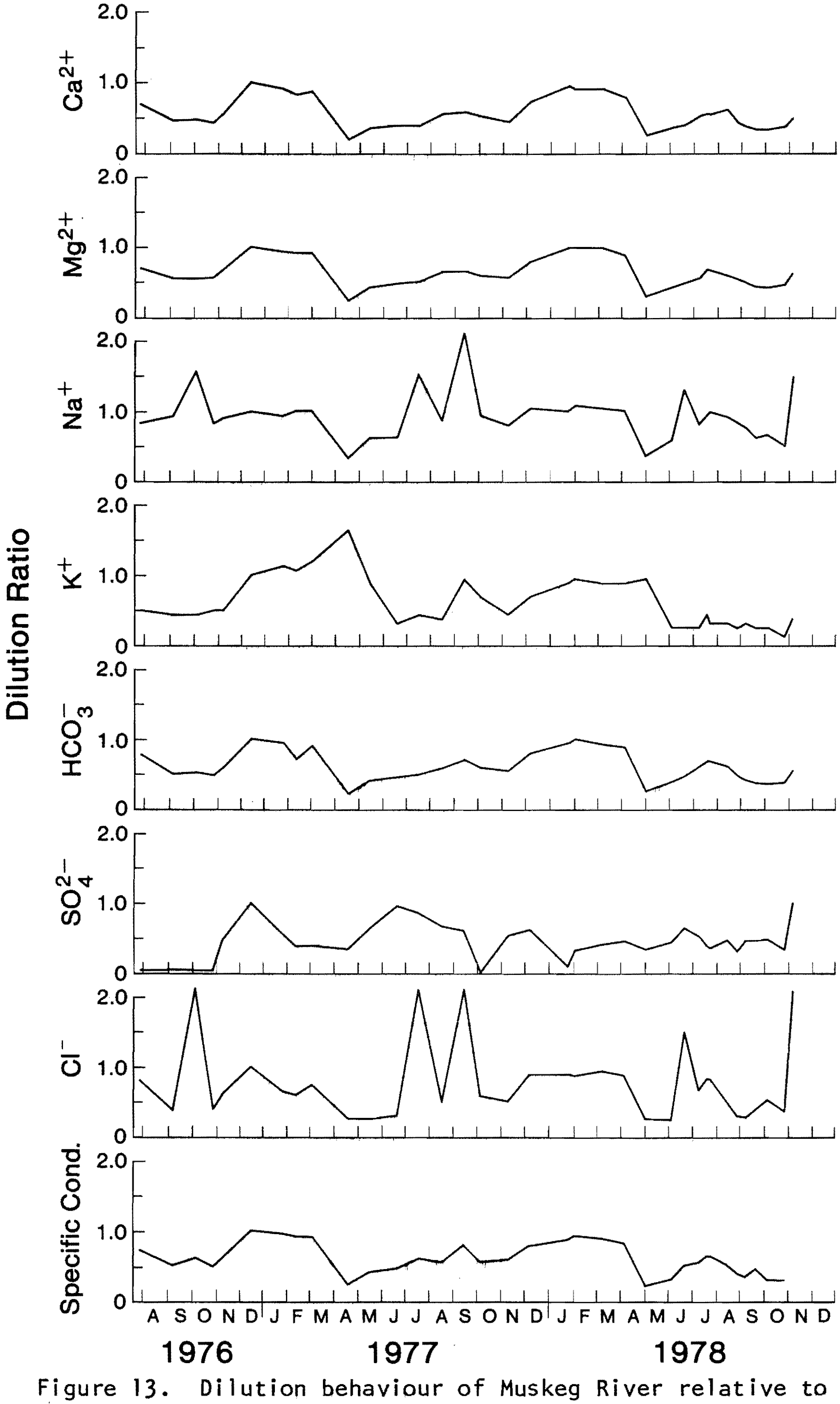

Figure 13. Dilution behaviour of Muskeg River relative to winter concentration values.

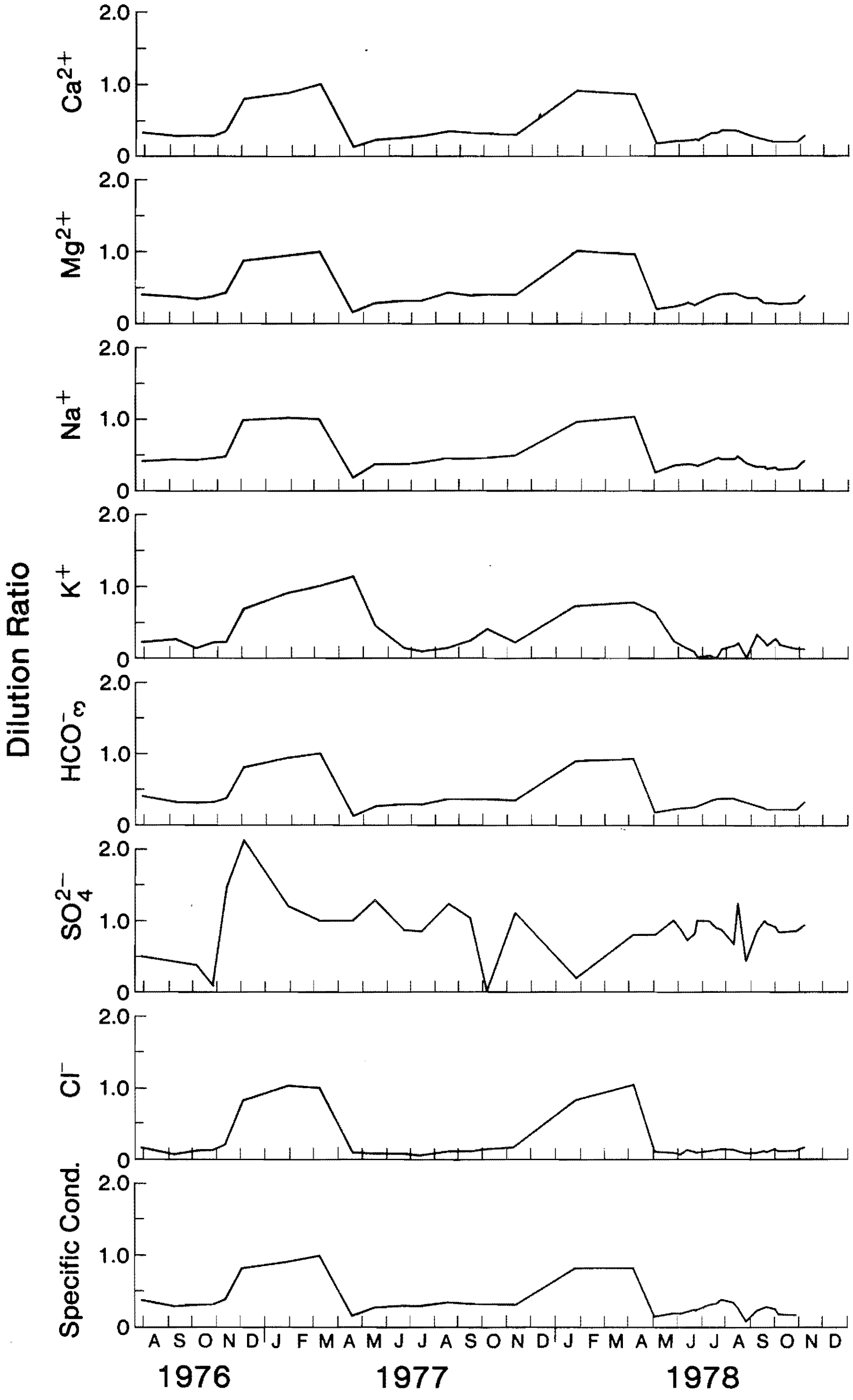

Figure 14. Dilution behaviour of Hartley Creek relative to winter concentration values.

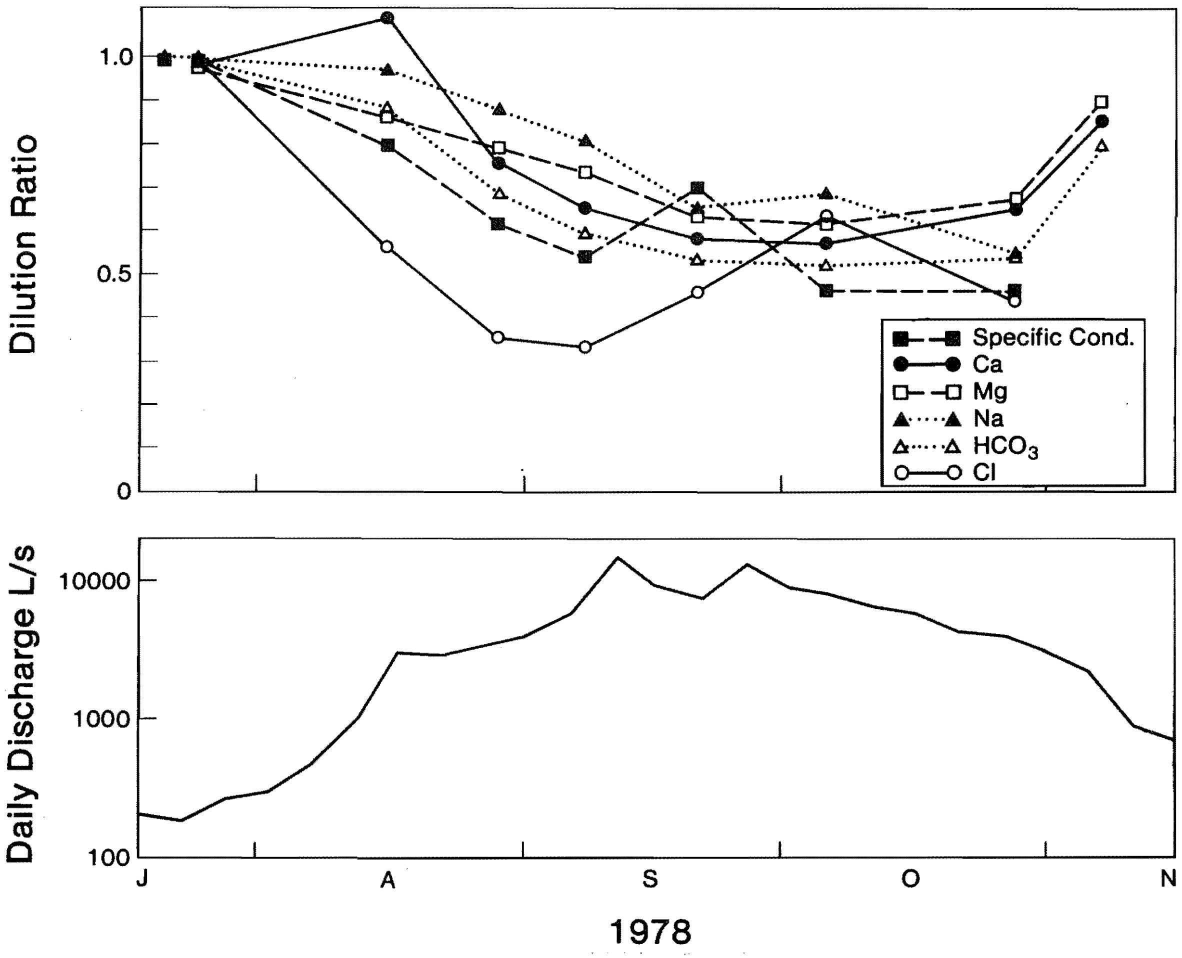

Figure 15. Dilution behaviour of Muskeg River through the late summer-fall storm runoff period, 1978.

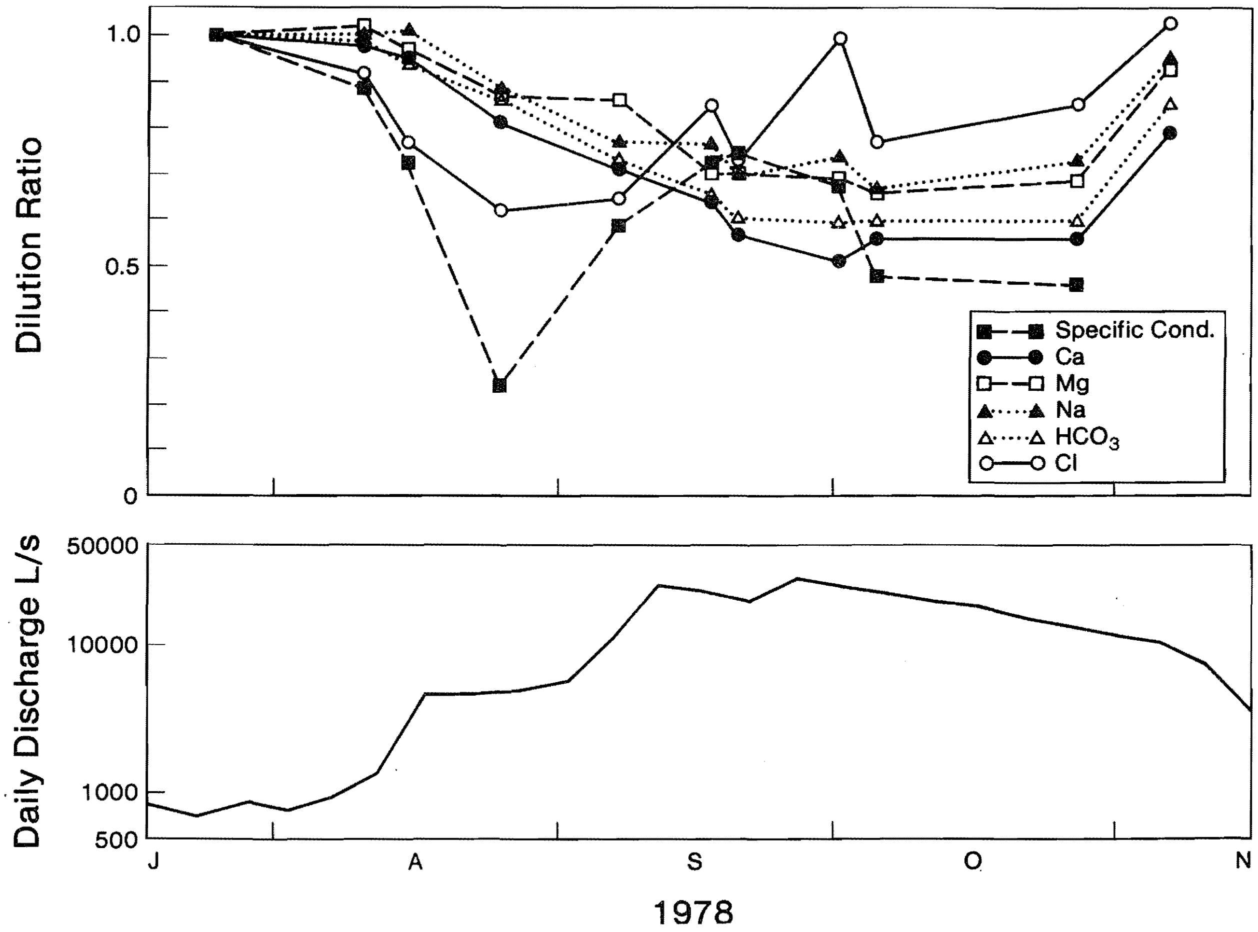

Figure 16. Dilution behaviour of Hartley Creek through the later summer-fall storm runoff period, 1978.

and conductivity values which for Site 1 are the day 932 values and for Site 2 are the day 937 values (Appendix 7, Table 8).

Both Muskeg River and Hartley Creek dilute to approximately 50 to 80% of their pre-storm concentrations (depending upon the ion). Maximum dilution coincides approximately with peak flow for Muskeg River but not for Hartley Creek (Figures 15 and 16). Generally, the dilution ratios do not increase immediately after peak flows. The early part of the rising discharge limb for Hartley Creek, where flow increases from 200 to 3000 L/s, is characterized by only minor dilution of the major cations and anions.

Clear differences in dilution behaviour are noticeable. For Muskeg River, the dilution sequence: specific conductance $> HCO_3^- > Ca^{2+} > Mg^{2+} > Na^+$ is generally valid (Figure 15). For Hartley Creek, the dilution sequence: specific conductance $> Ca^{2+} > HCO_3^- > Mg^{2+} > Na^+$ holds (Figure 16). Although slight differences in the ordering are evident, all the dilution sequences are consistent.

3.2 MUSKEG

3.2.1 Surface Water

As part of chemical characterization of surface waters in the Hartley Creek sub-basin, 16 muskeg sites were sampled in 1977 and 1978. Table 1 summarizes the pattern of sampling for each site. At several sites, only one or two standing water samples were collected because of the difficulty in relocating the same site.

A tabulation of the mean ion concentrations and specific conductance of standing waters in muskeg collected during 1977 and 1978 are presented in Table 2. With the exception of waters at Site 4, Ca^{2+} is the most important cation with lesser concentrations of Na^+ and Mg^{2+}. Bicarbonate dominates the anions with relatively small concentrations of SO_4^{2-} and Cl^-. The standing waters collected from Site 4 are completely different from the others because of very high concentrations of Na^+ and HCO_3^- ions.

Table 1. Details of the sampling programme for standing waters in muskeg areas.

Site Number	Samples Collected July to Aug. 1977	 May to Oct. 1978
1A	1	0
1B	0	6
2	1	0
3	1	0
4	2	8
5	2	9
6	1	9
7	2	0
8	2	0
9	0	9
10	0	1
11	0	9
12	0	9
13	0	5
14	0	1
15	0	2

Table 2. Statistical summary of major ion and specific conductance data for standing water in muskeg areas.

Muskeg site number	Mean concentration (mg/L)								Specific Conductance µs/cm
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	
1A	7.5	1.6	2.0	0.0	ND[b]	22.0	7.2	1.4	50.0
1B	18.6	6.6	17.0	0.5	0.4	112.0	7.2	3.6	178.0
2	0.7	0.5	2.0	0.6	ND	0.0	6.0	2.0	260.0
3	23.9	7.1	18.2	0.4	ND	95.0	3.2	4.0	252.0
4	11.7	1.3	212.0	2.4	0.6	566.0	15.6	9.1	811.0
5	14.0	3.1	5.3	0.4	0.3	52.2	9.3	1.8	94.3
6	6.5	1.8	1.3	0.5	0.3	19.5	6.3	1.6	59.6
7	19.7	5.9	8.0	0.2	0.0	104.0	4.6	2.0	160.0
8	21.5	5.6	7.5	0.1	0.0	96.5	5.3	1.5	147.0
9	33.6	9.9	20.9	0.6	0.5	176.0	7.5	4.2	265.0
10	20.0	5.9	3.2	2.2	0.1	83.5	6.4	1.5	120.0
11	20.1	6.0	12.0	0.6	0.3	108.0	3.9	1.9	165.0
12	12.9	4.4	5.8	0.9	0.3	61.5	6.5	1.7	101.0
13	10.7	2.4	2.3	0.4	0.2	43.0	4.8	1.3	67.2
14	22.5	6.5	16.5	0.5	0.2	117.0	5.8	5.0	160.0
15	22.9	6.8	13.7	0.4	0.06	171.0	5.3	2.8	203.0

continued ...

Table 2. Concluded.

Muskeg site number	Mean concentration (mg/L)								Specific Conductance µs/cm
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	
Population									
MEAN	17.0	4.9	4.1	0.6	0.2	80.7	5.9	2.4	137.0
SD[a]	8.3	2.6	6.8	0.5	0.2	47.0	1.5	1.2	71.6

[a] Standard deviation

[b] No data

Means and standard deviations calculated for 15 of the 16 similar water types show that the standing waters in muskeg have variations in their chemistry that lie within a relatively narrow range of concentrations and specific conductances (Table 2). The standing waters in muskeg areas are less mineralized than either the groundwater or the surface waters.

A sufficient number of samples were collected from nine of the sites to evaluate the temporal variability in chemistry of standing water during 1978 when the muskegs were unfrozen. Figures 17 to 25 compare the variability in Ca^{2+}, Mg^{2+}, Na^+, K^+, Fe, HCO_3^-, SO_4^{2-}, and Cl^- ions, and the specific conductance at each of the nine sites. Examination of these figures reveals similar patterns of variation. Calcium, Mg^{2+}, Na^+, Fe, and HCO_3^- ion concentrations and specific conductance increase from a minimum in May 1978 to a maximum in mid-August 1978. This change in chemistry probably is caused by the evaporitic concentration of ions in the standing water during a period of low rainfall. The series of rainstorms that began in late August and continued into October 1978 reduced these ion concentrations and specific conductance to levels similar to those observed in May 1978.

Trends in the SO_4^{2-} and Cl^- data (Figures 23 and 24) are not apparent. At nearly all the sites where K^+ ion data are available a variation on the previously described pattern is observed (Figure 20). Potassium ion concentrations in May 1978 are higher than subsequent values. Such a maximum in spring is similar to K^+ ion behaviour in the streamwater during snowmelt runoff.

The magnitude of concentration changes is generally different for each ion. This result can be demonstrated by comparing the ratio of standard deviation in concentration or conductance to the mean concentration or conductance for the 1978 data used to prepare Figures 16 to 24. Ratios for Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, and Cl^- ions and specific conductance are generally less than 0.3 except in the case of Site 4, a muskeg with an obviously different water chemistry (Table 3). Potassium, Fe, and SO_4^{2-} ratios are typically

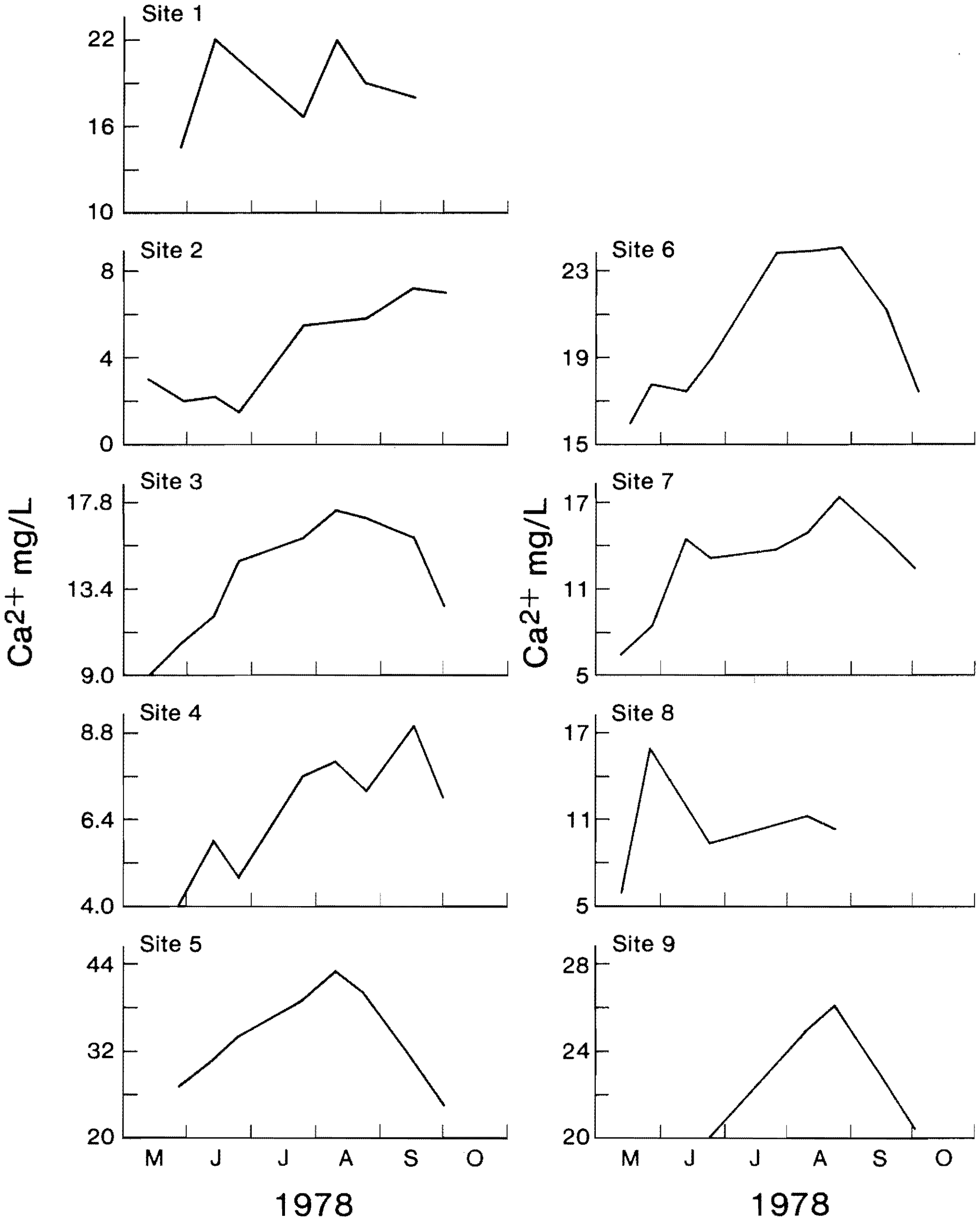

Figure 17. Time variation in Ca^{2+} ion concentration in standing waters in muskeg.

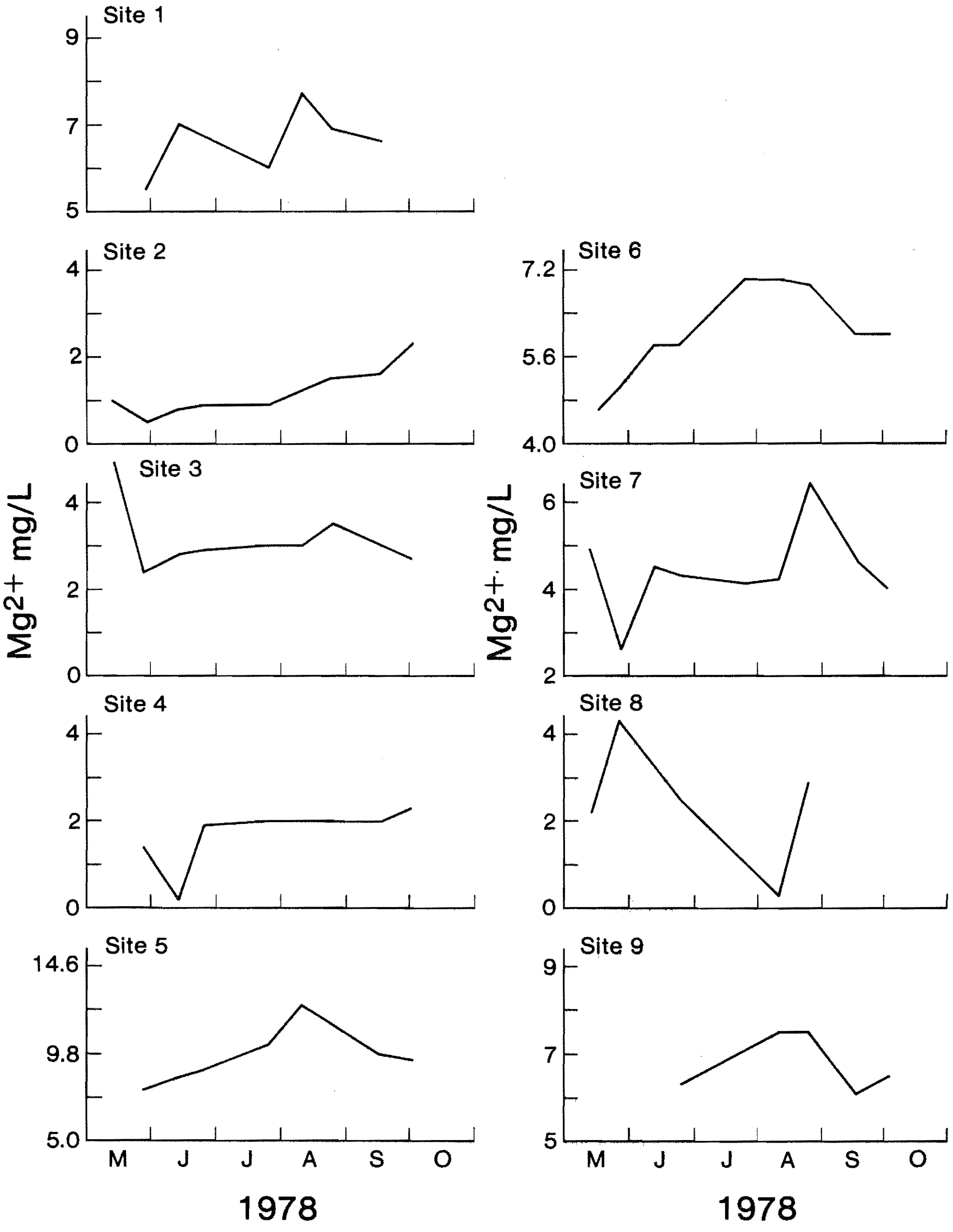

Figure 18. Time variation in Mg^{2+} ion concentration in standing waters in muskeg.

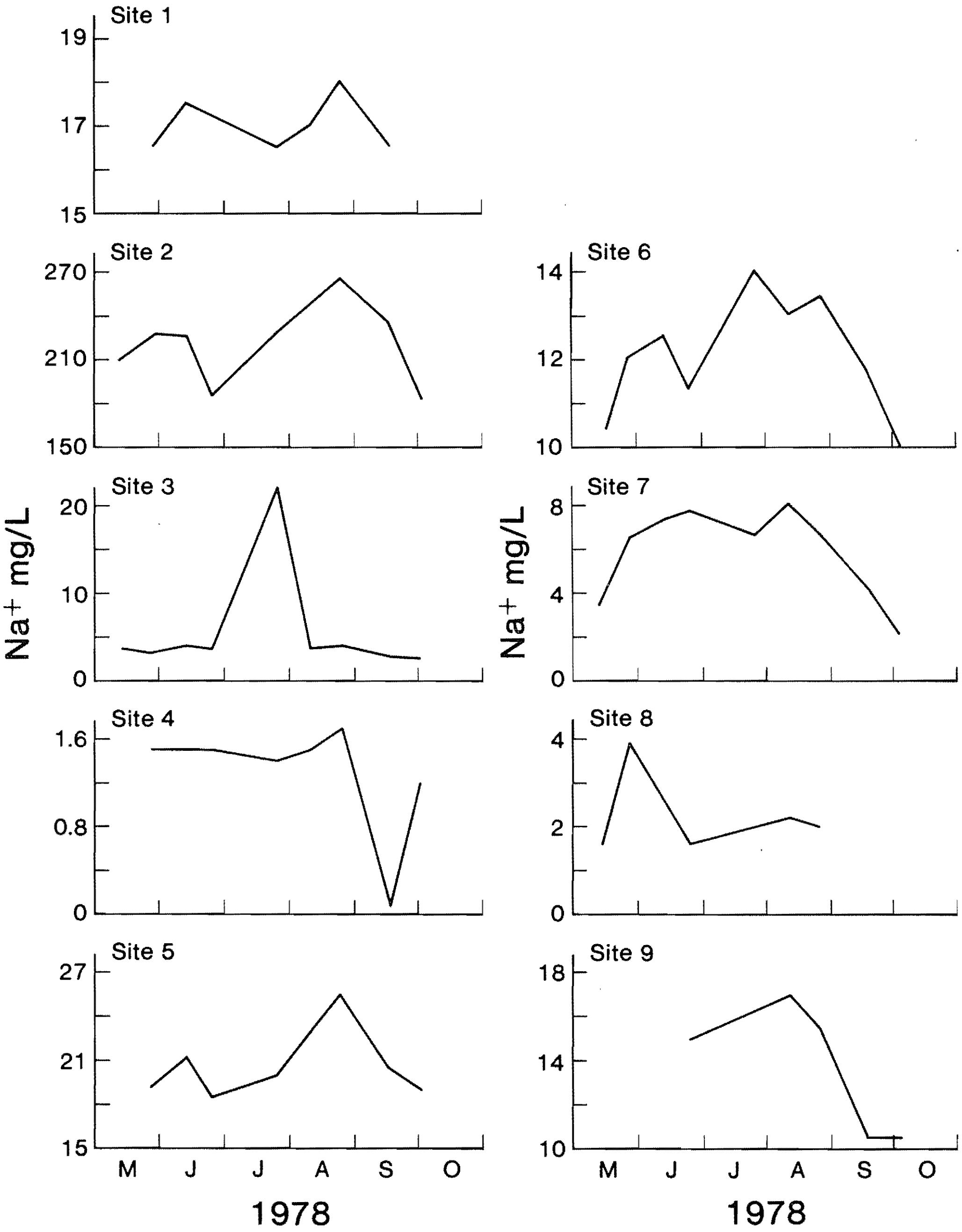

Figure 19. Time variation in Na^+ ion concentration in standing waters in muskeg.

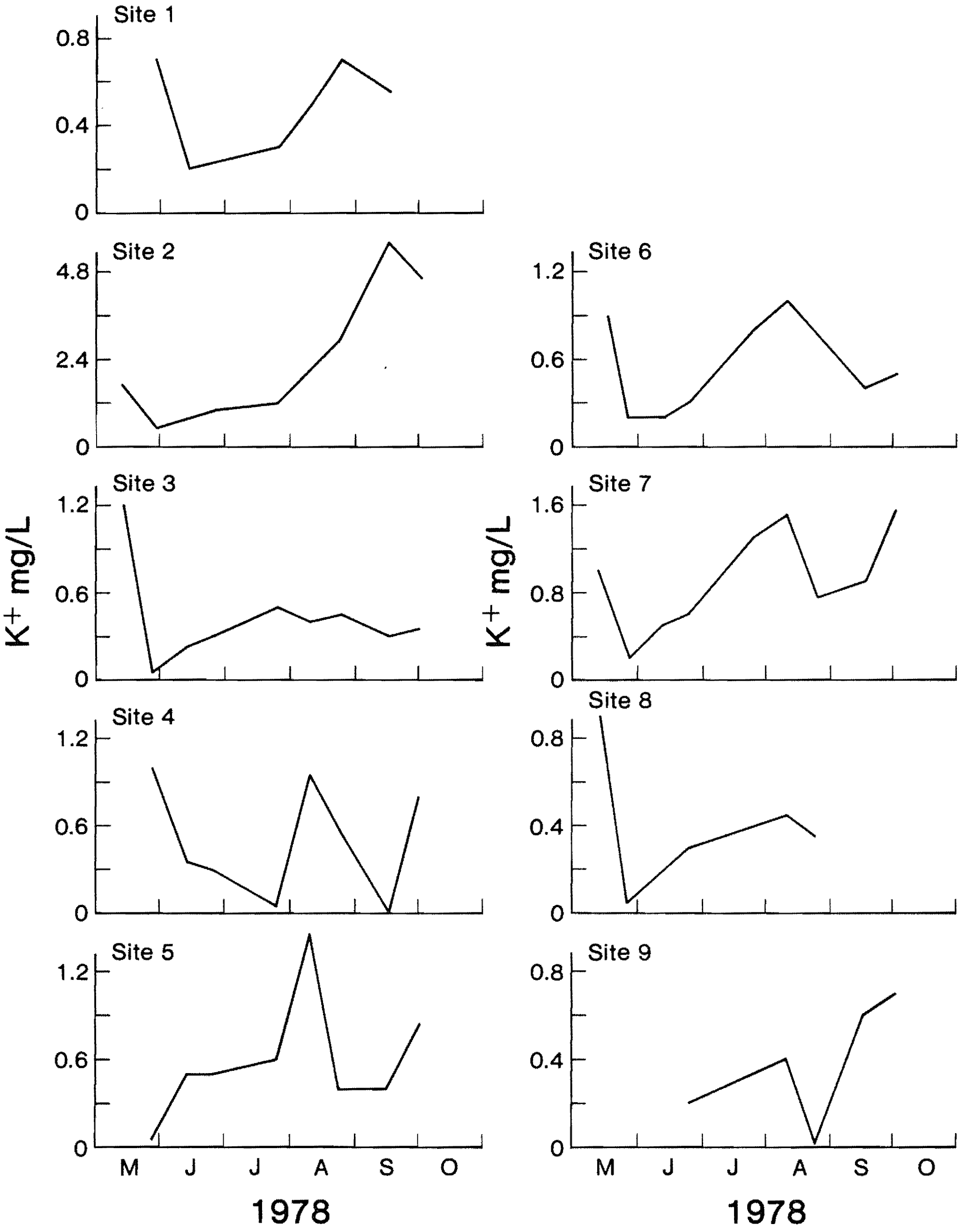

Figure 20. Time variation in K^+ ion concentration in standing waters in muskeg.

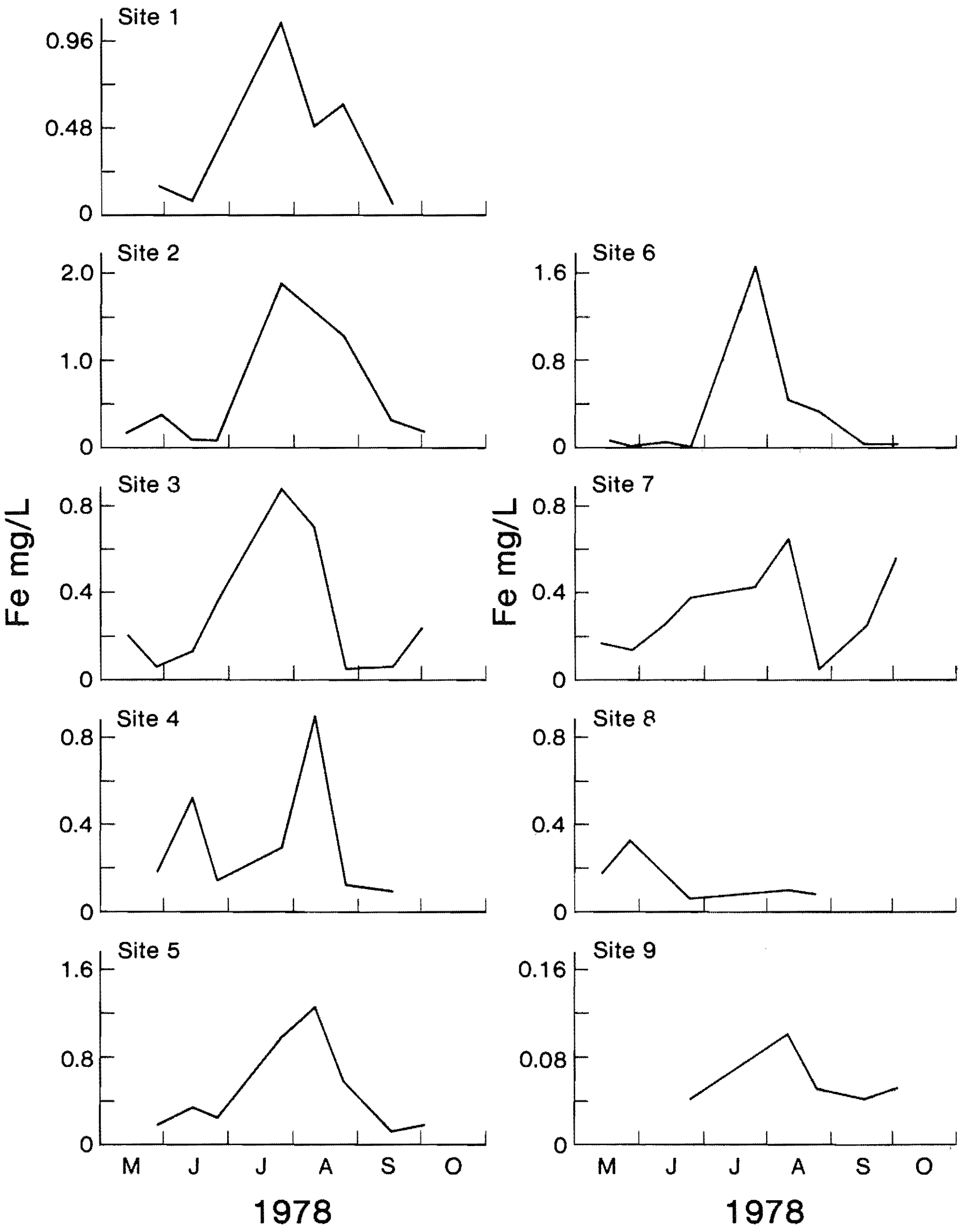

Figure 21. Time variation in Fe ion concentration in standing waters in muskeg.

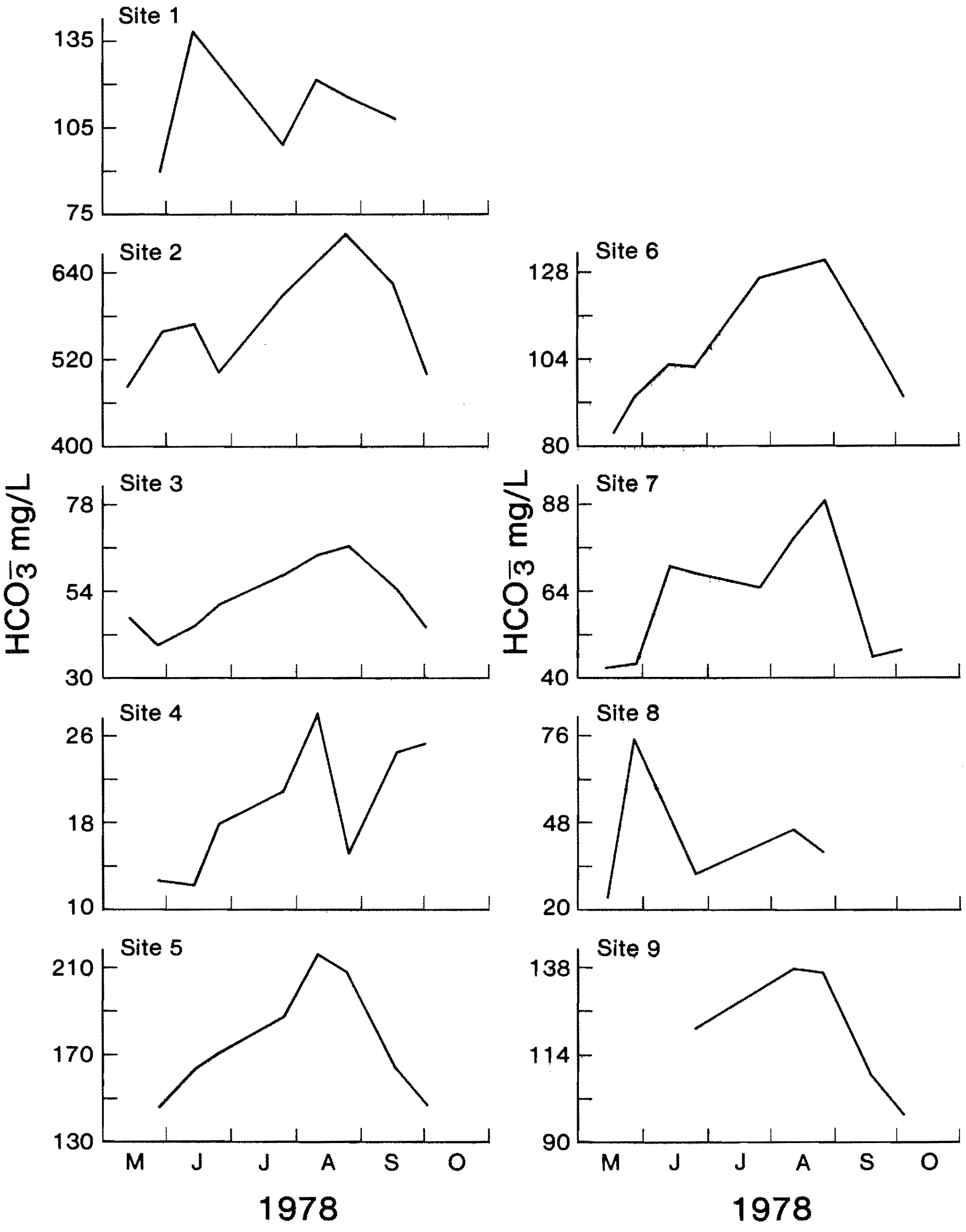

Figure 22. Time variation in HCO_3^- ion concentration in standing waters in muskeg.

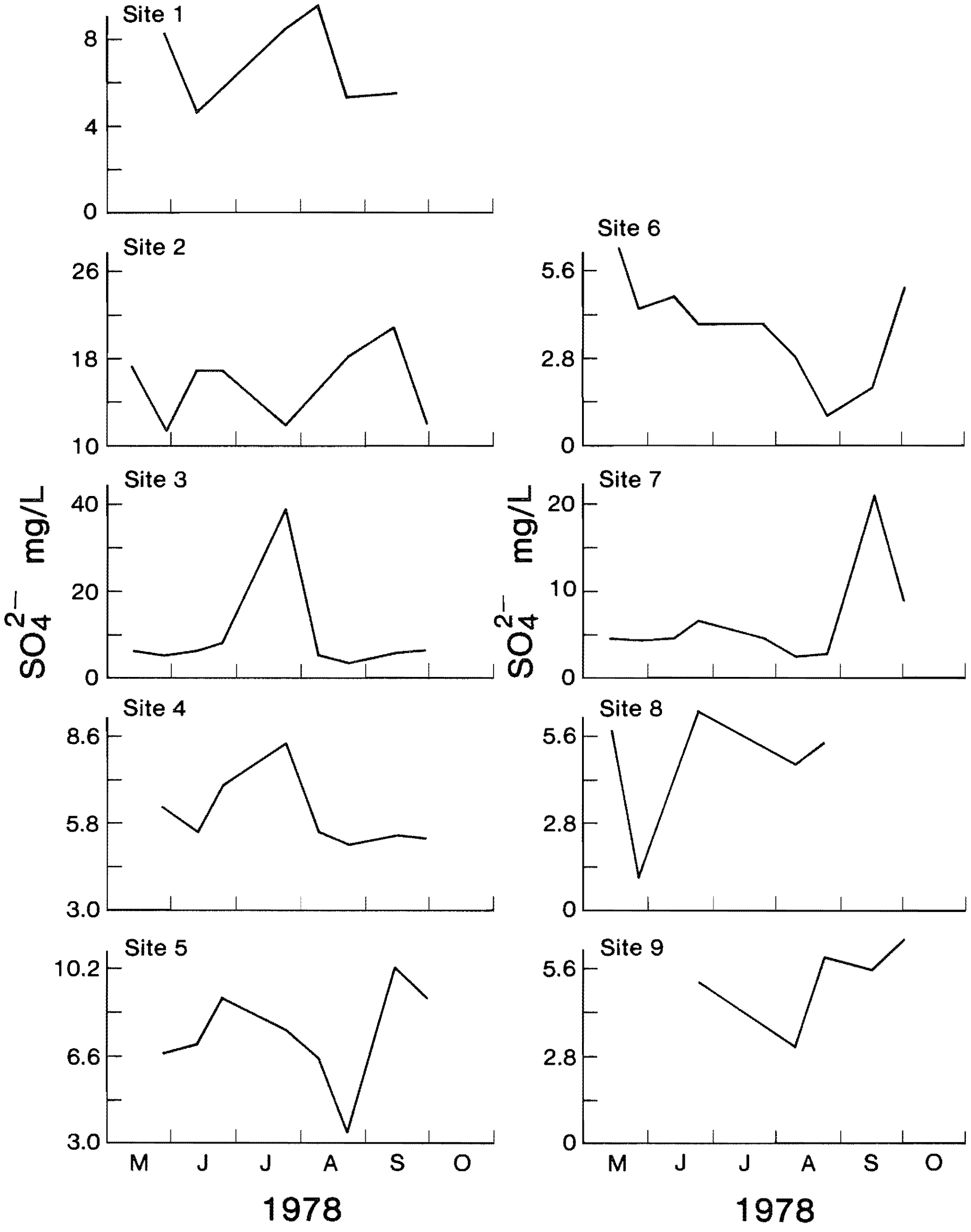

Figure 23. Time variation in SO_4^{2-} ion concentration in standing waters in muskeg.

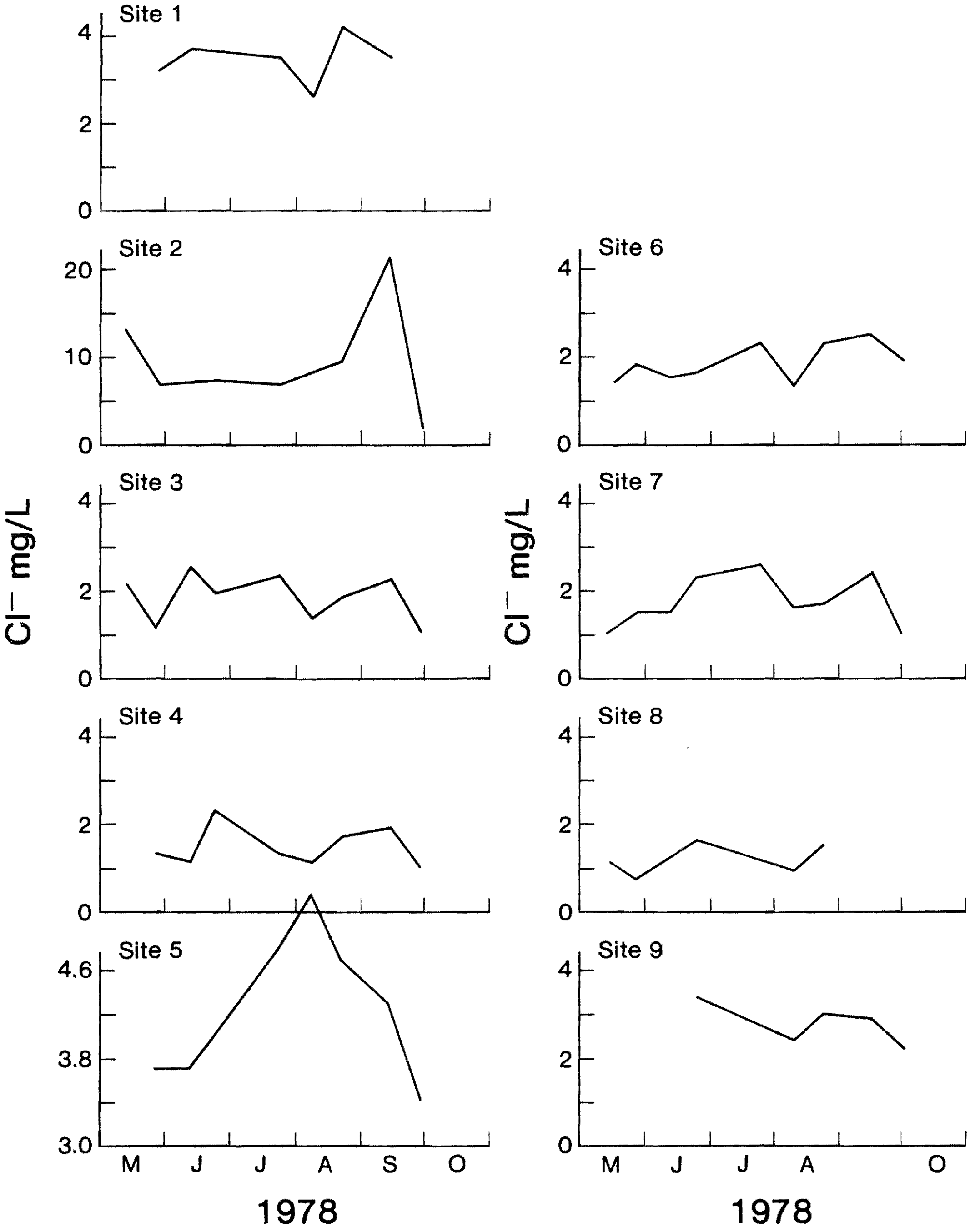

Figure 24. Time variation in Cl^- ion concentration in standing waters in muskeg.

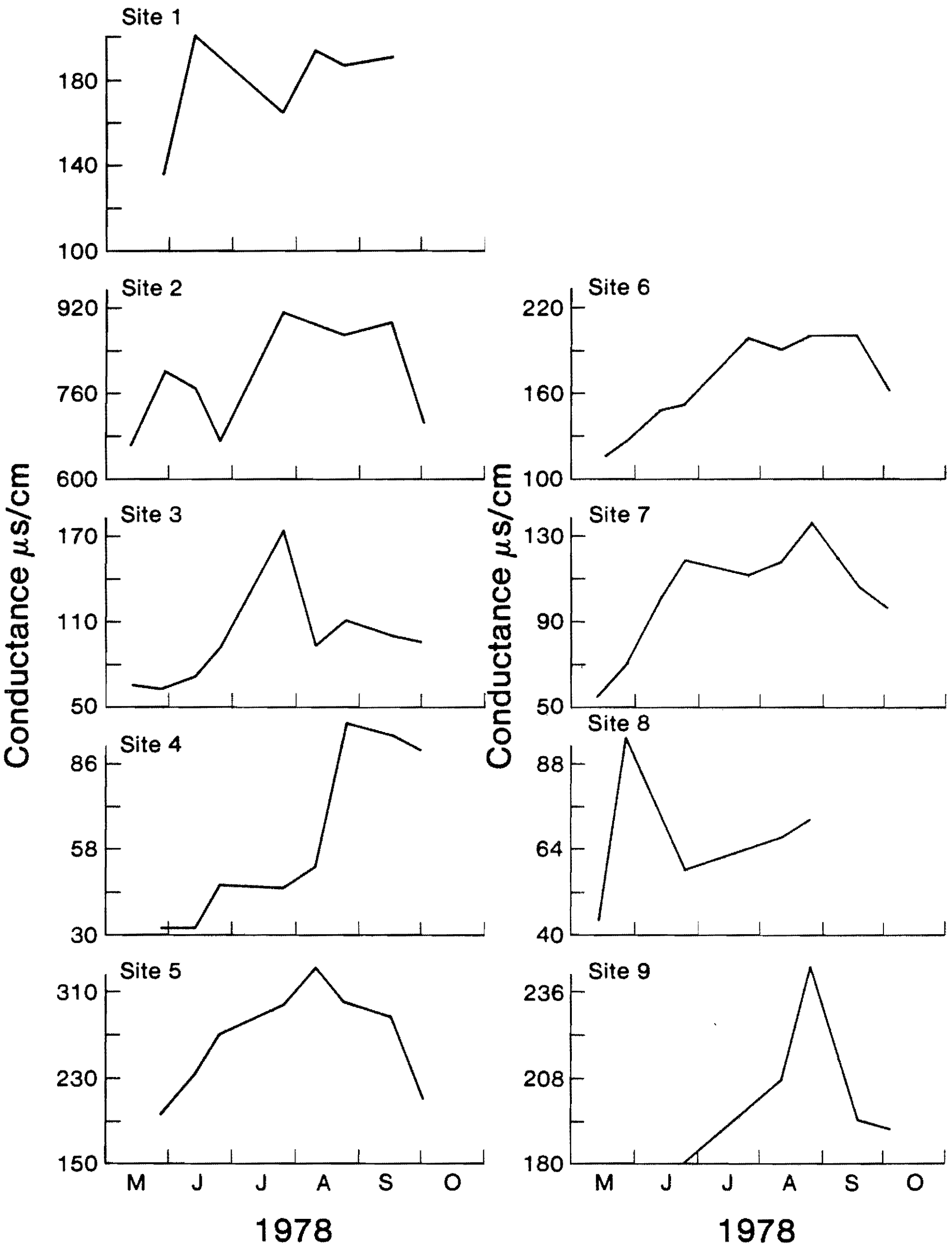

Figure 25. Time variation in specific conductance in standing waters in muskeg.

Table 3. Ratios of standard deviation to mean concentration or specific conductance for nine sites in muskeg.

Muskeg site number	Mean ratio								Specific Conductance µs/cm
	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	
1	0.16	0.12	0.04	0.42	0.93	0.15	0.29	0.15	0.14
4	0.55	0.49	0.12	0.83	1.20	0.13	0.22	0.64	0.13
5	0.22	0.23	1.13[a]	0.76	1.00	0.18	1.20	0.29	0.35
6	0.25	0.39	0.39	0.77	0.92	0.31	0.18	0.29	0.46
9	0.19	0.16	0.11	0.69	0.91	0.15	0.28	0.15	0.18
11	0.16	0.14	0.11	0.55	1.80	0.16	0.44	0.22	0.20
12	0.26	0.22	0.36	0.50	0.62	0.27	0.88	0.34	0.25
13	0.34	0.59[a]	0.42	0.76	0.74	0.45	0.45	0.31	0.28
15	0.12	0.10	0.22	0.74	0.45	0.14	0.25	0.17	0.12

[a] Statistical summary influenced by one inconsistent value.

larger, reflecting the tendency for concentrations of these ions to vary more in standing waters in muskeg, or possibly, in the case of SO_4^{2-}, problems with sample preservation.

3.2.2 Groundwater in Muskeg

The chemical composition of water from sediments in muskeg areas is presented in Table 4. These waters generally represent a transitional group with compositions ranging from approximately that of groundwater to that of surface water in muskegs. Waters from sediments are generally more mineralized than surface water from the muskeg (Table 2). Calcium is the dominant cation at all sites, except 3, 4, and 6, where Na^+ predominates over Ca^{2+}. Magnesium and K^+ ion concentrations are usually lower. With a few exceptions, the most dominant anion is HCO_3^- with much smaller concentrations of SO_4^{2-} and Cl^-. These patterns of ion dominances are similar to those discussed previously for standing water in muskeg.

The temporal variability evident in the standing waters in muskeg is not nearly as marked in the subsurface waters. However, several features are evident. Samples collected in the deepest piezometers at Site 4 exhibited a significant reduction in Ca^{2+} and Mg^{2+} concentrations in 1978 as compared to 1977 (Appendix 7, Table 9). This reduction also is evident in the surface waters between 1977 and 1978 (Appendix 7, Table 9). The data from the deepest piezometer at Site 9 exhibit a progressive reduction in the concentration of all major ions. At present, the origin of these temporal variations is not understood.

With the exception of Sites 4, 9, and 13, there is an apparent increase in salinity with depth beneath the muskeg. Often the composition of the deepest samples resembles that of the groundwater. The concentration of all major ions increases with depth (Table 4). The data at Site 4 cannot readily be interpreted because samples from the shallowest depths were collected in 1977 and those from greater depths mainly in 1978. Differences between the deep and

Table 4. Statistical summary of major ion and specific conductance data for groundwater in muskeg areas.

MSN[a]	WD[b]	NofS	Mean concentration (mg/L) Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^{-}	SO_4^{2-}	Cl^{-}	Specific Conductance µs/cm
1	1.2	1	17.8	3.1	4.4	0.6	ND[c]	82.0	4.2	2.0	130.0
1	2.4	1	32.0	6.5	7.2	1.5	ND	133.0	8.0	6.5	221.0
1	4.9	1	43.5	9.9	8.1	2.0	ND	192.0	7.6	2.0	280.0
2	1.2	1	14.0	2.1	8.5	1.6	ND	56.0	10.5	6.0	108.0
2	2.4	1	9.1	1.5	5.7	2.1	ND	33.0	8.1	4.0	109.0
2	4.9	1	18.4	2.1	3.2	0.8	ND	6.0	22.8	1.8	163.0
3	4.3	1	57.0	10.0	127.0	43.0	ND	516.0	9.9	14.0	780.0
4	2.4	1	41.0	2.1	216.0	4.8	ND	638.0	57.5	38.0	1080.0
4	4.9	1	10.0	1.5	249.0	3.7	ND	684.0	29.0	16.0	1015.0
4	6.7	7	7.9	1.4	235.0	2.0	0.2	560.0	30.2	16.7	924.0
5	2.1	1	49.0	8.8	7.8	0.2	ND	180.0	7.4	2.0	280.0
5	4.9	7	82.0	11.9	14.0	1.4	0.8	336.0	4.4	2.9	472.0
6	2.4	2	6.5	2.6	10.2	3.7	0.2	54.2	6.6	3.7	110.0
6	5.2	7	78.9	40.1	8.6	3.1	0.7	480.0	1.3	2.4	668.0
7	2.4	1	46.0	5.4	9.5	0.9	ND	165.0	5.8	4.0	238.0
7	4.9	1	106.0	8.5	8.8	1.4	ND	204.0	116.0	2.0	560.0
8	3.0	1	114.0	18.0	12.9	0.8	ND	421.0	5.6	4.0	590.0
8	4.9	1	97.0	24.0	37.1	4.3	ND	490.0	0.5	2.0	665.0

continued ...

Table 4. Concluded.

MSN[a]	WD[b]	NofS	Mean concentration (Mg/L)								Specific Conductance µs/cm
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	
9	3.3	3	119.0	33.5	35.0	4.3	0.2	618.0	6.1	15.6	701.0
9	5.7	4	44.0	10.8	44.6	2.6	0.8	263.0	2.6	36.5	509.0
11	5.0	3	55.7	17.4	25.2	2.4	1.3	316.0	4.8	25.7	532.0
12	3.3	4	36.2	10.1	9.7	2.9	0.3	279.0	2.5	21.5	431.0
12	4.5	4	46.1	13.7	7.5	2.9	0.4	215.0	1.4	28.3	430.0
13	3.3	2	102.5	18.9	5.1	0.8	0.3	410.0	1.8	10.8	571.0
13	4.4	2	86.3	15.5	5.9	1.3	0.4	374.0	0.5	3.1	549.0
15	2.4	2	45.0	9.0	45.5	1.2	0.6	323.0	2.8	7.9	425.0

[a] Muskeg site number.

[b] Well depth (m).

[c] No data.

Shallow groundwater at Site 13 are quite small. Only Site 9 data exhibit what could be considered to be significantly different behaviour. The reasons for this behaviour are unknown.

3.3 GROUNDWATER

3.3.1 Chemistry

No piezometers or observation wells were added to the groundwater network in 1978. However, additional chemical data collected for the existing wells in 1978 did not substantially alter the observations or conclusions discussed previously (Schwartz 1979). Presented in Table 5 is a statistical summary of chemical data for sites in the Hartley Creek sub-basin. Waters with similar compositions are typically found in drift units elsewhere in Alberta (Schwartz and Gallup 1978). Typically, Ca^{2+}, Mg^{2+}, and HCO_3^- are dominant ions. High Ca^{2+} and Mg^{2+} concentrations are thought to be caused by the relative abundance of rapidly weathering minerals such as calcite, dolomite, gypsum, olivine, and montmorillonite, and the lack of equilibrium constraints on concentration until relatively high concentrations are reached. High bicarbonate concentrations result from a lack of mineral equilibrium constraints until high concentrations are reached and from the significant sources for HCO_3^- in the soil zone. Sodium and SO_4^{2-} concentrations for groundwaters from the Hartley Creek sub-basin are somewhat lower than those elsewhere in Alberta. Because similar geochemical conditions probably exist over the AOSERP study area, it can be expected that groundwaters in drift will probably have very similar compositions.

At several sites (17, 20, 22, and 24) the relatively high concentrations of Na^+ and Cl^- ions previously reported by Schwartz (1978) are evident also in the 1978 data (Appendix 7, Table 7). It is probable that shallow groundwaters at these sites are being influenced by bedrock waters. The synthesis of existing data on groundwater by Schwartz (1979) showed that bedrock waters

Table 5. Statistical summary of shallow groundwater chemistry.[a]

	Concentration (mg/L)								
Statistics	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	SC[b]
Mean	82.9	22.1	13.3	3.0	1.1	392.	11.0	7.8	570.0
Std. Dev.	33.2	8.0	13.1	2.6	1.6	125.	15.3	14.8	164.0

[a] Samples from Sites 17, 20, 22, 24 excluded.

[b] Specific conductance µs/cm.

are characterized by the following patterns of dominance:
$Na^+ >> Ca^{2+} > Mg^{2+}$ and $HCO_3^- > Cl^- > SO_4^{2-}$ except in some cases where $HCO_3^- > Cl^-$ or $Cl^- > HCO_3^-$.

3.3.2 Water Levels

Examination of water level data for piezometers emplaced in the Hartley Creek sub-basin shows that the water table is typically within 3 m of the ground surface. The greatest depth to water, approximately 5.5 m, is found at Site HC-20.

Considerable variation in water levels was observed from May to October 1978. Highest water levels were measured immediately following spring snowmelt. Levels fell through summer until a succession of rains in 1978 produced a marked rise in the water table.

3.4 A WATERSHED MODEL

Previous work by Schwartz (1979) presented a conceptual model of a watershed system in which muskegs are dominant. Hartley Creek is at baseflow for a few months during winter when contributions to streamflow from muskeg are negligible and there are no other important sources of streamflow. Comparison of the mean groundwater chemistry data with those of Hartley Creek during winter shows them to be almost identical with respect to Ca^{2+}, Mg^{2+}, and HCO_3^- ion concentrations, and specific conductance (compare Table 5 and Figure 7).

Following spring snowmelt, drainage from muskeg is the main contributor to streamflow along with groundwater inflow. It was demonstrated by Schwartz (1979) that, during the summer and fall months, streamflow is chemically more similar to standing water in muskeg than to groundwater. During snowmelt runoff and other storm runoff periods, for example September and October 1978, ion concentration and specific conductance is reduced further as direct precipitation and occasionally surface runoff contribute to streamflow.

At present, it has not been possible to characterize the chemistry of surface runoff. However, studies elsewhere in Alberta by Schwartz and Gallup (1978) have shown surface runoff to be similar but slightly less concentrated than standing waters in Hartley Creek muskeg. Both have high K^+ ion concentrations. Thus, the few times when the K^+ ion concentration of Hartley Creek is high probably correspond to periods of important surface runoff.

The standing waters in muskeg exhibit an increase in K^+ ion concentration immediately following the spring runoff period. Thus, the waters in muskeg themselves probably represent a mixture of surface runoff and melted snow with minor amounts of groundwater.

Results of the 1978 studies support this model. The annual pattern of variation in ion chemistry and specific conductance in the 1978 data is similar to that previously described (Schwartz 1979). Whereas the chemistry of waters in muskeg changes in response to local climatic effects, in most cases the magnitude of the change is relatively small (Figures 17 to 25). As a first approximation in later analyses, it will be assumed that waters in muskeg over the long term have a chemical character that does not change.

It should be expected that upstream storage may contribute significantly to streamflow on a year-round basis. Under conditions such as this, streamflow chemistry will not follow the cyclical behaviour described previously. As will be shown in a later section, this situation is evident in at least one other watershed in the AOSERP study area.

It is apparent that the dilution behaviour of Muskeg river and Hartley Creek, which was discussed in Section 3.1.3, can be explained with this model. Inspection of Figures 15 and 16 shows generally that chemical components, such as specific conductance, HCO_3^-, and Ca^{2+} which are high in groundwater and low in waters from muskeg, tend to be most diluted. Ions such as Na^+, whose concentration is much more similar in both these sources, tend to be less diluted.

3.4.1 Hydrograph Separation

This model of mass and water cycling facilitates the separation of the stream discharge hydrograph into components. The details of a three-component mixing model have been presented in detail previously (Schwartz 1979). Briefly, the chemical characteristics of three end members [groundwater (not discharging into muskeg); muskeg water; and direct precipitation (not falling on muskeg)] are mixed in various proportions. One of the large number of hypothetical mixtures generated in this manner should most resemble a fourth component, for example, streamwater. The set of mixing proporations can then be used directly to separate the composite hydrograph.

Following the method used previously, standing waters in muskeg, direct precipitation (not falling on muskeg), and groundwater (not discharging into muskeg) have been selected as the end member components for the analysis. Surface runoff, occasionally present in the streamflow, is included with the muskeg water component. However, indications are that surface runoff in the Hartley Creek sub-basin is probably rare. This observation is consistent with observations made in other forested Canadian watersheds.

It is theoretically possible to use all the major ions and specific conductance in the analysis. However, species, such as K^+, whose concentration in surface water changes on a seasonal basis, and those such as SO_4^{2-} and Cl^-, whose concentration determinations may be unreliable, are excluded. The representative values for Ca^{2+}, Mg^{2+}, Na^+, HCO_3^- and specific conductance are based on the present detailed study of the Hartley Creek sub-basin and existing chemical data.

Because ion concentrations in precipitation are extremely low but variable, for the purpose of calculation it is assumed that the ion concentration and specific conductance values are zero. In the case of waters in muskeg, the mean ion concentrations and specific conductance values listed in Table 2 are used to characterize this end member. Representative concentrations for the third component, groundwater, are the mean values presented in Table 5 except that the Na^+ and specific conductance were assigned values of 28.4 mg/L and 545 μs/cm which are representative of winter baseflow for Hartley Creek (Appendix 7, Table 8).

The results of the hydrograph separation for Hartley Creek are presented graphically in Figure 26. Discharge values are plotted on a logarithmic scale so that low flow values are more apparent.

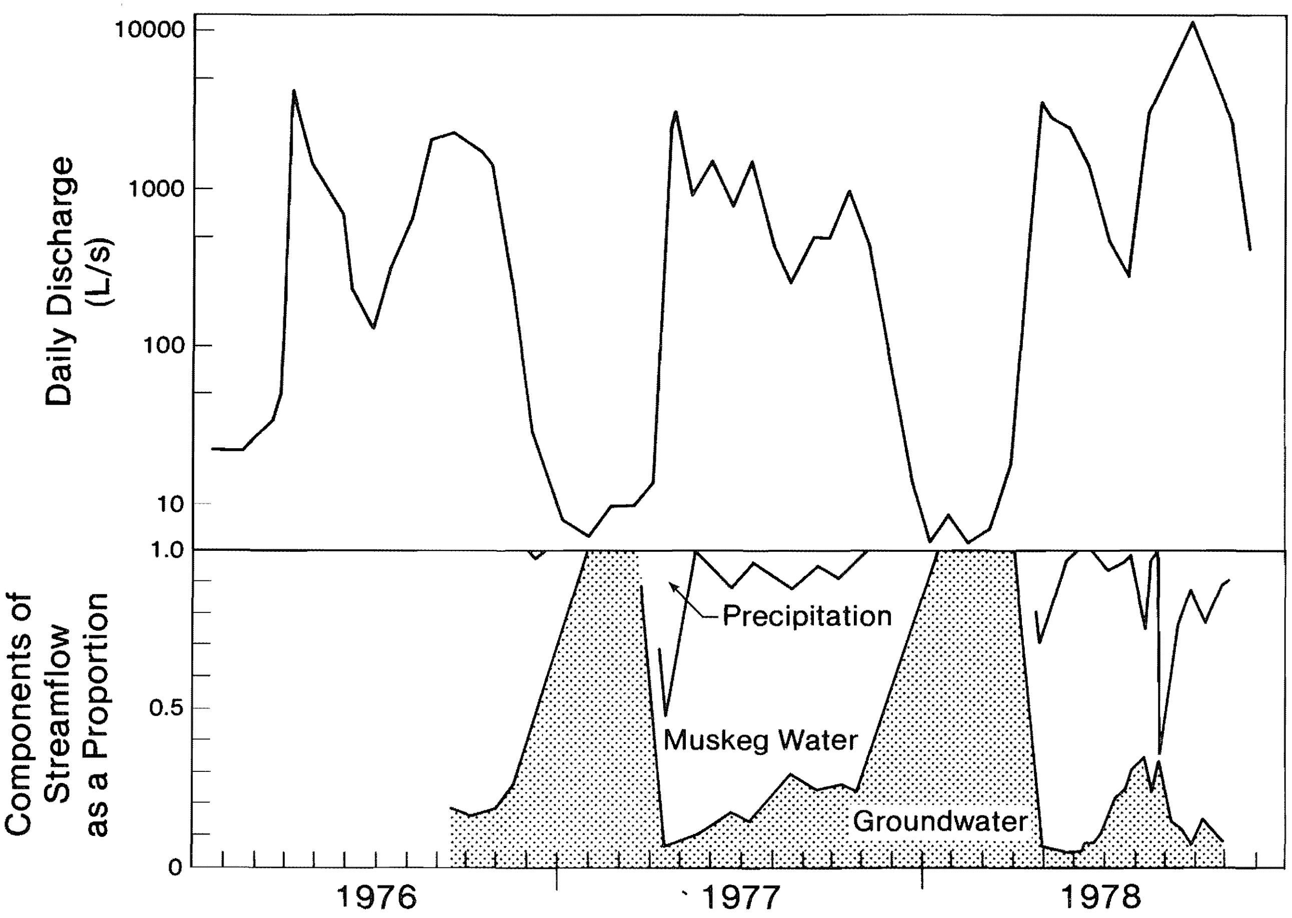

Figure 26. Hydrograph separation for Hartley Creek.

The hydrograph separations are similar to previous results (Schwartz 1979). The streamflow minima during winter represent conditions when groundwater sustains the streamflow. At other times of the year, groundwater contributions to streamflow usually average approximately 20% but fall to as little as 4% during the spring snowmelt period. It should be noted that the separation between muskeg water and direct precipitation (not falling on muskeg) is probably weak. With the same groundwater proportion, a different set of muskeg water and direct precipitation proportion will yield a poorer but still reasonably good fit with stream chemistry.

4. APPLICATIONS

4.1 REGIONAL GROUNDWATER CHEMISTRY

The conceptual model of water systems developed for the Hartley Creek sub-basin should have potential applicability to other basin systems in the AOSERP study area. Because shallow groundwater in the Hartley Creek sub-basin is chemically similar to shallow drift water elsewhere in Western Canada, it can be expected that a similar concentration should exist over the AOSERP study area (Schwartz and Gallup 1978; May and Schwartz 1978).

Information on the standing water in muskeg is more difficult to generalize because the chemical data collected from the Hartley Creek sub-basin represent the most detailed study to date. However, the consistency of the data for this sub-basin suggests that one could expect similar chemical characteristics elsewhere. In addition, comparison of the chemistry of streamwater in Hartley Creek during the snowmelt runoff period with the water from muskeg shows them to be similar. This result is not unexpected because runoff from melting snow will be an important source of water for muskegs. Thus, in cases where chemical data on waters from muskeg are not available, concentrations probably can be approximated from stream runoff data.

Winter streamwater compositions for Muskeg, Firebag, and Steepbank rivers and Thickwood Creek can be compared with Hartley Creek data to establish whether baseflow exists during winter and what can be learned about the composition of groundwater systems in these basins (Table 6).

The chemical data for Muskeg River are very similar to those collected from Hartley Creek (Table 6). However, with the exception of SO_4^{2-}, none of the major ion concentrations and conductivity exceeds Hartley Creek values. This result would suggest that Muskeg River never quite reaches baseflow during winter. There is probably a very minor contribution of waters other than groundwater which are derived from upstream ponds, lakes, or muskegs. The results for Muskeg River compare very well with the mean values of drift

Table 6. Chemical comparison of streamwater in winter and groundwater from glacial drift.

Sample Source	Sample Date	Concentration (Mg/L)							Specific Conductance µs/cm
		Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^{2-}	Cl^-	
Muskeg R.	15 Dec 1976	82.0	18.5	14.5	1.6	352.	9.5	6.3	520.0
Firebag R.	11 Feb 1976	59.9	18.8	9.0	2.0	267.	8.6	7.0	433.0
Steepbank R.	4 Jan 1977	70.0	23.8	55.0	2.2	441.	13.4	7.1	625.0
Hartley Cr.	7 Mar 1977	91.0	21.8	29.5	2.2	424.	5.0	16.5	660.0
Thickwood Cr.	1 Mar 1977	46.0	16.2	14.0	2.9	222.	10.0	4.3	360.0
Drift ground water[a]	--	82.9	22.1	13.3	3.0	392.	11.0	7.8	570.0

[a] Hartley Creek sub-basin.

groundwater (Table 6). Thus, it can be concluded that groundwater inflow to Muskeg River occurs predominantly from glacial drift units.

The only influence of bedrock waters is reflected possibly in Hartley Creek data which show that the streamwater in winter is slightly higher in Na^+ and Cl^- than the drift groundwater. During winter, only the lowest reaches of Hartley Creek, where the drift is relatively thin, remain unfrozen. Accordingly, small quantities of bedrock water may be flowing into the stream.

The pattern of ion abundances for Firebag River is similar to that observed for Muskeg River and for drift groundwater (Table 6). Actual concentrations are usually 10 or 20% less. Thus, Firebag River in winter probably receives a moderate quantity of lower salinity water from muskeg or pond drainage. In a later section, the actual proportions are estimated. The fact that Na^+ concentrations are not more abundant relative to the other cations in Firebag River strongly implies that there is a minimal inflow of groundwaters from bedrock units, which are characterized by waters with high Na concentrations and lower concentrations of Ca^{2+} and Mg^{2+}. Thus, it can be concluded for Firebag River that the main inflow of groundwater comes from shallow glacial drift units and that the groundwater chemistry is probably similar to that shown in Table 6.

The streamwater in winter in Steepbank River appears different from the others in that Na^+ and HCO_3^- ion concentrations are much higher (Table 6). Because the patterns of ion dominance for the cations have changed, it is difficult to determine whether the sample represents true baseflow conditions. The high concentrations of all ions does suggest that the contribution by winter drainage of surface waters is probably minimal. The high concentration of Na^+ and HCO_3^- ions in the water indicates that bedrock units discharge significant quantities of water. It is assumed that shallow bedrock waters can be assigned a mean Na^+ concentration of approximately 500 mg/L and a HCO_3^- concentration of 1000 to 1200 mg/L, based on summaries in Schwartz (1979); approximately 5% of the total groundwater inflow is from bedrock sources.

The pattern that emerges on a regional basis is that, in the broad upland area east of Athabasca River, winter streamflow is predominantly derived from groundwater. With exception of Steepbank River, groundwater inflow to the surface water system is from glacial drift. Only Steepbank River appears to receive significant contributions of deeper bedrock waters. However, this contribution is probably only about 5%.

Thickwood Creek was the only basin studied east of Athabasca River. Maximum Ca^{2+}, Mg^{2+}, and HCO_3^- ion concentrations and specific conductance are approximately half that of Hartley Creek (Table 6). Streamwater during winter is generally more dilute than any of the others. The pattern of relative ion abundances indicates that the sole source of groundwater to the stream is glacial drift. However, it is clear that other surface water sources for streamflow are important. The prevalence of muskeg terrain and the absence of large lakes upstream points to muskeg as a major source of drainage.

4.2 HYDROGRAPH SEPARATIONS

For those systems, such as Muskeg River, Firebag River, and Thickwood Creek, which probably receive all their groundwater contributions from glacial drift units, it is possible to use the hydrograph separation technique described previously to quantify the various contributions to streamflow over a period of several years. It is assumed that the muskeg water in these basins is similar in concentration to that in the Hartley Creek sub-basin or to that of the most dilute stream water. The estimates of the chemistry of groundwater in glacial drift are based on the mean values calculated for Hartley Creek groundwaters and indications from baseflow chemistry (Table 6). The end member values used for Muskeg River, Firebag River, and Thickwood Creek hydrograph separations are indicated in Figures 27 to 29.

The groundwater contribution to the streamflow of Muskeg River usually ranges from 30 to 50% during summer (Figure 27). This range is higher than for Hartley Creek. During the spring snowmelt period, this value is reduced to approximately 14 to 18% (Figure 27).

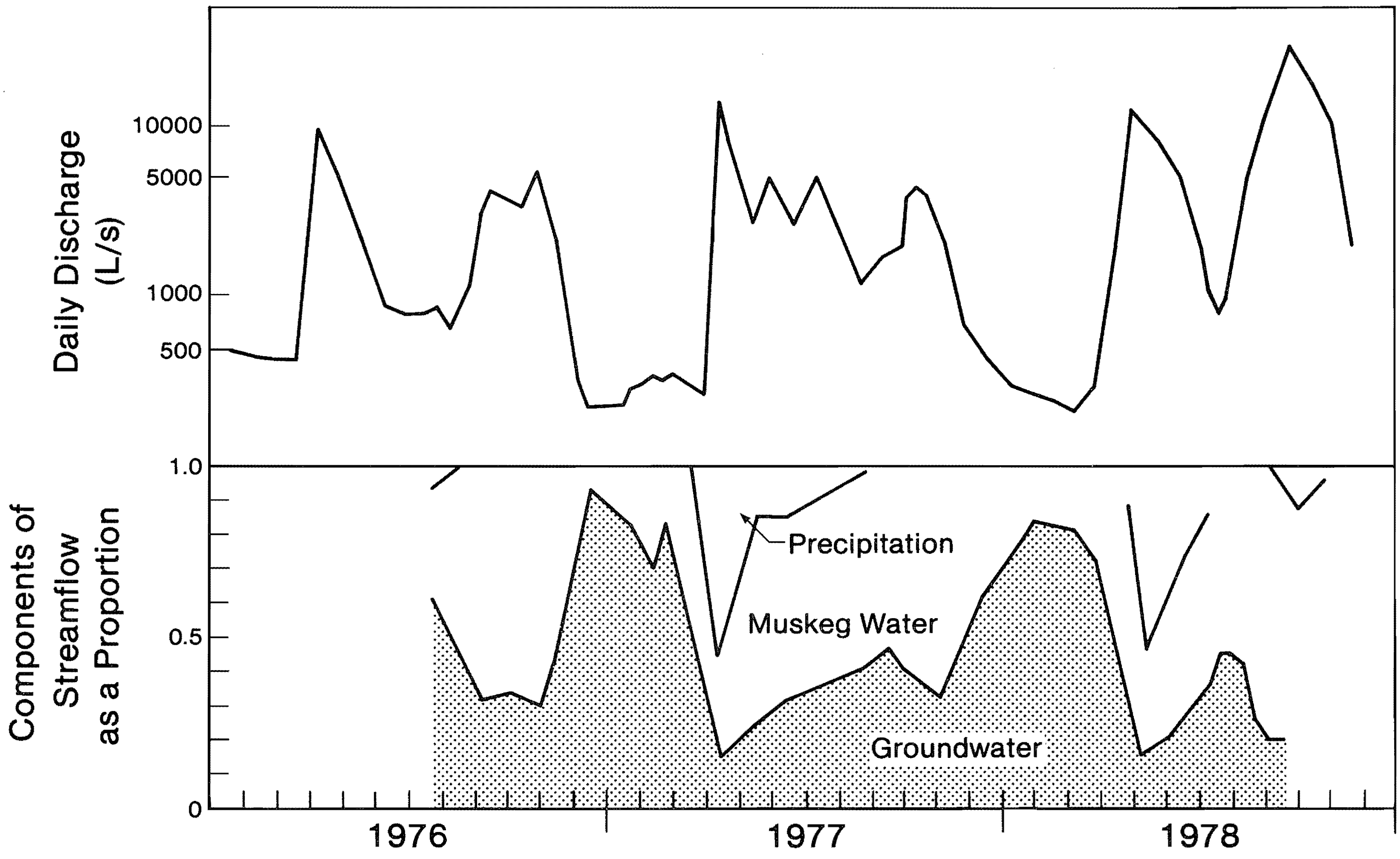

Figure 27. Hydrograph separation for Muskeg River, Site 1.

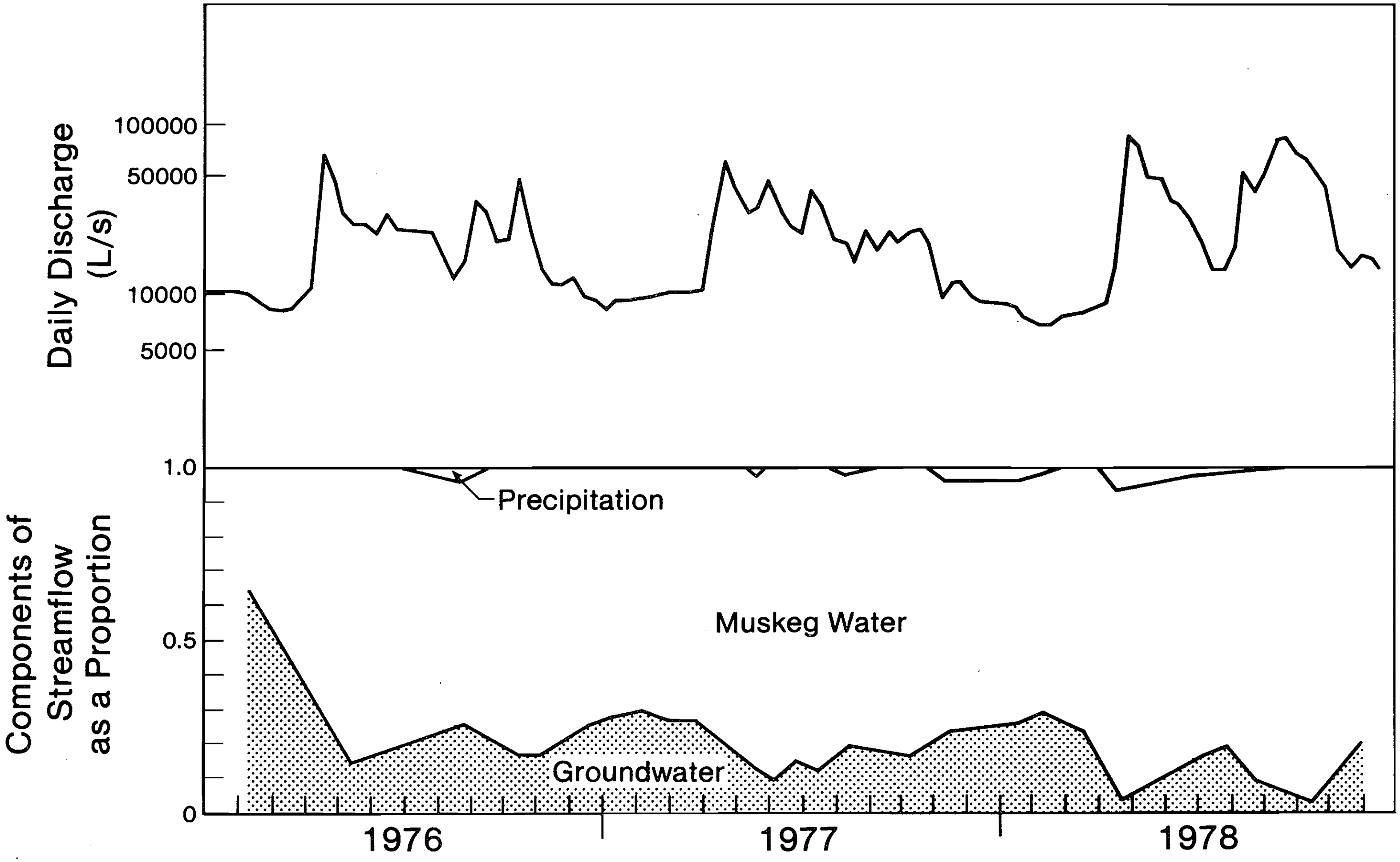

Figure 28. Hydrograph separation for Firebag River.

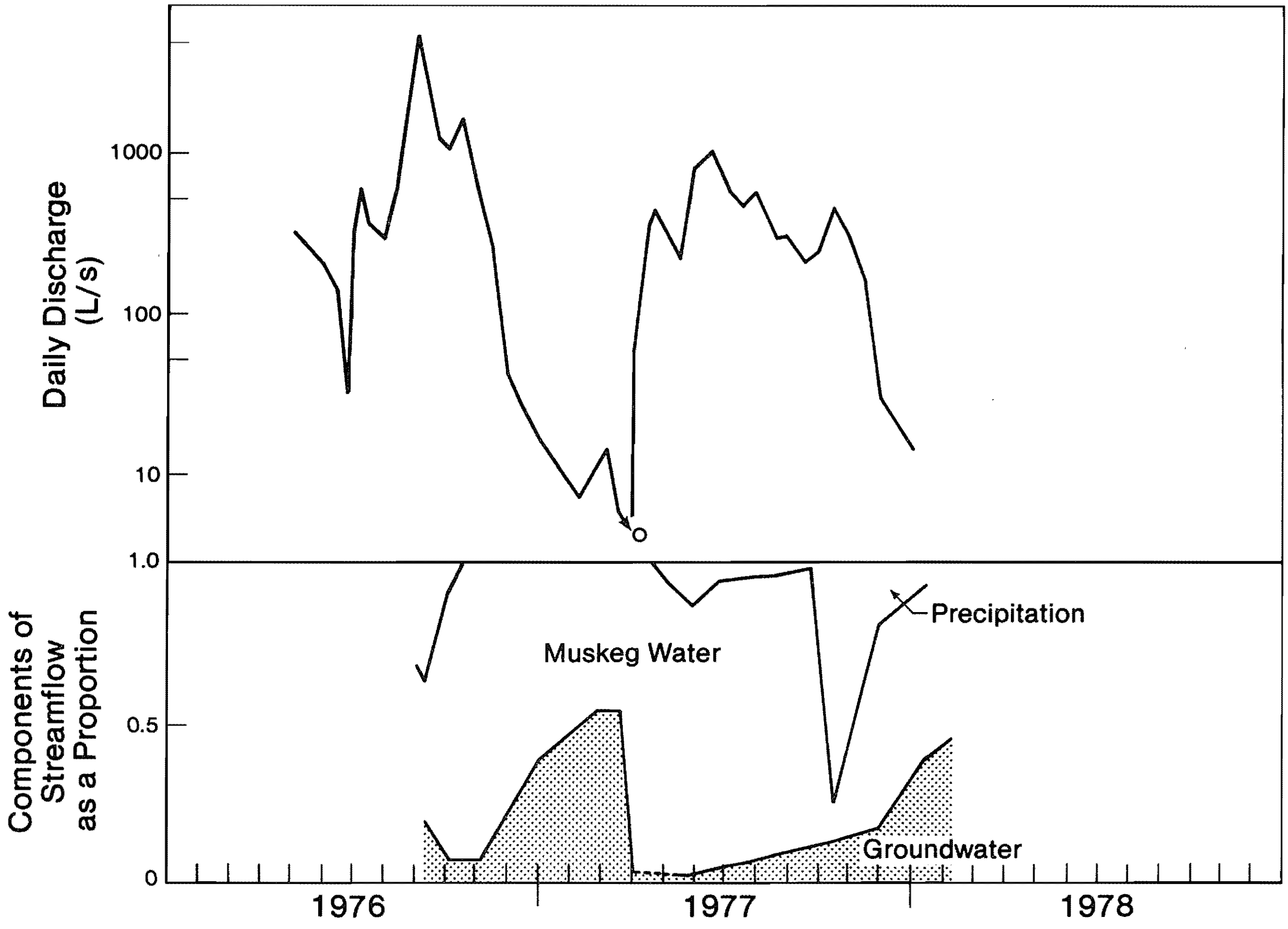

Figure 29. Hydrograph separation for Thickwood Creek.

The reason why groundwater in Muskeg River upstream from Hartley Creek constitutes a greater proportion of the total streamflow could be that contributions from muskeg areas are less significant. Neill and Evans (1979) showed that the total runoff from Hartley Creek averaged 58 mm in 1976 and 1977 compared to about 43 mm for the remainder of the Muskeg River watershed.

The results for the analysis of Firebag River are presented in Figure 28. During winter, groundwater comprises approximately 30% of the streamflow. Indications from a single analysis in 1976 are that this proportion could be as high as 65% (Figure 28). During summer, the proportion ranges from approximately 10 to 20%. A minimum groundwater contribution of 2% is calculated for the snowmelt period in 1978 (Figure 28).

As could be expected, the hydrograph separation for Thickwood Creek suggests that drainage from muskeg comprises a significant proportion of the streamflow (Figure 29). Values range from 85 to 90% during summer and spring to approximately 40 to 50% during winter (Figure 29).

In summary, the watersheds can behave in very different ways. In some cases, streamflow in winter may be maintained exclusively by groundwater discharge. In other cases, drainage of surface waters from muskegs or lakes may dominate. However, in spring and summer, no streams that were studied returned to baseflow.

4.3 EVALUATION OF POTENTIAL ENVIRONMENTAL IMPACTS

4.3.1 Muskeg Disturbance

One important result of this project has been to demonstrate the important role that muskeg terrains play in controlling the quantity and quality of stream discharge throughout most of the year. This result was evident for all the watersheds studied on the east side of Athabasca River and for Thickwood Creek.

Accordingly, activities that may directly or indirectly affect muskeg could have a profound influence on the quality and quantity of streamflow in a basin. The magnitude of the impact will depend upon such factors as: (1) the specific hydrologic setting; (2) the proportion of the total muskeg in the basin actually affected; and (3) the way in which the muskeg has been altered. Following is a discussion of these factors in relation to possible developments in basins east of Athabasca River.

Although this research has shown generally that muskeg is a dominant source of streamflow, smaller areas more directly involved in mining must be evaluated on a site-specific basis. For example, areas of muskeg are not distributed homogeneously and some areas could have very little muskeg. The result is that groundwater systems may be more important than muskeg in controlling stream chemistry.

In addition, drainage of muskeg may not necessarily provide the major control on the discharge and chemistry of a small tributary. Upstream storage in ponds or lakes may also contribute to streamflow. Accordingly, the surface water systems most influenced by muskeg disturbance are those, such as Hartley Creek, with no upstream storage other than muskeg.

The second factor to be considered is the proportion of muskeg in an area actually disturbed. For example, if almost all the muskeg is removed from a small drainage area, the impact may be very significant. However, as the drainage from this area mixes with waters from more of the watershed, the impact will be attenuated. Thus, for major changes to be evident in the quality and quantity of outflow from the large eastern basins (Muskeg, Firebag, and Steepbank) a significant proportion of the muskeg in each watershed must be disturbed.

The question of how the surface water system will respond to various types of muskeg disturbance is the most complex factor to be considered. The particular case where the muskeg is removed and replaced by mineral soil is amenable for analysis. Once an area has been reclaimed and vegetation has been re-established, it is assumed that its hydrologic response will be similar to watersheds without muskeg. This assumption is reasonable as a first approximation because the presence or absence of surface water storage in muskeg will be one of the most important controls on streamflow. Many watersheds without significant storage of surface waters have been studied in Canada and a very consistent set of results obtained.

In these kinds of basins, groundwater controls the quantity and quality of the streamwater. Thus, during summer between storm events, stream discharge depends on features of the hydrogeologic regime, such as hydraulic conductivity and water table gradient, and the stream chemistry resembles the groundwater chemistry.

Removal of the muskeg terrain and replacement by mineral soils should cause these watersheds to behave in the following way. Discharge will be greater during spring runoff period and less during summer because the storage capabilities of muskeg have been eliminated from the system. During summer, between storm events, the ion concentrations in the stream will increase to groundwater levels because drainage from muskeg, low in dissolved mineral matter, will no longer act to dilute the more mineralized groundwaters. During winter, very little change in the quality and quantity of the streamflow can be expected because the groundwater often exerts the major control. However, the impact of development on the groundwater system cannot be assessed.

If possible effects of muskeg removal on streamflow are environmentally unacceptable, the impact can be reduced by adopting specific reclamation strategies. For example, a terrain could be developed with characteristics similar to the muskeg: off-stream storage of spring runoff with continuous discharge to the surface water system.

Disturbances to muskeg other than partial or complete removal, for example channeling and drainage, cannot be evaluated in the context of the model presented here. Understanding such impacts of necessity requires detailed studies of the hydrogeological and engineering properties of muskeg and carefully controlled field trials.

4.3.2 Discharge of Bedrock Groundwaters

The present study has demonstrated that the source of the groundwater component of streamflow is almost always glacial drift. In the process of development or operation of some mines, it may become necessary to dispose of large quantities of groundwater from bedrock units. Because these waters are typically much more mineralized than glacial drift waters and because their patterns of ion dominance are different, discharge to the surface water system may cause major changes in stream chemistry.

The existing data from Site 1 in Muskeg River basin do exhibit increased Na^+ and Cl^- ion concentrations caused by discharge of groundwater from the Shell pit. Clearly, the magnitude of any impact will depend on the quantity of discharge relative to the stream discharge. It remains to be demonstrated what the biological consequences would be from changes in stream chemical composition.

5. CONCLUSIONS

The application of geochemical techniques to water systems in the AOSERP study area provides a useful way to investigate the role that drainage of muskeg and inflow of shallow groundwater plays in controlling the quantity and quality of streamwater. The annual variation in chemistry of creeks and rivers draining several parts of the AOSERP study area is similar. Typically, maxima in specific conductance and major ion concentrations, except for K^+ and SO_4^{2-} ions, are observed during winter.

Because the composition of Hartley Creek in winter is very similar to what was measured for shallow groundwaters in the basin, it can be concluded that baseflow conditions were obtained. Comparisons of Muskeg, Firebag, and Steepbank rivers, and Thickwood Creek data to those from the Hartley Creek sub-basin show that inflow of groundwater is a major source of streamflow in winter. Groundwater from the Hartley Creek sub-basin has a composition similar to that of other areas in Alberta with similar geological settings. Thus, extrapolation of chemical data on groundwater in the Hartley Creek basin to other basins is probably a valid first approximation. Evaluation of the stream data in winter for all basins studied points to glacial drift as the dominant source of groundwater inflow to surface water systems. Only in the Steepbank River basin is there evidence of an important contribution of groundwater discharge from bedrock. However, this contribution is small, probably around 5%.

During spring snowmelt, concentration minima for ions, except K^+ and SO_4^{2-}, and specific conductance minima are observed for all the creek and river systems studied. Unlike watersheds in the Prairie Parkland without extensive muskeg, the surface water systems do not return to baseflow following the snowmelt period. The specific conductance and ion concentrations lie between the mean concentrations of shallow groundwater and the less mineralized water from muskeg. From these observations and statistical analysis of the chemical data (Schwartz 1979), it can be concluded that the drainage of muskeg provides a major source of late spring, summer, and fall streamflow.

The multicomponent mixing model developed in this study quantifies this relationship. Streamflow from Hartley Creek, Muskeg River, Firebag River, and Thickwood Creek can be partitioned into three major components: (1) direct precipitation, (2) drainage from muskeg, and (3) groundwater inflow. In all stream systems studied, the contribution of drainage from muskeg to streamflow is usually more than 50% (Muskeg River) and as much as 90% (Thickwood Creek).

Because of the important role that muskeg plays in controlling discharge and water quality, stream systems will be especially responsive to disturbance of muskeg. Three controlling factors, the specific hydrologic setting, the proportion of the total muskeg in a basin actually affected, and the way in which the muskeg is disturbed, can be considered most important.

If surface mining east of Athabasca River causes the removal of muskeg and its replacement by mineral soil, discharge from these areas will be less during summer and more during spring runoff and stormflow periods. Considerable variation in water chemistry in late spring, summer, and fall streamwater should be expected. Clearly, the impact of local disturbances in a larger basin system will be increasingly diminished as waters from the affected area are mixed with progressively greater quantities of water from other parts of the basin.

In some areas, upstream storage in lakes or ponds may exert a more important control than muskeg on the streamflow. Thus, disturbance of muskeg in this situation may not have nearly as great an impact. However, in Muskeg River, Hartley Creek, and Thickwood Creek, drainage from muskeg is more important than upstream storage.

The chemically based approaches for analyzing large basins have provided an inexpensive technique for preliminary reconaissance of hydrologic and groundwater settings. The data necessary for the analyses are being collected in the monitoring of baseline states for the AOSERP study area. Accordingly, it will be possible in future years to apply these techniques to other areas.

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7. APPENDIX

Tables 7 to 9 present a summary of the water chemistry data for groundwater, surface water, and muskeg water in the Muskeg River basin. For each chemical analysis, the sample location, date of sampling, and the analysis results are included. Table 10 is a summary of water level measurements for piezometers which were monitored in the 1978 field program.

TABLE 7. Summary of chemical data[a] for groundwater.

S[b]	D[c]	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
1	533	110.8	25.0	5.9	3.4	-1.0	391	20.9	5.5	7.74	585
1	552	107.5	30.0	5.0	3.6	-1.0	436	45.0	3.8	7.50	690
1	585	83.0	25.0	5.4	2.5	-1.0	361	21.3	4.0	8.24	468
1	587	74.0	25.0	6.1	2.5	-1.0	358	21.0	10.0	8.12	437
1	881	78.5	20.5	4.0	1.9	-1.0	312	27.5	3.1	7.45	650
1	1004	75.0	25.0	2.9	1.5	1.5	372	14.4	2.3	7.65	550
2	527	117.9	27.5	6.7	3.5	-1.0	459	2.9	5.0	7.65	645
2	586	35.5	10.0	3.9	1.3	-1.0	156	7.7	3.3	7.80	256
2	1004	85.0	23.0	2.5	1.3	0.9	368	11.0	2.5	7.70	500
4	533	139.4	21.0	24.9	13.3	-1.0	518	5.9	13.5	7.67	810
4	551	107.5	18.5	13.0	5.1	-1.0	441	11.5	7.2	7.35	662
4	585	110.0	15.0	8.9	2.7	-1.0	437	0.5	4.0	7.74	600
4	878	118.0	14.5	8.8	1.7	1.9	423	1.0	2.6	7.32	560
4	1005	95.0	12.0	7.9	1.6	7.2	393	3.4	3.0	7.55	550
6	540	100.0	26.6	11.9	14.6	-1.0	506	11.0	8.0	7.63	740
6	551	87.5	32.5	9.0	8.6	-1.0	502	10.2	3.9	7.40	848
6	585	130.0	29.0	5.6	2.1	-1.0	583	0.5	4.0	7.80	680
6	881	150.0	30.0	5.0	1.3	0.3	602	1.0	2.2	8.40	760
6	1004	95.0	30.0	5.3	1.2	0.3	486	3.3	2.1	7.85	725
7	540	66.0	20.0	11.1	5.0	-1.0	301	-1.0	15.0	8.10	-1
7	551	110.0	23.5	6.0	2.6	-1.0	430	41.0	7.2	7.30	672
7	585	98.0	22.0	4.2	1.0	-1.0	371	0.5	2.0	7.76	570
7	881	109.5	22.5	4.5	1.0	-1.0	440	34.2	2.1	7.81	480
7	1004	85.0	20.0	3.2	1.4	4.6	379	16.5	2.6	7.82	550
8	557	36.5	18.0	11.0	1.9	-1.0	328	7.8	3.3	7.55	368
8	585	38.7	22.0	12.4	2.7	0.2	250	0.5	4.0	8.47	363
8	881	25.1	11.8	12.0	1.8	0.1	151	1.0	3.3	7.25	230
8	1006	24.0	21.0	9.9	1.7	-1.0	218	2.4	4.0	8.08	250

continued...

TABLE 7. Continued.

S[b]	D[c]	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
9	585	20.0	7.6	5.2	0.6	-1.0	98	9.2	4.0	7.84	165
9	881	12.0	3.2	4.9	0.5	-1.0	45	10.3	2.8	6.73	97
10	546	102.0	18.5	14.0	3.5	-1.0	431	15.5	5.2	7.20	642
10	585	117.0	25.0	7.3	2.0	-1.0	484	3.5	4.0	7.67	685
10	1004	105.0	27.0	6.2	1.6	0.3	491	3.2	3.3	7.70	650
12	557	117.5	25.0	6.0	2.2	-1.0	484	17.0	4.2	7.15	705
12	585	110.0	25.0	7.0	1.9	-1.0	503	0.5	2.0	7.77	670
12	878	115.0	26.5	8.4	2.2	0.4	487	1.0	3.9	7.30	640
12	1005	85.0	25.0	5.4	1.5	0.8	430	0.9	2.0	7.70	650
13	547	123.0	31.2	14.6	4.0	-1.0	568	26.0	5.9	7.40	838
13	586	110.0	30.0	16.0	2.2	-1.0	534	9.5	4.0	7.79	690
13	881	55.0	10.5	5.8	3.6	0.8	205	8.1	3.5	7.30	315
14	1004	10.5	2.7	1.0	5.1	0.3	162	3.6	50.0	7.40	425
15	548	77.5	31.0	2.5	4.7	-1.0	433	14.0	5.3	7.45	732
15	586	90.0	28.0	5.1	3.2	-1.0	500	0.5	4.0	7.72	665
15	881	112.0	30.0	6.3	2.2	1.1	502	1.0	3.2	7.30	650
15	1004	65.0	27.0	4.5	2.1	2.1	501	1.8	3.1	7.65	650
16	549	85.0	22.5	7.2	2.6	-1.0	376	11.5	3.1	7.20	560
16	586	73.4	21.3	7.6	2.0	-1.0	368	0.5	4.0	7.82	508
16	881	87.5	21.5	8.8	2.6	0.2	364	1.0	4.4	7.45	480
16	1004	65.0	20.0	8.3	1.2	0.1	343	2.7	2.0	7.80	500
17	552	75.0	24.0	6.0	4.1	-1.0	408	16.2	3.5	7.85	630
17	586	12.0	6.2	9.2	4.2	-1.0	131	4.0	46.0	8.21	344
17	881	15.3	13.8	6.5	4.6	0.5	111	1.0	18.5	9.60	340
17	1004	24.0	20.5	3.0	4.1	0.1	265	2.7	11.8	8.08	400
18	555	65.0	31.0	6.5	10.9	-1.0	403	18.0	5.4	7.60	680
18	586	82.0	33.0	4.6	8.9	-1.0	499	0.5	4.0	7.92	650
18	881	110.0	33.5	4.0	5.6	0.3	532	1.0	2.4	7.50	690

continued...

TABLE 7. Continued.

S^b	D^c	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	Fe	HCO$_3^-$	SO$_4^{2-}$	Cl$^-$	pH^d	SC^e
18	1004	65.0	35.0	13.5	5.6	0.5	450	0.1	3.0	7.95	600
20	584	60.7	20.0	35.7	6.8	-1.0	344	22.2	22.0	8.14	560
21	555	65.0	36.0	4.4	2.3	-1.0	393	15.5	9.2	8.00	612
21	584	66.0	35.0	7.0	2.1	-1.0	428	0.5	10.0	8.31	550
21	1005	41.5	18.5	3.2	1.1	0.8	233	8.1	4.2	7.65	350
22	555	92.5	21.0	44.0	3.5	-1.0	375	15.5	75.0	7.45	778
22	584	86.0	21.0	51.3	3.3	-1.0	411	0.5	80.0	7.67	790
22	878	105.0	21.5	65.0	2.2	0.2	390	3.6	90.0	7.52	770
22	1005	80.0	20.8	55.0	1.7	-1.0	361	5.2	105.0	7.72	775
23	555	87.5	20.0	37.5	2.3	-1.0	324	11.0	71.0	7.60	702
23	584	73.4	18.0	41.0	1.4	-1.0	350	0.5	76.0	8.46	650
23	1015	70.0	14.8	38.0	1.3	3.8	263	13.5	75.0	7.55	575
24	555	25.0	21.0	12.5	13.6	-1.0	516	11.0	5.2	7.60	805
24	589	27.0	17.6	37.0	9.1	-1.0	578	0.5	4.0	8.13	780
24	901	8.5	10.3	77.5	7.2	0.2	593	3.5	5.6	8.08	792
25	555	60.0	13.5	33.0	4.9	-1.0	239	97.5	1.8	7.60	547
25	589	27.0	11.1	36.0	5.8	-1.0	236	15.8	4.0	8.06	375
25	901	27.1	5.3	43.5	3.0	0.1	216	4.7	2.3	7.45	310
25	1006	24.5	7.7	42.0	3.4	0.6	241	1.9	2.8	7.80	350
26	589	63.1	10.8	7.9	3.2	-1.0	280	0.5	4.0	7.95	392
26	906	-1.0	-1.0	-1.0	1.0	1.1	-1	-1.0	-1.0	-1.00	-1
26	1006	44.5	8.8	7.1	2.0	-1.0	214	3.8	2.8	7.85	250
27	555	82.5	30.0	9.1	2.5	-1.0	406	49.4	6.1	7.90	755
27	585	110.0	26.0	10.4	1.1	-1.0	430	10.0	4.0	7.98	625
27	881	109.5	27.5	11.3	0.6	-1.0	452	32.4	9.8	7.75	680
28	881	120.0	21.5	6.0	0.8	0.4	396	39.3	4.4	7.55	605
28	1006	80.0	27.0	9.6	0.9	-1.0	393	22.6	15.0	7.80	600
29	575	139.0	20.0	7.7	5.3	-1.0	565	0.5	6.0	7.95	760

continued...

TABLE 7. Concluded.

S[b]	D[c]	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
29	589	98.0	20.0	38.0	5.0	-1.0	550	0.5	4.0	8.10	720
30	901	100.0	23.0	7.0	1.4	0.2	477	1.3	2.8	7.39	600
31	901	30.0	36.0	9.1	1.7	0.5	670	1.0	2.0	7.67	810
34	878	125.5	20.0	12.3	1.3	0.3	464	4.2	3.5	7.50	620
34	1005	105.0	17.0	9.2	1.1	1.1	466	4.3	3.7	7.90	555
99	495	80.4	27.3	13.4	1.7	-1.0	303	21.0	41.5	7.43	630
99	556	110.0	36.0	39.0	1.5	-1.0	502	21.9	48.0	7.93	900
99	608	180.0	40.0	35.5	2.3	-1.0	635	0.5	92.0	7.38	1080
98	556	9.1	21.0	1340.0	114.0	-1.0	2073	15.0	1112.0	8.49	6000
97	495	60.7	21.5	44.8	4.2	-1.0	356	2.3	7.5	7.88	515
97	556	38.6	18.6	53.3	2.9	-1.0	356	0.5	9.0	7.84	525
97	608	53.0	20.0	42.0	4.9	-1.0	350	0.5	6.0	8.19	498
96	556	54.3	42.6	364.9	42.6	-1.0	610	0.5	452.0	7.44	3090
95	495	65.6	22.4	141.0	5.0	-1.0	459	0.5	67.5	8.10	980
95	556	35.7	15.8	132.4	5.5	-1.0	396	0.5	52.0	8.19	815
95	608	53.7	19.3	136.0	9.4	-1.0	439	0.5	58.5	8.18	915

[a] Concentration in mg/L; - 1 indicates the constituent was not analyzed.

[b] Sites 95 to 99 represent Research Council of Alberta observation wells.

[c] Day of sampling in consecutive numerical order 1 Jan. 1976 = day 1.

[d] Expressed in pH units.

[e] Specific conductance expressed as μs/cm.

TABLE 8. Summary of chemical data[a] for surface water.

S^b	D^c	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH^d	SC^e
1	208	57.0	13.0	12.0	0.8	0.8	278	0.5	5.1	7.80	380
1	250	38.0	10.3	13.5	0.7	0.4	180	0.6	2.5	7.80	270
1	279	39.5	10.2	22.7	0.7	0.6	188	0.5	13.9	7.80	325
1	302	36.0	10.5	12.0	0.8	0.9	174	0.5	2.5	7.60	260
1	314	45.5	12.5	13.0	0.8	1.3	211	4.5	3.9	7.40	320
1	350	82.0	18.5	14.5	1.6	2.1	352	9.5	6.3	7.40	520
1	391	75.0	17.2	13.5	1.8	2.6	332	5.3	4.1	7.30	500
1	408	68.0	16.9	14.5	1.7	1.8	252	3.7	3.8	7.30	480
1	428	71.5	16.9	14.5	1.9	1.8	319	3.8	4.7	8.20	480
1	474	16.5	4.5	4.9	2.6	1.3	79	3.3	1.7	7.50	126
1	502	29.5	8.0	9.0	1.4	0.7	144	6.0	1.7	7.90	220
1	537	33.0	9.0	9.2	0.5	1.1	163	9.1	2.0	8.10	250
1	564	32.5	9.5	22.0	0.7	0.8	174	8.2	14.4	7.80	320
1	594	45.5	12.0	12.5	0.6	1.2	207	6.4	3.1	7.95	294
1	622	48.0	12.2	38.5	1.5	0.7	249	5.8	29.7	7.96	420
1	643	43.0	11.0	13.5	1.1	0.8	210	0.1	3.7	8.06	295
1	698	36.5	10.5	11.5	0.7	0.9	194	5.1	3.2	7.72	310
1	706	60.0	14.5	15.0	1.1	2.8	280	5.9	5.6	7.28	410
1	755	77.5	18.2	14.4	1.4	1.9	333	1.0	5.6	7.89	455
1	764	74.0	18.3	15.5	1.5	1.9	351	3.1	5.5	7.45	485
1	799	74.0	18.2	15.0	1.4	2.1	325	4.0	5.9	7.55	464
1	827	65.0	16.3	14.5	1.4	1.9	310	4.4	5.5	7.50	430
1	854	20.5	5.5	5.3	1.5	1.3	92	3.3	1.7	7.79	120
1	887	30.0	8.0	8.4	0.4	0.7	139	4.2	1.6	7.75	170
1	903	32.7	9.0	18.7	0.4	0.9	167	6.1	9.4	7.76	267
1	922	42.5	10.3	11.7	0.4	1.4	216	5.0	4.3	8.10	294
1	932	45.5	12.5	13.5	0.7	-1.0	242	3.6	5.3	7.80	240

continued...

TABLE 8. Continued.

S^b	D^c	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH^d	SC^e
1	936	44.5	12.3	14.2	0.5	-1.0	240	3.4	5.2	7.90	336
1	958	50.0	10.9	13.2	0.5	0.7	215	4.5	3.1	7.80	272
1	971	34.5	10.0	12.0	0.4	0.6	168	3.0	1.9	8.10	210
1	981	30.2	9.2	11.0	0.5	0.7	146	4.4	1.8	8.10	187
1	994	26.9	8.0	8.9	0.4	0.4	130	4.4	2.5	7.98	243
1	1009	26.5	7.7	9.5	0.4	0.4	128	4.6	3.4	7.30	160
1	1031	30.0	8.5	7.4	0.2	0.4	134	3.2	2.4	7.35	160
1	1041	39.5	11.4	21.5	0.6	1.4	195	9.4	13.0	8.70	-1
1A	232	52.2	12.1	12.0	0.8	0.4	224	5.1	4.1	8.10	395
1A	252	64.0	13.0	12.5	1.2	1.3	269	0.5	3.5	7.70	430
1A	298	38.5	11.5	11.5	1.0	1.0	188	0.5	2.5	7.40	290
1A	322	60.0	15.3	14.5	1.0	1.3	262	5.0	5.1	7.70	412
2	208	30.0	8.8	12.0	0.5	0.8	174	2.5	2.7	7.70	250
2	250	25.0	8.2	13.0	0.6	0.9	138	-1.0	1.2	7.70	190
2	277	26.5	7.4	12.5	0.3	0.5	135	1.9	2.0	7.60	202
2	298	25.5	8.2	13.5	0.5	0.6	138	0.5	2.1	7.60	205
2	314	32.0	9.3	14.0	0.5	0.9	159	7.2	3.5	7.50	250
2	336	72.5	19.0	29.0	1.5	1.8	344	12.5	13.6	7.50	540
2	392	80.0	20.5	30.0	2.0	5.0	397	6.0	17.0	8.10	600
2	432	91.0	21.8	29.5	2.2	1.2	424	5.0	16.5	7.80	660
2	474	11.5	3.5	5.5	2.5	1.2	57	5.0	1.7	7.20	105
2	502	21.0	6.2	11.0	1.0	0.5	113	6.4	1.4	8.20	179
2	539	23.5	7.0	11.0	0.3	0.4	126	4.3	1.4	7.70	197
2	560	25.5	7.0	11.5	0.2	0.5	123	4.2	1.0	7.70	196
2	594	32.0	9.5	13.5	0.3	0.7	158	6.1	2.0	7.95	230
2	622	30.0	8.5	13.0	0.5	0.5	156	5.1	2.0	7.81	214
2	643	29.5	9.0	13.5	0.9	0.5	157	0.1	2.6	7.93	214

continued...

TABLE 8. Continued.

S[b]	D[c]	CA^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^{-}	SO_4^{2-}	Cl^{-}	pH[d]	SC[e]
2	678	27.0	8.7	14.5	0.5	0.5	148	5.5	3.0	7.79	205
2	755	82.5	22.0	28.4	1.6	10.7	381	1.0	13.7	7.72	545
2	827	78.5	21.0	30.5	1.7	0.8	395	4.0	17.2	7.90	545
2	854	15.9	4.4	7.5	1.4	0.8	78	4.0	1.8	7.80	100
2	877	19.3	5.3	10.5	0.5	0.3	98	5.0	1.6	7.45	133
2	887	20.0	6.0	10.8	0.4	0.5	105	4.3	1.3	7.65	130
2	894	20.0	6.5	11.1	0.3	1.0	107	3.6	2.4	7.46	144
2	903	21.9	5.7	10.7	0.2	0.4	110	4.1	1.9	7.48	166
2	906	20.6	6.3	10.3	0.1	0.3	115	5.0	1.7	7.25	161
2	922	28.7	7.9	12.4	0.1	0.7	146	5.0	2.1	7.80	211
2	932	30.0	9.0	13.7	0.0	0.6	161	4.5	2.4	7.50	227
2	937	33.1	9.1	13.0	0.3	0.4	163	4.4	2.6	7.60	259
2	953	32.4	9.3	13.0	0.4	0.4	161	3.4	2.4	7.50	230
2	958	31.3	8.8	14.1	0.5	0.6	153	6.2	2.0	7.40	186
2	968	26.9	7.9	11.5	0.0	0.2	139	2.2	1.6	7.55	61
2	981	23.4	7.8	10.0	0.8	0.9	119	4.2	1.7	7.78	153
2	991	21.3	6.4	10.0	0.5	0.1	105	5.0	2.2	7.60	186
2	994	19.0	6.4	9.1	0.4	0.4	98	4.8	1.9	7.55	193
2	1005	17.0	6.3	9.6	0.6	0.2	97	4.6	2.6	7.40	175
2	1009	18.5	6.0	8.7	0.4	0.4	97	4.2	2.0	7.35	125
2	1031	18.7	6.3	9.6	0.3	0.4	97	4.3	2.2	7.50	120
2	1041	26.0	8.5	12.5	0.3	0.8	140	4.7	3.0	7.40	-1
2A	208	30.0	8.5	11.5	0.4	0.8	177	0.1	2.2	7.80	240
2A	251	24.0	6.2	12.5	0.5	1.5	126	0.5	1.5	7.50	187
2A	272	48.5	12.0	13.6	0.5	0.8	222	0.5	3.3	7.80	340
2A	298	25.5	8.5	13.5	0.5	0.5	141	0.5	2.1	7.50	205
2A	316	35.0	10.4	14.5	0.6	1.0	172	2.3	3.4	7.50	270

continued...

TABLE 8. Continued.

S^b	D^c	CA^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH^d	SC^e
2A	350	77.5	20.0	24.0	1.7	3.1	369	13.2	9.2	8.00	550
2A	480	13.5	4.2	6.8	2.2	0.8	69	4.5	2.1	7.30	115
2A	501	20.0	6.0	10.5	1.0	0.5	121	6.0	1.2	8.30	175
2A	536	22.0	6.7	10.5	0.3	0.4	120	6.7	1.4	7.90	190
2A	564	23.5	7.0	10.5	0.2	0.4	122	5.1	1.0	7.70	196
3	210	45.0	12.8	23.5	2.0	1.0	280	0.5	5.5	7.20	370
3	287	21.5	7.2	14.6	0.5	0.3	131	0.5	0.3	8.00	192
3	316	29.0	10.4	18.0	0.9	0.7	160	7.5	3.0	7.20	250
3	250	47.0	15.4	24.0	1.9	2.1	256	14.2	3.8	7.30	400
3	390	33.5	11.1	19.5	3.3	0.9	191	6.2	3.0	7.10	300
3	410	37.0	13.2	21.0	2.6	1.8	206	8.5	2.5	7.20	320
3	432	38.0	13.0	20.5	2.6	0.8	211	6.0	2.0	7.20	320
3	481	11.0	3.7	7.1	2.0	0.9	60	6.3	1.6	7.10	105
3	502	18.5	6.2	13.0	1.2	0.5	111	7.6	0.7	7.80	170
3	536	21.0	7.2	13.0	0.4	0.6	120	6.3	1.6	7.60	187
3	564	23.0	7.5	13.5	0.4	0.5	123	6.8	1.1	8.00	203
3	593	27.5	9.2	13.5	0.6	0.8	145	7.3	1.2	7.85	206
3A	210	48.0	10.8	2.1	0.5	0.2	219	0.5	0.2	7.30	300
3A	253	49.0	10.2	2.2	0.8	2.0	207	0.5	0.2	7.60	310
3A	287	39.5	9.8	2.3	0.5	4.4	173	0.5	0.6	7.80	320
3A	316	52.0	13.3	2.5	1.0	2.7	224	2.0	0.5	7.20	320
3A	389	48.0	11.9	2.5	1.2	2.8	209	4.5	0.5	7.30	310
3A	410	45.0	11.9	2.0	1.0	0.7	185	4.0	1.0	7.50	300
3A	431	46.0	11.9	2.3	1.2	0.8	201	3.3	0.4	7.70	300
3A	503	31.5	8.0	1.8	0.9	0.4	143	3.4	0.3	7.70	210
3A	537	38.0	9.2	1.9	0.4	0.1	166	5.2	0.6	8.40	260
3A	566	42.0	10.0	1.4	0.1	0.2	183	3.4	0.2	7.85	233

continued...

TABLE 8. Continued.

S^b	D^c	CA^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH^d	SC^e
4	210	60.0	17.5	7.7	1.0	1.0	273	0.5	2.7	7.40	400
4	253	62.0	16.0	7.0	1.0	1.4	263	0.5	1.7	7.60	420
4	287	37.5	12.6	5.7	0.5	0.5	179	0.5	1.3	7.70	280
4	319	62.5	20.3	9.0	1.1	1.9	294	4.5	3.4	7.10	430
4	389	80.0	24.0	9.5	1.6	5.0	378	4.5	1.5	7.30	550
4	410	69.0	16.4	10.0	1.5	19.0	305	6.0	2.7	7.30	460
4	432	87.0	24.5	10.5	1.8	2.4	398	4.5	3.6	7.60	590
4	481	20.0	7.2	2.7	2.0	0.3	96	4.0	1.1	7.50	151
4	502	33.5	11.2	4.6	1.2	0.4	168	7.6	0.8	8.20	250
4	540	41.5	14.0	5.0	1.7	0.9	208	9.2	1.6	7.80	320
4	559	38.0	13.0	4.5	0.3	0.5	191	5.4	1.0	7.90	295
4	564	40.0	13.0	4.8	0.4	0.5	188	4.2	1.0	7.80	296
4	649	39.5	15.0	6.3	1.1	0.5	200	0.1	1.2	7.91	275
5	253	47.0	10.2	8.0	1.0	7.1	201	0.5	1.2	7.40	310
5	295	27.5	9.0	10.0	1.2	1.3	138	1.1	2.2	7.10	230
5	319	41.0	12.5	17.5	1.3	4.8	211	6.4	2.6	7.10	310
5	389	62.0	14.5	9.5	1.4	19.0	280	6.0	1.4	7.00	410
5	414	79.0	22.0	10.0	1.5	4.4	361	5.0	3.2	7.30	530
5	431	68.0	14.6	8.0	1.5	20.0	283	5.8	1.8	6.90	440
5	480	13.5	4.2	4.6	2.2	1.8	66	3.5	1.3	7.20	112
5	502	21.5	7.0	6.4	1.2	0.8	111	8.6	0.5	7.60	170
5	537	30.5	9.2	7.4	0.5	2.6	149	8.1	1.2	7.80	226
5	564	30.0	8.5	7.0	0.3	1.3	132	6.7	1.0	7.70	211
6	209	25.0	7.8	12.0	0.4	0.7	153	0.6	2.3	7.50	220
6	298	22.0	7.2	13.0	0.5	0.3	123	0.6	2.0	7.30	188
6	319	32.0	10.0	14.5	0.5	0.9	164	6.7	2.9	7.10	250
6	480	13.5	4.2	6.9	2.2	0.6	70	4.6	1.8	7.30	117

continued...

TABLE 8. Continued.

S^b	D^c	Ca^{2+}	Mg^{2+}	Na$^+$	K$^+$	Fe	HCO$_3^-$	SO$_4^{2-}$	Cl$^-$	pH^d	SC^e
6	502	18.5	6.0	11.0	0.9	0.4	106	6.0	1.1	7.90	167
6	537	22.0	6.7	11.0	0.1	0.4	124	8.3	1.0	8.30	110
6	549	29.0	7.4	10.8	0.1	-1.0	129	2.8	1.0	7.71	190
6	550	26.0	6.8	10.2	0.3	-1.0	118	3.3	2.0	7.62	176
6	551	29.0	6.4	11.6	0.3	-1.0	116	4.8	2.0	7.63	169
6	552	29.0	6.4	11.3	0.2	-1.0	118	3.5	2.0	7.69	170
6	553	29.0	6.4	11.6	0.2	-1.0	118	3.3	2.0	7.63	171
6	556	29.0	6.6	11.9	0.1	-1.0	124	3.3	2.0	7.71	179
6	559	32.0	6.8	11.5	0.4	-1.0	125	5.2	2.0	7.94	188
6	566	24.0	6.8	11.0	0.1	0.4	124	6.4	1.0	7.65	166
6	570	31.0	6.6	11.9	0.1	-1.0	133	3.1	2.0	7.75	191
6	575	36.0	7.7	12.8	0.2	-1.0	146	4.2	2.0	8.07	211
6	576	38.0	8.2	12.8	0.2	-1.0	157	3.6	2.0	7.85	226
6	583	30.0	8.4	12.5	0.2	-1.0	157	3.8	2.0	8.03	225
6	590	40.0	8.1	12.9	0.3	-1.0	163	3.5	2.0	7.81	241
6	649	25.0	7.5	14.0	0.9	0.3	136	2.8	3.0	7.88	185
7	209	30.0	8.8	10.0	0.4	3.0	167	0.5	1.2	6.50	250
7	320	32.0	10.0	14.5	0.7	1.2	163	6.3	2.2	7.00	250
7	389	68.0	16.7	18.0	0.9	2.5	312	6.9	2.3	7.10	480
7	480	11.5	3.5	6.0	1.8	0.6	60	3.0	1.5	7.40	101
7	502	15.5	4.7	8.5	0.6	0.2	88	5.1	0.5	7.80	137
7	537	20.5	6.0	10.0	0.1	0.2	108	10.0	1.2	7.90	165
7	566	22.5	6.6	10.5	0.1	0.5	115	6.8	0.7	7.80	151
8	236	37.0	12.5	16.5	1.1	4.5	201	-1.0	0.7	6.90	310
8	252	24.5	7.2	16.5	0.8	0.6	140	0.5	0.7	7.40	230
8	272	22.0	7.4	17.5	0.3	0.3	143	1.1	0.6	7.30	200
8	300	19.5	8.0	19.0	0.6	0.2	134	0.5	1.4	7.20	205

continued...

TABLE 8. Continued.

S[b]	D[c]	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
8	319	28.5	10.7	22.0	0.6	0.5	170	6.7	3.1	7.50	270
8	390	64.5	20.0	30.0	1.6	4.8	346	10.1	2.3	7.20	510
8	414	74.0	23.0	27.0	2.5	0.1	394	7.3	5.0	6.90	600
8	431	54.0	17.5	27.5	1.4	12.2	293	6.6	3.2	6.90	460
8	502	18.0	5.7	13.0	1.0	0.3	107	7.1	0.6	7.50	170
8	537	20.5	6.7	15.0	0.3	0.4	124	8.6	1.8	8.20	195
8	566	20.0	6.5	14.5	0.1	0.3	118	7.5	0.9	7.70	160
9	281	21.5	7.8	10.8	0.6	0.2	123	0.5	1.0	7.40	185
9	390	54.0	18.2	30.0	1.3	13.0	307	8.0	2.8	7.00	450
9	480	9.5	3.5	8.0	1.8	0.4	56	5.0	1.5	7.20	96
9	537	18.0	6.7	15.5	0.2	0.3	117	10.4	1.2	8.00	187
9	565	19.0	6.5	14.5	0.1	0.3	113	7.6	2.4	7.70	150
10	222	14.0	6.6	10.5	1.3	0.6	93	-1.0	3.5	6.50	135
10	272	18.0	6.4	9.5	0.4	-1.0	103	0.5	0.1	6.60	154
10	298	21.0	7.2	12.0	1.7	0.1	120	1.3	1.2	7.10	183
10	390	32.5	10.9	19.5	4.6	1.3	218	6.3	2.7	6.70	370
10	427	32.5	11.9	19.5	2.6	0.8	185	7.5	1.4	7.10	295
10	480	13.0	4.8	7.7	1.8	0.4	72	4.3	1.3	7.10	120
10	537	12.5	5.5	8.0	1.1	0.2	79	4.8	0.8	7.40	134
10	565	13.5	5.7	8.1	0.8	0.1	81	5.8	0.5	7.60	120
11	222	22.0	9.1	15.5	0.7	1.0	134	-1.0	7.0	6.80	190
11	277	19.5	7.4	14.0	0.7	0.3	124	0.5	0.7	6.90	177
11	298	22.0	7.2	13.0	0.5	0.2	123	0.5	1.4	7.20	188
11	302	18.5	8.9	15.5	1.0	0.3	120	7.2	0.7	7.20	196
11	390	48.0	17.5	18.0	1.8	7.6	252	10.3	2.4	7.10	390
11	481	12.0	4.7	8.8	2.1	0.4	69	6.5	1.4	7.30	118
11	537	18.5	7.5	12.5	0.2	0.3	113	11.6	1.4	8.30	179
11	565	19.0	7.3	11.0	0.2	0.5	106	8.6	1.1	7.70	147

continued...

TABLE 8. Continued.

S^b	D^c	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH^d	SC^e
12	253	54.0	15.8	3.2	0.8	2.0	237	0.5	0.3	7.60	390
12	287	38.0	13.6	3.5	0.4	0.3	177	0.5	0.6	7.90	275
12	428	144.0	72.0	8.5	3.5	1.0	878	8.5	2.0	7.80	1200
12	481	19.5	7.2	2.0	1.7	0.6	90	5.2	0.9	7.50	142
12	538	36.0	13.0	3.1	0.4	0.3	177	7.2	1.4	7.80	265
12	565	38.5	13.2	2.7	0.1	0.4	184	5.4	0.5	8.00	231
13	211	35.0	10.5	22.5	0.9	0.8	217	1.2	2.2	7.60	290
13	221	38.0	11.2	21.0	0.9	1.5	218	4.5	2.4	7.60	320
13	252	26.0	7.0	15.0	0.6	0.4	142	0.6	1.8	7.60	270
13	298	25.0	8.5	10.0	0.6	0.9	131	1.1	1.0	7.50	200
13	389	69.0	19.5	29.0	2.0	28.0	374	10.8	3.0	7.00	590
13	428	66.5	18.2	26.0	1.3	43.5	345	6.0	5.1	7.20	520
13	483	16.0	5.0	9.1	1.7	1.4	85	5.8	2.3	7.30	131
13	538	23.0	6.7	13.0	0.1	0.2	128	9.7	1.2	7.90	195
13	566	23.5	6.8	13.5	0.0	0.2	132	6.8	0.9	8.10	172
14	252	19.0	4.9	5.5	0.4	0.4	91	0.5	0.3	7.40	140
14	298	18.5	5.7	6.5	0.2	0.4	93	0.5	0.5	7.20	145
14	389	50.5	13.7	10.0	0.9	7.6	234	6.4	1.2	7.10	370
14	428	64.5	17.5	12.0	1.2	15.0	290	11.1	1.2	7.10	460
14	482	10.0	3.0	4.0	1.1	0.5	51	4.0	0.8	7.30	82
14	566	18.0	5.0	4.3	0.1	0.3	82	4.7	1.1	7.80	110
30	481	28.5	7.5	1.5	1.5	2.0	125	1.8	0.6	7.40	185
R1	990	22.9	7.1	8.0	0.4	0.1	110	4.4	1.8	7.60	189
R2	990	7.8	1.5	2.9	0.0	0.1	30	2.7	1.6	6.82	190
R3	990	20.0	6.4	10.5	0.4	0.1	99	8.2	2.2	7.38	182

continued...

TABLE 8. Concluded.

[a] Concentrations in mg/L; -1 indicates the constituent was not analyzed.

[b] Sites R1 to R3 are grab samples from various locations along Hartley Creek.

[c] Day of sampling in consecutive numerical order 1 Jan. 1976 = day 1.

[d] Expressed in pH units.

[e] Specific conductance expressed as μs/cm.

TABLE 9. Summary of chemical data[a] for muskeg water.

S[b]	De[f]	D[c]	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
1	0.0	559	7.5	1.6	2.0	0.0	-1.0	22	7.2	1.4	6.50	50
1	0.0	878	14.5	5.5	16.5	0.7	0.2	90	8.5	3.3	6.82	135
1	0.0	894	22.0	7.0	17.5	0.2	0.1	138	4.8	3.8	7.30	200
1	0.0	937	16.6	6.0	16.5	0.3	1.1	99	8.7	3.6	6.90	164
1	0.0	953	22.0	7.7	17.0	0.5	0.5	122	9.8	2.7	6.70	193
1	0.0	967	19.0	6.9	18.0	0.7	0.6	116	5.5	4.3	6.90	186
1	0.0	991	18.0	6.6	16.5	0.6	0.1	108	5.7	3.6	7.05	190
1	1.2	559	17.8	3.1	4.4	0.6	-1.0	82	4.2	2.0	7.21	130
1	2.4	559	32.0	6.5	7.2	1.5	-1.0	133	8.0	6.5	7.40	221
1	4.9	559	43.5	9.9	8.1	2.0	-1.0	192	7.6	2.0	7.69	280
2	0.0	559	0.7	0.5	2.0	0.6	-1.0	0	6.0	2.0	3.10	26
2	1.2	559	14.0	2.1	8.5	1.6	-1.0	56	10.5	6.0	7.12	108
2	2.4	559	9.1	1.5	5.7	2.1	-1.0	33	8.1	4.0	6.30	109
2	4.9	559	18.4	2.1	3.2	0.8	-1.0	6	22.8	1.8	5.50	163
3	0.0	559	23.9	7.1	18.2	0.4	-1.0	95	3.2	4.0	7.32	252
3	4.3	559	57.0	10.0	127.0	43.0	-1.0	516	9.9	4.0	8.23	780
4	0.0	559	45.0	3.0	167.0	3.0	-1.0	494	15.2	8.0	8.30	920
4	0.0	585	38.0	0.9	195.0	2.8	-1.0	631	14.4	9.0	7.68	930
4	0.0	862	3.0	1.0	209.0	1.7	0.2	482	17.4	3.2	7.35	660
4	0.0	879	2.0	0.5	227.0	0.5	0.4	558	11.4	6.8	7.75	800
4	0.0	894	2.2	0.8	226.0	0.8	0.1	569	17.0	7.1	7.67	768
4	0.0	906	1.5	0.9	185.0	1.0	0.1	501	17.0	7.3	7.53	669
4	0.0	937	5.5	0.9	228.0	1.2	1.9	609	11.9	6.8	7.40	909
4	0.0	967	5.8	1.5	265.0	2.9	1.3	693	18.2	9.5	1.98	867
4	0.0	990	7.2	1.6	235.0	5.6	0.3	623	21.0	1.5	8.15	890
4	0.0	1006	7.0	2.3	183.0	4.6	0.2	499	12.0	1.7	7.55	700
4	2.4	585	41.0	2.1	216.0	4.8	-1.0	638	57.5	8.0	8.24	1080

continued...

TABLE 9. Continued.

S[b]	De[f]	D[c]	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
4	4.9	559	10.0	1.5	249.0	3.7	-1.0	684	29.0	16.0	9.13	1015
4	6.7	559	10.0	1.6	267.0	3.8	-1.0	697	26.7	32.0	8.82	1055
4	6.7	585	37.0	5.1	50.0	1.7	-1.0	212	15.3	4.0	8.45	354
4	6.7	877	2.0	0.5	280.0	1.6	0.1	564	32.3	15.5	9.02	930
4	6.7	906	0.5	0.9	246.0	1.7	0.1	602	31.0	13.0	8.77	1100
4	6.7	937	2.1	0.5	280.0	1.7	0.2	598	33.1	17.0	8.80	1110
4	6.7	967	2.3	0.6	270.0	1.6	0.2	587	35.5	17.0	8.75	975
4	6.7	1006	2.0	0.8	250.0	1.9	0.3	658	38.0	18.5	8.30	950
5	0.0	559	13.9	3.0	4.7	0.2	-1.0	52	5.6	1.0	6.84	89
5	0.0	585	14.3	3.2	4.1	0.1	-1.0	54	8.7	2.0	7.66	90
5	0.0	863	9.0	4.9	3.6	1.2	0.2	47	6.3	2.2	6.38	65
5	0.0	877	10.5	2.4	3.1	0.1	0.1	39	5.2	1.2	6.48	62
5	0.0	894	12.0	2.8	4.0	0.2	0.1	44	6.4	2.6	6.33	71
5	0.0	906	14.8	2.9	3.6	0.3	0.4	50	8.3	2.6	6.41	91
5	0.0	937	16.0	3.0	22.0	0.5	0.9	59	39.4	2.4	6.40	173
5	0.0	953	17.4	3.0	3.7	0.4	0.7	64	5.4	1.4	6.30	92
5	0.0	968	17.0	3.5	4.0	0.4	0.1	67	3.6	1.9	6.68	110
5	0.0	991	16.0	3.0	2.8	0.3	0.1	55	6.1	2.3	6.60	99
5	0.0	1005	12.5	2.7	2.6	0.4	0.2	44	6.6	1.1	6.55	95
5	2.1	559	49.0	8.8	7.8	0.2	-1.0	180	7.4	2.0	7.37	280
5	4.9	559	104.0	13.6	6.2	1.5	-1.0	407	0.5	2.0	7.95	580
5	4.9	559	106.0	12.1	13.8	1.3	-1.0	393	0.5	2.0	8.19	540
5	4.9	863	51.0	9.2	14.2	1.0	0.4	225	5.6	2.2	7.42	285
5	4.9	877	69.5	10.5	16.7	1.8	0.8	293	5.0	3.8	7.45	410
5	4.9	906	75.0	13.0	15.8	0.9	0.4	365	2.0	3.2	7.63	489
5	4.9	937	110.5	15.7	18.7	1.2	1.4	437	2.5	3.0	7.50	629
5	4.9	968	58.0	9.0	12.6	1.8	0.8	235	15.0	4.1	7.10	372

continued...

TABLE 9. Continued.

S^b	De^f	D^c	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH^d	SC^e
6	0.0	559	5.4	2.0	1.3	0.4	-1.0	19	7.6	2.0	6.27	45
6	0.0	863	6.5	5.0	15.8	5.2	0.2	32	3.9	3.0	9.15	150
6	0.0	877	4.0	1.4	1.5	1.0	0.2	13	6.4	1.4	5.85	32
6	0.0	894	5.8	0.2	1.5	0.4	0.5	12	5.6	1.2	6.02	32
6	0.0	906	4.8	1.9	1.5	0.3	0.1	18	7.1	2.4	6.31	46
6	0.0	937	7.6	2.0	1.4	0.1	0.3	21	8.5	1.4	5.90	45
6	0.0	953	8.0	2.0	1.5	0.9	0.9	28	5.6	1.2	6.00	52
6	0.0	968	7.2	2.0	1.7	0.6	0.1	15	5.2	1.8	5.85	99
6	0.0	991	9.0	2.0	0.1	0.0	0.1	25	5.5	2.0	6.38	95
6	0.0	1005	7.0	2.3	1.2	0.8	-1.0	25	5.4	1.1	6.10	90
6	2.4	863	4.0	1.4	1.3	1.6	0.2	12	6.8	1.2	5.90	30
6	2.4	877	9.0	3.7	19.0	5.8	0.1	96	6.4	6.2	7.30	190
6	4.9	585	127.0	12.2	27.7	1.4	-1.0	449	0.5	4.0	7.79	610
6	4.9	863	26.9	41.0	5.8	3.1	0.2	260	2.2	1.2	8.58	400
6	4.9	877	80.0	47.0	6.4	3.5	0.3	529	1.0	2.0	7.82	620
6	4.9	906	59.0	43.0	4.6	3.1	0.5	516	1.0	2.3	7.58	652
6	4.9	937	90.0	43.0	5.2	3.4	1.0	546	2.3	2.1	7.50	760
6	4.9	968	90.0	55.0	5.1	3.4	1.2	557	0.1	2.6	7.70	984
6	4.9	1005	80.0	40.0	5.1	3.7	1.2	505	1.8	2.3	7.68	650
7	0.0	559	14.3	4.3	5.0	0.2	-1.0	68	4.2	2.0	6.80	109
7	0.0	585	25.0	7.4	11.0	0.2	-1.0	140	5.0	2.0	7.58	211
7	2.4	585	46.0	5.4	9.5	0.9	-1.0	165	5.8	4.0	8.46	238
7	4.9	585	106.0	8.5	8.8	1.4	-1.0	204	116.0	2.0	8.01	560
8	0.0	559	29.0	7.0	10.2	0.1	-1.0	127	4.0	1.0	7.08	188
8	0.0	585	13.9	4.1	4.8	0.1	-1.0	66	6.6	2.0	7.39	106
8	3.0	585	114.0	18.0	12.9	0.8	-1.0	421	5.6	4.0	7.74	590
8	4.9	559	97.0	24.0	37.1	4.3	-1.0	490	0.5	5.0	7.95	665

continued...

TABLE 9. Continued.

S^b	De^f	D^c	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH^d	SC^e
9	0.0	862	3.5	1.0	2.9	0.6	0.4	14	6.2	1.1	6.03	35
9	0.0	877	27.0	7.8	19.2	0.1	0.2	146	6.7	3.7	7.22	195
9	0.0	894	30.8	8.5	21.2	0.5	0.3	163	7.1	3.7	7.02	233
9	0.0	906	34.0	8.9	18.5	0.5	0.2	171	9.0	4.0	7.01	270
9	0.0	937	39.0	10.3	20.0	0.6	1.0	188	7.7	4.8	7.10	297
9	0.0	953	43.0	12.5	23.0	1.4	1.3	217	6.5	5.3	7.10	332
9	0.0	967	40.0	11.5	25.5	0.4	0.6	209	3.4	4.7	7.42	300
9	0.0	990	31.0	9.8	20.5	0.4	0.1	165	10.3	4.3	7.45	286
9	0.0	1006	24.5	9.5	19.0	0.9	0.2	147	9.0	3.4	7.45	210
9	3.3	906	103.0	26.5	31.5	3.7	0.0	554	14.7	3.7	7.40	718
9	3.3	967	130.5	44.0	36.6	4.3	0.0	641	0.1	23.0	7.90	585
9	3.3	1006	125.0	30.0	37.0	5.0	0.4	660	3.5	20.0	7.78	800
9	5.7	906	69.0	14.3	44.5	3.5	-1.0	316	1.0	66.0	7.62	649
9	5.7	937	41.9	11.4	47.0	2.6	0.8	260	3.5	35.5	7.70	510
9	5.7	967	38.0	9.4	44.0	2.1	0.8	253	1.8	25.4	7.40	525
9	5.7	1006	27.0	8.3	43.0	2.1	0.8	224	4.2	19.0	7.80	350
10	0.0	867	20.0	5.9	3.2	2.2	0.1	84	6.4	1.5	7.00	120
11	0.0	867	16.0	4.6	10.4	0.9	0.1	84	6.5	1.5	7.02	115
11	0.0	877	17.8	5.0	12.0	0.2	0.0	93	4.5	1.9	7.15	125
11	0.0	894	17.5	5.8	12.5	0.2	0.1	103	4.9	1.6	7.13	147
11	0.0	906	19.0	5.8	11.3	0.3	0.0	102	4.0	1.7	7.13	151
11	0.0	937	23.9	7.0	14.0	0.8	1.7	127	4.0	2.4	7.10	197
11	0.0	953	24.0	7.0	13.0	1.0	0.4	129	2.9	1.4	7.20	189
11	0.0	968	24.2	6.9	13.4	0.8	0.3	132	1.0	2.4	7.35	199
11	0.0	990	21.3	6.0	11.7	0.4	0.0	110	1.9	2.6	7.50	199
11	0.0	1006	17.5	6.0	10.0	0.5	0.0	94	5.2	2.0	7.60	160
11	4.1	906	48.0	12.3	21.0	2.0	2.5	235	10.0	52.0	7.40	485
11	4.1	937	80.0	25.0	28.8	2.8	0.8	428	2.1	21.0	7.10	700

continued...

TABLE 9. Continued.

S[b]	De[f]	D[c]	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
11	4.1	1006	39.0	15.0	25.7	2.5	0.6	284	2.4	4.2	7.50	410
12	0.0	863	6.5	4.9	3.4	1.0	0.2	43	4.4	1.0	6.40	54
12	0.0	878	8.5	2.6	6.5	0.2	0.1	44	4.2	1.5	6.52	70
12	0.0	894	14.5	4.5	7.3	0.5	0.3	71	4.5	1.5	6.57	100
12	0.0	906	13.2	4.3	7.7	0.6	0.4	69	6.5	2.3	6.55	118
12	0.0	937	13.8	4.1	6.6	1.3	0.4	65	4.5	2.6	6.50	111
12	0.0	953	15.0	4.2	8.0	1.5	0.6	79	2.3	1.6	6.70	117
12	0.0	968	17.5	6.4	6.6	0.8	0.1	89	2.7	1.7	6.84	135
12	0.0	991	14.5	4.6	4.1	0.9	0.3	46	21.0	2.4	6.50	105
12	0.0	1005	12.5	4.0	2.1	1.6	0.6	48	8.7	1.0	6.45	95
12	3.4	906	32.4	8.0	14.7	2.4	0.6	266	3.6	9.9	6.96	375
12	3.4	937	35.7	10.1	9.4	2.5	0.1	159	4.1	21.0	6.80	549
12	3.4	967	41.3	11.4	8.1	3.3	0.1	361	0.1	29.1	7.28	400
12	3.4	1005	35.5	11.0	6.5	3.6	0.3	328	2.0	26.0	7.30	400
12	4.5	906	47.5	15.0	8.0	3.2	0.2	169	1.0	29.0	7.60	530
12	4.5	937	29.9	8.6	6.0	1.6	0.6	124	2.2	14.5	7.00	340
12	4.5	968	60.0	14.7	8.0	2.9	0.0	328	0.1	21.0	7.45	425
12	4.5	1005	47.0	16.3	7.9	3.8	0.7	240	2.1	18.5	7.42	425
13	0.0	864	6.0	2.2	1.6	0.9	0.2	24	5.9	1.2	6.32	44
13	0.0	877	16.0	4.3	3.9	0.1	0.3	75	1.1	0.8	6.90	95
13	0.0	906	9.5	2.5	1.6	0.3	0.1	32	6.5	1.7	6.61	58
13	0.0	953	11.4	0.3	2.2	0.4	0.1	46	4.8	1.0	6.50	67
13	0.0	967	10.5	2.9	2.0	0.4	0.1	39	5.5	1.6	6.45	72
13	3.3	953	100.0	17.8	5.7	1.1	0.6	384	3.5	4.8	7.30	542
13	3.3	967	105.0	20.0	4.5	0.5	0.0	436	0.1	16.8	7.60	600
13	4.4	653	80.0	15.5	6.0	1.3	0.2	360	0.8	2.6	7.00	513
13	4.4	968	92.5	15.5	5.8	1.3	0.6	387	0.1	3.6	7.65	585

Continued...

TABLE 9. Concluded.

S[b]	De[f]	D[c]	Ca^{2+}	Mg^{2+}	Na^+	K^+	Fe	HCO_3^-	SO_4^{2-}	Cl^-	pH[d]	SC[e]
14	0.0	878	22.5	6.5	16.5	0.5	0.2	117	5.8	5.0	7.12	160
15	0.0	906	20.0	6.3	15.0	0.2	0.0	122	5.2	3.4	7.24	180
15	0.0	953	25.0	7.5	17.0	0.4	0.1	138	3.1	2.4	7.10	207
15	0.0	967	26.2	7.5	15.5	0.0	0.1	137	6.0	3.0	7.40	244
15	0.0	990	22.9	6.1	10.5	0.6	0.0	109	5.6	2.9	7.32	194
15	0.0	1006	20.5	6.5	10.5	0.7	0.1	98	6.6	3.3	7.60	191
15	2.4	967	50.0	9.6	45.0	1.1	0.1	355	2.0	4.3	7.51	450
15	2.4	1006	40.0	8.5	46.0	1.4	1.2	291	3.6	11.9	7.62	400

[a] Concentration in mg/L; -1 indicates the constituent was not analyzed.

[b] Sites 95 to 99 represent Research Council of Alberta observation wells.

[c] Day of sampling in consecutive numerical order 1 Jan. 1976 = day 1.

[d] Expressed in pH units.

[e] Specific conductance expressed as µs/cm.

[f] Depth of well in metres.

Table 10. Summary of water level measurements.

Piezometer Number	Date Sampled (1978)	Depth (m)
HC-1	10 May	1.05
	30 May	1.08
	17 June	1.35
	26 July	1.71
	9 Aug	1.76
	24 Aug	1.17
HC-2	10 May	2.19
	30 May	2.73
	17 June	3.27
	26 July	P E
	9 Aug	P E
	24 Aug	2.90
HC-4	10 May	0.54
	27 May	0.40
	15 June	0.43
	25 July	0.59
	9 Aug	0.54
	26 Aug	0.47
HC-B[d]4	26 May	0.05
	25 July	P F
	25 Aug	P F
	17 Sept	P F
HC-B5	26 May	0.32
	12 June	0.35
	25 July	0.42
	25 Aug	0.43
Hc-B6S[e]	12 May	0.95
	26 May	2.94
	26 July	4.50
	25 Aug	4.59
HC-B6D	12 May	0.93
	26 May	0.91
	25 July	1.00
	25 Aug	0.95

continued ...

Table 10. Continued.

Piezometer Number	Date Sampled (1978)	Depth (m)
HC-6	10 May	3.02
	30 May	3.42
	15 June	2.92
	26 July	3.40
	9 Aug	3.37
	24 Aug	2.71
HC-7	10 May	3.63
	30 May	2.59
	15 June	2.17
	26 July	2.19
	9 Aug	1.19
	24 Aug	1.88
HC-8	10 May	2.84
	30 May	2.81
	15 June	2.67
	26 July	2.68
	9 Aug	2.60
	24 Aug	2.37
HC-9	10 May	1.37
	30 May	1.05
	15 June	1.44
	26 July	1.70
	10 Aug	1.60
	25 Aug	1.43
HC-B9S	25 Aug	0.52
	17 Sept	0.47
HC-B9D	25 Aug	1.62
	17 Sept	1.92
HC-10	10 May	0.42
	17 June	1.42
	26 July	3.60
	9 Aug	0.56
	24 Aug	0.53
HC-B11	25 Aug	0.47

continued ...

Table 10. Continued.

Piezometer Number	Date Sampled (1978)	Depth (m)
HC-12	10 May	2.13
	30 May	1.29
	17 June	0.84
	25 July	1.40
	9 Aug	1.23
	25 Aug	0.83
HC-B12S	25 July	0.69
	25 Aug	0.50
HC-12D	25 July	0.89
	25 Aug	1.00
HC-13	10 May	P E
	30 May	0.06
	9 Aug	0.42
	24 Aug	0.20
HC-B13S	25 Aug	0.81
HC-B13D	25 Aug	0.22
HC-B14	10 May	3.71
	30 May	5.89
	15 June	5.95
	25 July	5.40
	9 Aug	5.47
	25 Aug	5.88
HC-15	10 May	0.75
	30 May	0.51
	15 June	0.61
	26 July	1.16
	9 Aug	0.97
	25 Aug	0.70
HC-B15	24 Aug	0.34
	17 Sept	0.27

continued ...

Table 10. Continued.

Piezometer Number	Date Sampled (1978)	Depth (m)
HC-18	30 May	0.90
	16 June	0.91
	26 July	1.48
	9 Aug	1.03
	24 Aug	0.82
HC-17	10 May	1.63
	30 May	1.32
	15 June	1.29
	26 July	1.89
	9 Aug	1.42
	25 Aug	1.23
HC-18	10 May	1.95
	30 May	1.08
	15 June	1.10
	25 July	1.09
	9 Aug	1.37
	25 Aug	1.12
HC-20	12 May	5.01
	26 May	5.49
	14 June	5.55
	25 July	5.62
	9 Aug	5.78
	25 Aug	5.68
HC-21	12 May	-
	26 May	1.13
	14 June	1.33
	25 July	2.40
	9 Aug	2.65
	25 Aug	1.45
HC-22	10 May	1.82
	26 May	1.82
	9 June	1.91
	25 July	2.40
	9 Aug	2.33
	25 Aug	2.05

continued ...

Table 10. Continued.

Piezometer Number	Date Sampled (1978)	Depth (m)
HC-23	11 May	1.95
	26 May	1.96
	10 June	2.07
	25 July	2.53
	10 Aug	2.47
	25 Aug	1.91
HC-24	12 May	-
	19 June	4.22
	10 Aug	4.69
	17 Sept	3.28
HC-25	12 May	2.15
	19 June	2.25
	10 Aug	2.38
	17 Sept	2.18
HC-26	12 May	1.98
	19 June	2.03
	9 Aug	2.15
	17 Sept	1.90
HC-27	30 May	0.79
	15 June	2.45
	26 July	3.05
	9 Aug	3.22
	24 Aug	2.85
HC-28	10 May	1.77
	30 May	2.60
	15 June	2.80
	26 July	3.25
	9 Aug	3.32
	25 Aug	2.97
HC-29	12 May	1.23
HC-30	12 May	3.15
	19 June	0.94
	9 Aug	2.75

continued ...

Table 10. Concluded.

Piezometer Number	Date Sampled (1978)	Depth (m)
HC-31	12 May	2.14
	31 June	2.84
	9 Aug	0.81
HC-32	10 May	0.57
	27 May	0.60
	15 June	0.44
	25 July	0.62
	9 Aug	0.60
	25 Aug	0.54

[a] Depth to water from top of casing.

[b] PE - Piezometer empty.

[c] PF - Piezometer full.

[d] Piezometer in muskeg.

[e] D and S designate deep and shallow peizometers at same site.

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

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

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

79.	AF 3.6.1	The Multiple Toxicity of Vanadium, Nickel, and Phenol to Fish.
80.	LS 22.3.1	Biology and Management of Peregrin Falcons (*Falco peregrinus anatum*) in Northeastern Alberta.
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85.	HY 2.5	An intensive Surface Water Quality Study of the Muskeg River Watershed. Volume I: Water Chemistry.
86.	AS 3.7	An Observational Study of Fog in the AOSERP Study Area.
87.	WS 2.2	Hydrogeological Investigation of Muskeg River Basin, Alberta

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

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