INTERIM REPORT ON A HYDROGEOLOGICAL INVESTIGATION OF THE MUSKEG RIVER BASIN, ALBERTA

by

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for

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ABSTRACT

The Muskeg River in northeast Alberta drains a large highland area east of the Athabasca River. The availability of thick, oil sands deposits at depths less than 30 m in parts of the watershed makes this area an obvious candidate for future mining development. The results of this detailed, chemically-based study of waters from major portions of the hydrologic cycle--precipitation, surface water, and groundwater, in addition to providing descriptive details of pre-mining baseline states has provided useful information about groundwater and surface water processes in the watershed.

Baseflow, as it is known in streams in the southern part of the province, probably exists during a few winter months when standing water in muskeg and shallow lakes is frozen and ceases to contribute to streamflow. During times of the year when the muskegs are unfrozen they constitute the bulk of the streamflow. The results of chemically-based hydrograph separation techniques indicate that 12 to 40% of streamflow during the late spring, summer and fall months consists of groundwater with the remainder coming from lake and muskeg drainage, as well as direct precipitation on the stream channels. This preliminary report will form a basis for more detailed evaluation of mining impact on water systems in the Muskeg River basin.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

Over a large area of the Muskeg River basin (Figure 1) less than 30 m of glacial drift overlies thick, oil sand deposits. It is likely that mining and extraction will begin on leases within the basin in the next several years. Thus, it is essential that the physical, chemical, and biological baseline states be evaluated in order to guide the long-term environmental management of the watershed.

Studies in many other areas have shown that groundwater often plays an important role in determining the quantity and quality of surface water outflow from a watershed. This research focuses on the groundwater-surface water interface and is designed primarily to study the hydrogeology of shallow, near-surface goundwater systems and muskeg units within the watershed. More specific objectives of this program are to:

1. Collect and interpret existing hydrogeological data for Muskeg River basin;
2. Collect and interpret hydrogeological data that may be easily obtainable for the watershed;
3. Evaluate the role of muskeg in the groundwater regime;
4. Interpret chemical parameters of streamflow and relate these to features of the groundwater system; and
5. Model the interaction of shallow near-stream groundwater systems and the surface water systems.

The particular orientation of this study toward the chemically-based methodologies is designed to provide a maximum amount of information about the groundwater system with a minimum amount of drilling within the watershed. It is hoped that this strategy can help to overcome two very serious practical problems: the prohibitive costs of conventional programs of hydrogeological study involving piezometer installation and monitoring; and the inevitability of having to make management decisions based upon a very limited quantity of conventional hydrogeologic information. Although such an approach cannot hope to provide detailed information about water table configurations, hydraulic conductivity,

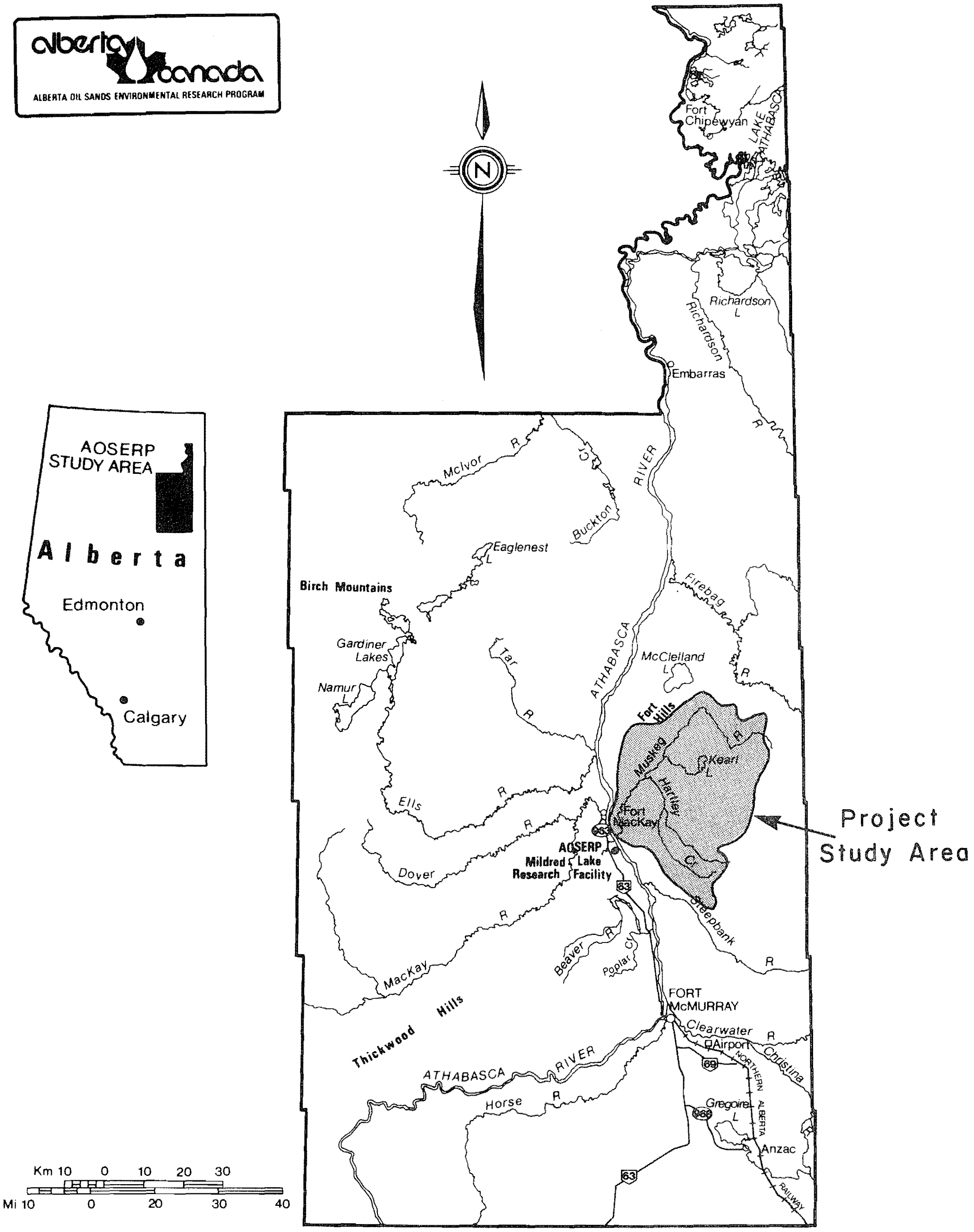


Figure 1. Alberta Oil Sands Environmental Research Program study area location.

distributions, and flow patterns, it should yield significant new information about the nature of groundwater-streamflow interactions and new methods to overcome the problems mentioned previously.

2. REVIEW OF CURRENT KNOWLEDGE

The various events and pathways that describe the movement of water from the atmosphere to the land masses and oceans is termed the hydrologic cycle. In many situations, it is possible to isolate parts or subsystems of the whole cycle for more detailed description. However, isolation of a subsystem, for example the groundwater system, cannot exclude the pathways by which water enters or leaves that subsystem. Methodologies used in this study exploit this concept. By being able to characterize the quantity and quality of water entering or leaving the system, one may gain information about that system.

The term recession refers to the decline of natural outflow from a system in response to the absence of inflow. During a given time period, occasionally all and often at least a portion of streamflow is sustained by the depletion of the groundwater reservoir. This groundwater contribution to streamflow has been termed baseflow (Hall 1968).

Analysis of some characteristics of stream baseflow can provide valuable indications about the nature of the groundwater system. Studies by Schwartz (1970; 1974) in two Canadian watersheds found that the major ion chemistry of the baseflow precisely reflects the major ion chemistry of groundwaters within those watersheds. Other studies for example, Meyboom (1961) showed how baseflow recession characteristics of a stream provide a basis for estimating the quantity of recharge entering the groundwater system.

Other than providing estimates on recharge, recession characteristics can be used to indicate relationships between geology and streamflow. Hely and Olmstead (1963) demonstrated that low flows and baseflows are more directly related to rock type (i.e. hydraulic parameters) than to physiography. Thus, it is easy to see how information about a groundwater system can be determined from stream baseflow characteristics.

The problem of separating the composite hydrograph into components and interpreting these components has been a perplexing one. In addition to the baseflow component, streamflow during storm runoff and snowmelt periods consists of surface runoff, interflow, and direct precipitation (Meyboom 1961; Hall 1968; Pinder and Jones 1969). Surface runoff is that water, which failing to infiltrate, flows on top of the ground surface to the nearest drainage-way. The term interflow refers to the lateral movement of water in the unsaturated zone to surface water systems. Direct precipitation is that component produced by rain falling on the stream or by melting snow on stream ice. Under certain conditions, other components could be present, for example the slow summer melting of glaciers in high elevation watersheds or in the case of the Athabasca Oil Sands area, the delayed drainage of muskeg.

Hydrologists have used a variety of empirical techniques for streamflow hydrograph separation. Practical experience in Canada (Newbury et al. 1969; Schwartz 1970; Sklash et al. 1976) suggests that these conventional methods consistently underestimate the groundwater contribution to streamflow. The hydrochemical techniques for hydrograph separation (Voronkov 1963; Kunkle 1965; Pinder and Jones 1969; Sklash et al. 1976) have been used frequently to yield hydrograph separations that probably account more realistically for the various processes involved. All of the hydrochemical methods are based on the observation that waters proceeding along different pathways in the land-based portion of the hydrological cycle will possess unique chemical features.

Almost all the existing chemical methodologies fit a detailed set of chemical observations of the surface water system to a conceptual model of the watershed. In other words, the chemical dilution behaviour of the stream is simply interpreted in light of chemical processes that are assumed to occur within the watershed. Typical of this approach is the work of Newbury et al. (1969), Pinder and Jones (1969), Schwartz (1970), and Hall (1971).

The approach in this study is different. By actually characterizing the chemistry of major inflow components to the surface water system--groundwater, muskeg drainage, and direct precipitation--it will be possible to develop more realistic conceptual and mathematical models. At this stage of the study, emphasis has been placed on field aspects of the program, involving the chemical characterization of groundwater and muskeg waters. Although work on model development will accelerate in future investigations, the concepts proposed here are workable and will be suitable for application to other watershed systems.

3. MUSKEG RIVER STUDY AREA

3.1 LOCATION, PHYSIOGRAPHY, AND DRAINAGE

Muskeg River (Figures 1 and 2) drains the highland areas east of the Athabasca River. Within a relatively short distance, streams rising at the top of the muskeg covered upland descend approximately 350 m and flow into the Athabasca River.

Locally, the topography is smooth to slightly rolling. The uppermost reaches of the watershed are poorly drained and generally muskeg covered. The regional topographic slope in the middle reaches has facilitated the development of a reasonably well defined surface water drainage system. However, the terrain is only very slightly dissected by the stream channel system. Along steeper and better drained portions of this slope, a mixed deciduous-coniferous forest may be found. The flat-lands in the lower reaches of the watershed along the main stem of the Muskeg River are mantled by muskeg and are generally poorly drained. It is only along the lowermost reaches of the watershed that the surface water system is deeply entrenched.

Although a number of tributaries drain the upland regions of the watershed only two have received formal names. Hartley Creek is the largest western tributary of the Muskeg River (Figure 2). Stanley Creek drains the small upland area north-northeast of the Muskeg River (Figure 2). The only large surface water body in the study area is Kearl Lake (Figure 2).

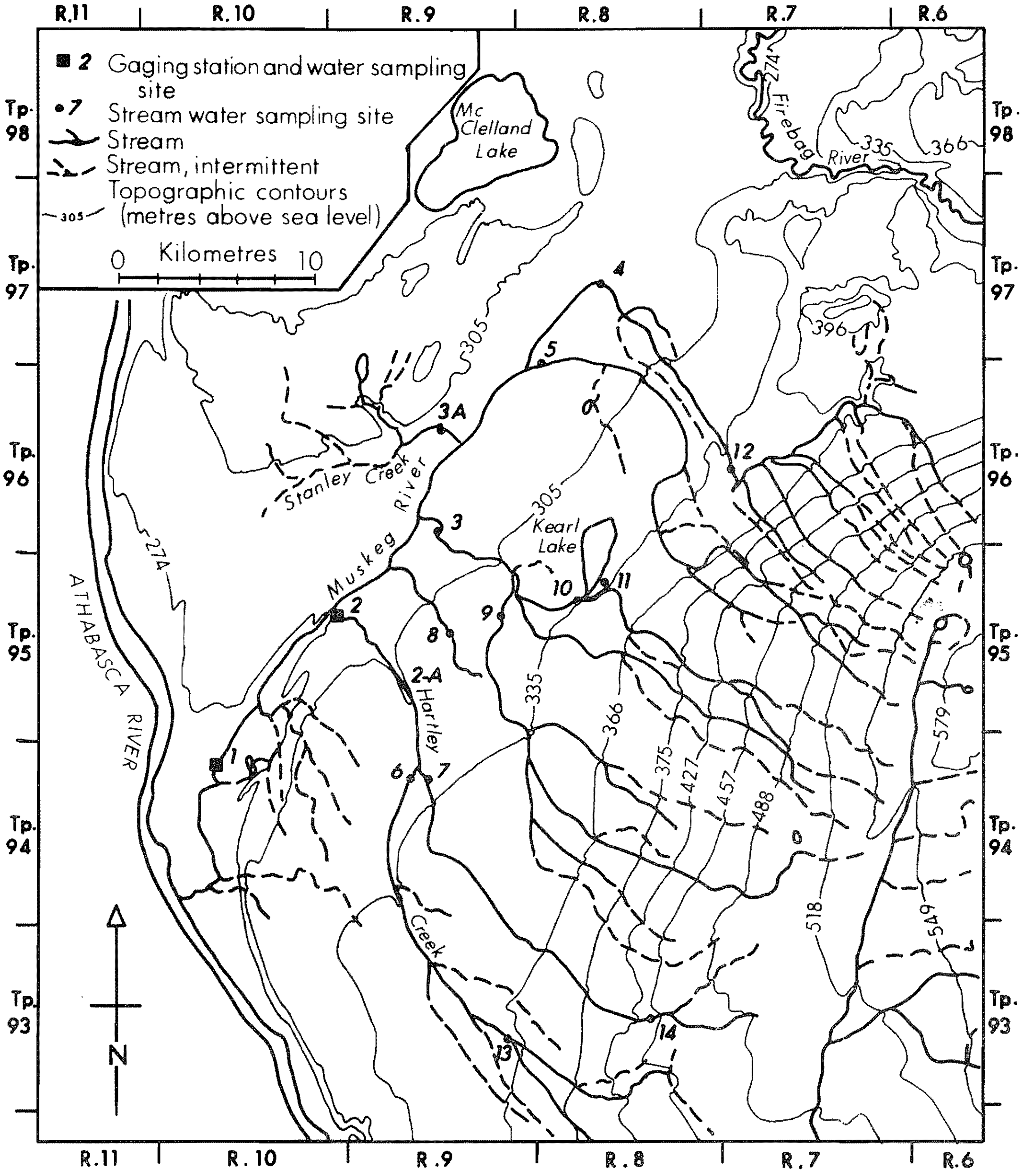


Figure 2. Topography, drainage, and surface water sampling sites in the Muskeg River basin.

4. MATERIALS, METHODS, AND SOURCES OF DATA

4.1 FIELD

4.1.1 Climatological and Surface Water Data

Basic climatological and surface water data necessary for this study were provided by other research projects within the Alberta Oil Sands Environmental Research Program (AOSERP). Accordingly, the detailed technical aspects of how these data were collected will not be discussed here. At the present time, the only climatological information that is being utilized are the summaries of the chemical analyses of precipitation in the Athabasca Oil Sands area. These analyses include determination for major and minor ions and some nutrient species. Almost all of the precipitation samples to date have been rainfall. It is hoped that the sampling program ultimately will include snow fall because of its obvious importance.

The surface water data provided to date has been an integral part of this study. Summaries of mean daily discharge from 1 January 1976 to the present are available for the two permanent streamflow gauging sites (Figure 2) in the watershed. In addition, all the available point-discharge measurements are being obtained for tributary streams. The major and minor ion, and nutrient chemistry of surface waters in the watershed have been characterized as part of AOSERP Project HY 2.5. This entire data set was available and was updated as further results were obtained. The samples were collected from 27 July 1976 to 20 July 1977 at approximately 14 sites.

One problem that is reflected in this set of data was the inability to sample the entire network within a short period of time. In some cases, the sampling period extended over 10 days. During storm runoff periods (spring runoff - rainstorms) when flow conditions are changing rapidly, these delays in sampling and a haphazard pattern of site selection make correlation among the various sites difficult.

4.1.2 Groundwater Instrumentation and Sampling

Thirty-six piezometers or watertable observation wells were emplaced at 28 sites in the Hartley Creek watershed (Figure 3). In all cases, open stand-pipe type wells or piezometers have been utilized. This type of instrumentation basically consists of a stand-pipe with a perforated end section acting as an intake.

Wells or piezometers were constructed from semi-rigid polyvinylchloride (P.V.C.) piping with an inside diameter of 3.175 cm and in the normal case installed in a shallow borehole. In cases where the borehole did not remain open after drilling, it was necessary to complete the well to its proper depth by driving the pipe through the debris blocking the borehole. Steel casing (3.175 cm inside diameter) with drive points as an intake provided the necessary strength and rigidity required to complete the well in this way. The completion details for each piezometer are summarized in Appendix 9.1.

Boreholes up to 10 m deep were drilled using a small power auger. The small size and weight of the unit and accessories are ideal for transport by helicopter. The auger drill was capable of drilling all surficial deposits found in the watershed. However, like all drills of this type, it was unable to drill bedrock.

Groundwater data obtained from these observation wells and piezometers were supplemented by data gathered in a variety of consultant and government research studies in the watershed. The existing information will be discussed in section 9.4.

Although much of this initial field season was involved with installing observation wells and piezometers, preliminary testing began using the shallow well network. Work to date has involved development of the wells by bailing, collection of samples for chemical analysis, water level measurement, and some drawdown response testing. Bailing and sampling were accomplished by using a small diameter pipe with a one-way valve at its base attached to a rope. Using this technique, water samples were collected close

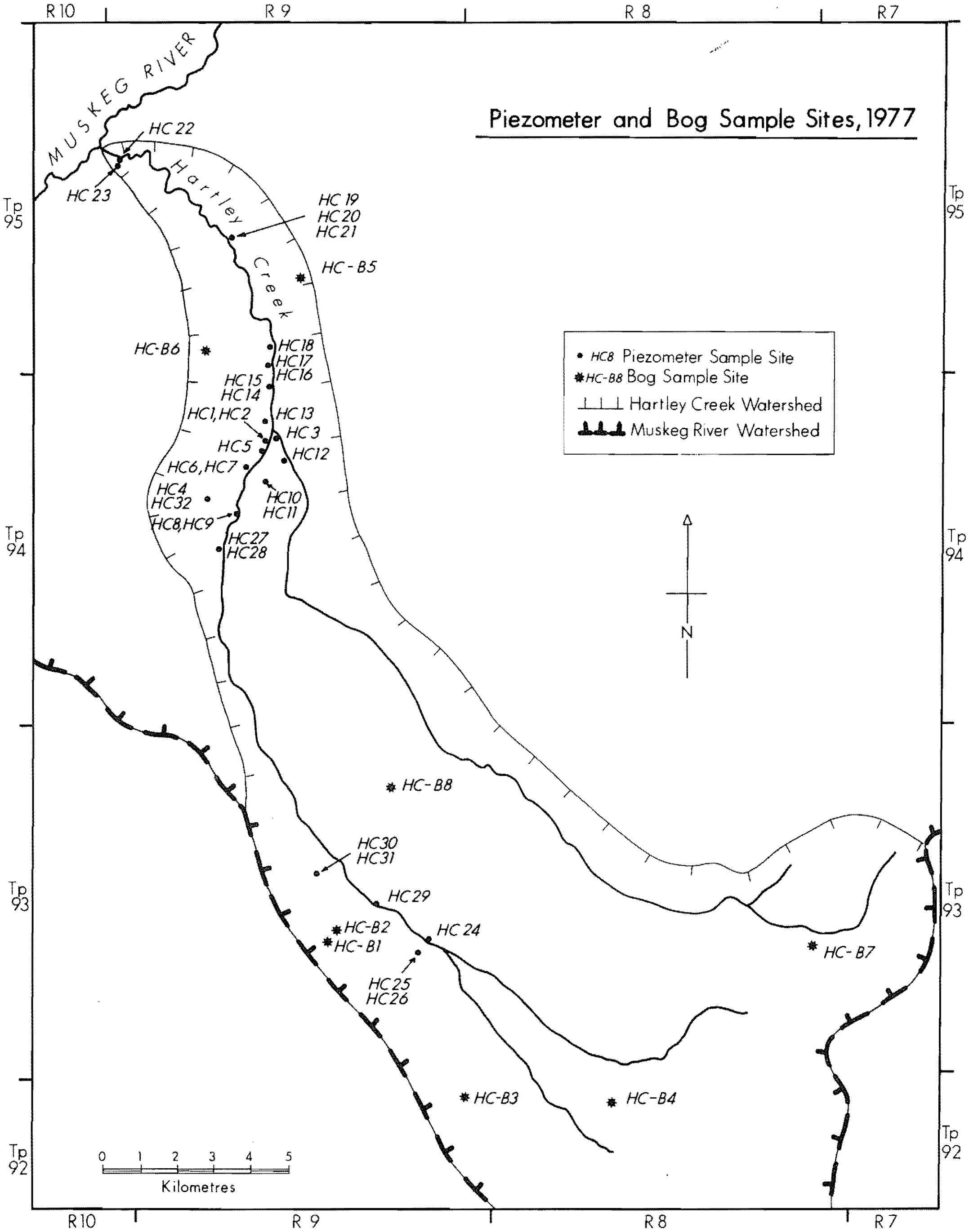


Figure 3. Location of geologic test holes in the Hartley Creek watershed.

to the inlet portion of the observation well or piezometer. In any case, before sampling commenced, the casing was emptied of water and allowed to refill. Each groundwater sample was chemically treated in the field following the normal procedures developed for the AOSERP water quality sampling program (Seidner, in prep.).

4.1.3 Muskeg Studies

A part of this program has involved the investigation of the hydrologic properties of muskeg areas. Eight relatively diverse muskeg terrains were selected for detailed investigation. Emplacement of piezometers in muskeg proved to be a very formidable task. Because the auger drill could not be used in muskeg areas with standing water, it was necessary to drive the 3.175 cm steel casing and drive points from the surface with a heavy pounder. Periodically, driving was halted to collect samples at successive depths within the muskeg. Before sampling, the casing was completely emptied and allowed to refill in order to insure that water was sampled from specific depths.

At six locations, the completed piezometer has been left in the muskeg to facilitate future sampling. Standing water at each muskeg site was also sampled.

4.2 LABORATORY

Work in the laboratory to date has consisted of major ion and environmental isotope (oxygen-18 and tritium) analyses. Where possible complete chemical analyses were conducted by Chemex Labs (Alberta) Ltd., in Calgary. The large number of samples generated in the study has required that some of the analyses be completed at the water quality laboratory in the Department of Geology. However, when piezometers were sampled more than once, usually one of the analyses was conducted by Chemex Labs. (Alberta) Ltd.

Standard methods were used for samples analysed at the University of Alberta. Concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+} ions were determined using a Perkin Elmer model 503 atomic absorption spectrophotometer. Turbidometric and volumetric titration methods were used to determine SO_4^{2-} and Cl^{-} concentrations respectively. Concentrations of HCO_3^{-} and CO_3^{2-} were determined by potentiometric titration. The quality of these analytical procedures was verified by duplicating the determinations for several samples, by repeated checks with standard solutions and comparison to Chemex Labs (Alberta) Ltd. determinations for other samples from the same site.

Oxygen-18 concentrations were determined at the University of Alberta for 39 selected samples of melted snow, surface water, groundwater, and muskeg water. The snow melt samples were provided by researchers in AOSERP and a few of the groundwater samples were provided by D. Hackbarth (Research Council of Alberta). Oxygen ratios were determined by the CO_2 equilibration method of Epstein and Mayeda (1953). Data are reported in the usual delta notation. The standard is SMOW (Craig 1961).

As a preliminary experiment to test the usefulness of tritium analyses to evaluate the source of streamwater, three stream samples were sent for analysis to the Weizmann Institute of Science in Israel. No facilities presently exist in Alberta for this type of analysis.

4.3 DATA ANALYSIS

A wide variety of techniques has been utilized in the preliminary interpretations of the data collected to date. Rigorous description of the techniques is not practical. However, as study results are considered in the following section, references will be cited to guide interested readers to pertinent descriptions of the methods. Most of the techniques are well known methodologies for data interpretation, for example tabulations, statistical summaries, simple graphical representations, multivariate statistics, and mathematical models.

4.3.1 Theory of a Three Component Mixing Model

In spite of the obvious complexity in the manner in which mass and water cycle through a watershed system, it is possible to develop mixing models that utilize the major ion chemistry of inflow components to the stream system to approximate the mixing proportions of the components. A simple model can be developed for the situation where known volumes of water Q_1, Q_2, Q_3 representing groundwater, muskeg water, and direct precipitation with known concentrations of the i^{th} species C_1^i, C_2^i, C_3^i, are mixed together to form streamwater C_4^i. The mass balance equation will take the form:

$$C_1^iQ_1 + C_2^iQ_2 + C_3^iQ_3 = C_4^iQ_4 \tag{1}$$

with the additional condition that:

$$Q_1 + Q_2 + Q_3 = Q_4 \tag{2}$$

This form of the equation assumes that the ion species under consideration does not interact chemically in the surface water system and that ion concentration by evaporation is negligible. The first assumption is reasonable for many of the major ion species that are dealt with here. The second assumption can usually be shown to hold for relatively small surface water systems, such as the Muskeg River system.

Rearranging (1) in the following way provides the working equation:

$$C_1^iQ_1/Q_4 + C_2^iQ_2/Q_4 + C_3^iQ_3/Q_4 = C_4^i \tag{3}$$

It is clear from inspecting (3) that if the concentration of a particular ion species in the groundwater, muskeg water, direct precipiation, and streamwater is known, the only unknowns are the ratios Q_1/Q_4, Q_2/Q_4, and Q_3/Q_4.

It is possible to write a set of equations similar in form to (3)--one for each ion species, for example Ca^{2+}, Mg^{2+}, Na^{2+}, or HCO_3^-. Simple algebraic solution of the resulting set of equations is frustrated by two problems. The problem in most cases is overdetermined. In other words, more than three equations must be solved for only three unknowns. The second problem arises because mean values are used for concentrations. In every case, the use of mean value guarantees that the left and right sides of (3) are only approximately equal.

To overcome these problems, an approximation procedure has been developed that will utilize the entire set of equations. In a systematic manner, each Q/Q_4 value is assigned a value between 0 and 1 in steps of 0.02 with the following condition:

$$Q_1/Q_4 + Q_2/Q_4 + Q_3/Q_4 = 1 \tag{4}$$

After the Q/Q_4 values are selected, the numerical sum of the left-hand side of (3) is compared to the value on the right-hand side. The percentage root-mean-square deviation is calculated for each equation. In most cases, the minimum root-mean-square value points to three Q/Q_4 values which best reflect the manner in which the three main inflow components are combined in the streamflow.

5. RESULTS

5.1 GEOLOGY

5.1.1 Existing Information

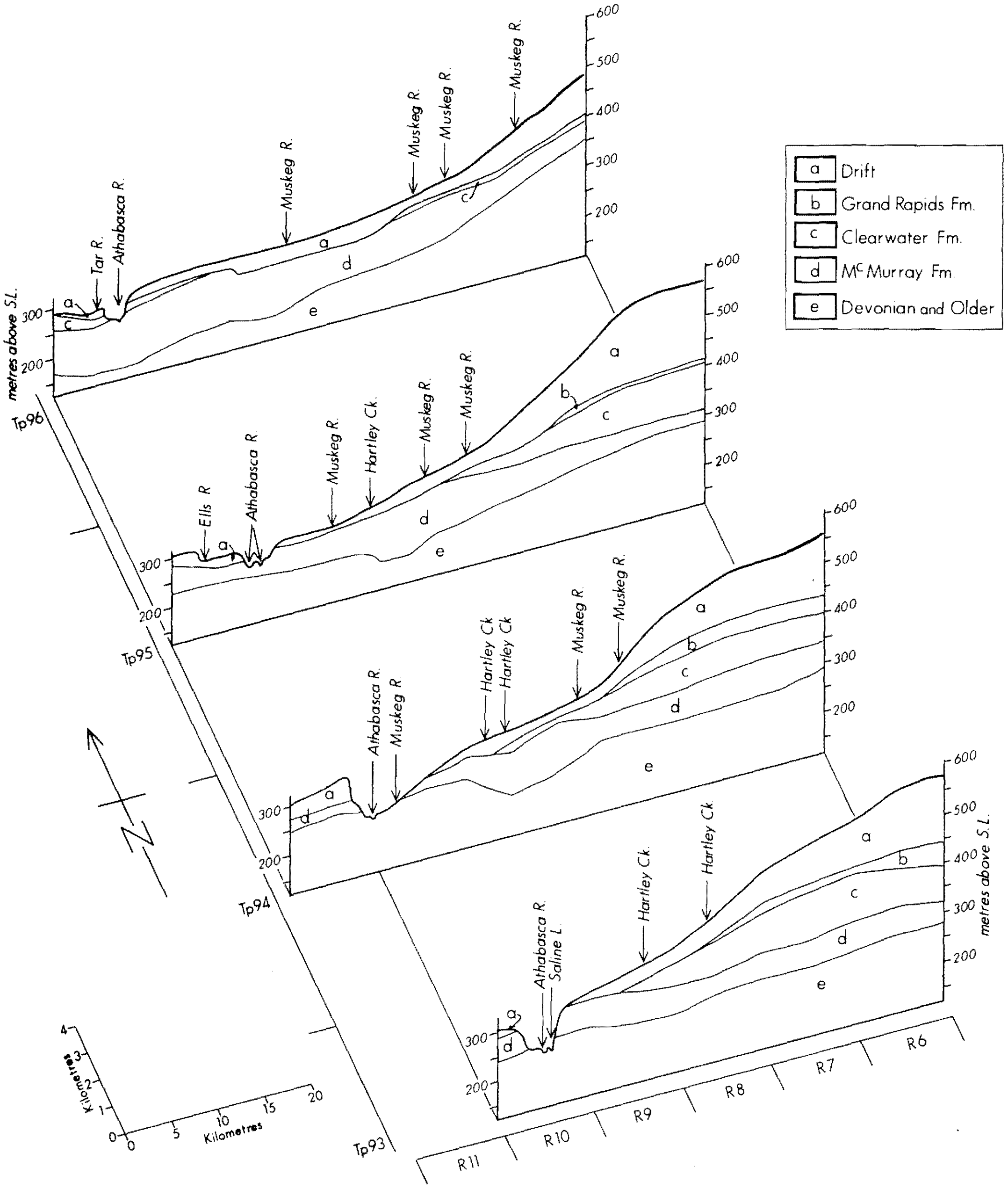
A variety of work has been published on various aspects of the geology of the Athabasca Oil Sands. The existance of these publications provides a reasonable argument for not repeating this material in this report. The interested reader should refer to excellent papers by Carrigy (1959; 1963; 1966; 1967), Carrigy and Kramers (1973), Stewart (1963), Martin and Jamin (1963), Ansley and Bierlmeier (1963), and the Oil Sands Environmental Study Group (1974).

5.1.2 Geology of the Project Study Area

Figure 4 is a three-dimensional representation of the near-surface geology of the Muskeg River basin. The cross-sections are oriented east-west. This description of the geology (Figure 4) is based on published literature cited previously, unpublished structure contour maps prepared by the Research Council of Alberta (Hackbarth in prep.), borehole geophysical records from test drilling in the area, on file with the Research Council of Alberta, and sample logs for test drilling conducted in this study which may be found in Appendix 9.2.

Table 1, which has been modified after Carrigy (1959), summarizes the stratigraphy and lithology of units from the Devonian Beaverhill Lake Formation upward. The thickness of these units in the study area can be determined from the detailed sections (Figure 4).

Most of the surface water systems in the watershed are developed on glacial or post-glacial deposits. As a result, these units are of particular interest. The most recent published work that includes the surficial geology of the study area is a large scale map of the Bitumount sheet (Bayrock 1971). Unfortunately this type of map gives no subsurface information.



GEOLOGY OF THE MUSKEG RIVER BASIN

Figure 4. Three-dimensional representation of the near surface geology.

Table 1. Regional Statigraphy (modified from Carrigy, 1959)

System or Series	Formation or Group	Member	Lithology
Pleistocene and Recent			Glacial and post-glacial deposits of till, silt, and sand
Erosional Unconformity			
Cretaceous	La Biche		Shale
	Pelican		Sandstone
	Joli Fou		Shale
	Grand Rapids		Lithic sands and sandstones
	Clearwater		Shale and sandstone
		Wabiskaw	Sandstone, glauconitic
	McMurray	No. 3 (Upper)	Fine-grained quartz sands, oil-cemented.
		No. 2 (Middle)	Medium-grained quartz sands, oil-cemented, lenticular beds of siltstone, shale, and coal;
		No. 1 (Lower)	Conglomerate, detrital clays and shales, siltstone and coarse-grained sands;
Erosional Unconformity			
Devonian	Woodbend Group Grosmont		Limestone reef
	Ireton		Shale and argillaceous limestone
	Duvernay		Brown limestone and shale
	Cooking Lake		Limestone
	Beaverhill Lake	Mildred	Grey-green and buff, argillaceous limestone
		Moberly	Grey-buff, mottled limestone
		Christina	Green-grey, calcareous shale
		Calumet	Clastic limestone
		Firebag	Argillaceous limestone

The distribution of major surficial deposits over most of the study area is shown in Figure 5. This map and its legend are taken from Bayrock (1971). Notice that most of the upland areas of the watershed are covered with glacial till (Figure 5). The lowlands along the main stem of the Muskeg River are covered mainly by thin outwash sands or ice contact deposits (Figure 5).

A portion of this study is concerned with the detailed chemical evaluation of waters from eight muskeg areas. A description of each of these areas is presented in Appendix 9.3.

5.2 GROUNDWATER GEOLOGY

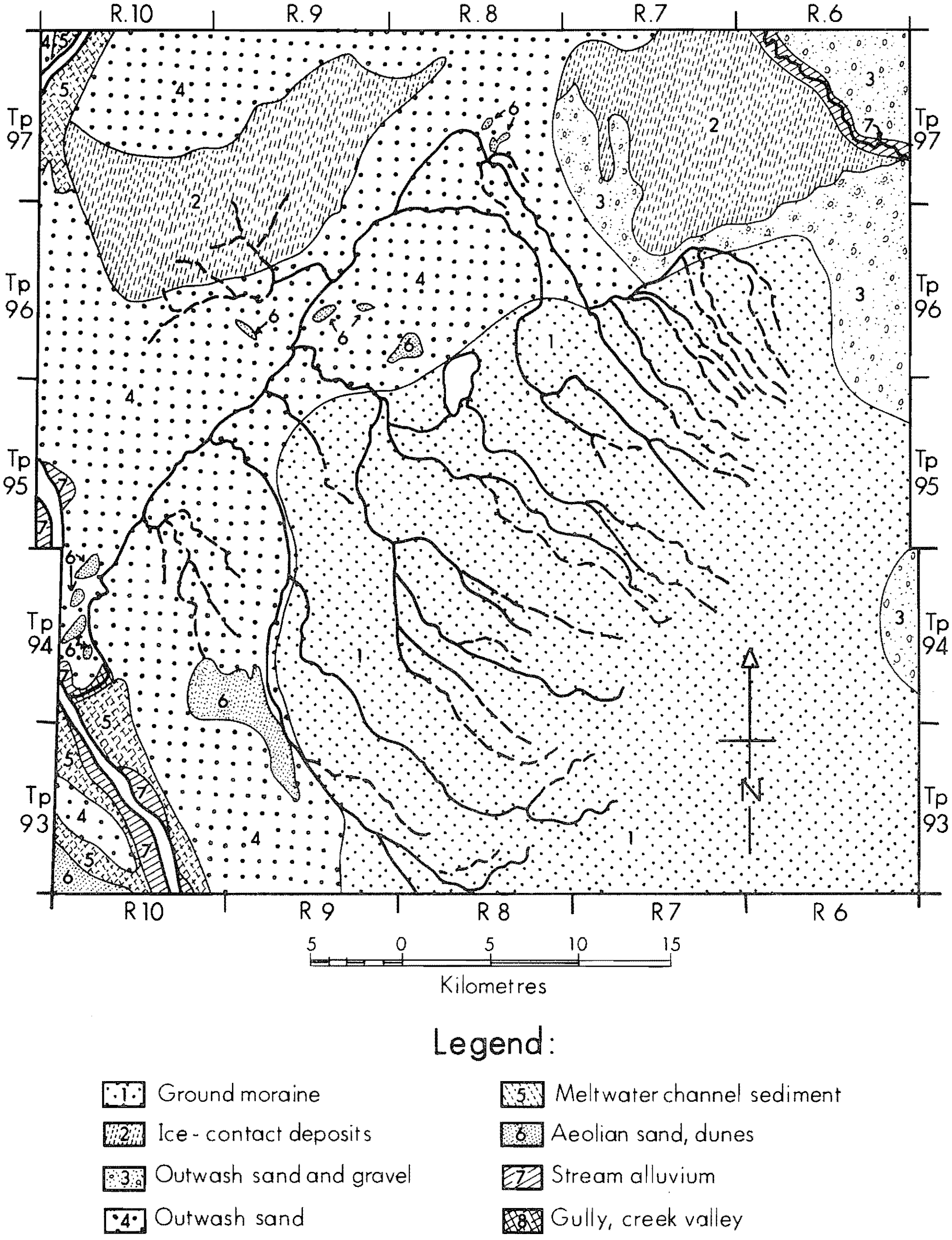
5.2.1 Existing Information - Athabasca Oil Sands Area

Very little hydrogeological data are available for the Athabasca Oil Sands area. Only when the results of regional studies conducted by the Research Council of Alberta are reported (Hackbarth, in prep.), will the amount of regional information be more than preliminary. However, a summary of the results from other hydrogeological studies will be presented in three parts in Appendix 9.4.

The first and second parts are discussions of the hydrogeology and hydrochemistry of the Athabasca Oil Sands area generally and are based on the interpretations presented in the Oil Sands Environmental Study Group (OSESG) (1974) report. In the third part, unpublished data from Tenneco Oil and Minerals Ltd., Home Oil Co. Ltd., and Research Council of Alberta (Hackbarth, in prep.) which relate specifically to the Muskeg River basin are summarized.

5.2.2 Groundwater levels

Because emphasis in this first full field season was placed on the installation of the piezometers, only a relatively small amount of water level data has been collected. These data are summarized in Appendix 9.5. In most cases, depth to the water table ranges from approximately 0.5 to 3.5 m.



(modified from Bayrock, 1971)

Figure 5. Surficial geology map of the Muskeg River basin in the project study area.

5.3 CHEMICAL FRAMEWORK

5.3.1 Major Ion Data

The chemically-oriented approach to the evaluation of water systems requires that detailed major ion data be assembled for all the major components of the hydrological cycle. In the following sections, the data collected to date will be summarized.

5.3.1.1 Groundwaters. As discussed previously, all observation wells and piezometers were completed in surficial materials or very occasionally in the upper few centimeters of the bedrock.

The chemistry of waters from these wells (Appendix 9.6) is characteristic of waters in surficial deposits elsewhere in Alberta. From the statistical summary (Table 2), it is evident that the most dominant cations are usually Ca^{2+} and Mg^{2+} and that the most dominant anion is usually HCO_3^-.

Groundwaters from several of the wells, for example 17, 20, 22, and 24 have important concentrations of Na^+ and Cl^- ions. Samples from these sites are probably influenced by bedrock waters which are typically higher in Na^+ and Cl^- ion concentrations (Appendix 9.4 - Table 3).

In order to interpret possible patterns in the chemical data, a variety of mapping and other data synthesis methods were employed. However, no well defined patterns of chemical variation were observed with respect to depth or on maps. This absence of a well defined chemical pattern is typical of many other shallow groundwater systems in Alberta and is not surprising.

5.3.1.2 Muskeg waters. The results of the analyses of waters collected from muskeg sites are presented in Appendix 9.6. Inspection of these data reveals generally that muskeg waters, defined as the standing surface water in muskeg areas, are more dilute than groundwaters with respect to major ion species and that occasionally a

Table 2. Summary statistics for groundwater chemistry.[a]

	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^-	$SO_4^=$	Cl^-	Specific Conductance[b]
$\bar{x}$[c]	83.30	23.18	22.62	3.19	425.21	4.33	12.84	599.42
S[d]	30.57	6.48	31.12	2.49	119.47	7.00	23.38	148.26
Cv%[e]	934.78	42.03	968.59	6.21	14,273.25	48.96	546.81	21,980.56

[a] 19 analyses used; values expressed in mg/L.

[b] values expressed in μmhos/cm

[c] mean

[d] standard deviation

[e] variance

common pattern of Ca^{2+} cation dominance is broken by muskeg waters with high Na^+ ion concentrations. Presumably, such a situation results from the discharge of bedrock waters into muskeg areas.

At almost all sites, there is a marked variation in major ion concentration with depth. Figure 6 is a series of plots of ion variation versus depth for muskeg sites.

A comparison of samples collected from the surface of the muskeg at two different times (sites, 4, 5, 6, 7, 8) (Appendix 9.6) shows that temporal changes in chemistry are extremely variable. For example, they are small at sites 4 and 5 and large at sites 6, 7, and 8. There are insufficient repeat samples of water from within the muskeg to characterize the temporal variabily in more detail.

5.3.1.3 Surface waters. A list of chemical data relating to the various surface water sampling sites within the watershed is presented in Appendix 9.7. The most complete record exists for sites 1 and 2 which are the locations of the recording stage gauge for Muskeg River and Hartley Creek. In order to illustrate the temporal variability in water quality at these sites, each of the major ions is plotted versus time in Figures 7 and 8. What can be observed is an annual pattern of concentration variation at both sites. Highest concentrations of nearly all ion species are measured during the winter months. Lowest concentrations of all species except K^+ are measured during the spring snowmelt period (Figures 7 and 8). Throughout the summer and fall months, concentrations intermediate to the extreme values are obtained.

Also evident in Figures 7 and 8 is an apparent correlation between concentration and discharge. In Figure 9, the concentration of major ion species at both sampling sites 1 and 2 is plotted versus mean daily discharge. Good correlations exist between Ca^{2+}, Mg^{2+}, Na^+, HCO_3^-, Cl^- and specific conductance. In the case of K^+ and SO_4^{2-} ions, the correlation is poor. As will be discussed in

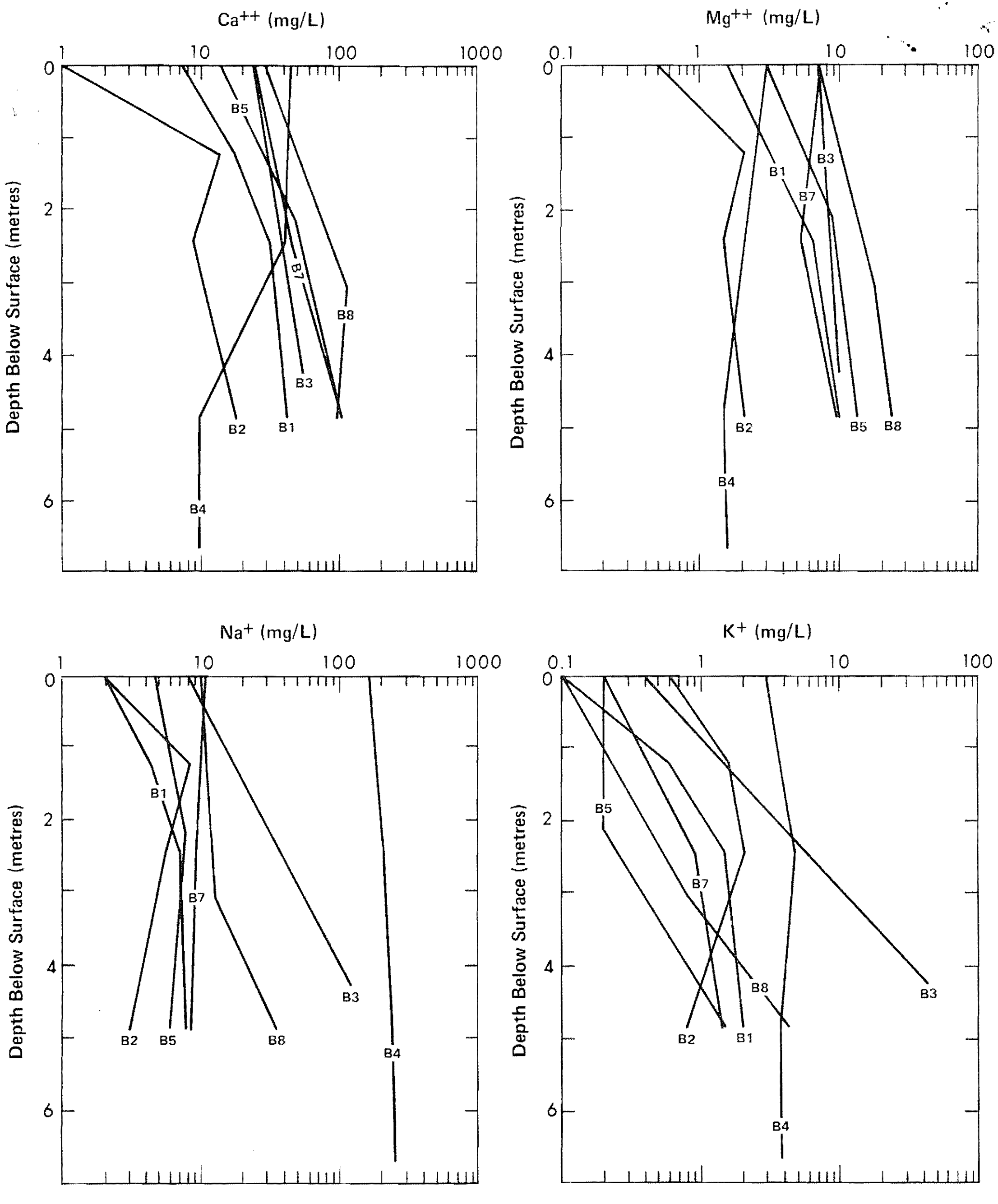


Figure 6. Variation in major ion concentration of muskeg waters with depth.

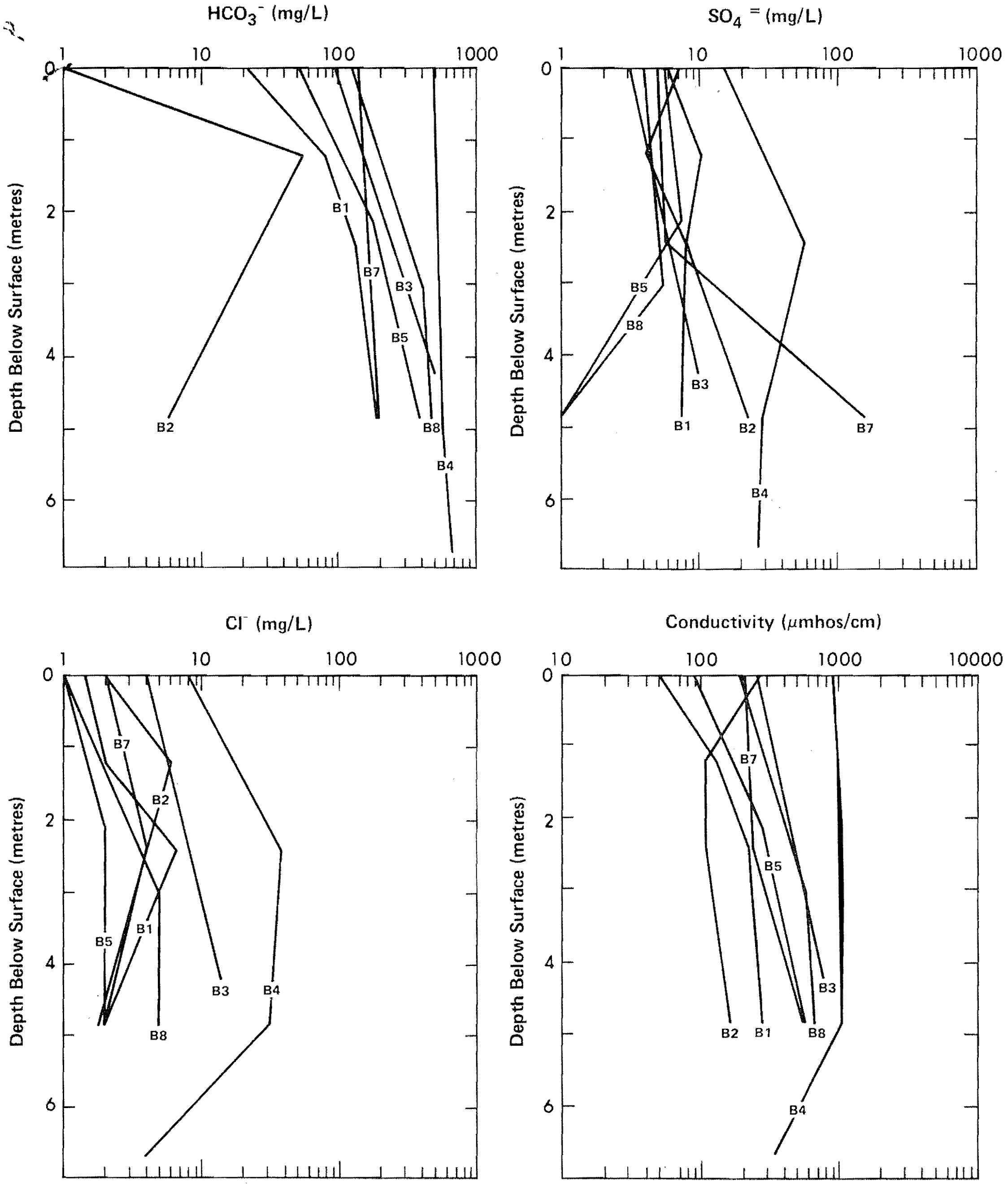


Figure 6. (Concluded).

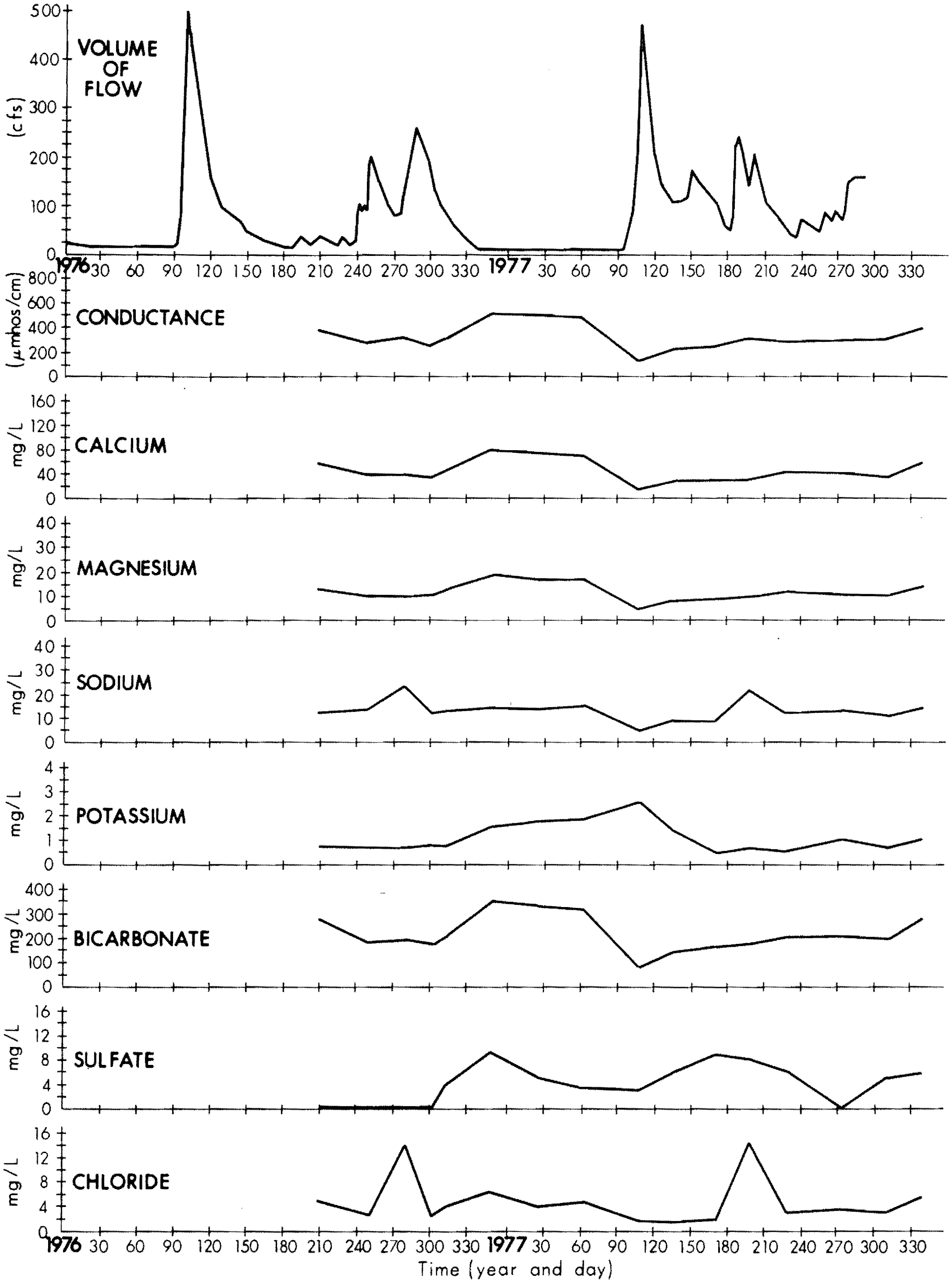


Figure 7. Geochemical and discharge hydrographs for site 1.

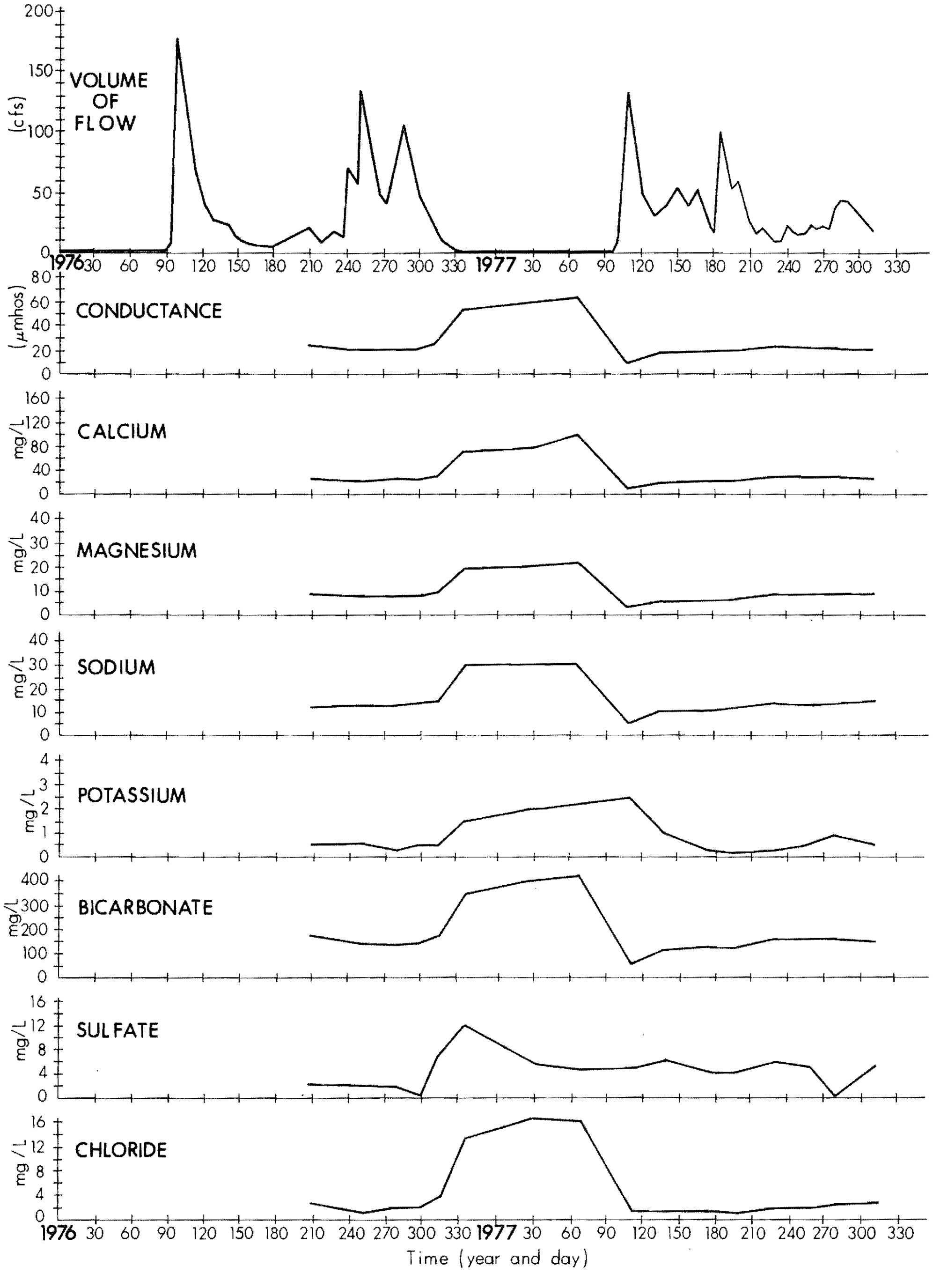


Figure 8. Geochemical and discharge hydrographs for site 2.

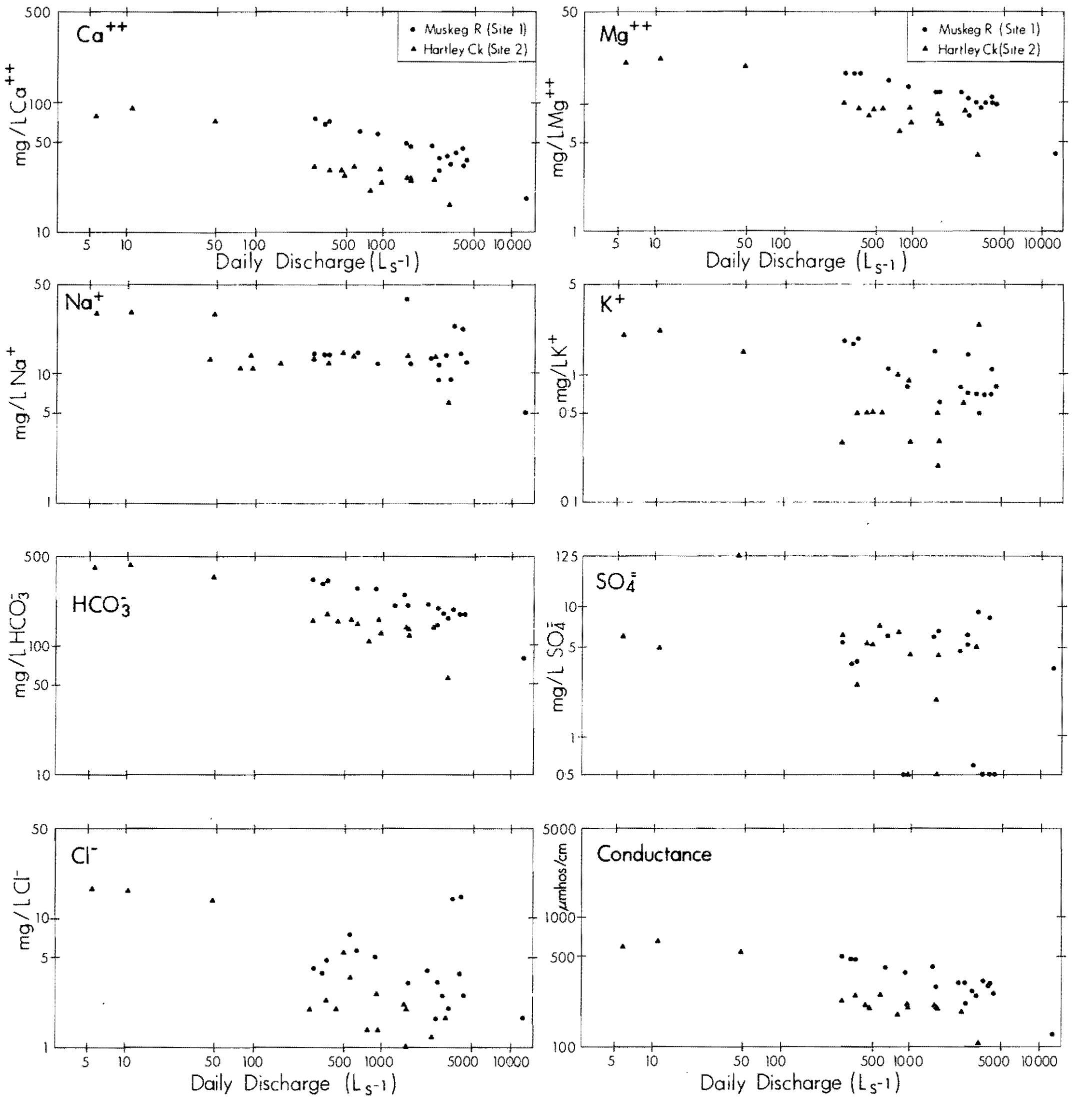
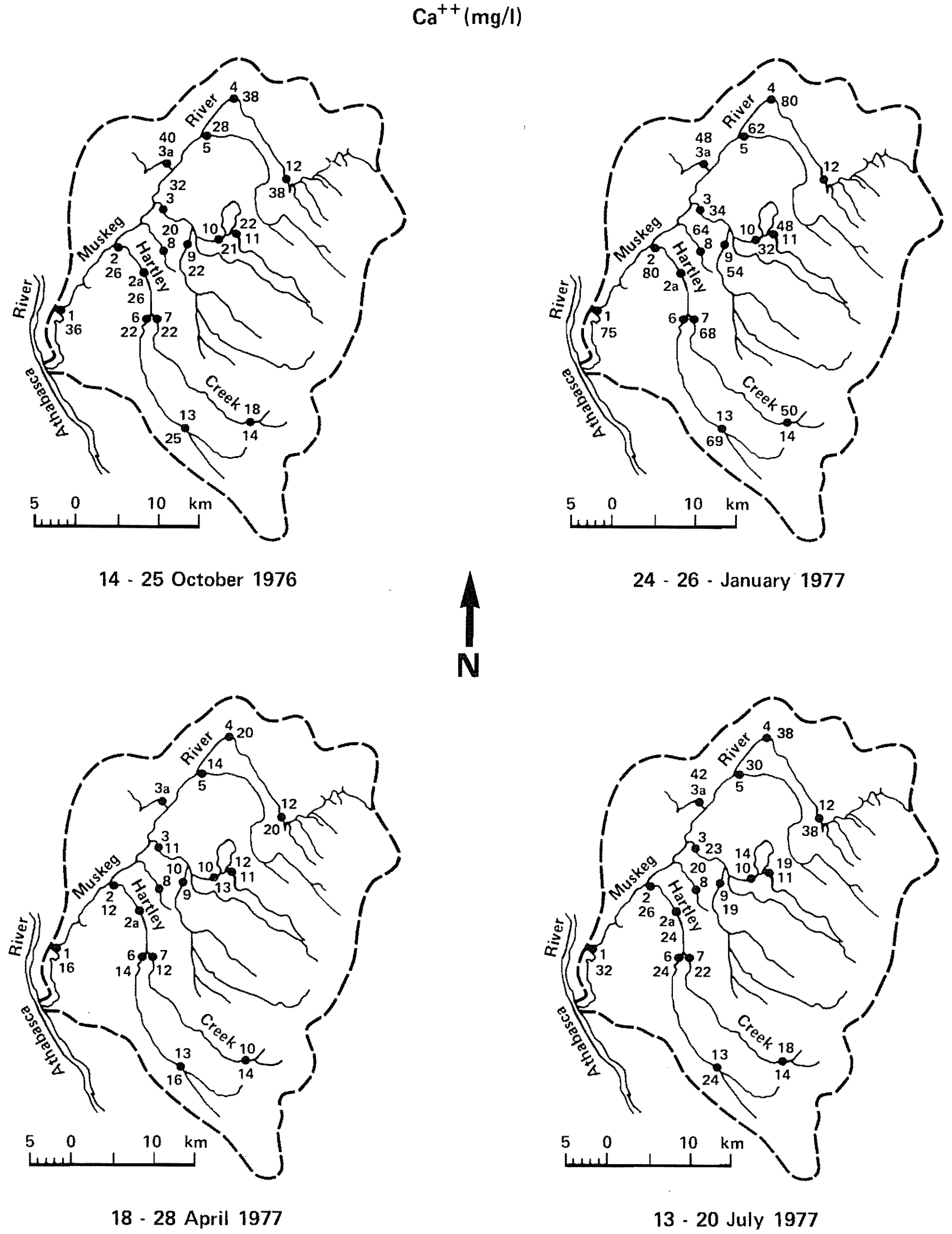


Figure 9. Concentration and specific conductance versus discharge at sites 1 and 2.

a later section, the K^+ ion response to changing discharge exhibits a very interesting cyclical progression on a seconal basis (Gunnerson 1967). Inspection of the extreme scatter in the SO_4^{2-} data simply suggests poor laboratory determinations possibly caused by high concentrations of organic materials.

The series of diagrams which comprise Figures 10 to 17 illustrate the temporal and spatial variability of ions within the watershed. The temporal patterns, which have been described above for sampling sites 1 and 2, appear to hold at all sampling sites within the watershed. However, samples collected downstream from Kearl Lake at sites 10 and 3 (Figures 10 to 17) do not exhibit the wider range in concentrations evident at the other sampling sites. Whereas the stream chemistry at most sites changes seasonally in response to different sources of inflow, the relatively large volumes of water stored in Kearl Lake and upstream Muskeg lakes tend to dampen the seasonal changes in chemistry at sites downstream.

In addition to the obvious temporal variability in the surface water data, there is spatial variability as well (Figures 10 to 17). Because our studies of the watershed to date have concentrated on the Hartley Creek sub-basin, and because this is the only tributary with a reasonable number of upstream sampling sites, the discussion of spatial variability will concentrate on this sub-basin. During periods in the winter (24-26 January 1977), when the discharge was low, there was a consistent downstream increase in concentration of major and minor ion species except for SO_4^{2-} ion (for which the chemical data are thought to be unreliable). During the periods of intermediate flow (October and July 1977; Figures 10 to 17), this pattern was not nearly as consistent. Often the highest concentrations were measured at site 13, for example Mg^{2+}, K^+, SO_4^{2-} in October 1977 (Figures 11, 13, and 15) and Na^-, HCO_3^-, and SO_4^{2-} July 1977 (Figures 12, 14, and 15). The highflow data (April 1977, Figures 10 to 17) could not be interpreted because there was an appreciable time gap in sample collection during a period when stream discharges were rapidly changing.



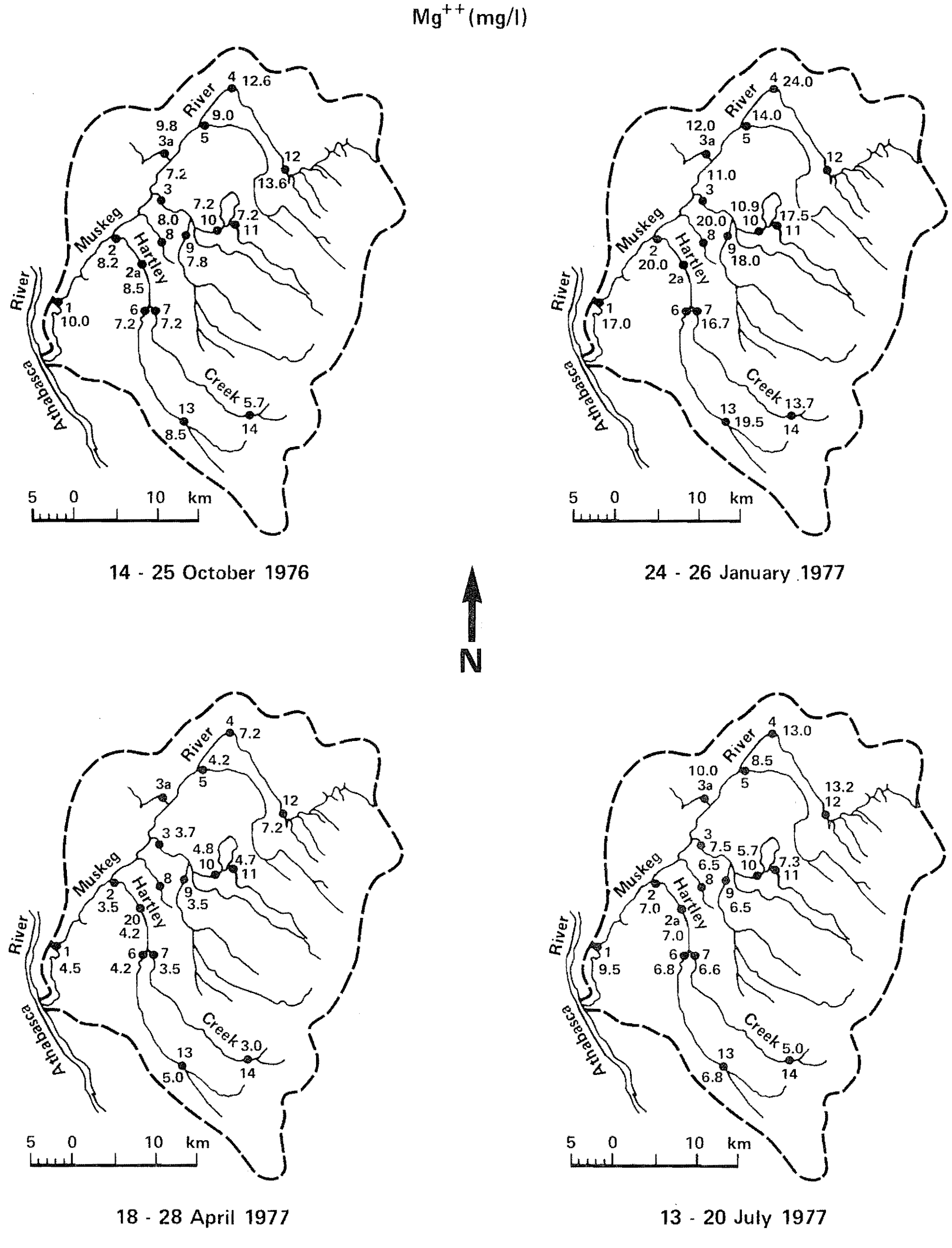
14 - 25 October 1976

24 - 26 - January 1977

18 - 28 April 1977

13 - 20 July 1977

Figure 10. Areal variation in calcium concentration of stream samples.



14 - 25 October 1976

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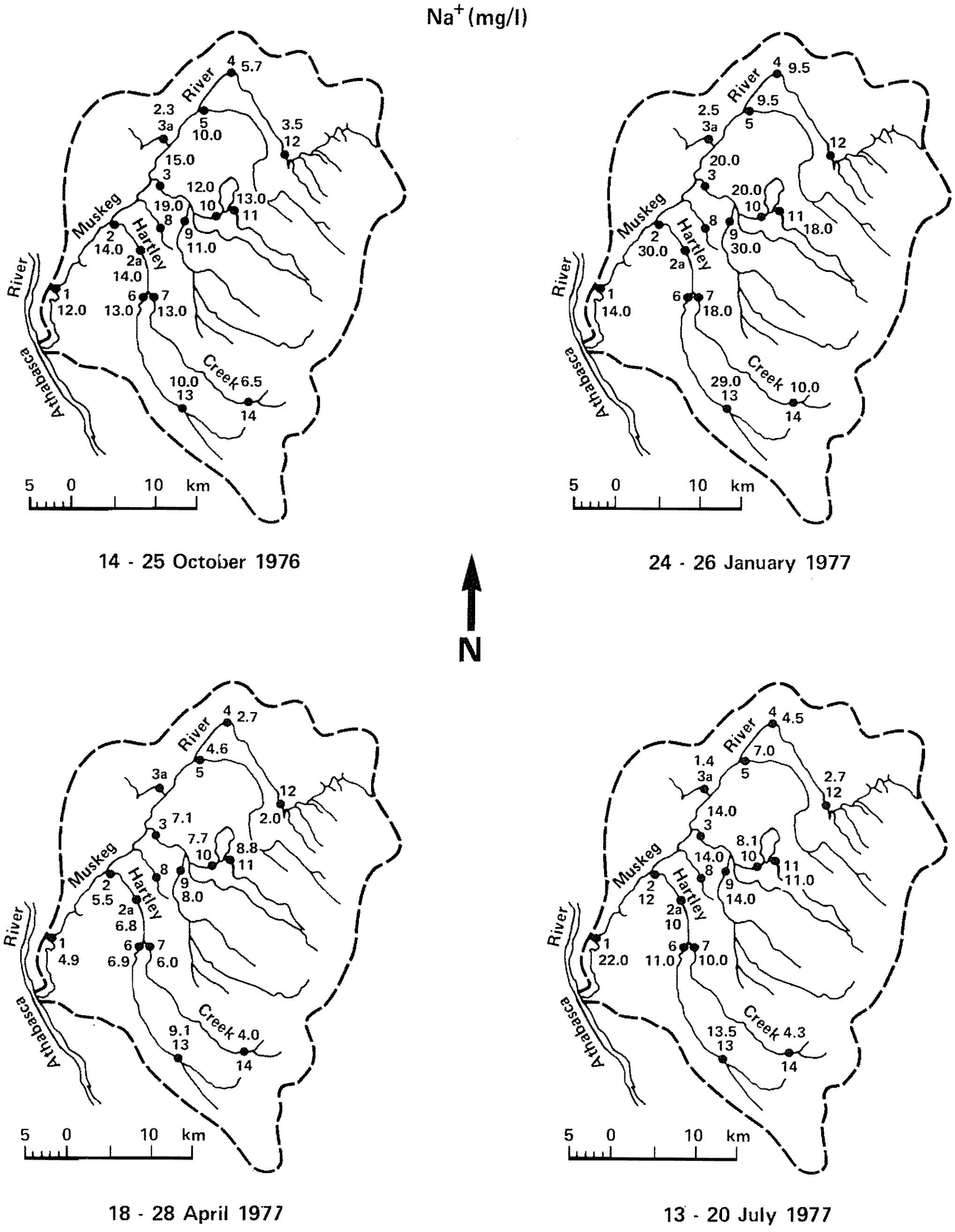
18 - 28 April 1977

13 - 20 July 1977

Figure 11. Areal variation in magnesium concentrations of stream samples.



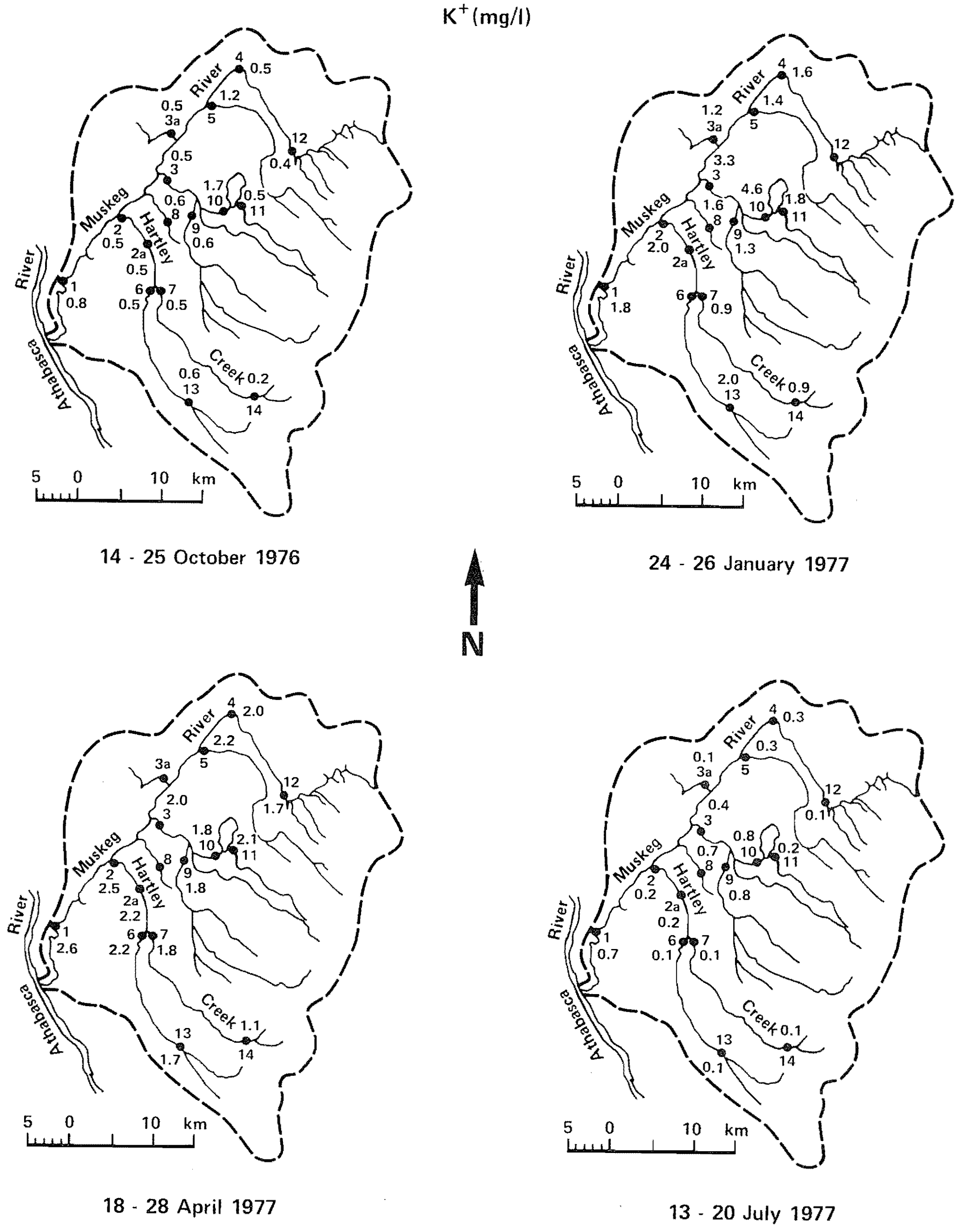
14 - 25 October 1976

24 - 26 January 1977

18 - 28 April 1977

13 - 20 July 1977

Figure 12. Areal variation in sodium concentrations of stream samples



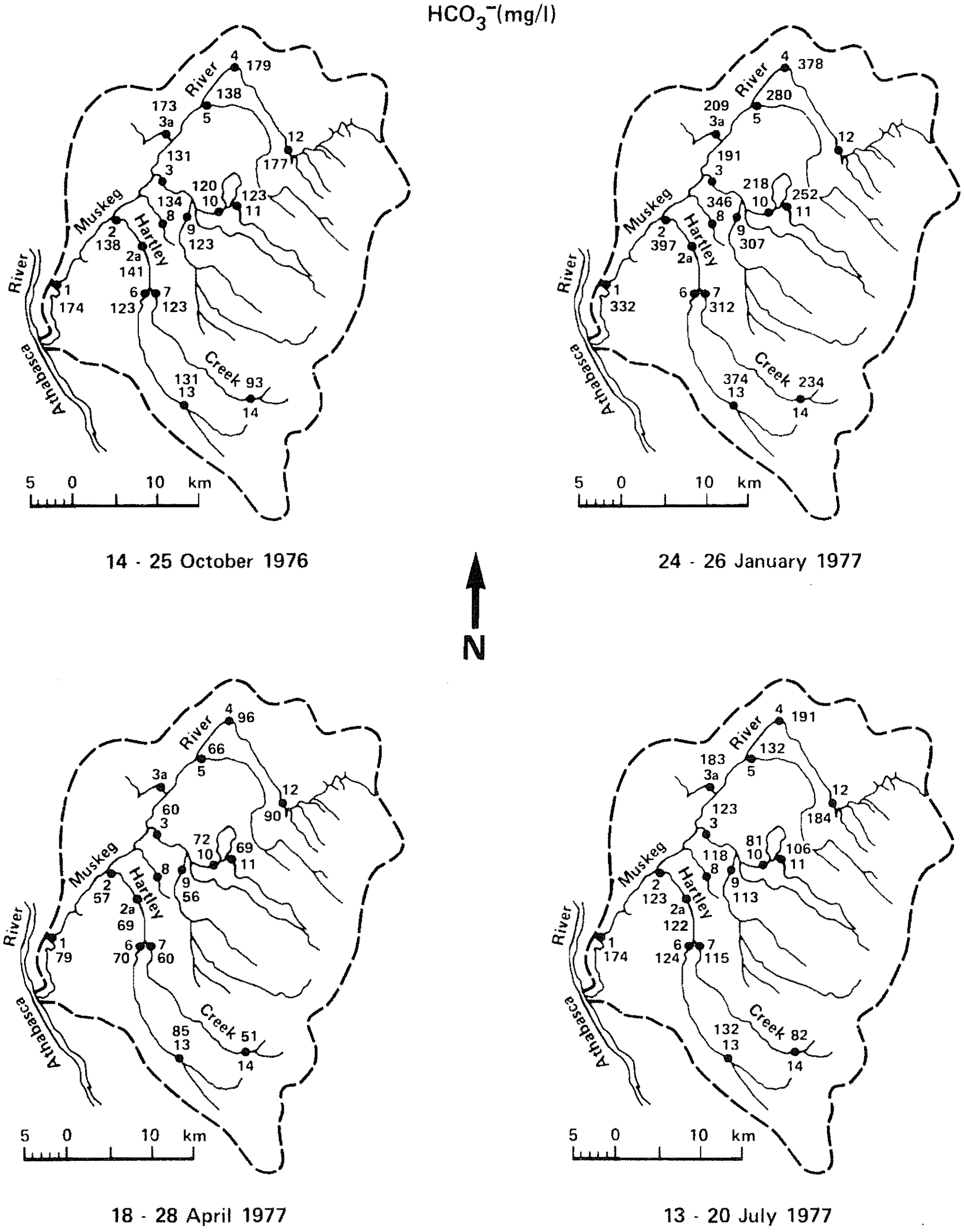
14 - 25 October 1976

24 - 26 January 1977

18 - 28 April 1977

13 - 20 July 1977

Figure 13. Areal variation in potassium concentrations of stream samples.



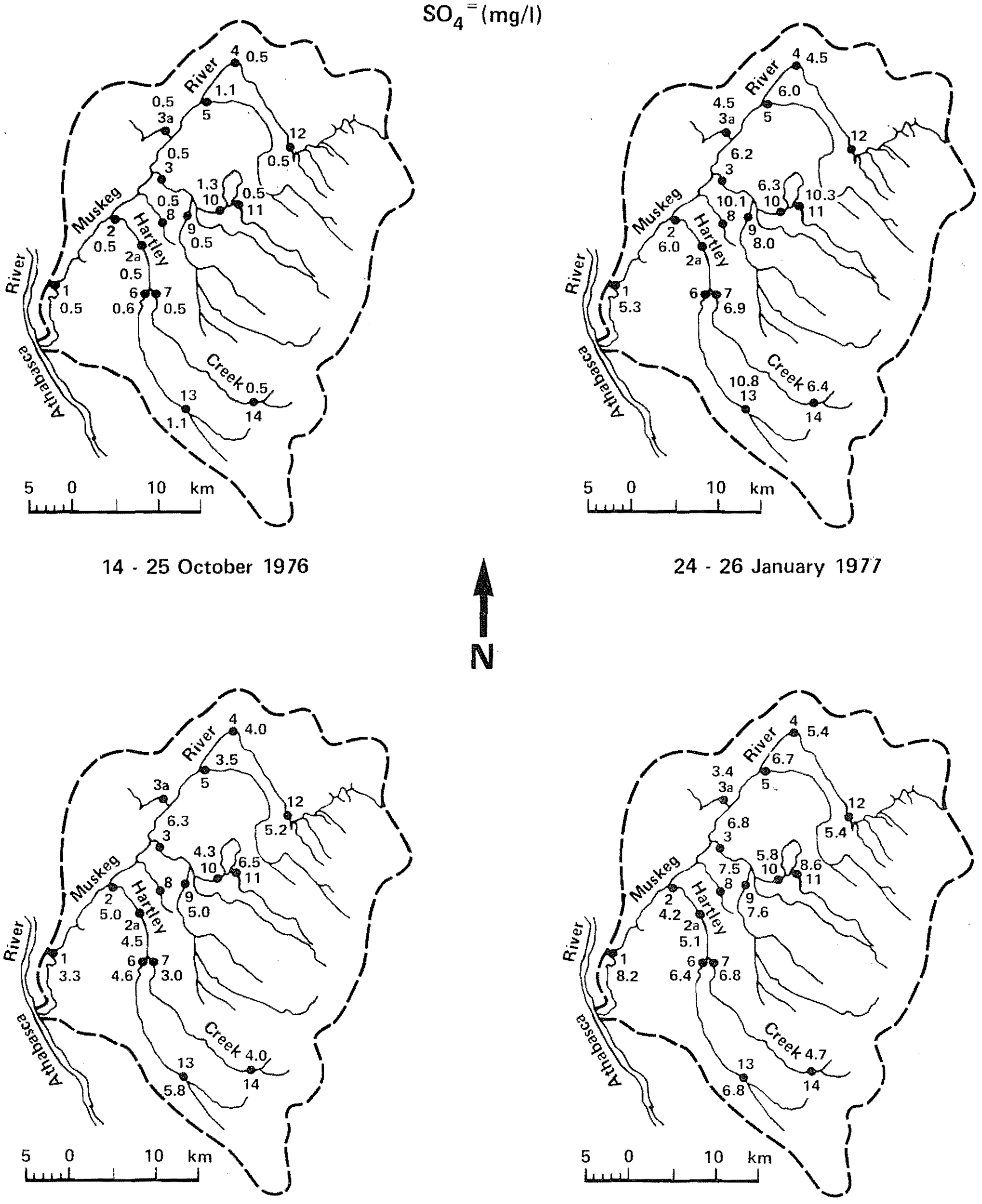
14 - 25 October 1976

24 - 26 January 1977

18 - 28 April 1977

13 - 20 July 1977

Figure 14. Areal variation in bicarbonate concentrations of stream samples.



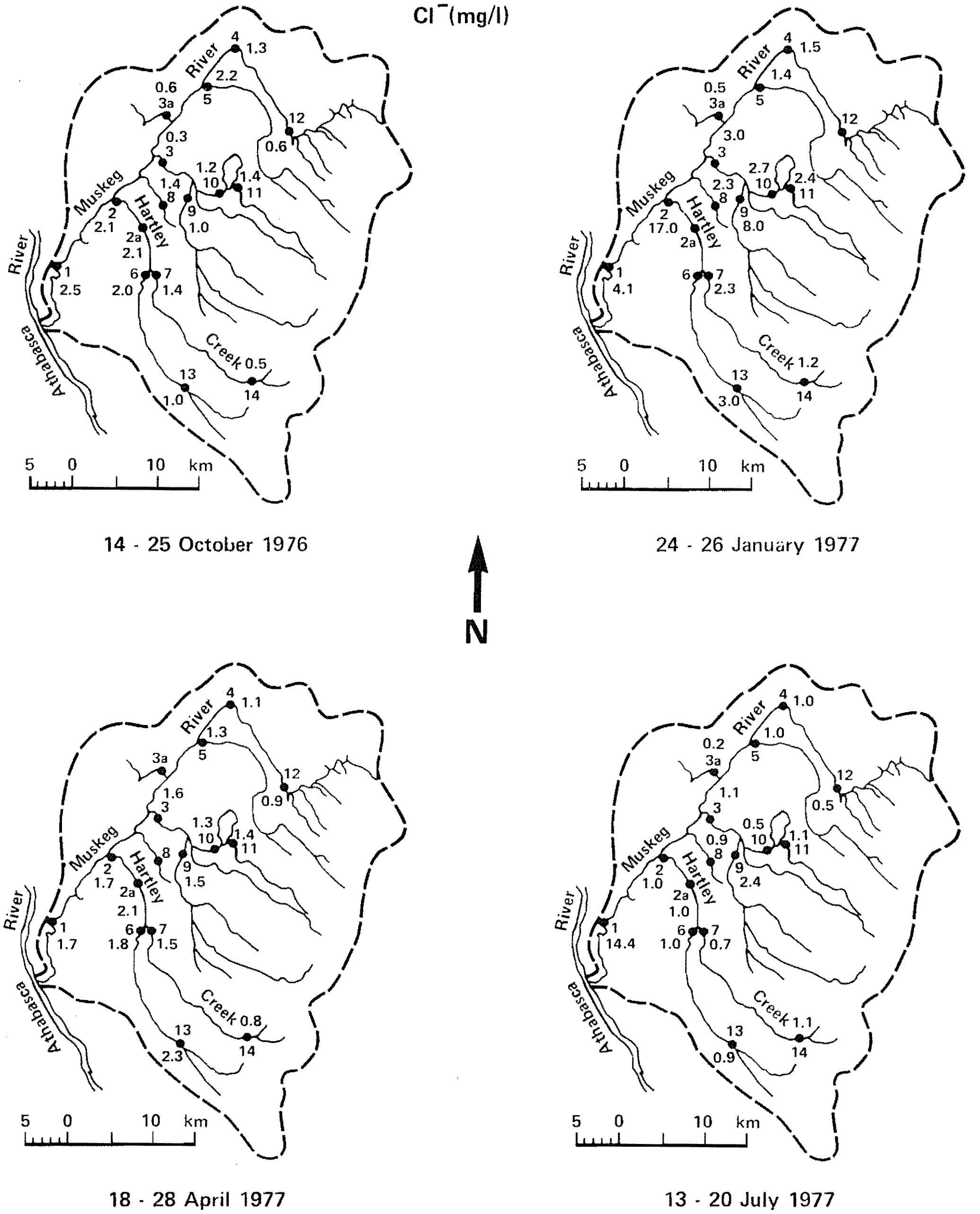
14 - 25 October 1976

24 - 26 January 1977

18 - 28 April 1977

13 - 20 July 1977

Figure 15. Areal variation in sulfate concentrations of stream samples.



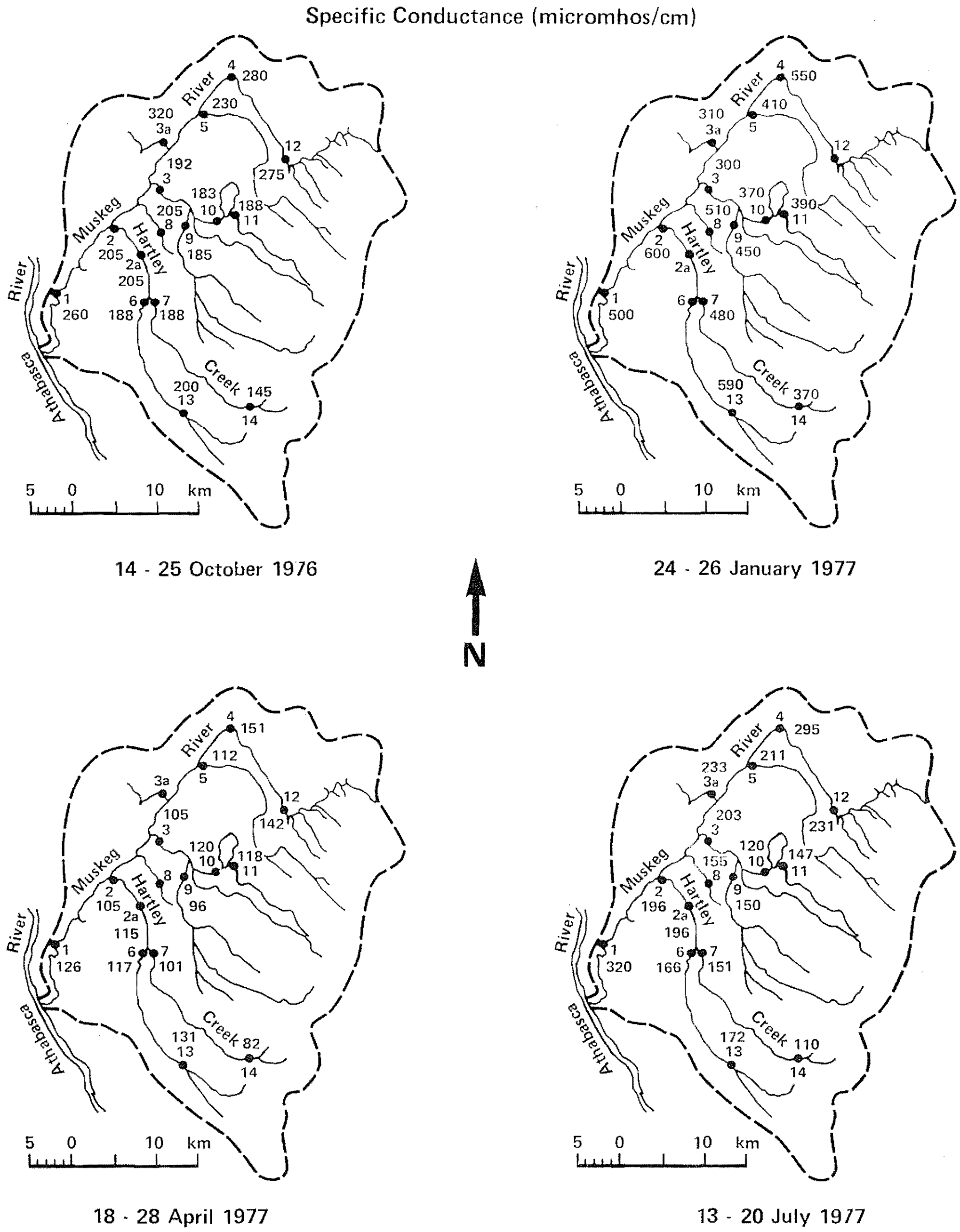
14 - 25 October 1976

24 - 26 January 1977

18 - 28 April 1977

13 - 20 July 1977

Figure 16. Areal variation in chloride concentrations of stream samples.



14 - 25 October 1976

24 - 26 January 1977

18 - 28 April 1977

13 - 20 July 1977

Figure 17. Areal variation in the specific conductance of stream samples.

5.3.1.4 Potassium ion concentrations in streamflow. The concentration variation of K^+ ion in samples collected at locations 1 and 2 exhibit a complex hysteretic behaviour (Figure 18). Potassium ion concentrations are relatively high during winter months as are the other ion species (Figure 18). However, during the high discharge period that accompanies spring snowmelt, K^+ ion concentration tends to rise to a maximum for the year. In the period from June to August, concentration falls to a minimum only to rise slightly during the fall months. The relatively small number of samples makes it difficult to determine whether this latter effect is actually significant.

This increase in K^+ ion concentrations especially during the period of snowmelt probably is related to widespread surface runoff in the watershed. As waters move over soil surfaces, they readily accumulate K^+ ion. At other times of the year, surface runoff is probably much less important. Because cation exchange reactions most often reduce the mobility of K^+ ion in groundwater and muskeg systems, a concentration reduction will be noticeable at these times. More study will be required to elucidate this phenomenon in detail.

5.3.1.5 Statistical prediction of surface water chemistry. The relatively strong correlation between discharge and ion concentrations or specific conductance (Figure 9) provides a quantitative way of estimating discharge from particular ion concentrations and specific conductance; or of estimating ion concentration and specific conductance from measurements of discharge. Table 3 summarizes the sets of regression equations obtained with both chemical parameters and discharge as independent parameters. These equations are only written for those chemical parameters which are shown to correlate well with discharge (Figure 9). A quadratic regression equation was chosen over a linear one to fit the data because the discharge concentration function is not linear at high and low concentration values.

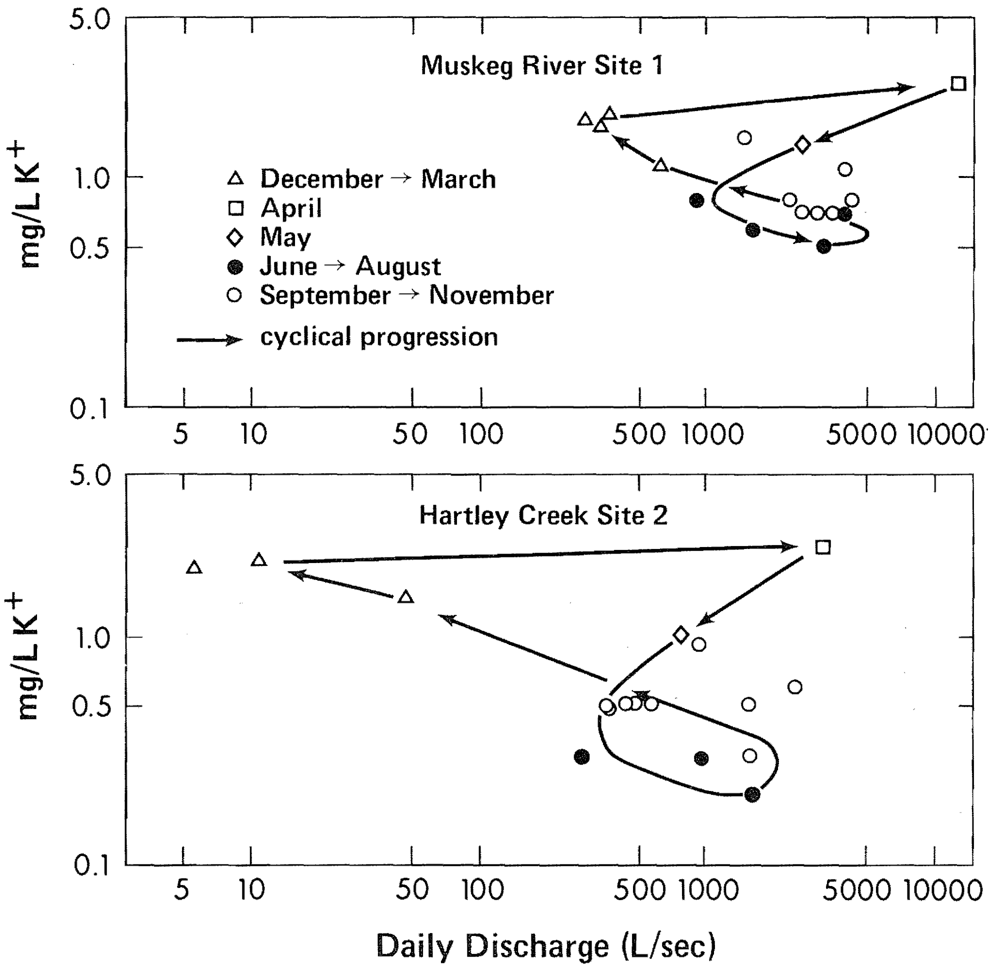


Figure 18. Idealization of cyclical progressions in K^+ ion concentrations.

Coefficients of determination are also included in Table 3 to provide an assessment of the goodness-of-fit of the regression equations. The statistical significance of the fit at the 0.05 probability level (Table 3) were determined using a standard F test.

Because these regression equations are developed for a specific set of data, it is important that the equations not be utilized predictively for variables lying outside the range of the actual data. For this reason, upper and lower bounds of ion concentration and discharge are included in Table 3 to guide users of the equation. In the event that extrapolations above or below these bounds are required, it is suggested that the graphical correlations (Figure 3) be utilized.

5.3.1.6 Prediction of upstream chemistry. Preliminary studies have been undertaken to predict upstream surface water chemistry in the Hartley Creek sub-basin by correlating the upstream chemical analyses with the more complete chemical record that exists at site 2. Figure 19 illustrates graphically the nature of scatter within the data. A lack of available data especially during low and high streamflow periods and disparity in sampling dates makes any kind of statistical treatment of these data futile at this point. The lines joining data points are only speculative and are intended to illustrate possible trends. It is interesting to note that reasonably good correlations are emerging between sites 14 and 2 and between sites 7 and 2. In the case of site 6, the range in values is, unfortunately, too small to define a relationship with site 2.

There is considerable scatter of the data relating sites 13 and 2. Some of the scatter in the site 13 data may arise because the sampling could not take place at exactly the same location due to muskeg conditions. The work on this project has not proceeded to the point where the apparent form of the trend line can be interpreted. For example, the relationship between sites 7 and 2 is often curvi-linear (Figure 19).

Table 3. Summary of regression equations.

Sampling Site	Parameters	Equation	R^2	Dependent Variable Range
1	Q^a vs. Ca	$\log Q = -0.92 + 6.23 \log Ca - 2.77 (\log Ca)^2$	0.89 *	82.0 - 16.5 mg/L
	Q vs. Mg	$\log Q = 0.50 + 6.18 \log Mg - 4.64 (\log Mg)^2$	0.92 *	18.5 - 4.5 mg/L
	Q vs. Na	$\log Q = 6.91 - 8.42 \log Na + 3.33 (\log Na)^2$	0.27	22.0 - 4.9 mg/L
	Q vs. HCO_3	$\log Q = -11.52 + 14.82 \log HCO_3 - 3.90 (\log HCO_3)^2$	0.92 *	352.0 - 79.0 mg/L
	Q vs. Cl	$\log Q = 3.05 -3.70 \log Cl + 2.09 (\log Cl)^2$	0.36 *	14.4 - 1.7 mg/L
	Q vs. Cond	$\log Q = -16.21 + 17.77 \log Cond - 4.22 (\log Cond)^2$	0.87 *	520.0 - 126.0 μmho/cm
2	Q vs. Ca	$\log Q = 1.02 + 3.05 \log Ca - 1.96 (\log Ca)^2$	0.74 *	91.0 - 11.5 mg/L
	Q vs. Mg	$\log Q = 1.56 + 2.55 \log Mg - 3.05 (\log Mg)^2$	0.75 *	21.8 - 3.5 mg/L
	Q vs. Na	$\log Q = 0.54 + 4.78 \log Na - 3.65 (\log Na)^2$	0.75 *	30.0 - 5.5 mg/L
	Q vs. HCO_3	$\log Q = -4.62 + 8.33 \log HCO_3 - 2.58 (\log HCO_3)^2$	0.76 *	424.0 - 57.0 mg/L
	Q vs. Cl	$\log Q = 1.87 - 1.49 \log Cl - 0.29 (\log Cl)^2$	0.77 *	17.0 - 1.7 mg/L
	Q vs. Cond	$\log Q = -1.70 + 5.50 \log Cond - 1.80 (\log Cond)^2$	0.74 *	660.0 - 105.0 mg/L
1	Ca vs. Q	$\log Ca = 1.91 + 0.84 \log Q - 0.12 (\log Q)^2$	0.92 *	110.0 - 0.2 (cfs)
	Mg vs. Q	$\log Mg = 1.16 + 0.22 \log Q - 0.15 (\log Q)^2$	0.88 *	110.0 - 0.2 (cfs)
	Na vs. Q	$\log Na = 0.40 + 1.10 \log Q - 0.36 (\log Q)^2$	0.31	110.0 - 0.2 (cfs)
	HCO_3 vs. Q	$\log HCO_3 = 2.43 + 0.25 \log Q - 0.16 (\log Q)^2$	0.90 *	110.0 - 0.2 (cfs)
	Cl vs. Q	$\log Cl = 0.63 + 0.96 \log Q - 0.33 (\log Q)^2$	0.05	110.0 - 0.2 (cfs)
	Cond vs. Q	$\log Cond = 2.61 + 0.23 \log Q - 0.15 (\log Q)^2$	0.85 *	110.0 - 0.2 (cfs)
2	Ca vs. Q	$\log Ca = 1.75 - 0.23 \log Q - 0.03 (\log Q)^2$	0.72 *	110.0 - 0.2 (cfs)
	Mg vs. Q	$\log Mg = 1.18 - 0.18 \log Q - 0.01 (\log Q)^2$	0.72 *	110.0 - 0.2 (cfs)
	Na vs. Q	$\log Na = 1.35 - 0.17 \log Q - 0.01 (\log Q)^2$	0.70 *	110.0 - 0.2 (cfs)
	HCO_3 vs. Q	$\log HCO_3 = 2.45 - 0.20 \log Q - 0.01 (\log Q)^2$	0.72 *	110.0 - 0.2 (cfs)
	Cl vs. Q	$\log Cl = 0.87 - 0.52 \log Q + 0.08 (\log Q)^2$	0.78 *	110.0 - 0.2 (cfs)
	Cond vs. Q	$\log Cond = 2.62 - 0.22 \log Q + 0.01 (\log Q)^2$	0.73 *	110.0 - 0.2 (cfs)

*statistically significant.

[a] discharge values are in cfs to maintain consistency with original data.

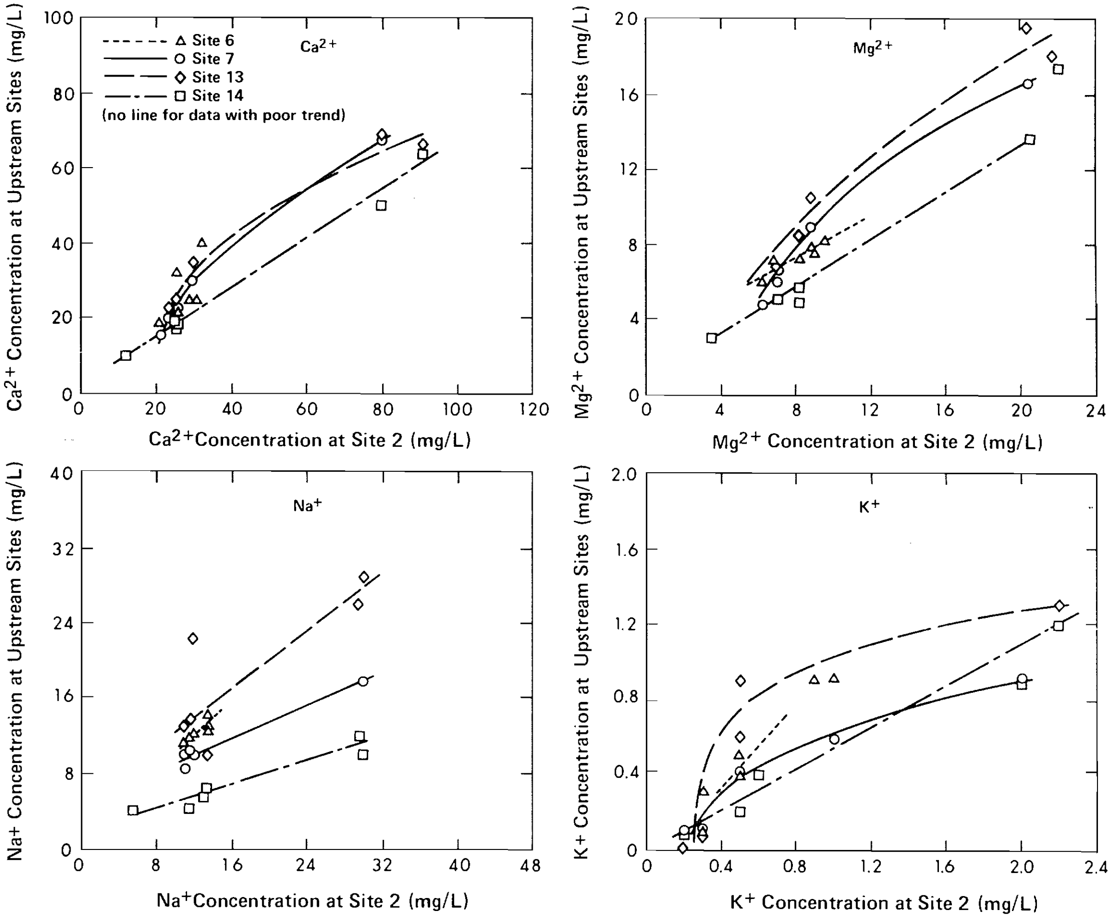


Figure 19. Relationships of ion concentrations and specific conductance at upstream sites on Hartley Creek to values at site 2.

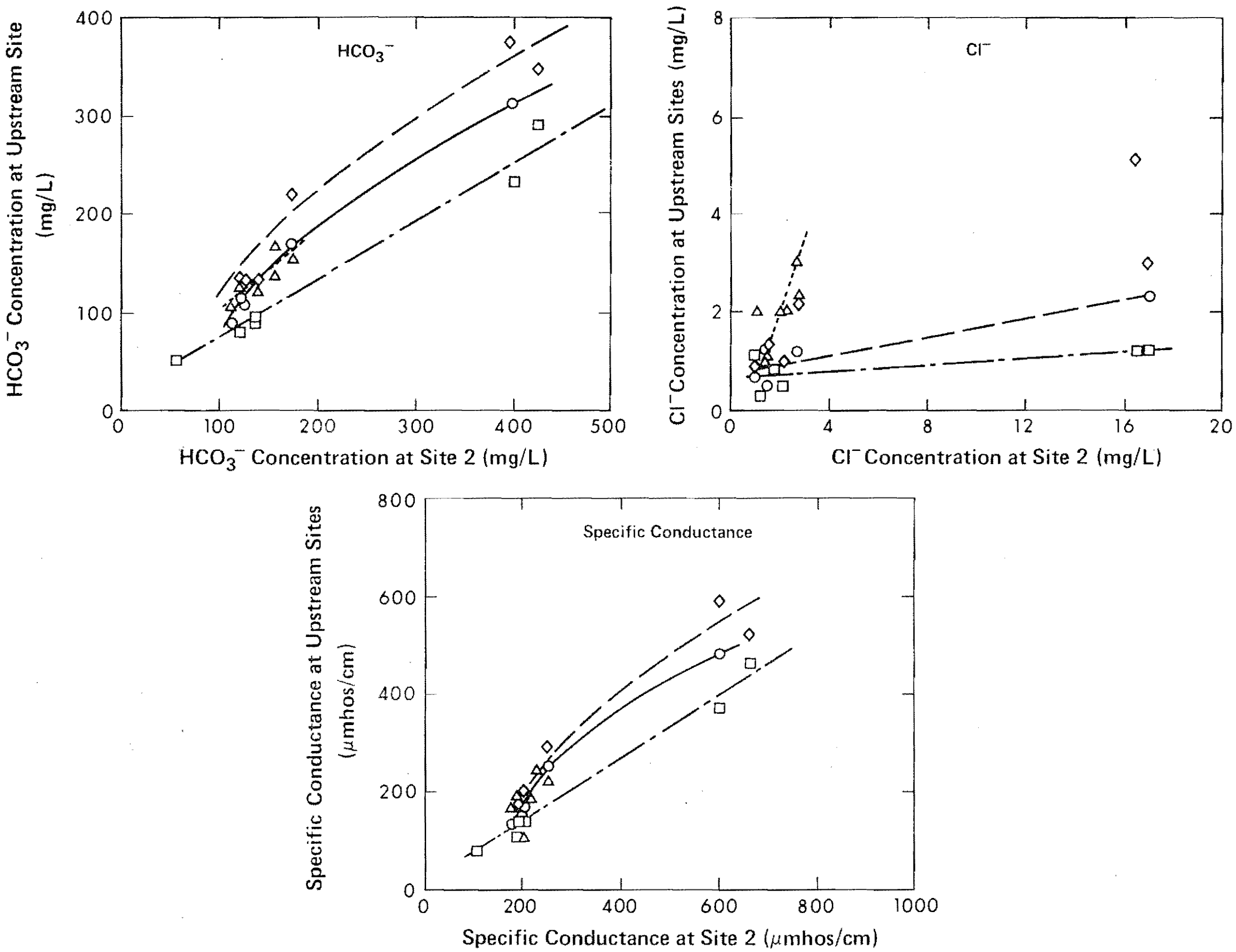


Figure 19. (Concluded).

With the general exception of Na^+ and possibly Cl^- ion concentrations, data points related to all four upstream sampling sites fall in a much tighter cluster at the lower concentration portion of the plot than in the higher concentration portion (Figure 19). This result suggests that waters contributing to streamflow during low-flow periods have a variable chemical composition.

5.3.1.7. Differentiation of muskeg waters and groundwaters. The chemical methods available to interpret the origin of streamflow in a watershed are almost entirely based on the assumption that waters contributed from particular components of the hydrologic cycle are chemically unique. An important aspect of this study has been to show whether muskeg waters form a chemically unique component of the hydrologic regime.

Cluster analysis of the chemical data provides a means of determining whether the groundwater and muskeg waters can be separated into more or less homogeneous groups. The term cluster analysis describes a variety of analytical procedures used to group together a set of individual samples into a smaller number of groups. The procedures are based upon the maximization or minimization of some objective function in such a way that the members of one group are more similar to each other than they are to members of any other group. This grouping or clustering operation is an attempt to evaluate the relationships existing in a larger collection of data. There are in cluster analysis two decisions which must be made--the choice of a similarity measure, and the choice of a clustering algorithm.

The similarity measure or similarity coefficient (Sneath and Sokal 1973) is a quantification of the resemblance between two samples. The choice of a coefficient is determined by the scale of measurement for the variables of the data matrix. Euclidean distance has been utilized in this study, and is a measure of dissimilarity rather than similarity as large distances between individuals in the invariable hyperspace imply greater similarity as in the case with true similarity coefficients.

The choice of a clustering algorithm is again somewhat subjective. Hartigan (1975), and Sneath and Sokal (1973) provide discussions of the various alternatives. In this investigation, a procedure known as Ward's method (Ward 1963) has been utilized. It is one of the many options available in the CLUSTAN package (Wishart 1975).

The results are plotted in the form of a dendrogram (Figure 20). The sequence of numbers along the bottom of Figure 20 are directly related to the chemical data listed in Appendix 9.6. For example, numeral 1 refers to the first sample in the list (Appendix 9.6). A total of 60 groundwater analysis and 30 muskeg water analyses comprise the data set.

The results of the analysis (Figure 20) indicate generally that the groundwaters and muskeg waters form distinct clusters. Some of the deeper samples of water from muskeg sites may actually be taken from silts below the peat material (for example 90, 80, 79, and 89, Figure 20). These samples are classified with the groundwaters. Groundwaters that are classified with muskeg analyses (for example, 6, 16, 44, 30, 43, 18, and 42, Figure 20) are samples that perhaps have been affected by leakage of surface waters along the piezometer casing. For example, analyses from 6 (HC2 - day 586) and 30 (HC17 - day 586) exhibited marked change in composition compared to results of earlier samplings. In other cases, it is possible that waters could be moving from muskeg areas into adjacent groundwater systems or that recharge to the groundwater system infiltrating through coarse, granular materials does not accumulate appreciable quantities of dissolved solids.

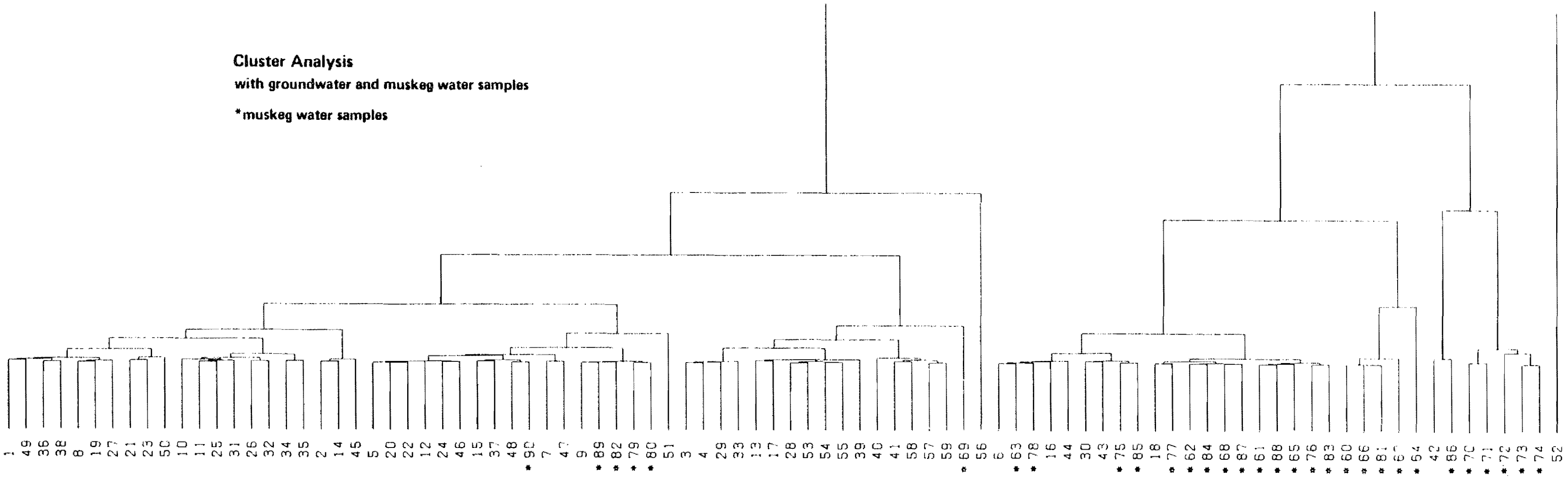


Figure 20. Dendrograph for muskeg and groundwater samples.

5.3.2 Isotope Data

Stable and radioactive isotopes have proven themselves to be important tools in hydrologic studies. In this study, the potential applicability of ^{18}O and tritium has been tested. Oxygen-18 determinations have been completed on 39 samples of melted snow, surface water, muskeg water, and groundwater. The results are listed in Appendix 9.8 and summarized in Figure 21. The range in isotopic concentrations for almost all the components tend to overlap one another (Figure 21). Only in the case of melted snow does there seem to be indications that these samples possess a unique isotopic composition. The lack of any marked variability among the samples, in our opinion, tends to limit the usefulness of the ^{18}O data.

The wide range in $\delta^{18}O$ values for the stream waters are particularly interesting. The set of samples were collected during the winter at locations indicated on Figure 21. The highest $\delta^{18}O$ value was obtained at site 3--downstream from Kearl Lake. This relatively enriched sample suggests that the ^{18}O concentrations of waters of Kearl Lake have been influenced by evaporation during the summer months. The relatively high $\delta^{18}O$ value measured at site 1 probably results from mixing waters with $\delta^{18}O$ values of $-19^{o}/oo$ to $-20^{o}/oo$ with Kearl Lake drainage ($\delta^{18}O$ of $-14.25^{o}/oo$) or other large upstream muskeg lakes with a somewhat similar isotopic composition. If this assumption is correct, it can be shown by simple dilution arguments that from 30 to 40% of streamflow in Muskeg River during some months comes from drainage from Kearl Lake and lakes in muskeg.

Up to now, tritum determinations have been made on only three streamflow samples. Samples collected at 1, 3A, and 4 on 8 March 1977 had respective tritium concentrations of 149 ± 4.5, 79 ± 2.5, and 230 ± 7.0 T.U. A lack of samples prevents meaningful interpretations. However, the broad range in values suggests that such analyses could be very helpful in identifying the components contributing to streamflow.

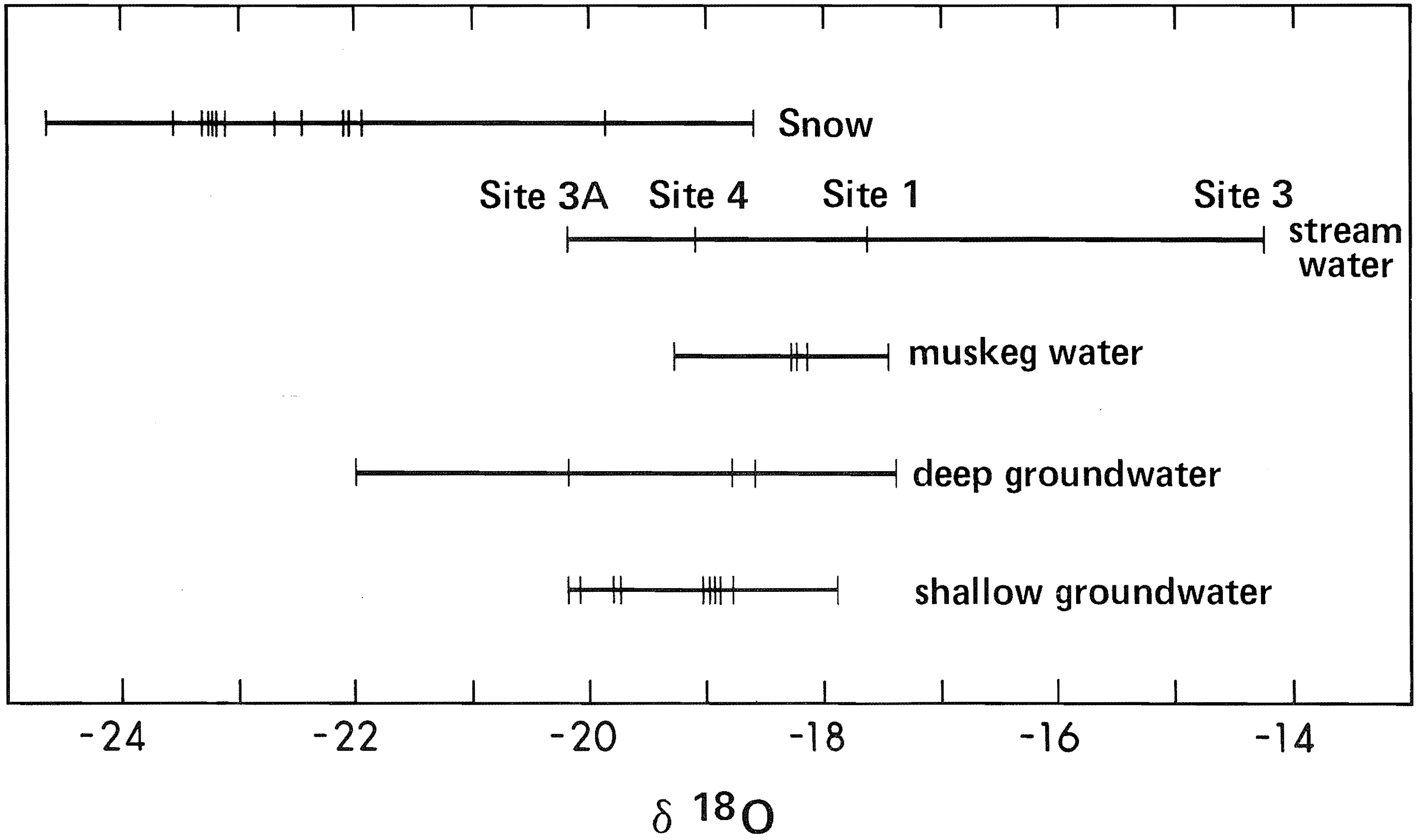


Figure 21. Range in concentration of oxygen-18.

5.3.3 Other Chemical Constituents

A variety of other chemical analyses were performed by Chemex Labs (Alberta) Ltd. in Calgary. This group of analyses was intended to provide background data for other AOSERP projects. The results are listed in Appendix 9.9. Because these data are not relevant to this project, they will not be discussed further.

5.4 THE ORIGIN OF STREAMFLOW

Two different techniques are utilized to begin to unravel the complex problem of the origin of streamflow in the watershed. The first is a very approximate technique based on cluster analysis. All chemical data available from site 2 have been merged with the groundwater and muskeg water data. The results of cluster analysis (Figure 22) with these data indicate that 14 surface water samples (numbered 91 to 104 inclusive, Figure 22 and corresponding to the list of sample results from site 2, Appendix 9.7) are variously clustered with either groundwaters or muskeg waters. Samples from the late fall and winter, for example 96, 97, and 98 (Figure 22) are clustered with the groundwaters; while those from the spring, summer, and fall are clustered with the muskeg waters (Figure 22). These results suggest that during the winter months when the surface waters reach their maximum concentrations with respect to nearly all ion species, the streamflow is maintained by groundwater discharge. At other times of the year, streamflow is maintained mainly by drainage from the muskeg into the surface water system.

The second technique goes farther than the first in trying to estimate quantitatively the contribution of inflow components to streamflow. It was described previously in section 4.3.1. Recall that input to the model was a representative concentration for each of the three inflow components and the derived water. For most watersheds, the components considered are direct precipitation, surface runoff, and groundwater. Because it has not been possible to chemically characterize surface runoff, a

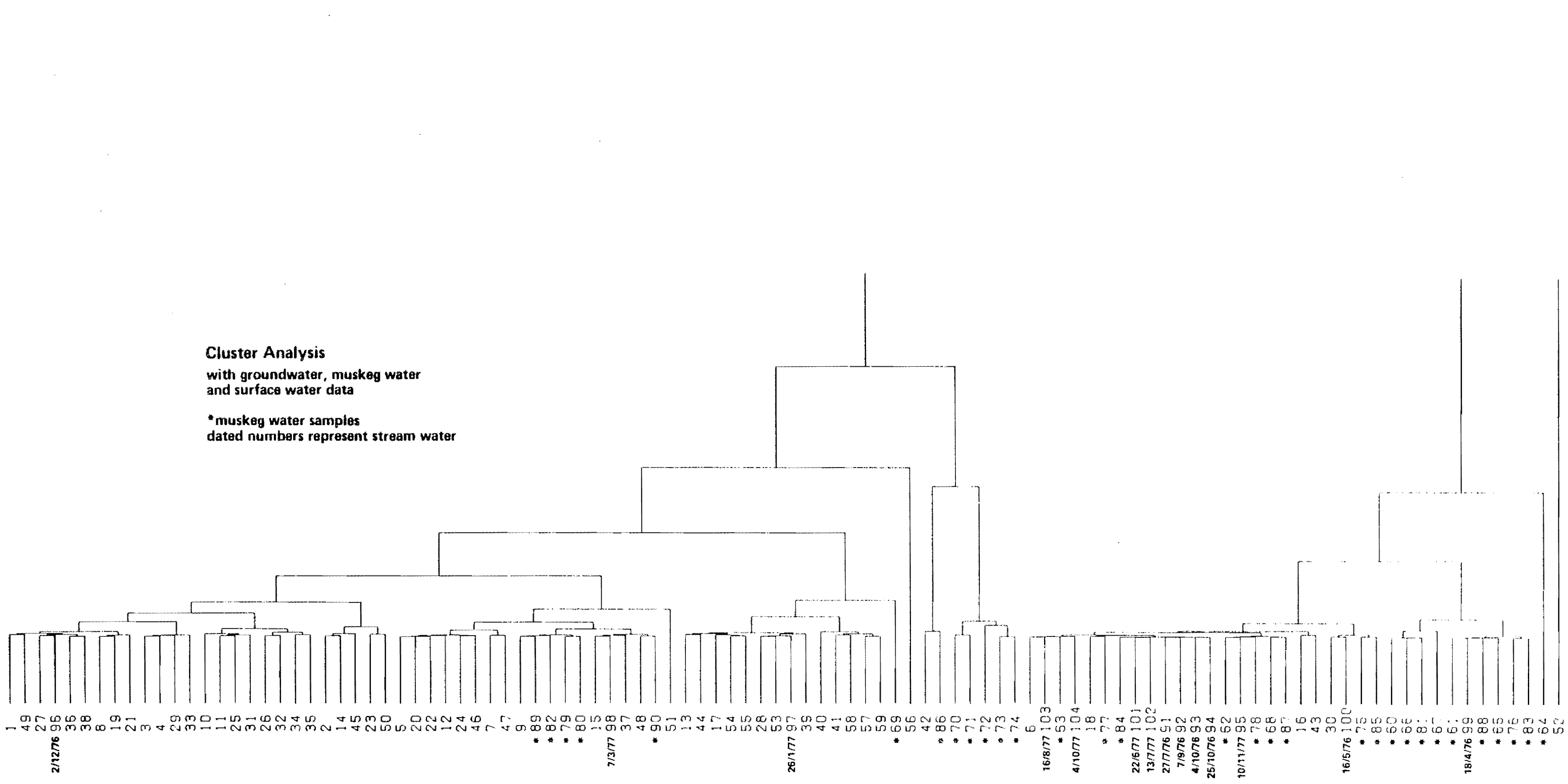


Figure 22. Dendrograph for muskeg waters, groundwater, and surface water.

different set of components--muskeg waters, direct precipitation (not falling on muskeg), and groundwater (not discharging into muskeg)--have been selected as components for the analysis. The derived water was Hartley Creek water measured at site 2.

Although it is theoretically possible to use all the major ions and chemical parameters, practical reasons, for example highly hysteretic behaviour, required that certain ones be eliminated. Thus, K^+, SO_4^{2-} and Cl^- ion data are excluded. Table 4 presents representative values of the chemical parameters used for the calculations.

The precipitation chemistry tends to exhibit a relatively wide range in concentration. As a first approximation, it is assumed that the concentration of ion species contributed by this component is zero. In the case of groundwaters (not discharging into muskeg), the values listed in Table 4 are mean values for groundwaters calculated in Table 2. The chemical character of muskeg water (Table 4) is approximated from surface samples collected from muskegs and those from piezometers at depths of less than 1.2 m. Note that muskeg waters exhibiting the chemical characteristics of bedrock groundwaters have not been included. It should be emphasized that the muskeg waters themselves probably represent a complex mixture of groundwater, surface runoff, and direct precipitation which may have undergone further chemical reaction with mineral and organic materials found in the muskeg. At this point, it is not possible to explain the origin of the chemical composition of the muskeg waters.

The results of the calculations are presented graphically in Figure 23. Discharge values are plotted on a logarithmic scale so that low flow values are most apparent. The resulting separation of the groundwater component of the hydrograph is consistent. When the stream-flow minima are observed during the winter months, streamflow is sustained almost completely by groundwater discharge. At

Table 4. Summary of input for the component identification problem.

	Representative Concentrations		
Parameter	Precipitation	Muskeg Water	Groundwater
Ca^{2+} (mg/L)	0.0	13.5	83.3
Mg^{2+} (mg/L)	0.0	3.6	23.2
Na^{+} (mg/L)	0.0	6.2	29.5
HCO_3^- (mg/L)	0.0	54.7	452.0
specific cond. (μmho/cm)	0.0	108.0	600.0

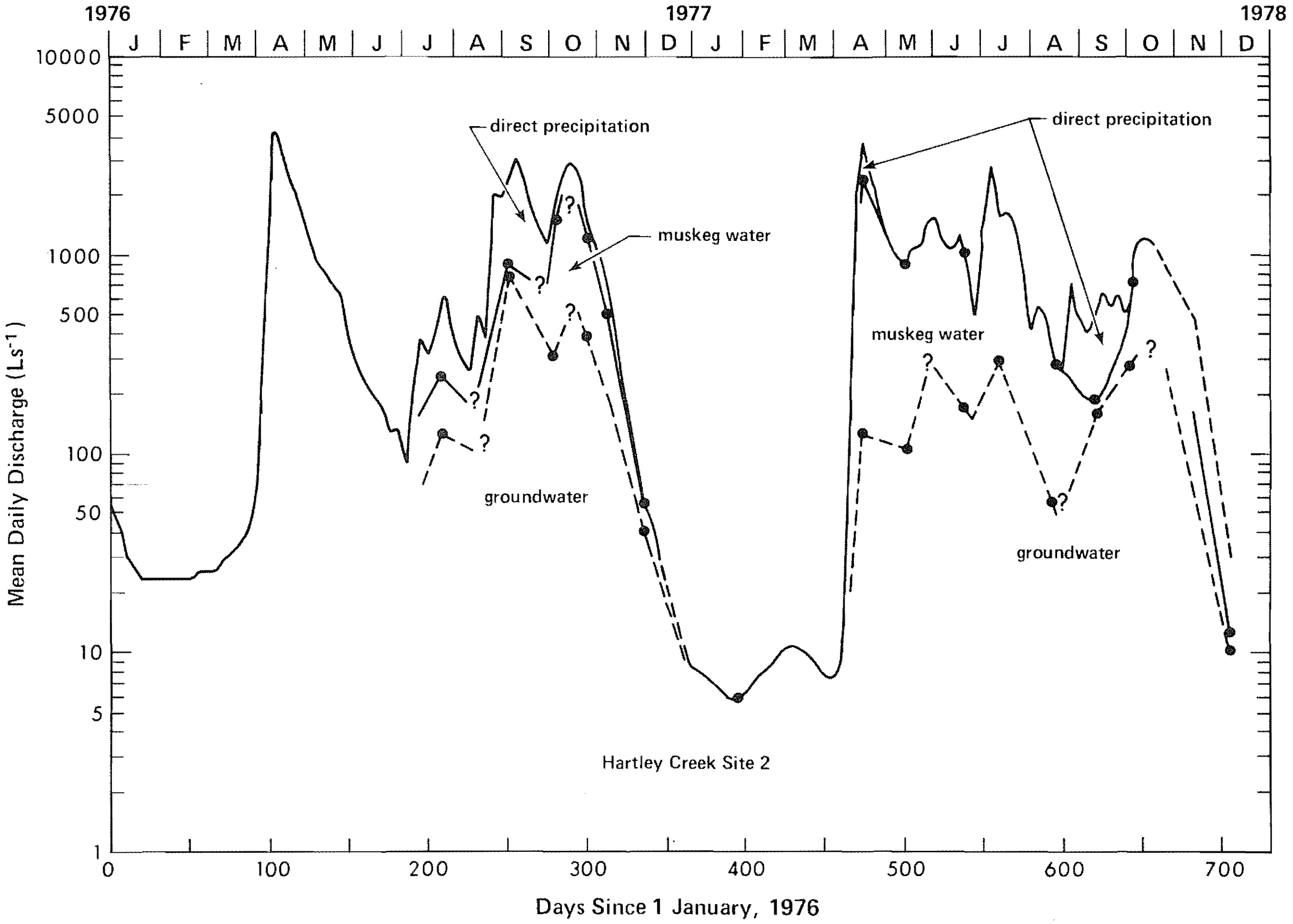


Figure 23. Preliminary results of hydrograph separations.

other times of the year, groundwater contributions range from 12 to 40% of the streamflow. It should be noted that the separation obtained between muskeg water and direct precipitation (not falling on muskeg) is probably weak. In other words, with the same groundwater proportion, a very different set of muskeg water and direct precipitation proportions will yield a poorer, but nevertheless, reasonably good fit with the stream chemistry (site 2).

6. DISCUSSION

Data collected to date have facilitated a description of water systems in the Muskeg River basin. The major ion and oxygen-18 concentrations of groundwaters in the overburden are very similar to those observed in similar shallow units throughout Alberta. Typically, overburden waters are hard and bicarbonate rich with relatively low Na^+ and Cl^- ion concentrations. Although most of the major ion concentrations fall within a reasonably narrow range of values, no contourable patterns in drift water chemistry have been evident. This situation has been evident with nearly all shallow drift systems studied in western Canada. It is caused by several factors including significant variability in the mineralogy of glacial deposits, in the effectiveness of evaporation from groundwater systems, and in the spatial distribution of recharge.

Examination of the results of existing major ion data for bedrock groundwaters from the watershed indicate that they are considerably different than the drift waters. The concentration of HCO_3^- and Cl^- ions is usually higher as is Na^+ ion. The increased Na^+ ion concentrations occur primarily as a result of cation exchange processes wherein the Ca^{2+} and Mg^{2+} ions present in waters flowing into bedrock are adsorbed on clay materials while Na^+ ions are released. This effect is reflected generally in the data depicted in Table 9 with water from bedrock sources often (but not always) depleted in Ca^{2+} and Mg^{2+} ions and enriched in Na^+ ions relative to measured drift waters. Other possible explanations for the increased Na^+ and Cl^- concentrations would be: i) dissolution of small quantities of soluble salts remaining in the rocks; or ii) the mixing of recharging meteoric waters with small quantities of connate water which have not yet been expelled completely from the marine sediments in which they were originally trapped. At the present time, existing data are not sufficient to evaluate the importance of these latter two mechanisms.

Water sampled from muskeg sediments shows a systematic variation in chemistry with depth. Often the deepest water samples collected in the muskeg have the highest concentration of ionic species--occasionally to the level of shallow groundwater. Concentrations of ions generally decrease upward and reach a minimum in the standing water at the ground surface. Information from muskeg sites is not yet sufficient to detail how these patterns arise. However, in the normal case, it is expected that the downward increase in the major ion chemistry generally might reflect either various chemical and biological interactions that might occur as muskeg surface waters move downward or a form of mixing between groundwaters flowing into the muskeg and water similar in concentration to the standing water in muskeg areas (or possibly some combination of these processes). While evidence so far suggests that bedrock waters do not influence the chemistry of the surface water system appreciably, in at least one muskeg site groundwater moving upward from the bedrock was detected.

The chemical character of streamwater varies markedly on a seasonal basis. At sampling sites 1 and 2, the concentrations of all ions except K^+ reach a minimum during the spring snowmelt period. Concentration maxima for all ions except K^+ at both sampling sites are reached in the latter part of the winter--February or March (Figures 7 and 8). Such a pattern is similar to that observed in other watersheds in western Canada (Schwartz 1970).

Potassium ion concentrations exhibit a marked cyclical behaviour in the streamwaters with the highest concentrations observed during the period of spring snowmelt. It is suggested that surface runoff mobilizes K^+ ion commonly found in materials on the soil surface. This explanation is consistent with observations of K^+ ion dilution behaviour in other watersheds (Schwartz 1970).

During the summer and autumn months, concentrations of most ion species achieve an intermediate level between these extremes. The fact that the streamwaters do not return to a chemistry typical of baseflow conditions in the summer and autumn is an indication of continuous inflow of surface water stored in lakes and muskeg areas. In watersheds without significant upstream storage (Schwartz 1970; 1974), the streams return to baseflow conditions during the summer and autumn months.

Baseflow in the Muskeg River basin during the winter is achieved because standing water in muskeg areas and lakes generally is frozen and ceases to contribute to streamflow. However, not all upstream sources of surface water cease to contribute to streamflow during the winter. There is some isotopic evidence that continued drainage of Kearl Lake and upstream muskeg lakes perhaps contributes 30 to 40% of Muskeg River streamflow in some winter months.

The seasonal set of processes controlling the major ion chemistry are also responsible for producing the discharge hydrographs recorded at sites 1 and 2. For this reason, chemistry and stream discharge are correlated. It is possible to develop meaningful regression equations to relate discharge to concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, HCO_3^{-}, Cl^{-}, and specific conductance. Sulfate ion concentrations are generally uncorrelated with discharge. In this case, it is possible that there are problems in the laboratory measurements of SO_4^{2-} ion concentrations.

The results of our analyses indicate that the waters from muskeg areas are significantly different from groundwater and rainwater. On this basis, it is possible to construct mixing models that calculate the proportion of these components which combine to produce streamflow. The results of preliminary mixing model calculations suggest that only 12 to 40% of the streamflow during the late spring, summer, and autumn months comes from groundwater inflow to the stream channel system.

The preliminary indications of watershed response will be improved as additional data become available. At this stage in the study, it is premature to evaluate the implications of these results on the assessments of environmental disruptions caused by mining in the watersheds. These important aspects will be dealt with in the final report of this study.

7. CONCLUSIONS

Following, in summary form, are the most important conclusions reached to date.

1. Baseflow, as it is known in streams in the southern portion of the province, probably exists only during a few winter months. At these times, the standing water in muskeg areas is frozen and ceases to contribute to streamflow. The streamwater chemistry during these winter low-flow periods corresponds closely to the observed groundwater chemistry in shallow surficial units along Hartley Creek. These results suggest that it should be possible to characterize the groundwater chemistry of other watersheds using similar techniques. However, the isotopic data from site 1 have shown how upstream reservoirs such as Kearl Lake or muskeg lakes can apparently disrupt such a pattern.
2. During times of year when the muskegs are unfrozen they continually add waters with a chemically unique composition to the surface water systems. As a result, the streams do not return to baseflow conditions until the late winter months.
3. The results of mixing model calculations suggest that from 12 to 40% of streamflow during the late spring, summer, and fall months consists of groundwater with the remainder coming from muskeg drainage and direct precipitation on the stream channels.
4. The chemical composition of groundwaters sampled from glacial drift and bedrock units does not differ appreciably from that observed elsewhere in Alberta.

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9. APPENDICES

9.1 DETAILS OF PIEZOMETER COMPLETION

Table 5. Details of piezometer completion.

Piezometer Number	Length of Pipe (m)	Hole Diameter (cm)	Slotted Interval (m)	Completion Details[a]
HC1	2.45	7.62	0.92	1
HC2	3.99	7.62	0.92	1
HC3				3
HC4	4.44	7.62	0.92	1
HC5				3
HC6	6.14	7.62	0.92	1
HC7	3.70	7.62	0.92	1
HC8	5.31	7.62	0.92	2
HC9	3.10	7.62	0.92	1
HC10	2.90	7.62	0.92	1
HC11				3
HC12	3.62	7.62	0.92	1
HC13	2.60	7.62	0.92	1
HC14	6.74	7.62	0.92	2
HC15	3.88	7.62	0.92	1
HC16	3.67	7.62	0.92	1
HC17	6.44	7.62	0.92	2
HC18	5.40	7.62	0.92	1
HC19				3
HC20	6.73	7.62	0.92	1
HC21	3.65	7.62	0.92	1
HC22	5.21	7.62	0.92	1
HC23	3.60	7.62	0.92	1
HC24	8.27	7.62	0.92	1
HC25	8.43	7.62	0.92	2
HC26	4.90	7.62	0.92	1
HC27	4.29	7.62	0.92	1
HC28	4.14	7.62	0.92	1
HC29	6.21	7.62	0.92	1
HC30	9.14	7.62	0.92	1
HC31	3.05	7.62	0.61	1
HC32	4.47	7.62	0.92	1
HC-B1				3
HC-B2				3

continued . . .

Table 5. Concluded.

Piezometer Number	Length of Pipe (m)	Hole Diameter (cm)	Slotted Interval (m)	Completion Details
HC-B3-7	2.13	3.57	0.61	2
HC-B3-14	4.27	3.57	0.61	2
HC-B4	6.71	3.57	0.61	2
HC-B5	4.88	3.57	0.61	2
HC-B6-8	2.44	3.57	0.61	2
HC-B6-17	5.18	3.57	0.61	2
HC-B7	4.88	3.57	0.61	2
HC-B8	4.88	3.57	0.61	2

[a] Completion Details: 1 Portable auger, PVC pipe installed, annulas covered with clay at surface; 2 Stainless steel well point and galvanized steel pipe driven into ground; 3 abandoned borehole.

9.2 LITHOLOGIC AND SAMPLE LOGS

Table 6. Lithologic and sample logs.

Site	Depth (m)	Lithology	Remarks
HC1	0.00-2.75	clay, sandy	
HC2	0.00-0.92	clay, sandy	
	0.92-2.75	clay	plastic, contains pebbles
	2.75-5.51	sand, clayey	very fine-grained, water table at 3 m
HC3	0.99-3.67	clay	dark brown
	3.67-5.20	clay	as above but with pebbles
HC4	0.00-1.83	organic material	increasing clay content with depth
	1.83-4.90	clay	contains fine-grained sand and silt
HC5	0.00-0.92	clay, sandy	overlain by sandy topsoil
	0.92-2.14	clay	dark brown, contains pebbles
	2.14-4.59	silt	dark brown, occasional pebbles
	4.59-5.35	clay, silty	slightly saturated, slight bitumen content
HC6	0.00-0.31	sand	
	0.31-0.92	sand, silty	brown
	0.92-1.83	silt	dark brown
	1.83-5.20	clay, silty	water table at 2.75 m bitumen stains at 3.67 m very fine-grained, saturated, minor bitumen content
HC7	0.00-3.67	same as HC6	abandoned
HC8	0.00-0.92	sand	overlain by sandy topsoil
	0.92-8.27	sand and sandy clay	water table 1.8 m, minor bitumen content below 4.59 m
HC9	0.00-0.92	sand	overlain by sandy topsoil
	0.92-2.75	sand and sandy clay	water table at 1.5 m
HC10	0.00-0.92	organic material	wet, mixed with brown clay
	0.92-2.64	clay	

continued ...

Table 6. Continued.

Site	Depth (m)	Lithology	Remarks
HC11	0.00-3.36	same as HC11	abandoned
HC12	0.00-0.92	clay	light brown, overlain by organic material
	0.92-3.67	clay	light brown, water table at 1.2 m
HC13	0.00-2.60	clay	dark brown
HC14	0.00-0.92	clay, silty	light brown
	0.92-1.83	clay	light brown
	1.83-6.74	clay	light brown, water table at 3.67 m
HC15	0.00-3.67	same as HC14	
HC16	0.00-0.92	clay	reddish-brown
	0.92-3.67	clay	water table at 2.8 m
HC17	0.00-4.57	clay	water table near 2.8 m
HC18	0.00-0.92	clay, silty	dark brown, overlain by sandy topsoil
	0.92-5.41	clay, silty	dark brown, coarser than above, saturated below 2.8 m
HC19	0.00-2.14	silt and boulders	abandoned
HC20	0.00-1.83	sand	coarse, well sorted, subangular, grading to brown clay
	1.83-2.75	clay	brown, water table at 2.75 m
	2.75-6.73	silt and clay	saturated
HC21	0.00-3.67	same as HC20	
HC22	0.00-2.75	silt and sand	saturated at 0.92 m
	2.75-5.21	silt	dark brown, contains grey clay oily odour
HC23	0.00-3.67	same as HC22	

continued ...

Table 6. Continued.

Site	Depth (m)	Lithology	Remarks
HC24	0.00-0.92	clay loam	very dark brown
	0.92-2.75	organic clay	
	2.75-7.35	clay	slight bitumen content
HC25	0.00-3.67	sand	medium to fine-grained, well-sorted subangular
	3.67-8.11	sand	fine-grained, clay content increases with depth, water table near 3.7 m
HC26	0.00-3.67	sand	yellow, medium to fine-grained
	3.67-4.59	sand	grey, fine-grained
HC27	0.00-0.92	sand	coarse, well-sorted, gradually changes to a red-brown clay
	0.92-3.51	clay	brown, slightly silty, water table near 3.00 m
HC28	0.00-0.92	clay, sandy	
	0.92-3.51	clay	dark brown, sticky below water table (near 3.00 m)
HC29	0.00-5.90	clay	black, organic rich, water table at 1.8 m
HC30	0.00-9.14	silt	sandy, clayey, massive
HC31	0.00-3.00	silt	as above
HC32	0.00-0.92	clay	dark brown and black, silty, overlain by organic material
HC-B1	0.00-0.92	sphagnum	
	0.92-2.59	carex	decomposed
	2.59-3.66	carex and silt	highly decomposed
	3.66-4.57	silt	moderate organic content
	4.57-5.83	sand	silty, quartz-rich
HC-B2	0.00-0.92	sedge and sphagnum	
	0.92-2.59	carex	decomposed
	2.59-3.66	silt	moderate organics
	3.66-4.57	silt, sandy	moderate organics
	4.57-5.33	sand, silty	aeolian, quartz-rich, very low organic content

continued ...

Table 6. Concluded.

Silt	Depth (m)	Lithology	Remarks
HC-B3	0.00-0.61	fen peat	fibrous
	0.61-2.74	peat	highly decomposed, very low permeability
	2.74-4.27	silt, sandy	highly permeable
HC-B4	0.00-0.30	carex	floating on free water
	0.30-0.91	free water	with dispersed decomposed peat
	0.91-2.44	peat	decomposed
	2.44-4.57	silt	high organic content
	4.57-6.70	silt, sandy and clayey	contains pockets of methane gas
HC-B5	0.00-2.13	peat	fibrous
	2.13-3.35	peat	decomposed, low permeability
	3.35-3.96	organic ooze and silt	
	3.96-4.88	silt, sandy	
HC-B6	0.00-0.46	free water	with floating lilies and sphagnum fungus
	0.46-1.22	mesic peat	highly permeable
	1.22-3.96	mesic-humic peat	highly decomposed, low to very low permeability
	3.96-5.18	clay and organic ooze	very low permeability
HC-B7	0.00-0.91	peat	fibrous
	0.91-3.05	mesic peat	decomposed, low permeability
	3.05-3.96	silt	highly organic
	3.96-4.88	silt	minor organic content
HC-B8	0.00-1.07	peat	fibrous
	1.07-2.74	peat	mesic, humic, very decomposed, low permeability
	2.74-3.35	sand, silty	high organic content
	3.35-4.88	silt	moderate organic content

9.3 DESCRIPTION OF MUSKEG SITES

9.3.1 Site HC-B1

This site is located in a large fen-sphagnum transitional bog which is saturated to the surface. The surface vegetation is comprised of sphagnum, carex, dwarf birch, and compositae-Peat and extends to an approximate depth of 2.1 to 2.7 m.

9.3.2 Site HC-B2

Site HC-B2, located approximately one-third of a mile from HC-B1, represents a "true" bog. The two sites are separated by aeolian dunes up to 1.2 m high which prevent surface connection. HC-B2 has no obvious surface drainage. Vegetation at the site is restricted to sphagnum and carex. The peat layer reaches a depth of 2.1 to 2.7 m and is underlain by highly permeable silts.

9.3.3 Site HC-B3

This site is situated in a long, narrow "true" fen. Water discharging from the bog flows into the randomized headwaters of Hartley Creek.

9.3.4 Site HC-B4

Site HC-B4 is positioned at the headwaters of Hartley Creek in a floating fen. Highly decomposed peat is separated from an overlying layer of carex by approximately 0.60 m of free water.

9.3.5 Site HC-B5

This site is located in a large bog on the east side of Hartley Creek about 1 km south of the Shell runway. The bog is approximately 2 km long and 1 km wide. Vegetation consists of sedges and tamarack surrounds the elevated portions of the bog.

9.3.6 Site HC-B6

Site HC-B6 is situated on a 0.5 km^2 fen-bog complex on the west side of Hartley Creek. The site is similar to HC-B5.

9.3.7 Site HC-B7

Site HC-B7 is located on a 5 km^2 transitional fen-bog complex at the headwaters of the east branch of Hartley Creek. The surface vegetation is comprised of sphagnum, carex, and tamarack. Ribbons of forested muskeg are found within the bog. The muskeg is highly representative of the muskeg in the entire catchment of the branch of Hartley Creek.

9.3.8 Site HC-B8

Site HC-B8 is positioned in wooded muskeg between the east and west branches of Hartley Creek in the interfluence area. Surface vegetation consists of equusetum, moss (not sphagnum), and carex. Typical 0.002 km^2 open areas are separated by flooded tree thickets of tamarack, black spruce, and dwarf birch.

9.4 EXISTING INFORMATION - ATHABASCA OIL SANDS AREA

9.4.1 Regional Hydrology

9.4.1.1 Pre-Devonian. The Pre-Devonian rocks are all Precambrian in age and form an essentially impermeable basement. Although groundwater does exist in fractures, the extent and effect of these waters on regional groundwater flow is not known, but is assumed to be minimal.

9.4.1.2 Devonian - La Loche and McLean River formations. The La Loche Formation which overlies the Precambrian basement is referred to as the "granite wash". It is composed of arkosic sandstone derived from the erosion of Precambrian rocks. The La Loche is thin over Precambrian highs and thicker over the lows. The thick sections found in the lows have limited areal extent. The La Loche Formation is porous and permeable. Hackbarth (in prep.) reported a hydraulic conductivity measurement of 1.6 x 10^5 cm/sec at site 1-1040. The McLean River Formation consists mostly of dolomitic siltstone that probably has a low hydraulic conductivity.

9.4.1.3 Devonian - Methy Formation. The Methy Formation is a very important hydrostatigraphic unit in the Athabasca Oil Sands area. It is composed primarily of dolomite. Reefal buildups are found throughout, especially in the eastern part of the Athabasca Oil Sands area. The water contained within the Methy is confined and is often under high pressure. Porosity and hydraulic conductivity is extremely variable throughout the Methy. A test hole drilled in 10-25-95-10 W4 lost circulation when the Methy was encountered and the Formation water, under considerable artesian pressure, rose to within 18.3 m of ground level. Yet, in another test hole 1.6 km away, the Methy Formation exhibited very low hydraulic conductivity and no loss of circulation was encountered.

The Methy Formation waters are very saline. A water sample taken from a test hole southwest of the Muskeg River basin contained approximately 200,000 mg/L Cl^- which is close to NaCl saturation. It is suspected that saline waters from the Methy Formation discharge from several flowing wells and springs along the Athabasca River. The high salinity can be attributed, in part, to the dissolution of Elk Point evaporite that overlies and surrounds the Methy Formation at some locales.

Regional information suggests that in the western part of the Athabasca Oil Sands area groundwater in the Methy Formation may be moving eastward. Extensive testing will be required to actually determine the locations and mechanisms of recharge to this unit.

9.4.1.4 Devonian-Prairie Evaporite Formation. The Prairie Evaporite Formation, in type section, is composed mostly of rock salt (halite) with lesser amounts of anhydrite, gypsum, and silty shale. Halite is generally absent in the Prairie Evaporite east of the Athabasca River because of extensive subsurface erosion by circulating groundwaters. Several salt outliers, however, are assumed to exist east of the Athabasca River. The Prairie Evaporite Formation overlies the Methy Formation except east of the Athabasca River where the Prairie Evaporite produces major collapse structures due to the dissolution of salt. The Prairie Evaporite Formation probably acts to confine waters in the Methy Formation effectively and may contribute dissolved salts to the Methy Formation and overlying formations.

9.4.1.5 Devonian - Watt Mountain and Slave Point Formations. The Watt Mountain Formation is a minor stratigraphic unit. It is probably a low conductivity unit that may act to confine the Methy Formation. The Slave Point Formation is a relatively thin carbonate sequence that is, generally characterized by a low porosity and very low hydraulic conductivity. However, one hole drilled west of the Athabasca River encountered a thin porous waterbearing bed within the Slave Point indicating that higher porosities and conductivities may be present. The water contained in these local beds is probably under artesian pressure. The Slave Point Formation, where undisturbed and poorly permeable, will confine the underlying formations.

9.4.1.6 Upper Devonian - Beaverhill Lake Formation. The shale and shaly limestone of the Beaverhill Lake Formation generally have a low hydraulic conductivity. The five members of the unit, if undisturbed, form one hydrostratigraphic unit.

9.4.1.7 Upper Devonian - Woodbend Group. The three formations comprising the Woodbend Group subcrop in the western half of the Athabasca Oil Sands area. However, because these formations are absent in the area studied, they will not be discussed further.

9.4.1.8. Devonian Surface. The Devonian surface is a stream-sculptured erosional surface that exhibits karst-like topography. This topography was produced by the partial solution of the Prairie Evaporite Formation and the subsequent collapse of overlying strata. This phenomena which is believed to be continuing today is most extensive east of the Athabasca River. Several major karst-like lows are found on the Devonian surface and include the Bitumount Basin (96-11 W4) and a depression between Townships 94 and 95, Range 9, W4. Although it was earlier thought that these lows may act as drains for Lower McMurray Formation waters or as conduits for upward moving Devonian waters, Hackbarth (in prep.) suggests that pre-Cretaceous lows are in reality filled with clayey sediments and exhibit low hydraulic conductivities. In other cases, thick water-bearing sands of the McMurray Formation are often found in lows on the Devonian surface. Two examples are found at 2-29-95-9 W4 and at 16-27-96-11 W4 where the water-bearing basal portion of the McMurray Formation is 37 m and 73 m thick, respectively. The location of the basal water-bearing portion, however, is not always related to the structure of the Devonian surface.

The topography of the Devonian surface appears to exert a major control on the hydrogeology of the region. Accordingly, a detailed topographic map of the Devonian surface is needed when examining regional groundwater movement because of the manner in which the Devonian landscape has affected the deposition of the water-bearing portions of Lower McMurray Formation.

9.4.1.9 Lower Cretaceous - McMurray Formation. Two aquifers have been described in the McMurray Formation--the Lower McMurray (basal) water-bearing sands and the intra-McMurray water-bearing sands. Although earlier workers believed that the basal water sand and the majority of the intra-McMurray aquifers were effectively confined by oil sands, on a regional scale there appears to be hydraulic connection through the McMurray Formation (Hackbarth in prep.). Lower McMurray aquifers have been found to underly most leases in the Athabasca Oil Sands area. Typically, they are comprised of thick, clean sands with waters often under considerable artesian pressure.

The transmissivity of the Lower McMurray aquifer appears to be high, but quite variable. Aquifer tests conducted at 10-25-95-10 W4 and 10-20-96-7 W4 produced transmissivity values of 7,000 gpd/ft and 18,000 gpd/ft, respectively. An aquifer test with the well in 10-20-96-7 W4 also indicated that on a local scale, there is no vertical hydraulic continuity between the Lower McMurray aquifer and overlying intra-McMurray aquifers. However, continuity appears to be good locally within the Lower McMurray. On a larger scale, this latter continuity may be disrupted by the presence of collapse features or by the thinning of the Lower McMurray sands over the topographic highs on the Devonian erosional surface.

Aquifers that we term intra-McMurray are usually thin and have a limited areal extent. These units were deposited as the foreset and topset beds of an ancient delta. Aquifter testing indicates that there is poor hydraulic continuity between individual sand bodies.

9.4.1.10 Lower Cretaceous - Clearwater Formation. The Clearwater Formation is composed mainly of shale. It has a low permeability and is considered to be an aquitard. The basal 6 m is a glauconitic sandstone (Wabiskaw Member) and much of its porosity is infilled with silt and clay. However, locally it may be an important aquifer (Hackbarth in prep.).

9.4.1.11 Lower Cretaceous - Grand Rapids Formation. The Grand Rapids Formation is the uppermost bedrock unit east of the Athabasca River. This formation is comprise of salt-and-pepper sandstone and shale up to 91 m thick. The sandstone beds are porous, conductive, and water-bearing. Contact springs are often found where sandstone beds outcrop or where the unit is in contact with the underlying Clearwater Formation. These contact springs erode unconsolidated sands to form blind valleys and vertical cliff faces.

9.4.1.12 Pelistocene and Recent. Very little information has been published concerning the hydrogeologic characteristics of the Pleistocene and Recent deposits. The information that is available indicates that there are appreciable quanitites of good quality water in these units. An aquifer test conducted with a well that was completed in surficial deposits at 10-24-95-9 W4 indicated that the safe pumping rate was 2,000 gpm. Several small circular lakes and ponds may be the surface expressions of sink holes that derived most of their water in the same way. No information is available on the effect that discontinuous permafrost and climafrost has on the hydrogeologic setting.

9.4.2 Regional Hydrochemistry

The information presented in this section is a summary of the chemical data that was presented in the OSESG (1974) report. The chemical analysis or partial analyses used in interpretations were relatively few in number and came from wells concentrated in a few small areas. The quality of the data varies and there is some doubt as to the stratigraphic source of many water samples. In spite of these short comings, it was possible to deduce the general characteristics of water from the three major stratigraphic sources.

9.4.2.1 Devonian. Twenty-seven chemical analyses, or partially analyses, were interpreted and showed that the majority of Devonian groundwater is the Na/Cl type[1]. This water type results from the dissolution of halite and minor amounts of anhydrite, gypsum, and some carbonate minerals.

Groundwater from the Middle Devonian Elk Point Group is one order of magnitude greater in TDS and chloride concentration than groundwater from the Upper Devonian Beaverhill Lake Formation. The total dissolved solids content and chloride concentration of Elk Point Group water are typically greater than 200,000 mg/L and 100,000 mg/L respectively. The values for the same constituents in the Beaverhill Lake Group water analyses are 10,000 and 20,000 mg/L TDS and 5,000 to 10,000 mg/L Cl^-.

The Devonian water is believed to originate from meteoric sources rather than connate formation waters. An isotope study by Hitchon (1969) assigns a meteoric origin to the La Saline spring water in 16-15-93-10 W4. The spring water is believed to originate from the Methy Formation. However, it is not completely clear whether brines from the deeper parts of the Western Canada Sedimentary basin may contribute significantly to the regional groundwater flow in the Athabasca Oil Sands area.

The hydrochemical patterns for Devonian waters suggest that inflow is received from surface water in the eastern part of the Athabasca Oil Sands area. Regionally the groundwater flows westward towards the Athabasca River, dissolving some of the remaining salts of the Prairie Evaporite Formation.

9.4.2.2 McMurray Formation. One hundred analyses or partial analyses were used to interpret the chemical character of McMurray Formation water. The water was either the Na/Cl type or the Na/HCO_3 type. The Na/HCO_3 type predominates in the eastern part of the Athabasca Oil Sands area.

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[1] Na/Cl type water refers to waters whose ionic composition is dominated by these ionic forms.

There is considerable local variation with respect to salinity, as indicated by the Cl^- ion concentration. Chloride concentrations range from less than 100 mg/L to over 15,000 mg/L. Twenty-five percent of the samples analysed had chloride concentrations less than 100 mg/L and more than 50% had concentrations ranging between 1,000 to 10,000 mg/L Cl^-.

9.4.2.3 Post-McMurray. The results of 68 chemical analyses (OSESG 1974) reveal that water in the Pleistocene deposits is the calcium-magnesium/bicarbonate type with total dissolved solids content usually less than 1,000 mg/L. The chemistry of the water changes rapidly with depth to a Na/HCO_3 type. Waters sampled from the Grand Rapids Formation have a total dissolved solids content ranging from 1,000 to 3,000 mg/L. Seventy-five percent of all the samples had chloride concentrations of <50 mg/L. Highly saline waters in post-McMurray deposits have not been detected yet but may exist.

9.4.3 Hydrogeology of the Muskeg River Basin

Three hydrogeologic investigations have been conducted in the Muskeg River basin since 1974. The pertinent results of these studies will follow.

9.4.3.1 Tenneco Oil and Minerals Ltd. Underwood McLellan and Associates Ltd. (1974) conducted a hydrogeologic study for Tenneco Oil And Minerals Ltd. at the Athabasca Oil Sands Lease No. 87. The Lease is located within the Muskeg River basin approximately 80 km north of Fort McMurray in Tp. 96, R7, W4. The purpose of the study was to evaluate the aquifer characteristics of the McMurray Formation and of the overburden. A drilling program conducted in March 1974 resulted in the emplacement of one pumping well and four observation wells at 10-20-96-7 W4. Another hole was completed in drift above the McMurray Formation at 10-20-96-7 W4. Two main aquifers were discovered within the McMurray Formation. Both are composed of water-bearing bituminous sands. The upper aquifer is separated from the underlying one by a grey shale. This latter aquifer is made up of two sand layers, one of which is the base of the Upper McMurray Formation and the other is the top of the Lower McMurray Formation.

The transmissivity of the lower aquifer is 15,000-20,000 USGPDPF. The upper aquifer has transmissivity values of 5,000-10,000 USGPDPF and apparently has little or no hydraulic relationship with the lower aquifer. The lithologs for the two test holes are presented in Table 7 and the transmissivity and storage coefficient values for observation wells one, two, and four are summarized in Table 8. Chemical analyses were performed on three samples and the results are shown in Table 9. Geophysical logs can be found in the report by Underwood McLellan and Associates Ltd.

9.4.3.2 Alberta Research Council. The Alberta Research Council (Hackbarth in prep.) began a regional groundwater study of the Athabasca Oil Sands in the winter of 1974. The purpose of the study was to produce a hydrogeological model for technical and environmental planning.

Thirty-six wells at seven sites were drilled in the Athabasca Oil Sands area during the winter of 1974. Twenty of these wells at four sites are in the Muskeg River basin. The site number and their locations are:

Site 6	LSD	2-18-95-9 W4
Site 7	LSD	13-20-95-8 W4
Site 8	LSD	5-30-94-7 W4
Site 9	LSD	1 and LSD 16-4-94-6 W4

A separate publication (Alberta Research Council Information Series 69) has been compiled for each site and included in each are:

geological and geophysical logs
annual hydrographs

Table 7. Lithologs from lease No. 87 (Tenneco Oil).

Site	Depth (ft.)[a]	Lithology	Formation
10-32-96-7 W4	0-16	muskeg	Organic
	16-35	sandy gravel	Drift
	35-40	clay	Drift
	40-87	sandy w/gravel	Drift
	87-95	sand	Drift
	95-96	shale	Clearwater
10-20-96-7 W4	0-20	muskeg	Organic
	20-70	sand w/clay stringers	Drift
	70-71	shale	Clearwater

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[a] Units have not been converted to metric units in order to maintain consistency with the original work.

Table 8. Summary of aquifer test data on lease No. 87 (Tenneco Oil).

Well No.	Formation	Transmissivity (USGPDPF)[a]	Storativity
1	Top of Lower McMurray	16,250	5.68×10^{-3}
2	Bottom of Upper McMurray	15,840	2.47×10^{-4}
4	Bottom of Upper McMurray	15,840	2.49×10^{-4}

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[a] Units have not been converted to metric units in order to maintain consistency with the original work.

Table 9. Summary of published chemical data.

Formation	Well No.	Lithology	Date	Concentrations (mg/L)								Type	Conductivity (μmhos/cm)
				Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	$CO_3^{=}$	$SO_4^{=}$	Cl^{-}		
Drift	7-32	Sandy Till	31 Jan./75	41.5	15.3	101.0	2.1	408.0	16.8	35.2	5.0	Na/HCO_3	660
			10 Sept./75	6.3	10.9	108.0	11.3	322.0	0.0	26.3	14.0	Na/HCO_3	610
	8-34	Sand	22 Feb./75	49.4	22.1	146.3	2.9	517.0	0.0	7.3	44.0	Na/HCO_3	860
			10 Sept./75	23.0	14.2	133.0	6.3	444.0	0.0	0.0	22.0	Na/HCO_3	820
	9-161	Sandy Clay Till	8 Mar./75	40.6	24.1	40.0	14.6	325.0	0.0	8.2	25.0	$Ca-Mg-Na/HCO_3$	560
Clearwater	8-114	Clay	22 Feb./75	19.6	6.6	239.0	13.3	525.0	16.8	97.0	54.0	Na/HCO_3	1,100
	8-220	Clay	6 Mar./75	34.0	3.2	700.0	117.0	1,898.0	9.6	5.7	4.0	Na/HCO_3	1,800
	8-370	Clay	23 Feb./75	17.9	7.0	409.0	15.4	1,054.0	9.6	117.0	27.0	Na/HCO_3	1,710
McMurray	6-21	Tar Sand	18 Feb./75	100.0	22.0	6.3	0.8	378.0	0.0	10.0	44.0	Ca/HCO_3	640
			11 Sept./75	31.0	5.2	17.5	1.7	137.0	0.0	3.3	12.0	Ca/HCO_3	280
	6-220	Tar Sand	18 Feb./75	6.8	22.8	1,431.0	18.8	1,715.0	146.0	73.5	1,320.0	Na/Cl	6,500
			11 Sept./75	6.9	21.1	1,400.0	125.0	2,079.0	86.0	2.5	658.0	Na/HCO_3	-
	7-135	Tar Sand	2 Feb./75	9.4	17.4	355.0	19.6	947.0	53.0	18.5	31.0	Na/HCO_3	1,550
			10 Sept./75	9.6	15.0	345.0	20.8	1,017.0	0.0	4.6	14.0	Na/HCO_3	1,600
	7-337	Water Sand	6 Feb./75	9.2	28.7	583.0	22.1	1,235.0	31.0	12.7	321.0	Na/HCO_3	2,780
			7 Feb./75	42.5	29.0	586.0	22.1	1,369.0	0.0	10.5	315.0	Na/HCO_3	2,900
			8 Feb./75	7.0	28.0	585.0	22.1	1,171.0	79.0	12.2	323.0	Na/HCO_3	2,780
			9 Sept./75	14.7	28.0	575.0	22.1	1,239.0	0.0	2.7	218.0	Na/HCO_3	3,200
			10 Sept./75	14.7	28.0	575.0	22.1	1,239.0	0.0	2.7	218.0	Na/HCO_3	3,200
	Home #2	Water Sand	18 Feb./75	47	34	-	-	965	0.0	2	1,800	Na/Cl	-
	Home #4	Water Sand	10 Mar./75	64	58	-	-	1,625	0.0	20	3,150	Na/Cl	-
	Tenneco 1	Water Sand	6 Mar./74	41	15	114	9	453	31	9	2	Na/HCO_3	-
	Tenneco 3	Water Sand	27 Feb./74	128	84	190	-	560	42	528	Trace	Na/SO_4	-
	Tenneco 4	Water Sand	18 Feb./74	42	62	161	-	431	0.0	344	Trace	Na/SO_4	-
Beaverhill Lake	6-310	Limestone	10 Feb./75	9.2	27.3	1,469.0	38.0	1,720.0	72.0	123.0	1,480.0	Na/Cl	6,800
			19 Feb./75	5.4	27.5	1,563.0	20.8	1,708.0	240.0	25.0	1,440.0	Na/Cl	7,000
			11 Sept./75	117.0	144.0	2,850.0	77.0	1,996.0	0.0	43.7	2,238.0	Na/Cl	-
	8-532	Clay	24 Feb./75	19.5	27.5	775.0	14.6	1,396.0	0.0	7.7	511.0	Na/HCO_3	3,500
			7 Mar./75	5.5	25.9	813.0	15.0	1,161.0	110.0	12.5	717.0	$Na/Cl-HCO_3$	3,600
	8-716	Limestone	7 Mar./75	7.5	10.3	738.0	49.2	215.0	106.0	81.0	895.0	Na/Cl	-
			10 Sept./75	47.0	142.0	2,125.0	50.0	1,491.0	0.0	160.0	2,838.0	Na/Cl	-
	9-1150	Limestone	4 Mar./75	38.5	1.6	21.3	13.8	83.0	7.2	0.0	54.0	Ca/Cl	330
Prairie Evaporite	7-594	Gypsum	19 Feb./75	380.0	346.0	1,688.0	67.0	422.0	0.0	2,500.0	2,875.0	Na/Cl	8,000+
Precambrian	7-933	Granite	11 Mar./75	25.4	1.5	251.0	76.0	146.0	12.0	134.0	300.0	Na/Cl	1,480

drill-stem test results
aquifer testing results
well histories
water analyses
well completion details

Geological logs were recorded for the deepest hole at each site and are assumed to be representative of the lithology of the other holes at the site. In addition, a suite of geophysical logs were run including spontaneous potential, single point resistance, natural gamma, and uncompensated density. Because of the difficulty in reproducing these data, we have not included them here. However, the results of the aquifer testing and the drill-stem test results are summarized in Table 10.

A summary of the results of chemical analyses of samples collected from these wells by the Alberta Research Council are presented in Table 9. Several samples that obviously were contaminated by cement are not included. It is apparent (Table 9) that samples taken from the McMurray and younger formations are of the Na/Cl type. These results are in agreement with the regional observations reported in the previous section. Twenty-nine different elements were also analyzed using the spectral emission estimate method. The results, however, are not presented in this report.

9.4.3.3 Home Oil Co. Ltd. E.B.A. Engineering Consultants Ltd. undertook a groundwater investigation for Home Oil Co. Ltd. on their Athabasca Oil Sands Lease No. 30 in February and March 1975. A total of seven test holes were located in sections 21 and 28, township 94, range 9, W4. Drilling took place at four sites. At three of the sites, an observation well was emplaced approximately 30 m away from the production well. At the remaining site, only a production well was emplaced. It is now being used as a permanent observation well.

Table 10. Summary of Alberta Research Council aquifer test data.

				Drawdown Plot Data						Drill Stem Test Data			
				Recovery			Pumping						
Formation	Well No.	Screened[a] Interval (ft.)	Lithology	Q[a] (igpd)	T (m^2/day)	Date (1975)	Q[a] (ipgd)	T (m^2/day)	Date (1975)	T (m^2/day)	Extra.Res.[a] Pressure (p.s.i.)	Hydraulic Conduct (cm/sec)	Date (1975)
Drift	7-32	22-27	Sandy Till	3.0	6.4×10^{-2}	29 Jan.							
	9-449	405-420	Sltst. & Gravel								97.0		5 Mar.
Clearwater	8-114	99-109	Clay	6.1	9.5×10^{-1}	22 Feb.	5.8	1.9	2-3 Mar.				
				11.0	9.5×10^{-1}	23 Feb.							
	8-220	185-205	Clay								27.0		6 Mar.
McMurray	6-220	195-215	Tar Sand		1.2×10^{-1}	17 Feb.	1.7	1.6×10^{-1}	17 Feb.				
	7-135	120-130	Tar Sand	4.4	6.9×10^{-2}	30 Jan.	1.7	2.1×10^{-1}	1 Feb.				
				0.8	6.9×10^{-2}	1 Feb.	0.8	5.2×10^{-2}	2 Feb.				
							1.7	8.5×10^{-2}	2 Feb.				
	7-337	322-332	V.F. Sand	81.0	2.2	4 Feb.							
				25.0	4.0	6-7 Feb.	25.0	12.0	6-7 Feb.				
				25.0	1.2	7-8 Feb.	25.0	2.5	7-8 Feb				
	9-951	931-946	Clay							1.4×10^{-3}	21.2	3.5×10^{-7}	3 Mar.
	9-1056	1046-1056	Sand							4.9×10^{-2}	50.1	1.9×10^{-5}	4 Mar.
Beaverhill Lake	6-310	Open Casing 310 ft.	Limestone		1.5×10^{-2}	18-19 Feb	2.5	5.8×10^{-2}	18-19 Feb.				
					1.3×10^{-1}	17 Feb.	2.5	2.1×10^{-1}	19 Feb				
	8-532	517-527	Clay								65.0		7 Mar.
	8-716	Open Casing 716 ft.	Limestone							3.1×10^{-2}	57.2	3.0×10^{-6}	7 Mar.
	9-1150	Open Casing 1150 ft.	Limestone							8.5×10^{-3}	69.6	8.0×10^{-7}	4 Mar.
Prairie Evaporite	7-594	Open Casing 594 ft	Gypsum							3.2×10^{-3}	163.0	3.0×10^{-7}	11 Mar.
Precambrian	7-933	Open Casing 933 ft.	Granite							2.3×10^{-3}	30.0	2.0×10^{-7}	11 Mar.

[a] Units have not been converted to metric units in order to maintain consistency with the original work.

Drilling at all sites encountered two McMurray Formation aquifers below the bitumen-rich zone. These aquifers are separated by a green shale bed that is not continuous everywhere. Both aquifers appear to have different hydraulic characteristics even through communication does exist.

Lithologs, geophysical logs, aquifer test results, grain size analyses, and three water analyses are presented in the EBA report. A summary of the aquifer test data is presented in Table 11 of this report. The results of two chemical analyses are entered in Table 9.

Table 11. Summary of Home Oil's aquifer test data.

Site No.	Well No.	Aquifer	Transmissivity (igpd/ft)[a]	Storativity	Pumping Rate (igmp)[a]
1	1	Upper and Lower	5,077	5.68×10^{-5}	-
	2	Upper	5,280	-	50
2	1	Upper and Lower	4,400[b]	1.7×10^{-4}	-
			5,080[c]	2.2×10^{-5}	-
			1,910[d]	2.3×10^{-4}	-
	2	Upper	4,400	1.68×10^{-4}	-
			1,377	7.1×10^{-7}	-
			-	-	-
	4	Lower	1,325	-	50
			1,100	-	50
			-	-	-
	5	Lower	1,443	5.8×10^{-5}	
			-	-	
			1,245	7.6×10^{-5}	
	6	Upper and Lower	1,529	6.5×10^{-5}	-
			-	-	
			1,193	8.9×10^{-5}	-
	7	Lower	1,500	6.3×10^{-5}	
			-	-	
			1,193	-	

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[a] Units have not been converted to metric units in order to maintain consistency with the original work.

[b] Calculated from drawndown data.

[c] Calculated from recovery data.

[d] The type curve solution.

9.5 PIEZOMETER WATER LEVEL MEASUREMENTS

Table 12. Piezometer water level measurements, 1977 dates.

Piezometer Number	Date Measured	Depth[a]	Piezometer Number	Date Measured	Depth
HC1	17 June	0.84	HC16	5 July	1.78
	6 July	n.d.[b]		9 Aug.	1.52
	24 July	1.35	HC17	3 July	4.50
	6 Aug.	1.52		28 July	5.79
HC2	17 June	3.07		9 Aug.	5.66
	24 July	3.18	HC18	7 July	2.90
	6 Aug.	3.38		28 July	2.13
HC4	17 June	1.14		9 Aug.	2.22
	5 July	0.91	HC20	7 Aug.	5.76
	27 July	0.48	HC21	29 July	1.78
	8 Aug.	0.57		7 Aug.	2.02
HC5	5 July	n.d.	HC22	9 July	1.78
HC6	24 June	4.83		29 July	2.16
	5 July	n.d.		7 Aug.	2.26
	27 July	3.05	HC23	9 July	2.02
	8 Aug.	3.25		29 July	n.d.
HC7	24 June	3.05		7 Aug.	2.69
	27 July	n.d.	HC24	10 July	6.43
	8 Aug.	2.14		12 Aug.	4.98
HC8	27 July	n.d.	HC25	11 July	5.92
	8 Aug.	3.52		29 July	3.66
HC9	27 July	n.d.		12 Aug.	2.51
	8 Aug.	1.14	HC26	11 July	2.41
HC10	10 July	0.58		29 July	n.d.
	24 July	0.46		12 Aug.	2.16
HC12	11 July	0.74	HC27	12 July	2.97
	6 Aug.	1.27		27 July	n.d.
HC13	2 July	0.77	HC28	12 July	2.92
	7 July	1.12		27 July	n.d.
	9 Aug.	0.85	HC29	29 July	1.22
HC14	5 July	5.79		12 Aug.	1.30
	28 July	n.d.	HC30	Not reported	
	9 Aug.	6.10	HC31	Not reported	
HC15	5 July	0.48	HC32	13 Aug.	3.51
	9 Aug.	1.23			

[a] in metres.

[b] not detected.

9.6 CHEMICAL DATA FROM GROUNDWATER SAMPLES

Table 13. Chemical data[a] from groundwater samples.

Type[b]	Site[c,g]	Day[d]	Ca	Mg	Na	K	Fe	HCO_3	CO_3	SO_4	Cl	F	pH[e]	Cond.[f]
1	1	533	110.8	25.0	5.9	3.4	-1.	391.	0.0	20.9	5.5	-1.	7.74	585.
1	1	552	107.5	30.0	5.0	3.6	-1.	436.	0.0	45.0	3.8	-1.	7.50	690.
1	1	585	83.0	25.0	5.4	2.5	-1.	361.	0.0	21.3	4.0	-1.	8.24	468.
1	1	587	74.0	25.0	6.1	2.5	-1.	358.	0.0	21.0	10.0	-1.	8.12	437.
1	2	527	117.9	27.5	6.7	3.5	-1.	459.	0.0	2.9	5.0	-1.	7.65	645.
1	2	586	35.5	10.0	3.9	1.3	-1.	156.	0.0	7.7	3.3	-1.	7.80	256.
1	4	533	139.4	21.0	24.9	13.3	-1.	518.	0.0	5.9	13.5	-1.	7.67	810.
1	4	551	107.5	18.5	13.0	5.1	-1.	441.	0.0	11.5	7.2	-1.	7.35	662.
1	4	585	110.0	15.0	8.9	2.7	-1.	437.	0.0	.5	4.0	-1.	7.74	600.
1	6	540	100.9	26.5	11.9	14.6	-1.	506.	0.0	11.0	8.0	-1.	7.63	740.
1	6	551	87.5	32.5	9.0	8.6	-1.	502.	0.0	10.2	3.9	-1.	7.40	848.
1	6	585	130.0	29.0	5.6	2.1	-1.	583.	0.0	.5	4.0	-1.	7.80	680.
1	7	540	66.0	20.0	11.1	5.0	-1.	301.	0.0	-1.0	15.0	-1.	8.10	-1.
1	7	551	110.0	23.5	6.0	2.6	-1.	430.	0.0	41.0	7.2	-1.	7.30	672.
1	7	585	98.0	22.0	4.2	1.0	-1.	371.	0.0	.5	2.0	-1.	7.76	570.
1	8	557	36.5	18.0	11.0	1.9	-1.	238.	0.0	7.8	3.3	-1.	7.55	368.
1	8	585	38.7	22.0	12.4	2.7	-1.	250.	0.0	.5	4.0	-1.	8.47	363.
1	9	585	20.0	7.6	5.2	.6	-1.	98.	0.0	9.2	4.0	-1.	7.84	165.
1	10	546	102.5	18.5	14.0	3.5	-1.	431.	0.0	15.5	5.2	-1.	7.20	642.
1	10	585	117.0	25.0	7.3	2.0	-1.	484.	0.0	3.5	4.0	-1.	7.67	685.
1	12	557	117.5	25.0	6.0	2.2	-1.	484.	0.0	17.0	4.2	-1.	7.15	705.
1	12	585	110.0	25.0	7.0	1.9	-1.	503.	0.0	.5	2.0	-1.	7.77	670.
1	13	547	123.0	31.2	14.6	4.0	-1.	568.	0.0	26.0	5.9	-1.	7.40	838.
1	13	586	110.0	30.0	16.0	2.2	-1.	534.	0.0	9.5	4.0	-1.	7.79	690.
1	15	548	77.5	31.0	12.5	4.7	-1.	433.	0.0	14.0	5.3	-1.	7.45	732.
1	15	586	90.0	28.0	15.1	3.2	-1.	500.	0.0	.5	4.0	-1.	7.72	665.
1	16	549	85.0	22.5	7.2	2.6	-1.	376.	0.0	11.5	3.1	-1.	7.20	560.
1	16	586	73.4	21.3	7.6	2.0	-1.	368.	0.0	.5	4.0	-1.	7.82	508.
1	17	552	75.0	24.0	16.0	4.1	-1.	408.	0.0	16.2	3.5	-1.	7.85	630.
1	17	586	12.0	6.2	49.2	4.2	-1.	131.	0.0	4.0	46.0	-1.	8.21	344.
1	18	555	65.0	31.0	16.5	10.9	-1.	403.	0.0	18.0	5.4	-1.	7.60	680.
1	18	586	82.0	33.0	14.6	8.9	-1.	499.	0.0	.5	4.0	-1.	7.92	650.
1	20	584	60.7	20.0	35.7	6.8	-1.	344.	0.0	22.2	22.0	-1.	8.14	560.
1	21	555	65.0	36.0	4.4	2.3	-1.	393.	0.0	15.5	9.2	-1.	8.00	612.
1	21	584	66.0	35.0	7.0	2.1	-1.	428.	0.0	.5	10.0	-1.	8.31	550.
1	22	555	92.5	21.0	44.0	3.5	-1.	375.	0.0	15.5	75.0	-1.	7.45	778.
1	22	584	86.0	21.0	51.3	3.3	-1.	411.	0.0	.5	80.0	-1.	7.67	790.
1	23	555	87.5	20.0	37.5	2.3	-1.	324.	0.0	11.0	71.0	-1.	7.60	702.
1	23	584	73.4	18.0	41.0	1.4	-1.	350.	0.0	.5	76.0	-1.	8.46	650.
1	24	555	25.0	21.0	112.5	13.6	-1.	516.	0.0	11.0	5.2	-1.	7.60	805.
1	24	589	27.0	17.6	137.0	9.1	-1.	578.	0.0	.5	4.0	-1.	8.13	780.
1	25	555	60.0	13.5	33.0	4.9	-1.	239.	0.0	97.5	1.8	-1.	7.60	547.
1	25	589	27.0	11.1	36.0	5.8	-1.	236.	0.0	15.8	4.0	-1.	8.06	375.
1	26	589	63.1	10.8	7.9	3.2	-1.	280.	0.0	.5	4.0	-1.	7.95	392.
1	27	555	82.5	30.0	9.1	2.5	-1.	406.	0.0	49.4	6.1	-1.	7.90	755.
1	27	585	110.0	26.0	10.4	1.1	-1.	430.	0.0	10.0	4.0	-1.	7.98	625.
1	29	575	139.0	20.0	37.7	5.3	-1.	565.	0.0	.5	6.0	-1.	7.95	760.
1	29	589	98.0	20.0	38.0	5.0	-1.	550.	0.0	.5	4.0	-1.	8.10	720.
1	99	495	80.4	27.3	13.4	1.7	-1.	303.	0.0	21.0	41.5	-1.	7.43	630.
1	99	556	110.0	36.0	39.0	1.5	-1.	502.	0.0	21.9	48.0	-1.	7.93	900.
1	99	608	180.0	40.0	35.5	2.3	-1.	635.	0.0	.5	92.0	-1.	7.38	1080.
1	98	556	9.1	21.0	1340.1	14.0	-1.	2073.	49.8	15.0	1112.	-1.	8.49	6000.

continued ...

Table 13. Concluded.

Type[b]	Site[c,g]	Day[d]	Ca	Mg	Na	K	Fe	HCO_3	CO_3	SO_4	Cl	F	pH[e]	Cond.[f]
1	97	495	60.7	21.5	44.8	4.2	-1.	356.	0.0	2.3	7.5	-1.	7.88	515.
1	97	556	38.6	18.6	53.3	2.9	-1.	356.	0.0	.5	9.0	-1.	7.84	525.
1	97	608	53.0	20.0	42.0	4.9	-1.	350.	0.0	.5	6.0	-1.	8.19	498.
1	96	556	54.3	42.6	364.9	42.6	-1.	610.	0.0	.5	452.0	-1.	7.44	3090.
1	95	495	65.6	22.4	141.0	5.0	-1.	459.	0.0	.5	67.5	-1.	8.10	980.
~~1~~	~~95~~	~~556~~	~~35.7~~	~~15.8~~	~~132.4~~	~~5.5~~	~~-1.~~	~~396.~~	~~0.0~~	~~.5~~	~~52.0~~	~~-1.~~	~~8.19~~	~~815.~~
1	95	608	53.7	19.3	136.0	9.4	-1.	439.	0.0	.5	58.5	-1.	8.18	915.
4	10	558	7.5	1.6	2.0	0.0	-1.	22.	0.0	7.2	1.4	-1.	6.50	50.
4	14	558	17.8	3.1	4.4	.6	-1.	82.	0.0	4.2	2.0	-1.	7.21	130.
4	18	558	32.0	6.5	7.2	1.5	-1.	133.	0.0	8.0	6.5	-1.	7.40	221.
4	116	558	43.5	9.9	8.1	2.0	-1.	192.	0.0	7.6	2.0	-1.	7.69	280.
~~4~~	~~20~~	~~558~~	~~.7~~	~~.5~~	~~2.0~~	~~.6~~	~~-1.~~	~~0.~~	~~0.0~~	~~6.0~~	~~2.0~~	~~-1.~~	~~3.10~~	~~264.~~
4	24	558	14.0	2.1	8.5	1.6	-1.	56.	0.0	10.5	6.0	-1.	7.12	108.
4	28	558	9.1	1.5	5.7	2.1	-1.	33.	0.0	8.1	4.0	-1.	6.30	109.
4	216	558	18.4	2.1	3.2	.8	-1.	6.	0.0	22.8	1.8	-1.	5.50	163.
4	30	558	23.9	7.1	18.2	.4	-1.	95.	0.0	3.2	4.0	-1.	7.32	252.
4	314	558	57.0	10.0	127.0	43.0	-1.	516.	0.0	9.9	14.0	-1.	8.23	780.
~~4~~	~~40~~	~~558~~	~~45.0~~	~~3.0~~	~~167.0~~	~~3.0~~	~~-1.~~	~~494.~~	~~0.0~~	~~15.2~~	~~8.0~~	~~-1.~~	~~8.30~~	~~920.~~
4	40	584	38.0	.9	195.0	2.8	-1.	631.	0.0	14.4	9.0	-1.	7.68	930.
4	48	584	41.0	2.1	216.0	4.8	-1.	638.	0.0	57.5	38.0	-1.	8.24	1080.
4	416	558	10.0	1.5	249.0	3.7	-1.	684.	0.0	29.0	16.0	-1.	9.13	1015.
4	422	558	10.0	1.6	267.0	3.8	-1.	697.	0.0	26.7	32.0	-1.	8.82	1055.
4	422	584	37.0	5.1	50.0	1.7	-1.	212.	0.0	15.3	4.0	-1.	8.45	354.
~~4~~	~~50~~	~~558~~	~~13.9~~	~~3.0~~	~~4.7~~	~~.2~~	~~-1.~~	~~52.~~	~~0.0~~	~~5.6~~	~~1.0~~	~~-1.~~	~~6.84~~	~~89.~~
4	50	584	14.3	3.2	4.1	.1	-1.	54.	0.0	8.7	2.0	-1.	7.66	90.
4	57	558	49.0	8.8	7.8	.2	-1.	180.	0.0	7.4	2.0	-1.	7.37	280.
4	516	558	104.0	13.6	6.2	1.5	-1.	407.	0.0	.5	2.0	-1.	7.95	580.
4	516	558	106.0	12.1	13.8	1.3	-1.	393.	0.0	.5	2.0	-1.	8.19	540.
4	60	558	5.4	2.0	1.3	.4	-1.	19.	0.0	7.6	2.0	-1.	6.27	45.
~~4~~	~~60~~	~~584~~	~~127.0~~	~~12.2~~	~~27.7~~	~~1.4~~	~~-1.~~	~~449.~~	~~0.0~~	~~.5~~	~~4.0~~	~~-1.~~	~~7.79~~	~~610.~~
4	70	558	14.3	4.3	5.0	.2	-1.	68.	0.0	4.2	2.0	-1.	6.80	109.
4	70	584	25.0	7.4	11.0	.2	-1.	140.	0.0	5.0	2.0	-1.	7.58	211.
4	78	584	46.0	5.4	9.5	.9	-1.	165.	0.0	5.8	4.0	-1.	8.46	238.
4	716	584	106.0	8.5	8.8	1.4	-1.	204.	0.0	116.0	2.0	-1.	8.01	560.
4	80	558	29.0	7.0	10.2	.1	-1.	127.	0.0	4.0	1.0	-1.	7.08	188.
~~4~~	~~80~~	~~584~~	~~13.9~~	~~4.1~~	~~4.8~~	~~.1~~	~~-1.~~	~~66.~~	~~0.0~~	~~6.6~~	~~2.0~~	~~-1.~~	~~7.39~~	~~106.~~
4	810	584	114.0	18.0	12.9	.8	-1.	421.	0.0	5.6	4.0	-1.	7.74	590.
4	816	558	97.0	24.0	37.1	4.3	-1.	490.	0.0	.5	5.0	-1.	7.95	665.

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

[b] type: 1-ground water; 4-standing water in muskeg areas and water collected from piezometers in muskeg.

[c] sites 95 to 99 represent Research Council of Alberta observation wells.

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

[e] expressed in pH units.

[f] specific conductance expressed as micromhos per cm.

[g] for sites located in muskeg areas the first of the site #'s referes to site location followed by sample depth, e.g., 2.16 site 2, 16 foot depth.

9.7 CHEMICAL DATA FROM STREAM SAMPLES (PRELIMINARY)

Table 14. Chemical Data[a] from stream samples (preliminary)

Type[b]	Site	Day[c]	Ca	Mg	Na	K	Fe	HCO_3	CO_3	SO_4	Cl	F	pH[d]	Cond.[e]
2	1	208	57.0	13.0	12.0	.8	0.8	278.	0.0	.5	5.1	.1	7.80	380.
2	1	250	38.0	10.3	13.5	.7	.4	180.	0.0	.6	2.5	.1	7.80	270.
2	1	279	39.5	10.2	22.7	.7	.6	188.	0.0	.5	13.9	.1	7.80	325.
~~2~~	~~1~~	~~302~~	~~36.0~~	~~10.5~~	~~12.0~~	~~.8~~	~~.9~~	~~174.~~	~~0.0~~	~~.5~~	~~2.5~~	~~.1~~	~~7.60~~	~~260.~~
2	1	314	45.5	12.5	13.0	.8	1.3	211.	0.0	4.5	3.9	.1	7.40	320.
2	1	350	82.0	18.5	14.5	1.6	2.1	352.	0.0	9.5	6.3	.1	7.40	520.
2	1	390	75.0	17.2	13.5	1.8	2.6	332.	0.0	5.3	4.1	.1	7.30	500.
2	1	427	71.5	16.9	14.5	1.9	1.8	319.	0.0	3.8	4.7	.2	8.20	480.
2	1	473	16.5	4.5	4.9	2.6	1.3	79.	0.0	3.3	1.7	.1	7.50	126.
~~2~~	~~1~~	~~501~~	~~29.5~~	~~8.0~~	~~9.0~~	~~1.4~~	~~.7~~	~~144.~~	~~0.0~~	~~6.0~~	~~1.7~~	~~.1~~	~~7.90~~	~~220.~~
2	1	536	33.0	9.0	9.2	.5	1.1	163.	0.0	9.1	2.0	.1	8.10	250.
2	1	563	32.5	9.5	22.0	.7	.8	174.	0.0	8.2	14.4	.2	7.80	320.
2	1	593	45.5	12.0	12.5	.6	1.2	207.	0.0	6.4	3.1	.1	7.95	294.
2	1	642	43.0	11.0	13.5	1.1	.8	210.	0.0	.1	3.7	.1	8.06	295.
2	1A	232	52.2	12.1	12.0	.8	.4	224.	0.0	5.1	4.1	.1	8.10	395.
~~2~~	~~1A~~	~~252~~	~~64.0~~	~~13.0~~	~~12.5~~	~~1.2~~	~~1.3~~	~~269.~~	~~0.0~~	~~.5~~	~~3.5~~	~~.2~~	~~7.70~~	~~430.~~
2	1A	298	38.5	11.5	11.5	1.0	1.0	188.	0.0	.5	2.5	.1	7.40	290.
2	1A	322	60.0	15.3	14.5	1.0	1.3	262.	0.0	5.0	5.1	.1	7.70	412.
2	2	208	30.0	8.8	12.0	.5	.8	174.	0.0	2.5	2.7	.1	7.70	250.
2	2	250	25.0	8.2	13.0	.6	.9	138.	0.0	-1.	1.2	.1	7.70	190.
2	2	277	26.5	7.4	12.5	.3	.5	135.	0.0	1.9	2.0	.1	7.60	202.
~~2~~	~~2~~	~~298~~	~~25.5~~	~~8.2~~	~~13.5~~	~~.5~~	~~.6~~	~~138.~~	~~0.0~~	~~.5~~	~~2.1~~	~~.1~~	~~7.60~~	~~205.~~
2	2	314	32.0	9.3	14.0	.5	.9	159.	0.0	7.2	3.5	.1	7.50	250.
2	2	336	72.5	19.0	29.0	1.5	1.8	344.	0.0	12.5	13.6	.2	7.50	540.
2	2	391	80.0	20.5	30.0	2.0	5.0	397.	0.0	6.0	17.0	.2	8.10	600.
2	2	431	91.0	21.8	29.5	2.2	1.2	424.	0.0	5.0	16.5	.2	7.80	660.
2	2	473	11.5	3.5	5.5	2.5	1.2	57.	0.0	5.0	1.7	0.0	7.20	105.
~~2~~	~~2~~	~~501~~	~~21.0~~	~~6.2~~	~~11.0~~	~~1.0~~	~~.5~~	~~113.~~	~~0.0~~	~~6.4~~	~~1.4~~	~~.1~~	~~8.20~~	~~179.~~
2	2	538	23.5	7.0	11.0	.3	.4	126.	0.0	4.3	1.4	-1.	7.70	197.
2	2	559	25.5	7.0	11.5	.2	.5	123.	0.0	4.2	1.0	.1	7.70	196.
2	2	593	32.0	9.5	13.5	.3	.7	158.	0.0	6.1	2.0	.1	7.95	230.
2	2	642	29.5	9.0	13.5	.9	.5	157.	0.0	.1	2.6	.1	7.93	214.
2	2A	208	30.0	8.5	11.5	.4	.8	177.	0.0	.1	2.2	.1	7.80	240.
~~2~~	~~2A~~	~~251~~	~~24.0~~	~~6.2~~	~~12.5~~	~~.5~~	~~1.5~~	~~126.~~	~~0.0~~	~~.5~~	~~1.5~~	~~.1~~	~~7.50~~	~~187.~~
2	2A	272	48.5	12.0	13.6	.5	.8	222.	0.0	.5	3.3	.1	7.80	340.
2	2A	298	25.5	8.5	13.5	.5	.5	141.	0.0	.5	2.1	.1	7.50	205.
2	2A	316	35.0	10.4	14.5	.6	1.0	172.	0.0	2.3	3.4	.1	7.50	270.
2	2A	350	77.5	20.0	24.0	1.7	3.1	369.	0.0	13.2	9.2	.1	8.00	550.
2	2A	480	13.5	4.2	6.8	2.2	.8	69.	0.0	4.5	2.1	.1	7.30	115.
~~2~~	~~2A~~	~~501~~	~~20.0~~	~~6.0~~	~~10.5~~	~~1.0~~	~~.5~~	~~121.~~	~~0.0~~	~~6.0~~	~~1.2~~	~~0.0~~	~~8.30~~	~~175.~~
2	2A	536	22.0	6.7	10.5	.3	.4	120.	0.0	6.7	1.4	-1.	7.90	190.
2	2A	564	23.5	7.0	10.5	.2	.4	122.	0.0	5.1	1.0	-1.	7.70	196.
2	3	210	45.0	12.8	23.5	2.0	1.0	280.	0.0	.5	5.5	.2	7.20	370.
2	3	287	21.5	7.2	14.6	.5	.3	131.	0.0	.5	.3	.1	8.00	192.
2	3	316	29.0	10.4	18.0	.9	.7	160.	0.0	7.5	3.0	.1	7.20	250.
~~2~~	~~3~~	~~350~~	~~47.0~~	~~15.4~~	~~24.0~~	~~1.9~~	~~2.1~~	~~256.~~	~~0.0~~	~~14.2~~	~~3.8~~	~~.1~~	~~7.30~~	~~400.~~
2	3	390	33.5	11.1	19.5	3.3	.9	191.	0.0	6.2	3.0	.1	7.10	300.
2	3	410	37.0	13.2	21.0	2.6	1.8	206.	0.0	8.5	2.5	.1	7.20	320.
2	3	432	38.0	13.0	20.5	2.6	.8	211.	0.0	6.0	2.0	.1	7.20	320.
2	3	481	11.0	3.7	7.1	2.0	.9	60.	0.0	6.3	1.6	.1	7.10	105.
2	3	502	18.5	6.2	13.0	1.2	.5	111.	0.0	7.6	.7	-1.	7.80	170.
~~2~~	~~3~~	~~536~~	~~21.0~~	~~7.2~~	~~13.0~~	~~.4~~	~~.6~~	~~120.~~	~~0.0~~	~~6.3~~	~~1.6~~	~~-1.~~	~~7.60~~	~~187.~~

continued ...

Table 14. Continued.

Type	Site	Day	Ca	Mg	Na	K	Fe	HCO_3	CO_3	SO_4	Cl	F	pH	Cond.
2	3	564	23.0	7.5	13.5	.4	.5	123.	0.0	6.8	1.1	-1.	8.00	203.
2	3	593	27.5	9.2	13.5	.6	.8	145.	0.0	7.3	1.2	.1	7.85	206.
2	3A	210	48.0	10.8	2.1	.5	.2	219.	0.0	.5	.2	.2	7.30	300.
2	3A	253	49.0	10.2	2.2	.8	2.0	207.	0.0	.5	.2	.1	7.60	310.
2	3A	287	39.5	9.8	2.3	.5	4.4	173.	0.0	.5	.6	.1	7.80	320.
2	3A	316	52.0	13.3	2.5	1.0	2.7	224.	0.0	2.0	.5	.2	7.20	320.
2	3A	389	48.0	11.9	2.5	1.2	2.8	209.	0.0	4.5	.5	.1	7.30	310.
2	3A	410	45.0	11.9	2.0	1.0	.7	185.	0.0	4.0	1.0	.1	7.50	300.
2	3A	431	46.0	11.9	2.3	1.2	.8	201.	0.0	3.3	.4	.2	7.70	300.
2	3A	503	31.5	8.0	1.8	.9	.4	143.	0.0	3.4	.3	-1.	7.70	210.
2	3A	537	38.0	9.2	1.9	.4	.1	166.	1.6	5.2	.6	-1.	8.40	260.
2	3A	566	42.0	10.0	1.4	.1	.2	183.	0.0	3.4	.2	-1.	7.85	233.
2	4	210	60.0	17.5	7.7	1.0	1.0	273.	0.0	.5	2.7	.2	7.40	400.
2	4	253	62.0	16.0	7.0	1.0	1.4	263.	0.0	.5	1.7	.1	7.60	420.
2	4	287	37.5	12.6	5.7	.5	.5	179.	0.0	.5	1.3	.1	7.70	280.
2	4	319	62.5	20.3	9.0	1.1	1.9	294.	0.0	4.5	3.4	.1	7.10	430.
2	4	389	80.0	24.0	9.5	1.6	5.0	378.	0.0	4.5	1.5	.1	7.30	550.
2	4	410	69.0	16.4	10.0	1.5	19.0	305.	0.0	6.0	2.7	.1	7.30	460.
2	4	432	87.0	24.5	10.5	1.8	2.4	398.	0.0	4.5	3.6	.2	7.60	590.
2	4	481	20.0	7.2	2.7	2.0	.3	96.	0.0	4.0	1.1	.1	7.50	151.
2	4	502	33.5	11.2	4.6	1.2	.4	168.	0.0	7.6	.8	-1.	8.20	250.
2	4	540	41.5	14.0	5.0	1.7	.9	208.	0.0	9.2	1.6	-1.	7.80	320.
2	4	559	38.0	13.0	4.5	.3	.5	191.	0.0	5.4	1.0	-1.	7.90	295.
2	4	564	40.0	13.0	4.8	.4	.5	188.	0.0	4.2	1.0	-1.	7.80	296.
2	4	649	39.5	15.0	6.3	1.1	.5	200.	0.0	.1	1.2	.1	7.91	275.
2	5	253	47.0	10.2	8.0	1.0	7.1	201.	0.0	.5	1.2	.1	7.40	310.
2	5	295	27.5	9.0	10.0	1.2	1.3	138.	0.0	1.1	2.2	.1	7.10	230.
2	5	319	41.0	12.5	17.5	1.3	4.8	211.	0.0	6.4	2.6	.1	7.10	310.
2	5	389	62.0	14.5	9.5	1.4	19.0	280.	0.0	6.0	1.4	.1	7.00	410.
2	5	414	79.0	22.0	10.0	1.5	4.4	361.	0.0	5.0	3.2	.1	7.30	530.
2	5	431	68.0	14.6	8.0	1.5	20.0	283.	0.0	5.8	1.8	.1	6.90	440.
2	5	480	13.5	4.2	4.6	2.2	1.8	66.	0.0	3.5	1.3	.1	7.20	112.
2	5	502	21.5	7.0	6.4	1.2	.8	111.	0.0	8.6	.5	-1.	7.60	170.
2	5	537	30.5	9.2	7.4	.5	2.6	149.	0.0	8.1	1.2	-1.	7.80	226.
2	5	564	30.0	8.5	7.0	.3	1.3	132.	0.0	6.7	1.0	.1	7.70	211.
2	6	209	25.0	7.8	12.0	.4	.7	153.	0.0	.6	2.3	.1	7.50	220.
2	6	298	22.0	7.2	13.0	.5	.3	123.	0.0	.6	2.0	.1	7.30	188.
2	6	319	32.0	10.0	14.5	.5	.9	164.	0.0	6.7	2.9	.1	7.10	250.
2	6	480	13.5	4.2	6.9	2.2	.6	70.	0.0	4.6	1.8	.1	7.30	117.
2	6	502	18.5	6.0	11.0	.9	.4	106.	0.0	6.0	1.1	.1	7.90	167.
2	6	537	22.0	6.7	11.0	.1	.4	124.	0.0	8.3	1.0	-1.	8.30	110.
2	6	549	29.0	7.4	10.8	.1	-1.	129.	0.0	2.8	1.0	-1.	7.71	190.
2	6	550	26.0	6.8	10.2	.3	-1.	118.	0.0	3.3	2.0	-1.	7.62	176.
2	6	551	29.0	6.4	11.6	.3	-1.	116.	0.0	4.8	2.0	-1.	7.63	169.
2	6	552	29.0	6.4	11.3	.2	-1.	118.	0.0	3.5	2.0	-1.	7.69	170.
2	6	553	29.0	6.4	11.6	.2	-1.	118.	0.0	3.3	2.0	-1.	7.63	171.
2	6	556	29.0	6.6	11.9	.1	-1.	124.	0.0	3.3	2.0	-1.	7.71	179.
2	6	559	32.0	6.8	11.5	.4	-1.	125.	0.0	5.2	2.0	-1.	7.94	188.
2	6	566	24.0	6.8	11.0	.1	.4	124.	0.0	6.4	1.0	-1.	7.65	166.
2	6	570	31.0	6.6	11.9	.1	-1.	133.	0.0	3.1	2.0	-1.	7.75	191.
2	6	575	36.0	7.7	12.8	.2	-1.	146.	0.0	4.2	2.0	-1.	8.07	211.
2	6	576	38.0	8.2	12.8	.2	-1.	157.	0.0	3.6	2.0	-1.	7.85	226.
2	6	583	30.0	8.4	12.5	.2	-1.	157.	0.0	3.8	2.0	-1.	8.03	225.
2	6	590	40.0	8.1	12.9	.3	-1.	163.	0.0	3.5	2.0	-1.	7.81	241.
2	6	649	25.0	7.5	14.0	.9	.3	136.	0.0	2.8	3.0	.1	7.88	185.
2	7	209	30.0	8.8	10.0	.4	3.0	167.	0.0	.5	1.2	.1	6.50	250.
2	7	320	32.0	10.0	14.5	.7	1.2	163.	0.0	6.3	2.2	.1	7.00	250.
2	7	389	68.0	16.7	18.0	.9	2.5	312.	0.0	6.9	2.3	.1	7.10	480.
2	7	480	11.5	3.5	6.0	1.8	.6	60.	0.0	3.0	1.5	.1	7.40	101.
2	7	502	15.5	4.7	8.5	.6	.2	88.	0.0	5.1	.5	-1.	7.80	137.

Continued ...

Table 14. Concluded.

Type	Size	Day	Ca	Mg	Na	K	Fe	HCO_3	CO_3	SO_4	Cl	F	pH	Cond.
2	7	537	20.5	6.0	10.0	.1	.2	108.	0.0	10.0	1.2	-1.	7.90	165.
2	7	566	22.5	6.6	10.5	.1	.4	115.	0.0	6.8	.7	-1.	7.80	151.
2	8	236	37.0	12.5	16.5	1.1	4.5	201.	0.0	-1.	.7	.1	6.90	310.
2	8	252	24.5	7.2	16.5	.8	.6	140.	0.0	.5	.7	.1	7.40	230.
2	8	272	22.0	7.4	17.5	.3	.3	143.	0.0	1.1	.6	.1	7.30	200.
~~2~~	~~8~~	~~300~~	~~19.5~~	~~8.0~~	~~19.0~~	~~.6~~	~~.2~~	~~134.~~	~~0.0~~	~~.5~~	~~1.4~~	~~.1~~	~~7.20~~	~~205.~~
2	8	319	28.5	10.7	22.0	.6	.5	170.	0.0	6.7	3.1	.1	7.50	270.
2	8	390	64.5	20.0	30.0	1.6	4.8	346.	0.0	10.1	2.3	.1	7.20	510.
2	8	414	74.0	23.0	27.0	2.5	.1	394.	0.0	7.3	5.0	.1	6.90	600.
2	8	431	54.0	17.5	27.5	1.4	12.2	293.	0.0	6.6	3.2	.1	6.90	460.
2	8	502	18.0	5.7	13.0	1.0	.3	107.	0.0	7.1	.6	0.0	7.50	170.
~~2~~	~~8~~	~~537~~	~~20.5~~	~~6.7~~	~~15.0~~	~~.3~~	~~.4~~	~~124.~~	~~0.0~~	~~8.6~~	~~1.8~~	~~-1.~~	~~8.20~~	~~195.~~
2	8	566	20.0	6.5	14.5	.1	.3	118.	0.0	7.5	.9	-1.	7.70	160.
2	9	281	21.5	7.8	10.8	.6	.2	123.	0.0	.5	1.0	.1	7.40	185.
2	9	390	54.0	18.2	30.0	1.3	13.0	307.	0.0	8.0	2.8	.1	7.00	450.
2	9	480	9.5	3.5	8.0	1.8	.4	56.	0.0	5.0	1.5	.1	7.20	96.
2	9	537	18.0	6.7	15.5	.2	.3	117.	0.0	10.4	1.2	-1.	8.00	187.
~~2~~	~~9~~	~~565~~	~~19.0~~	~~6.5~~	~~14.5~~	~~.1~~	~~.3~~	~~113.~~	~~0.0~~	~~7.6~~	~~2.4~~	~~-1.~~	~~7.70~~	~~150.~~
2	10	222	14.0	6.6	10.5	1.3	.6	93.	0.0	-1.	3.5	.1	6.50	135.
2	10	272	18.0	6.4	9.5	.4	-1.	103.	0.0	.5	.1	.1	6.60	154.
2	10	298	21.0	7.2	12.0	1.7	.1	120.	0.0	1.3	1.2	0.0	7.10	183.
2	10	390	32.5	10.9	19.5	4.6	1.3	218.	0.0	6.3	2.7	.1	6.70	370.
2	10	427	32.5	11.9	19.5	2.6	.8	185.	0.0	7.5	1.4	.1	7.10	295.
~~2~~	~~10~~	~~480~~	~~13.0~~	~~4.8~~	~~7.7~~	~~1.8~~	~~.4~~	~~72.~~	~~0.0~~	~~4.3~~	~~1.3~~	~~.1~~	~~7.10~~	~~120.~~
2	10	537	12.5	5.5	8.0	1.1	.2	79.	0.0	4.8	.8	-1.	7.40	134.
2	10	565	13.5	5.7	8.1	.8	.1	81.	0.0	5.8	.5	-1.	7.60	120.
2	11	222	22.0	9.1	15.5	.7	1.0	134.	0.0	-1.	7.0	.1	6.80	190.
2	11	277	19.5	7.4	14.0	.7	.3	124.	0.0	.5	.7	.1	6.90	177.
2	11	298	22.0	7.2	13.0	.5	.2	123.	0.0	.5	1.4	.1	7.20	188.
~~2~~	~~11~~	~~302~~	~~18.5~~	~~8.9~~	~~15.5~~	~~1.0~~	~~.3~~	~~120.~~	~~0.0~~	~~7.2~~	~~.7~~	~~.1~~	~~7.20~~	~~196.~~
2	11	390	48.0	17.5	18.0	1.8	7.6	252.	0.0	10.3	2.4	.1	7.10	390.
2	11	481	12.0	4.7	8.8	2.1	.4	69.	0.0	6.5	1.4	.1	7.30	118.
2	11	537	18.5	7.5	12.5	.2	.3	113.	0.0	11.6	1.4	-1.	8.30	179.
2	11	565	19.0	7.3	11.0	.2	.5	106.	0.0	8.6	1.1	-1.	7.70	147.
2	12	253	54.0	15.8	3.2	.8	2.0	237.	0.0	.5	.3	.1	7.60	390.
~~2~~	~~12~~	~~287~~	~~38.0~~	~~13.6~~	~~3.5~~	~~.4~~	~~.3~~	~~177.~~	~~0.0~~	~~.5~~	~~.6~~	~~.1~~	~~7.90~~	~~275.~~
2	12	428	144.0	72.0	8.5	3.5	1.0	878.	0.0	8.5	2.0	.1	7.80	1200.
2	12	481	19.5	7.2	2.0	1.7	.6	90.	0.0	5.2	.9	.1	7.50	142.
2	12	538	36.0	13.0	3.1	.4	.3	177.	0.0	7.2	1.4	-1.	7.80	265.
2	12	565	38.5	13.2	2.7	.1	.4	184.	0.0	5.4	.5	-1.	8.00	231.
2	13	211	35.0	10.5	22.5	.9	.8	217.	0.0	1.2	2.2	.1	7.60	290.
~~2~~	~~13~~	~~221~~	~~38.0~~	~~11.2~~	~~21.0~~	~~.9~~	~~1.5~~	~~218.~~	~~0.0~~	~~4.5~~	~~2.4~~	~~.1~~	~~7.60~~	~~320.~~
2	13	252	26.0	7.0	15.0	.6	.4	142.	0.0	.6	1.8	.1	7.60	270.
2	13	298	25.0	8.5	10.0	.6	.9	131.	0.0	1.1	1.0	.1	7.50	200.
2	13	389	69.0	19.5	29.0	2.0	28.0	374.	0.0	10.8	3.0	.1	7.00	590.
2	13	428	66.5	18.2	26.0	1.3	43.5	345.	0.0	6.0	5.1	.2	7.20	520.
2	13	483	16.0	5.0	9.1	1.7	1.4	85.	0.0	5.8	2.3	.1	7.30	131.
~~2~~	~~13~~	~~538~~	~~23.0~~	~~6.7~~	~~13.0~~	~~.1~~	~~.2~~	~~128.~~	~~0.0~~	~~9.7~~	~~1.2~~	~~-1.~~	~~7.90~~	~~195.~~
2	13	566	23.5	6.8	13.5	0.0	.2	132.	0.0	6.8	.9	-1.	8.10	172.
2	14	252	19.0	4.9	5.5	.4	.4	91.	0.0	.5	.3	.1	7.40	140.
2	14	298	18.5	5.7	6.5	.2	.4	93.	0.0	.5	.5	.1	7.20	145.
2	14	389	50.5	13.7	10.0	.9	7.6	234.	0.0	6.4	1.2	.1	7.10	370.
2	14	428	64.5	17.5	12.0	1.2	15.0	290.	0.0	11.1	1.2	.1	7.10	460.
~~2~~	~~14~~	~~482~~	~~10.0~~	~~3.0~~	~~4.0~~	~~1.1~~	~~.5~~	~~51.~~	~~0.0~~	~~4.0~~	~~.8~~	~~0.0~~	~~7.30~~	~~82.~~
2	14	566	18.0	5.0	4.3	.1	.3	82.	0.0	4.7	1.1	-1.	7.80	110.
2	30	481	28.5	7.5	1.5	1.5	2.0	125.	0.0	1.8	.6	.1	7.40	185.

Table 14. Concluded.

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

[b] type: 2 means stream sample.

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

[d] expressed in pH units.

[e] specific conductance expressed as micromhos per cm.

9.8 OXYGEN ISOTOPE DATA

Table 15. Oxygen isotope data.

Sample Source	Site	$\delta 0^{18}$
Piezometer	HC4	-20.09
	HC6	-18.83
	HC7	-18.90
	HC12	-20.16
	HC13	-17.91
	HC15	-19.82
	HC18	-19.05
	HC21	-19.78
	HC24	-19.04
	HC29	-18.97
Observation Well[a]	6-21	-17.43
	6-220	-22.02
	7-32	-18.63
	7-135	-20.24
	8-34	-18.80
Bog	HC-B1-0	-17.47
	HC-B1-4	-18.31
	HC-B1-8	-18.29
	HC-B1-16	-18.16
	HC-B4-16	-19.32
Stream	Muskeg R. R-1	-17.63
	Muskeg R. Site 3	-14.25
	Muskeg R. Site 4	-19.10
	Stanley Ck. 3A	-20.19
Snow	Muskeg R. Site 1	-23.68
	Muskeg R. Site 3	-23.60
	Muskeg R. Site 4	-19.87
	Hartley Ck. Sites 6 and 7	-23.56
	Harlety Ck. Sites 13 and 14	-24.14
	Hartley Ck. Shell 6/1/77	-24.64
	Hartley Ck. Shell 5/2/77	-22.45
	Hartley Ck. Shell 1/3/77	-22.06
	Stanley Ck. Headwaters	-23.32
	Stanley Ck. Site 3A	-22.08
	Kearl Lake 5/2/77	-22.68
	Kearl Lake 1/3/77	-23.10
	Wolf Lake 6/1/77	-23.24
	Wolf Lake 1/3/77	-21.96
	Wolf Lake Top Sheet	-18.62

[a] completed by the Research Council of Alberta in 1975.

9.9 ORGANIC AND NUTRIENT CHEMICAL DATA

Table 16. Organic and nutrient chemical data in mg/L.

Type of Sample	Site	Date Sampled	Total Organic Carbon	Total Inorganic Carbon	Total Dissolved Organic Carbon	Nitrate Nitrogen	Nitrite Nitrogen	Ortho-Phosphorous	Ammonia Nitrogen	Total Kjeldahl Nitrogen	Total Phosphorous	Chemical Oxygen Demand
Ground-water	HC1	10/7/77	6.0	86.0	5.0	0.095	0.015	0.011				
		6/8/77	10.0	59.0	10.0	0.003	0.003	0.010				
	HC2	6/7/77	16.0	108.0	6.0	0.033	0.019	0.012				
	HC4	14/7/77							0.16	1.97	0.48	164
		8/8/77	44.0	70.0	35.0	0.081	0.006	0.003				
	HC6	7/7/77	23.0	109.0	18.0	0.007	0.004	0.007				
		8/8/77	23.5	82.5	16.5	0.147	0.003	0.013				
	HC7	7/7/77	159.5	87.0	155.0	0.003	0.003	0.011				
		8/8/77	22.5	64.0	16.5	0.633	0.007	0.007				
	HC8	14/7/77							0.25	2.04	0.78	217
		8/8/77	16.5	47.5	11.0	0.137	0.003	0.003				
	HC10	10/7/77	53.0	88.0	50.0	0.003	0.003	0.007				
		8/8/77	51.0	83.0	49.0	0.003	0.003	0.007				
	HC12	8/8/77	26.0	74.0	20.0	0.003	0.003	0.010				
	HC13	8/8/77	56.0	88.0	48.0	0.003	0.003	0.018				
	HC14	5/7/77	25.0	70.5	13.0	0.003	0.003	0.008				
	HC15	7/7/77	65.0	108.0	59.0	0.004	0.003	0.009				
		14/7/77							0.25	5.15	0.61	294
		9/8/77	44.0	70.0	35.0	0.003	0.003	0.011				
	HC16	6/7/77	35.5	76.5	33.0	0.003	0.003	0.007				
		14/7/77							0.18	5.62	1.60	129
		9/8/77	8.5	59.0	7.0	0.003	0.003	0.010				
	HC18	7/7/77	21.4	67.5	193.0	0.023	0.066	0.009				
		9/8/77	42.0	79.0	34.0	0.003	0.003	0.018				
	HC22	7/8/77	37.5	68.0	24.5	0.066	0.003	0.003				
	HC23	9/8/77	16.5	57.0	16.0	0.033	0.007	0.011				
	HC31	14/7/77							0.04	1.21	0.22	99
Bog	HC-B1-0	13/7/77							0.03	1.23	0.22	87
	HC-B1-4	13/7/77							0.24	1.45	1.30	110
	HC-B1-8	13/7/77							0.95	2.12	8.80	135
	HC-B1-16	13/7/77							0.45	2.50	8.60	142
	HC-B2-0	13/7/77							0.01	1.67	0.12	101
	HC-B2-4	13/7/77							0.96	2.95	0.92	128
	HC-B2-8	13/7/77							1.21	3.88	2.30	78
	HC-B2-16	13/7/77							0.16	1.06	0.72	44
	HC-B4-0	7/8/77	44.0	123.0	40.0	0.003	0.003	1.450				
	HC-B5	7/8/77	34.0	13.0	33.5	0.003	0.003	0.010				
	HC-B5-0	7/8/77	17.5	11.5	15.5	0.003	0.003	0.003				
	HC-B6-Shallow	7/8/77	39.5	77.5	21.5	0.166	0.004	0.014				
	HC-B6-0	7/8/77	29.0	74.0	25.5	0.101	0.009	0.004				
	HC-B6-Deep	7/8/77	16.0	50.5	11.0	1.070	0.003	0.003				
	HC-B7	7/8/77	11.5	39.0	8.5	0.024	0.008	0.003				
	HC-B7-0	7/8/77	19.5	31.0	17.0	0.003	0.003	0.004				
	HC-B8-0	7/8/77	19.0	14.0	19.0	0.330	0.003	0.023				
	HC-B3	7/7/77	16.0	108.0	15.0	0.054	0.004	0.009				
Stream	Site 6	10/7/77	23.5	25.0	18.5	0.013	0.006	0.005				

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