Environment Canada
Environmental Management

Environnement Canada
Gestion de l'environnement

WATER INVESTIGATIONS
ALONG THE
ALASKA HIGHWAY PIPELINE ROUTE
IN THE YUKON TERRITORY

APPENDIX E

WATER QUALITY PROCESSES AND CONDITIONS IN THE OGILVIE AND SWIFT RIVER BASINS YUKON TERRITORY

by

H. Schreier

December 1978

Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

WATER INVESTIGATIONS

ALONG THE

ALASKA HIGHWAY PIPELINE ROUTE

IN THE YUKON TERRITORY

APPENDIX E

WATER QUALITY PROCESSES AND CONDITIONS IN THE OGILVIE AND SWIFT RIVER BASINS YUKON TERRITORY

Prepared Under Contract

For

Water Quality Branch
Inland Waters Directorate
Pacific and Yukon Region
Vancouver, B.C.

by

H. Schreier

December 1978

ACKNOWLEDGEMENTS

The help of all those who contributed to this project is gratefully acknowledged. The staff of the Water Quality Branch, Inland Waters Directorate, in Vancouver, participated in all phases of the project. Jim Taylor was instrumental in the initiation of the project and his assistance and expertise in the winter field operations were greatly appreciated. Woody Erlebach, Steve Sheehan, Leslie Churchland, Gordon Ennis, and Eric Michnowsky participated in a number of project discussion sessions and the latter three also assisted in field operations at different times of the year.

Fred Mah arranged for the water sample analysis in the Water Quality Laboratory of Inland Waters Directorate in North Vancouver. Thanks go to all members of the Laboratory staff for their cooperation, particularly Eric Michnowsky whose advice and help were invaluable.

Monty Alford, of Water Survey of Canada in Whitehorse, Yukon Territory, was helpful in many phases of the field operations, and together with Bud Skinner and P. Williams, provided assistance in obtaining gauging records for the two river basins. Graham Humphries of D.P.W. kindly looked after the turbidity meter recording and daily sampling in the Ogilvie River. Karl Ricker provided geological information for the Ogilvie area; Kayo Masuda was responsible for the biological experiments and his cooperation and help in the field are thankfully acknowledged.

Finally, special thanks go to Peter Strilaeff who acted as overall coordinator for the Inland Waters Directorate Project and who was responsible for the design and set-up of the continuously recording turbidity meter.

WINTER WATER QUALITY PROCESSES AND CONDITIONS
IN THE OGILVIE AND SWIFT RIVER BASINS, YUKON TERRITORY

TABLE OF CONTENTS

Table of Contents (cont'd)

LIST OF FIGURES

List of Figures (cont'd)

LIST OF PLATES

LIST OF TABLES

WINTER WATER QUALITY PROCESSES AND CONDITIONS IN THE OGILVIE AND SWIFT RIVER BASINS, YUKON TERRITORY

I. PURPOSE AND SCOPE

The present report contains the results of a one-year water quality study of two Yukon watersheds and is part of the environmental impact analysis program for the Alcan pipeline, initiated by the Water Quality Branch of the Federal Department of the Environment. The pipeline construction will affect some 250 rivers in an area for which very little scientific information is available. Due to time restrictions and economic constraints an extensive study of a large number of those rivers was not possible. In addition it was felt that an intensive study of two basins would be more beneficial than an extensive assessment since emphasis could be placed on the identification and understanding of processes rather than on attempting the impossible task of establishing baseline water quality information.

In a review paper (Schreier 1977) it was pointed out that the pipeline construction is most likely to affect water quality conditions in three ways:

1. Sedimentation will be increased during the construction of the river crossings;
2. Groundwater and surface flow will be altered as a result of trenching;
3. Water will be contaminated by spillage of oil and sewage at maintenance camps.

The third effect can be monitored and controlled during the construction phase but more information was needed to understand the first two problems so as to more accurately predict their effects on water quality and biological activities.

The present project was thus initiated having as its aims the following topics:

1. To study the water quality conditions through the winter to determine variabilities and trends of chemical parameters;
2. To identify processes which influence and control water quality conditions in these northern environments;

3. To relate water quality to the flow regime and geology so as to gain a better understanding of the role and influence of groundwater;
4. To determine natural sediment conditions and variability;
5. To provide a water quality data base for experiments in which biological productivity at the lower end of the aquatic food chain is measured;
6. To develop and modify analytical methods to obtain reliable results under the extreme winter conditions experienced along the Alcan pipeline route.

II. GENERAL DESCRIPTION OF THE TWO SELECTED DRAINAGE BASINS

A. Reasons for Choice of Watersheds

The following criteria were essential in the selection of the two drainage basins to be investigated:

1. Both rivers had to be affected by the Alcan pipeline construction;
2. Both rivers had to be biologically productive especially in terms of fish production;
3. Lateral ground access was essential in order to conduct a spatial analysis under winter conditions;
4. A hydrological gauging record was needed for both streams.

The Swift River basin was chosen because it fulfilled all the above requirements and was thought to be representative of conditions found in the southeastern part of the Yukon Territory. The Ogilvie River basin was chosen because it represents a somewhat extreme case of a basin in a permafrost environment where the groundwater regime is considered more important due to its difference in drainage basin geology; and its selection was thought to be appropriate as the potential site for the proposed northern extension to the Alcan pipeline.

Interpolation from one river basin to the next is always difficult and in many ways questionable, but it was felt that because of the contrasting hydrologic, geologic and climatic conditions between the two basins a legitimate data base would be provided from which general process information could be produced.

B. General Description of Swift and Ogilvie Watersheds

The Swift River is located in the southeastern part of the Yukon Territory while the Ogilvie River is part of the Peel-drainage system in the north-central Yukon. The general location of the study area is provided in Figure 1. Very little base information is available for the Ogilvie River. A basic 1:250,000 scale topographic map is the only data source and no basic geological survey has yet been conducted in the study area. To have a better overview an uncontrolled photo mosaic was produced from conventional aerial photographs, a copy of which is included in Appendix 1. The Dempster Highway parallels the river for 70 km and this road served as an access to the area in the spring, summer and fall. A water survey gauging station has been operating there since the summer of 1974.

More information was available for the Swift River area located between Teslin Lake and Rancheria along the Alaska Highway. Basic geological surveys (Gabrielse 1969) and surficial geological maps (Klassen 1978) have been produced for the area and a 22-year hydrologic gauging program has been conducted by Water Survey of Canada. The watershed is located in the Cassiar Mountains and covers part of northern British Columbia and part of the Yukon Territory. At the time this study was initiated there was no adequate single survey air photo coverage available and as a result only a partial mosaic could be produced for the study area (see Appendix 1).

A general description and comparison of environmental conditions of the two basins are given in Table 1. It should be noted that the Ogilvie River is under the influence of a much more severe polar climate than the Swift River. This is not only evident from climatic records, but also from the size and distribution of trees and the presence of permafrost in August at 20-30 cm from the surface.

Figure 1. Location of study areas.

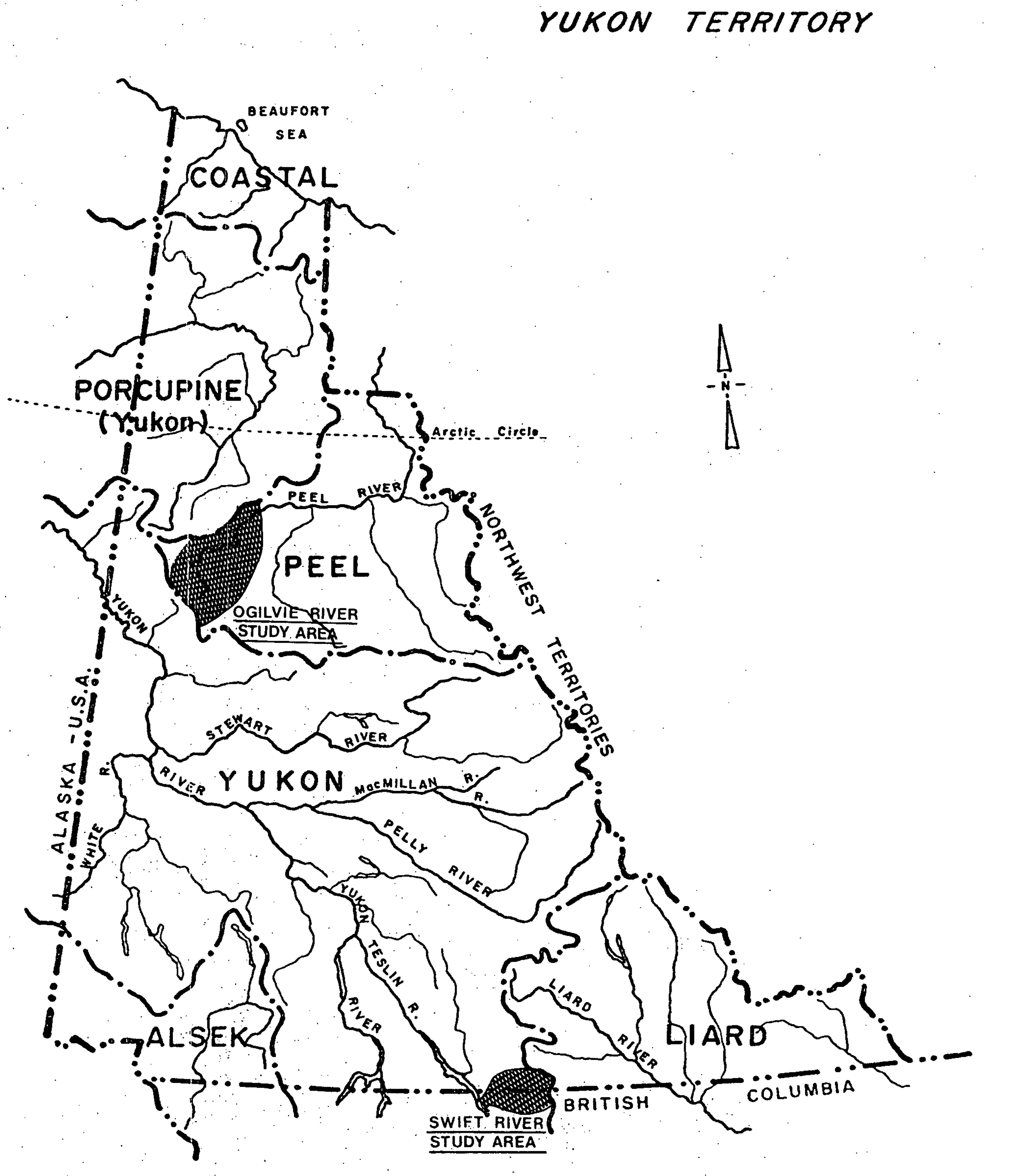


Table 1: Comparison of conditions between the Swift and Ogilvie Watersheds

PARAMETERS & CONDITIONS	SWIFT RIVER	OGILVIE RIVER
Location:		
coordinates	130°45'-132°W / 59°45'-60°15'	137°30'-138°30'W/65°-65°45'N
geographic location	Southeastern Yukon Territory	Northcentral Yukon Territory
Hydrologic Parameters:		
size of watershed	3870 km^2 (to mouth at Teslin Lake)	7220 km^2 (to Blackstone confluence)
maximum relief	1410 m	1190 m
discharge record	22 years	4 years
maximum discharge	15200 cfs (6.11.64)	23400 cfs (5.31.75)
minimum discharge	205 cfs (3.26.69)	20 cfs (2.12.75)
Water Supply:		
source	springs in headwaters & run-off	springs all along drainage channel and run-off
control	series of mountain lakes	little water retention because of sparse vegetation cover, absence of substantial soils & presence of permafrost, but significant groundwater storage
Geological Parameters:		
bedrock geology	igneous and metamorphic rocks	sedimentary rocks
dominant bedrock type	granodiorite	limestone
geomorphological setting	well-rounded mountainous terrain	structurally controlled mountainous terrain
dominant surficial material	till, alluvium, peat	colluvium, alluvium, peat
evidence of glacial history	dominant	very little
channel geology	gravel bed	gravel and bedrock channel
Soils:		
dominant type	regosol, brunisols, gleysols and organic	regosols, cryosols, renzinas and organic
Vegetation:		
dominant ground cover	sphagnum moss, labrador tea	lichens & sphagnum moss, tundra
dominant tree cover	white and black spruce & lodgepole pine	stunted black spruce in protected areas
approximate tree cover	60%	25%
Climatic conditions:		
temperatures (max-min)	-42°C to +32°C	-47°C to +31°C
precipitation (max-min/year, snowfall incl.)	450 to 660 mm	290 to 350 mm
approx. time of freeze-up	mid to end of October	early October
approx. time of break-up	beginning of May	late May

III. METHODS AND TECHNIQUES USED

A. Sampling Program

In order to establish seasonal and spatial trends it was necessary to set up a number of stations in each basin and to sample each at different times throughout the year.

1) The use of past flow records to determine the frequency and time of sampling

It was thought necessary to sample the water in each watershed during the major hydrological periods such as: prior to freeze-up, mid-winter low flow, end-winter prior to break-up, at or after ice break-up, during high flow conditions, and mid-summer run-off. The past hydrographs were consulted for each basin. For the Swift River the mean daily run-off record for the past 22 years was used for the prediction of the sampling time (see Figure 2). The same type of prediction was considerably more difficult for the Ogilvie River for which only a 3½ year gauging record exists and which has a flow record showing enormous year to year fluctuations (Figure 3).

For logistical and economic reasons it was necessary to arrange each field trip in such a way that both basins were sampled within a two-week period. The exact sampling dates are provided in Table 2 below.

Table 2: List of Sampling Dates

Ogilvie River	Swift River
October 4-6, 1977	October 7 - 10, 1977
December 18-19, 1977	December 11 - 16, 1977
March 27 - 30, 1978	March 22 - 25, 1978
May 22 - 25, 1978	May 16 - 21, 1978
June 26 - 29, 1978	June 19 - 24, 1978
August 1 - 3, 1978	August 4 - 7, 1978

Variability in Mean Daily Discharge - SWIFT RIVER 1956-1977

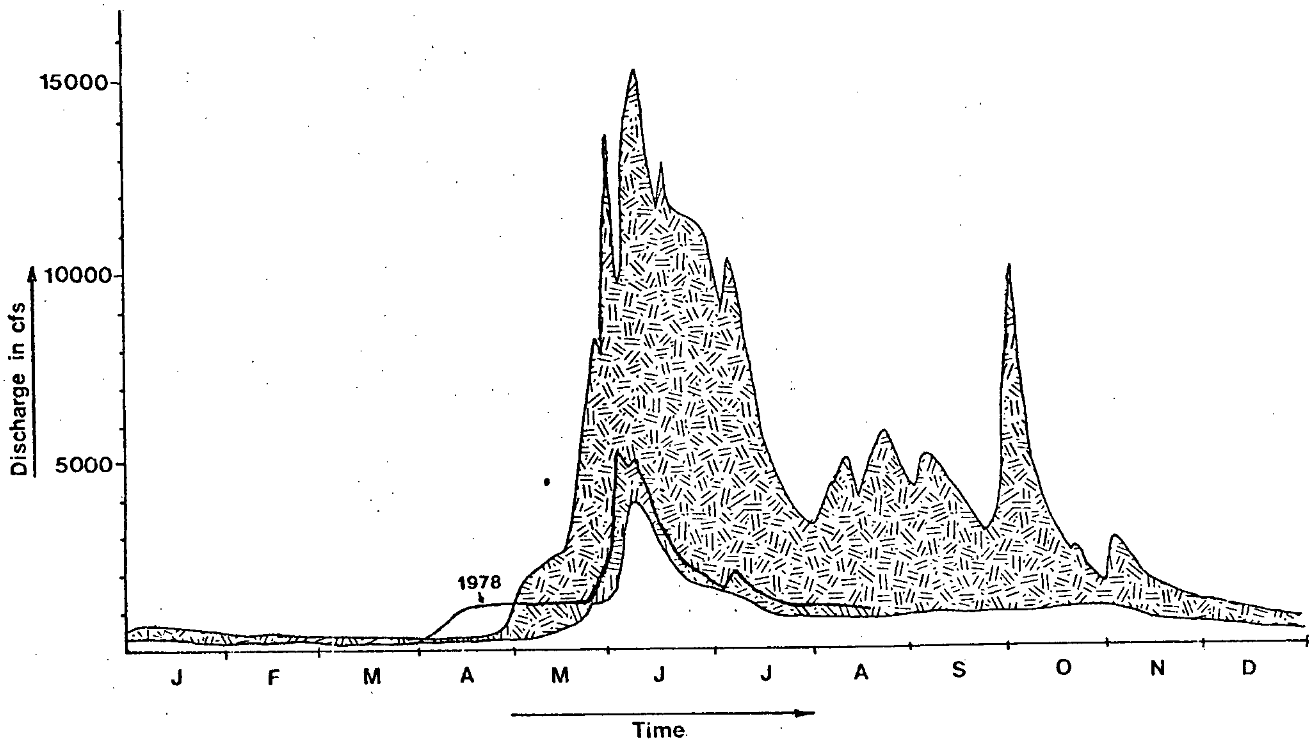


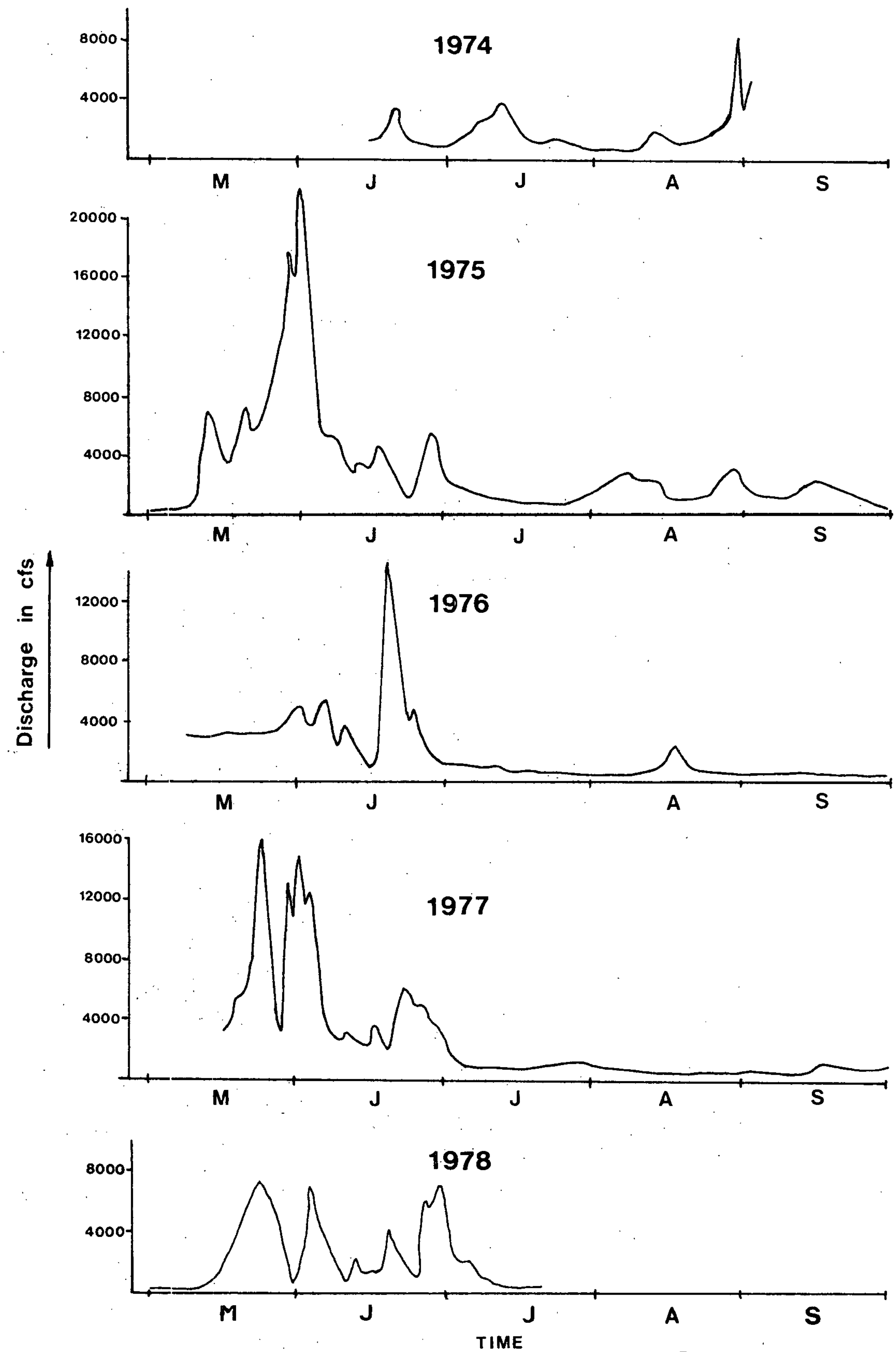
Figure 2.

An indication of how well the actual sampling periods coincided with the predicted major hydrological events during the 1977-78 season can be seen from Figures 4 and 5 (please note that the 1978 discharge record is preliminary and subject to slight modifications by Water Survey of Canada).

There is a good correlation between sampling time and major hydrological events in the Ogilvie River. The same is the case for the Swift River with the exception of the high peak flow which was missed by about ten days.

Mean Daily Discharge - Ogilvie River

Figure 3.



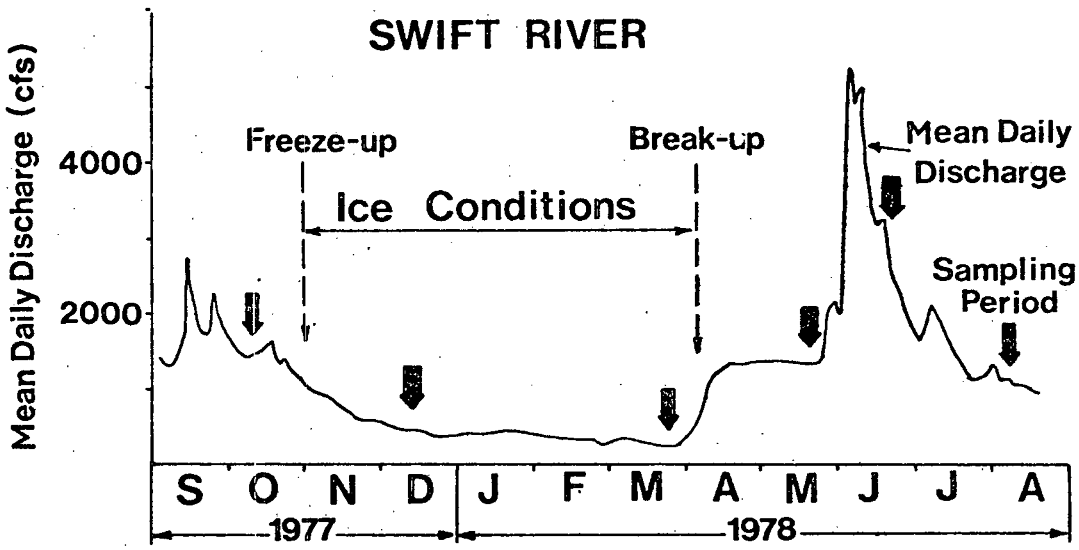


Figure 4. Sampling periods and corresponding hydrological events, Swift River.

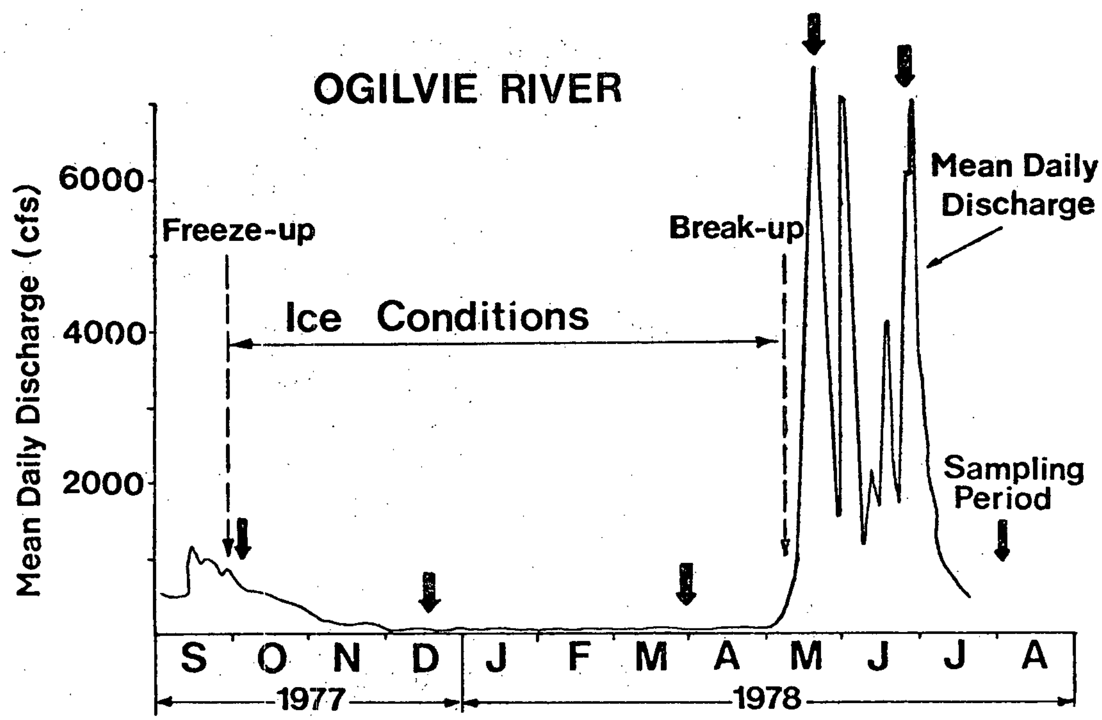


Figure 5. Sampling periods and corresponding hydrological events, Ogilvie River.

2) The use of geological and hydrological information in the selection of sampling stations

A number of considerations were instrumental in the selection of sampling stations. Access to each sampling station had to be relatively easy as winter sampling had to be performed at very cold temperatures and, with no boat available, river crossing in the lower parts of the watersheds was impossible. Geological maps were consulted for the Swift River so as to determine what type of bedrock and surficial deposit is drained by each tributary. Traditional water quality sampling procedures were also emphasized, such as selecting stations above major tributaries and sufficiently downstream of major confluences to allow for a proper mixing.

The location of all sampling stations in each watershed is presented in Figures 6 and 7 and a description of the station is provided in Appendix 2.

B. Sampling Techniques

1) Sampling through ice

Access to the Swift River basin during the winter was accomplished by truck and by foot. The December and March sampling in the Ogilvie took place by helicopter since the Dempster Highway was not open to traffic during the winter months.

A thick ice cover existed in most sections of the rivers both in December and in March. This necessitated the modification of conventional sampling techniques. A hole of approximately 70 cm cross section was cut through the ice with an ice chisel (Plate 1). A power drill was used in December in the Ogilvie but was eliminated from further use because of its bulkiness. The ice was removed so that the water could freely flow from the hole. A small plastic hand pump was then used to fill the sample bottles (Plate 2). Two sample bottles (glass was used for phosphorus samples and teflon for phenol samples) had to be collected by hand so as to avoid possible contamination through contact with plastic material.

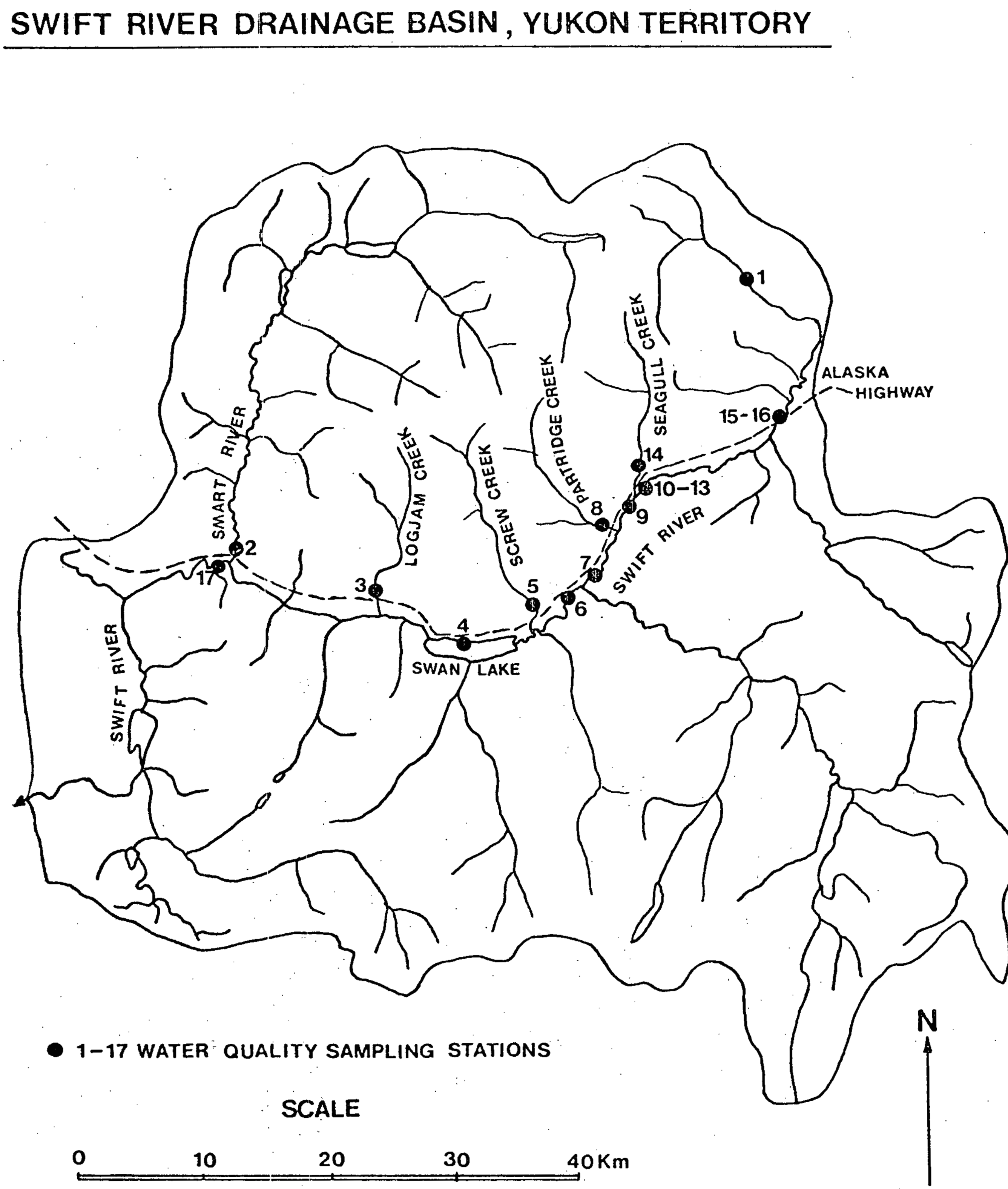


Figure 6. Distribution of sampling stations, Swift River

OGILVIE RIVER DRAINAGE BASIN , YUKON TERRITORY

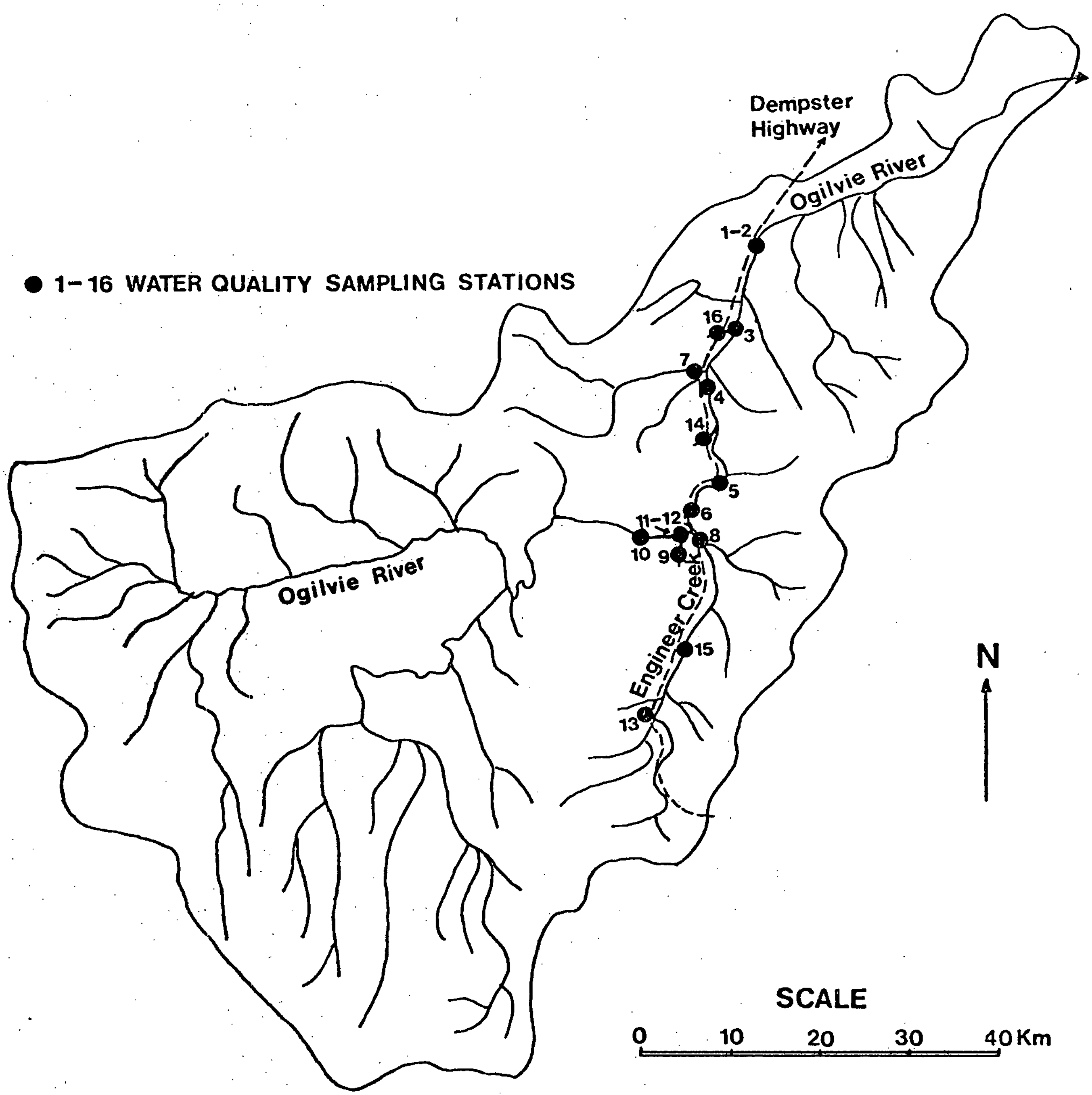


Figure 7. Distribution of sampling stations, Ogilvie River

Plate 1. Preparation of sampling hole with ice chisel

Plate 2. Water sampling with hand pump

The sample bottles were placed in the inside pocket of the arctic parka for transport between sampling stations and truck so as to prevent the samples from freezing. The samples were then transferred to coolers, transported to Whitehorse by truck, and shipped to Vancouver by air.

2) In situ analysis of dissolved oxygen

To determine dissolved oxygen conditions an in situ analysis was required. A tent was erected adjacent to the sampling station (Plate 3) and, using a Hack DO titration kit, multiple samples collected from the stream using a DO dunker could be analysed despite freezing conditions.

Plate 3. The use of a tent for in situ analysis

For the spatial analysis at Swift River it also became necessary to use the truck as a laboratory and the DO samples were again transported to the truck in the inside pocket of the parka. The DO-Hack kit proved adequate for such an operation especially since the method is the least delicate to be performed under such conditions. However it should be noted that a trade-off had to be made between simplicity and accuracy. For the present study which emphasized the examination of trends, a level of accuracy of ± 1 ppm was thought to be adequate. For a detailed DO study however it might be necessary to design a specific method for northern operations. To increase the reliability of our observations analyses were performed at least in duplicate at all stations at all times.

C. Choice of Water Quality Parameters

Thirty-three water quality parameters were chosen for this project. Some of these, such as dissolved oxygen, phosphorus, total nitrogen, ammonium-nitrogen, total organic and total inorganic carbon, were thought to be indicative and important for an analysis of biological conditions. Others such as specific conductance, hardness, Ca, Mg, K, Na, Si, SO_4, Cl, HCO_3 were used as indicators for geological conditions. Residuals were measured to determine sediment contributions, and metals such as Pb, Mn, Co, Ni, Zn, Se, As and Cu were analysed as indicators of potential toxicity and metal sources in the area. Iron, SO_4, and pH were thought to be partially indicative of acid water production from oxidation of pyrite. A list of the water quality parameters is provided in Table 3 below.

Table 3. List of Water Quality Parameters used in Study

PARAMETERS	UNITS	PARAMETERS	UNITS
pH	standard	total hardness as $CaCO_3$	mg/l
specific conductance	umho/cm	dissolved Ca	mg/l
turbidity		dissolved Mg	mg/l
color		Na	mg/l
total inorganic carbon	mg/l	K	mg/l
total organic carbon	mg/l	Mn	mg/l
residue non-filterable	mg/l	Cu	mg/l
residue filterable	mg/l	Zn	mg/l
residue non-filterable, fixed	mg/l	As	mg/l
residue filterable, fixed	mg/l	Pb	mg/l
ammonia nitrogen	mg/l	Fe	mg/l
total dissolved nitrogen	mg/l	Cl	mg/l
dissolved NO_3+NO_2	mg/l	F	mg/l
phenolic material	mg/l	Si	mg/l
total phosphorus	mg/l	SO_4	mg/l
total alkalinity as $CaCO_3$	mg/l	Bicarbonate + DO	mg/l

* Co, Ni, Se were analyzed on selected samples in the Ogilvie River.

D. Analytical Procedure

The dissolved oxygen analyses were accomplished in situ but all other water quality parameters were determined in the water quality branch laboratory, of the Inland Water Directorate, Environment Canada, North Vancouver. Standard analytical procedures were used to determine all parameters mentioned above. The accuracy of each method is dependent on concentration levels of the sample and will be referred to in different sections of the report.

IV. RESULTS OF WATER QUALITY INVESTIGATIONS

A. Ice Conditions during 1977-78 Winter Season

1) Observations and discussion

Great variations in ice conditions were found to exist in both the Swift and the Ogilvie Rivers. Despite consistently cold temperatures ranging from -25°C to -50°C in December, open water sections were found in both rivers. In the case of the Swift River only one small section just below the Swift River camp was open in December. An accelerated stream flow at that river section and possible influences resulting from camp discharges could be responsible for keeping that section of the stream open.

In the Ogilvie system at least five sections of open water were found both in December and in March. In these cases the geological structure is primarily responsible for the different groundwater discharges, which cause permanently open water sections throughout the winter. An example of such a section is provided in Plate 4 and a detailed discussion of the groundwater system is given in Section D.

Plate 4. Open water section resulting from groundwater discharge in the Ogilvie River.

Various types of ice were encountered in both river systems; the most common types can be described as:

- block ice (black in color, no banding)
- layer ice (various contrasting colors in different bands)
- cavernous ice (air space in ice, with icicles)

Examples of each are provided in Plates 5 - 9.

Plate 5. Block ice

Plate 6. Layer ice

Plate 7. Cavernous ice
Ogilvie River

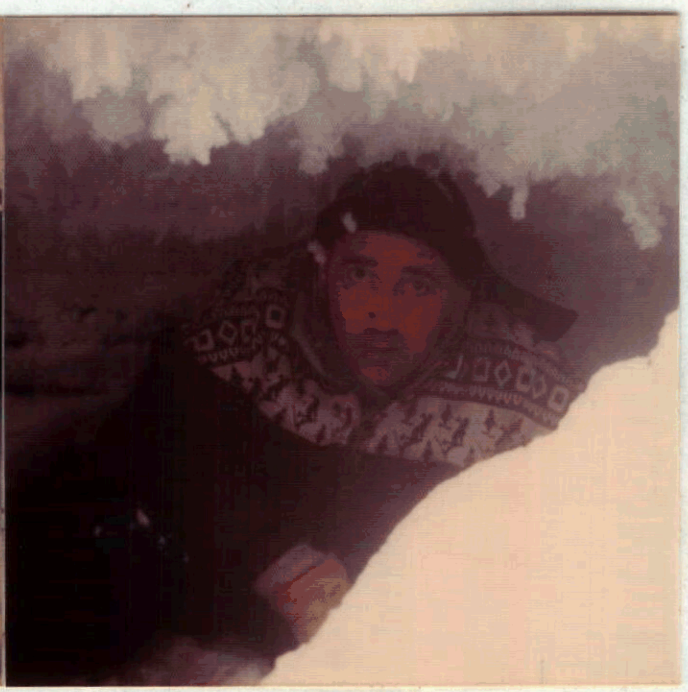


Plate 8. Cavernous ice
Swift River

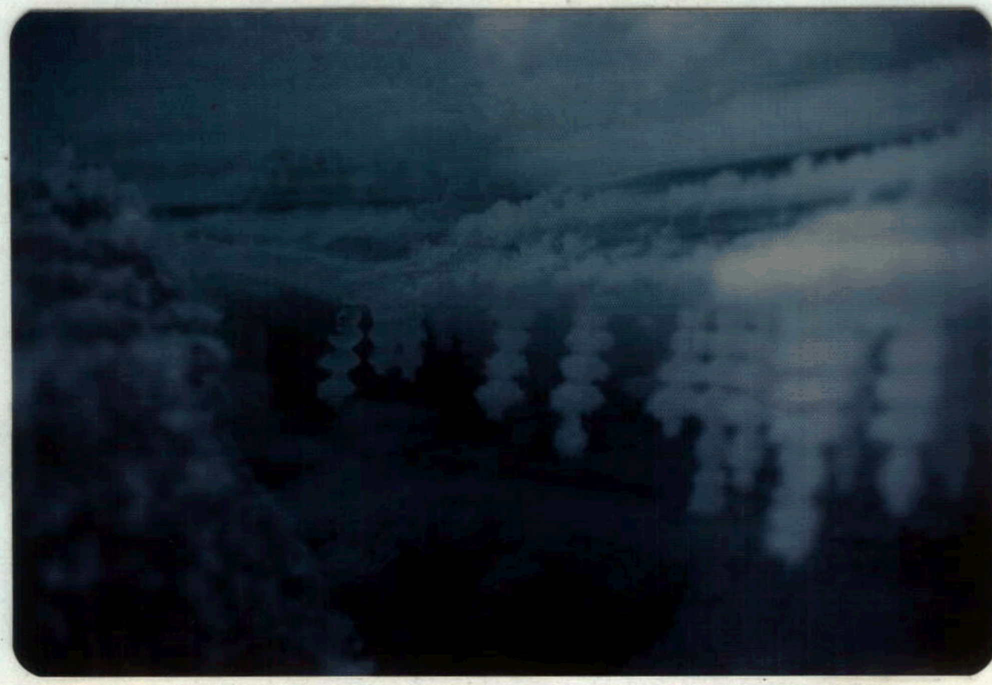


Plate 9. Cavernous ice crystal formations

The Swift River ice regime differed drastically from that of the Ogilvie in that the water channel of the Swift River could be found with ease beneath the ice layer. Water was found to flow under the ice in all selected stations at all times, and the ice thickness ranged from 25-50 cm in December to 25-90 cm in March. A relatively mild February and March probably contributed to the collapse of the ice layer in a few sections in the upper reaches of the river (Plate 10). This contributed to water seepage and flow on top of the ice and beneath the snow surface.

Ice conditions in the Ogilvie system contrasted considerably with those in the Swift in that the sources and controls of groundwater varied greatly thus affecting the stream flow all along the main channel. Groundwater flow was responsible for the creation of aufeis (icings) which were widespread and of considerable thickness. An example of surface build-up of ice by an overflow is shown in Plate 11.

Plate 10. Collapsed ice layer in Swift River basin

Plate 11. Icings from overflow

In a number of stations water could not be collected because the ice cover was so thick (> 180 cm) that the use of an extended ice drill would have been necessary. In at least three Ogilvie River stations ice was encountered down to the stream gravel and water was observed to flow in a number of small seepage type channels between the ice and the bed. Often they were very difficult to find and several holes had to be prepared before enough water could be found for sampling. In at least two sections upstream no water was found in the main channel despite the construction of several ice test holes. In these cases it is assumed that the water flows as groundwater below the gravel bed especially in view of the fact that running water was observed a few miles above and below these sections.

The majority of Ogilvie ice was layered with distinct blue, grey and black banding. One extreme water course was found between ice layers at a depth of 30 cm from the surface in the upper section of the Ogilvie River. The layer was under considerable pressure and, once tapped, continued to flow for at least 30 minutes. An example of this is provided in Plate 12.

Plate 12. Water flow under pressure from ice layer

A number of springs were discovered as the winter progressed. The most interesting of these was found at Engineer Creek (Dempster Highway Mile 107). It consisted of water with high sulphur content and a year-round temperature of +4° to +7°C (see plate 13). The role of this spring and its contribution to the water chemistry of the Ogilvie will be discussed in more detail in Sections D and E of this chapter.

Plate 13. Discharge from sulphur spring in Engineer Creek

2) <u>Summary of observations on ice conditions</u>

Three findings are of interest:

(a) Despite consistently cold temperatures, sections of open water were encountered in both river systems;

(b) A great variability in ice type and ice thickness was found; they included block ice, layer ice, cavernous ice, and aufeis, and ranged in thickness from 25 cm to $>$ 180 cm.

(c) The groundwater sources and regimes differed greatly between the two basins resulting in drastically different flow regimes and ice build-up.

B. Seasonal Trends in Water Quality

Schallock and Lotspeich (1974), Childers et al (1975), Lotspeich et al (1976) all noted that differences in groundwater contribution and the build-up of ice cover result in a profound change in water quality. To demonstrate this a number of parameters were examined over the one-year study period and some of the more important observations are presented below.

1) Seasonal trends in dissolved oxygen concentrations

Schallock et al (1970), Schallock and Lotspeich (1974) and Lotspeich et al (1976) observed a depletion in dissolved oxygen over the winter in a number of Alaskan streams. To see whether this was a widespread phenomenon dissolved oxygen values were examined in both watersheds. In both cases only those stations with a complete sampling record were used. The seasonal variations in dissolved oxygen were plotted in Figures 8 and 9 showing a distinct trend in both cases.

A progressive DO-depletion was found as the winter advanced. Upon ice break-up a quick recovery took place, which was then followed by a much smaller depression during the early summer. It is possible that the biological demand on oxygen during the latter period is partially responsible for this secondary DO-decrease. Winter conditions in general seem to reduce DO levels, but from the present study it is not possible to determine the exact causes of the decrease. It is felt that a large number of factors probably contribute to the decrease, particularly since low values were obtained in a great variety of site and flow conditions.

Substantial spatial variations in dissolved oxygen were found in both watersheds. The variation was noted to be highest during the late part of the winter and might in part be caused by differences in ice cover. Both the variations and seasonal trends were found to be similar in both watersheds despite drastic differences in climatic, hydrologic and geologic conditions. A partial explanation for the spatial variability in dissolved oxygen can be deduced from Figure 10, in which the values of three Swift River stations

SEASONAL VARIATIONS IN DISSOLVED OXYGEN IN THE SWIFT RIVER BASIN, YUKON TERRITORY: 1977-1978.

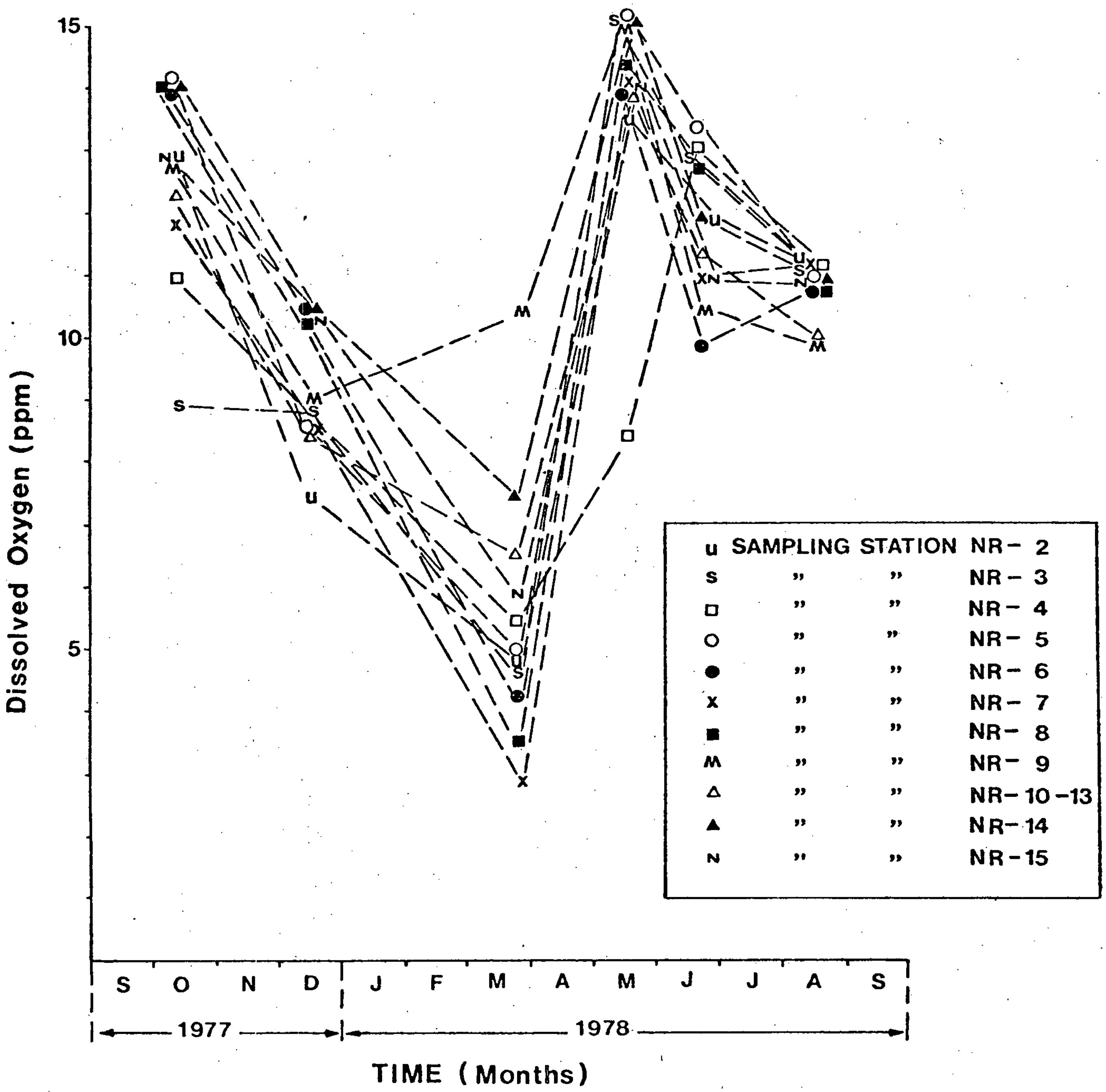


Figure 8. Seasonal trends in dissolved oxygen in the Swift River basin

SEASONAL VARIATIONS IN DISSOLVED OXYGEN IN THE OGILVIE RIVER BASIN, YUKON TERRITORY : 1977 - 1978.

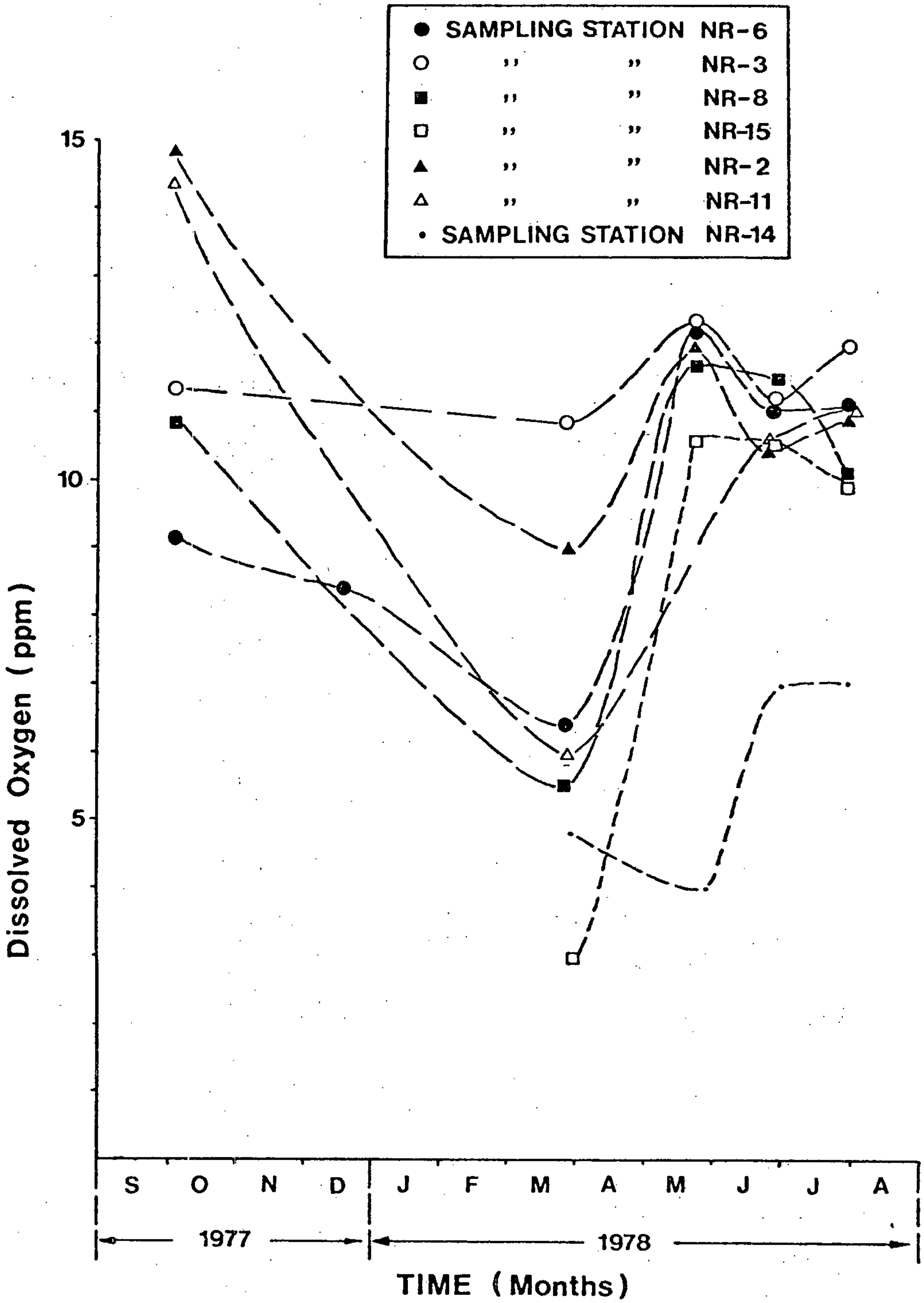


Figure 9. Seasonal trends in dissolved oxygen in the Ogilvie River basin

are compared. A substantial difference in the depletion rate was found between open water and under-ice conditions. Also there is a substantial lag time in the recovery rates between the stream samples and the lake situation.

Two stations on the Ogilvie River produced somewhat anomalous values for dissolved oxygen in that the depletion over the winter was minimal. The reason for this could be that both stations are substantially controlled by groundwater flow which seems to moderate dissolved oxygen variability. The groundwater flow in these cases is responsible for maintaining open water conditions all winter and the DO-values probably reflect those found in the groundwater. A more detailed discussion on the groundwater conditions in the Ogilvie River is provided in Section D.

Besides the DO-depletion from October to March a severe decrease was observed by Schallock and Lotspeich (1974) in Alaskan streams as one proceeds from the headwaters towards the mouth of the river. This trend did not exist in either of the two rivers investigated in this project. The most likely explanations for the absence of such a trend are that (1) groundwater influences the downstream conditions of the Ogilvie River, and (2) a major lake (Swan Lake) exists in the lower section of the Swift River which is probably responsible for a substantial moderation in flow conditions and mixing.

In summary it can be stated that a depletion of dissolved oxygen occurred throughout the winter in a great variety of stream conditions within both watersheds. This is in agreement with observations published by Schallock and Lotspeich (1974) in Alaska who found that rivers of all sizes, drainage, and surface discharge exhibit severe natural DO-depletions. From the present study it is not possible to determine precisely those factors which are most instrumental in causing the DO-decrease. For this a specific investigation would be necessary. Nevertheless it can be stated that the evidence produced in this study suggests that the DO-depletion phenomenon is not limited to a few selected Alaska rivers but is present in other northern rivers. Also a number of factors are responsible for its occurrence, the most common ones probably being under-ice respiration, photosynthesis, and aeration.

DISSOLVED OXYGEN TREND UNDER DIFFERENT HYDROLOGICAL CONDITIONS IN THE SWIFT RIVER

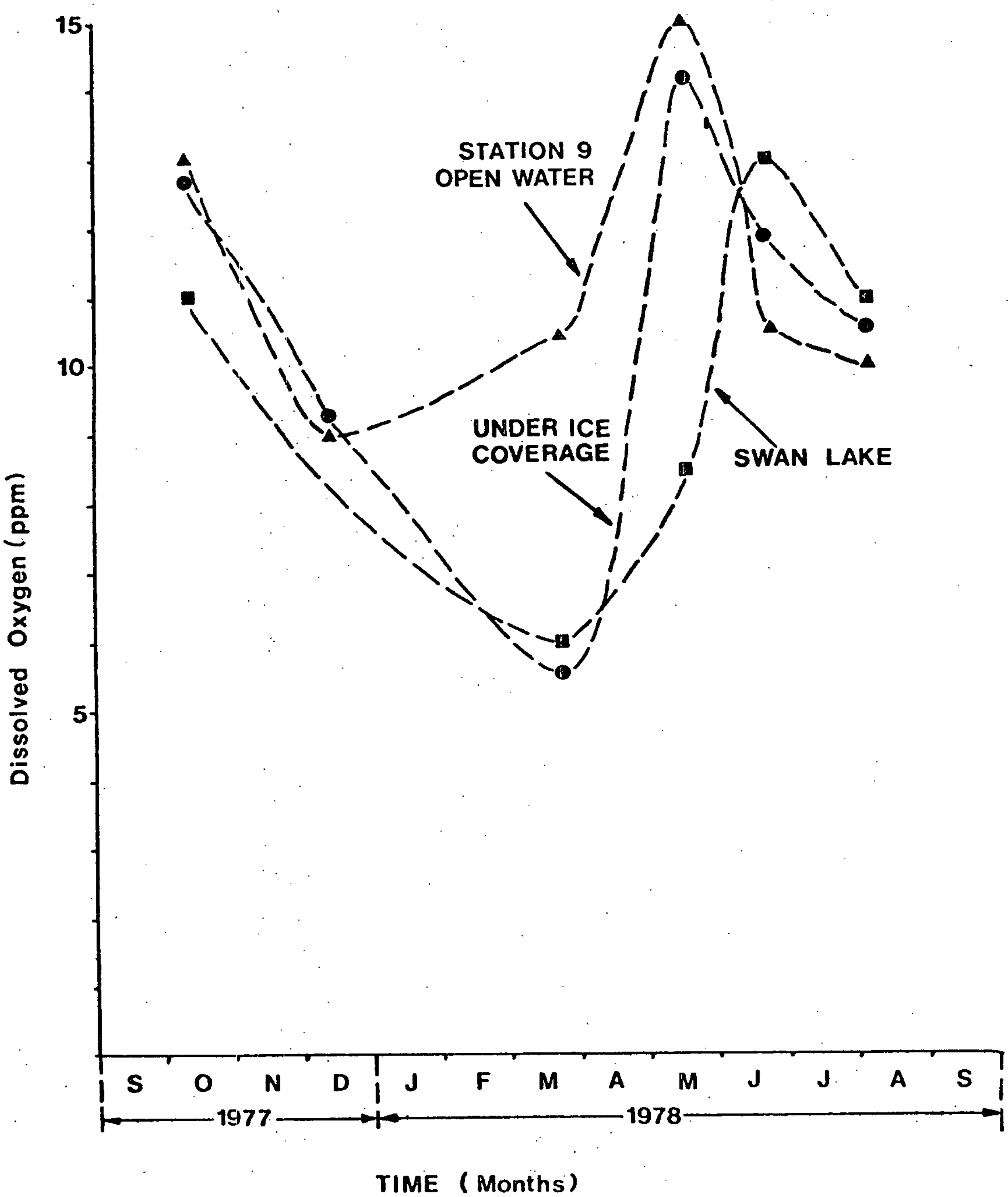


Figure 10. Dissolved oxygen trends

2) Seasonal trends in other water quality parameters

From the few investigations made in Alaska (Schallock et al 1970, 1974, Lotspeich et al 1976) it appears that the concentrations of a number of water quality parameters increased in these northern rivers with the advance of winter. This trend definitely exists for a number of parameters in both watersheds under investigation. The consistency of this trend is most evident in the Swift River basin, while the Ogilvie data is somewhat more complex. In the latter case this complexity could be caused by selective groundwater contributions along the downstream section of the river. Dilution, by increasing surface run-off during spring is probably the most important factor causing this trend. For the analysis the parameters were divided into three groups, (1) those indicative of geological conditions, (2) metals, and (3) those influenced by biological factors.

(a) Seasonal trends in parameters related to geology.- No consistent change in pH was observed during the winter (Figure 11) but all values dropped significantly after ice break-up and freshet, recovering again in late summer to levels equal to or above winter values. Specific conductance, alkalinity, silica, Ca, Mg, Na, and SO_4 concentrations (Figures 12 - 18) showed the same summer trends but differed from those of the pH values in that the concentration generally increased throughout the winter. The highest yearly concentrations were recorded immediately prior to break-up, under maximum ice cover. All stations in the Swift River basin and at least two in the Ogilvie confirm this trend. Exceptions were noted in the case of stations 2, 3 and 8 in the Ogilvie system where concentrations either stay the same or decrease slightly during the winter. These stations are influenced by groundwater discharge which is particularly evident during the winter and this seems to cause a change in the overall trend. The groundwater conditions in these stations will be discussed in greater detail in Section D.

(b) Seasonal trends in metal concentrations.- Extractable iron concentrations followed a distinctly different pattern from those recorded for the parameters discussed above. The highest concentrations of metals occurred in May during high water conditions (Figure 19). Some evidence exists that

FIGURE 11. SEASONAL VARIATIONS IN pH

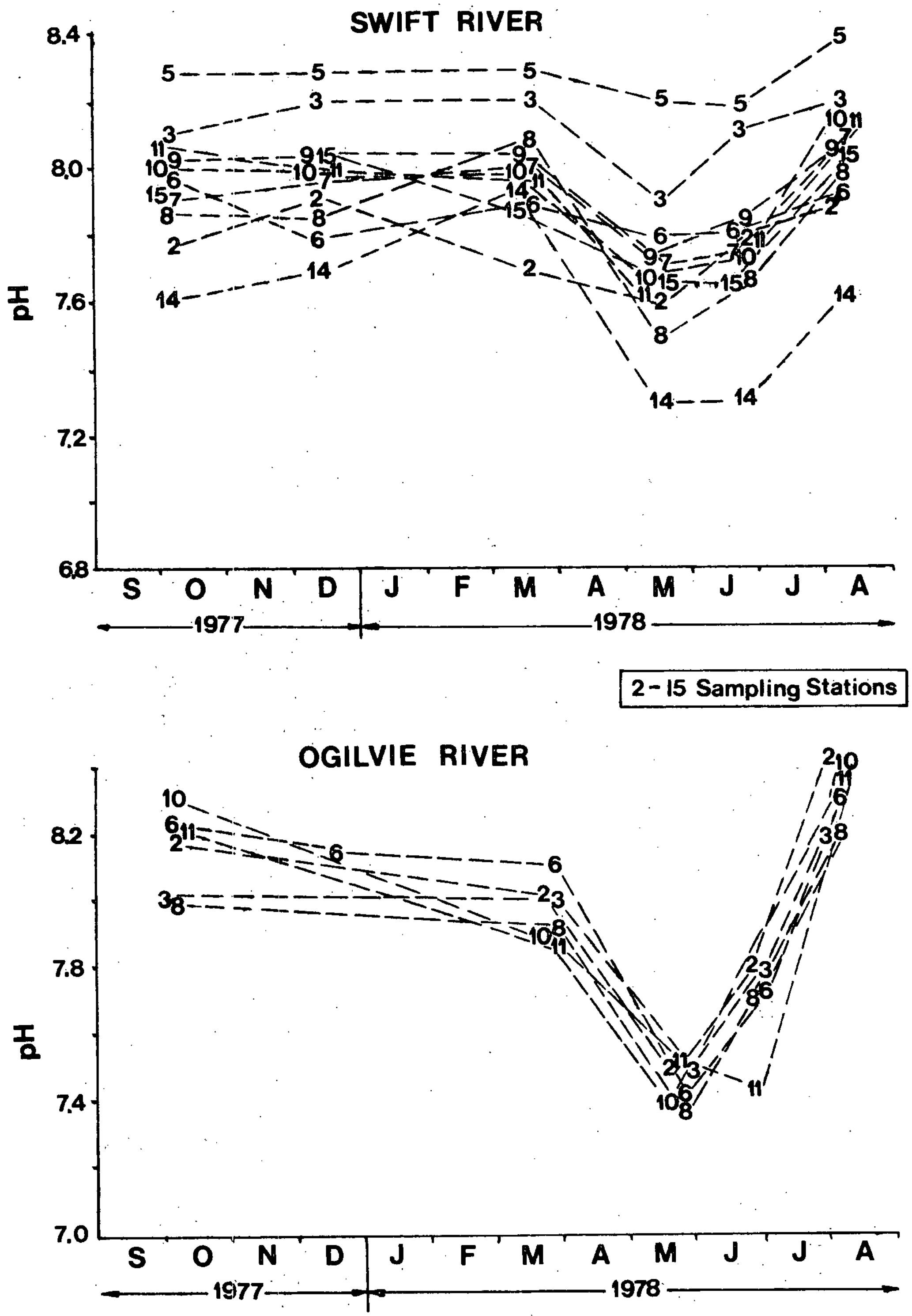


FIGURE 12. SEASONAL VARIATIONS IN SPECIFIC CONDUCTANCE

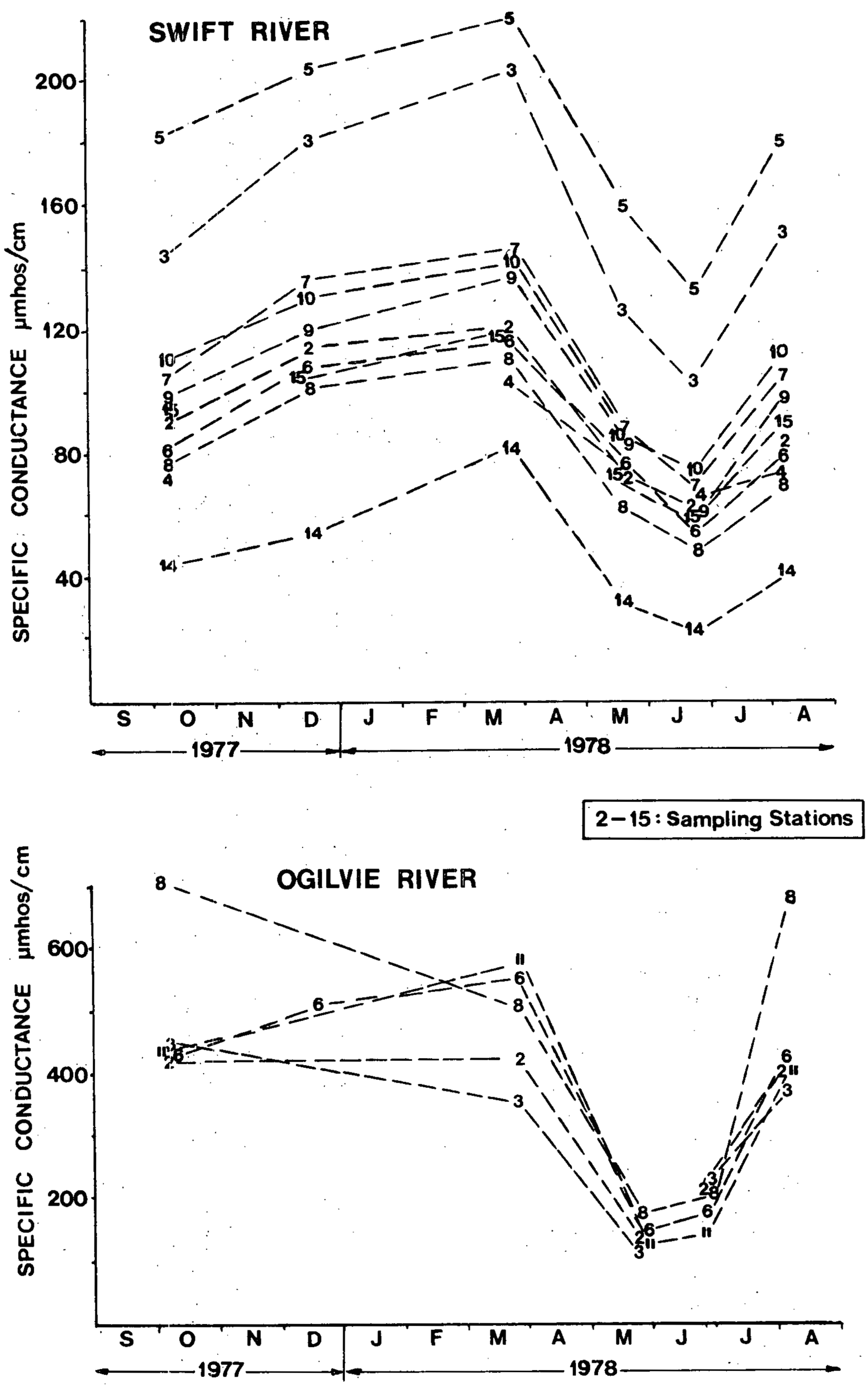
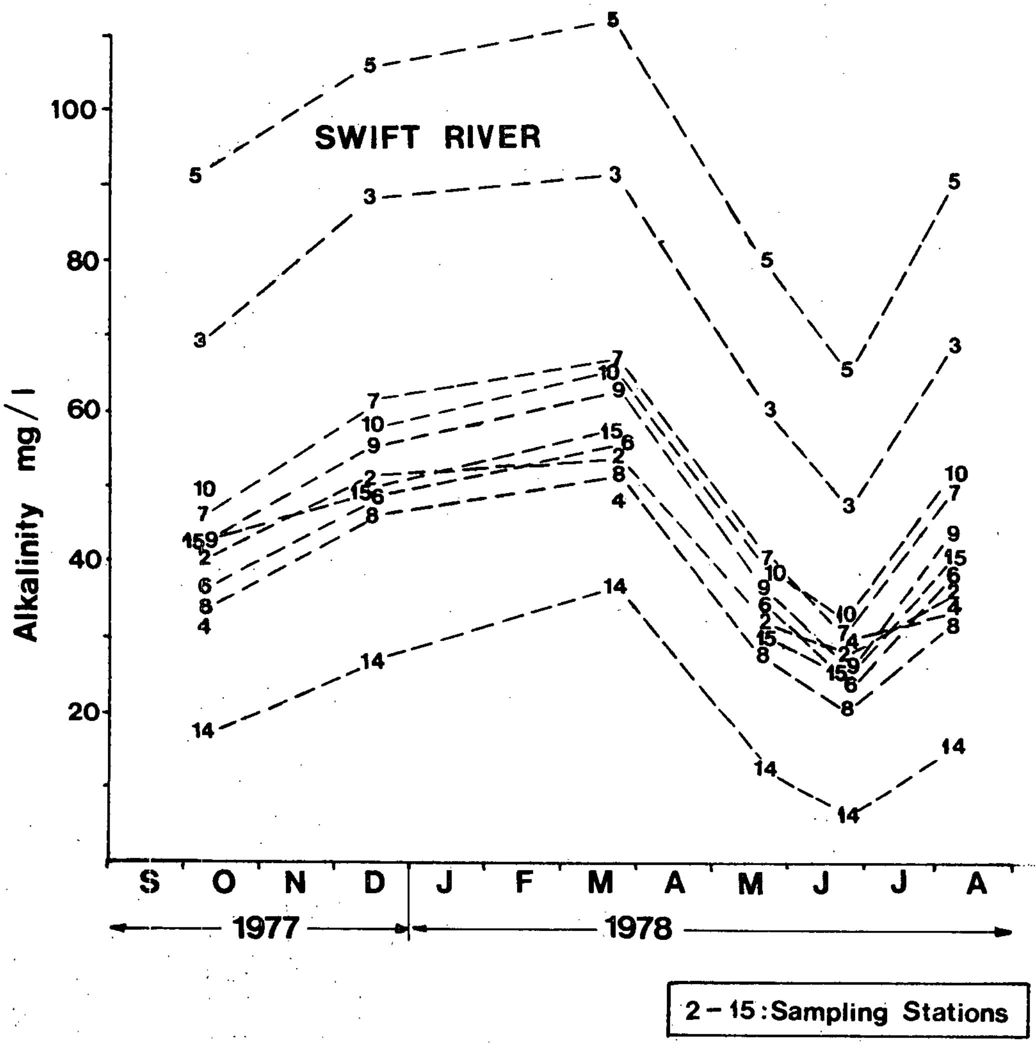


FIGURE 13. SEASONAL VARIATIONS IN ALKALINITY



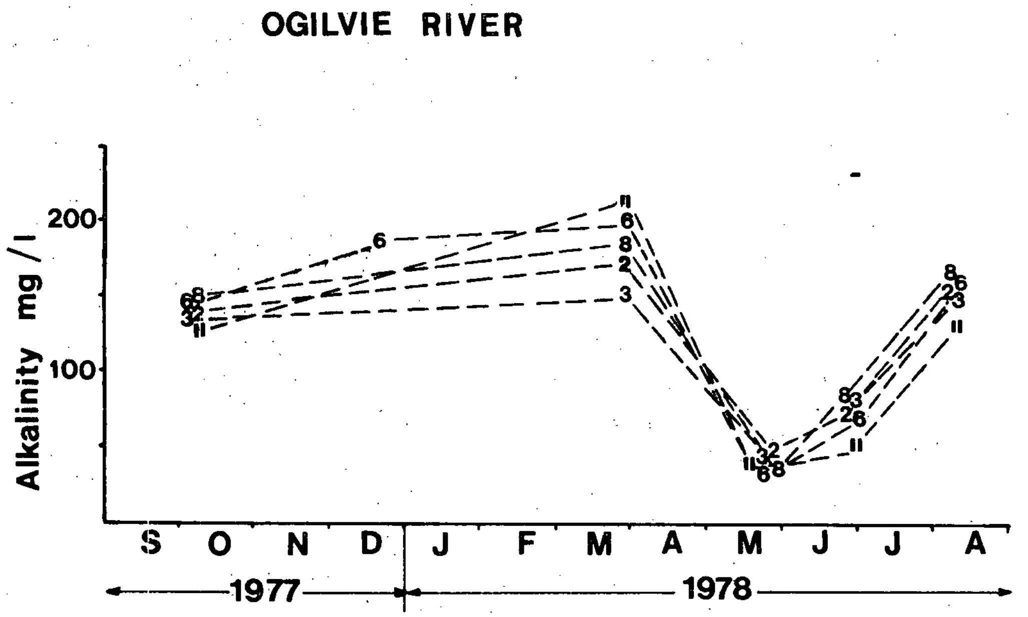


Figure 14. Seasonal Variations in Silica

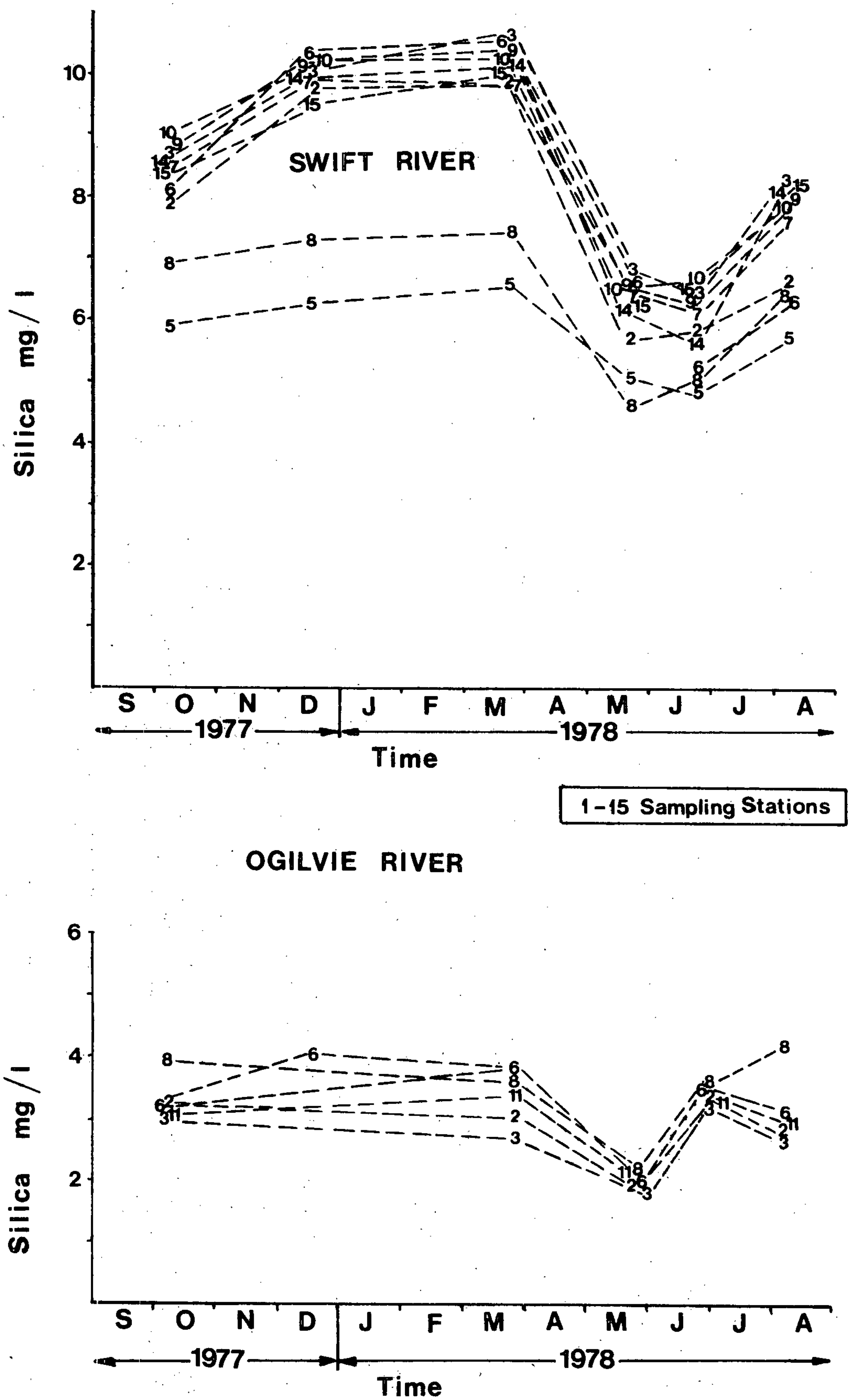
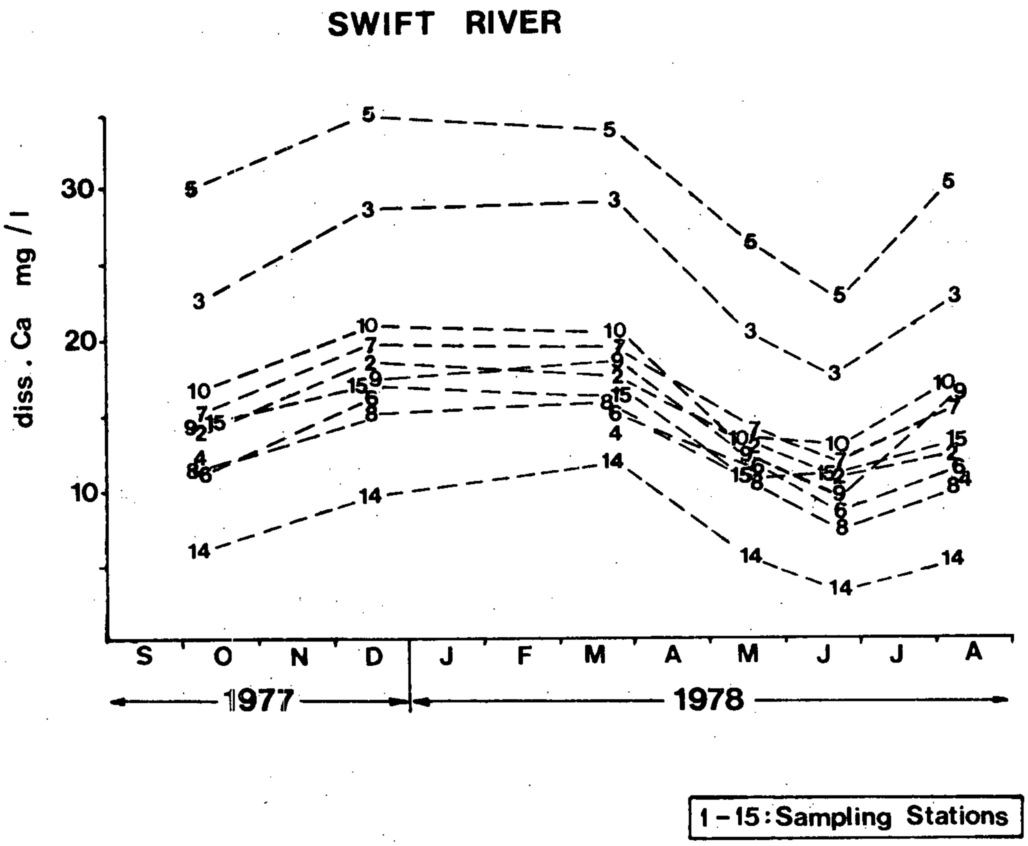


Figure 15. Seasonal Variations in Dissolved Calcium



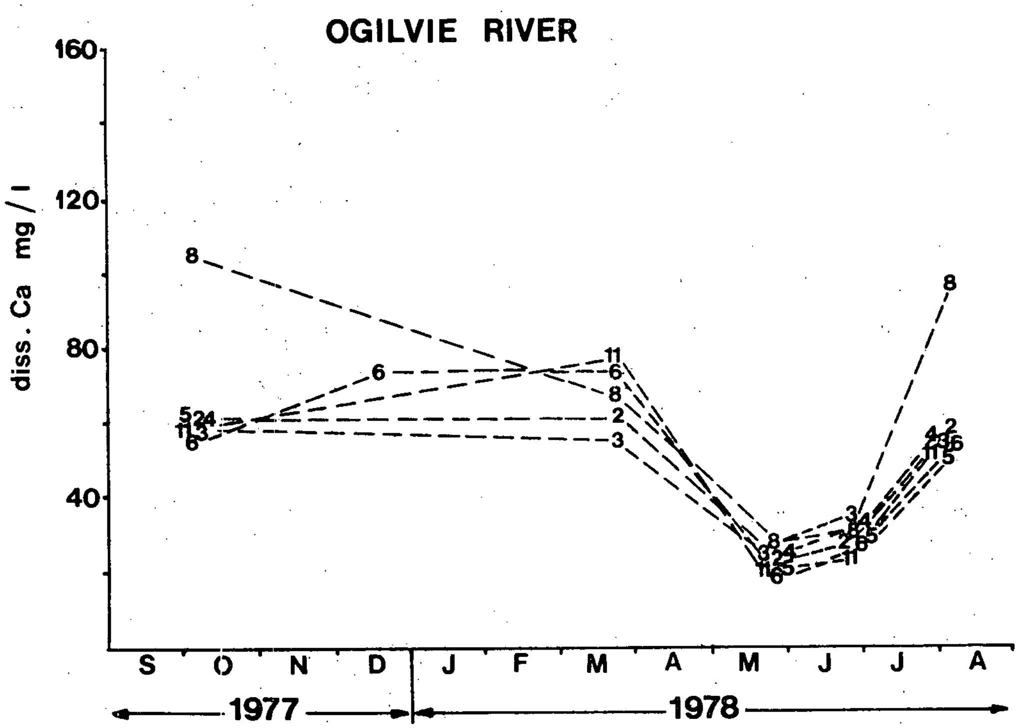


Figure 16. Seasonal Variations in Dissolved Magnesium

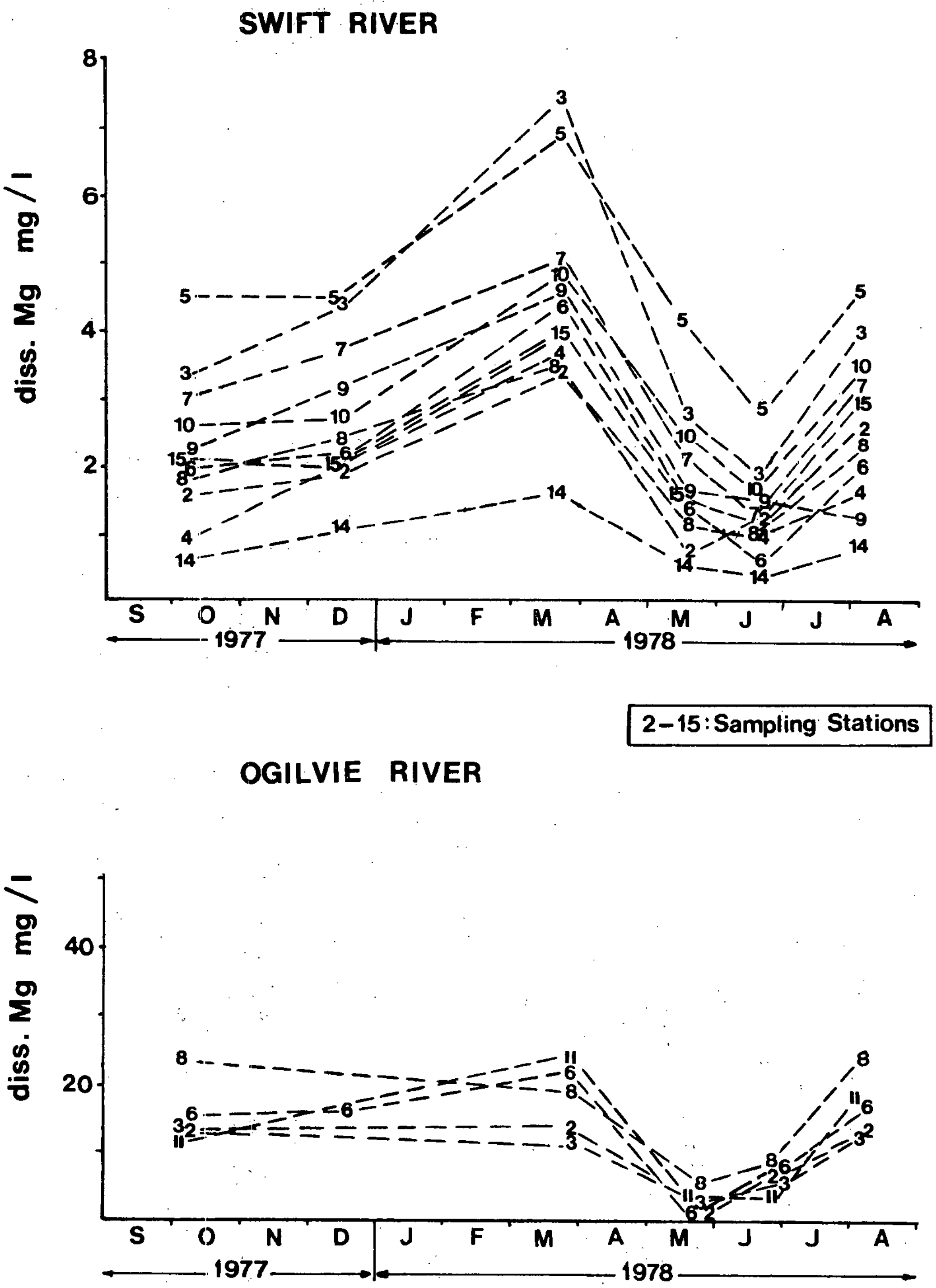
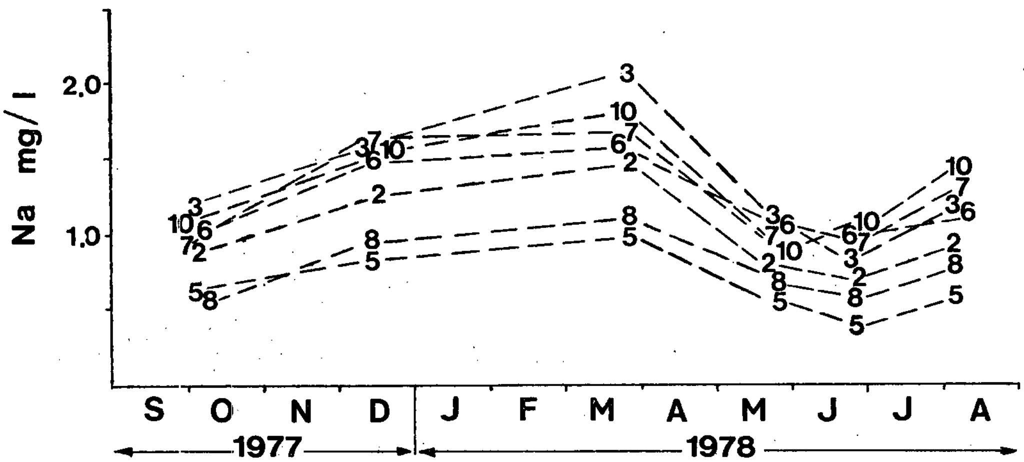


Figure 17. Seasonal Variations in Sodium

SWIFT RIVER



OGILVIE RIVER

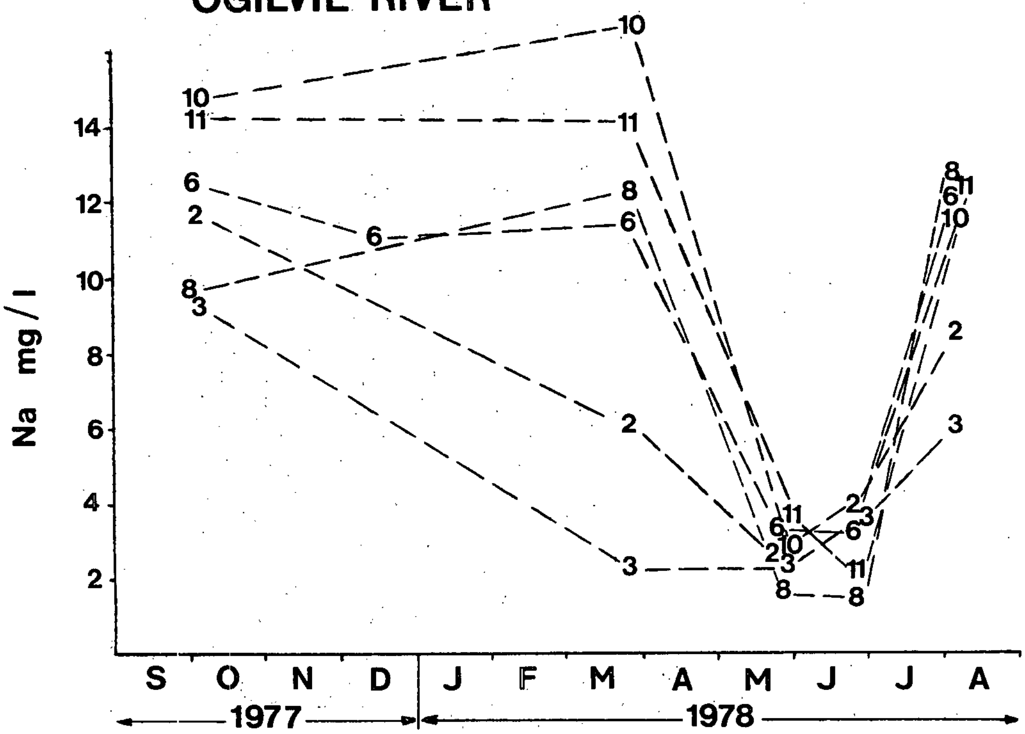


Figure18. Seasonal Variations in Sulphate

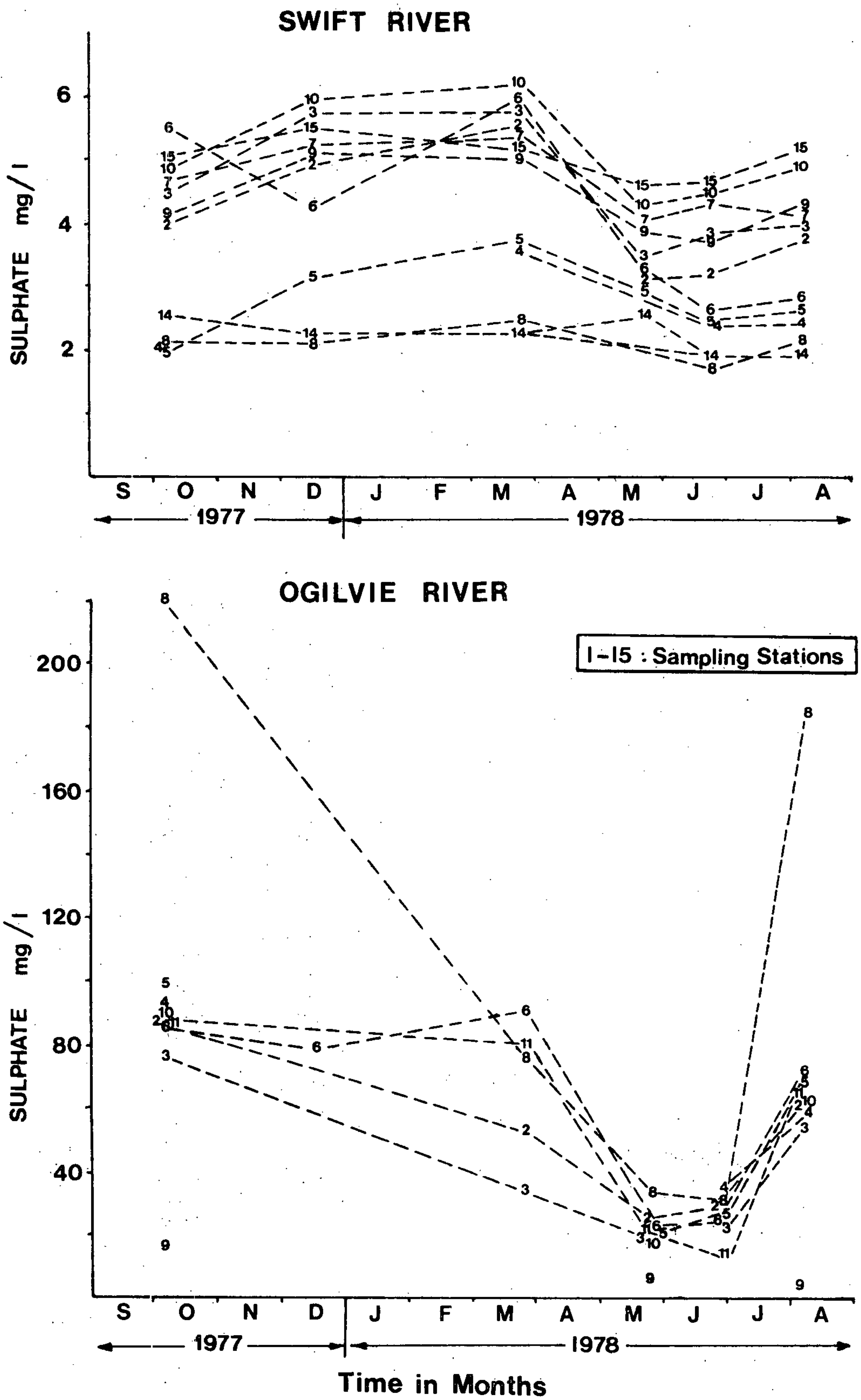
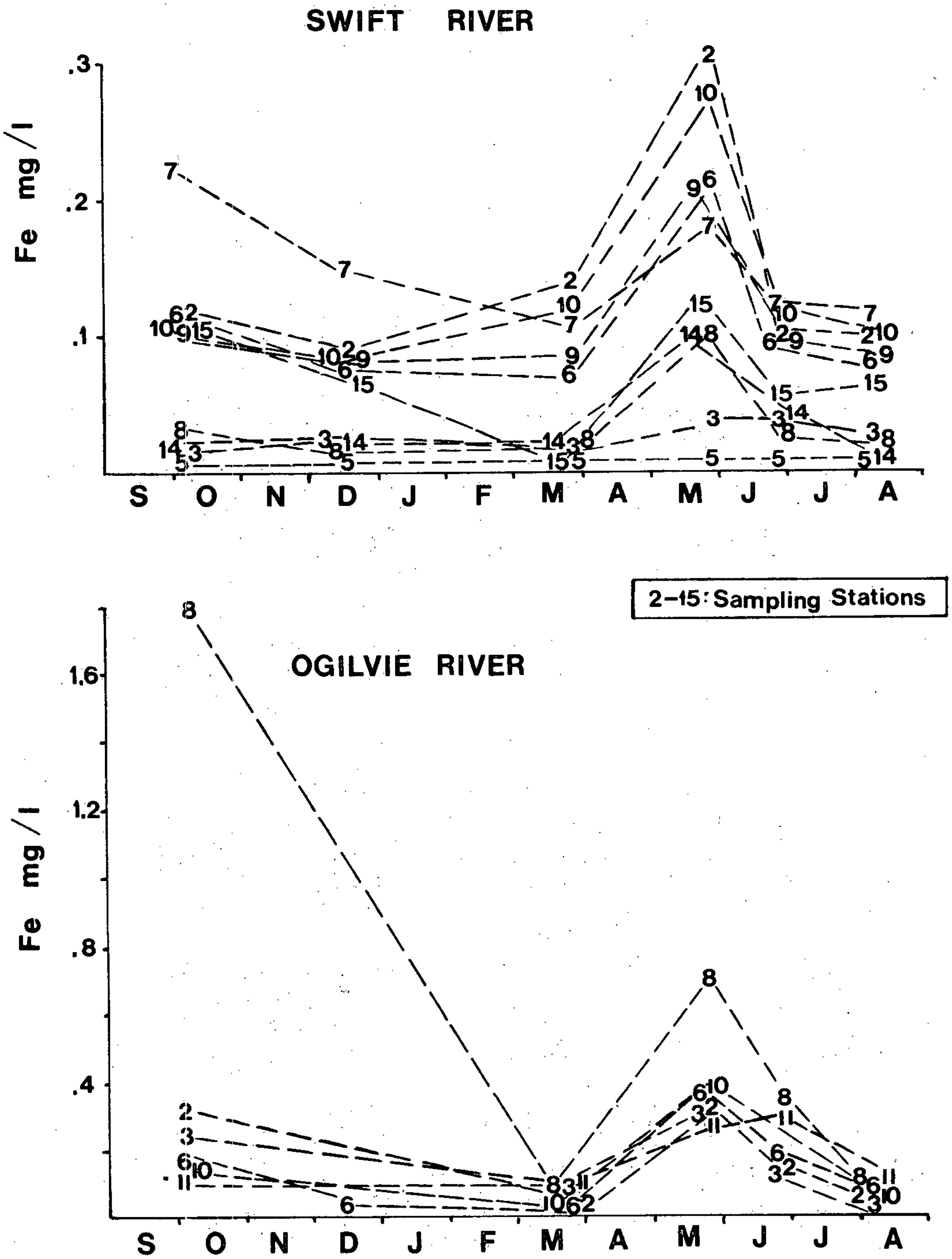


FIGURE 19. SEASONAL VARIATIONS IN Fe



other metals such as Cu, Mn, Ni and Zn behave in a similar way but, unfortunately, the concentrations of these metals were generally close to the detection limits thus making it impossible to carry out a satisfactory examination.

(c) Seasonal trends in parameters related to biology.- Total phosphorus, nitrate+nitrite, total dissolved nitrogen and ammonia-nitrogen are dynamic parameters and are influenced by both hydrologic and biological conditions in the stream. Total nitrogen and ammonia-nitrogen concentrations partially increased early in winter, then dropped slightly for the rest of the winter. Finally highest concentrations occurred in both watersheds during spring run-off (Figures 20-21). Phosphorus remained low throughout the winter and also reached highest values in May (Figure 22). Nitrate/nitrite in contrast followed the pattern of the geology related parameters in that the concentrations increased as winter progressed (Figure 23).

3) Summary of seasonal trends in water quality parameters

Three types of trends in water quality parameters were observed throughout the year:

(a) Those parameters for which the concentration increased throughout the winter to reach maximum annual concentration at thickest ice cover immediately prior to break-up. Examples include specific conductance, alkalinity, Ca, Mg, Na, Si, SO_4, and $N(NO_3+NO_2)$.

(b) Parameters which were consistently low or decreased as winter progressed to increase drastically during spring high water. These include a number of metals especially Fe, total phosphorus and dissolved oxygen.

(c) Parameters which showed an increase during early winter, followed by a slight decrease in late winter and reaching maximum concentrations during spring high water. Examples include nitrogen, and ammonia-nitrogen.

FIGURE 20. SEASONAL VARIATIONS IN DISSOLVED NITROGEN (Total)

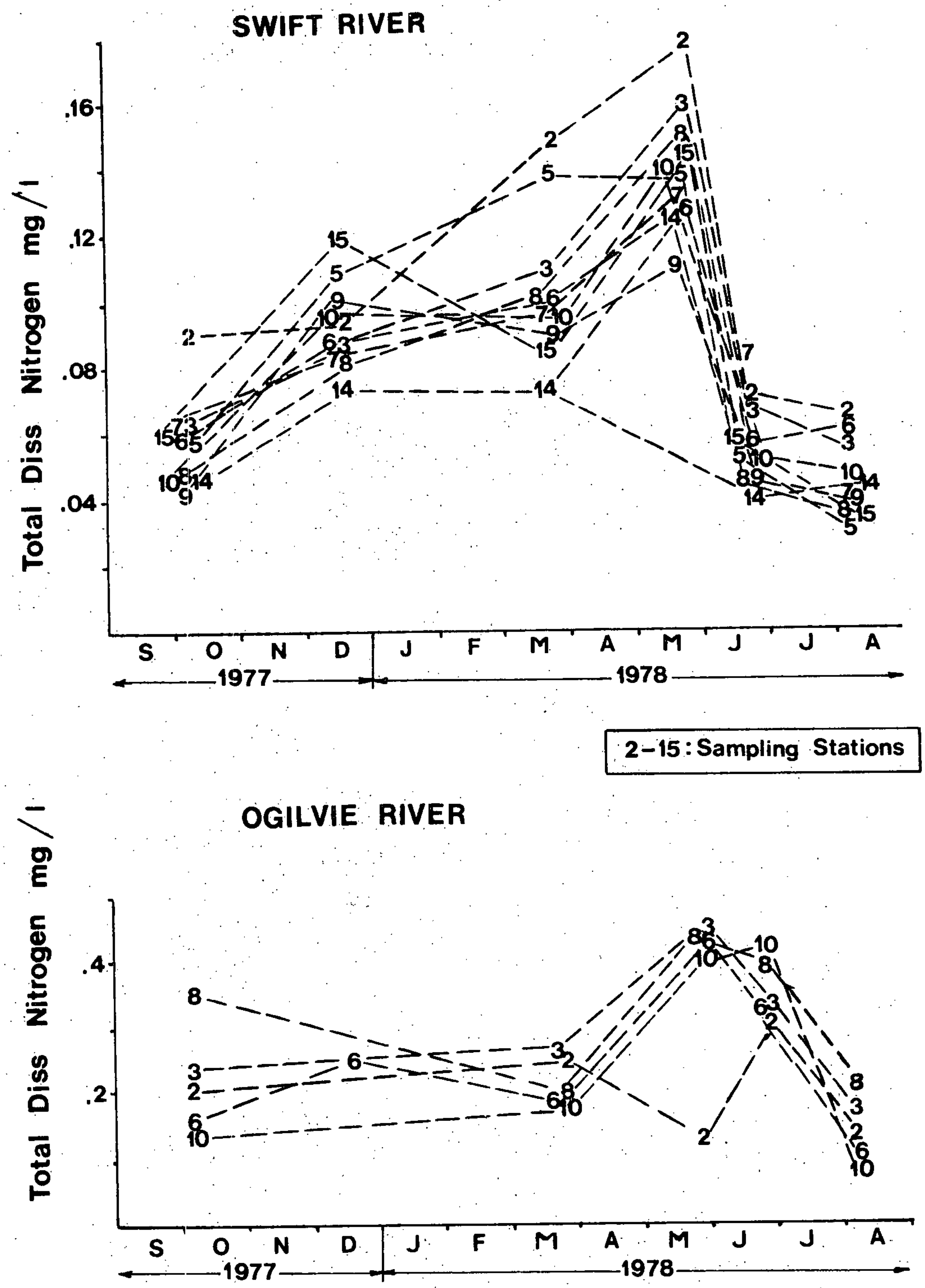


Figure 21. Seasonal variation in ammonia-nitrogen.

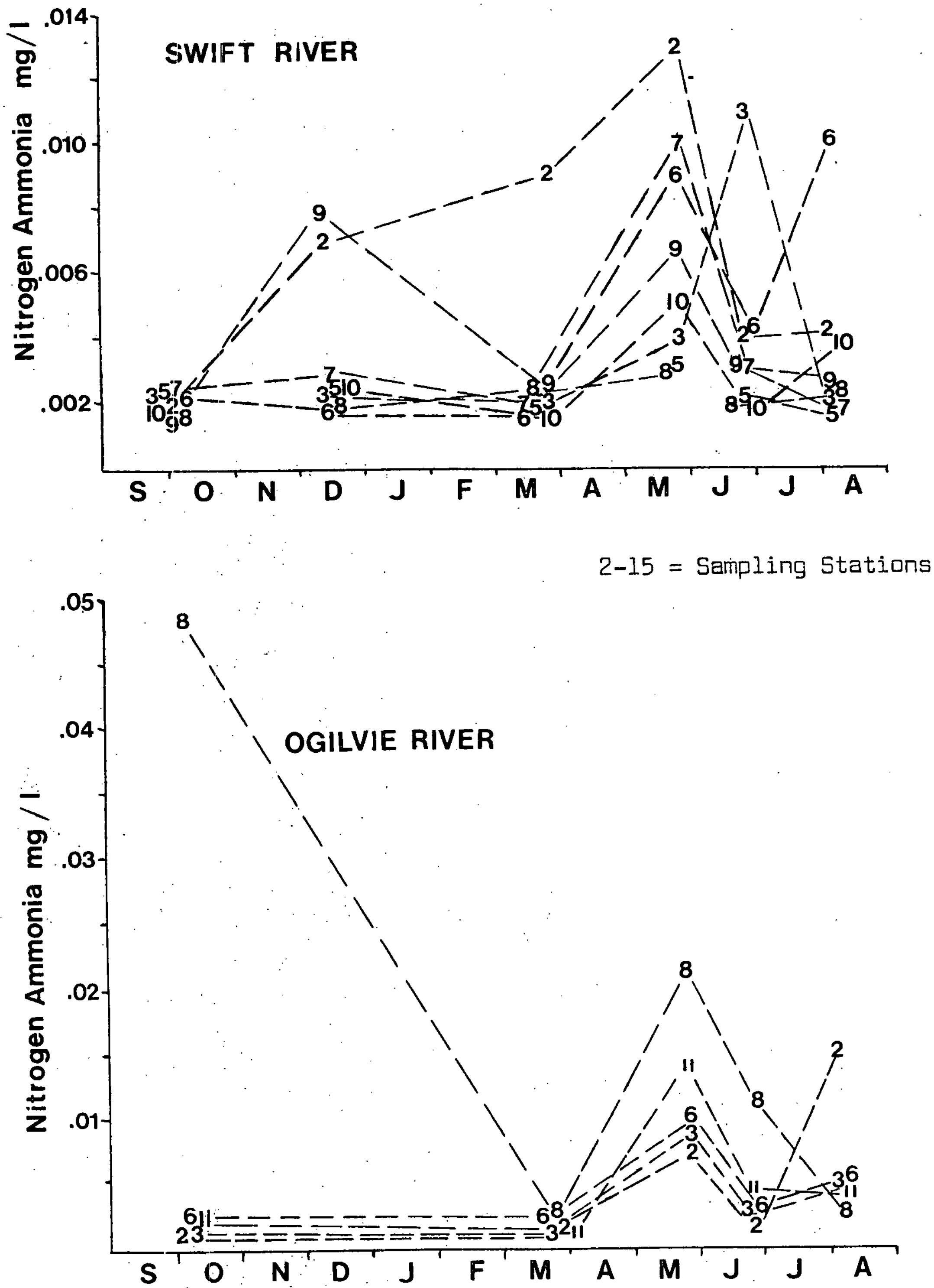


Figure 22. Seasonal variation in total phosphorus.

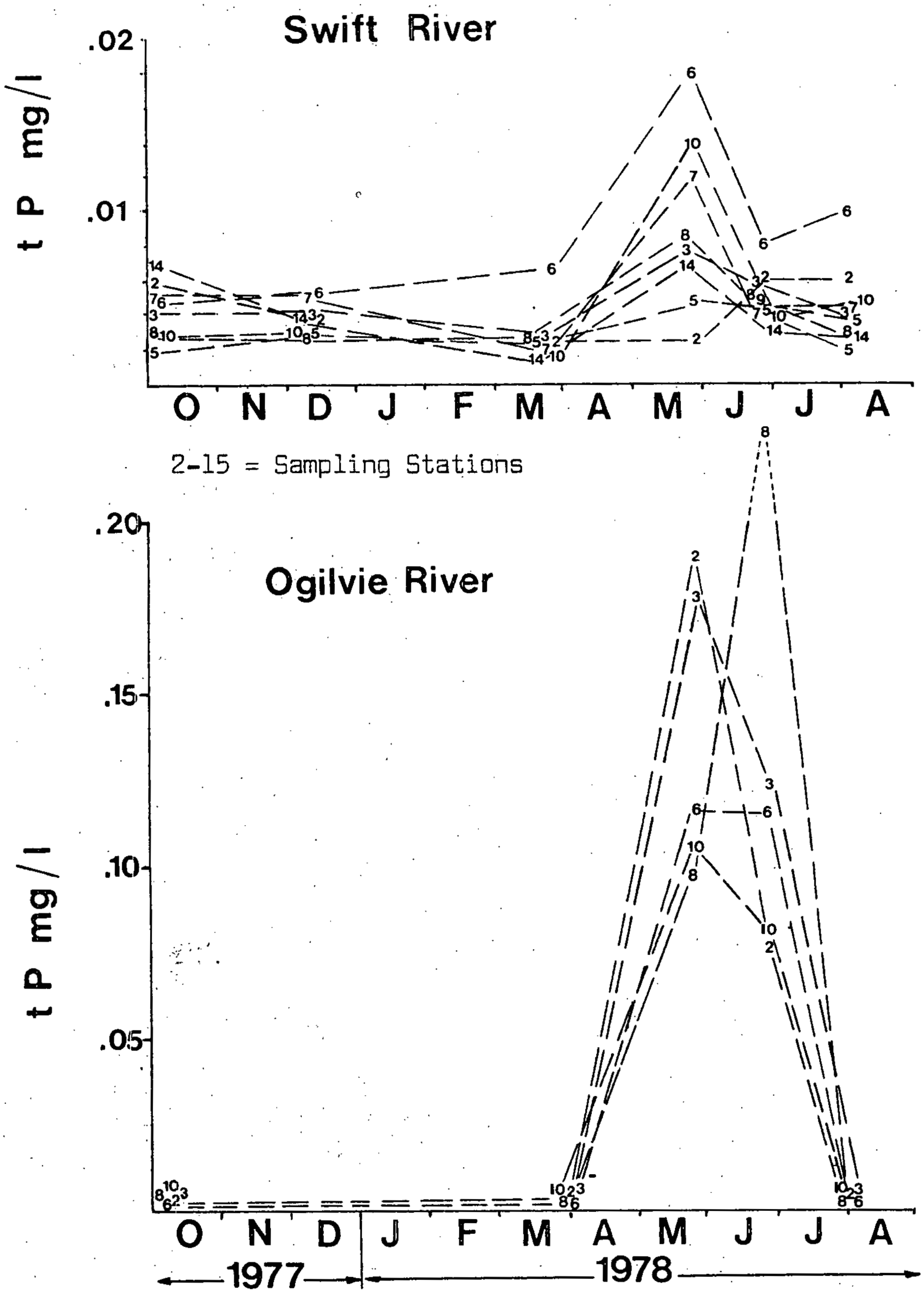
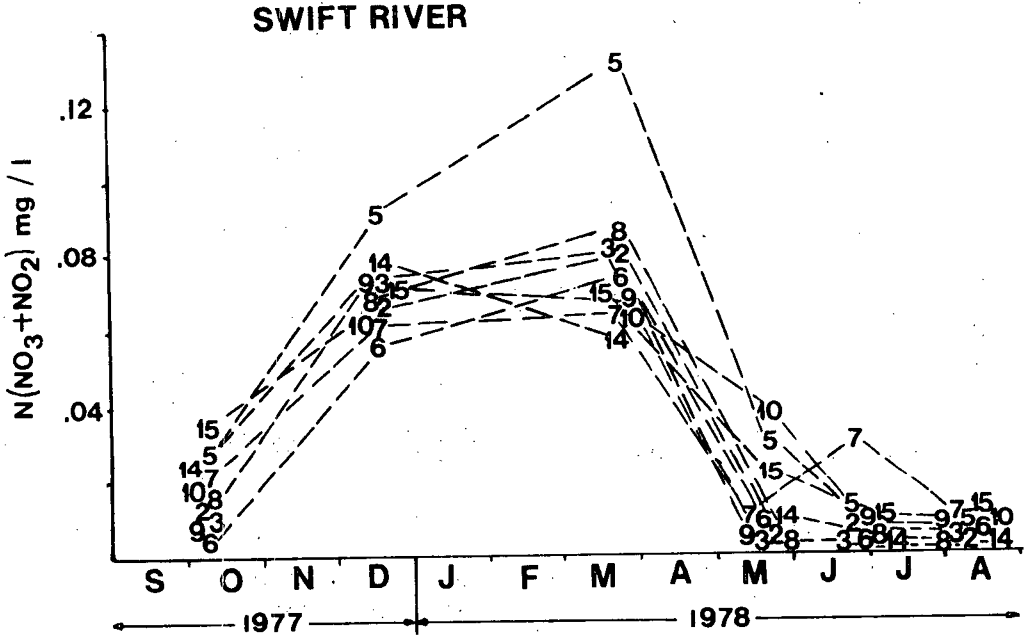


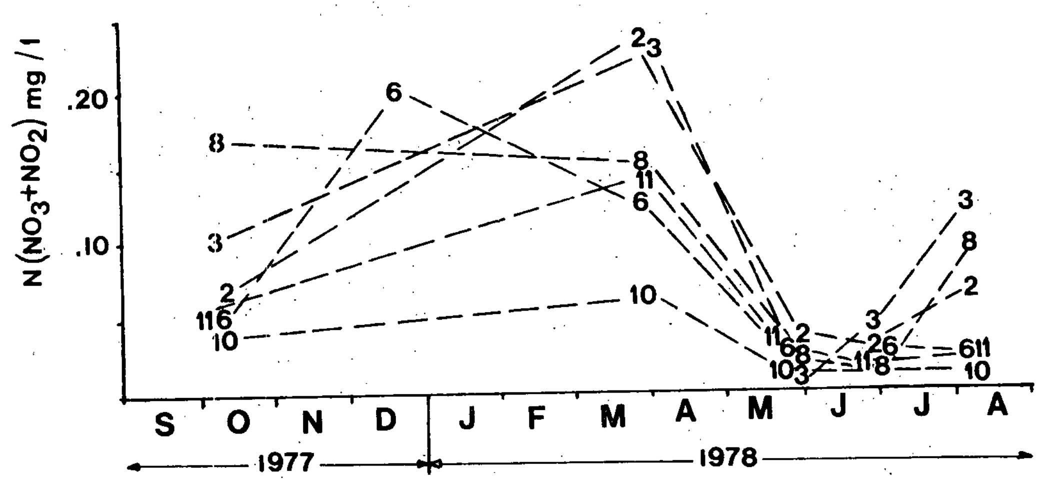
FIGURE 23. SEASONAL VARIATIONS IN $N(NO_3+NO_2)$

SWIFT RIVER



2-15 : Sampling Stations

OGILVIE RIVER



C. Sources of Variability in Water Quality

1) Cross-sectional and short term variability

In any environmental investigation it is first essential to determine the source and magnitude of variability in the experiment since this largely determines the accuracy and reliability of the interpreted results. Considerable evidence has been produced by Kleiber and Erlebach (1977) that single grab samples often do not accurately account for mean values at any one station in a river. To determine whether this is the case in the two rivers under investigation a number of small scale experiments were performed at two stations in the Swift River basin and three in the Ogilvie River basin. An overview of the type of experiments carried out is given in Table 4 below.

Table 4. An Overview of Sample Variability Assessments

TYPE OF VARIABILITY ASSESSMENT:	SWIFT RIVER		OGILVIE RIVER		
	STATION #10	STATION #15	STATION # 2	STATION # 1	STATION # 6
Cross-sectional Variability	4 samples (October)	2 samples (October)	2 samples (October)	2 samples (October)	3 samples (December)
At different times of the year	2 samples (December)	2 samples (May)		2 samples (August)	
Vertical Variability	4 samples June 20, 1978 (0-40 cm. depth)				
Short-term Variability Over 315 minutes:	4 samples (May 20, '78 10.30-15.45) (0, 105, 210, 315 minutes)				
Over 70 hours	4 samples March 22, 12.30 to March 25, 10.30 (0,23,47,70 hrs)				

Although the sample numbers in Table 4 are small they nevertheless provide a basis from which to determine sample reliability.

Variations in cross-sectional variability were tabulated in Table 5. The numbers refer to the difference between maximum and minimum values for each parameter and set of samples.

Table 5. Magnitude of Cross-Sectional Variability (expressed as difference between maximum and minimum values, usually in mg/l except pH and spec. cond.)

WATER QUALITY PARAMETERS	SWIFT RIVER STATIONS				OGILVIE RIVER STATIONS				Accuracy in Analytical Procedure 2 S.D. (95%) Concentration	
	#10 (Oct)	#10 (Dec)	#15 (Oct)	#15 (May)	# 2 (Oct)	#11 (Oct)	#11 (Aug)	# 6 (Dec)	Low	High
pH	0.1	0	0	0	0.1	0	0.1	0.1	0.1	0.1
specific cond.	1.0	1.0	1.3	0	0	1.0	8.0	10.0	0.8	18.0
hardness	0.2	0	0.2	0.8*	1.0	0	5.0*	3.0*	0.4	1.4
Ca	0.6	0.5	0.3	0.6	2.5	2.2	1.0	2.5	0.2	3.0
Mg	0.4*	0.3*	0.3*	0.2	1.3*	1.3*	1.4*	2.1*	0.05	0.2
Na	0.2	0.1	0	0	0.1	0.3	0.5	1.0	0.1	0.3
K	0.1	0.1	0.1	0	0	0	0	0.1	0.2	0.6
Si	0	0.1	0	0	0	0.1	0	0.1	0.1	0.34
SO_4	0.5*	0.3	0	0.5*	2.0*	0	2.0*	1.5*	0.08	0.44
Cl	0	0	0	0	0.1	0.1	0	0.3*	0.05	0.2
Fe	0.06	0	0	0	0.02	0.01	0.04	0.01	0.01	0.016
$N(NO_3+NO_2)$	0.004*	0.002	0.014*	0.002	0.001	0.003	0.006*	0.06*	0.001	0.003
t. N	0.010*	0.005	0.005	0.	0	0.005	0.002	0.06*	0.004	0.014

* Indicates variability > analytical accuracy

It is readily apparent that the cross-sectional variability is small for most parameters thus indicating that the streams under investigation are well mixed, and single grab samples adequately reflect stream condition at each given site.

To further substantiate these findings a comparison was made in Table 6 between cross-sectional variability, temporal and spatial variability. Short term time variability over 315 minutes and over 70 hours, and seasonal variability over 6 sampling periods were all computed for station #10 in the Swift River. Spatial variability was measured for each of the six sampling periods and included all Swift River sampling stations. Each parameter is controlled by a different set of factors each producing a different type of variability. This can be seen in Table 6 where the depth, cross-sectional and short term variabilities are shown to be consistently smaller than either the seasonal or spatial variability. As shown in Figures 11 to 23 trends derived from single samples are consistent, a factor which further justifies the use of single grab samples under the given conditions in the two rivers investigated.

Table 6 also produces evidence showing that the seasonal and spatial variabilities are significant but dependent on parameter type. To investigate this in greater detail a comparison was made between spatial and seasonal variability in each watershed.

2) <u>Spatial vs. seasonal variability</u>

Only those stations with a complete data set were used in this comparison. The seasonal range was computed for each sampling station and the spatial variability was based on data from all stations for each of the sampling periods. Results of this can be found in Figures 24 to 27.

The dissimilar behaviour of individual parameters is also apparent in Figures 24 to 27. Generally spatial variability seems to be more important than seasonal variability in the Swift system, while seasonal variations tend to be higher in the Ogilvie. To verify these observations a significance test was conducted (Mann Whitney U-Test) in which all spatial values were compared against all seasonal values. The results of this test are provided in Table 7 on page 51.

Table 6. Source and Magnitude of Variability in Swift River Water Quality.

Variability expressed as difference between min. and max. value for each sample population and parameter

	pH	Spec. Cond. µmho/cm	TIC mg/l	TOC mg/l	Non-filt. res. mg/l	Filt. res. mg/l	Non-filt. fixed mg/l	Filt. fixed mg/l	Hard-ness mg/l	Dis. Ca mg/l	Dis. Mg mg/l	K mg/l	Na mg/l	Si mg/l	tN mg/l	$NO_3^-NO_2$ mg/l	SO_4 mg/l	Fe mg/l
Spatial Variability in Watershed																		
Highest of 6 sampling sets (11 samples)	0.9	149	35.5	7.3	6.4	106	5.6	87	77.7	29.7	5.8	0.6	1.1	4.0	0.078	0.072	3.8	0.241
Lowest of 6 sampling sets (11 samples)	0.5	111	16.1	0.0	2.0	37	0.6	56	59.6	19.7	2.5	0.2	0.5	1.7	0.034	0.0	2.4	0.107
Temporal Variability																		
Seasonal (station 10, 6 samples)	0.4	68	5.7	9.0	6.2	36	3.4	45	32.0	8.4	3.4	0.4	0.8	3.9	0.095	0.067	1.9	0.190
Over 70 hrs. (station 10, March, 4 samples)	0.3	6	3.0	2.1	1.4	17	0.0	5	3.3	0.1	0.7	0.2	0.1	0.3	0.006	0.001	0.7	0.050
Over 5 hrs (station 10, May, 4 samples)	0.1	1	1.6	2.3	1.2	19	2.0	7	0.5	1.2	0.6	0.1	0.1	0.0	0.020	0.031	0.7	0.040
Cross-sectional Variability																		
October (station 10, 4 samples)	0.1	1	1.0	0.0	0.0	26	0.0	25	0.2	0.6	0.4	0.1	0.2	0.0	0.010	0.003	0.5	0.060
Depth Variability																		
June (station 10, 4 samples)	0.0	3	0.0	0.0	1.2	15	1.0	10	1.6	0.3	0.5	0.1	0.1	0.1	0.002	0.0	0.6	0.010
Accuracy of analytical procedure	0.1	18	1.6	1.0	4	10	4	10	1.4	3	0.2	0.6	0.3	0.36	0.014	0.003	0.44	0.016

Figure 24. Comparison Between Seasonal and Spatial Variability. SWIFT RIVER (Expressed as Difference Between Max.-Min. Values)

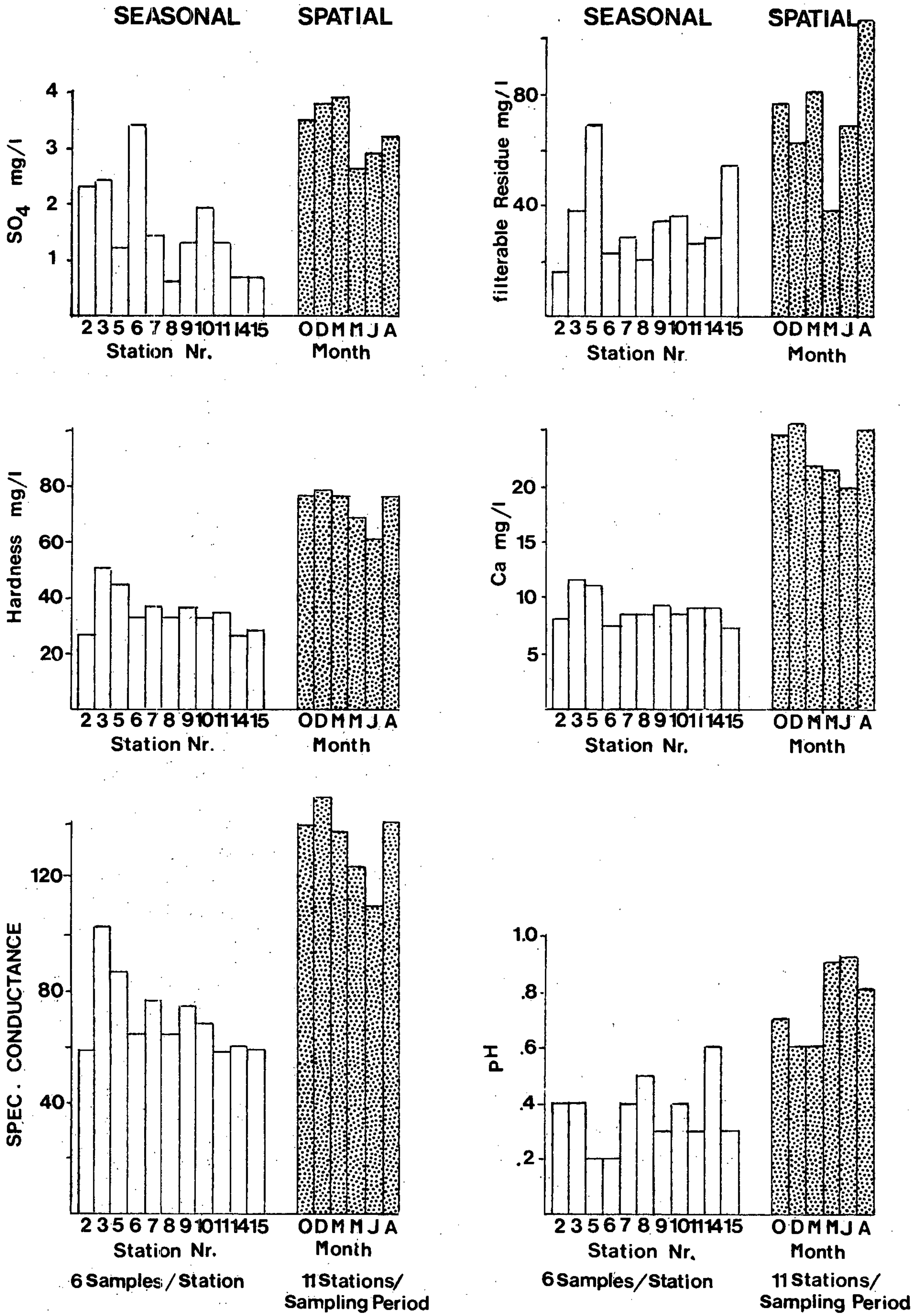


Figure 25. Comparison Between Seasonal and Spatial Variability SWIFT RIVER (Expressed as Difference Between Max.–Min. Values)

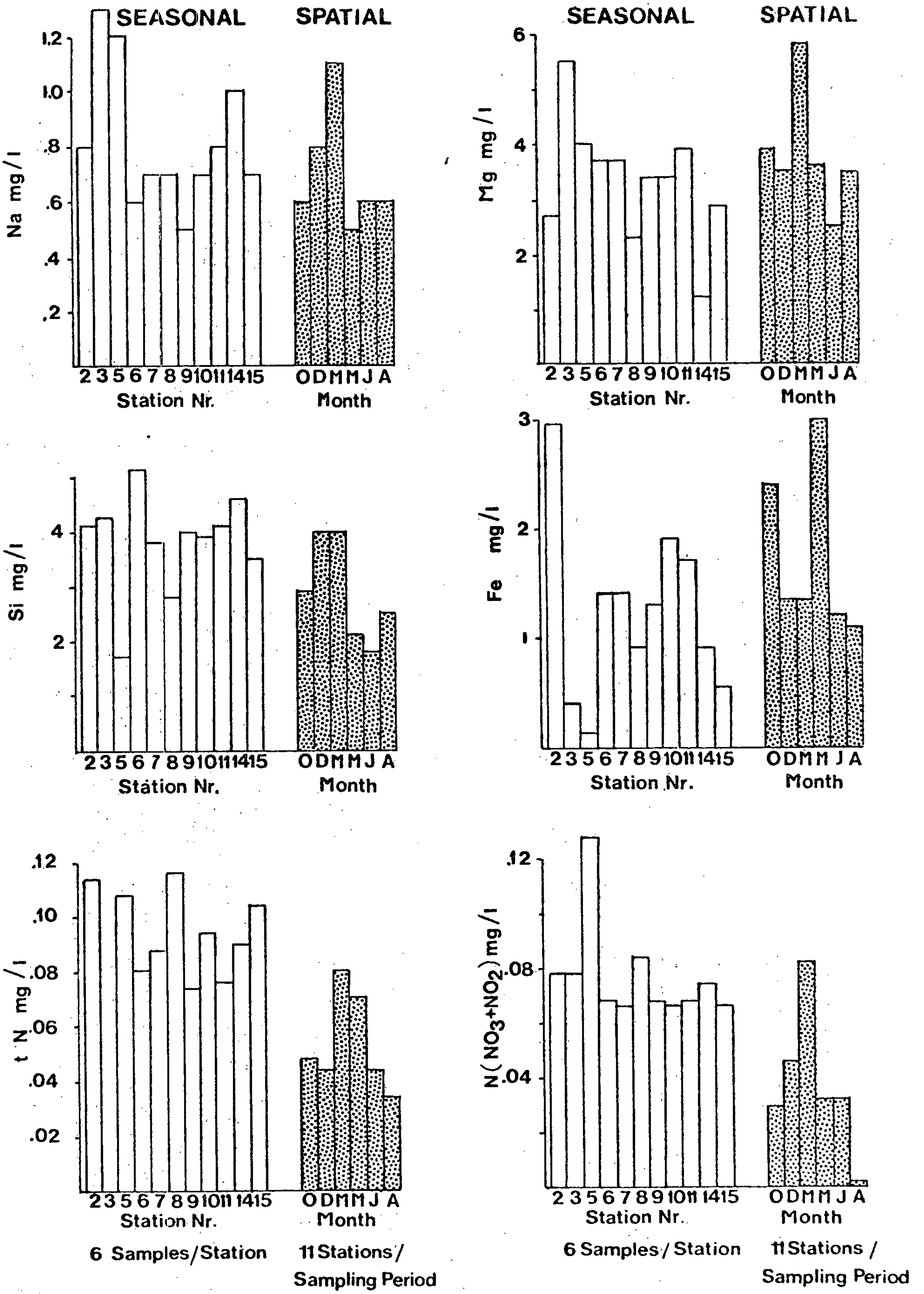


Figure 26. Comparison Between Seasonal and Spatial Variability

OGILVIE RIVER (Expressed as Difference Between Maximum – Minimum Values.)

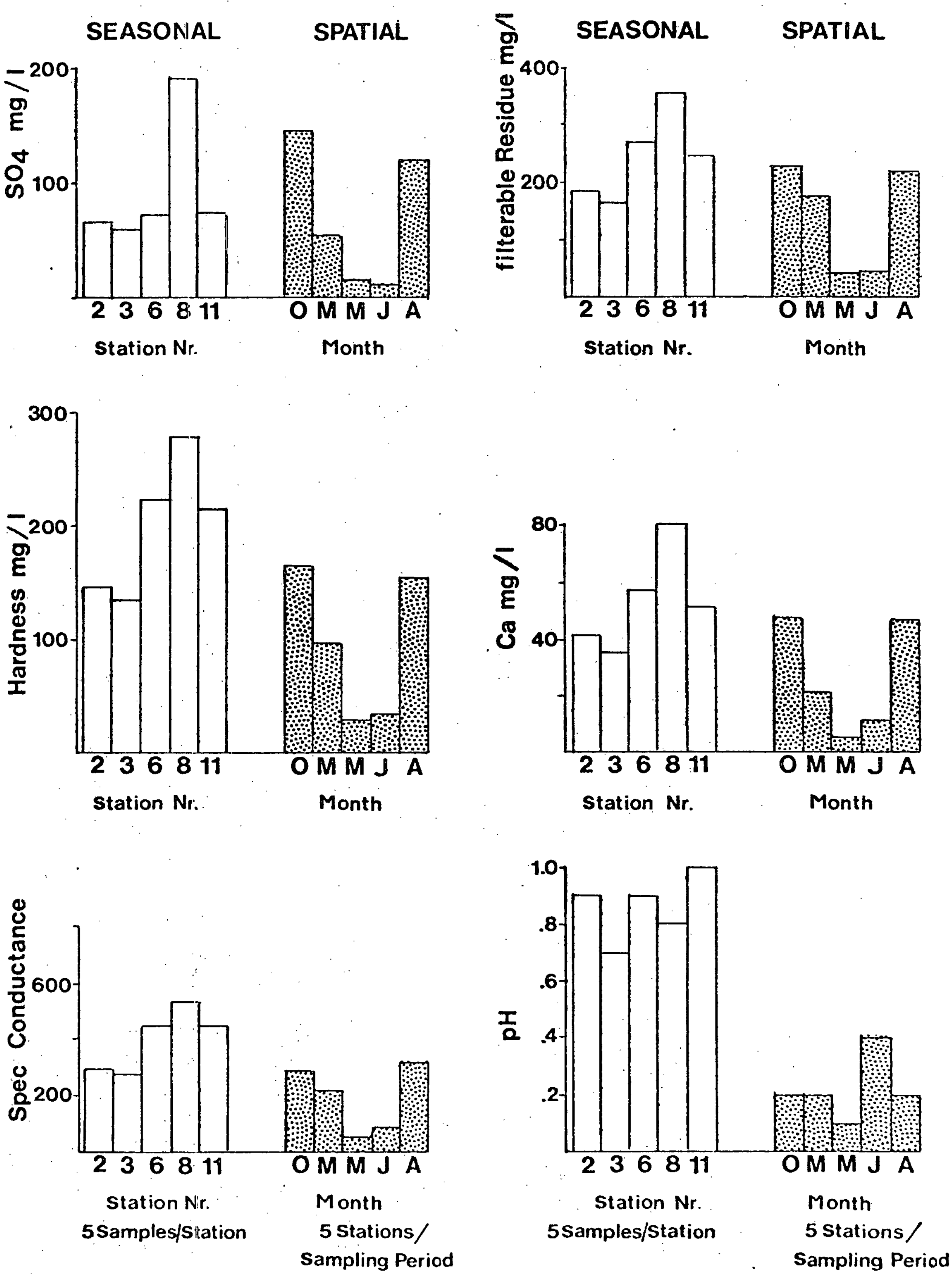


Figure 27. Comparison Between Seasonal and Spatial Variability.

OGILVIE RIVER (Expressed as Difference Between Maximum–Minimum Values)

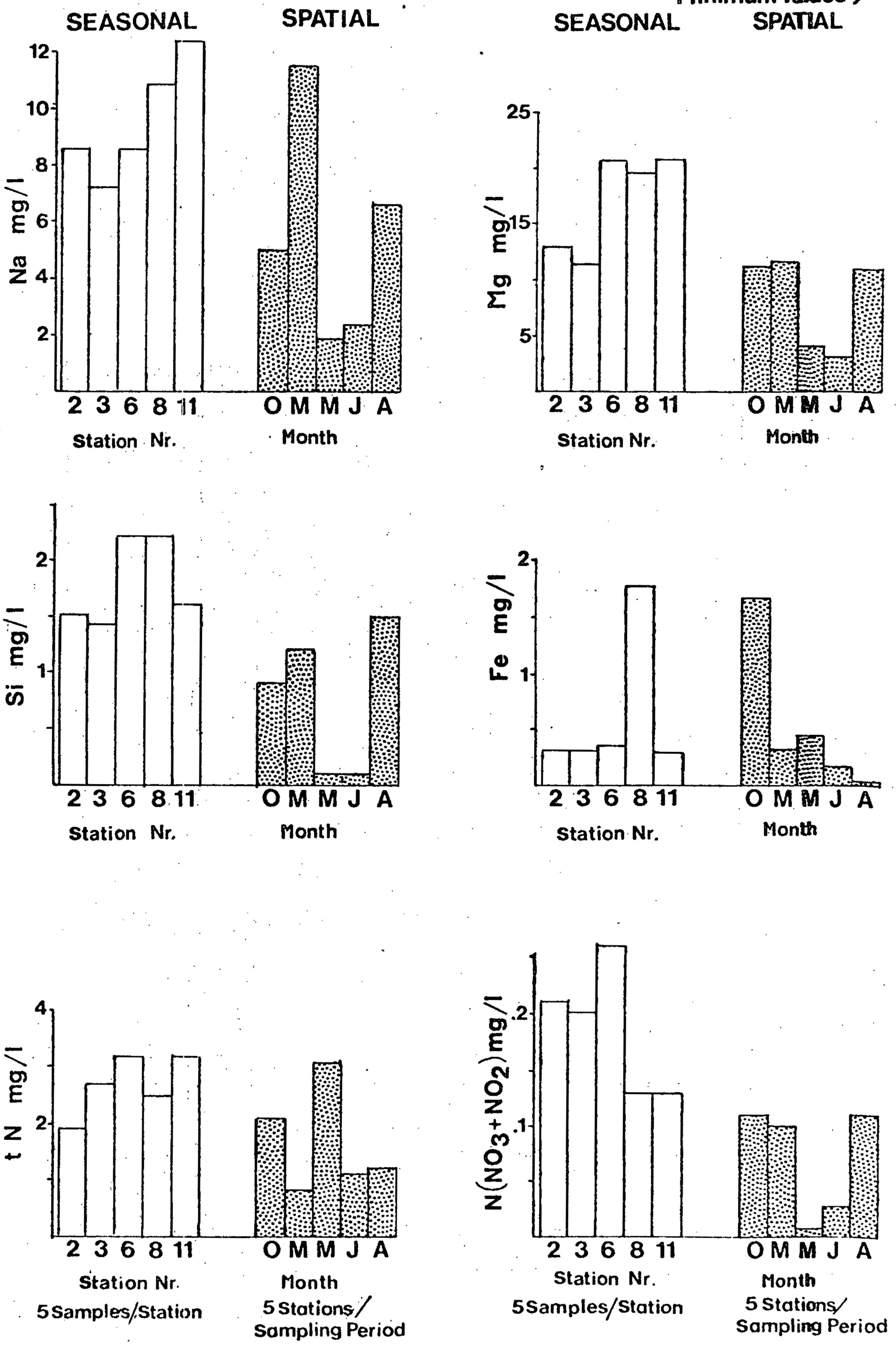


Table 7. Results of Significance Test Comparing Spatial with Seasonal Variability (based on Mann-Whitney U-Test at α = 0.05)

Water Quality Parameters	Spatial Variability Significantly higher than Seasonal Variability (α = 0.05)	Spatial Variability Significantly lower than Seasonal Variability (α = 0.05)	No Significant Difference between Spatial and Seasonal Variability (α = 0.05)
pH	yes (Swift)	yes (Ogilvie)	
specific conductance	yes (Swift)	yes (Ogilvie)	
filterable residue	yes (Swift)		Ogilvie
hardness	yes (Swift)		Ogilvie
Ca	yes (Swift		Ogilvie
Mg		yes (Ogilvie)	Swift
Na			Swift
SO_4	yes (Swift)		Ogilvie
Si		yes (Ogilvie)	Swift
Fe			Ogilvie & Swift
$N(NO_3+NO_2)$		yes (Ogilvie)	Swift
tN	yes (Swift)		Ogilvie

Table 7 shows that the two basins produce somewhat contradictory data for a number of parameters. Seasonal variation is indeed greater in the Ogilvie while spatial variability is more important in the Swift River. This can partially be explained by the fact that the groundwater influence in the Ogilvie is substantially greater during the winter. During the spring and summer a rapid surface run-off is dominant in the Ogilvie because the basin is sparcely vegetated and permafrost conditions exist very near the surface. This tends to reduce the contact time of incoming water with the ground and this increased surface flow generally exhibits substantially lower mineral concentrations than those found in groundwater.

Other trends extracted from Figures 24 to 27 indicate that the seasonal variability for Na, Mg, SO_4, Si, tN, and NO_3 + NO_2 increased with the advance of winter in the Swift River basin. Significantly reduced variations were noted for the Ogilvie during spring break-up and high water conditions. In each case these two observations were dominant only in one of the two watersheds examined, thus suggesting that the two basins are subject to different pressures and regime factors.

3) Ice conditions as a source of variability

During winter sampling in the Ogilvie water flowing between ice layers was found in station #10. The water was under considerable pressure and, once tapped, continued to flow to the surface throughout the 30-minute sampling period. Dissolved oxygen and water quality values were erratic to the extent that enormous differences were found between replicate analyses. The water flowing between ice layers produced significantly higher concentrations than water flowing below the ice. This can be seen in Figure 28 where the difference in specific conductance is contrasted. Similarly significantly higher values were obtained for alkalinity, hardness, Ca, Mg, K, Na, Silica, SO_4, etc.

It is assumed that the progressive freezing process was in part responsible for the high concentrations. Concentrations did decrease between the first analysis and those performed three to four weeks later suggesting that unstable conditions existed. Slight warming of samples during the transfer from the field to the laboratory could have caused various degrees of precipitation and possible redissolution which would be responsible for the erratic analytical results.

From these observations it is evident that water quality can be significantly altered by different ice conditions. Caution is therefore necessary when sampling water under such conditions since concentrations can be affected considerably by this process.

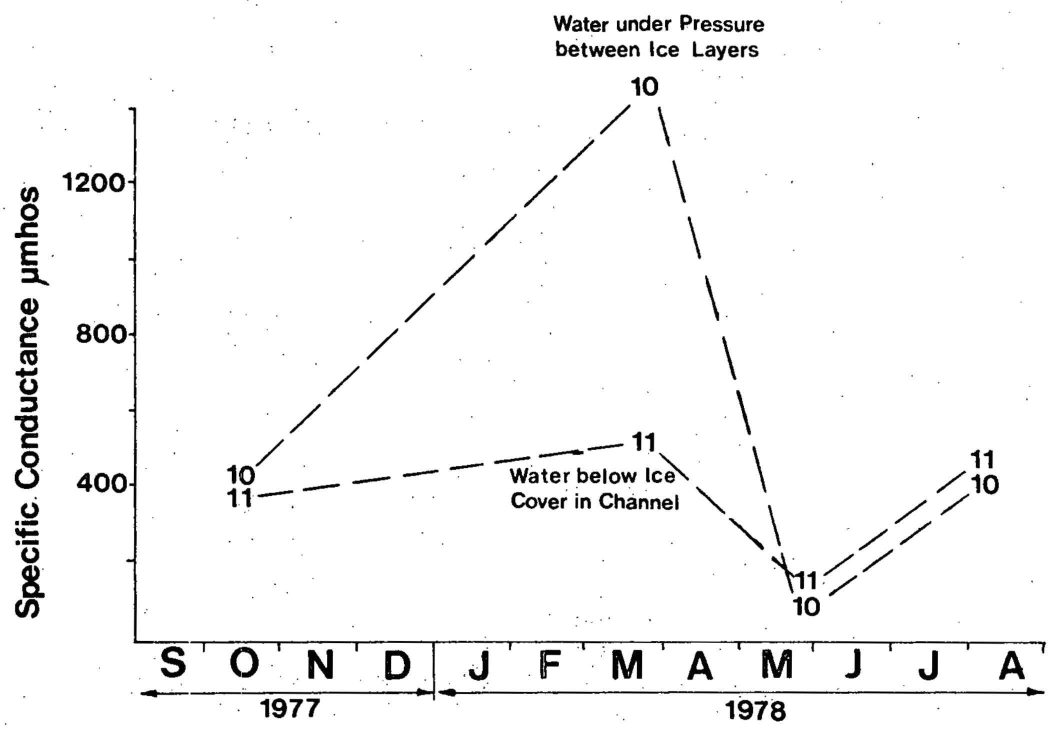


Figure 28. Differences in concentrations between water from ice layer and water in channel below ice cover.

4) Summary of sources and magnitude of variability

Based on several tests, cross-sectional and short-term variabilities were found to be very small and the use of single grab samples as a measure of river conditions in each station could be justified.

Cross-sectional and short-term variabilities were significantly smaller than either spatial or seasonal variability. A comparison between the latter two showed that seasonal variations were greater in the Ogilvie, while spatial variations were more significant in the Swift River basin. The differences in the hydrological regime and the conditions in the drainage basin were thought to be responsible for these contrasting results. Finally, water between ice layers showed considerably higher ion concentrations than water in the stream bed under ice cover. The former was under pressure and probably influenced by the continuous process of ice formation which could in part be responsible for the increase in concentrations. Care should therefore be taken when sampling water under such conditions.

D. General Water Quality Conditions in the Two Watersheds

1) Comparison between the Swift and Ogilvie River Basins

The Swift River watershed is underlain primarily by igneous and metamorphic rocks which are responsible for producing soft water with low Ca, and Mg values, and high silica concentrations. In contrast, the Ogilvie basin is dominated by limestone and shale which produce hard water with high concentrations of HCO_3, Ca, and Mg, and low values for Silica. These differences are affirmed in Figure 29 which compares the mean hardness and mean silica concentrations over the one-year sampling period. Such contrasting values were also found for other parameters such as SO_4, Mg, Na and Cl which showed differences of up to one order of magnitude.

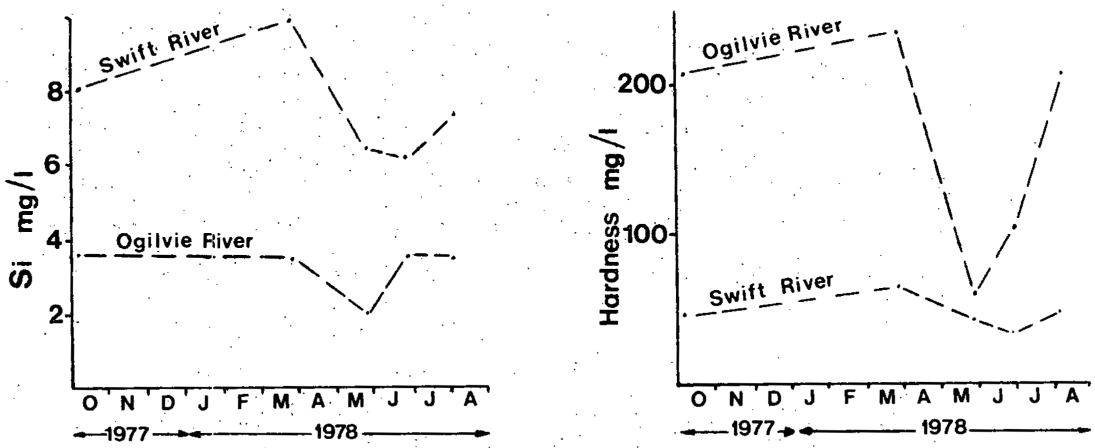


Figure 29. Comparison of mean water quality concentrations in the two study basins.

Processes which influence and control water quality conditions seem to differ significantly between the two basins and a more detailed examination of each watershed is required.

2) Swift River - Non-point sources

Most stations in the Swift River showed the same overall seasonal trends (Figures 11 to 23) despite considerable differences in base concentrations. Stations #14 and #8 for example showed consistently low values for specific conductance and hardness, low concentrations of Ca, Mg, and SO_4, and consistently high concentrations of silica. In contrast stations #5 and #3 showed high specific conductance and hardness values and low silica concentrations.

All four of these stations are located on major tributaries to the Swift River and on drainage areas which differ slightly from one another in size and surface composition. To determine the possible causes for these chemical differences an examination of the bedrock geology was made and mineralogical differences were compared with water quality observations. For this purpose a multiparameter approach was chosen because the use of a single parameter was thought to be insufficient for a geological analysis since each rock type is made up of a number of different base elements.

A hierarchical clustering procedure originally described by Ward (1963) was used, and the degree of similarity in overall chemistry was determined between all stations in the basin. Ten parameters (specific conductance, alkalinity, hardness, Ca, Mg, K, Na, Si, SO_4, and pH) were chosen for this process and the degree of similarity was measured as the mean distance between parameters once plotted in n-dimensional space. The UBC-C-Group computer programme (Patterson and Whitaker 1973) was used and the results of this analysis are presented in Figure 30. For each sampling period all 11 water quality stations were classified in terms of the ten chosen chemical parameters and those stations which group together at an early stage in the hierarchical classification were considered most similar.

From Figure 30 it is quickly evident that all major stations on the Swift River (6, 7, 9, 10, 11, 15) and the Smart River tributary (station 2) tend to form a cluster for much of the year, while the tributary stations

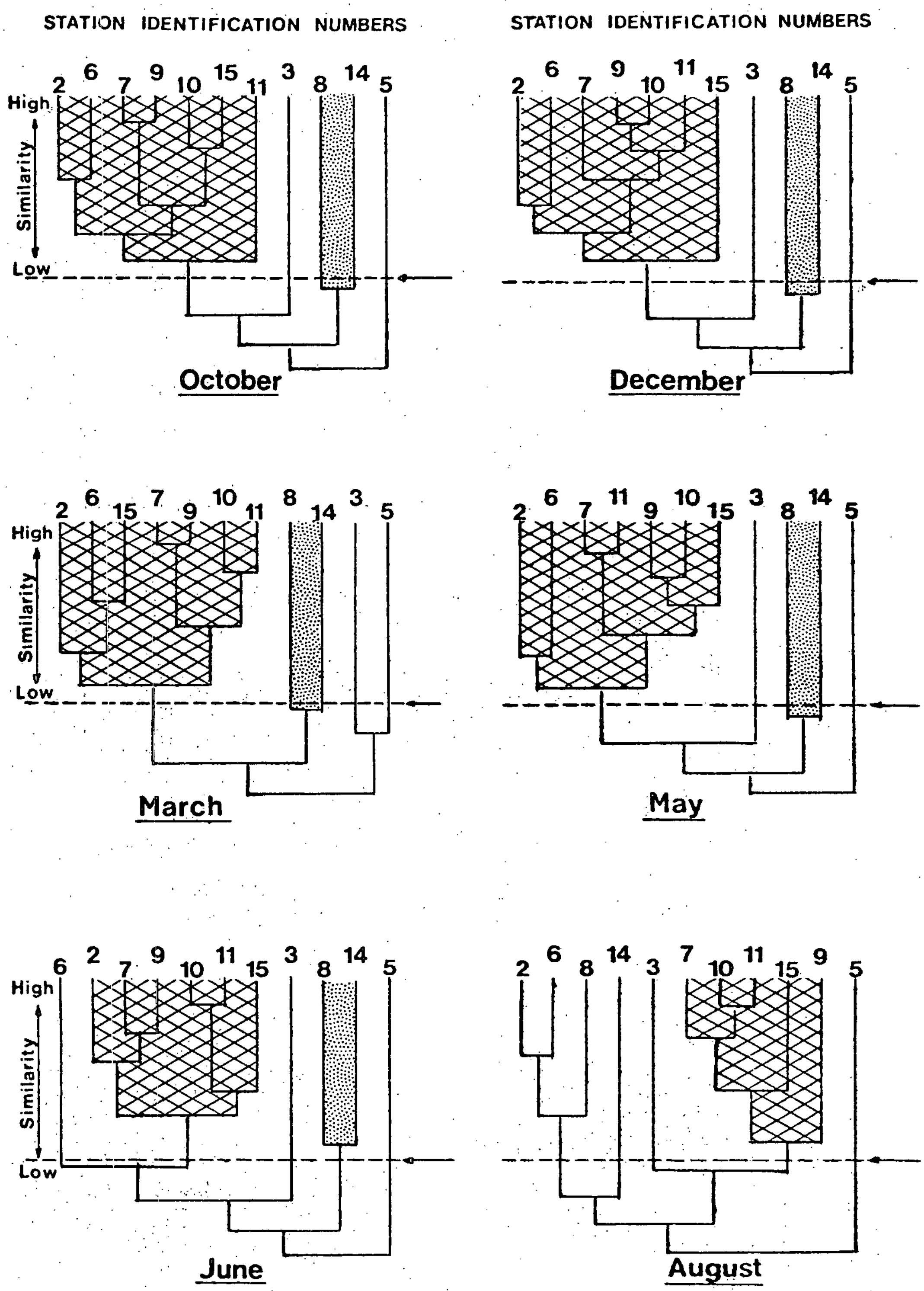


Figure 30. Degree of similarity between water quality stations in the Swift River basin (based on 10 chemical parameters).

(3, 5, 8 and 14) formed consistently separate grouping patterns. A low degree of similarity was found between stations 14 and 8 while stations 3 and 5 were only marginally related. This pattern is consistent for five of the six sampling periods examined suggesting that the chemical conditions are different and that the causative factor is permanent. Differences in geology is the likely cause of this pattern, which can be verified from the bedrock and surficial geology maps in Figures 31 and 32.

The Screw Creek (station 5) drainage basin contains limestone and dolomite bedrock in its headwaters. This is responsible for producing high specific conductance, hardness, Ca, and Mg values and low silica concentrations. The headwaters of Logjam Creek are close to these bedrock deposits and it is likely that material from this source was transported downwards during glaciation. Such till deposits as those occurring in the Logjam Basin (Figure 32) are likely to influence water chemistry. Since the material is reworked its influence is of course less intensive, resulting in values which are somewhat lower than those found in Screw Creek where direct bedrock drainage is dominant.

Seagull Creek (station 14), which showed high silica concentrations and low hardness, Ca, and Mg values, has its drainage almost entirely in igneous rocks of the granodiorite variety. This is responsible for the production of soft water with low alkalinity, Ca, Mg and pH values. The same effect but slightly less pronounced was found in the neighboring drainage (Partridge Creek, station 8). Here the reason is that a much smaller portion of the drainage is in granodiorite while the lower section of the watershed is influenced by metamorphic rocks which have a slightly modifying effect.

The above mentioned tributaries are relatively small in size and their overall influence on the Swift River water quality is localized. This is shown in Figure 34 where changes in water quality in the downstream direction of the Swift River are plotted.

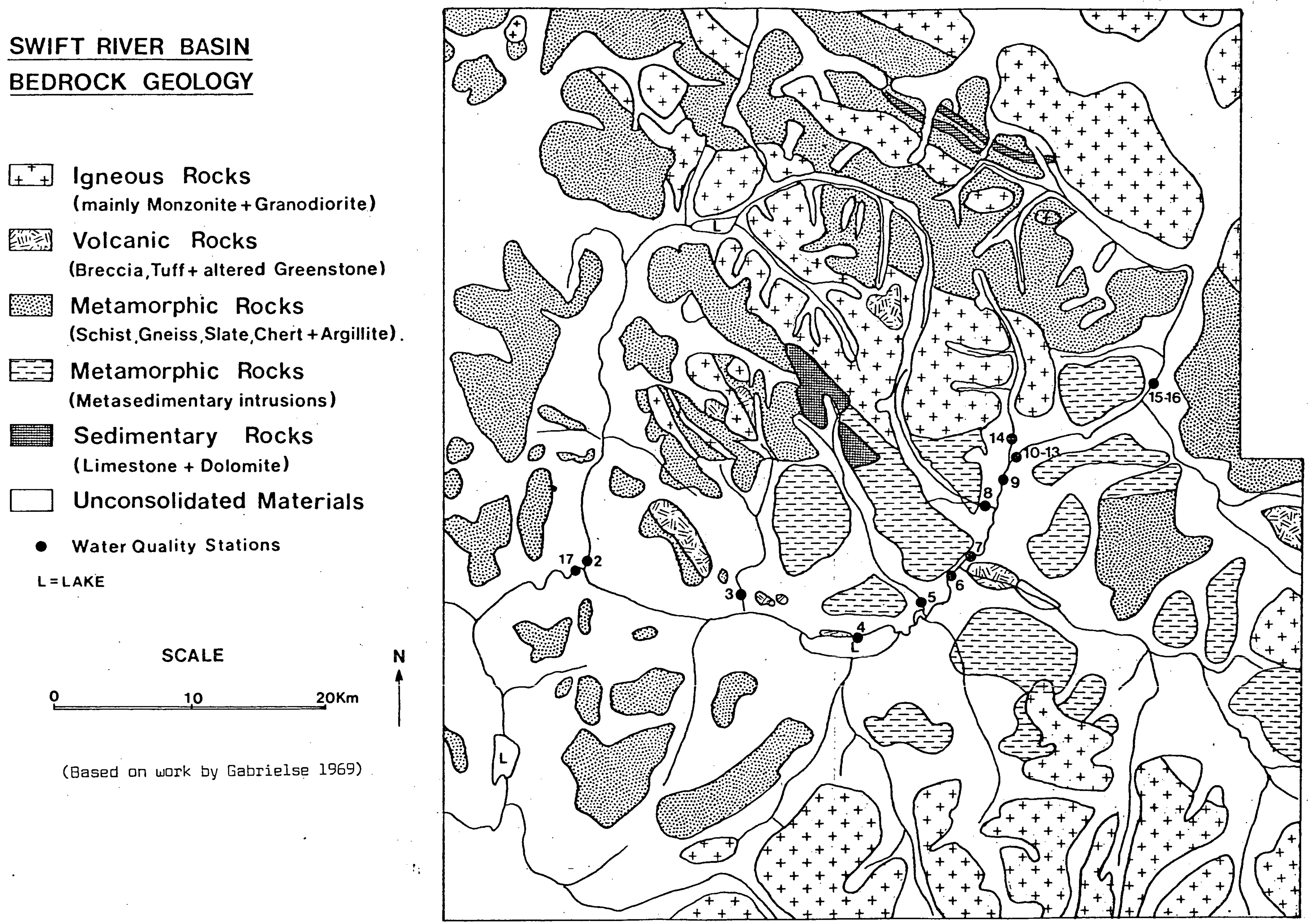

SWIFT RIVER BASIN
BEDROCK GEOLOGY
Igneous Rocks
(mainly Monzonite + Granodiorite)
Volcanic Rocks
(Breccia, Tuff + altered Greenstone)
Metamorphic Rocks
(Schist, Gneiss, Slate, Chert + Argillite).
Metamorphic Rocks
(Metasedimentary intrusions)
Sedimentary Rocks
(Limestone + Dolomite)
Unconsolidated Materials
Water Quality Stations
L = LAKE
SCALE
0
10
20Km
N
(Based on work by Gabrielse 1969)
L
17
2
3
4
5
6
7
8
9
10-13
14
15-16

Figure 31. Swift River-Basin Bedrock Geology

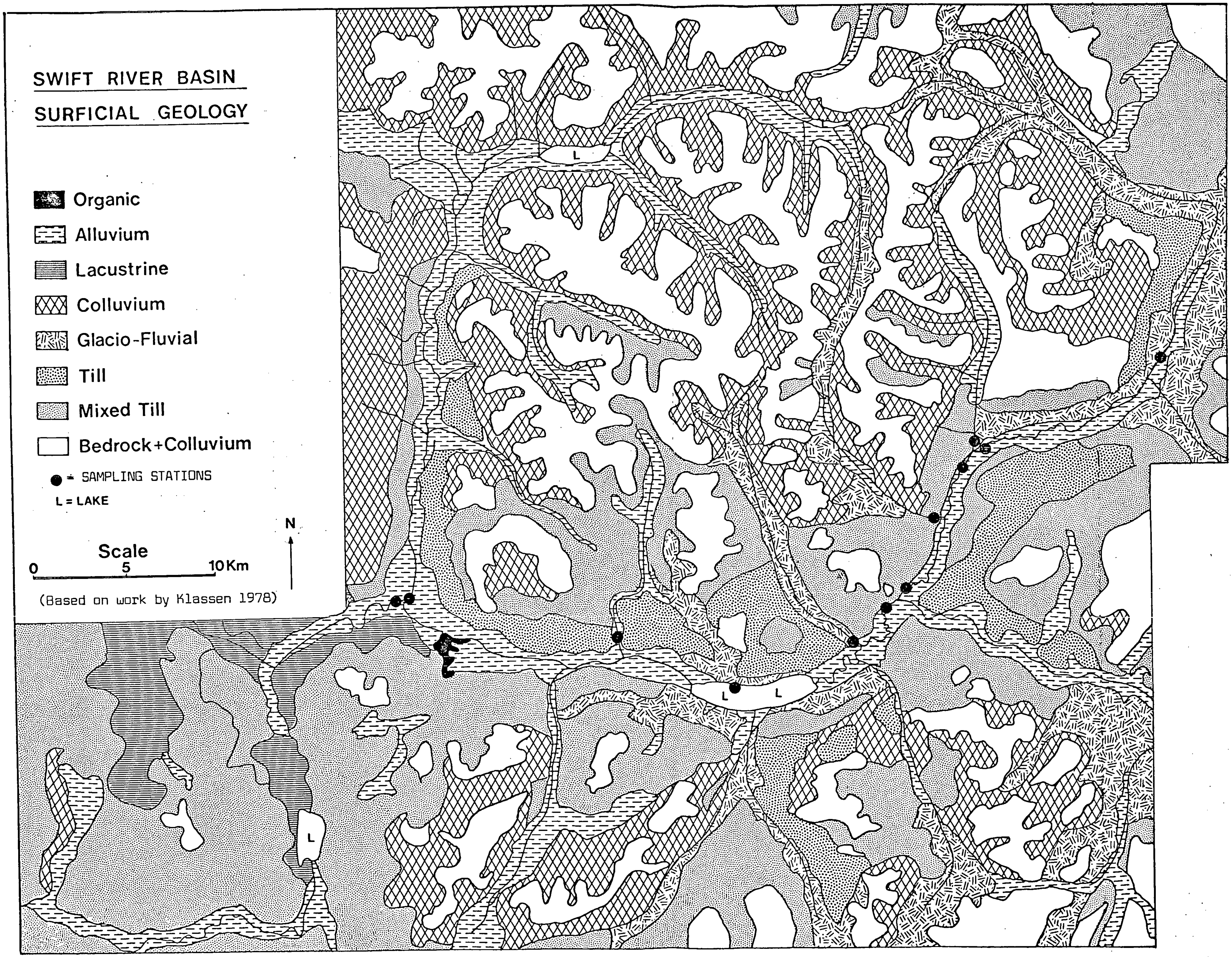

SWIFT RIVER BASIN
SURFICIAL GEOLOGY
Organic
Alluvium
Lacustrine
Colluvium
Glacio-Fluvial
Till
Mixed Till
Bedrock+Colluvium
● = SAMPLING STATIONS
L = LAKE
N
Scale
0 5 10Km
(Based on work by Klassen 1978)
L

Figure 32. Swift River Basin Surficial Geology

For orientation purposes the sequence of stations and location of major tributaries are given in Figure 33 in schematized form.

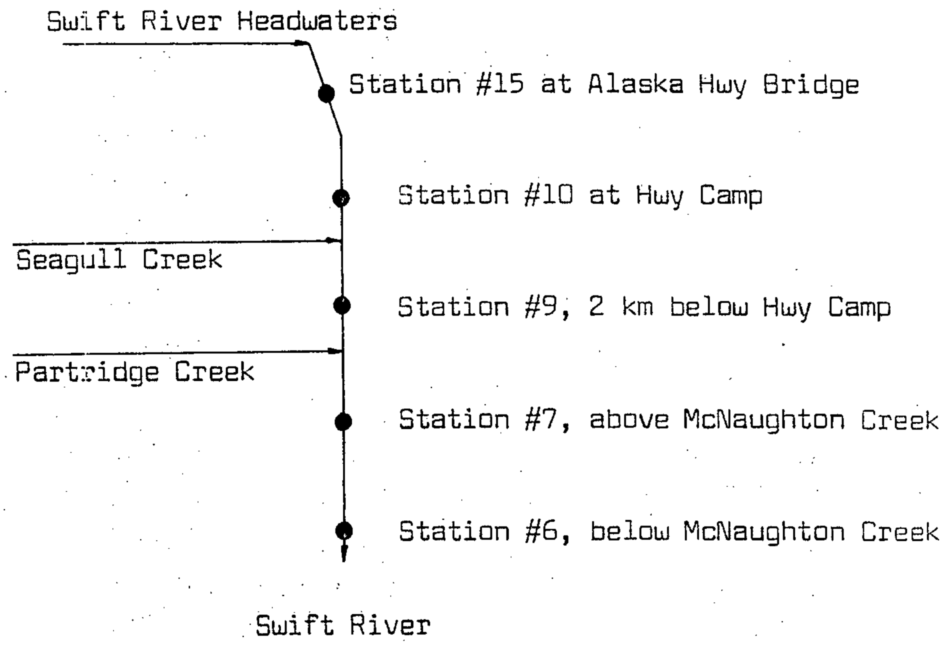


Figure 33. Schematic diagram of Swift River stations in downstream direction.

Changes in concentrations from station #15 to #6 are shown in Figure 34 which also shows trends for specific conductance, hardness, silica, and SO_4 concentrations. It is evident that some small changes occur as a result of differential tributary contribution. For example, Seagull Creek with its soft water is responsible for a slight decrease in hardness and specific conductance in the Swift River between stations #10 and #9. The changes are reasonably consistent throughout the year implying that a uniform flow regime exists for most water supply sources within the basin. One possible exception is McNaughton Creek which causes a change in SO_4 concentrations in the Swift at station #6. The changes are somewhat erratic and because McNaughton Creek was inaccessible during this study no definite interpretation could be made.

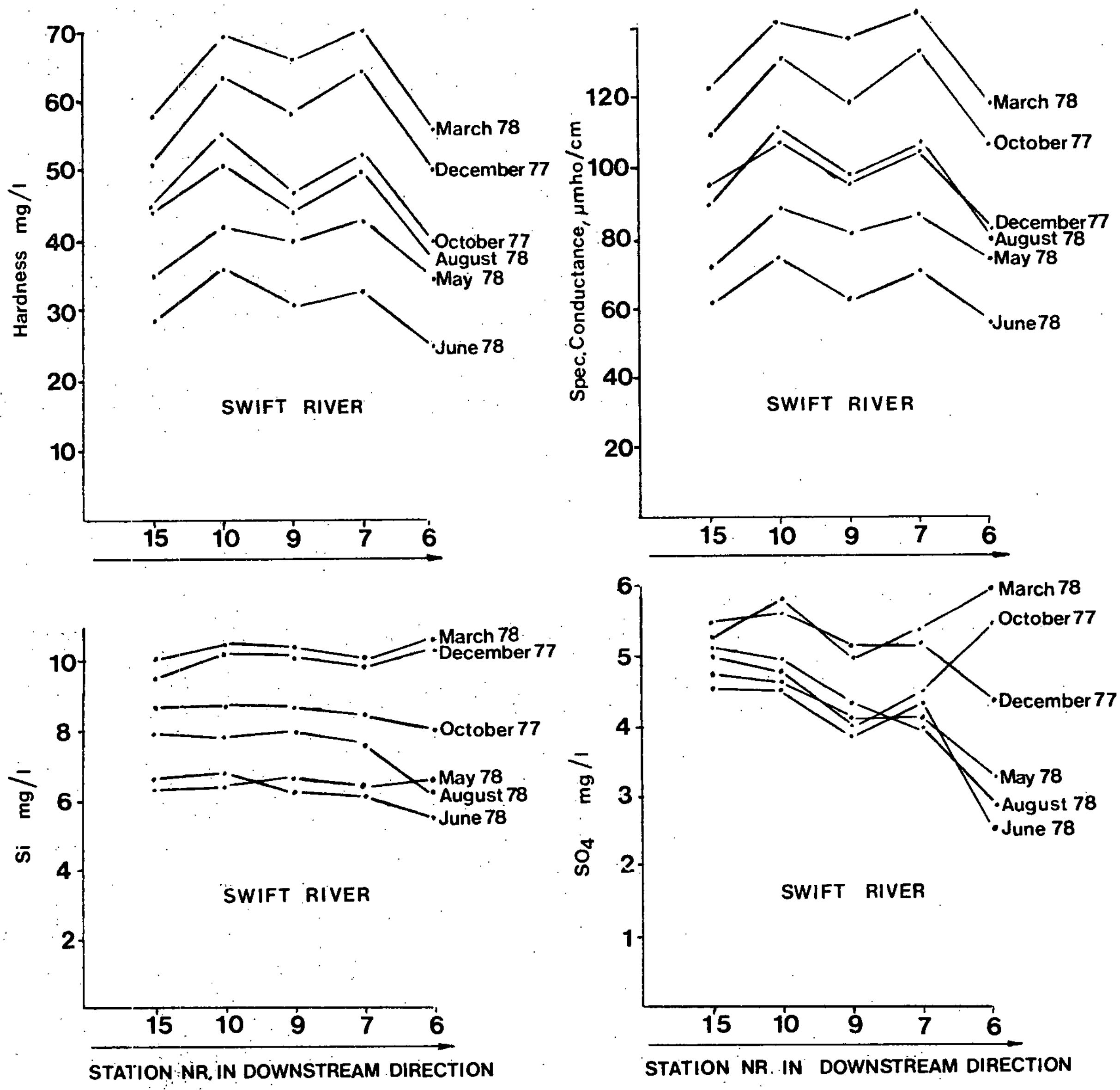


Figure 34. Changes in water quality concentrations in downstream direction.

The uniformity of the flow regime in the basin can partly be explained by the fact that a series of lakes exists in the headwaters as well as in the lower sections of the drainage basin which tends to regulate the flow regime.

In summary it was demonstrated that water quality in the Swift River basin is controlled by non-point sources and that local differences in water quality concentrations can readily be attributed to differences in the drainage basin geology. Tributaries have a localized effect on the water quality of the main stream but the influence is consistent throughout the year implying that the basin is under a relatively uniform flow regime.

3) Ogilvie River - Point and Non-Point Sources

The water quality conditions in the Ogilvie River are influenced to a large degree by dissimilar groundwater contributions along the entire stream bed. This subject is of particular interest to pipeline construction activities and will be treated separately in the next section of this report. The present discussion is limited to a general review of processes and provides background information on water quality conditions in the basin.

Limestone and shale deposits are dominant in the watershed and are responsible for the hard water and high salt concentrations found in the area. The water quality is however far from uniform as can readily be seen in Figures 35 and 36. The information presented in these figures was collected during a special survey conducted on June 27-28, in which 33 samples were taken during high water conditions in a number of tributaries and the main section of the river. The samples were collected over a 36-hour period so as to partially avoid short term changes in concentrations resulting from fluctuations in stream flow. Unusually high precipitation persisted over a five-day period prior to and during the sampling. This not only produced considerable run-off in every creek of the watershed, but also accentuated differences in water quality. As noted previously little vegetation cover exists in the watershed and permafrost conditions were found within 10-20 cm from the surface at that time of the year. These two factors inhibit infiltration and water retention of the precipitation and as a result direct surface run-off is increased. The contact time between water and the ground is therefore shortened thus producing relatively soft water. This was most evident on small tributaries where specific conductance values of < 130 mhos were frequently found despite the fact that the underlying geology of limestone and shale provided an ample supply of salts. Water with high specific conductance is therefore an indicator of groundwater contributions of mineral release from point sources, both of which are partially interdependent.

It should be noted that these spatial differences do not remain constant throughout the year particularly since many tributaries are without water most of the summer. In addition proportional contributions of snow melt, groundwater flow, and surface run-off from rainfall change radically from the time of ice break-up to winter freeze-up. It is therefore not surprising that slightly different pH conditions were observed by Goodfellow et al (1976) and Jonasson and Goodfellow (1976) in a GSC Reconnaissance Geochemical survey in Engineer Creek (Figure 37).

From Figures 35 and 36 it is clear that a number of unusual chemical conditions exist in Engineer Creek and these will be discussed in detail below.

(a) Sulphur springs (station 13)

Extremely high specific conductance values were obtained from a series of springs located in Engineer Creek (Dempster Highway Mile 107). These springs were observed to flow on a year round basis and showed small variations in water temperature (+4° to +8°C) and water quality. As can be seen from Plate 14 a white and yellow precipitate, thought to be calcium sulphate and sulphur, formed immediately upon surface contact. The observed smell of H_2S would suggest that sulphur is oxidized to sulphate and in the process H_2S gas is released. Evidence that bacteria participate in this oxidation process was observed but this needs further verification. It was also noted that the precipitate is more yellow during the winter and more white during the summer

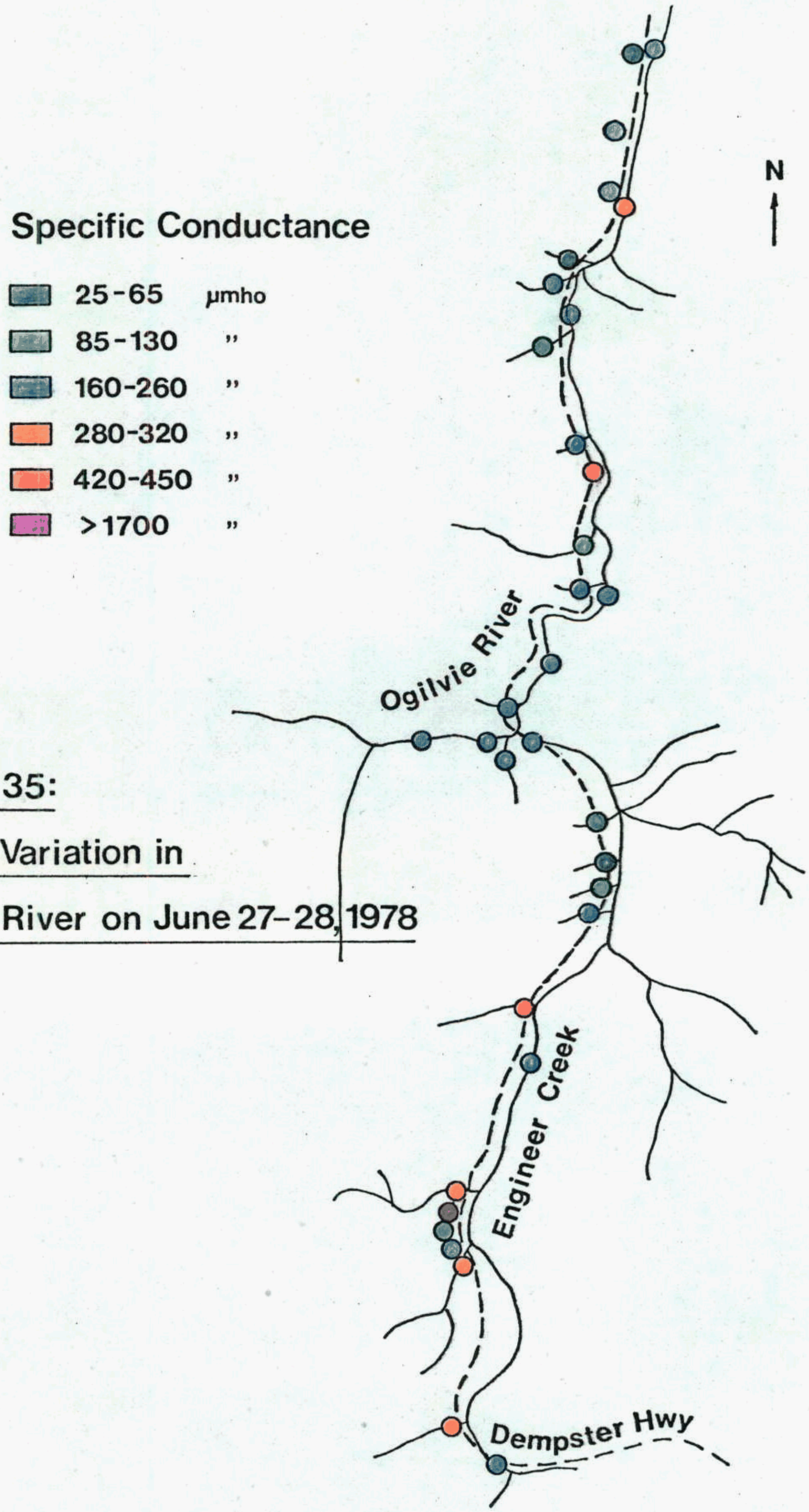


Figure 35:

Spatial Variation in

Ogilvie River on June 27-28, 1978

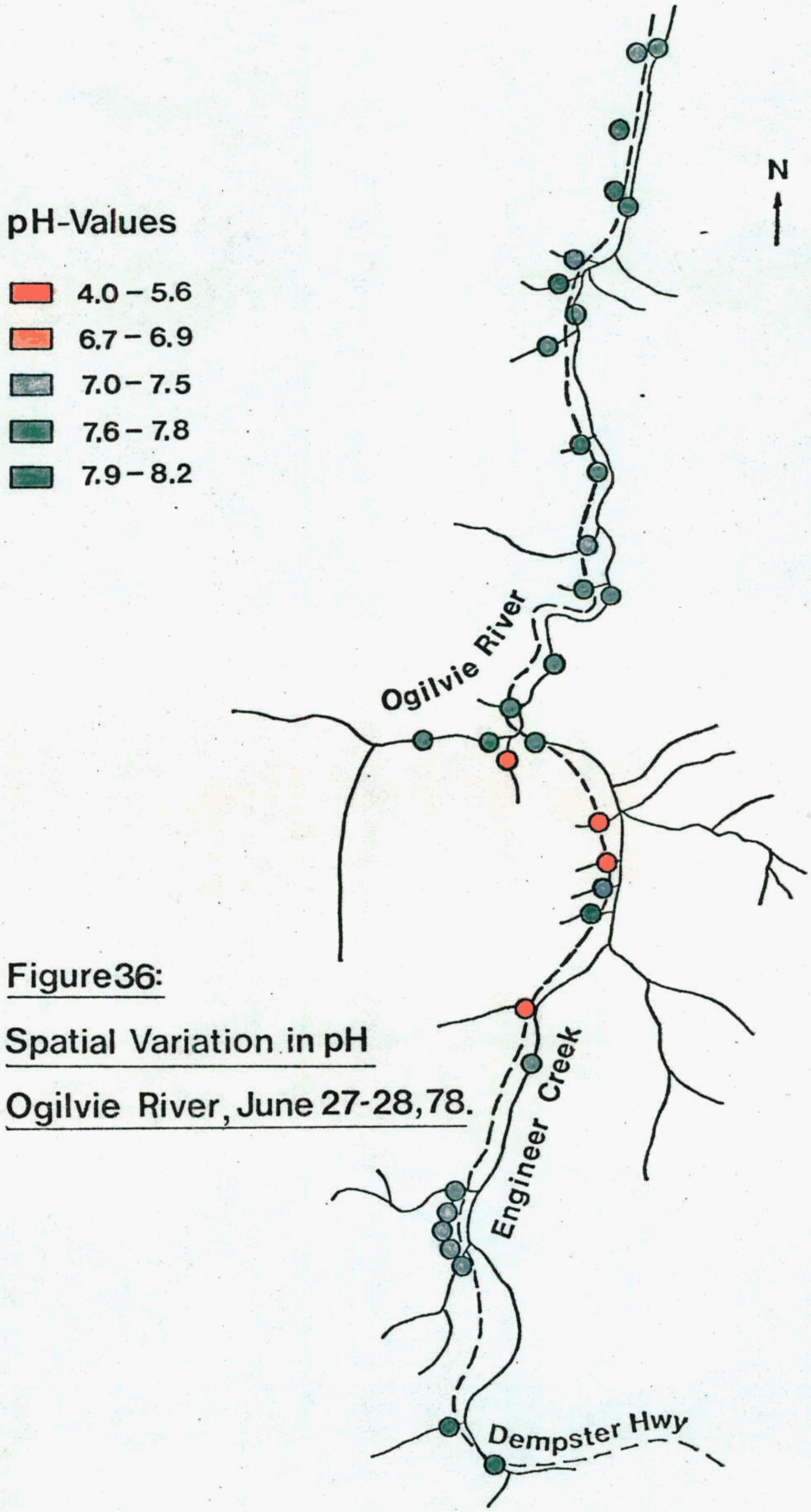
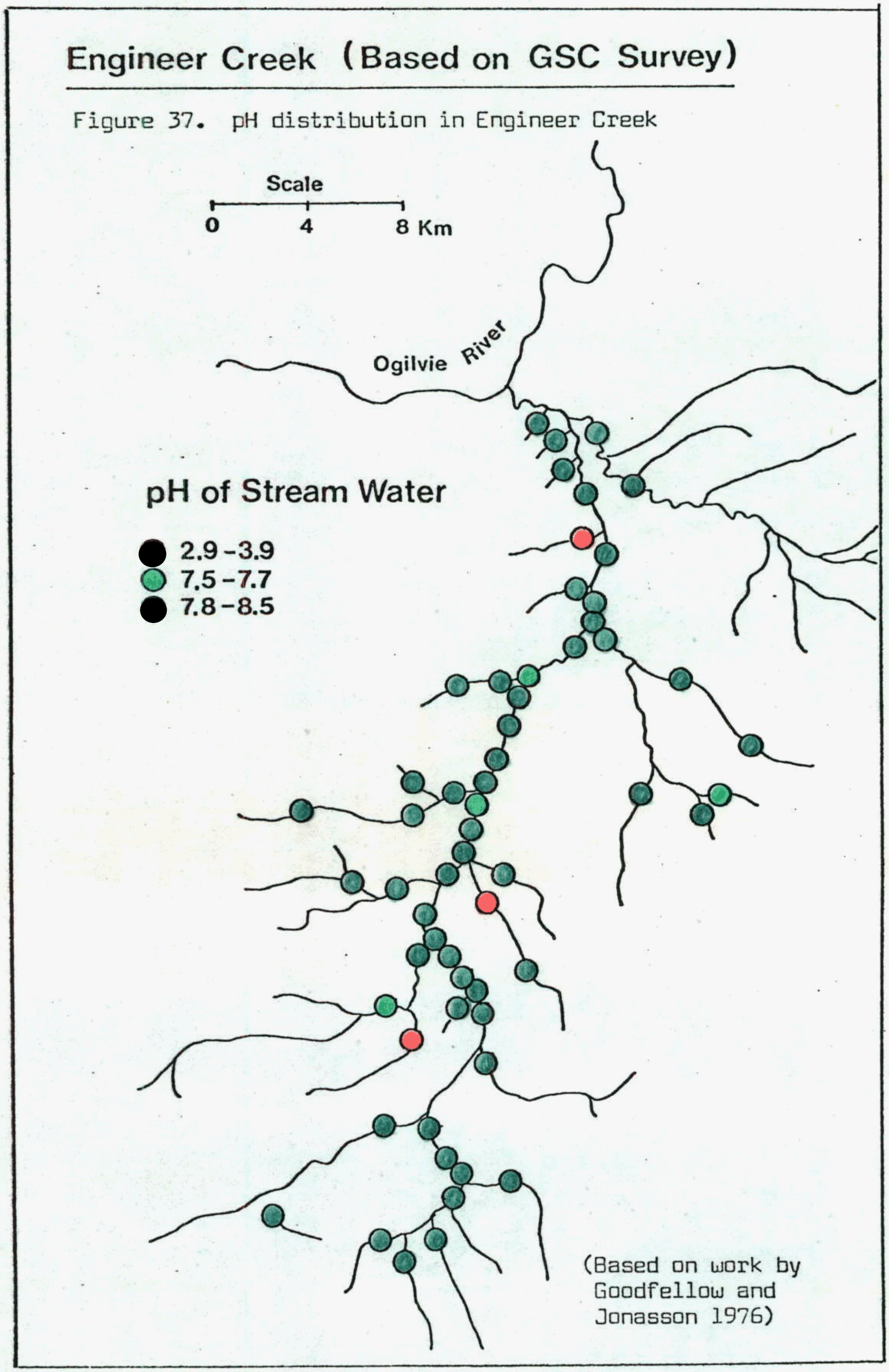


Figure36:

Spatial Variation in pH

Ogilvie River, June 27-28,78.


Engineer Creek (Based on GSC Survey)
Figure 37. pH distribution in Engineer Creek
Scale
0
4
8 Km
Ogilvie River
pH of Stream Water
2.9-3.9
7.5-7.7
7.8-8.5
(Based on work by Goodfellow and Jonasson 1976)

(Plate 14) suggesting that the oxidation process is more dominant during the summer. This is of course only a hypothesis and a detailed analysis is required to fully understand these processes.

Plate 14. Sulphur and sulphate exposed at Engineer Creek Springs (March versus June)

Other factors can contribute to the formation of a precipitate: If the geological formation has a large salt supply the groundwater can then become super-saturated and, once it is exposed to the surface and the pressure is released, solubility decreases and precipitation occurs. It is likely that both the difference in solubility resulting from pressure release, and the oxidation process contribute to the formation of the deposit.

As can be seen from Plate 15 the main stream is iron stained, a condition which results from the formation of iron carbonate in the alkaline-carbonitic environment. Iron, in the form of pyrite, is oxidized and acid water is produced in the process. This is responsible for the dissolution of iron hydroxide, sulphate and oxides. Because of the abundance of limestone, water is generally alkaline (pH 8.2), the acid is readily neutralized and siderite ($FeCO_3$) is precipitated in the process. The stability of siderite is most pronounced under high carbonate conditions and pH levels of 7.8-10.8 (Garrels and Christ 1965), both factors which are dominant in Engineer Creek. During the summer when water levels drop and siderite is exposed to oxidation, limonite can also be produced. When the high carbonate content streamwater (pH 8.2) interacts with the high sulphate spring water (pH 7.6) a new white precipitate is formed which is visible in Plate 16. This precipitate, most probably $CaSO_4$, causes considerable turbidity in the main stream at different times of the year and effects from this process were observed some 15 km downstream.

Plate 15. Iron precipitate in Engineer Creek

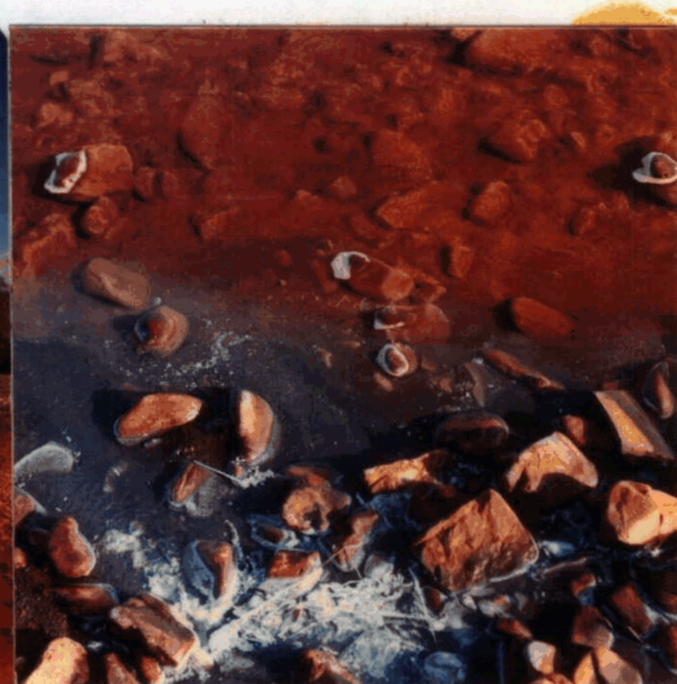


Plate 16. Contact between high iron stream water and high sulphur spring water

(b) Acid drainage

Acid drainage was observed on a small tributary below station #15 during both the June (pH 4.0) and August (pH 2.8) sampling periods. The tributary drains a series of black shale deposits which were identified as part of the Road River formation and which were found to be highly mineralized by Goodfellow et al (1976). The tributary drainage profoundly affects water quality in Engineer Creek as can readily be seen in Plates 17 and 18. The red colored highly acid drainage interacts with the alkaline stream water causing a white precipitate which forms a plume visible for several kilometers downstream (Plate 18). Water quality conditions were examined in the main stream above and below the contact zone as well as in the tributary during the August sampling period and the results of this analysis are presented in Figure 38.

The data indicate that concentrations and pH are drastically altered just below the tributary confluence but gradually return to those conditions found above the acid inflow. The white precipitate is thought to be $CaSO_4$, an observation which is partly confirmed by the fact that Ca values, in contrast to all other parameters, do not substantially increase below the acid inflow despite considerable input from the tributary. The most dramatic change was noted for iron which was subject to an increase by a factor of about three orders of magnitude. Again this increase was attributed to the substantially higher solubility rate of iron under acid conditions. Unfortunately flow rates could not be measured for an analysis of mass balance. Instead a small experiment was performed in which the source rock and its possible salt and metal contribution to the stream were examined.

Black shale deposits in the area were found to be highly folded and extensively fractured as a result of intensive physical weathering. The black shale consisted of a series of beds of highly variable thickness. The salt content in the shale formation is considerable and is more evident along cracks, bedding planes and fracture lines where salt crusts have formed probably as a result of evaporation and recrystalization (Plate 19).

Plate 17. Acid drainage in tributary (pH 2.8)

Plate 18. Acid drainage interaction with high alkaline stream water

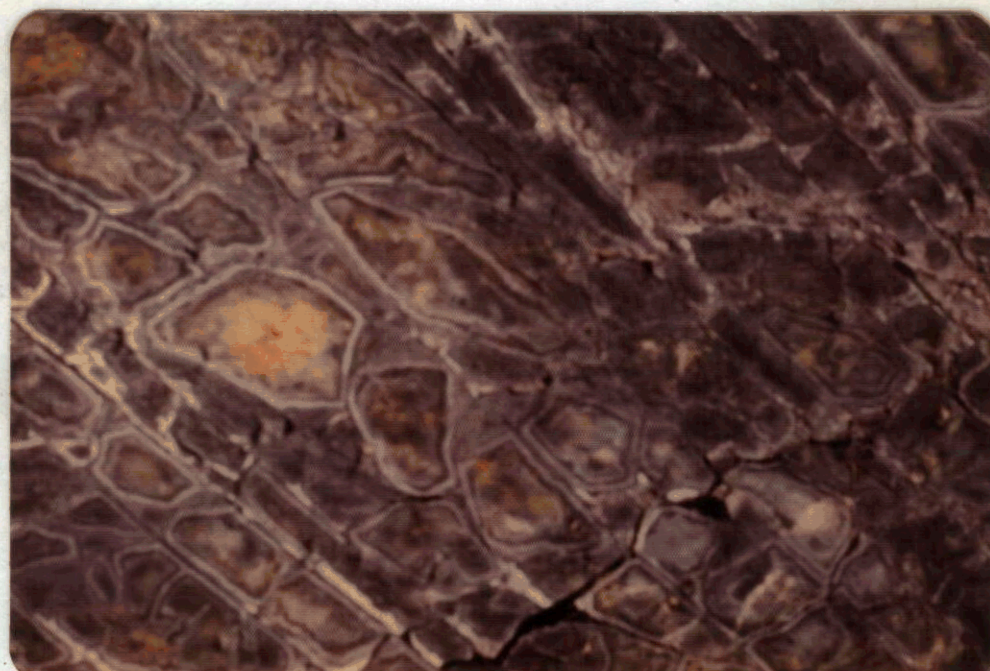
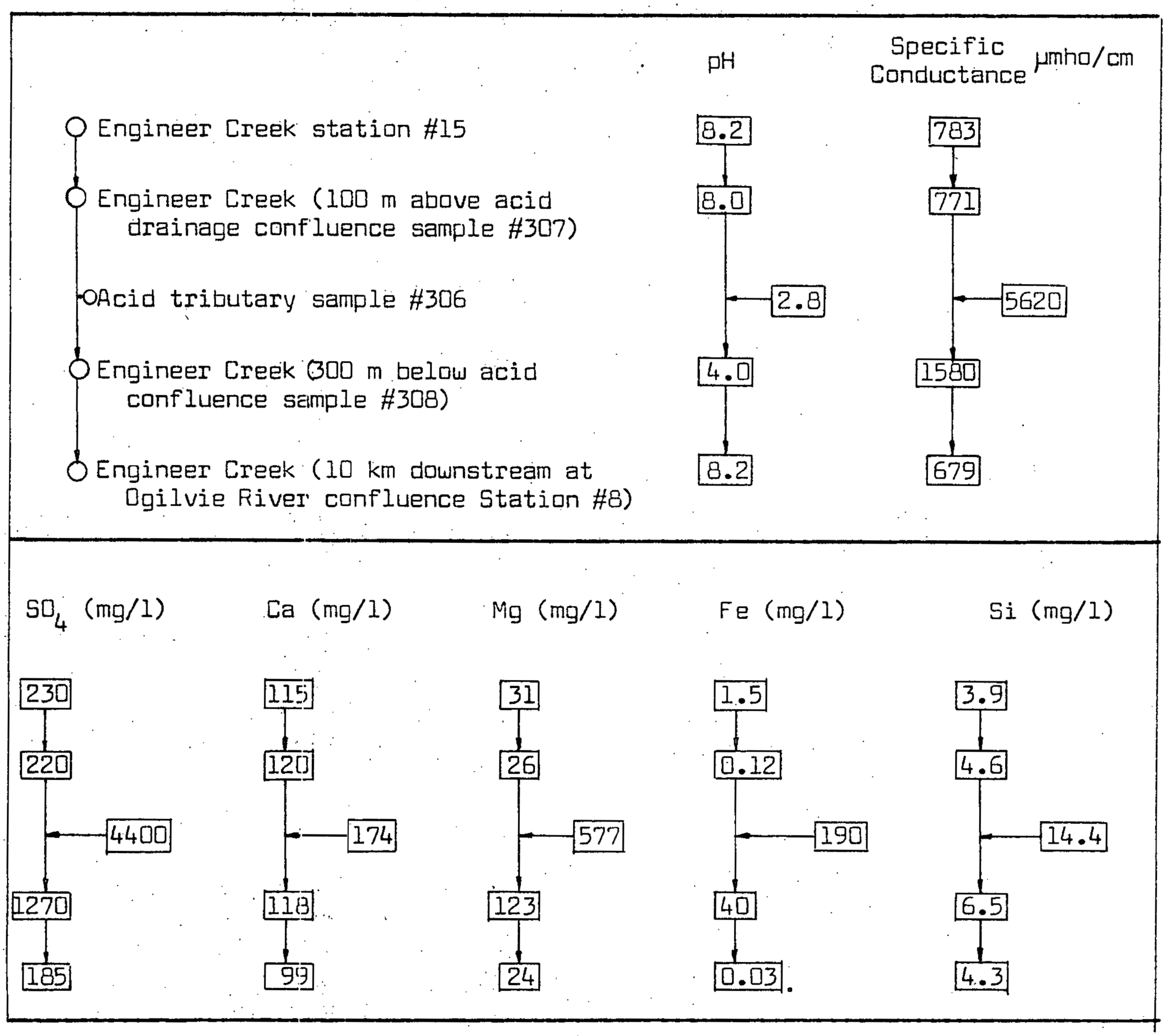


Plate 19. Salt crusts in black shale bedrock

Figure 38. Effect of acid drainage on water quality in Engineer Creek.



The salt crusts found in the bedrock, shown in Plate 19, were thought to be the source of the high nutrients, salt and metal values in the water of Engineer Creek. Gypsum ($CaSO_4$), Calcite ($CaCO_3$), Copper carbonates, such as Malachite and Azurite, elemental sulphur, and iron sulfides and oxides were positively identified in the salt matrix on the basis of appearance, color and crystalline structure.

Six shale samples with various types of salt deposits were collected and separate extractions were performed with distilled water and 0.1N HCl solutions. The rock fragments were extracted without initially crushing the rock so as to emphasize extractions of material present as surface coatings. The extractions were made over a 24-hour period and analyzed in the Water Quality Laboratory. The results compiled in Table 8 indicate that Ca, Mg and SO_4 were the most common components of the salts. When the water and acid extractions were compared it was found that concentrations drastically increased with acid extractions, particularly for such metals as Fe, Cu, Mn and Zn for which increases of between one and three orders of magnitude were observed. The difference in iron concentrations between the water and acid extraction was between two and three orders of magnitude thus closely resembling the natural conditions observed in the acid drainage situation described above.

Table 8. Results of Black Shale Rock Extractions

Parameters	Water Extraction mg/1/100 gr of shale	0.1N HCl Extraction mg/1/100 gr of shale	Minimum Differences Between Water and Acid Extraction
Cu	0.02 - 0.05	0.54 - 8.7	1 - 2 magnitudes
Fe	0.05 - 0.6	170 - 760	2 - 3 magnitudes
Pb	0.05 - 0.3	0.05 - 0.98	0 - 3 times
Mn	0.01 - 0.08	0.08 - 11.0	0 - 2 magnitudes
Zn	0.07 - 1.08	0.4 - 60	1 magnitude
Ca	55 - 1120	67 - 5800	0 - 5 times
Mg	0.2 - 108	1.4 - 290	2 - 7 times
Na	0.6 - 6.4	2.0 - 12.8	2 - 3 times
K	0.2 - 4.8	12.4 - 25.2	5 - 60 times
Si	0.2 - 7.4	5.5 - 530	1 - 2 magnitudes
Cl	0.4 - 1.4	extr. interfered with test	
SO_4	176 - 3350	468 - 9500	2 - 3 times
NO_3	0.04 - 0.51	extr. interfered with test	

These results strongly suggest that the black shale formations are a major source of salts, metals and nutrients and profoundly influence water quality conditions in the area. It should be mentioned that the geochemical survey conducted by the Geological Survey of Canada in 1975 and 1976 revealed that water analyzed from the same deposits produced high values for fluoride, uranium, chlorine, molybdenum, manganese, iron, zinc, sulphate and phosphorus. A number of these parameters were also analyzed in the present study; the seasonal distributions of the more important parameters are given in Figure 39.

The stream concentrations seem to be subject to the expected seasonal fluctuations while the spring water produced data which were relatively homogeneous. Unusually high phosphorus values were observed in the creek and are probably related to the presence of apatite in the shale formation, as suggested by Jonasson and Goodfellow (1976).

In summary it appears that the black shale formation in Engineer Creek is a substantial source of salts, nutrients and metals, which after a number of processes end up in the stream system at generally high concentration levels. Some of the more important processes include:

(1) Deposition of sulphur and $CaSO_4$ at a series of springs due to oxidation and CO_2 release.

(2) Precipitation of iron in the form of siderite as a result of contact with high carbonitic, high alkaline water. In the process a red stain is developed which is visible throughout a major portion of Engineer Creek.

(3) Acid water is produced through the oxidation process of pyrite and dissolves high quantities of Fe and SO_4. The sulphate precipitates in the form of $CaSO_4$ on contact with the main stream water, which is highly alkaline, and quickly neutralizes the acid.

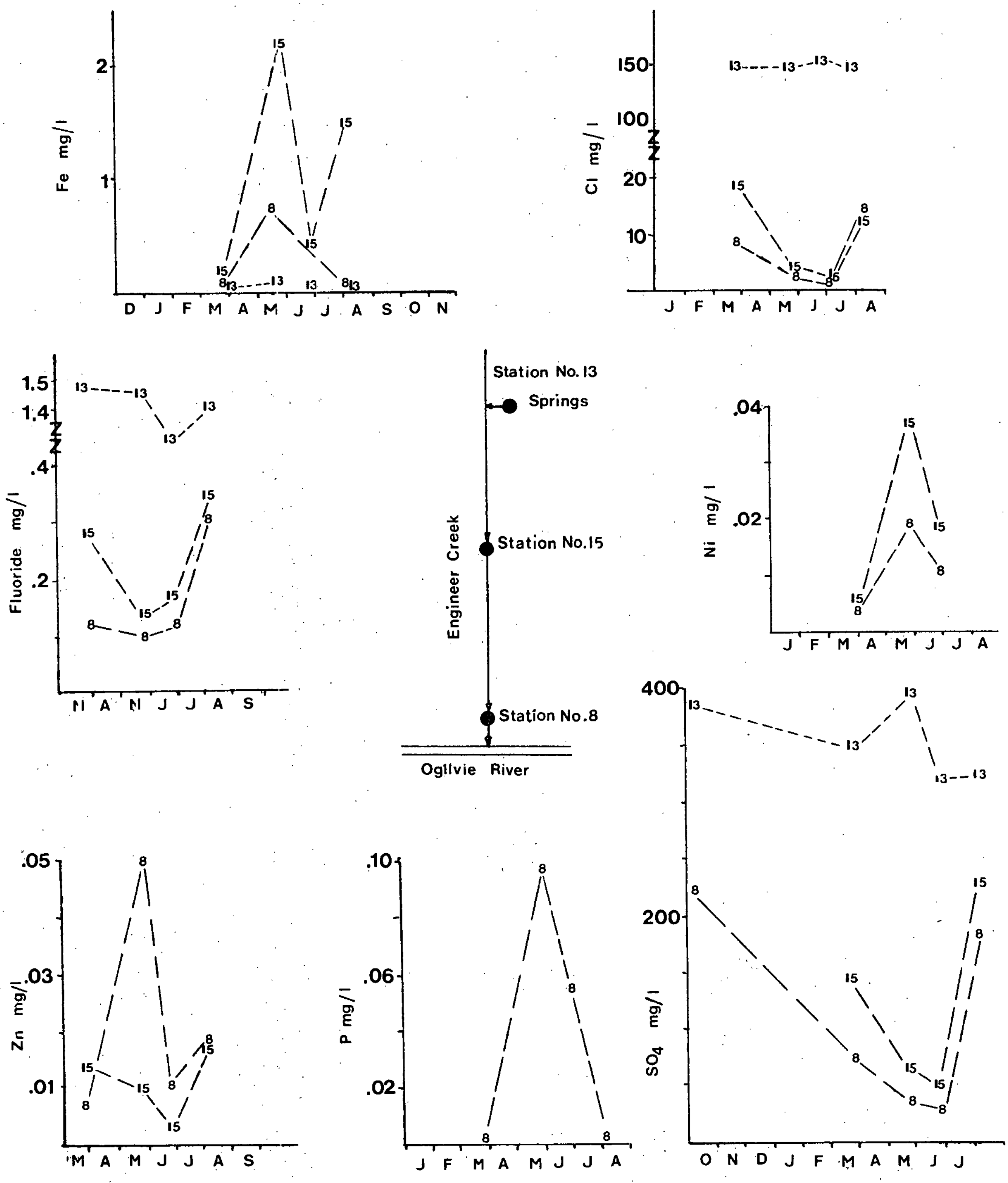


Figure 39. Variability and concentrations of selected parameters in Engineer Creek.

E. Groundwater Conditions

The importance of groundwater and the potential contributions it can make to the flow regime differ considerably between the Ogilvie and Swift Rivers. The water supply in the Swift River is mainly controlled by headwater springs, snowmelt, and summer precipitation. The flow is regulated by a series of high mountain lakes, and no evidence of groundwater seepage was observed in the downstream portion of the River. Possible aquifers are limited to quaternary deposits along the main channel and no icings were observed during the winter to suggest that substantial groundwater fluctuations occur in the middle section of the stream.

The Ogilvie River, in contrast, is greatly influenced by groundwater in numerous portions of the basin, and the proportional contribution of groundwater to the stream flow is substantial at specific times of the year. Groundwater substantially influences water quality and ice conditions, and to gain a better understanding of the processes involved a detailed discussion of the Ogilvie situation is provided below.

1) Geological Controls of Groundwater Flow

Unfortunately no basic geological survey data was available for the study area. The information provided below is therefore based on (1) field and air photo analysis, (2) published geological information on neighboring areas, and (3) information from general reconnaissance and regional surveys. This information is therefore incomplete and will be modified as soon as more detailed geological information becomes available. Nevertheless, important winter observations were made which can be used to highlight groundwater processes in that region of the world.

The Ogilvie basin is made up of a series of limestone+shale beds which have undergone intensive uplift and folding. A schematic representation of this process is provided in Figure 40. During or after the uplift the Ogilvie River has cut across the basic anticlinal structure, a process which was aided by a fault line which was used by the river to cut through the structure at a pace equally as rapid as the uplifting process. The former is probably a more likely explanation. In a number of sections the bedrock channel is clearly visible and during low flow conditions the cross river alignments of the limestone beds is evident (see Plate 20). Weathering and erosion processes have resulted in the partial destruction of the ridge tops leaving behind a landscape dominated by perched anticlines which can readily be seen from the aerial photo mosaic in Appendix 1.

Plate 20. Exposed limestone structure in the Ogilvie River at station #3

The probable sequence of geological events is provided in Figures 40 and 41 which represent a schematized view of the lower Ogilvie situation. The bedrock structures exposed in the river are of specific interest to hydrology and water quality because they control the groundwater flow particularly during

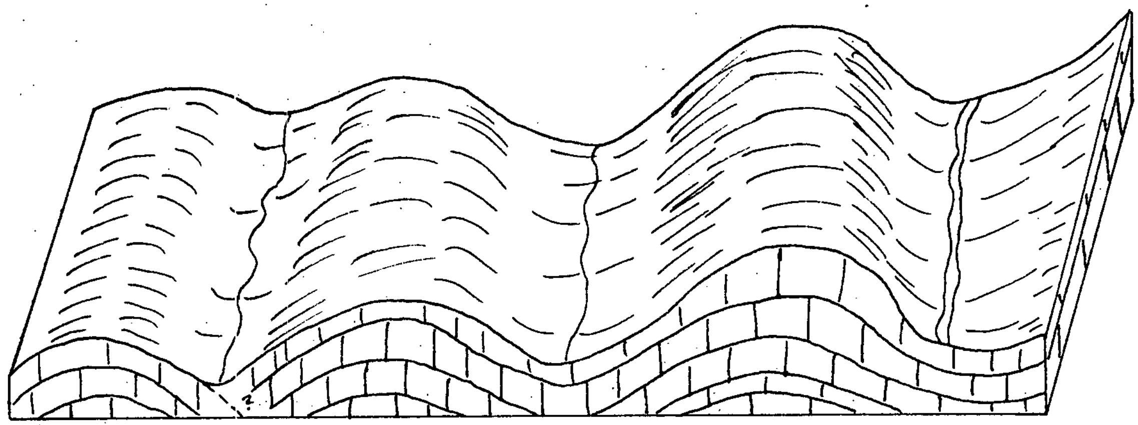


Figure 40. Original uplift and folding of limestone deposits

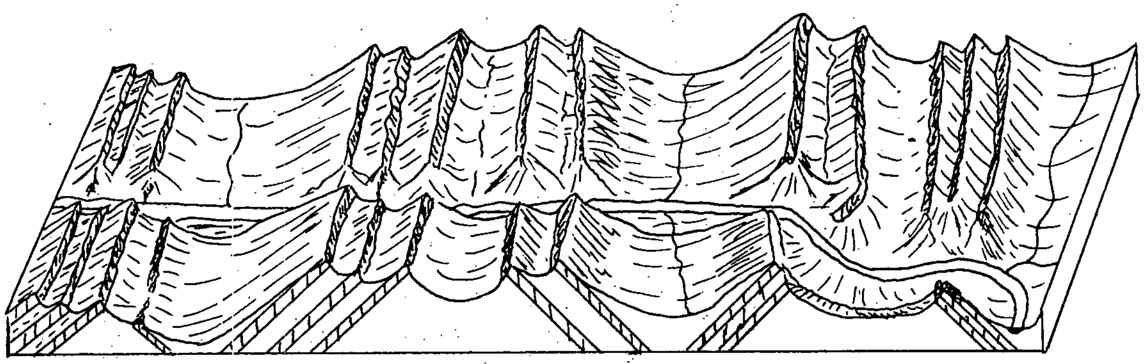


Figure 41. Schematic representation of geological conditions in the Ogilvie basin

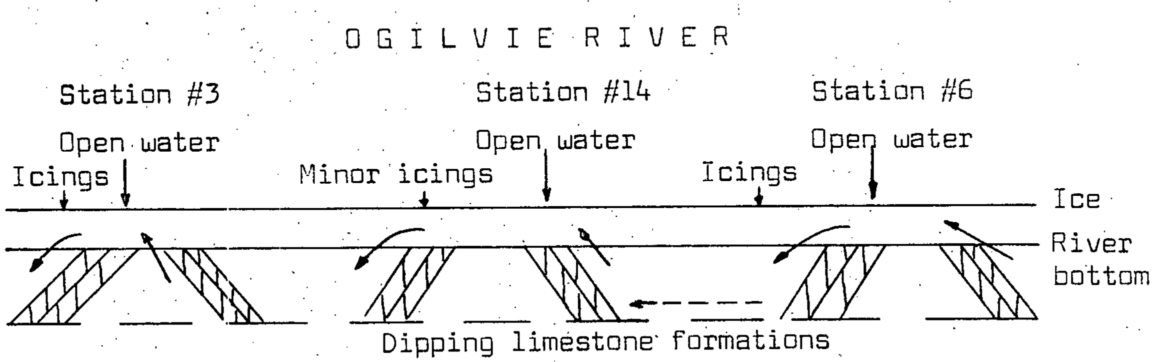


Figure 42. Idealized stream flow pattern during winter.

the winter. Many of the limestone bands act as aquifers and the groundwater in these formations flows in the direction of the bedding plane. It is at those sections in the river where open water conditions were found during the December and March sampling periods. The possible sequence of water flow under winter conditions is presented in Figure 42 and indicates that a substantial amount of stream water flows as groundwater probably below the river bed. When that water reaches one of the bedrock structures it is either forced upwards or downwards from the structural plane. Wherever it is forced up open water conditions occurred, an example of which was shown earlier in Plate 4. Immediately below such open sections icings were observed which resulted from overflows or water build-up. Ice thickness of $>$ 2 meters was common and sampling at these places was therefore impossible. Three, of a total of five, open water sections were found to operate under the described conditions. The remaining two were the result of spring water release in tributaries at close proximity to the main channel.

In the Ogilvie basin the overall groundwater flow concept presented in Figure 42 was further strengthened by the fact that little water flow could be detected in the main channel above two open water sections. Given the numerous bedrock exposures in the channels it is unlikely that the groundwater flow regime operates as a continuous system throughout the basin. Evidence of this will be provided from an analysis of the groundwater quality discussed below.

2) The Use of Water Quality in Groundwater Studies

(a) Identification of groundwater sources

Generally groundwater is less subject to variations in quality than stream water. The latter, being a mixture of groundwater, snow melt, surface run-off and precipitation, is subject to proportional changes from any of these sources, a process which is continuous throughout the year. In order to differentiate between groundwater sources and stream water seasonal sampling is necessary. Two sampling stations (#14 and #16) located in close proximity to the main stream were found to be in groundwater discharge areas

The water quality of these two stations was monitored from March until August and a comparison was made between those two stations and stations #3 and #4 on the main stream, immediately below the two groundwater inflow areas. A comparison between the two sets of stations is given in Figures 43 and 44 and shows that groundwater quality is fairly constant while stream water quality varies greatly throughout the year. The greatest contrast between the two sources was observed during spring run-off when the proportional contribution of spring snowmelt and surface run-off far outweigh the groundwater contribution . It is during those periods that the largest chemical contrast between groundwater and stream water was observed.

(b) Differentiation between types of groundwater sources

Groundwater is the dominant source of running water during the winter, and different sources can best be contrasted on the basis of a spatial analysis of water in late winter. To demonstrate this fact water quality conditions for the whole watershed were compared in Figures 45 and 46. The stations were arranged in a downstream sequence so that the concentrations found at each stations could readily be compared. As discussed previously Engineer Creek is known for its large contribution of salts and is included in this analysis since it probably affects the main stream at different times of the year. Ca, Mg, Si, SO_4, Na and Cl concentrations do not greatly differ from station to station in the main stream in May and June. In the fall and particularly during the late winter the situation is considerably different. The water quality conditions in stations 2 and 3 are drastically different from those in the upstream portion suggesting that groundwater release in this area is responsible for the difference. Station #3 has previously been identified as a groundwater discharge area because of the geological structure (Plate 20).

At the confluence of Engineer Creek a different situation exists. Ion concentrations in stations #8, 6 and 11 are very similar; in some instances those in Engineer Creek are slightly lower than those in the Ogilvie River above and below the confluence. This would suggest that the same type of groundwater controls water conditions in that section of the stream during the winter.

Figure 43. Comparison of seasonal pattern of groundwater versus stream water in Ogilvie River.

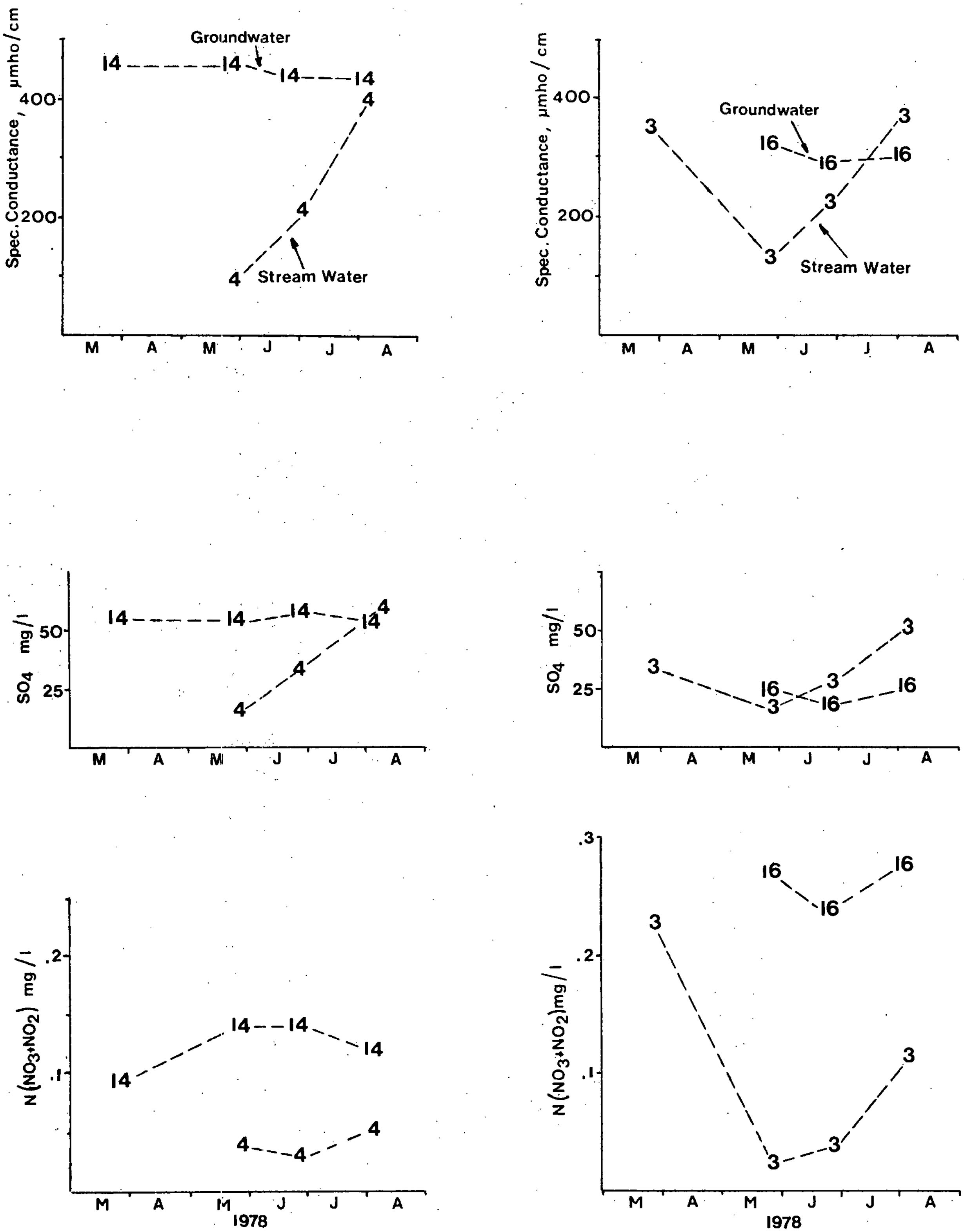


Figure 44. Comparison of seasonal pattern of groundwater versus stream water in Ogilvie River.

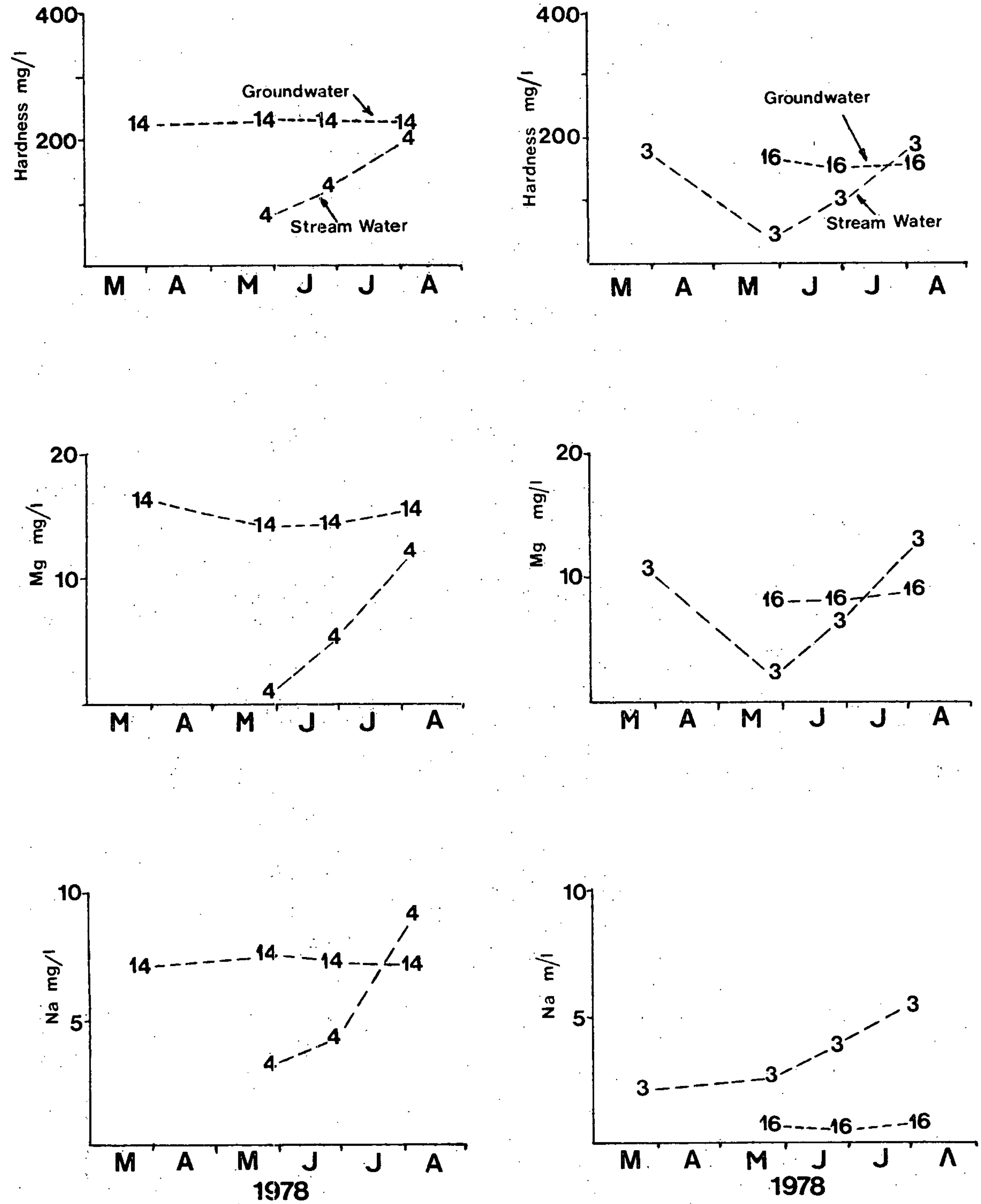


Figure 45. A spatial analysis of water quality to identify groundwater sources

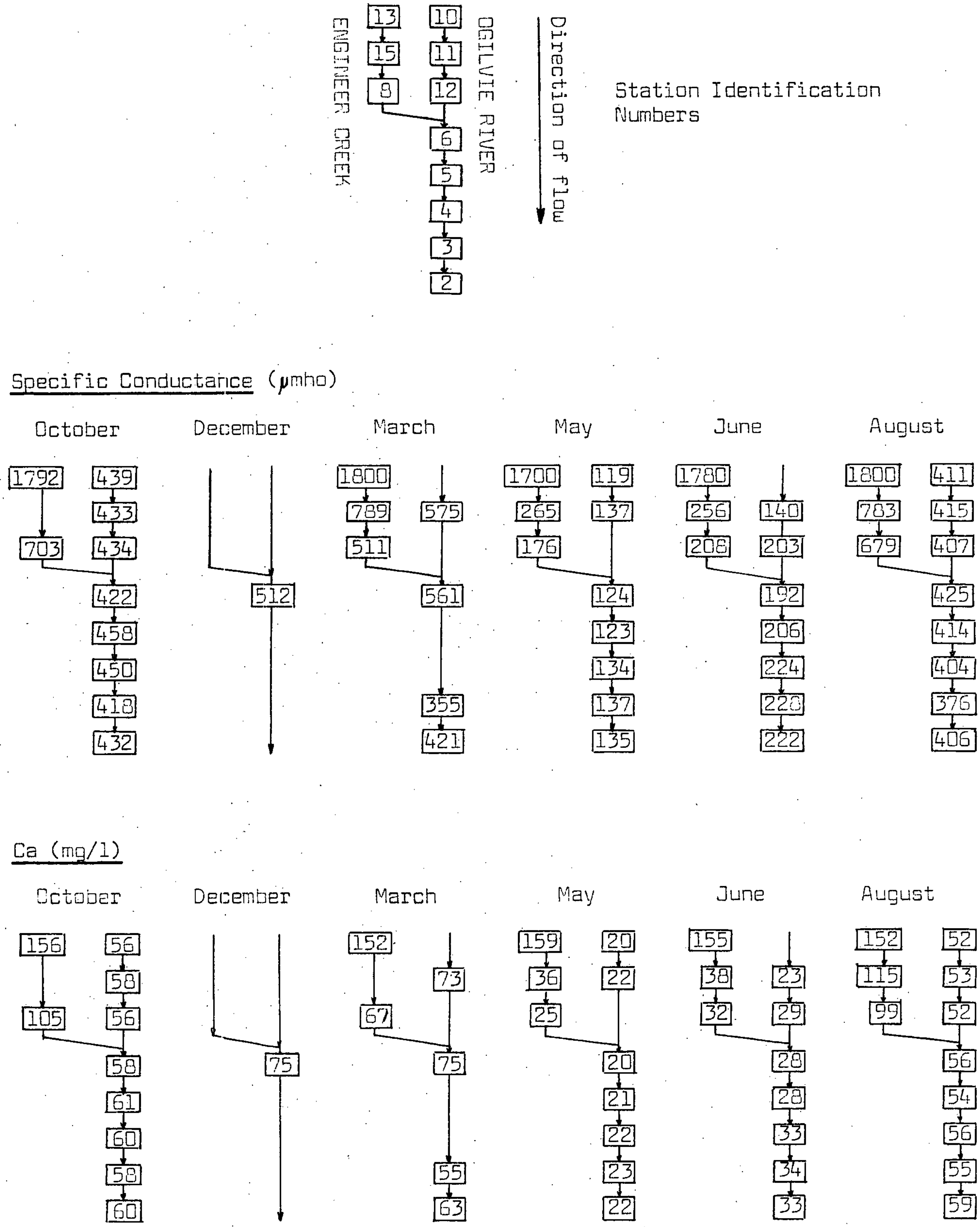
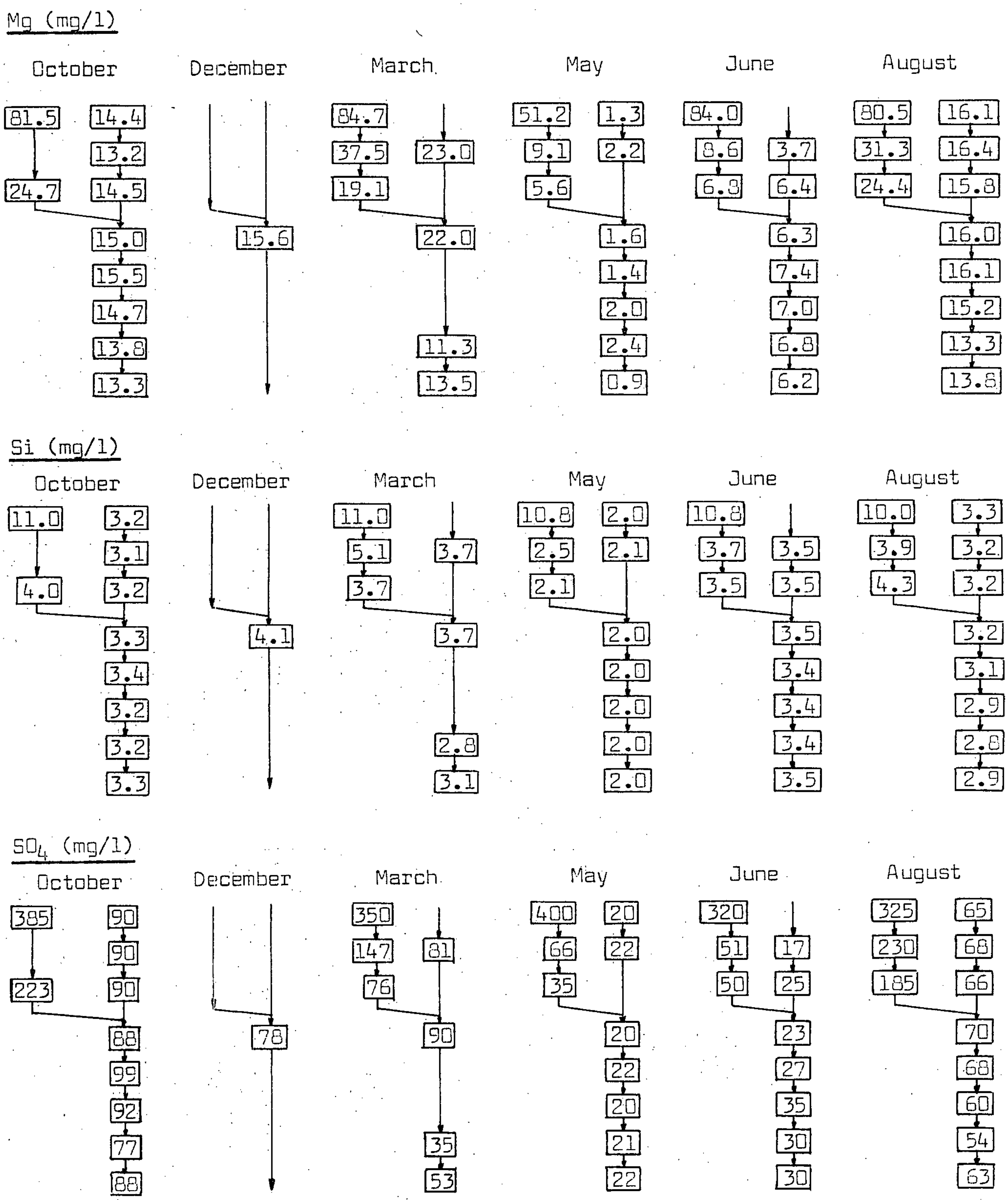


Figure 46. A spatial analysis of water quality to identify groundwater sources



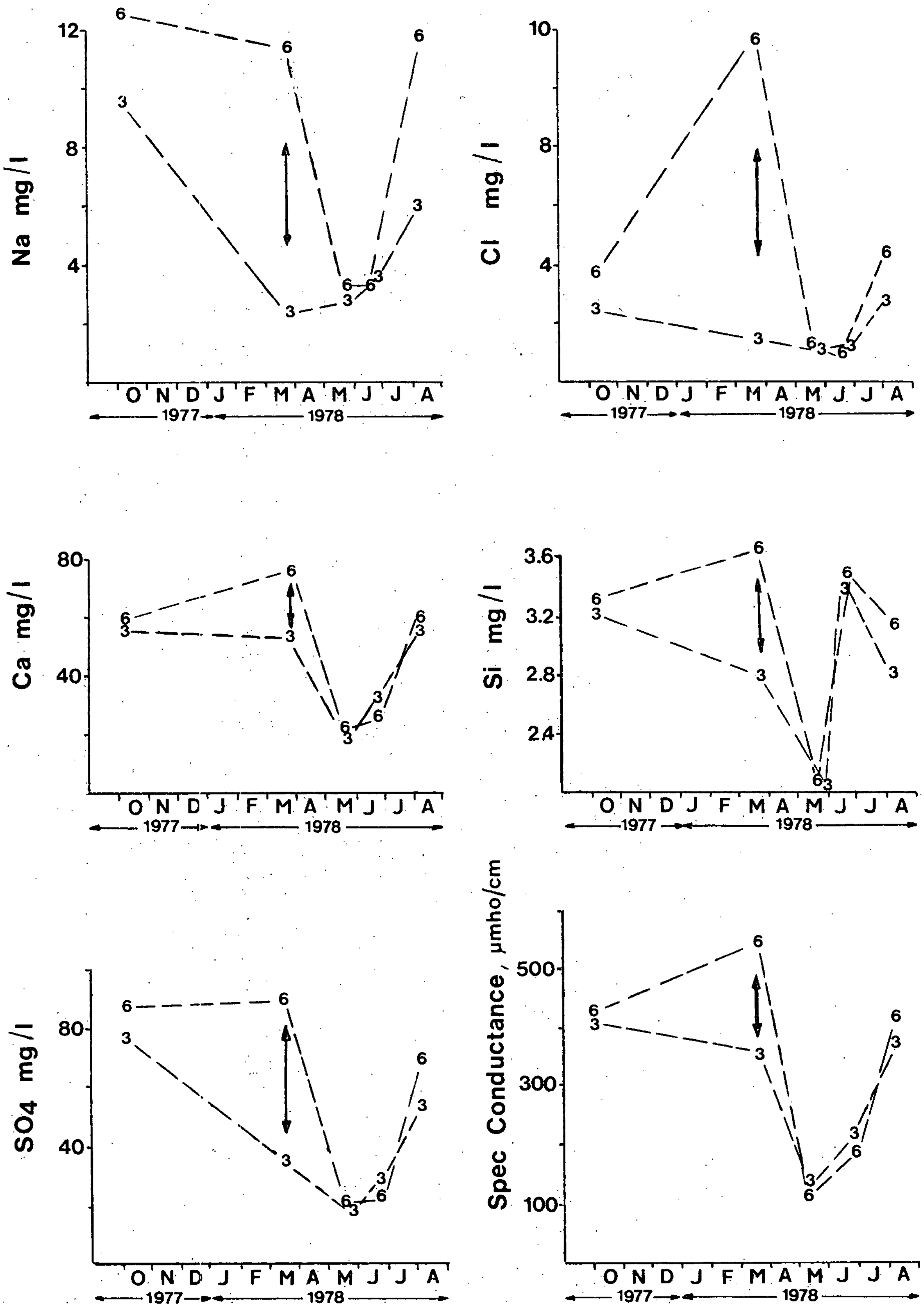
The third section of open water was found in Engineer Creek at station #15. The station exhibits very high salt concentrations throughout the year. Water from that source influences concentrations downstream particularly at the Ogilvie River confluence, where much higher salt concentrations are found throughout the spring, summer and fall. During the winter little water from this mineralized area seems to reach the Ogilvie as can be seen in Figures 45 and 46. This is further confirmed by the fact that sections on Engineer Creek were found to be frozen to the streambed with no evidence of water flow.

On the basis of this winter water chemistry it appears that at least three types of groundwater conditions dominate the open water sections in the river basin. The two other water sources (a tributary spring, station #14, and the sulfur spring in Engineer Creek, station #13) also showed characteristic water quality conditions, as shown in Table 9 where all five groundwater sources are compared. It therefore appears that the flow within the basin is at least in part discontinuous during the winter. To further accentuate this fact Figure 47 compares the changes in water quality between stations # 3 and 6 in the main stream. For most of the year conditions are similar but during winter a drastic change occurs in which ion concentrations generally increase in station #6 while they decrease in station #3. This would suggest that the water quality of the two aquifers is different, and there is little evidence to indicate that the two are inter-connected.

Table 9. Comparison of Water Quality between Five Different Groundwater Sources

STATIONS	PARAMETERS							
	pH	Specific Conductance	Ca mg/l	Mg mg/l	Na mg/l	Si mg/l	SO_4 mg/l	Cl mg/l
Station #3	8.0	355	55	12	2.4	2.8	35	1.6
Station #6	8.1	560	75	22	11.8	3.7	90	11.8
Station #14	8.0	456	64	16	7.4	3.6	62	4.5
Station #15	7.7	789	97	38	15.4	5.1	147	19.0
Station #13	7.6	1800	152	85	124.0	11.0	350	150.0

Figure 47: Differences in Water Chemistry Between Station 3 and 6 in Ogilvie River.



3) Summary of Groundwater Conditions

Groundwater stored in the limestone aquifers in the Ogilvie Basin is forced to flow along the tilted bedding plane and emerges to the surface at places where the bedrock formation crosses the river. In these sections open water was found in the winter and overflow water from that source was responsible for the build-up of icings downstream. Seasonal water quality data were used to identify groundwater sources and a spatial analysis of water quality during the winter revealed that at least five different groundwater sources exist and that the stream flow under ice is at least in part discontinuous.

F. Sediment Regime

An attempt was made to monitor continuously the sediment conditions of the Swift and Ogilvie Rivers between the time of ice break-up and late summer, 1978. Access to power supply was a major problem in these remote areas and despite several futile efforts monitoring was not possible on the Swift River. The sediment record on this river is therefore limited to the six times that water quality was sampled during the study year. The Ogilvie River operations were more successful and the results obtained are presented below.

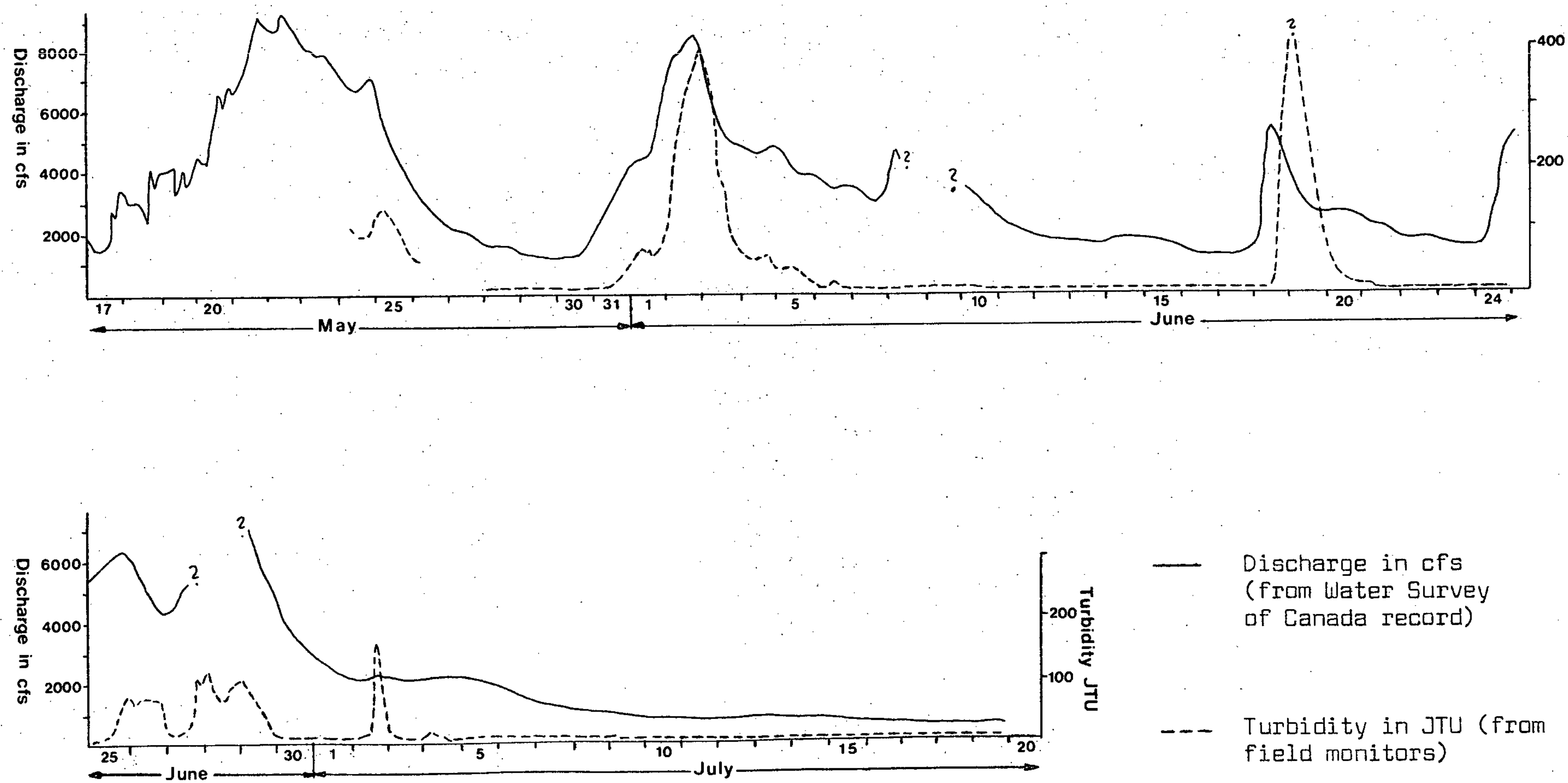
1) Description of Monitoring Program

A Keene Corporation Ltd. turbidity meter (Model 861 B) was set up next to the Dempster Highway (Mile 123) camp and river water was introduced into the turbidity meter from a stationary pump anchored in the gravelly river bottom about 10 meters from the north bank of the Ogilvie River. A special timer unit designed by Peter Strilaeff allowed for a recording of turbidity, calibration and zero instrument light transmission. The latter was thought to be a measure of how clean the transmission windows were at any time during the operation. With this set-up an hourly record consisting of 15-minute sections each of turbidity, calibration, and zero instrument transmission. The instrument was serviced by Graham Humphries of DPW who kindly agreed to collect daily samples at the outflow of the instrument for subsequent sediment analysis in the laboratory. In this way a continuous turbidity record and daily sediment record were obtained for the period of May 24 to August 1st, 1978.

2) Results of Experiments

Using the preliminary discharge data from the Water Survey of Canada, a comparison was made between the turbidity record and the flow rates. Data for each two-hour interval formed the basis of Figure 48 from which it is evident that in at least two instances (June 1-3 and June 18-19) a distinct lag time was observed between increases in turbidity as opposed to increases in flow rates. Further it was noted that although a relationship between flow

Figure 48. Turbidity record in relation to flow rate (based on measurements at two-hour intervals), Ogilvie River.



and turbidity exists it is not consistent. This is confirmed by the low correlation coefficient of r = 0.501.

Turbidity is not a direct measure of total non-filterable residues (Lobring and Booth 1975) and a relationship between the two has only been found in special circumstances. It certainly did not apply to the Ogilvie conditions. This is evident from a correlation/regression analysis conducted between turbidity and total non-filterable residue. No linear correlation was found for field turbidity versus total residue (r = 0.107) or laboratory turbidity versus total non-filterable residues (r = 0.205). Field turbidity (JTU's) and laboratory turbidity (NTU's) were significantly correlated at r = 0.983, thus partially confirming the field turbidity record.

The daily variation in total non-filterable residue is provided in Figure 49 and covers the data obtained from the laboratory analysis of the samples. The flow rates measured at or within the hour of sampling were also added to this diagram so that the two parameters can readily be compared.

Again the sediment load, expressed in terms of total non-filterable residue, appears to lag behind the flow rate during three out of four peak flow periods. Because of the differential lag time between flow rates and sediment load at different times of the year, correlation between the two parameters is poor (r = 0.147) and thus it is not possible to predict the sediment regime on a reliable basis. The turbidity and sediment record are provided as a basic reference of conditions and variability but the data should be treated cautiously particularly since the four-year water survey gauging program produced flow hydrographs which show considerable year by year variations. Further complexity is introduced by the fact that the turbidity and sediment monitoring program had to take place about 300 meters above the gauging station because of the need of a power supply. Unfortunately the Engineer Creek enters the Ogilvie River between these two stations, thus influencing the flow record but not the turbidity and sediment monitoring program. This causes some serious deficiencies in the compatibility of the flow versus sediment data. Nevertheless the sediment and turbidity records do provide base information on sediment conditions and variability over the spring period.

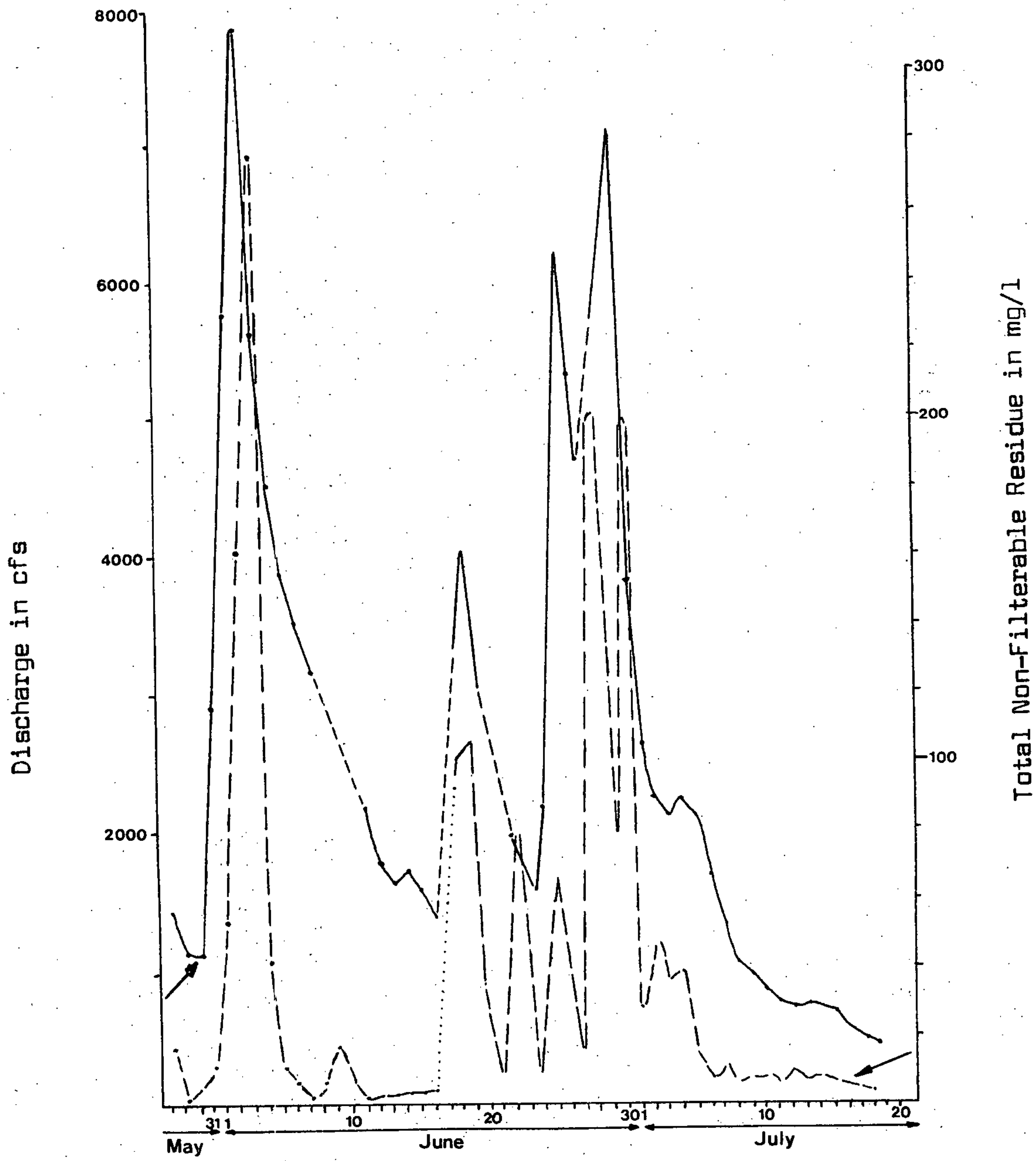


Figure 49. Discharge versus total non-filterable residue (based on daily samples), Ogilvie River.

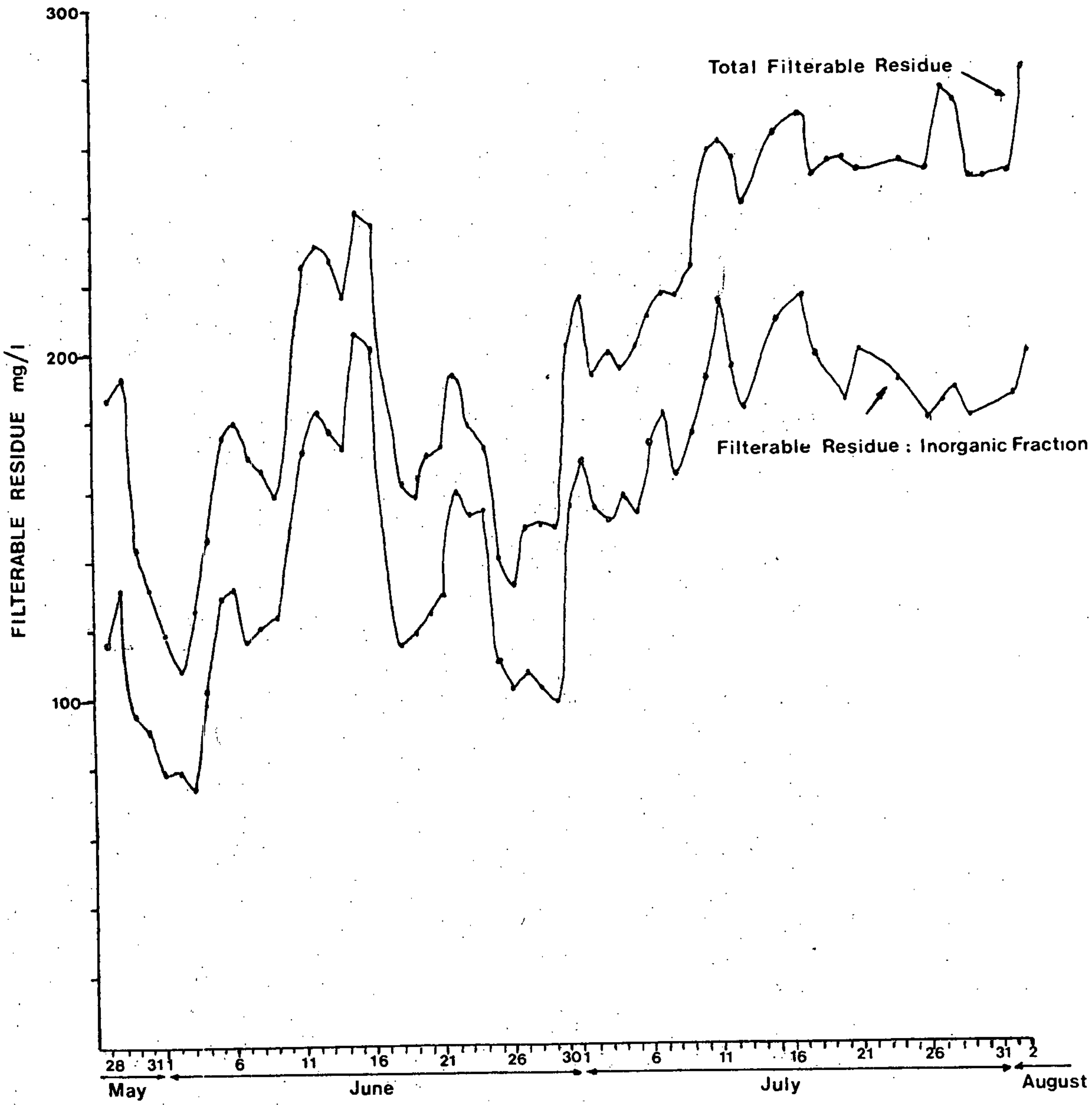
Finally an examination of the sediment composition was made by determining the inorganic and organic portion in each sample. On the average, 24% of the non-filterable portion of the residue was found to be organic. An almost identical value (25%) was found for the average organic proportion of the filterable residue, the variability of which is provided in Figure 50. It should be noted that although these two average values are very close, the day-to-day variability in composition was considerably greater for the non-filterable residue (0-64% versus 11-38%). No trend was found to indicate that the organic/inorganic portion changes significantly from break-up to the late summer flow period.

In summary it can be stated that no significant correlations were found for turbidity versus total non-filterable residues, or for discharge versus total non-filterable residues. Turbidity and suspended sediment rates seem to lag behind discharge rates in a number of cases but the data is not sufficient to make a more quantitative analysis. Based on the daily sampling program, suspended sediment load varies from < 1 mg/l to 277 mg/l and on the average 76% of the non-filterable residue was found to be inorganic material. Finally, the sediment analysis for the Swift River was limited to six sampling periods since a continuous recording could not be achieved due to problems with power supplies. The data on residues in the Swift River are summarized in Table 10 below.

Table 10. Sediment Data for Swift River Basin

Station #	Non-filterable Residue in mg/l					
	Oct. 8-10 1977	Dec.11-15 1977	Mar.22-25 1978	May 16-20 1978	June 19-22 1978	Aug. 5-7 1978
2	2.4	1.0	2.4	5.2	3.0	4.0
3	2.4	2.0	1.2	2.4	2.0	6.0
5	1.0	3.0	1.0	2.4	2.0	4.0
7	5.6	2.0	2.0	4.8	4.0	5.0
9	1.6	3.0	1.0	8.0	4.0	5.0
10	1.0	1.0	1.0	7.2	4.0	6.0
14	1.0	1.0	3.2	3.2	1.0	5.0
15	1.0	1.0	1.6	8.4	1.0	1.0
mean/ sample period	2.0	1.7	1.7	5.2	2.6	4.5

Figure 50. Daily variability in total filterable residue, Ogilvie River.



V. SUMMARY OF FINDINGS RELEVANT TO PIPELINE RELATED ACTIVITIES

A. Winter Depletion of Dissolved Oxygen Concentrations

Severe dissolved oxygen depressions were found during the winter in both study basins. The depressions occurred in the majority of stations despite a great variety of stream conditions, and were most extensive in late winter during maximum ice cover and highest water quality concentrations. The present findings are in agreement with results of a study in Alaska published by Schallock and Lotspeich (1974), and suggest that dissolved oxygen depressions are a widespread phenomenon in these northern areas.

No definite conclusion could be reached as to what factors determine the depletion process, and it is recommended that a more detailed analysis on this subject be initiated. From the present study it appears that ice conditions are not the only cause of the depressions and that other factors such as channel conditions, discharge rates, groundwater contributions, re-aeration, photosynthesis, and respiration all contribute to the process by means of complex interactions. Groundwater release which often produces stretches of open water during the winter does not necessarily produce higher dissolved oxygen concentrations. Groundwater is generally low in dissolved oxygen and aeration conditions in the aquifers are thought to determine oxygen concentration under such circumstances.

Some insight into the effects of DO-depressions on biological activity will be provided in a report by Larry Albright who conducted a biological productivity study in conjunction with the present research. With the results of this study it will be possible to partially determine how critical such late winter conditions are and what implications they have with regard to types of construction activities anticipated. As of now it is clear that oxygen stress is greatest during late winter implying that activities which lead to a further depletion of oxygen should be avoided during that period.

B. Importance of Groundwater Regime to Water Quality

It was found that water flows throughout the winter in both study basins, but the groundwater regimes of the two watersheds differed drastically. In the Swift River headwater springs and water release from high mountain lakes controlled the stream flow. Because of this regulated flow seasonal water quality trends were consistent and seasonal variations were found to be less important than spatial variabilities.

In the Ogilvie River dissimilar groundwater release was observed in a number of places along the stream network and this produced more complex water quality conditions. Seasonal trends were less consistent and in the main stream seasonal variability was generally greater than spatial variability. The latter conditions were produced by variations in the proportional contribution of groundwater during winter, spring and summer. Water from individual aquifers exert a dominating control over certain sections of the river during the winter. This influence is negated during the spring when snowmelt and precipitation dominate the flow. Because the Ogilvie River basin is in a permafrost environment, during spring and summer surface run-off is greatly increased, thus reducing the contact time of the water with the ground. This tends to produce very soft run-off water, in great contrast to the groundwater which is dominant during the winter.

Water quality analyses were found useful in identifying different groundwater sources, and it is suggested that water quality parameters be used as a type of "fingerprinting" for groundwater identification during winter. Five different source areas were identified by this method in the Ogilvie basin during the winter of 1978 and the resulting data strongly suggest that the stream flow dominated by groundwater is discontinuous, a finding which might be of considerable relevance in site selection for pipeline crossings.

C. The Importance of Geology in Water Quality Studies

Bedrock geology and structural geology were found to influence water quality conditions. Differences in the bedrock geology were responsible for altering water quality conditions in several tributaries in the Swift River basin and a spatial sampling was useful in identifying the black shale formation in the Ogilvie River as a major source of salt and metal found in the river system. In this way major point and non-point sources could readily be identified.

The groundwater flow in the Ogilvie River was found to be controlled by the structural arrangement of the bedrock. The river has cut through a series of folded and partially eroded anticlinal structures and in the process a number of sharply dipping limestone bands are exposed in several portions of the river bed. The limestone formations act as aquifers, and groundwater which is forced to flow along the structural bedding plane is eventually released into the river at those points where the structure crosses the river. Open water sections in the winter were found to coincide with these groundwater release areas in three out of four cases and icings were found immediately below these open water sections. These icings significantly reduced the flow in the downstream direction and forced the water to periodically overflow or to find its way into new aquifers.

It should be noted that such processes, although limited in size and occurrence, are of importance to pipeline location. They are easily overlooked, however, because they can only be observed during the late summer after spring snow melt and before freezing, and once such water is in contact with stream water the acids are readily neutralized.

D. Acid Water and Metal Corrosion

A somewhat unusual problem was found in the Ogilvie basin where acid conditions of the water reached pH 2.8 despite the otherwise extensive alkaline conditions. It is thought that the acid is produced as a result of pyrite oxidation present in the black shale formations. In the process sulfuric acid is produced which not only increases metal solubility in water but also acts as an effective corrosive agent. A good example of this process is provided in Plate 21 where a series of culverts are displayed after a one-year exposure to such conditions.

Plate 21. Corrosion of culverts after one year exposure to acid drainage

REFERENCES

CHILDERS, J.M., C.E. SLOAN, J.P. MECKEL, J.W. NAUMAN 1977 Hydrologic Reconnaissance of the Eastern North Slope, Alaska, 1955. USGS, Open File Report 77-492, Anchorage, Al.

GABRIELSE, H. 1969 Geology of Jennings River Map Area B.C. GSC Paper 68-55, pp. 1-34.

GARRELS, R. and C. CHRIST 1965 Solutions, Minerals and Equilibria. Harper and Row, N.Y., 450 pp.

GOODFELLOW, W.D. and I.R. JONASSON 1976 Detailed Geochemical Surveys in the Central Yukon, Part 2 of open file 399. Resource Geophysics and Geochemistry Division, Geol. Surv. of Canada, Open file 388.

JONASSON, I.R. and W.D. GOODFELLOW 1976 Uranium Reconnaissance Program: Orientation Studies in Uranium Exploration in the Yukon. Dept. of Energy, Mines and Resources, Geological Survey of Canada, Open file 388, 96 pp.

KLASSEN, R.W. 1978 Surficial Geology of the Southern Yukon Territory. GSC, Open file 539.

KLEIBER, P. and W.E. ERLEBACH 1977 Limitations of Single Water Samples in Representing Mean Water Quality. Inland Water Directorate, Techn. Bull. #103, p. 9.

LOBRING, L. and R. BOOTH 1975 Understanding Measurements. AWWA Proceeding on the Water Quality Technology Conference, 1975, Atlanta; Am. Water Works Assoc., pp. 1-6.

LOTSPEICH, F., R. JACKSON, A. HELMERS 1976 Climatological and Water Quality Data, Caribou-Poker Creeks Research Watershed. AERS Working Paper #30, U.S. Env. Prot. Agency, Corvallis Env. Research Laboratory, Arctic Environmental Research Station College, Alaska, p. 41.

PATTERSON, J. and R. WHITAKER 1973 UBC-C-Group Computer Program, Univ. of B.C., Dept. of Computer Sciences, pp. 1-20.

SCHALLOCK, E.W., E.W. MUELLER, R.C. GORDON 1970 Assimilative Capacity of Arctic Rivers. Fed. Water Quality Laboratory, College, Alaska, Working Paper #7.

SCHALLOCK, E.W. and F.B. LOTSPEICH 1974 Low Winter Dissolved Oxygen in some Alaskan Rivers. Environ. Prot. Agency, Project 21 ARX; Nat. Env. Research Center, U.S. Env. Prot. Ag., Corvallis, EPA-660-3-74-008, 33 pp.

SCHREIER, H. 1977 An Assessment of the Yukon Section of the Alcan Pipeline emphasizing Water Quality Problems; for Dept. of the Environment, Inland Water Directorate, Water Quality Branch, 29 pp.

WARD, J. 1963 Hierarchical Grouping to Optimize an Objective Function; Am. Stat. Assoc. 58, pp. 236-244.

OTHER CONSULTED LITERATURE

BEAK CONSULTANTS LTD. 1977 A Survey of Fall Spawning Fish Species in Waterbodies within the Influence of the Proposed Alaska Highway Pipeline in Yukon Territory, Environm. Report for Foothill Pipelines Ltd. Yukon.

CASPER, L.A., R.C. GORDON, E.W. MUELLER 1973 Design Considerations for Sampling Program in Remote Areas. Working Paper #23, U.S. Env. Prot. Agency, Arctic Environmental Research Laboratory College, Alaska, 49 pp.

DAVENPORT, C., E. SPARROW, R. GORDON 1976 Fecal Indicator Bacteria Persistence under Natural Conditions in an Ice Covered River. Applied and Environmental Microbiology, Vol. 32/#4, pp. 527-536.

DEPARTMENT OF INDIAN AND NORTHERN AFFAIRS 1976 Small-Stream Investigations in Yukon Territory Water Resources Section, Northern Natural Resources and Environment Branch, DINA 1975 and 1976, 75 pp.

GORDON, R.C. 1970 Depletion of Oxygen by Microorganisms in Alaskan Rivers at Low Temperatures. Intern. Symp. on Water Pollution Control in Cold Climates, Univ. of Alaska College, Working Paper #40, Federal Water Quality Administration, 25 pp.

HUGHES, O.L., R.B. CAMPBELL, J.E. MULLER, J.O. WHEELER 1969 Glacial Limits and Flow Patterns, Yukon Territory, South of 65° North Latitude; Geol. Survey of Canada Paper 68-34, Dept. of Energy, Mines and Resources.

HYDROLOGICAL CONSULTANTS LTD. 1974 Review of Ground Water, Teslin, Yukon Territory; Edm., Alberta, 10 pp.

INTERA ENVIRONMENTAL CONSULTANTS LTD. 1975 Groundwater Management Study of the Yukon Territory.

LAVKULICH, L.M., W.J. GIVEN, M.E. WALMSLEY 1972 Physical Environmental Studies, Watson Lake Vicinity, Yukon Territory. Final Report on Land Use Research for Indian Affairs and Northern Development, ALUR Program, 1970, Dept. of Soil Science, U.B.C., 161 pp.

LAVKULICH, L.M., M.E. WALMSLEY, R.L. BEALE 1972 Physical Environmental Studies, Watson Lake area, Yukon Territory. Arctic Land Use Research Program Final Report, 1972, ALUR 1972, Dept. of Soil Science, U.B.C., 245 pp.

LAVKULICH, L.M. and M.E. WALMSLEY 1973 Physical Environmental Studies, Characterisation of Soil-Hydrology Parameters. Watson Lake area, Yukon Territory. Report on Land Use Research submitted to the Dept. of Indian and Northern Affairs, ALUR Program, Dept. of Soil Science, U.B.C., 148 pp.

LOTSPEICH, F.B. 1973 Permafrost and the Environment in Alaska, Working Paper #18. U.S.-Environmental Protection Agency, Arctic Environmental Research Laboratory College, Alaska.

LOTSPEICH, F.B. and E.W. SCHALLOCK 1972 Laboratory Evaluation on an Improved Sampling Procedure for Dissolved Oxygen. Working Paper #15, Environmental Protection Agency, Nat. Env. Research Center, Alaska Water Laboratory, College, Alaska, 16 pp.

MULLIGAN, R. 1965 Metallogenic Studies of the Beryllium-Tin Province of the Cassiar Batholith, Yukon and B.C. GSC Paper 66-1, pp. 45-47.

RICKER, K. 1977 Quaternary Geology of the North Klondike and Upper Blackstone River System, Southern Ogilvie Ranges, Yukon Territory, Dempster Hwy O-139; Geol. Survey of Canada, Open file 478.

VAN EVERDINGEN, R.O. 1974 Groundwater in Permafrost Regions of Canada, in: Permafrost Hydrology. Canadian Nat. Committee, pp. 83-93.

WILLIAMS, J.R. 1970 Groundwater in the Permafrost Region of Alaska. U.S. Geol. Survey Prof. Paper 696, 83 pp.

APPENDIX 2

Description and Illustration of Sampling Sites

STATION DESCRIPTION

SWIFT RIVER

STATION NO.

1 Swift River upstream near headwaters (passed Pine Lake air strip access road);
4-5 m wide stream with pools up to 40 cm deep;
Mountain stream with coarse gravel bed mostly of igneous and metamorphic rocks;
Sampling station 20 m above road crossing before road washout.

2 Swift River tributary: Smart River
~200 m upstream of Alaska Hwy Bridge at bend west banks;
Sand, silt and some gravel.

3 Tributary: Logjam Creek
~250 m upstream from Hwy bridge, channel ~ 7 m wide;
Samples taken 4 m from west bank, coarse gravel.

4 Swan Lake: N-Central shore
Small clearing provides access ~ 150 m from road;
Samples taken ~ 10 m from Spruce tree marker at depth of 75 cm;
Black rocks, volcanic origin, steep drop-off, clear water.

5 Tributary: Screw Creek
About 200 m upstream from Hwy bridge;
Channel ~ 10 m wide, coarse gravel, trees hanging over channel;
Sampling east bank 4 m.

6 Swift River, below McNaughton Confluence;
Straight stretch parallel to road, steep banks, strong current, ~ 1 m deep, 10 m from marker, 3 m from banks;
Channel ~ 30 m wide, shallow at south bank.

7 Swift River above McNaughton confluence;
Slow current, ~ 150 cm deep, parallel to road, North side of meander with steep slope between road and river;
Channel ~ 30 m wide, some schist outcrops.

8 Partridge Creek (tributary)
200 m above Hwy bridge, 5 m above burnt out cabin;
Channel ~ 10 m wide and ~ 30 cm deep, coarse gravel, igneous and metamorphics.

9 Swift River, 800 m downstream from Swift River Hwy camp;
Channel ~ 30 m wide, very rapid flow > 100 cm deep;
Rock and gravel bed, sampling 3 m from bank, parallel to Hwy (20 m off).

STATION NO.

10-13	Swift River main station: Above Seagull Creek confluence; Good moderate current, gravel, sand and silt beds; 30 m above confluence; Spruce forest (#10-13) sampling
14	Seagull Creek Upstream from Hyw Bridge ~ 100 m before river bend; Channel ~ 12 m wide, ~ 35 cm deep, gravel bed.
15-16	Swift River above Alaska Hwy bridge; Above lone spruce tree on west bank, channel ~ 14 m wide; #15 west bank 3 m, #16 east bank 10 m from free gravel with some silt and sand (braided river draining bog above).
17	Swift River at gauging station just below Smart River confluence.
18	Swift River above McNaughton (immediately above confluence); 40 m; Steep slope ~ 250 m between Hwy and river, with schist and shale outcrops.
19	Unnamed creek between Seagull and Swift River Hwy bridge, North of road ~ 3 m wide.

STATION DESCRIPTION

OGILVIE RIVER

STATION NO.	
1-2	Near Milepost 146, above tributary confluence on west bank; Bedrock exposure on east bank, samples taken at 60 and 75 m from west bank (channel width ~ 80 m).
3	Near Milepost 142, Churchward Hills, at point where exposed limestone beds cross the river; samples taken 45 m from west bank (channel width ~ 81 m).
4	Near Milepost 139, above black shale exposures and above culvert draining spruce bog; samples taken 27 m from banks (channel width 62 m).
5	Near limestone cave and yellow road sign; samples taken 45 m from bank (channel width 46 m).
6	Main winter station between Milepost 124 and 125 in canyon surrounded by steep limestone hills; samples taken at or near river centre (channel width 114 m).
7	Below Water Survey of Canada Gauging Station; 75 m from west bank (not used as a station after first field trip because unsuited as a water quality sampling station).
8	At mouth of Engineer Creek, 100 m above Hwy Bridge; samples taken in midstream (channel width 21 m).
9	Small tributary near game outfitter cabin; draining spruce bog.
10	Above trapper cabin; limestone bedrock exposure on northwestern bank.
11-12	500 m above Hwy camp; Samples taken 30 and 50 m from southeastern bank (channel width 136 m).
13	Sulphur springs, Engineer Creek, Mile 107; next to vertically uplifted black shale deposits.
14	Tributary next to massive limestone ridge; sample taken 200 m above confluence with Ogilvie; groundwater flow with very short drainage channel.
15	Middle Engineer Creek in centre of cut through anticlinal ridge.
16	Groundwater discharge next to station #3 in Ogilvie. Groundwater is released from the limestone formation and directly enters the main stream.
17	Tributary draining spruce bog below station #4 and above black shale outcrops.

SWIFT RIVER ABOVE SWIFT RIVER HIGHWAY CAMP - Station #10

December 1977

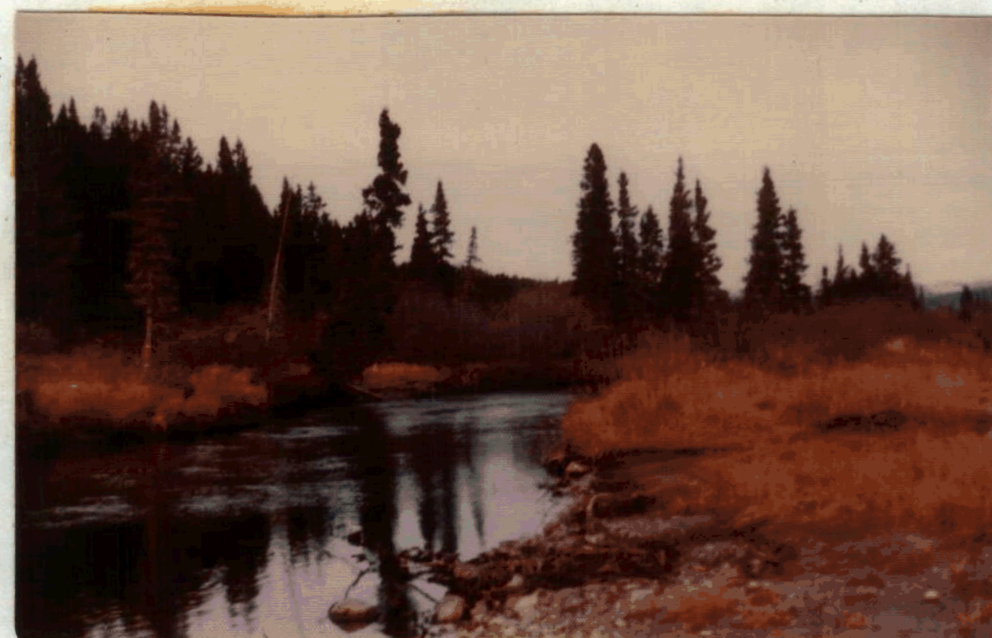
March 1978

June 1978

August 1978

SWIFT RIVER ABOVE
ALASKA HIGHWAY BRIDGE
Station #15

October 1977



December 1977

June 1978

SWIFT RIVER BELOW
McNAUGHTON CONFLUENCE
Station #6

December 1977

June 1978

August 1978

OGILVIE RIVER ABOVE
HIGHWAY CAMP
Station #11

October 1977

March 1978

OGILVIE RIVER BASIN
ENGINEER CREEK
Station #8

October 1977

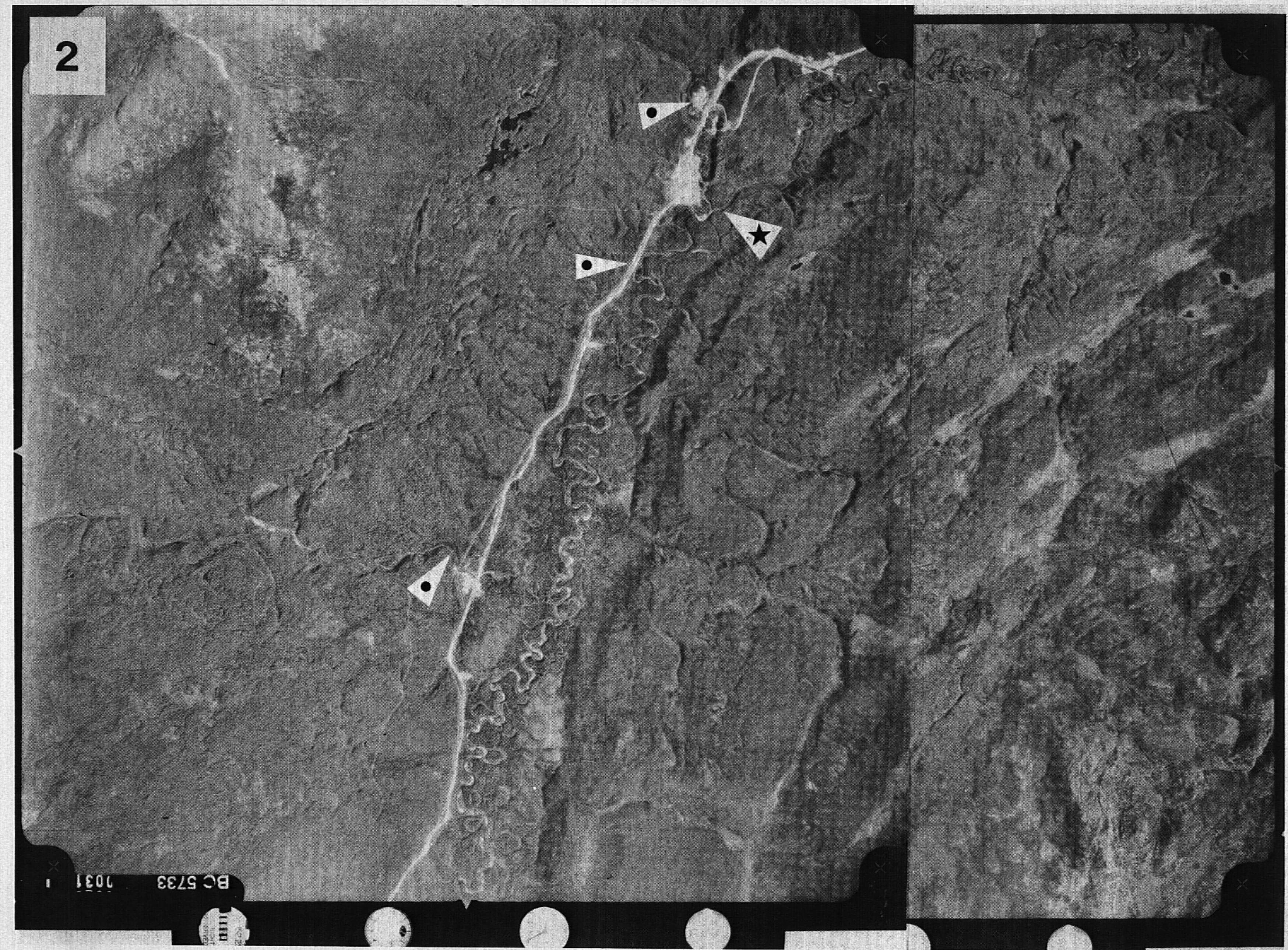
June 1978

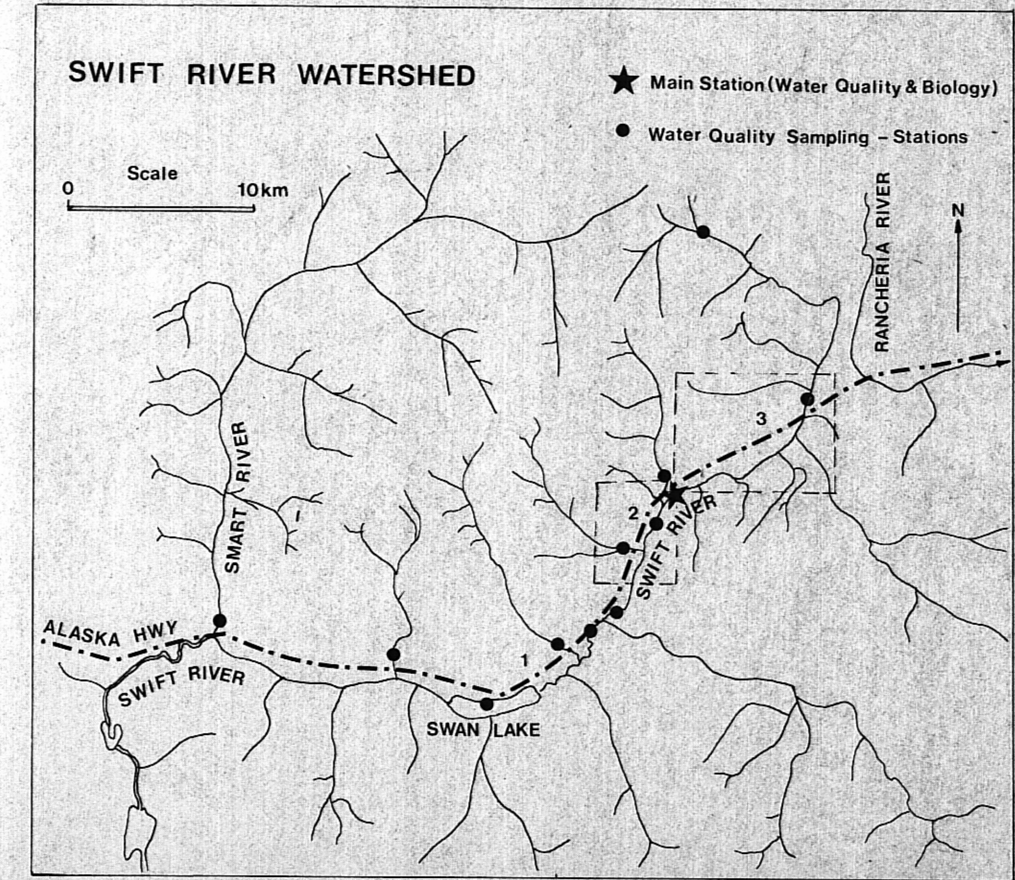
APPENDIX 1

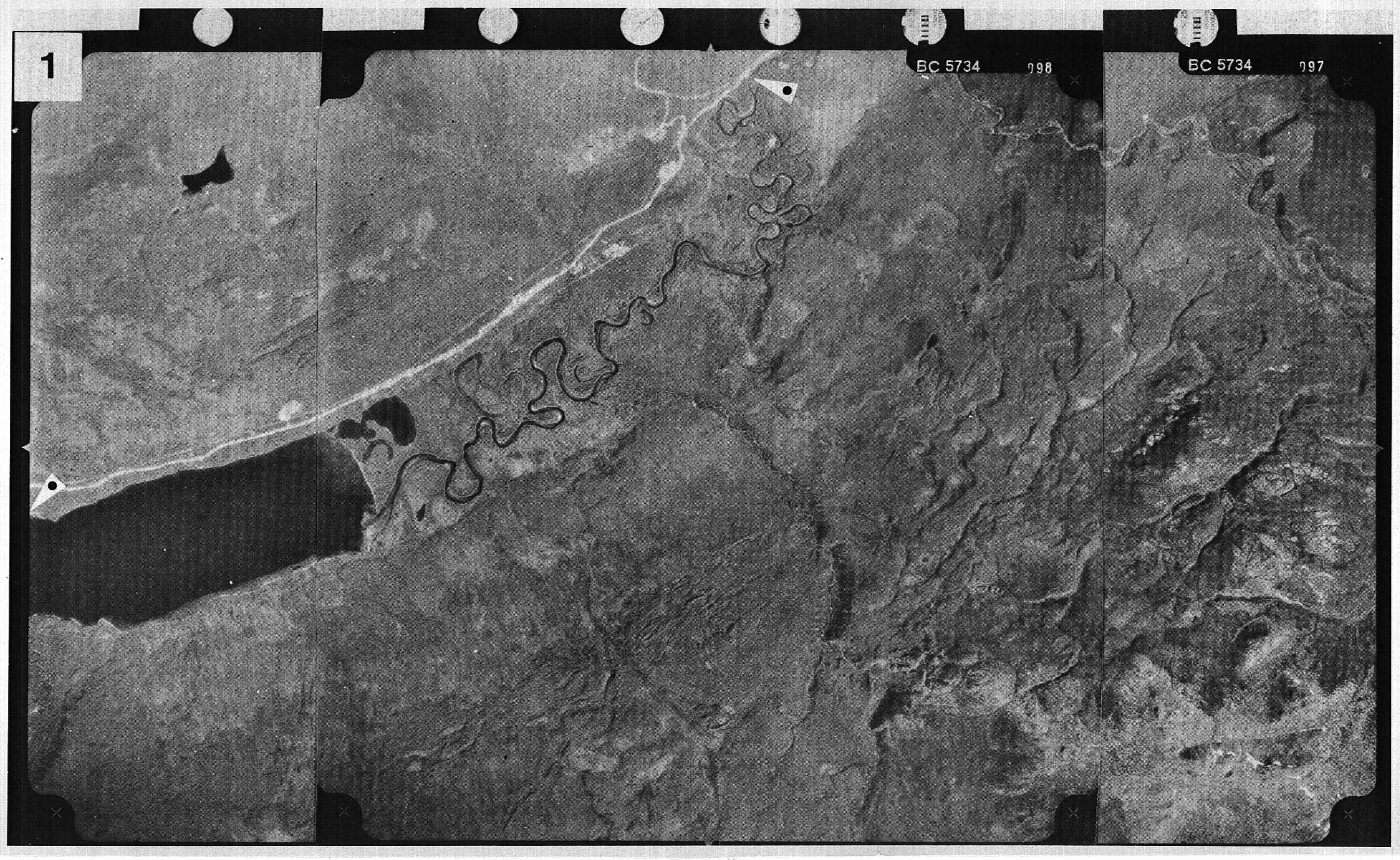
1. Uncontrolled Photo Mosaic of the Ogilvie River Study Area
2. Uncontrolled Photo Mosaic of the Swift River Study Area

SWIFT RIVER

Alcan Pipeline Water Quality Project







OGILVIE RIVER

★ MAIN SAMPLING STATION

● WATER QUALITY SAMPLING SITES

G WATER SURVEY GAUGING STATION

W WINTER SAMPLING STATION

Uncontrolled Mosaic

N

0 1 2 3 4 5 Km

Scale