1-1-1986

An isotopic and geochemical study of runoff in the Apex River watershed, Baffin Island, N.W.T.

Milan Mitch Obradovic
University of Windsor

Recommended Citation

Obradovic, Milan Mitch, "An isotopic and geochemical study of runoff in the Apex River watershed, Baffin Island, N.W.T." (1986). *Electronic Theses and Dissertations*. 6800.
https://scholar.uwindsor.ca/etd/6800

AN ISOTOPIC AND GEOCHEMICAL STUDY OF RUNOFF IN THE APEX RIVER WATERSHED, BAFFIN ISLAND, N.W.T.

by

Milan Mitch Obradovic

A Thesis
submitted to the Faculty of Graduate Studies
and Research through the Department of Geology
in Partial Fulfillment of the requirements
for the degree of
Master of Applied Science at
The University of Windsor

Windsor, Ontario, Canada

1986

ABSTRACT

Recent research in temperate, humid environments has indicated that groundwater is a much more important and active factor in the precipitation-runoff process than was previously thought. The main objective of this research project has been to determine the importance of groundwater in snowmelt and rain runoff in a catchment underlain by permafrost. In order to meet this objective, isotopic (^{18}O) and chemical (EC, Mg and Ca) parameters were used for hydrograph separations of snowmelt and rain runoff and standard hydrologic analyses were run on streamflow data for the Apex River watershed near Frobisher Bay, N.W.T. This basin is a small (60 km^2) watershed situated in the continuous permafrost zone where the bedrock is mostly Precambrian gneiss and glacial overburden is sparse.

Peak flow frequency analysis for the Apex River yielded results similar to those of comparably sized watersheds in southern Canada. Flow duration curves for 1982 and 1983 suggest that runoff in the Apex River watershed is dominated by overland flow. The recession analyses (1982 and 1983) resulted in large recession constants. The long recessions are likely a result of the increased storage capacity of the thawing active layer during the summer.

The groundwater is characterized by higher ionic concentrations and enriched isotopic ratios relative to the other sources which contribute to runoff. During snowmelt

runoff there is a dilution of most of the chemical parameters. The chemical and isotopic character of the waters which contribute to runoff in the Apex River watershed can be summarized for the 1983 season as follows: baseflow- EC= 32.2 µS/cm, Na= 0.59 mg/l, K= 0.12 mg/l, Mg= 0.64 mg/l, Ca= 4.84 mg/l, $\delta^{18}O$= -17.5‰ ; snow- EC= 8.1 µS/cm, Na= 0.45 mg/l, K= 0.36 mg/l, Mg= 0.11, Ca= 0.20 mg/l, $\delta^{18}O$= -23.1‰ ; snowmelt- EC= 15.8 µS/cm, Na= 0.42 mg/l, K= 0.15 mg/l, Mg= 0.34 mg/l, Ca= 1.71 mg/l, $\delta^{18}O$= -24.5‰ ; rain- EC= 11.6 µS/cm, Na= 0.39 mg/l, K= 0.32 mg/l, Mg= 0.24 mg/l, Ca= 0.40 mg/l, $\delta^{18}O$= -18.0‰ ; springs- EC= 40.7 µS/cm, Na= 0.65 mg/l, K= 0.31 mg/l, Mg= 0.96 mg/l, Ca= 3.92 mg/l, $\delta^{18}O$= -17.9‰ .

The hydrograph separation results indicate that "old" groundwater makes up approximately 50% of the peak stream discharge during snowmelt runoff and about 60% of the total discharge from June 16 to August 10, 1983. The groundwater response must have been rapid. When calculated by the $\delta^{18}O$ hydrograph separation method, the peak groundwater discharge occurred approximately one day after the peak stream discharge and on the same day as peak stream discharge when calculated by EC, Mg and Ca. Mg was found to be the most conservative chemical parameter, relative to ^{18}O, for use in hydrograph separation. It did, however, consistently underestimate the old water contribution by an average of 10%.

Based on the hydrograph separation results, the mechanism responsible for the major old water input is probably a displacement of suprapermafrost groundwater from the melting active layer by infiltrating snowmelt and rain water. Visual observations provided evidence of partial area overland flow in areas downslope from major snow accumulations. Interflow along the vegetation-bedrock interface was also observed in some areas. These results are not totally in agreement with the interpretations derived from hydrologic analysis of the streamflow data. This discrepancy may be another example of why hydrograph analysis by standard methods cannot yield reliable information on sources and pathways in the precipitation-runoff conversion process.

ACKNOWLEDGEMENTS

A number of people have provided valuable assistance through the course of this work. Without them, the task would have been much more difficult.

First and foremost, my advisor, Dr. Michael Sklash provided encouragement and helpful suggestions at all the right times. I would also like to thank the members of my examining committee, Dr. F. Simpson and Dr. J. Jacobs, for their comments and critical review of this manuscript.

Mr. J. M. A. Theriault, of the Department of Indian and Northern Affairs (DINA), Frobisher Bay, and his staff: Peter Bannon, Ezio Del Degan, Fiona Paton and Kathy Hanson, provided logistical support and accomodation at the Ikaluit Research Lab. Helicopter time was provided by Mr. Theriault in 1983 and by Mr. Ian Carwardine of Canterra Energy, Ltd. in 1982.

I would like to thank Greg Mills, my field assistant for "most" of the two summers, who always carried the heaviest pack and went first across the deep snowbanks. Phil Ingenkamp helped obtain some stream samples in 1983. Doug Stenton of Trent University provided a sample of ground ice.

Drs. A. Turek and C. Huang of the Geology Department provided their expertise for the chemical analyses. Their help is much appreciated. I would also like to thank Pat McQuarrie and the Great Lakes Institute for their assistance in some of the chemical analyses.

Mr. R. A. Hale of the Inland Waters Directorate, Yellowknife, provided discharge records for the Apex River. Mr. Bernie Yorke of the Canadian Climate Centre, Downsview, provided climatic data from Frobisher Bay.

I would like to acknowledge the assistance of the Computing Consultants at the University of Windsor, who helped troubleshoot my SAS programs.

Thanks go to my word processing team of Carole St. Louis, Lazywriter and Radio Shack for their fine job in producing this manuscript. Their work would have been in vain were it not for Dr. P. Hudec who came to the rescue when the computer burped.

Funding for this project was provided by Northern Scientific Training Grants from DINA in 1982 and 1983. Funding for the isotope analyses came from an NSERC operating grant to Dr. M. Sklash.

Thanks also go to my friends and colleagues for their encouragement. Finally, I would like to express my sincere gratitude to my family for their lifelong support and encouragement.

CONTENTS

TABLES

FIGURES

APPENDICES

1. INTRODUCTION

Approximately one-half of Canada as well as large areas of other parts of the world lie in Arctic regions (Brown, 1974). These are some of the only areas of the world where the environment has remained relatively undisturbed by man's activities.

Since the late 1960's considerable interest has been shown in developing northern Canada in search of minerals and oil. Unfortunately, very little is known about the delicate northern environment when compared to our knowledge of the more populated south. Thus, the impact of any major development such as pipeline construction, road building, mining and urbanization, is difficult to assess.

One of the problems in development of northern regions is that hydrologic engineering techniques necessary for prudent development are not as well tested as those of more temperate regions. The unique factors which dictate the use of specialized hydrologic techniques are the climate and the presence of permafrost. Both of these factors are very important influences on the hydrologic cycle (Ferris, 1975).

In more temperate, humid environments, recent research has indicated that groundwater is a much more important and active factor in the rainfall-runoff process than previously acknowledged (e.g. Dincer _et al._, 1970; Martinec, 1975; Sklash _et al._, 1976; Sklash, 1978). This study is an extension of a similar type of research: to determine the role of groundwater in storm and snowmelt runoff in a small

Arctic watershed.

Because of the unique features and their effect on the hydrologic cycle in Arctic regions, it is important that research in this area be carried out so that we may understand the natural processes which take place. Once we understand the natural processes, we may be able to predict the consequences of man's activities on the quantity and quality of water resources. The increased knowledge of the mechanics of streamflow in an arctic environment will also permit engineering that will minimize the disruption of the natural environment.

1.1 Objectives and Scope of the Study

Field studies during July and August, 1982 and June, July and August, 1983 on the Apex River watershed near Frobisher Bay, N.W.T., were conducted to determine the importance of groundwater in the precipitation-runoff process in a permafrost environment.

The main objectives of the research program were to determine the magnitude and timing of groundwater contributions to the Apex River during snowmelt and summer storm events and to achieve a better understanding of runoff-generation mechanisms in a permafrost watershed. In order to achieve these goals, the following secondary objectives were to:

(i) determine how groundwater chemistry affects surface-water chemistry during runoff events;

(ii) characterize the chemical and isotopic nature of the waters which contribute to runoff; and to,

(iii) examine the areal and temporal variations in water chemistry of the Apex River watershed.

To meet these objectives, samples of water were taken from the sources which contribute to streamflow in the Apex River watershed. These samples were later analyzed for various chemical and natural isotopic constituents. The water sources included: rain, snowbanks, snowmelt, groundwater springs, ponds, lakes, tributaries and the main stream channel of the Apex River at the gauging station. Nearly 1000 samples were collected and analyzed for calcium, magnesium, sodium and potassium. Electrical conductivity and pH were measured for all samples in the field or immediately on return to the laboratory. Selected samples were analyzed for oxygen-18.

These chemical and isotopic parameters were inserted into the appropriate mass balance equations to determine the relative contributions of the various components of streamflow. Standard engineering methods of hydrograph analysis were also performed on stream discharge data for the Apex River and these results were compared to those obtained from the chemical and isotope mass balance techniques.

1.2 Study Area

1.2.1 Location

The watershed chosen for study was the Apex River watershed which is situated at approximately 63°48'N latitude and 68°31'W longitude. The basin is located at the intersection of NTS map sections 25 N/9, 25 N/10, 25 N/15, and 25 N/16 at a scale of 1:50 000.

The river is immediately adjacent to the town of Frobisher Bay, N.W.T., on the southern part of Baffin Island (Figure 1.1). This location was chosen becuase it is in an area of continuous permafrost with negligible man-made disturbance. Of equal importance is the easy access from Frobisher Bay which has daily jet service to southern Canada. Other reasons for choosing the Apex River watershed include:

(i) the availability of runoff data since 1973 obtained from the Water Survey of Canada stream gauge located near the mouth of the river.

(ii) the availabilty of chemical analysis data from the Frobisher Bay reservoir which gave an indication of the chemistry of the surface waters in the area.

(iii) the availability of laboratory and living facilities provided by the Department of Indian and Northern Affairs.

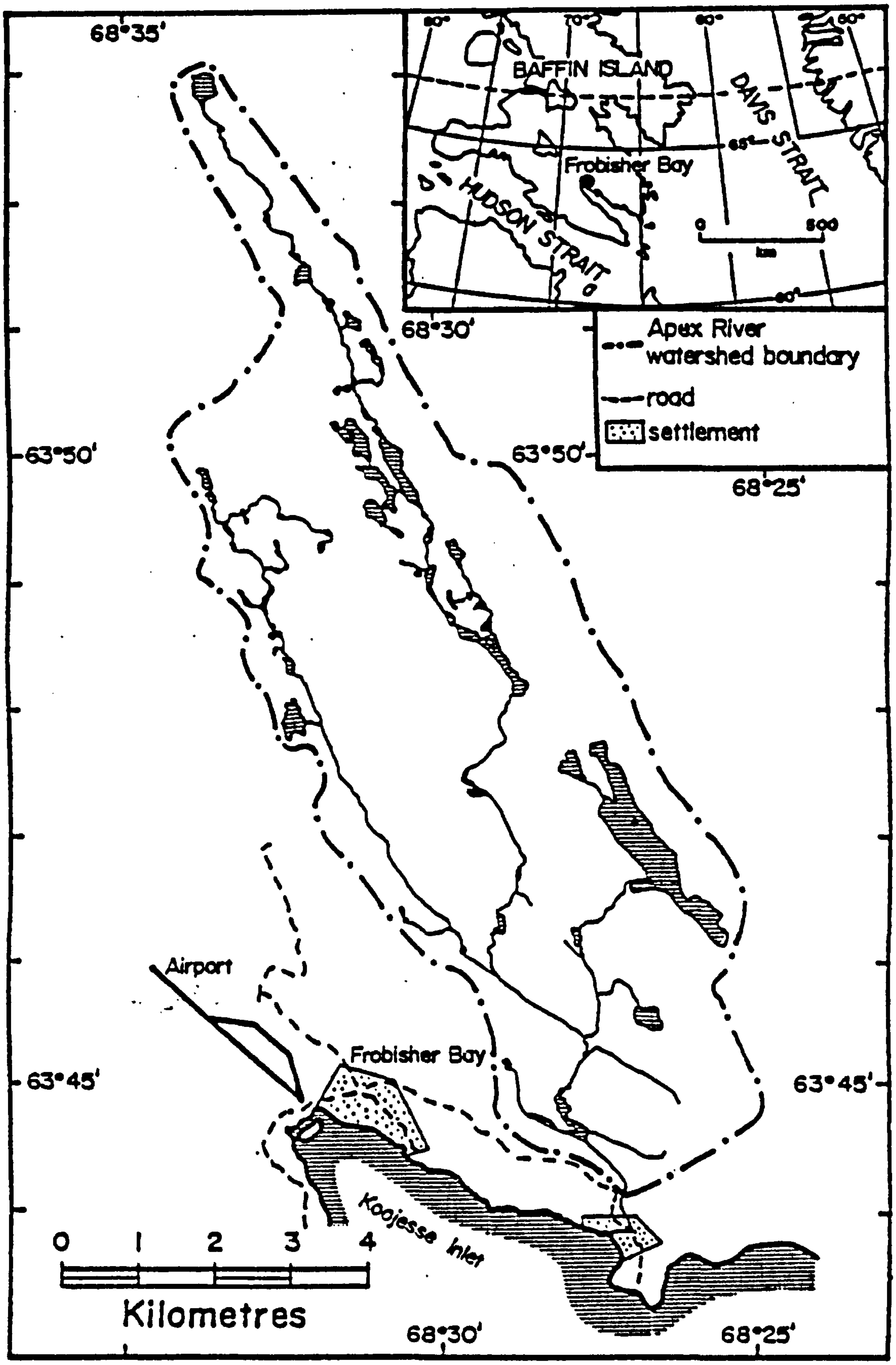


Figure 1.1: Location of the Apex River watershed.

1.2.2 Physiography and Drainage

The Apex River, draining an area of approximately 60 km ^{2}, discharges into Koojesse Inlet, near the head of Frobisher Bay. The study area is located in part of the Hall Upland near its western boundary with the Foxe Lowland. The Hall Upland is one of two uplands which form part of the Baffin Upland physiographic province (Blackadar, 1967) (Figure 1.2).

The Hall Upland is a southwesterly-inclined area with elevations exceeding 600 m in most areas but decreasing to less than 300 m near the settlement of Frobisher Bay where it merges with the Foxe Lowland (Blackadar, 1967). The elevation within the Apex River watershed ranges from about 365 m at the headwaters to about 35 m at the gauging station. Figure 1.3 shows typical relief in the study area.

Rivers in the upland form deeply incised valleys near the coast. The Apex River is no exception. It flows through two gorges which cover about 4 km of its final 8 km. The hydrological regime is typical of permafrost areas. The impermeability of the frozen ground results in the occurrence of many small, shallow ponds and lakes as well as other poor-drainage features such as muskeg. Figure 1.4 shows typical drainage characteristics in the study area.

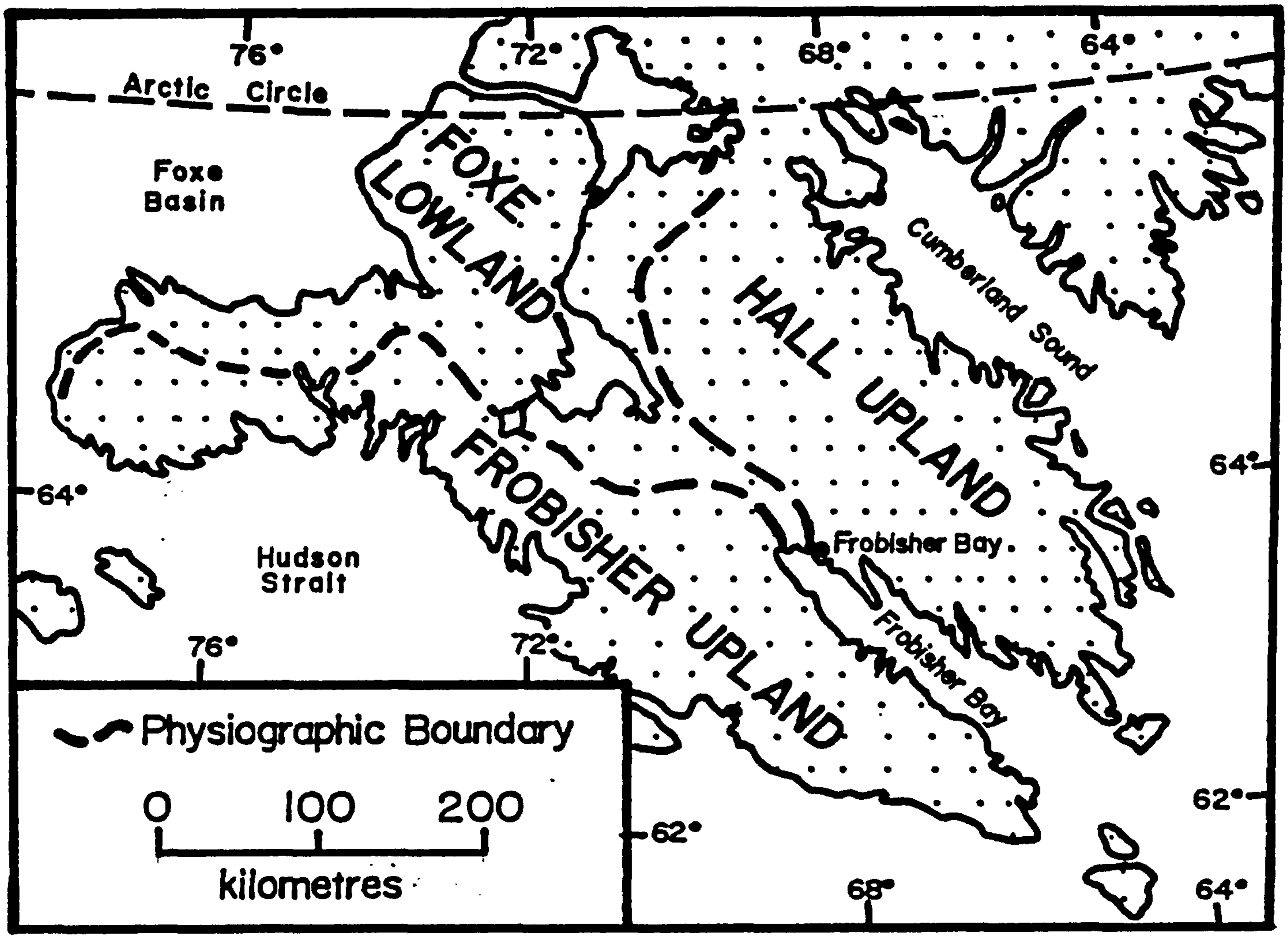


Figure 1.2: Physiographic regions of southern Baffin Island (after Blackadar, 1967).

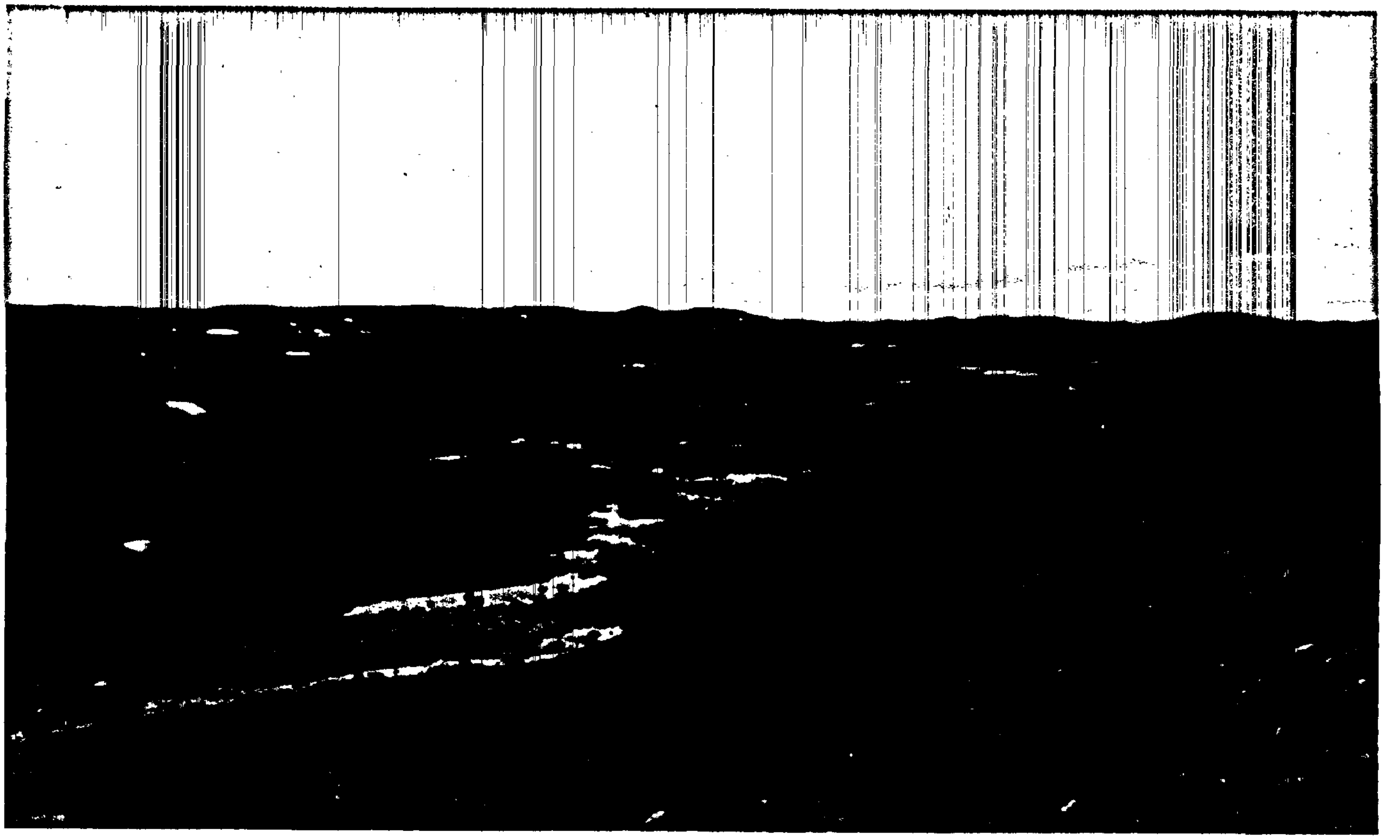


Figure 1.3: Photograph showing typical relief of the Apex River watershed.

Figure 1.4: Photograph showing typical drainage of the Apex River watershed.

1.2.3 Geology

Most of the southern part of Baffin Island is part of the geologic region known as the Canadian Shield. The Precambrian bedrock of the area around the Apex River consists of quartz-feldspar gneiss (Blackadar, 1967).

The bedrock surface has been extensively modified by Quaternary glaciation (Blackadar, 1967) leaving glacial drift over the northern and eastern portions of the watershed (Figure 1.5). The drift material within the watershed is mainly end moraines and moraine veneer (Squires, 1984), and is composed of material ranging from sand-sized particles to boulders. Figure 1.6 shows boulder-sized surficial material which typically covers the valleys in the northern part of the watershed. Other surficial deposits, including colluvial, fluvial, glaciofluvial and lacustrine types (Squires, 1984), are found in the rest of the watershed (Figure 1.5). The rolling bedrock hills have been smoothed by glacial action and appear as a succession of parallel ridges trending northwest.

Southern Baffin Island lies in the continuous permafrost zone (Figure 1.7). Brown (1974) defines permafrost as the thermal condition of earth materials when the temperature remains below 0°C continuously for more than one year. In the continuous zone permafrost occurs everywhere beneath the ground surface and roughly corresponds with the -5°C isotherm of mean annual ground

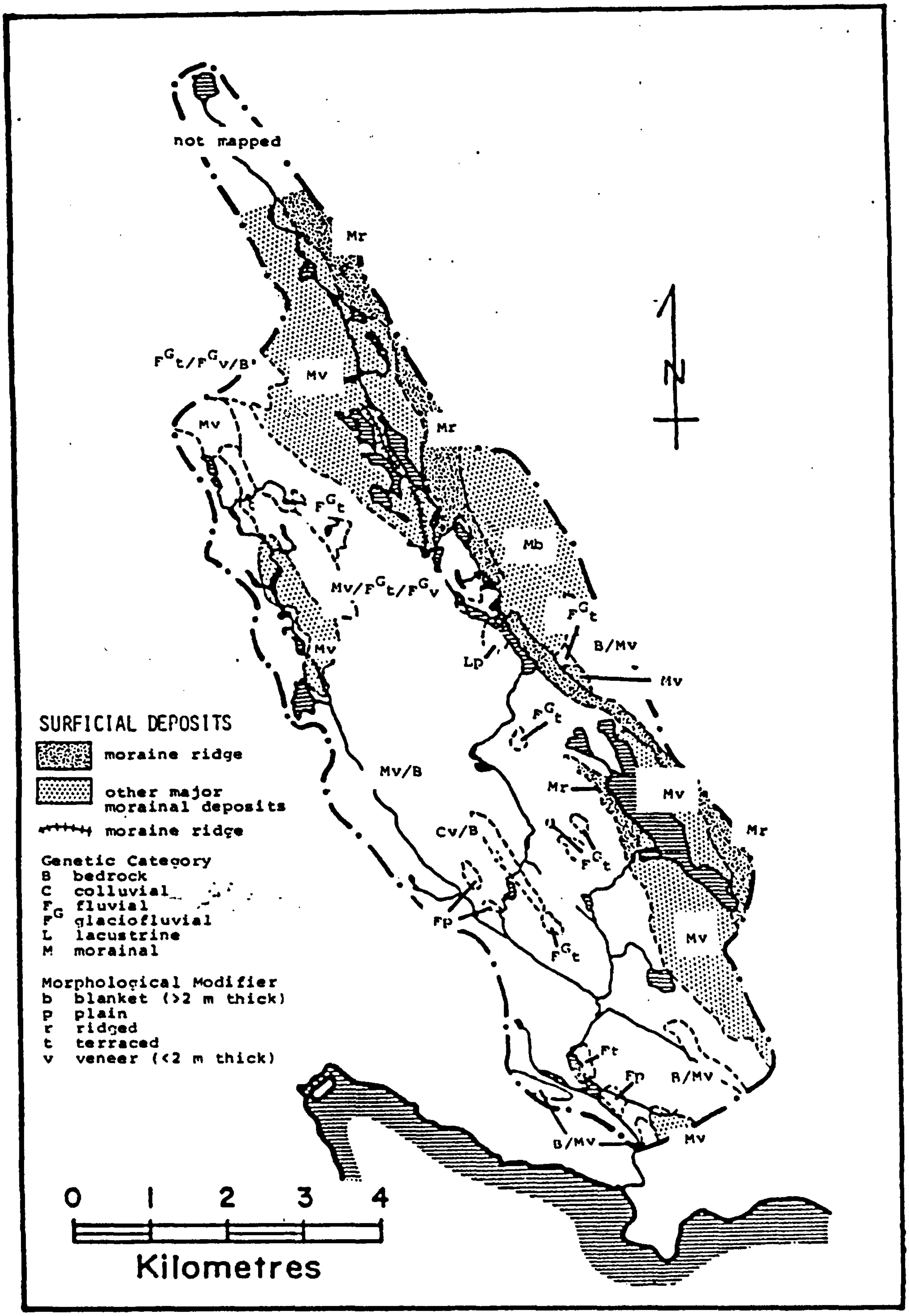


Figure 1.5: Surficial geology of the Apex River watershed (after Squires, 1984).

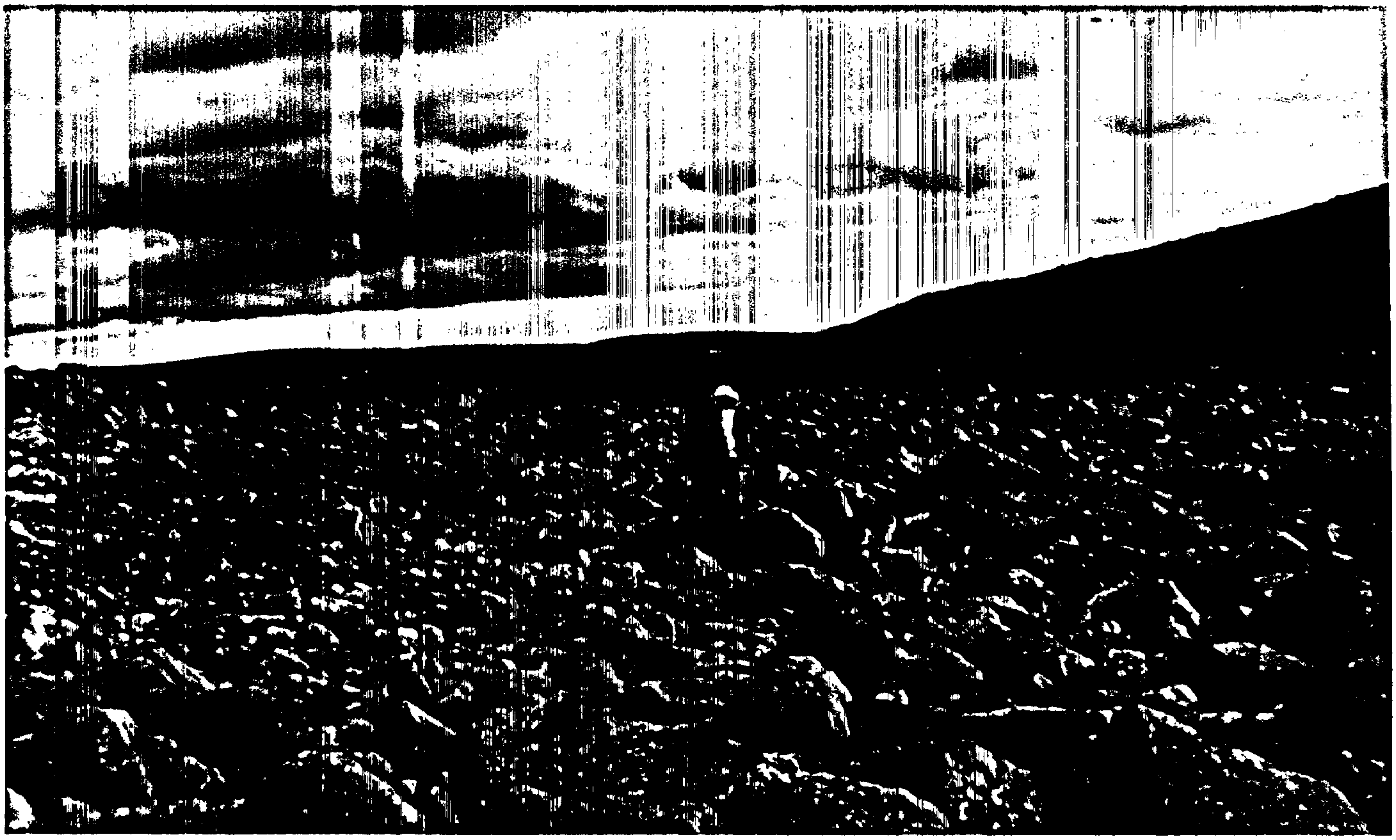
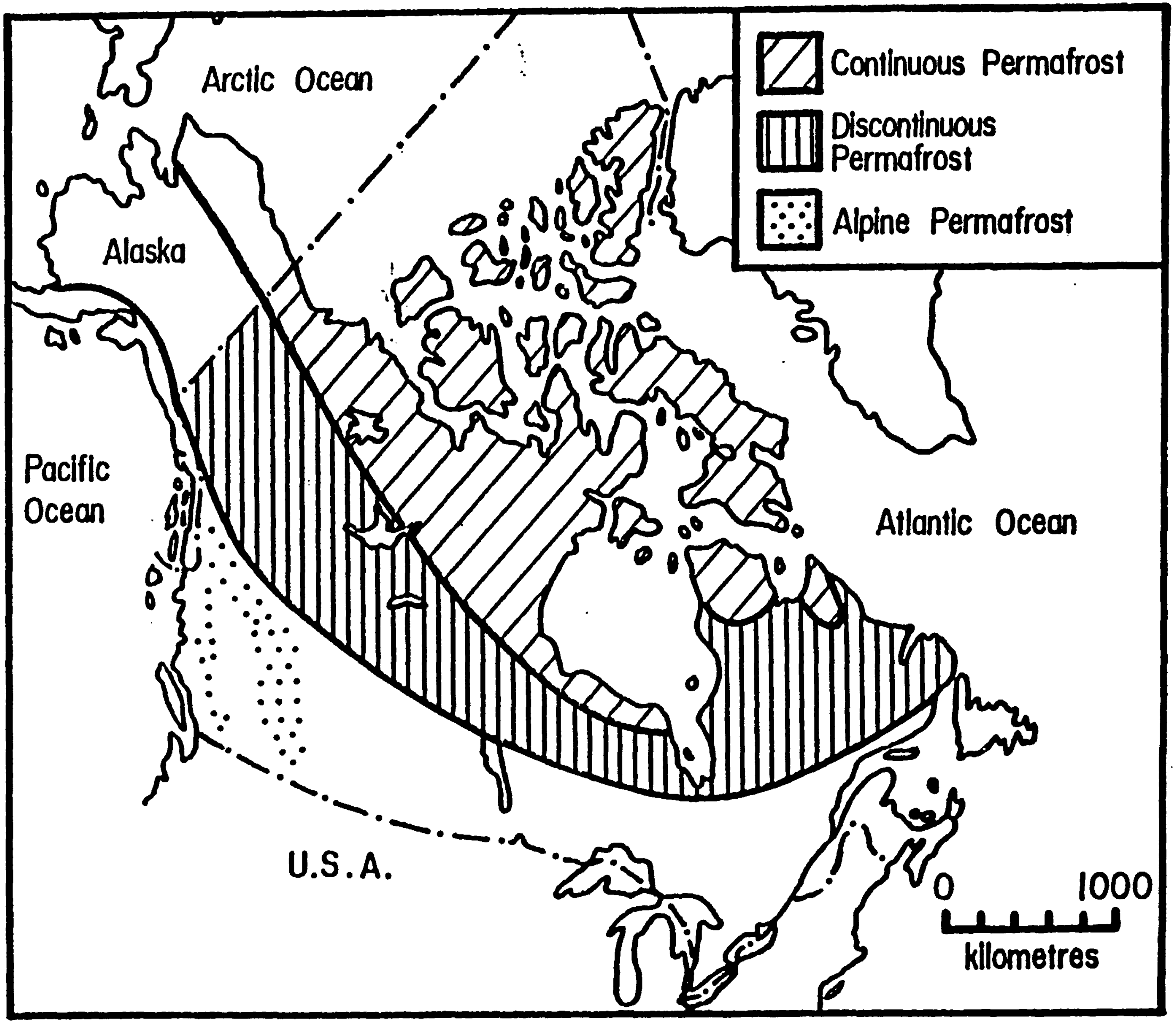


Figure 1.6: Photograph of boulder cover in the northern part of the watershed.

Figure 1.7: Permafrost map of Canada (Michel, 1982).



temperature (Brown, 1970).

Permafrost and its effects on hydrology are discussed in detail in a later section.

1.2.4 Climate

The Frobisher Bay area is, as is much of the Canadian Arctic, a cold, dry region. Its mean daily temperature and mean annual precipitation are -9.3° C and 432.6 mm, respectively (Environment Canada, 1984). Other climatological data are summarized in Table 1.1. From these data it can be seen that approximately 60% of the total annual precipitation falls in the form of snow. The remaining 40% falls as rain, essentially during the four summer months: June, July, August and September. These same four months are also the only months of the year for which the daily mean temperature is above freezing.

The amount of water made available to the hydrologic system is likely to be even greater than the data in Table 1.1 suggest. Studies by Walker and Lake (1975) and Woo and Marsh (1978) indicate that winter snowfall in the Arctic may be significantly underestimated by as much as 50% according to Woo and Marsh, and from 200-400% according to Black (1954; referenced in Maxwell, 1980). The main problem in obtaining accurate measurements of snowfall is dealing with wind-blown snow. In many instances it is difficult to distinguish between a period of falling snow and a period of blowing snow (Maxwell, 1980).

Table 1.1: Climatological Data for Frobisher Bay, N.W.T. (Environment Canada, 1984).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
TEMPERATURE (°C)													
MAXIMUM	-21.5	-21.5	-17.9	-9.4	0.2	6.6	11.4	10.3	5.0	-2.1	-9.0	-17.6	-5.5
MINIMUM	-29.7	-30.3	-27.5	-19.1	-6.6	0.3	3.7	3.4	-0.3	-7.8	-16.9	-25.9	-13.1
MEAN	-25.6	-25.9	-22.7	-14.3	-3.2	3.4	7.6	6.9	2.4	-5.0	-13.0	-21.8	-9.3
PRECIPITATION													
RAINFALL (mm)	0.3	0.1	T	0.1	2.0	28.6	62.9	58.4	32.6	6.2	0.9	T	192.1
SNOWFALL (cm)	27.6	24.4	25.3	28.7	23.6	10.1	0.3	0.4	13.9	39.7	36.8	24.7	255.5
TOTAL (mm)	26.1	23.3	23.3	26.4	25.3	39.4	63.3	58.9	46.0	44.1	34.4	22.1	432.6

Normal Period: 1951-1980

The cold temperatures of the Frobisher Bay area result in a short runoff season. Snowmelt usually begins in late May or early June. Lakes in the area usually are ice free by mid-July and freeze up by mid-October (Maxwell, 1980).

1.2.5 Vegetation

The severe climate of the arctic is mainly responsible for the dearth of vegetation around Frobisher Bay. The mean frost-free period is only fifty-nine days (Hare and Thomas, 1979). As a result, vegetation is limited to that classified as tundra vegetation (Maxwell, 1980). Included in this group and found in the Apex River watershed are lower plants such as mosses and lichens and numerous varieties of low-lying grasses, herbs and shrubs such as dwarf birch and willows (Hebert, 1982; Maxwell, 1980).

1.3 Structure of This Report

The next chapters will provide some background on the different streamflow generation hypotheses, permafrost hydrology and techniques used in streamflow analysis. Following these chapters, the methods used in this study will be outlined and the results, discussion, conclusions and recommendations of the study will be presented.

2. MECHANISMS OF STREAMFLOW GENERATION

The increased discharge of a stream as a result of precipitation or snowmelt appears to be a reasonably simple relationship. However, the exact way in which precipitation is converted to streamflow is not well understood. Contrasting theories have been proposed to describe the mechanisms of streamflow generation with considerable disagreement surrounding the relative contributions of "new" rain or snowmelt water and "old" groundwater to the storm hydrograph (Pearce et al., 1985).

According to Fontes (1980), one of the most important problems of hydrology is the determination of the relative contributions of input waters to flood discharge. He sees this information as having applications to predicting surface water chemistry, to determining residence times of groundwater and to the evaluation of snowmelt to runoff. Sklash (1978) sees this knowledge as part of a solution to what he calls the three problems facing hydrologists today: the forecasting of storm runoff peaks, the maintenance of acceptable stream water quality standards, and the prediction of the effect of runoff quantity and quality brought about by watershed modifications.

Traditional theories used to explain storm runoff include: overland flow (Horton, 1933), partial area overland flow (Betson, 1964), variable source area saturation overland flow (Dunne and Black, 1970a,b), and variable source area subsurface flow (U.S. Forest Service, 1961). Pearce et al. (1985) have put together a good summary chart of studies supporting the variable source area mechanisms of storm runoff generation (Figure 2.1). Freeze (1974) dismisses groundwater contributions simply as sustaining streamflow between periods of storm runoff. Other researchers, however, have used natural ionic and environmental isotope tracers to demonstrate the dominance of the groundwater component to storm runoff (Table 2.1).

Sklash and Farvolden (1979) proposed a mechanism known as 'the groundwater ridging hypothesis' to explain the significant contribution of groundwater to storm and snowmelt runoff. Further work by Wilson (1981), Attanayake (1983), Gillham (1984), and Abdul and Gillham (1984) has supported this hypothesis.

The mechanisms mentioned above are described in more detail in the following sections.

2.1 Hortonian Overland Flow

Horton's (1933) concept of streamflow generation was based on surface runoff resulting from precipitation at an intensity greater than the rate at which the ground could absorb it. The infiltration capacity, as he termed it, decreased with time to a steady rate as pores were filled and the surface was compacted by the force of the falling raindrops. Excess rainfall then accumulates on the compacted surface and flows overland in sheets to streams at speeds and in quantities sufficient to cause the rapid rises

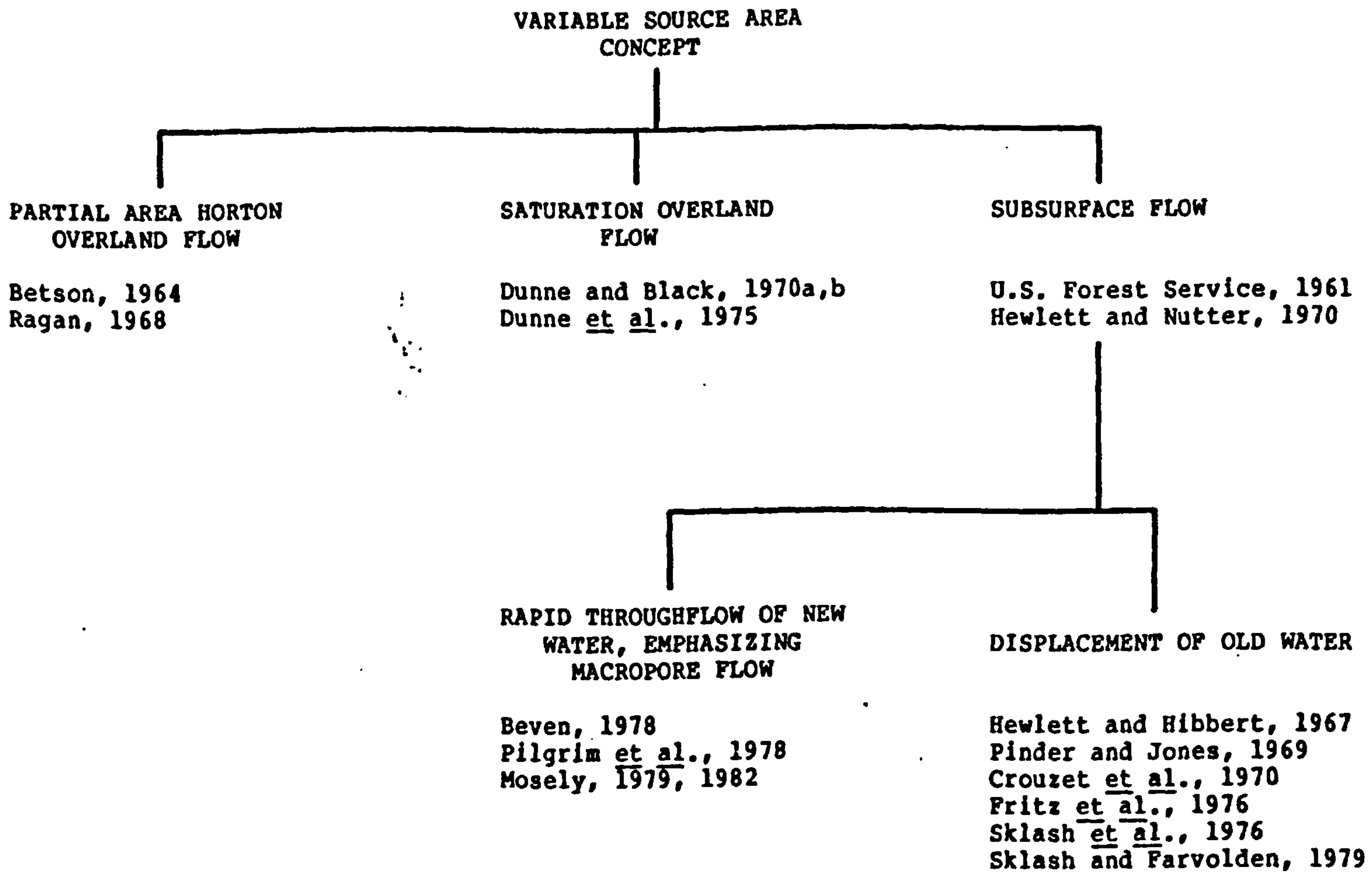


Figure 2.1: Some studies of variable source area mechanisms of runoff generation (after Pearce _et al._, 1985).

Table 2.1: Mass balance hydrograph separation studies.

AUTHOR(S)	LOCATION	AREA (km^2)	EVENT	TYPE OF STUDY	GROUNDWATER CONTRIBUTION (%)	
					TO TOTAL FLOW	TO PEAK FLOW
Newbury et al., 1969	Manitoba	22	R	C		50-70
Pinder and Jones, 1969	Nova Scotia	6.5,13.5	R	C	-	32-42
Crouzet et al., 1970	France	5.7-91	R	I	54-99	
Dincer et al., 1970	Czechoslovakia	2.65	S	I	major	60
Visocky, 1970	Illinois	246	R	C		25
Nakamura, 1971	Japan	10.3	R	C		25
Martinec et al., 1974	Switzerland	43.3	S	I	60	64
Cherry et al., 1975	Manitoba	22	R	I	90	60
	Ontario	1.8-700	R	I	50	50-70
Holecek and Noujaim, 1975	Alberta	0.06	S	R		54-64
Fritz et al., 1976	Manitoba	22	R	C,I	90	60
	Ontario	1.8-700	R	C,I	40-45	
Sklash et al., 1976	Ontario	73-700	R	C,I	70	52-75
Sklash and Farvolden, 1979	Ontario	1	R	I		60-80
	Quebec	1.2	R	I		65-80
Hermann and Stichler, 1980	Germany	18.7	R,S	I		70-80
Sklash and Farvolden, 1980	Alberta	9.2	R,S	I		65-75
	Ontario	1				>80
Rodhe, 1981	Sweden	4.0,6.6	R,S	I	70-90	
Sklash and Farvolden, 1982	Quebec	3.9	R	I		>85
	Ontario	1				>80
Stichler and Hermann, 1982	Germany	18.7	R	C,I	75	54-90
Duysings et al., 1983	Netherlands	0.115	R,S	C		59
Rodhe, 1983a	Sweden	0.03-0.04	R,S	I	67-95	
Rodhe, 1983b	Sweden	0.03-6.6	R,S	I	41-100	
Bottomley et al., 1985	Ontario	3.0,10.5	R,S	C,I	40-90	
Hooper and Shoemaker, 1985	New Hampshire	0.4	R,S	C,I		60-75
Kobayashi, 1985	Japan	13	S	T		80-85
Pearce et al., 1985	New Zealand	5.9	R	C,I	97	
Sklash et al., 1985	New Zealand		R	C,I	74-86	
Vreeland et al., 1985	Virginia	5	R	C,I	>60	

Event: R=Rain S=Snowmelt
Type of study: C=Chemical I=Isotopic R=Radioactive Tracer T=Temperature

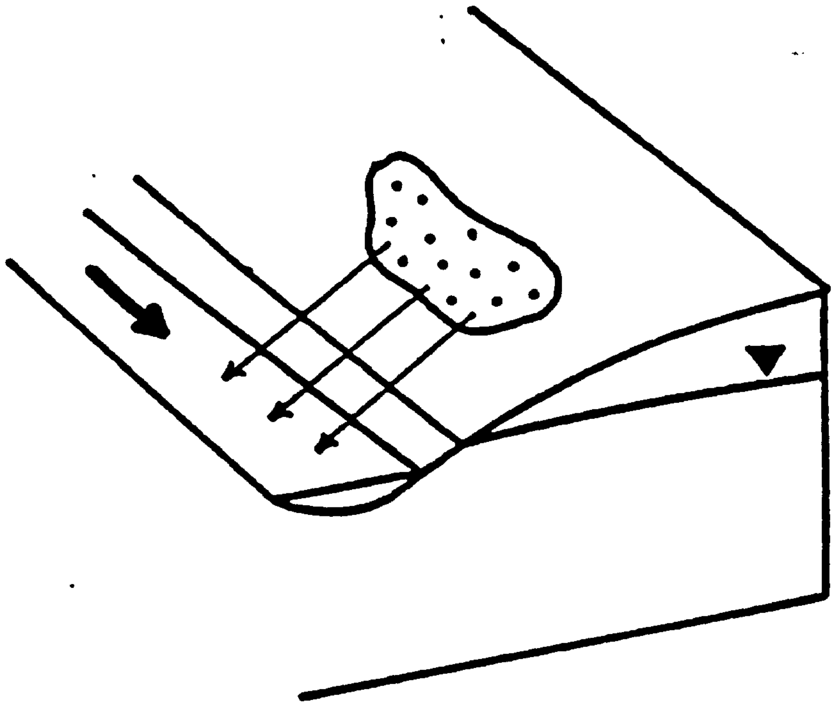
in streamflow in response to storm events (Freeze, 1974).

The theory, as proposed by Horton, presumed that most rainfall events exceeded the infiltration capacity and that overland flow occurred over large areas of a watershed. Field studies have demonstrated that overland flow is a rare occurrence in humid, vegetated areas (Betson, 1964; Ragan, 1968; Dunne and Black, 1970a,b; Freeze, 1972b). Ward (1982) described Horton's work as being, "based on a number of false premises...", and having had, "...a significant and stifling influence on the development of hydrology for three or four decades...".

2.2 Partial Area Overland Flow

Betson (1964) developed a non-linear mathematical model to equate the difference between rainfall and runoff to hydrologic variables. The results of his model concluded that overland flow only occurs on small but relatively consistent parts of a watershed; as little as 5% of the area. This concept, known as the partial area overland flow theory, is illustrated in Figure 2.2.

The generating mechanism for partial area overland flow is the same as that for Hortonian overland flow. That is, surface runoff is produced in areas where the rainfall intensity is greater than the infiltration capacity of the soil. According to Betson (1964) this usually occurs in areas with a shallow A soil horizon or exposed bedrock, and these areas may be widespread throughout a basin.



Overland flow occurs on areas of the watershed where the input of rain or snowmelt water exceeds the infiltration capacity of the watershed materials.

Figure 2.2: Partial area overland flow concept.

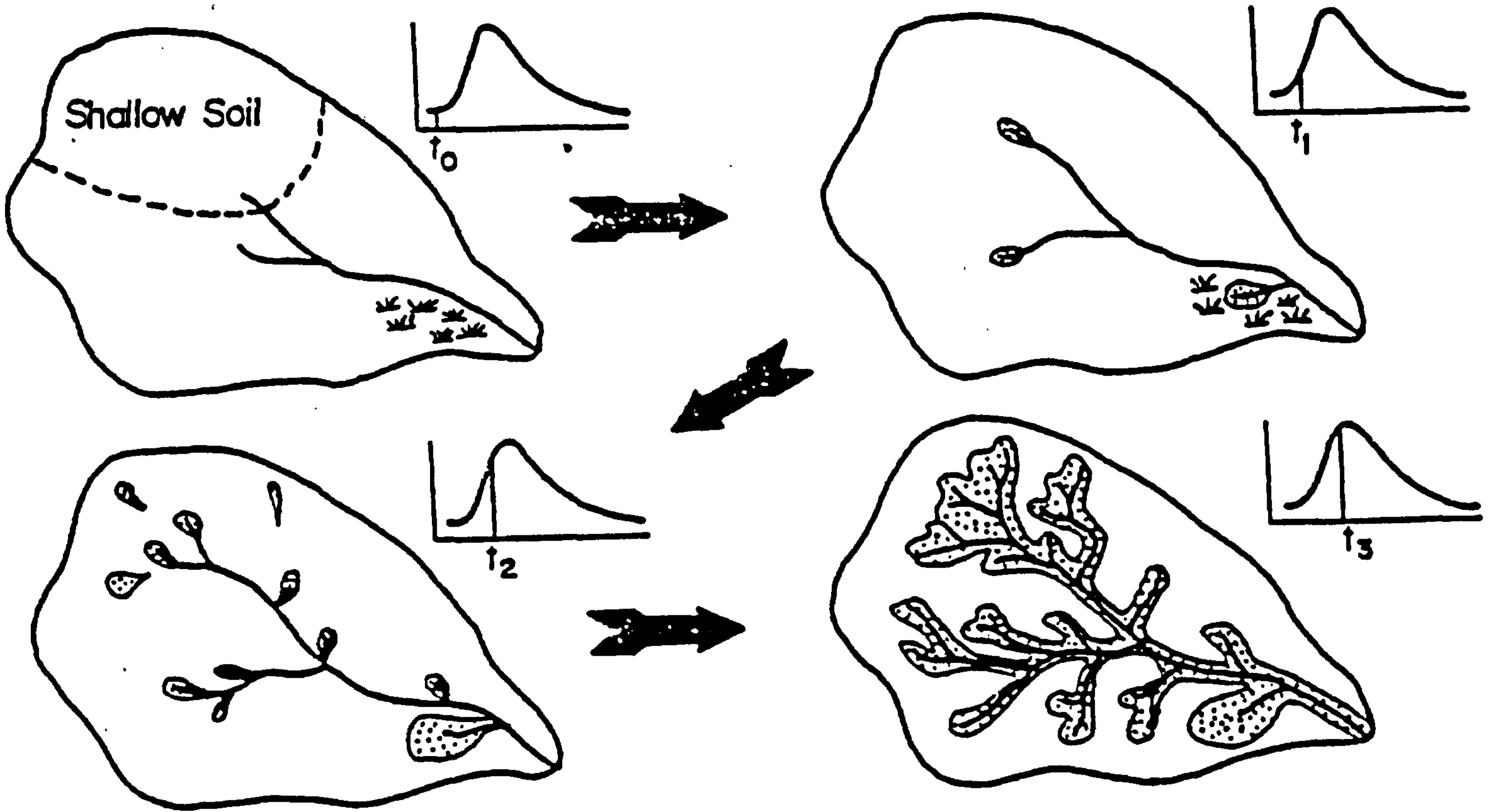
2.3 Variable Source Area Subsurface Flow

Hewlett (U.S. Forest Service, 1961) and Hewlett and Hibbert (1967) proposed the variable source area subsurface flow concept when their field evidence indicated that no overland flow occurred even during heavy storms. They maintained that most precipitation even during intense and prolonged storms is infiltrated into the soil surface. Then, as a result of infiltration and throughflow in the soil profile, the near stream and lower valley slopes become saturated as the groundwater table reaches the surface. Hewlett and Hibbert (1967) suggested that much of the water transmitted to the stream may be groundwater which has been displaced by the infiltrating precipitation.

Hewlett and Nutter (1970) described this process as an expanding channel network where the stream channel "reaches out" to tap the subsurface flow systems (Figure 2.3). They suggested that the rapidly expanding channel is capable of transmitting subsurface flow to the stream fast enough to sustain the upland storm hydrograph.

Other researchers (e.g. Pilgrim _et al_., 1978; Beven, 1978; Mosley, 1979, 1982) have suggested that infiltrated rainfall may flow to the stream through "macropores" (Pearce _et al_., 1985) resulting in storm runoff dominated by event water.

The variable source area subsurface flow concept differs from the partial area concept in that the partial areas are thought of as being fixed in size and location



Lower valley slopes become saturated as groundwater is displaced to the stream during storm events.

Figure 2.3: Variable source area subsurface flow (Hewlett and Nutter, 1970).

while the variable source areas can expand, and contract, into near stream areas (Freeze, 1974). Also, partial areas transmit water in a manner similar to Hortonian overland flow; the soil is saturated from above and subsequent rainfall flows overland to the stream. In the variable source area concept, subsurface flow is the mechanism by which the water is transmitted to the channel (Freeze, 1974).

While Hewlett, Hibbert, Nutter and others maintained that the variable source area subsurface flow concept is the main source of storm flow, other researchers have questioned whether sufficient quantities of water can be transmitted fast enough to produce the observed response (Freeze, 1974). Dunne and Black (1970a,b) contended that subsurface inputs are, "too small, too late and too insensitive to fluctuations of rainfall intensity to add significantly to stormflow in the channel ...". Dunne (1978) acknowledged the occurrence of subsurface stormflow, however, he considered that other mechanisms such as variable source area overland flow could provide runoff more quickly.

2.4 Variable Source Area Overland Flow

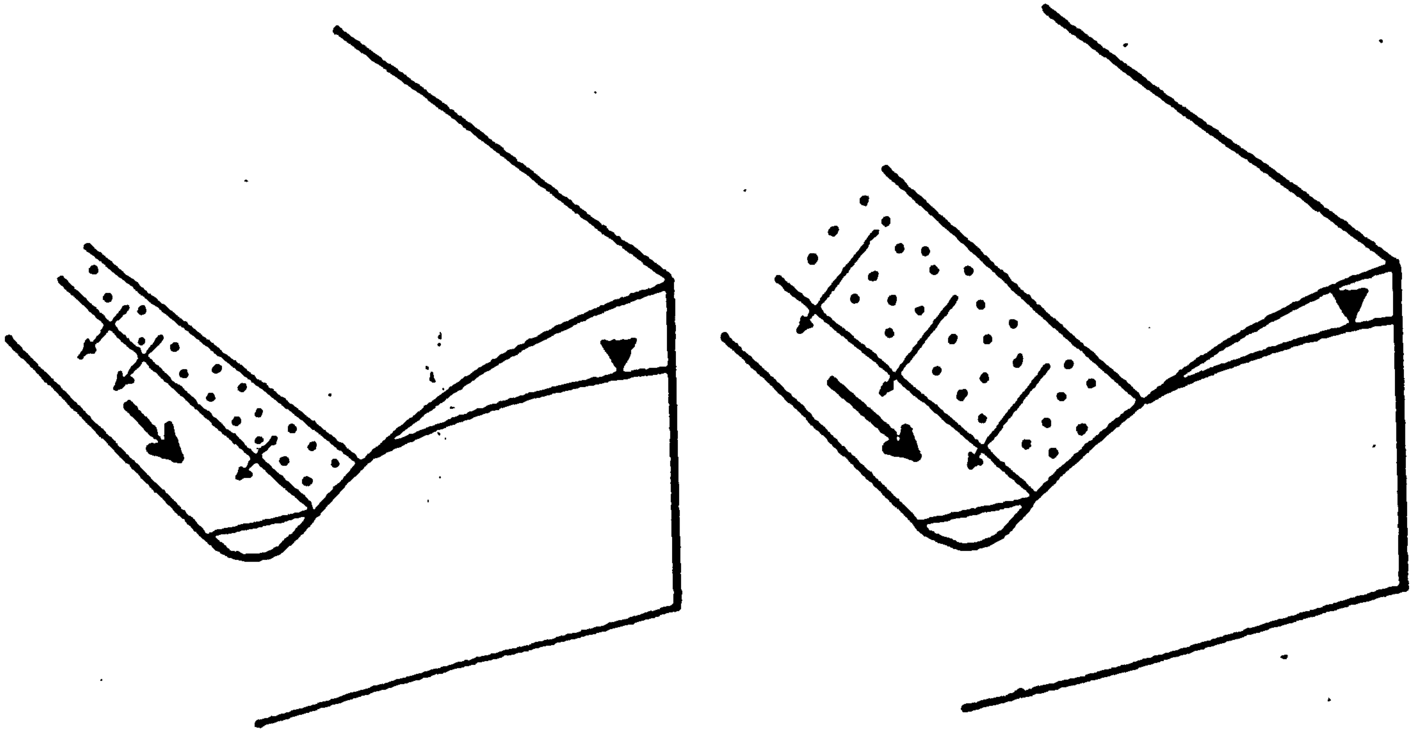
Many recent studies (Ragan, 1968; Dunne and Black, 1970a,b; Freeze, 1972a,b; Dunne _et_ _al_., 1975) have identified the variable source area overland flow mechanism as the primary source of storm flow. This type of overland flow is generated by precipitation falling on small portions of the watershed which have become saturated during rainfall events (Figure 2.4).

Unlike the partial area concept where saturation of the soil is from infiltrating precipitation, the soil in the variable source areas is saturated by rising groundwater (Freeze, 1974). The location of these variable sources is a function of topography and hydrogeologic conditions, and are often wetland areas usually located near the stream (Ragan, 1968; Freeze, 1974). The size of the variable source areas can grow or shrink in response to climatic conditions.

The source of the runoff is unclear. Freeze (1974) felt that it is totally a result of rainfall falling onto the wetlands, with groundwater only controlling the size of the wetland area. Dunne and Black (1970b), on the other hand, said it is a combination of rain falling directly on the wetland surface and water coming out of the ground. In any case, both agree that this mechanism can transmit sufficient quantities of water fast enough to account for the rapid hydrograph response.

2.5 Channel Interception

Channel interception is a comparatively minor contributor to the storm flow system. It is simply the precipitation which falls directly into the stream. It is seen as a minor input because of the relatively small areal extent of the stream surface in comparison with the entire watershed.



Overland flow occurs on near-stream areas that have been saturated by rising groundwater during storms.

Figure 2.4: Variable source area overland flow.

According to Sklash (1978) channel interception may be important during brief storms following long periods of drought when other mechanisms may not be operative.

2.6 Groundwater Flow

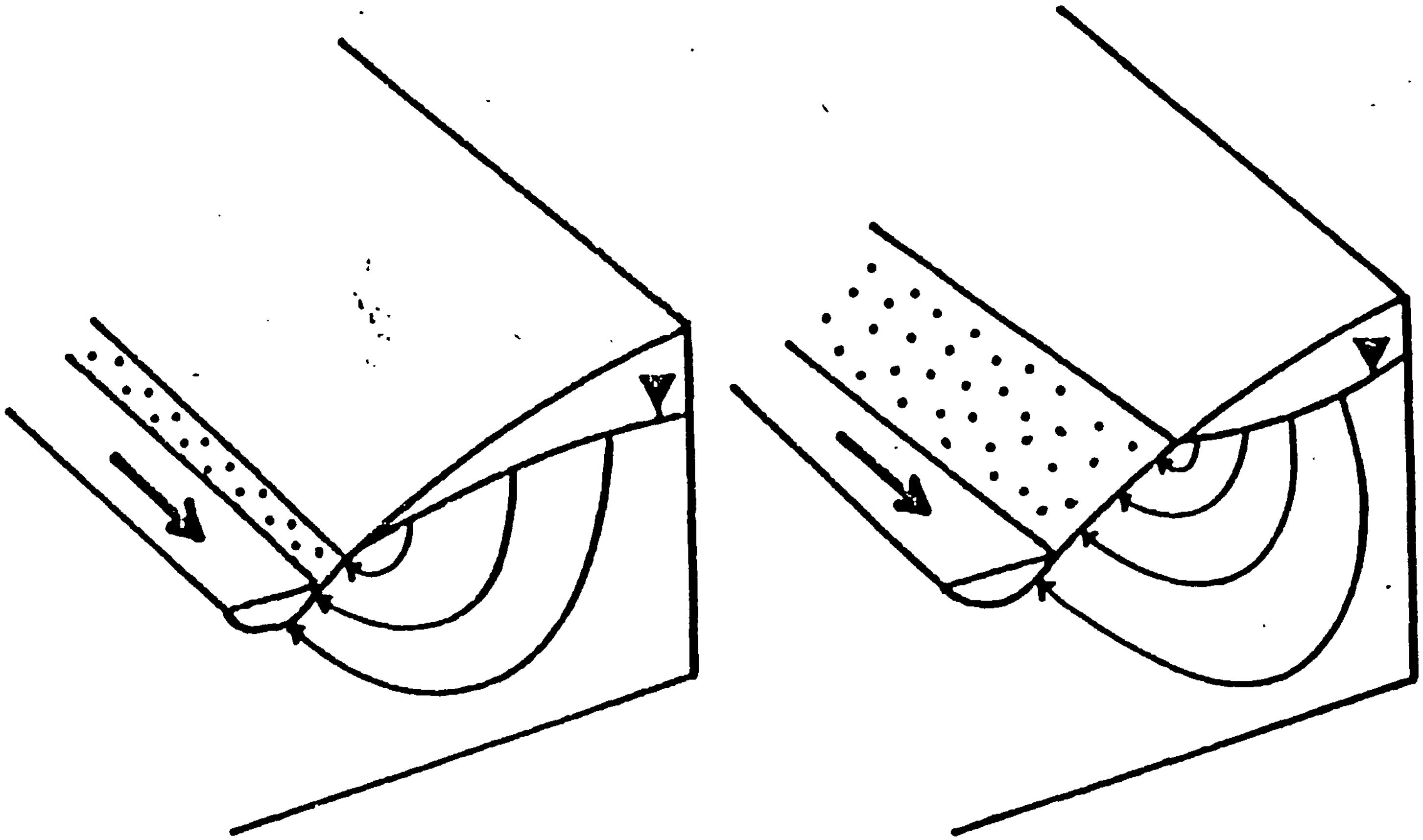
Freeze (1974) defined groundwater flow as water from the permanent saturated subsurface water flow system that discharges into the stream channel. It can be discharged to the stream through near-stream springs or seeps, through the seepage face or directly through the stream bed.

Much of the streamflow research has not considered groundwater as a major contributor to the storm runoff process (Betson, 1964; Dunne and Black, 1970; and others). Freeze (1974) stated that, "...true groundwater flow is seldom the cause of the major runoff during storms ...".

Numerous workers have, however, determined groundwater to be a significant source of storm runoff. Pinder and Jones (1969) used chemical mass balances to determine that groundwater constituted between 32 and 42% of peak discharge in three small Nova Scotia watersheds. Dincer _et_ _al_. (1970), Martinec _et_ _al_. (1974), Fritz _et_ _al_. (1976), Sklash _et_ _al_. (1976), Sklash and Farvolden (1979, 1980) and others have used environmental isotope studies involving oxygen-18, deuterium and tritium as tracers in rain and snowmelt runoff to indicate groundwater dominance. O'Brien (1980), using hydrometric data, showed that about 93% of the total annual discharge of two wetland controlled basins in Massachusetts was derived from groundwater.

These studies all concluded that groundwater was a significant factor in the storm runoff process but the exact mechanism which allowed the groundwater to appear so quickly in the stream was unclear (Martinec, 1975). Sklash and Farvolden (1979) presented a possible solution to this uncertainty with the introduction of their groundwater ridging hypothesis. This hypothesis suggests that surrounding perennial and transient discharge areas, the water table and associated capillary fringe lie near the ground surface. With the addition of infiltrating rain or snowmelt, the tension saturated capillary fringe is converted to a ridge-shaped pressure-saturated zone of groundwater (Figure 2.5). The formation of this groundwater ridge provides an increased hydraulic gradient and a larger discharge area which allows for a larger discharge of groundwater to the stream.

This phenomenon was noted earlier by Ragan (1968) who found, "... a ridge in the groundwater table ... formed along the length of the ... stream.". Hewlett (1969) observed, "... an ephemeral rise in the groundwater table ... (which) helps produce the storm hydrograph.". O'Brien (1980) reported a rapid rise in both the groundwater table and stream levels in response to precipitation. Abdul and Gillham (1984) used laboratory experiments to examine the role of the capillary fringe in the runoff process and concluded that the response of the water table to



Infiltrating rain or snowmelt water converts the tension-saturated capillary fringe to a ridge-shaped pressure-saturated zone of groundwater.

Figure 2.5: Groundwater ridging hypothesis.

precipitation can result in a rapid increase in groundwater discharge to the stream. Other recent studies by Wilson (1981), Sklash and Wilson (1982) and Attanayake (1983) supported the hypothesis of Sklash and Farvolden (1979) that groundwater ridging is a reasonable explanation of the mechanism of groundwater flow during storm runoff.

3. PERMAFROST HYDROLOGY

3.1 The Nature of Permafrost

Permafrost is a term used to describe perennially frozen ground. Brown (1974) defined permafrost as the thermal condition of earth materials such as rock and soil when the temperature remains below 0°C continuously for more than one year.

One-half of Canada's land surface is underlain by permafrost (Brown, 1970, 1974) which can be subdivided into two principal zones: the continuous and discontinuous permafrost zones (Figure 1.7). In the discontinuous zone, permafrost exists together with unfrozen ground. In the continuous permafrost zone, permafrost exists everywhere beneath the earth's surface in varying thicknesses. Unfrozen zones which can exist within the permafrost are known as taliks. Discontinuous permafrost ranges in thickness from a few centimetres near the southern limit to about 60 m at the boundary with the continuous zone. The continuous zone varies in thickness from approximately 60 m to 1000 m in the northern Arctic Islands (Brown, 1974). Figure 3.1 is a schematic diagram which illustrates the two principal zones and their variation in thickness; generally increasing from south to north.

A third zone of permafrost, alpine permafrost, occurs in areas of high altitude (Brown, 1970). Alpine permafrost tends to be more extensive on north-facing slopes than on south facing slopes owing to the angle of incoming solar

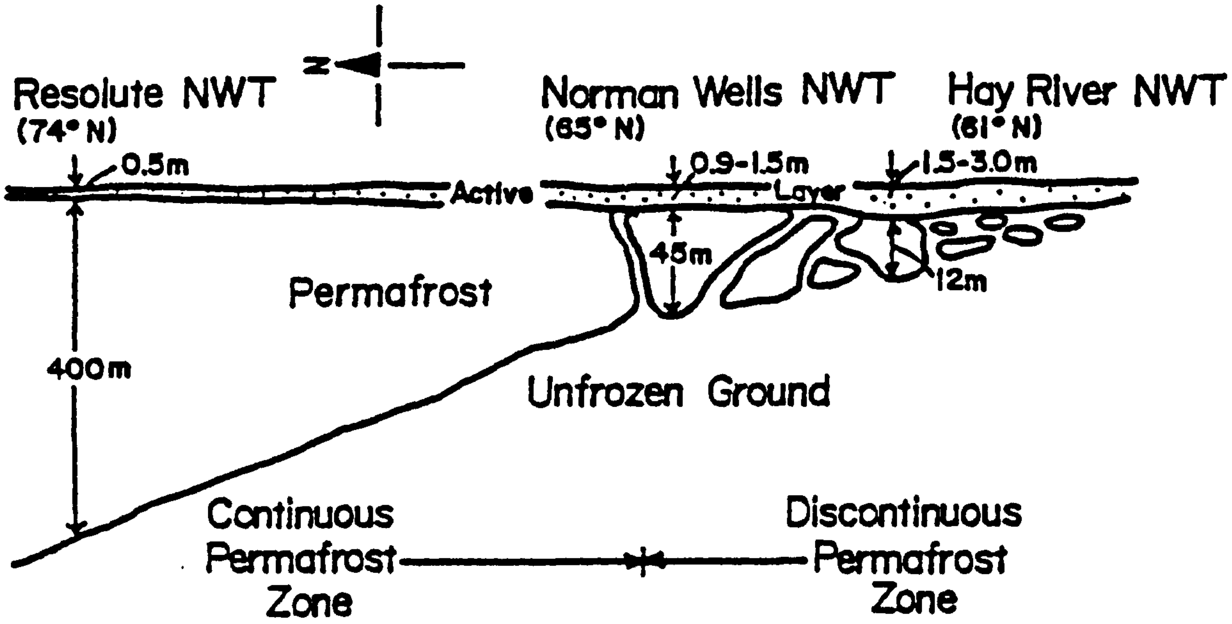


Figure 3.1: Longitudinal cross section of permafrost zones in Canada (Brown, 1970).

radiation. The extent of the alpine permafrost zone is shown in Figure 1.7.

In permafrost areas, the uppermost part of the ground is called the active zone. The active layer (Figure 3.1) is the layer of ground above the permafrost table which thaws in the summer and freezes in the winter. Thicknesses of the active zone vary locally (Brown et al., 1981) but they are generally within the range of 0.3 - 1.0 m in the continuous permafrost zone and 0.5 - 3.0 m in the discontinuous zone (Brown, 1974). At Frobisher Bay, the active layer thickness ranges from 0.6 - 1.8 m (Maxwell, 1980).

Minor alterations to the ground thermal regime of permafrost areas can drastically change the physical stability of the system. These alterations may be natural, such as: changes in climatic conditions, landslides and fires; or man-made: clearing of surface vegetation or snow, altering of drainage systems and the building of structures. These changes can result in a thickening of the active zone, which Brown et al. (1981) indentify as, "... one of the most dangerous of the disruptive human activities in northern engineering projects ...". Another possible result of changes to the ground thermal regime is the formation of thermokarst topography. Thermokarst features are depressions such as thaw lakes, sinkholes and beaded streams which form by the thawing of ground ice (Brown et al., 1981).

3.2 Surface Water

Church (1974a) defined four different runoff regimes found in permafrost regions based on the source and timing of runoff: subarctic nival, arctic nival, proglacial and muskeg. Figure 3.2 compares typical hydrograph shapes for the four different runoff regimes. The subarctic nival regime is characterized by a snowmelt flood in the spring followed by low levels of flow through the rest of the summer which are punctuated by periodic rain events. The arctic nival regime occurs in continuous permafrost zones where groundwater baseflow is not likely to be important. The spring snowmelt flood is the most severe because rainfall intensities in the arctic are usually light. The proglacial regime occurs where streams derive most of their flow from glacial meltwaters. Rather than an early, intense peak discharge as in the nival regimes, discharge continues to rise during the summer as more of the glacier contributes to flow. The muskeg regime is characterized by poor drainage because of the high water retaining capacity of muskeg and its resistance to runoff. As a result, flood flows are attenuated.

The unique hydrograph shapes of the nival regimes (Figure 3.2) are the result of the thermal conditions associated with extreme latitudes. The distribution of flow is concentrated during the summer months because of the effect of snow storage (Church, 1974a). Much of the year's precipitation remains on the ground as snow and during the

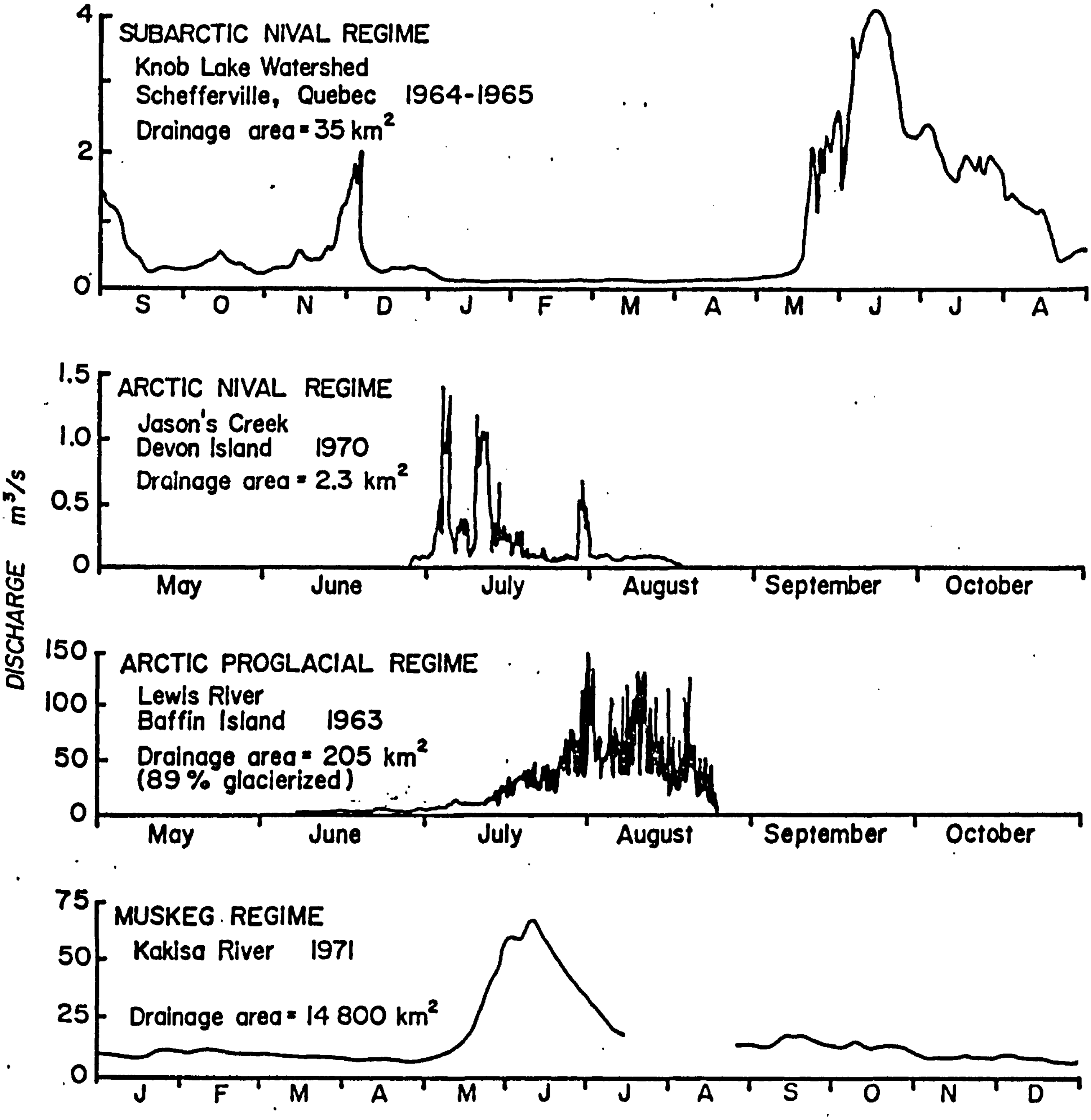


Figure 3.2: Typical hydrograph shapes of the four runoff regimes found in permafrost regions (Church, 1974a).

brief summers it is released to the stream as snowmelt.

Ground thermal conditions also affect streamflow characteristics in northern basins. Williams and van Everdingen (1973) have suggested considering frozen ground (permafrost) as a confining bed of low but finite permeability. A number of studies have used the impermeability of frozen ground to explain the response of northern streams to runoff events. Dingman (1973) identified overland flow as one of the principal sources of rainfall runoff in a small watershed in the discontinuous permafrost zone. Overland flow was said to occur because the thin active layer saturated quickly thus preventing further infiltration of rainfall. This rainfall excess ran off as overland flow. The other principal source of rainfall runoff according to Dingman (1966; 1973) was stored water in the moss cover which flowed along the impermeable (frozen) soil surface to the stream. He used this mechanism to account for the drawn out streamflow recessions he noted in his study watershed. Decay constants (see Chapter 4) for Dingman's study area were of the order of 22 h/km^2.

McCann and Cogley (1972; Cogley and McCann, 1975) used the rapid basin response and short duration of flood flow to conclude that streamflow was a result of surface runoff of rainfall or snowmelt. Newbury (1974) used runoff ratios (the ratio of runoff to rainfall) to illustrate the low capacity of permafrost watersheds for interflow or groundwater storage.

The overland flow described by Dingman (1973) and Brown et al. (1968) is consistent with the variable source area overland flow concept of Freeze (1972b). That is, overland flow originates in near stream source areas which can vary in size. Woo (1976) and Lewkowicz and French (1982a), however, determined that overland flow occurs in areas with heavy snow accumulation, and these areas are topographically controlled. Only areas downslope of these areas produced overland flow. The occurrence of surface flow in the form of overland flow or rill runoff is also controlled by slope material and slope profile (Woo and Steer, 1982).

The importance of subsurface flow was raised by Woo and Steer (1982) who indicated that it dominates during most summers. Steer and Woo (1983) used surface and subsurface collection devices to determine the relative inputs of surface and subsurface flow. Subsurface flow was found to be about 40% of the surface runoff. The studies by Lewkowicz and French (1982a,b) portray subsurface flow through the active layer as a significant contributor to streamflow. They noted in the second study that there was a very rapid decline in subsurface flow following the end of snowmelt, indicating that snowmelt was the major source of subsurface water.

Lewkowicz and French (1982b) used electrical conductance as an estimate of solute concentration to study variations in water chemistry in the active layer. They found an increase of solute concentration with depth and in general, these values were high (200-240 mg/l). They also noted relatively low values of solute concentration during snowmelt and increasing at low subsurface flow discharges. Brown et al. (1968) measured major cation concentrations and conductivity of stream discharge and noted an inverse relationship between chemical concentration and discharge. Church (1974b) presented water quality data from surface waters in various environments on Baffin Island. He concluded that in a non-glacial environment, waters carry very little dissolved load (5 mg/l) which probably reflects the composition of precipitation inputs.

3.3 Groundwater

Tolstikhin and Tolstikhin (1974) have identified three types of groundwater in permafrost areas which they classified according to their location relative to the permafrost layer. Suprapermafrost groundwater is found above the permafrost in the active zone and originates from meltwater, rain and surface water seepage. Since suprapermafrost water is in the active zone, it undergoes annual freezing and thawing. Intrapermafrost groundwater is found in taliks within the permafrost layer and originated from above or below. Subpermafrost groundwater is found beneath the permafrost layer.

Groundwater flow in permafrost zones has historically been regarded as an insignificant contributor to streamflow because of the low hydraulic conductivity of frozen soils

(Figure 3.3) (Williams and van Everdingen, 1973). However, as early as 1963, Brandon (1963) presented evidence of groundwater flow in a permafrost environment. He cited the existence of springs and data from drilled wells as part of his argument. He also metioned that baseflow in rivers, and the inverse relationship between conductivity and discharge was proof of groundwater input. Van Everdingen (1974) presented the same evidence to support the existence of groundwater flow. Kalanin (1968) used water balance data for a permafrost basin in the U.S.S.R. to show that the formation of floods fed by groundwater are comparable in size to those produced by surface flow.

Dingman (1966) suggested the possibility that melting of the active layer may be capable of supporting small baseflows. Later, however, he concluded (Dingman, 1973) that water from the thawing active layer does not contribute to streamflow. Lewkowicz and French (1982b) acknowledged the possibility of active layer melt to sustain low baseflows, but dismissed this source of flow as unimportant.

The melting of ground ice was considered by Woo and Steer (1982) to be of local importance only, with the majority of water in the subsurface flow system originating from snowmelt or rainfall. They later noted (Woo and Steer, 1983), however, a hydrograph rise during a snow-free, rain-free period. This rise was attributed to the formation of a groundwater "pocket" due to uneven melting of the active layer, and this pocket eventually melted some sills

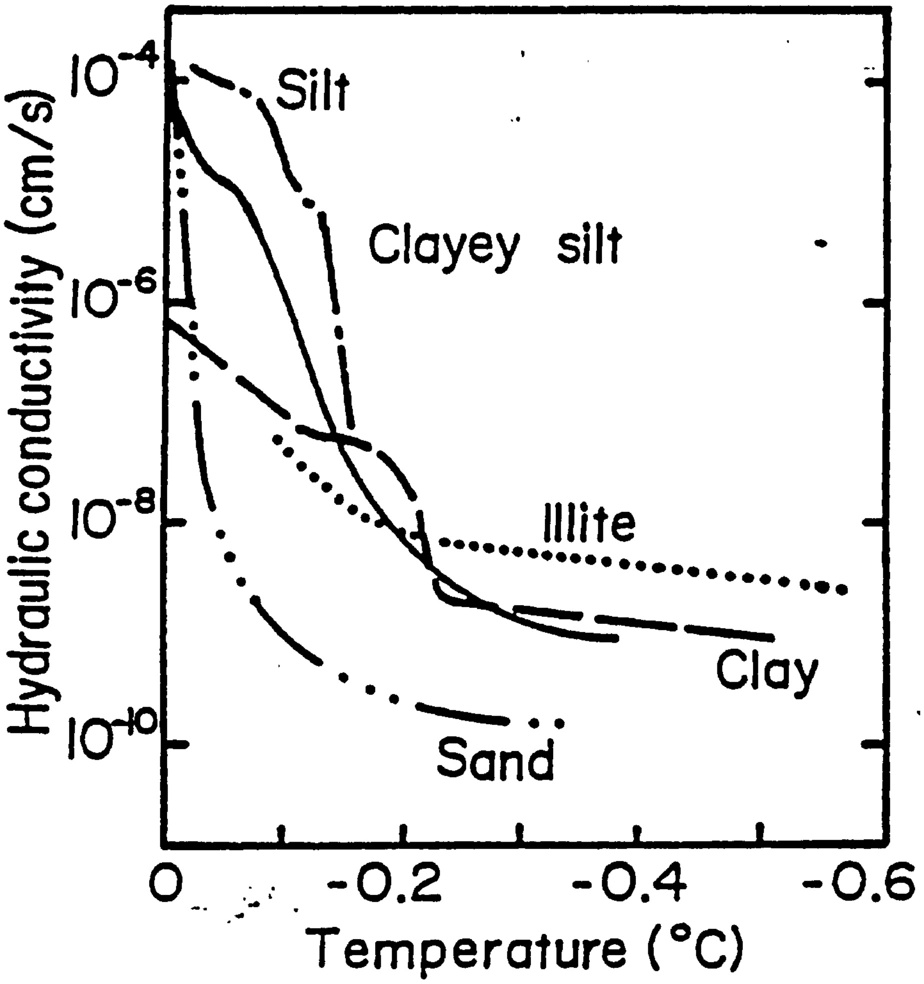


Figure 3.3: Relationship of soil temperature and hydraulic conductivity for various soils (Burt and Williams, 1976).

in the frost table, releasing the water downslope to the stream. Since the area had been snow-free for over two weeks and without rain for over one week it was felt that the water could not be from either source. They concluded from a dye tracer study that the source of groundwater was partly from outside the topographical divide due to the uneven melting of the active layer. They felt this mechanism could also operate during the rain and snowmelt periods to contribute to stream flow.

4. METHODS OF STREAMFLOW ANALYSIS

Early methods of stream flow analysis have centred on predicting runoff extremes such as flood peaks and low flows. Many of the techniques developed were statistically derived using historical records of high and low flows to predict the likelihood of flows of specific magnitudes. Two examples of this type of technique which are discussed in the following section are peak (or low) flow frequency analysis and flow duration analysis. These analyses are still used in assessing risk in the design and construction of large engineering structures.

Other early methods of streamflow analysis have focused on examining the discharge record or hydrograph of a stream. Analysis of the falling limb of the hydrograph, known as recession analysis, has been used to obtain a variety of information. It has been used to estimate groundwater recharge (Meyboom, 1961), to predict low flows (Raudkivi, 1979) and as a comparative characteristic of watersheds (Holtan and Overton, 1963). Another approach to streamflow analysis has been the separation of the components which contribute to streamflow. Historically, methods used for hydrograph separation were purely arbitrary and relied on graphical separation to distinguish direct runoff and baseflow components (Gray and Wigham, 1970). Direct runoff encompasses surface runoff and interflow (subsurface stormflow) while baseflow is dominantly composed of groundwater (Linsley _et al._, 1958).

More recently, techniques have been developed which use the distinct chemical and/or isotopic characteristics of the different sources of streamflow to separate them into "old" groundwater and "new" direct runoff components.

The following sections describe the various procedures used in this study: peak flow frequency, flow duration, recession analysis and hydrograph separation by graphical and chemical/isotopic mass balance.

4.1 Peak Flow Frequency Analysis

Frequency analyses are methods of estimating streamflows using runoff records. They are usually directed towards the prediction of maximum (flood) and minimum (drought) flows.

In the design of hydraulic structures, it is standard practice to design on the basis of discharge rates of a specified return period. The return period (or recurrence interval) is the number of years on average during which a specified discharge is likely to be equalled or exceeded (or less than) (Gray and Wigham, 1970). The return period is determined from

$$T = 1/p = (n+1)/m \tag{4.1}$$

where: T is the return period, p is the probability of occurrence of a flow of specified magnitude, n is the number of years of discharge records and m is the rank of a particular flow with rank $m=1$ being the highest flow. T is obtained by studying the entire record of stream discharge and picking out annual peaks and ranking them in order of highest to lowest. The return periods are then plotted on arithmetic probability paper (Dunne and Leopold, 1978) against the corresponding discharge and a line is fitted to the points. From this plot, the return period of a specified discharge can be read off.

A limitation to this type of analysis is that the return period does not indicate exactly when a specific flood will occur. For example, the 20-year return period flow does not mean that this flow will occur every 20 years. Instead, it indicates the probability of its occurrence in a particular year (i.e. $p = 1/T$), in this case a 5% chance. On the average, the flow will occur every 20 years.

The return period analysis is not very useful in water quality studies.

4.2 Flow Duration

Flow duration analysis is a type of frequency analysis that shows the proportion of time that a stream's discharge is greater or less than a particular value (Dunne and Leopold, 1978). The analysis is performed by plotting the cumulative distribution of the number of days a particular flow is exceeded (or lower than) against the discharge.

Flow duration curves can be prepared for any period but the most important is for an entire year using daily average flows as the basis for determining the frequency (Raudkivi, 1979). Raudkivi (1979), suggests using log-probability paper for hydrological studies because this type of paper provides good definition of the extremities. The extremities are important because they provide information about the hydrological characteristics of the watershed.

A steep slope of the entire flow duration curve indicates a stream with highly variable discharge which is typical of conditions where flow is mainly from surface runoff (Raudkivi, 1979). A shallow slope at the lower end of the curve suggests a relatively steady baseflow from groundwater storage (Figure 4.1)(Sibul, 1969). A shallow slope near the top end of the curve is characteristic of streams that have a large surface storage like lakes or swamps, or where high flows are mainly due to snowmelt (Sibul, 1969; Raudkivi, 1979).

The curves are also used to compare flow characteristics of different streams or to predict the distribution of future flows for water supply or pollution studies (Sibul, 1969).

4.3 Recession Analysis

The recession limb of a hydrograph represents the withdrawal of water from storage following the cessation of precipitation. The rate of decline of discharge has been described by the recession coefficient:

$$K = Q_{24}/Q_0 \qquad (4.2)$$

where: Q_0 is the average discharge on a certain day and Q_{24} is the discharge 24 hours later and

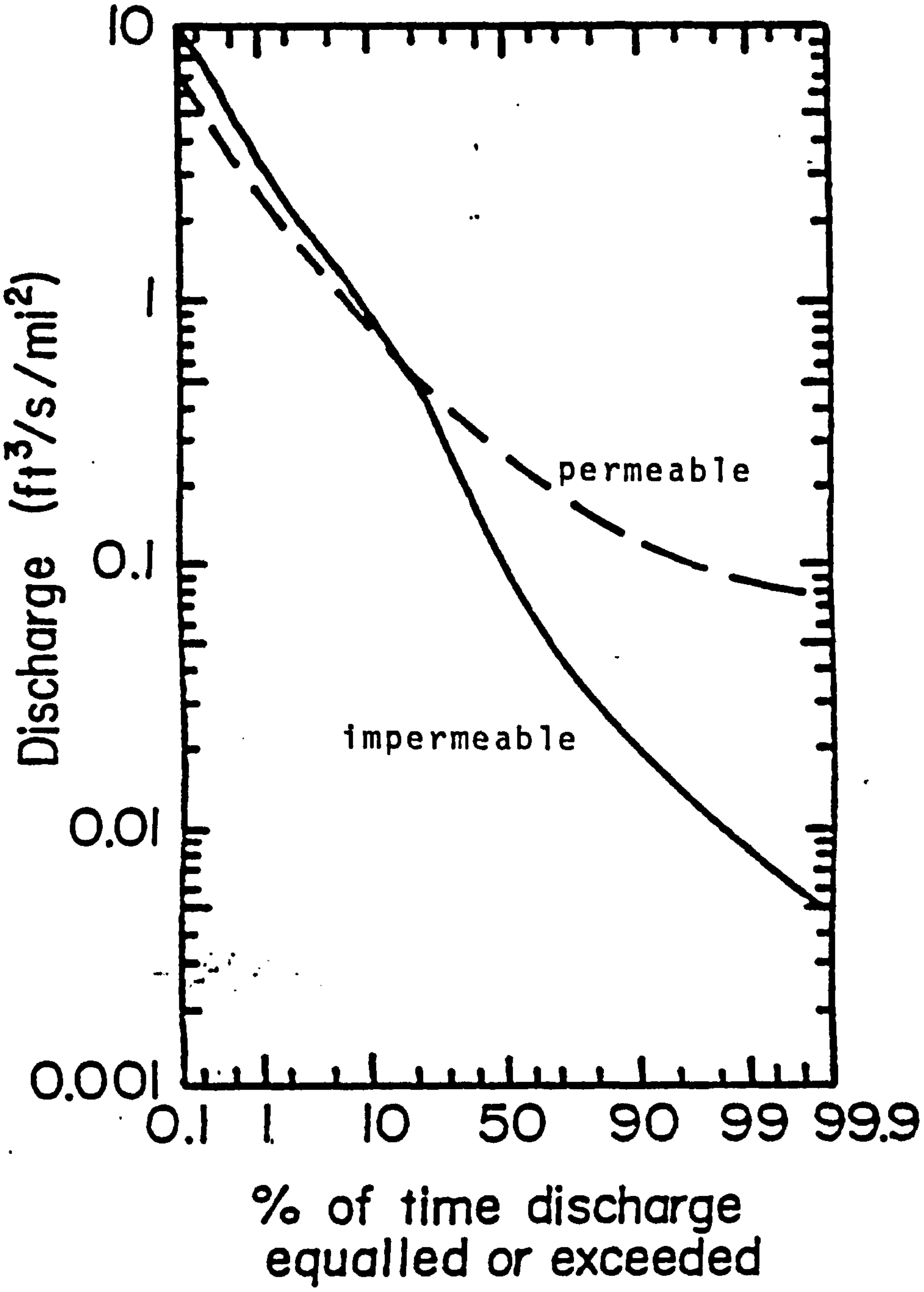


Figure 4.1: Flow duration curves for two watersheds underlain by different materials (Dunne and Leopold, 1978).

$$K = \exp(-1/m) \tag{4.3}$$

where: t is the time interval and m is variously known as the basin constant, reservoir coefficient or mean life (Martinec, 1985).

The basin constants have been used by various authors as a comparative tool to describe runoff characteristics in different watersheds (Holtan and Overton, 1963; Dingman, 1966; Anderson, 1974; Church, 1974a; Ingenkamp, 1984). A drawback to these comparisons is that many northern watersheds are fed by snowmelt until late in the summer so their recession limbs are not entirely the result of baseflow as is the case in most southern watersheds.

Recession analysis can be a very useful technique especially in northern watersheds where much of the year's precipitation is stored as snow. Since the distribution of snowfall is so variable, early summer discharges can be used to predict flows later in the summer.

4.4 Graphical Techniques

There are numerous graphical techniques of hydrograph separation which have been developed to suit the needs or models of their developers. They all, however, have one thing in common: they are all artificial and arbitrary techniques (Gray and Wigham, 1970).

Figure 4.2 illustrates three techniques for simple hydrograph separation (Gray and Wigham, 1970). Methods 1 and 3 use the baseflow recession curve as a basis for

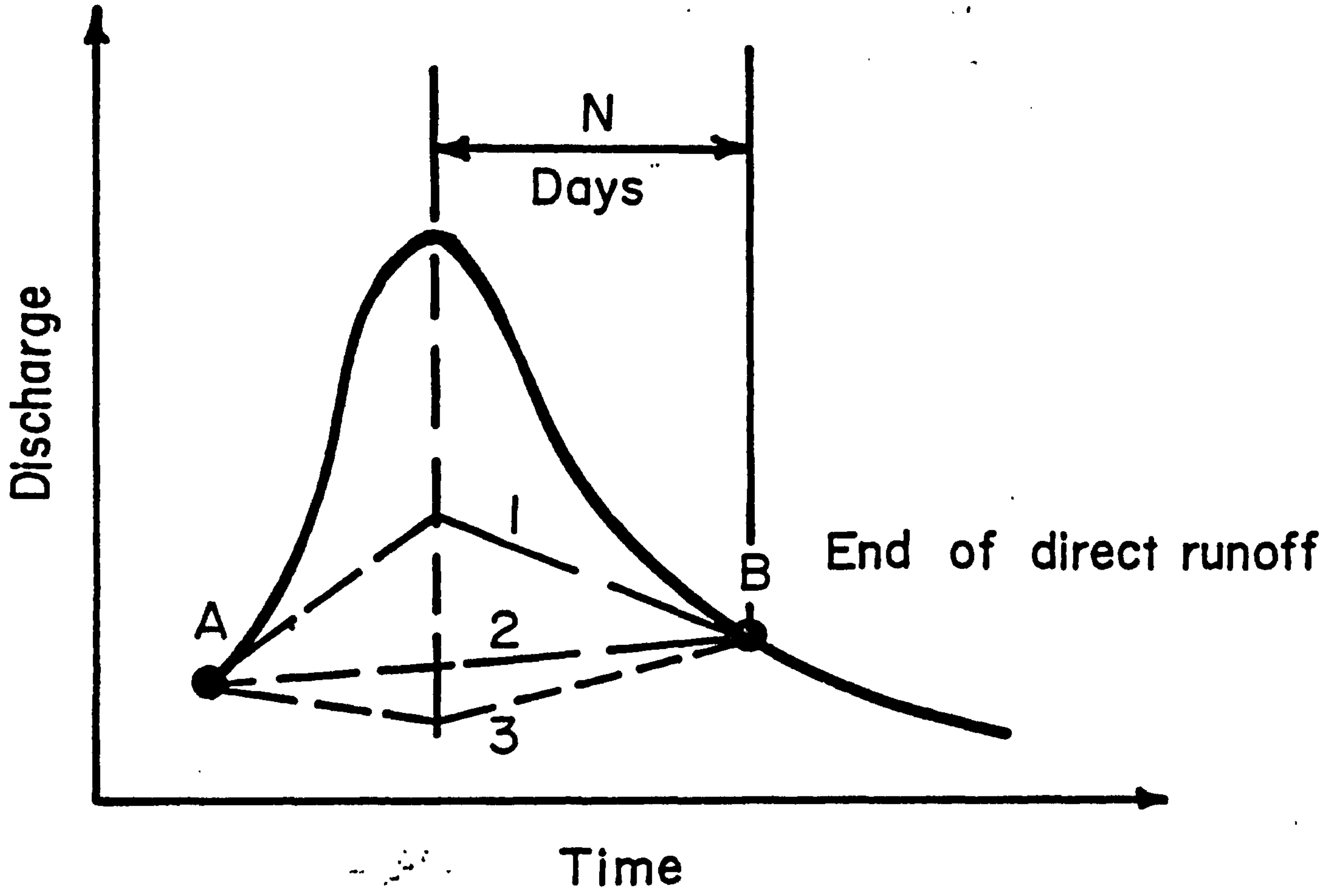


Figure 4.2: Three graphical methods of hydrograph separation (Gray and Wigham, 1970).

separation. In method 1, the baseflow recession following the peak discharge is extended back to a point under the peak. This point is then joined to the point representing the beginning of runoff. Method 3 requires the extension of the baseflow recession curve prior to the peak to a point beneath the peak. This point is then joined to a point representing the end of direct runoff, determined by an empirical relationship:

$$N = A^{0.2} \tag{4.4}$$

where: N is in days and A is the drainage area in square miles (Linsley et al., 1958). In method 2, the hydrograph is separated by joining the points representing the beginning of runoff and the end of direct runoff with a straight line.

Complex or multiple peaked hydrographs are separated using techniques similar to methods 2 and 3 (Figure 4.3). In this method, the effects of the individual events are separated by extending the total runoff recession curve (line AB in Figure 4.3). N is determined for both events and the points are connected as shown in Figure 4.3. For more complete descriptions and variations, the reader is referred to Gray and Wigham (1970) and Raudkivi (1979).

Hewlett and Hibbert (1967) proposed a graphical technique to be used for separating all hydrographs on all small watersheds (<50 km^2) into "quick" and "delayed" flow. Their technique involved constructing a straight line from the beginning of any stream rise at a constant slope of

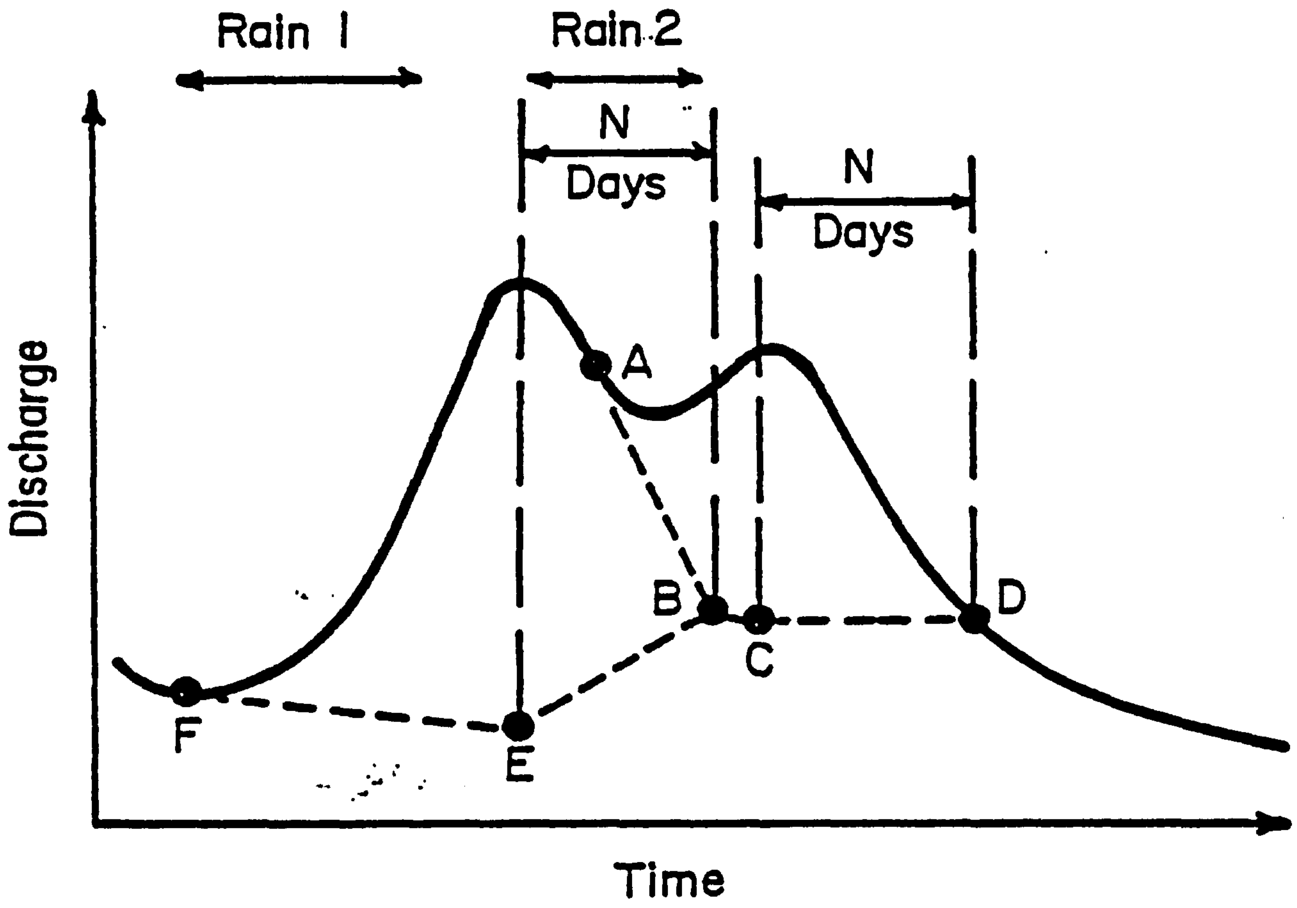


Figure 4.3: Graphical technique for separating complex hydrographs (Gray and Wigham, 1970).

0.00055 $m^3/s/km^2/h$ to where it intersects with the falling limb of the hydrograph.

4.5 Chemical Mass Balance Hydrograph Separation

The relationship between the chemical quality and discharge of a stream has long been established (Durum, 1953; Hem, 1959). Most ionic species found in stream water have concentrations which are inversely related to the discharge; that is, at high flows concentrations are low and at low flows concentrations are high (e.g. Hem, 1970; Glover and Johnson, 1974). This relationship has been described as, essentially, a dilution effect of storm flows whose input waters have low dissolved ion concentrations (Hem, 1970). Some species, like potassium, however, often show a direct relationship between concentration and discharge (Foster, 1978). Since there is a well known positive relationship between total dissolved solids and electrical conductivity (Rainwater and Thatcher, 1960; Hem, 1970; Singh and Kalra, 1975), electrical conductivity shows a similar relationship as individual ions with stream discharge.

A number of studies have used the concentration-discharge relationship to separate different hydrograph components (Voronokov, 1963; Zekster, 1963; Kunkle, 1965; Toler, 1965; Newbury _et_ _al_., 1969; Pinder and Jones, 1969; Visocky, 1970; and many others). The basis of these studies is the simultaneous solution of two mass balance equations describing the flux of water and any particular chemical species in the stream (Sklash and Farvolden, 1979):

$$Q_T = Q_N + Q_O \tag{4.5}$$

and,

$$C_T Q_T = C_N Q_N + C_O Q_O \tag{4.6}$$

where: Q is the discharge, C is the ionic concentration and subscripts T, N, and O refer to the total discharge, new water and old water, respectively. These equations simplify to:

$$Q_O = Q_T \left[(C_T - C_N)/(C_O - C_N) \right] \tag{4.7}$$

This method of analysis is based on the following assumptions (Sklash and Farvolden, 1978; Vreeland _et al._, 1985):

(i) concentrations of selected species in the old and new water components must be significantly different;

(ii) concentrations of old and new waters must be constant both areally and temporally;

(iii) vadose water and old water are chemically equivalent or the contribution of vadose water is negligible; and,

(iv) surface water storage contributions are minimal.

The first criterion is usually easily satisfied. The second, however, often is not. Nakamura (1971) noted a strong relationship between electrical conductance and flow distance of surface runoff. Pilgrim _et al_. (1979) were more blunt, referring to simple chemical mass balance methods for hydrograph separation as "misleading" because they fail to consider the relationship between chemical concentration (or electrical conductivity) and time of contact with soil.

Since concentration-contact time relationships are not well known or easy to determine, other data must be used to eliminate the uncertainties which simple chemical mass balance methods may raise. Conservative tracers, unlike chemical parameters, are unaffected by contact with soil or rock. They are only affected on mixing with waters of different isotopic content.

Pearce _et_ _al_. (1985) used a combination of electrical conductivity, chloride and isotope data to present strong evidence that new water is not what constitutes storm runoff.

The isotope method is discussed in more detail in the following section.

4.6 Isotopic Mass Balance Hydrograph Separation

Recently, environmental isotopes have been used as the tracer in mass balance studies similar to those described in the previous section (Dincer _et_ _al_., 1970; Mook _et_ _al_., 1974; Martinec _et_ _al_., 1974; Martinec, 1975; Fritz _et_ _al_. 1976; Sklash _et_ _al_., 1976; Sklash and Farvolden, 1979; Herman and Stichler, 1980; Rodhe, 1981; Sklash, 1983; Bottomley _et_ _al_., 1985; Pearce _et_ _al_., 1985; and many others). Environmental isotopes are naturally occurring isotopes whose natural abundance variations may be applied to hydrological studies (Payne and Halevey, 1968). The most commonly used isotopes in hydrologic studies are oxygen-18, deuterium and tritium (^{18}O, D, T). They are convenient to use because they are isotopes of the constituent atoms of water; oxygen and hydrogen. Because of this they are not affected by contact with soil like other chemical species dissolved in water at temperatures found in shallow and intermediate flow systems. The environmental isotope content of waters is only altered by physical processes such as mixing with isotopically different waters (Sklash, 1978).

Natural waters are made up of approximately 2000 ppm $H_2^{18}O$ and 997 680 ppm $H_2^{16}O$ (Dansgaard, 1964). Samples are analyzed by using a mass spectrometer, the details of which are available in, for example, Hoefs (1973). The concentration is expressed as a ratio (R) of the heavy to light isotope and reported in delta units (δ) as per mil differences (‰) relative to a known reference standard:

$$\delta^{18}O = \frac{(^{18}O/^{16}O)_{sample} - (^{18}O/^{16}O)_{standard}}{(^{18}O/^{16}O)_{standard}} \times 1000 \qquad (4.8)$$

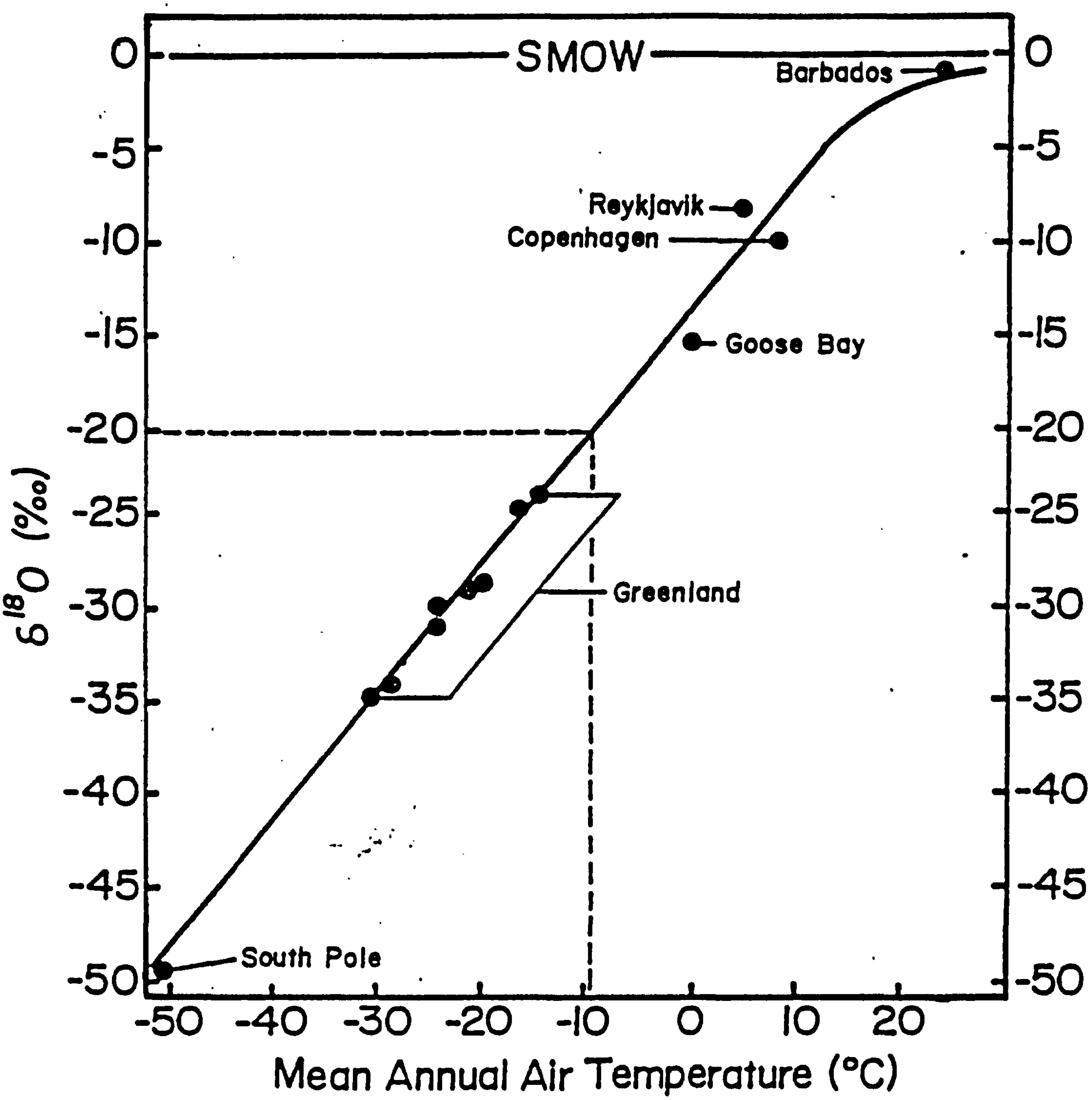
$$\delta^{18}O = \left(\frac{R_{sample}}{R_{standard}} - 1\right) \times 1000 \qquad (4.9)$$

The internationally accepted standard is known as SMOW, an acronym for Standard Mean Ocean Water (Craig, 1961).

Isotopic fractionation is any process which causes the isotopic ratios (e.g. $^{18}O/^{16}O$) in particular phases or regions to differ from one another (Drever, 1982). The most important physical process causing fractionation in the hydrologic cycle is the change of state during evaporation and condensation. The basic reason for the fractionation in water is that the vapour pressure of $H_2{}^{16}O$ is slightly higher than that of $H_2{}^{18}O$ because of the difference in mass. The different vapour pressures result in an enrichment of heavier molecules in the liquid phase and lighter molecules in the vapour phase in both the condensation and evaporation processes (Drever, 1982).

The isotopic content of precipitation is strongly controlled by temperature. Dansgaard (1964) reported a linear relationship between $\delta^{18}O$ and the surface air temperature over a wide range of temperatures (Figure 4.4). Other effects, related to temperature, which control the isotopic content of precipitation are: latitude effect, altitude effect, amount effect, seasonal effect and the distance from source effect (Sklash, 1983; Fontes, 1980; Dansgaard, 1964). In general, precipitation becomes progressively more depleted in $\delta^{18}O$ from the coast inland and from the equator towards the poles (Figure 4.5) (Drever, 1982).

The characteristics which make environmental isotopes such as oxygen-18 suitable for use as a tracer in storm runoff studies are that the isotopic content of groundwater within a watershed is generally uniform areally and that the isotopic contents of periodic precipitation events are often very different from that of the groundwater (Sklash, 1978).



The dashed line predicts the average $\delta^{18}O$ content of precipitation at Frobisher Bay from its mean annual air temperature of 9.3 C.

Figure 4.4: Relationship between $\delta^{18}O$ content in precipitation and mean annual air temperature (Dansgaard, 1964).

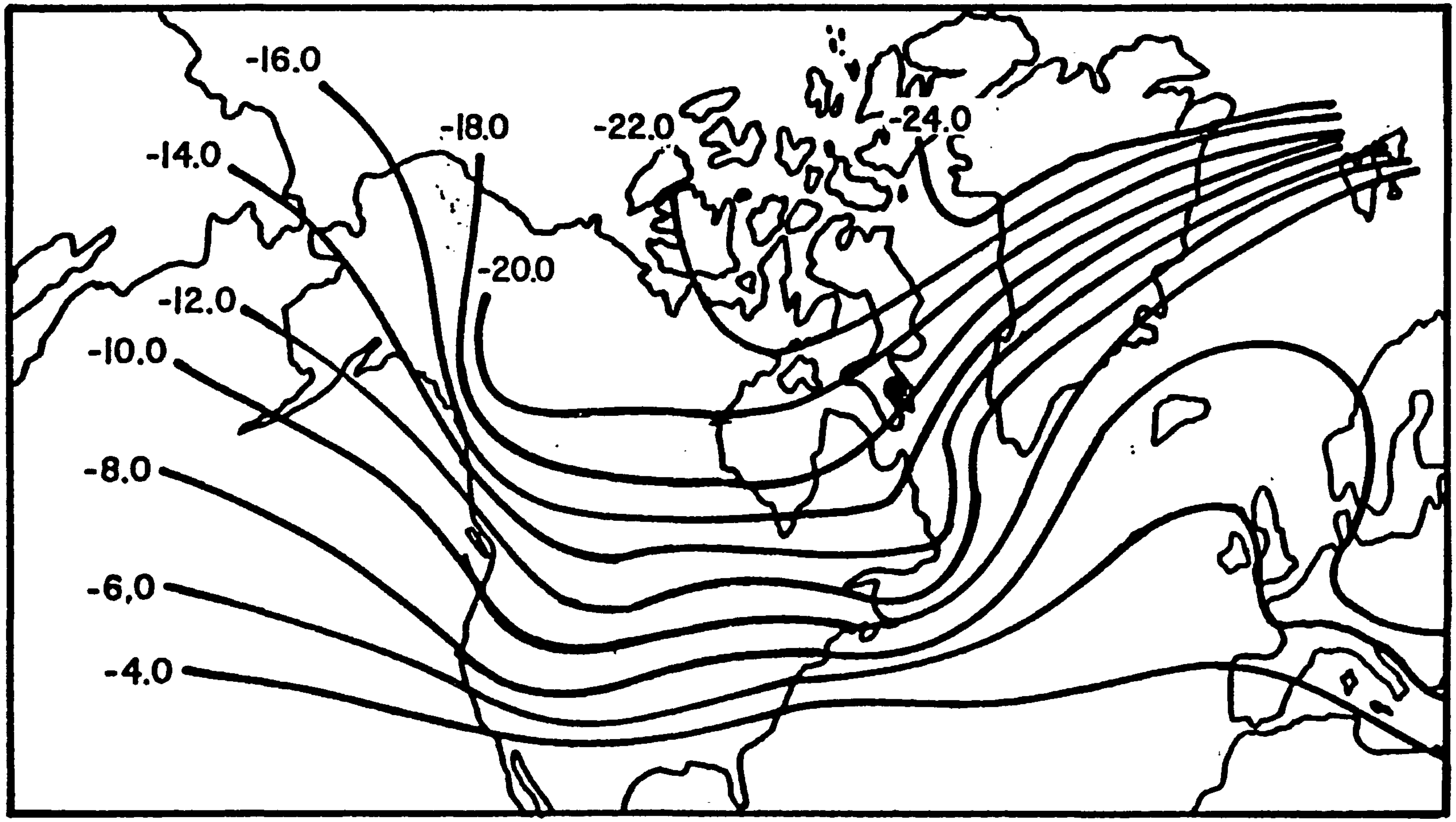


Figure 4.5: $\delta^{18}O$ (‰ SMOW) content of precipitation in North America (after Gat, 1980).

5. METHODS OF STUDY

In order to obtain solutions to the mass balance equations introduced in Chapter 4, a field sampling program was initiated in early July, 1982 lasting 26 days. The program was continued the following summer, from mid-June to mid-August, 1983. The first summer turned out to be primarily an orientation period, learning what could be done based on a number of factors: the physical nature of the watershed, local transportation and access to the watershed, and the typical response of the watershed both in terms of discharge and chemical variability. For example, initially several transects of piezometers were to be installed by hand near the stream. This plan was abandoned because of the many large boulders that covered the area or because bedrock was near the surface.

To obtain values for the ionic concentration inputs in the mass balance equations, stream water samples were taken approximately every 2 hours at the Water Survey of Canada gauging site near the outlet of the Apex River (Figure 5.1). Samples were obtained using a Cygnus Automatic Liquid Sampler (Figure 5.2). During the 1983 field season, samples were measured for pH and electrical conductivity at the site or immediately on return to the lab. These measurements were not taken in 1982 since both the pH and the conductivity meters failed. The meters used in 1983 were a pHox model 42 pH meter and a pHox model 52 conductivity meter. The pH meter was calibrated daily at the lab while

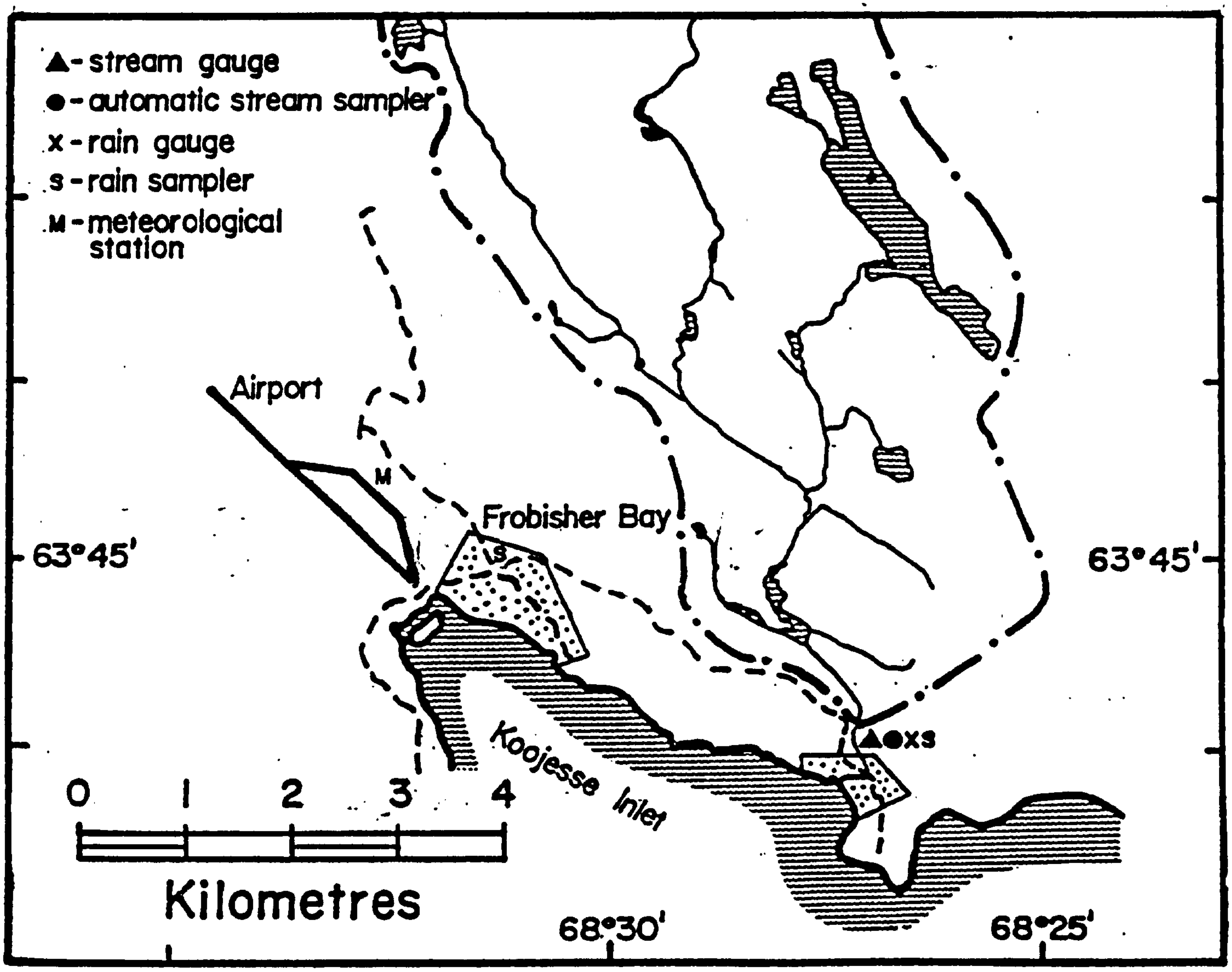


Figure 5.1: Location of instrumentation used in the study.

Figure 5.2: Photograph of the automatic stream sampler.

the conductivity meter was checked daily and periodically adjusted using a KCl standard solution.

The sampling frequency at the stream gauge site varied from about 2 to 6 hours with the more frequent sampling early in the snowmelt season and following rainstorms, and less frequent sampling later in the season and during long dry periods. Normally, two samples were taken in 60 or 125 ml Nalgene bottles, one to be used for later isotope analysis and the other to be used for later chemical analysis. The chemical samples were preserved by adding nitric acid to lower the pH to less than 2 (U.S. Environmental Protection Agency, 1974). The isotope samples were left untreated. Both sample bottles were then sealed by dipping the tops in melted paraffin wax.

Precipitation was collected using plastic buckets near the gauging site and at the laboratory. The same sampling and preservation procedures were used as for the stream samples: i.e., two samples were taken and prepared as above.

Snow samples were taken daily from snowbanks near the gauge. Sampling continued until very little snow remained on the ground. Samples were obtained by using a 30 cm long by 4 cm diameter plastic tube inserted into the snow bank (Figure 5.3). The snow from the tube was placed in plastic bags, melted at room temperature in the lab and then placed in bottles as above.

Snowmelt samples were taken daily from runoff originating at melting snowbanks near the stream gauge.

Figure 5.3: Photograph of the snow sampling procedure.

Discharge data necessary for solving the mass balance equations and for historical streamflow analysis (e.g. peak flow frequency) were obtained from the Water Survey of Canada. This data consisted of mean daily flow rates for the period of record 1973-1983.

Climatological data were obtained from the Environment Canada Meteorological Station at the Frobisher Bay airport. This information consisted of daily temperature and precipitation data. The precipitation data were compared with that obtained from a standard collecting rain gauge located at the stream gauging site. This gauge was monitored daily. The stream temperature was also recorded daily at the gauge site.

To determine if there was any areal variation in chemistry, samples from various sources were taken over the length of the main stream and parts of other tributaries. These samples included: stream, snow, snowmelt, incoming tributary, groundwater spring, lake and pond samples. This survey was performed three times: once in 1982 and twice in 1983 to see if there was any variation of chemistry with discharge. The two surveys performed in 1983 took place under different streamflow conditions. The first was made early in the runoff season during a period of high discharge and the second was performed during a low flow period. The 1982 survey took place at low discharge. pH, electrical conductivity and temperature measurements were made in the field and samples were collected for later chemical and isotope analysis.

All of the samples brought back to the University of Windsor were analyzed for Na, Ca, Mg, and K and some samples (1982) for Fe. The analysis was principally done using the Department of Geology's Varian AA-175 series atomic absorption spectrophotometer using standard methods (Varian Techtron, 1971). Some samples were analyzed in the Department of Geography using the Great Lakes Institute's Instrumentation Laboratories IL351 spectrophotometer. Selected samples were analyzed for oxygen-18 at the University of Waterloo by mass spectroscopy using the carbon dioxide equilibrium method (Hoefs, 1973).

6. RESULTS AND DISCUSSION

6.1 Physical Studies

6.1.1 Historical Hydrograph Data

For comparison purposes, hydrographs for all the years of record (1973-83) are illustrated in Appendix I along with the mean daily temperature and precipitation conditions during these periods. The 1975 hydrograph is particularly interesting. The peak daily flow occurred relatively late, on July 18, which is unlike any other year in which the peaks occurred earlier. The reason for this late peak flow is apparent upon examination of the temperature and precipitation data. Mid-June was relatively warm and July was very wet. The peak flow was a result of an 11-day period during which measureable rain fell every day totalling over 86 mm.

From an examination of the historical hydrographs in Appendix I, the Apex River can be classified as an Arctic Nival regime using Church's (1974a) classification system (see Section 3.2).

6.1.2 Peak Flow Frequency

Figure 6.1 is a peak flow frequency curve for the Apex River using annual peak daily discharges for the period 1973-1983, inclusive. Streamflow data has only been recorded at the Apex River since 1973. The irregular trend of the peak flow frequency curve may be attributed to two

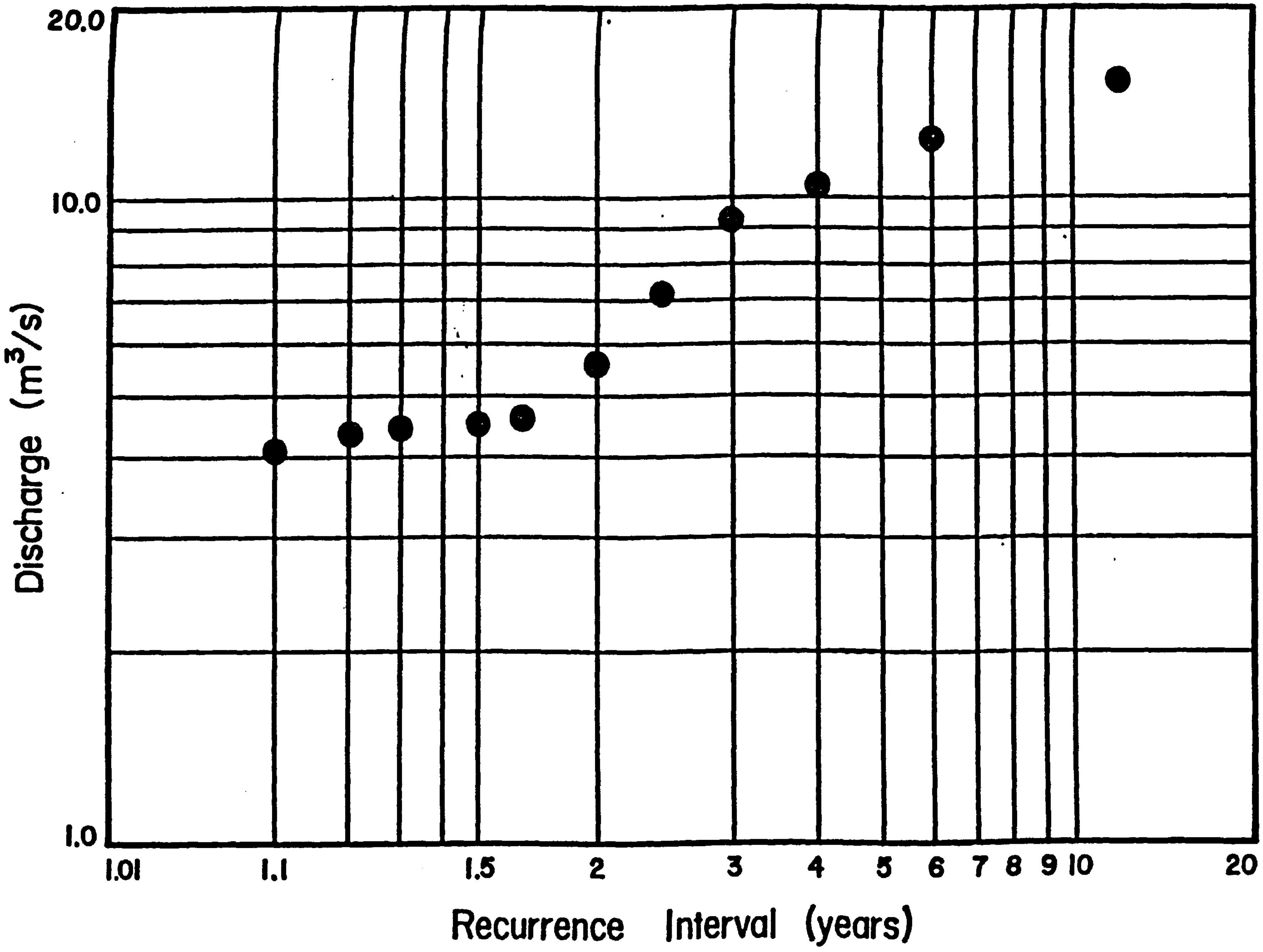


Figure 6.1: Peak flow frequency curve for the Apex River 1973-1983.

possible sources. Firstly, the period of recorded streamflow is relatively short. Viessman _et_ _al_. (1977) suggest that frequency curves from short term records yield results of limited reliability. The other reason, and probably most important, is that the period of recorded streamflow is not the same from year to year. Peak flows normally occur sometime in June, but for five of the eleven years, discharge measurements began on June 23 or later with three years' record beginning on July 1. It is likely that the peak daily flows were missed for these years. A more complete record would, therefore, likely yield a straighter flow frequency curve.

Sangal and Kallio (1977) presented peak flow frequency curves for numerous streams in southern Ontario. Curves for watersheds comparable in size to the Apex River (area=60 km^2) are remarkably similar in both magnitude and shape. Table 6.1 compares watershed characteristics of two southern Ontario streams to the Apex River.

The peak flow frequency curve can be used to characterize a particular year's flow. For example, the 1983 peak flow (10.9 m^3/s) was the third highest in the 11 years of record, while the 1982 peak flow (4.5 m^3/s) ranked ninth. Therefore, any results obtained from hydrologic studies for these two years cannot be dismissed as resulting due to extraordinary conditions not likely to be repeated often.

Table 6.1: Comparison of Apex River peak daily flow to similar sized watersheds in southern Ontario (data from Sangal and Kallio, 1977).

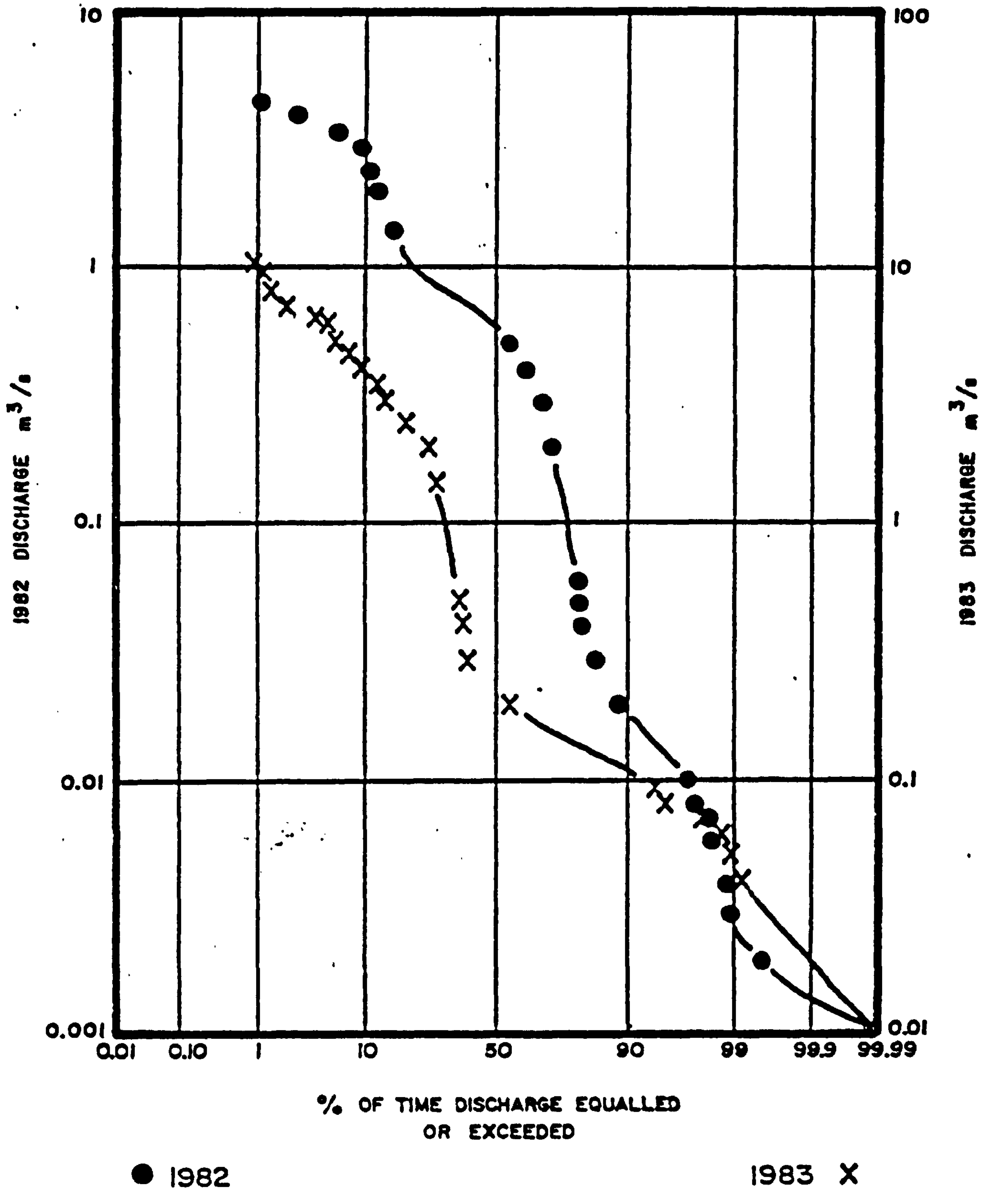
Watershed	Number of Years of Record	Area(km^2)	Maximum Daily Flow (m^3/s)
Laurel Creek at Waterloo	12	60	17.4
Ganaraska Creek near Osaca	12	67	19.8
Apex River	11	60	15.6

6.1.3 Flow Duration

Flow duration curves constructed for 1982 and 1983 are shown in Figure 6.2. The percentage of time a particular discharge was equalled or exceeded was calculated based on the number of days in the discharge record. For 1982, the discharge was recorded for 153 days and in 1983 for 116 days. This difference makes the curves difficult to compare. The curves are quite different (note different scales for 1982 and 1983) because the 1982 data includes very low flow values (< 0.06 m^3/s) for October while the 1983 data ends on September 30. In any case, the steepness of the middle part of the curves illustrates highly variable discharge, which is typical of conditions where flow is mainly from surface runoff (Raudkivi, 1979). A similar interpretation (Dunne and Leopold, 1978) suggests that the steep curve reflects the impermeable nature of the ground in the watershed (see Figure 4.1). The shallow upper slopes (especially for 1982) illustrate a large input from surface storage, where the high flows are mainly due to snowmelt. The absence of a shallow sloping low end of the flow duration curve indicates the absence of large groundwater storage inputs to baseflow.

6.1.4 Recession Analysis

Recession analysis (Figure 6.3) yielded a recession coefficient of about 0.86 for 1983 and 0.90 for 1982. In other words, during recession (on the falling limb of the



Note the different scales for the two years.

Figure 6.2: Flow duration curves for the Apex River for 1982 and 1983.

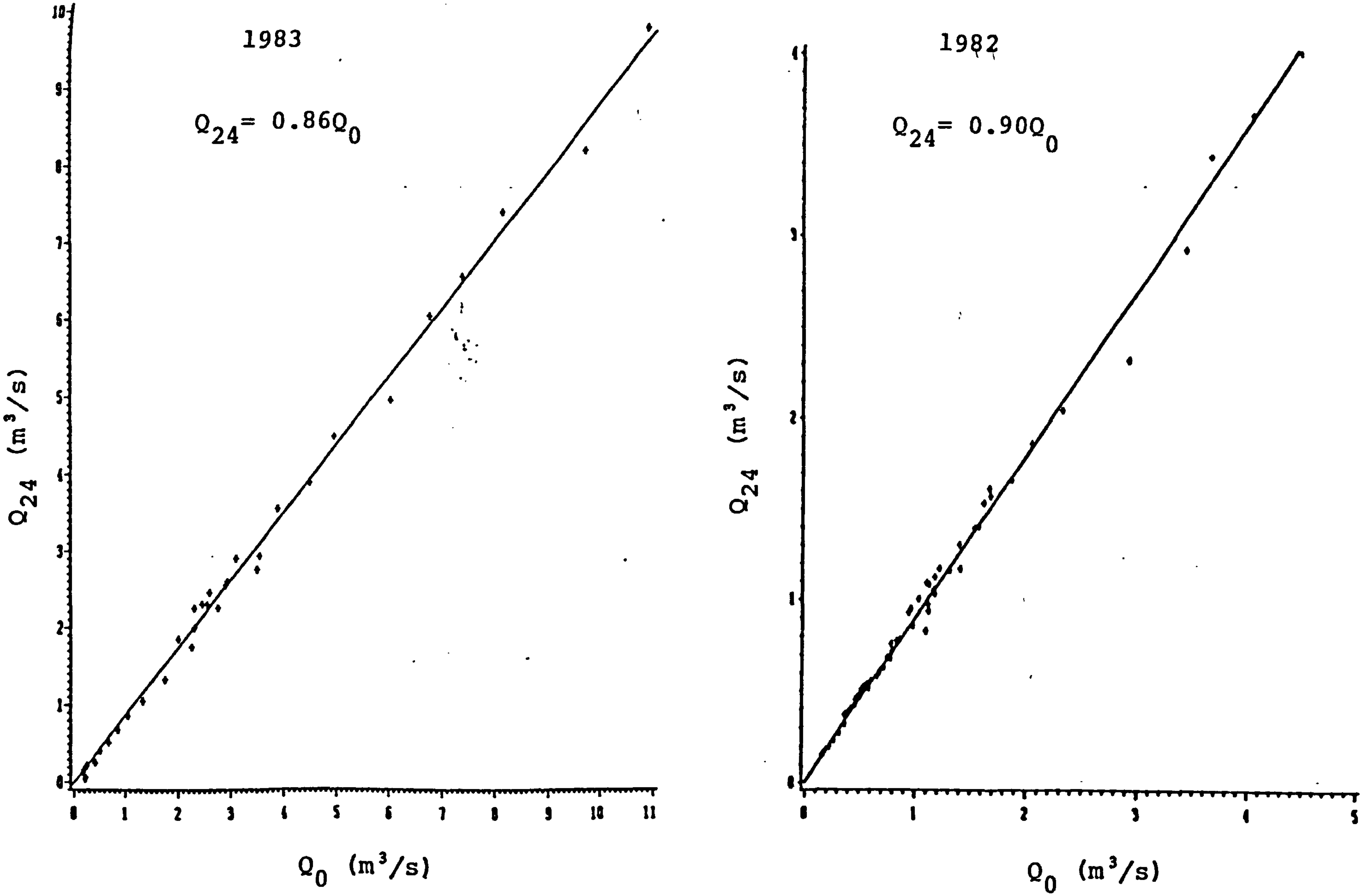


Figure 6.3: Recession analyses for the Apex River 1982, 1983.

hydrograph) the average daily discharge is about 86-90% of the preceding day's discharge.

Martinec (1977) states that if direct meltwater runoff corresponds to immediate runoff and subsurface runoff to the recession flow, then the proportion of subsurface runoff (Q_O/Q_T) corresponds to the recession coefficient, k. In this case, 86 % of the Apex River flow would be made up of subsurface flow.

The reservoir coefficient ('m' in Equation 4.3) for the Apex River is very high (m = 165 h) compared to those values presented by Holtan and Overton (1963) for much larger basins in the United States which get most of their recession flow from groundwater storage. It is small, however when compared to the results reported by Anderson (1974), who obtained reservoir coefficients in the range of 8-16 h/km^2 for a small watershed near Inuvik. He attributed the large reservoir coefficients and drawn out recessions to the increased storage capacity of the thawing active layer in June and July.

6.1.5 Graphical Hydrograph Separation

Attempts were made to use various graphical techniques to separate the discharge hydrograph of the Apex River for the 1983 runoff season. Problems were encountered in applying all of the techniques because it appears that these techniques were developed for more temperate conditions for short term runoff events associated with rainfall. No studies were found in the literature which used graphical methods for snowmelt hydrograph separation. The case of a prolonged snowmelt event, such as that which occurs in the Apex River and elsewhere in the north, is not adequately dealt with by graphical techniques.

The slope of the quickflow-delayed flow separation line proposed by Hewlett and Hibbert (1967) is much too steep for the Apex hydrograph. This is due to the long drawn out snowmelt recession ($k = 0.86$). Hewlett and Hibbert (1967) suggested their method be used only in basins smaller than approximately 50 km^2 (20 mi^2) and only in basins which flow for most of the year. The Apex River has an area of approximately 60 km^2, slightly above the suggested size, and is frozen for up to 7 months of the year.

The graphical technique proposed by Gray and Wigham (1970) also does not work for the Apex River hydrograph because of the long snowmelt recession.

6.2 Chemical and Isotopic Studies

6.2.1 Hydrochemical Characteristics

Chemical data for water samples from various sources are listed in Appendices II (1983 samples) and III (1982 samples). To illustrate the temporal variability in water quality at the gauge site, plots were made of the individual ion concentrations versus time for 1983 (Figure 6.4). In general, it appears that the highest concentrations of most ions occurs late in the summer. There also appears to be a correlation between ionic concentration and discharge, with higher concentrations occurring at low discharges and vice versa.

Streamflow is considered to consist of a baseflow fraction made up of groundwater that discharges into the stream channel and a direct runoff fraction which enters the stream during and soon after precipitation or snowmelt periods (Hem, 1970). Precipitation or snowmelt inputs generally are low in total dissolved solids (TDS). TDS can be computed, in mg/l, by multiplying the recorded electrical conductivity values by a factor of 0.55 to 0.75 (Hem, 1970). The direct runoff component, while having a short contact time with the watershed material, has enough contact to increase the TDS of the direct runoff over that of the original precipitation or snowmelt input. The longer the water is in contact with the watershed material, the higher the TDS will be since the water has more time to dissolve the minerals in the underlying rock or soil. The baseflow

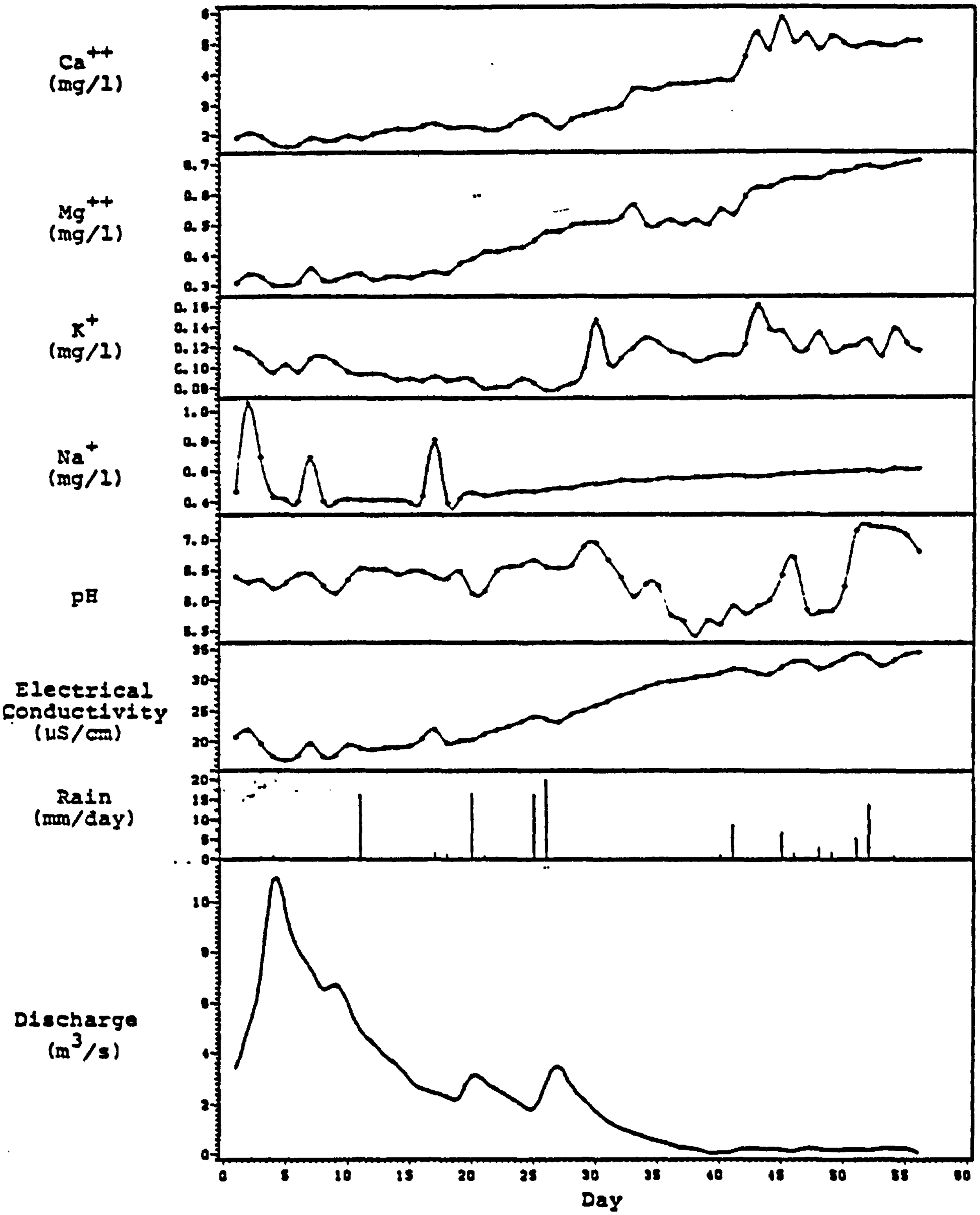


Figure 6.4: Hydrograph, rain and stream chemistry for the Apex River 1983. Note: Day 1= June 16, 1983.

(groundwater) component has an even higher TDS than the direct runoff because of its much longer contact time. This information is summarized for the 1983 season in Table 6.2 in terms of electrical conductivity values for the various sources of streamflow.

The chemical analyses (Appendices II and III) yielded results similar to those obtained by Church (1974b) on Baffin Island and from analyses of the municipal reservoir for Frobisher Bay (Health and Welfare Canada, 1981) (e.g. Table 6.3). In general, they found that the waters were low in TDS. The low characteristic TDS of Baffin Island waters was ascribed by Church (1974b) to be due to the Precambrian bedrock terrain, which weathers slowly when compared to consolidated and unconsolidated sediments (Hem, 1970), and the fact that the source of much of the water, namely rain and snow, is characteristically low in TDS.

To illustrate more clearly the relationship between ion concentration and discharge, the concentrations of the ions in the water are plotted against mean daily discharge for 1983 (Figure 6.5 a-f). Electrical conductivity (EC), Mg and Ca all illustrate strong inverse relationships, not necessarily linear, between ionic concentration and discharge. Na shows a similar, though not as dramatic, relationship to discharge. Values for pH and K do not exhibit any strong relationship with discharge.

EC, Mg and Ca all show similar behaviour with what appears to be two separate responses to changes in

Table 6.2: Summary of Electrical Conductivity and pH Values from Various Sources.

Source		EC (µS/cm)	pH
Baseflow	$\bar{x}$	32.2	6.2
	s	1.6	0.8
	n	242	242
High Flow	$\bar{x}$	21.8	6.5
	s	3.3	0.3
	n	337	337
Snow	$\bar{x}$	10.1	5.7
	s	7.6	0.7
	n	24	24
Snowmelt	$\bar{x}$	15.8	5.6
	s	11.1	0.9
	n	27	27
Rain	$\bar{x}$	11.6	5.6
	s	9.0	0.5
	n	16	16
Spring	$\bar{x}$	40.7	6.0
	s	9.2	0.6
	n	6	6

NOTE: Baseflow period = Day 35 to Day 56
High flow period = Day 1 to Day 34.

Table 6.3: Results of Water Analysis (Health and Welfare Canada, 1981)

Date of sample: November 9, 1981

Sample location: Raw water tank, water treatment plant, Frobisher Bay, N.W.T.

Parameter	mg/l
Calcium	8.3
Magnesium	0.8
Total Hardness	24
Total Alkalinity	11
Sodium	0.8
Potassium	0.1
Chloride	1.4
Sulphate	2.9
Nitrate/nitrite	0.26
Arsenic (total)	<0.01
Cadmium	<0.01
Iron	0.08
Lead	<0.01
Zinc	0.03
Manganese	<0.01
Chromium	<0.02

Mercury (ug/l)	0.04
pH	7.0
Specific Conductance (umho/cm)	32
Colour (colour units)	5

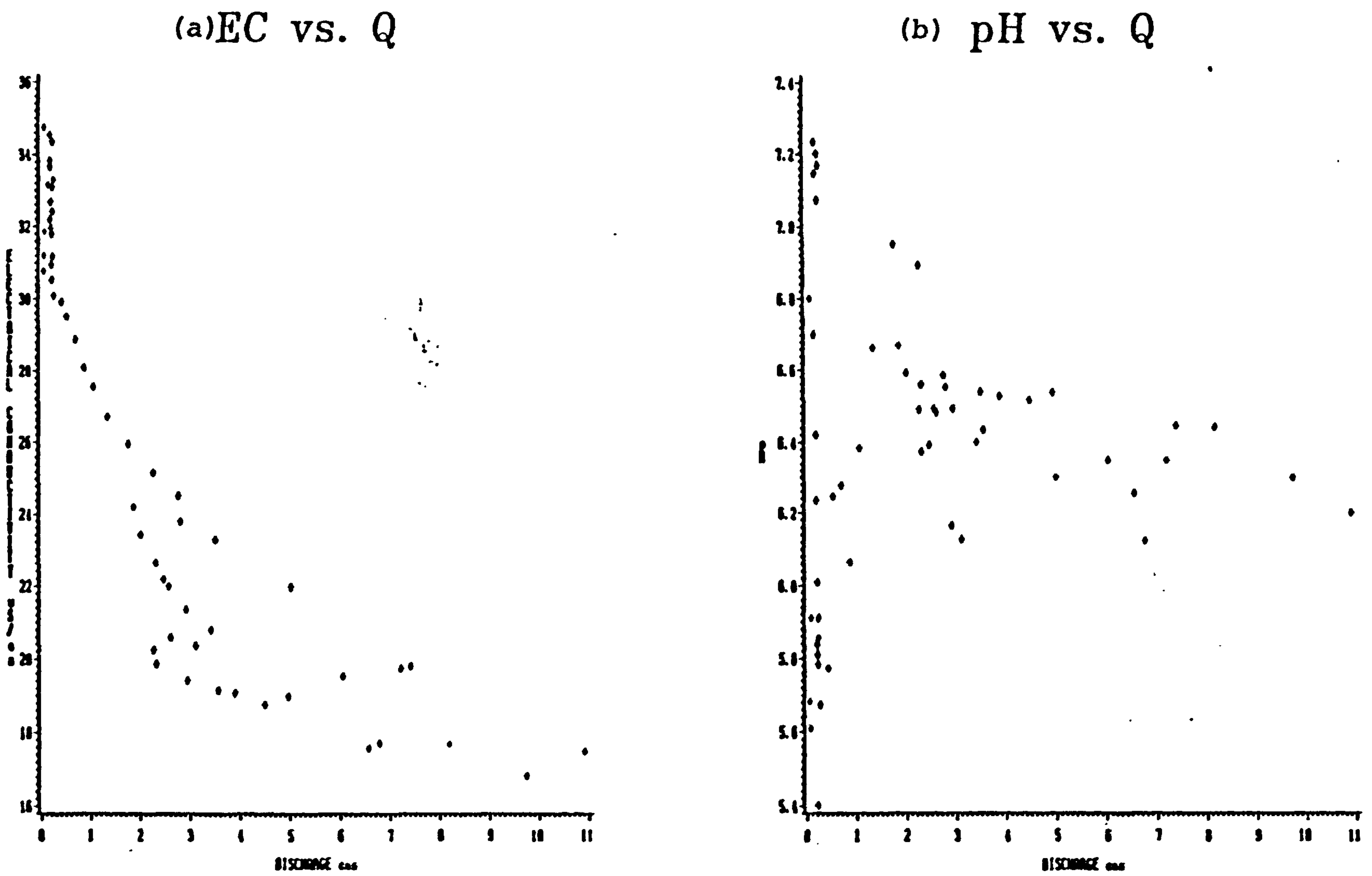


Figure 6.5: Plots of chemical parameters versus discharge for 1983.

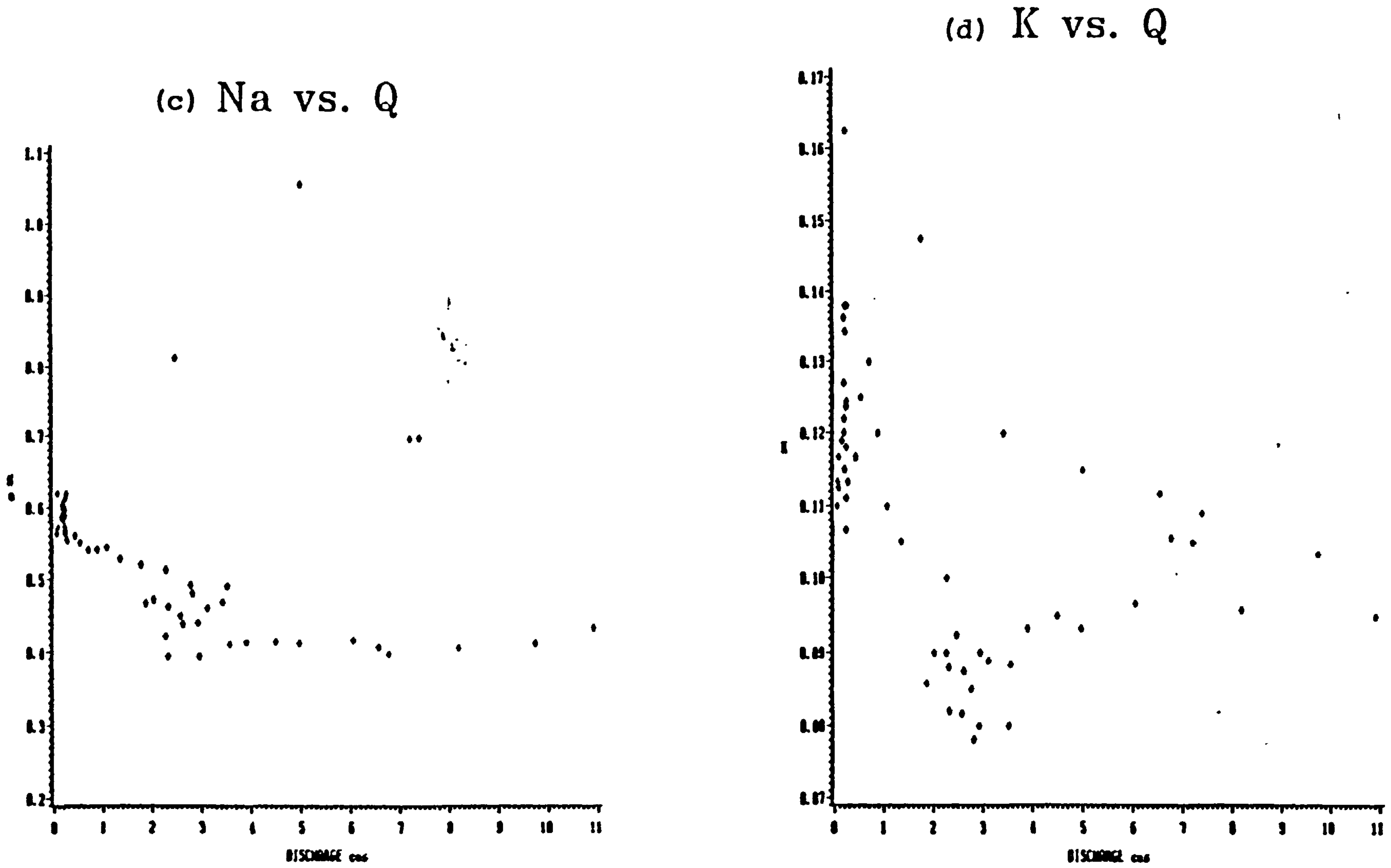
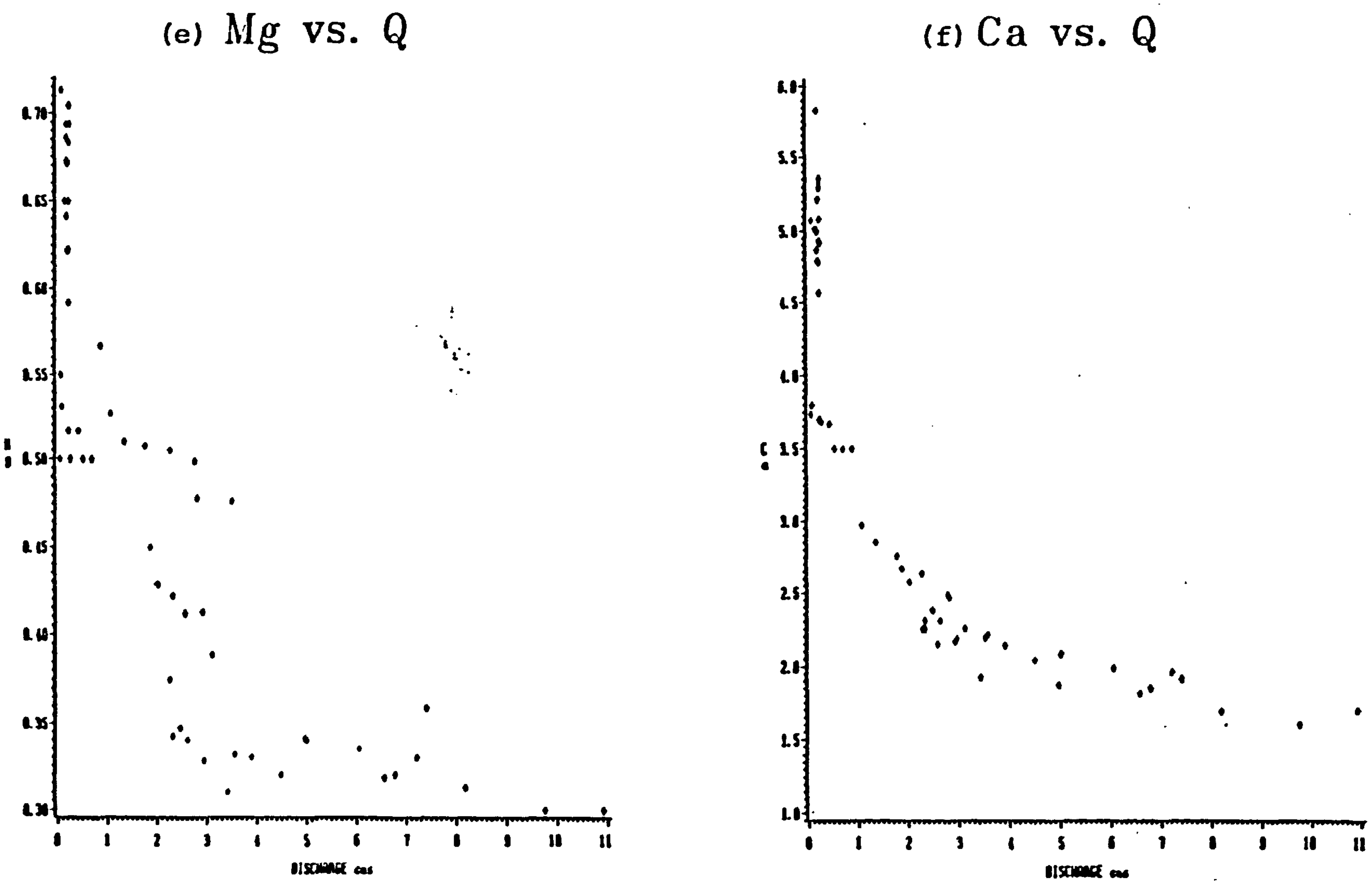


Figure 6.5: continued


(e) Mg vs. Q

(f) Ca vs. Q

Figure 6.5: continued

discharge. At discharges greater than about 1 m^3/s, there is a gradual increase in ion concentration with decreasing discharge (Figure 6.5). At discharges less than 1 m^3/s, the curve gets steeper, showing a sharper rise in concentrations. This segment (<1 m^3/s) appears to characterize baseflow conditions while the other segment represents the variable snowmelt period.

The source of the different chemical parameters in the waters is the dissolution of various minerals from the watershed materials. The dominant minerals which make up the Precambrian bedrock in the Apex River watershed are: quartz, plagioclase feldspars, potash feldspars, pyroxene and biotite (Blackadar, 1967). In the Apex River, as in most natural settings, Ca is the dominant cation (Appendices II and III)(Hem,1970). The differences in the cation concentrations arise because some minerals are more easily weathered than others. This explains the low K concentrations relative to the Ca, Mg, and Na results. All of the cations do not behave similarly in solution (Figure 6.5). While Ca, Mg, and Na have similar relationships with respect to discharge, K does not. The reason for this is that once in solution, K tends to react with other solids, such as clays, in the water (Hem, 1970; Foster, 1978). K may also be preferentially taken up by vegetation (Bottomley, 1974).

The stream pH values (Figure 6.4) exhibit a depression during the low flow period (after about Day 30). There is no "acid pulse" during the peak runoff resulting from the rapid input of acidic rain or snowmelt as is seen in many watersheds in southern Canada (Bottomley et al., 1985). Table 6.2 summarizes the pH values of the different sources. The reason for the absence of a pH depression during the peak flow is unclear. Bottomley et al. (1985) experienced a similar response. Their explanation was that much of the first meltwater from the acidic snowpack (in the Apex River snow pH=5.7) infiltrates into the subsurface displacing the higher pH groundwater to the stream. In the Apex River watershed, however, the pH of groundwater does not appear to be high enough (Table 6.2) to produce stream pH values such as the average high flow pH. A more likely explanation is the one reported by Zeman and Slaymaker (1975). They noted a substantial pH increase (1.3 pH units) between snow in place and snow runoff over the watershed surface a short distance away.

The pH depression later in the runoff season may be explained by an increase in the acidity of the runoff water due to organic decay of vegetation. This produces gaseous CO_2 which reacts with water to increase the hydrogen ion concentration (i.e. lowers the pH)(Stumm and Morgan, 1970).

Figures 6.6 (a-e), illustrate the temporal and spatial variability of the chemical constituents measured for various locations in the watershed at two different times in 1983 and the spatial variability for one period in 1982. These sample analyses are listed in Appendix II using the

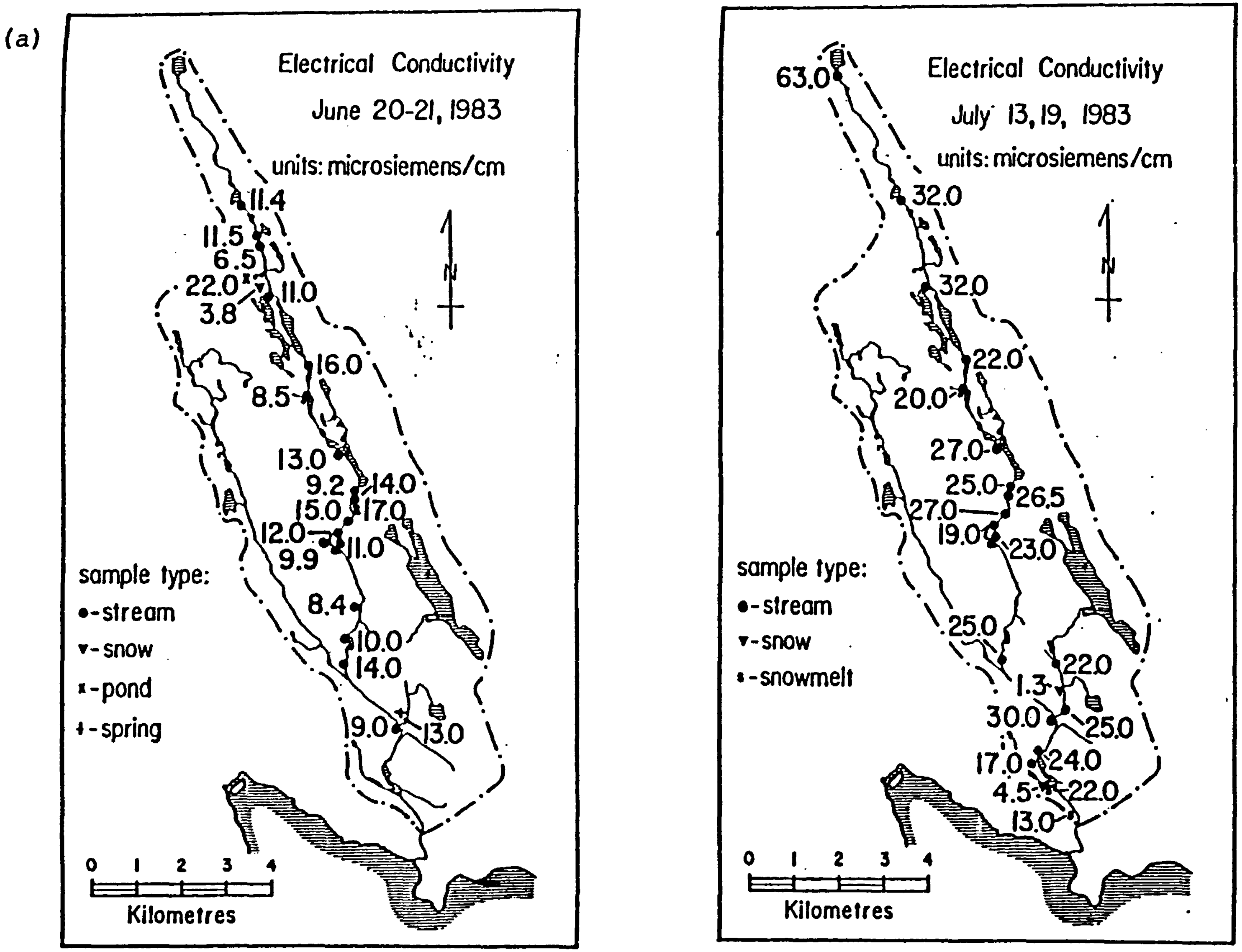


Figure 6.6: Maps illustrating temporal and areal variations of the different chemical parameters.

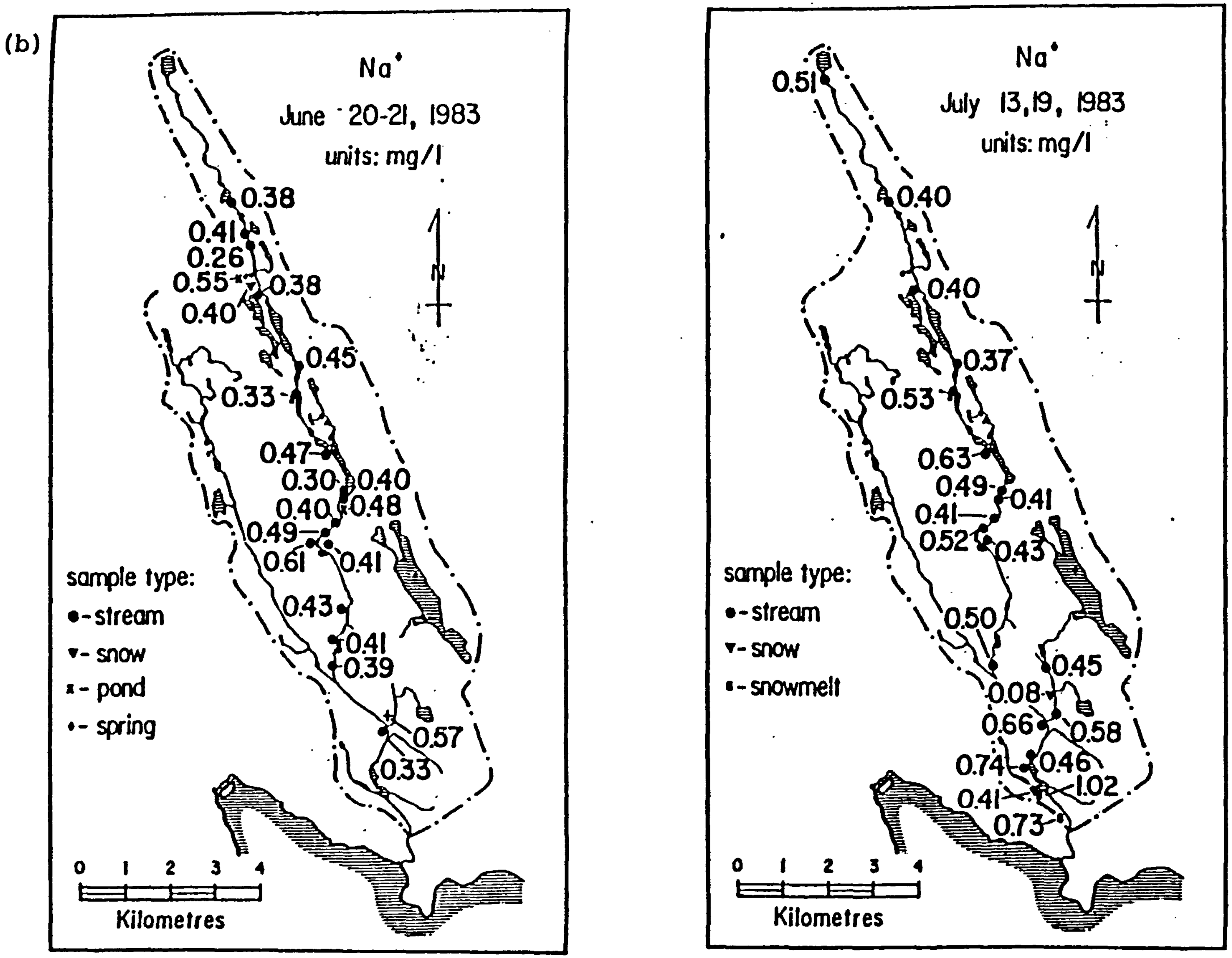


Figure 6.6: continued

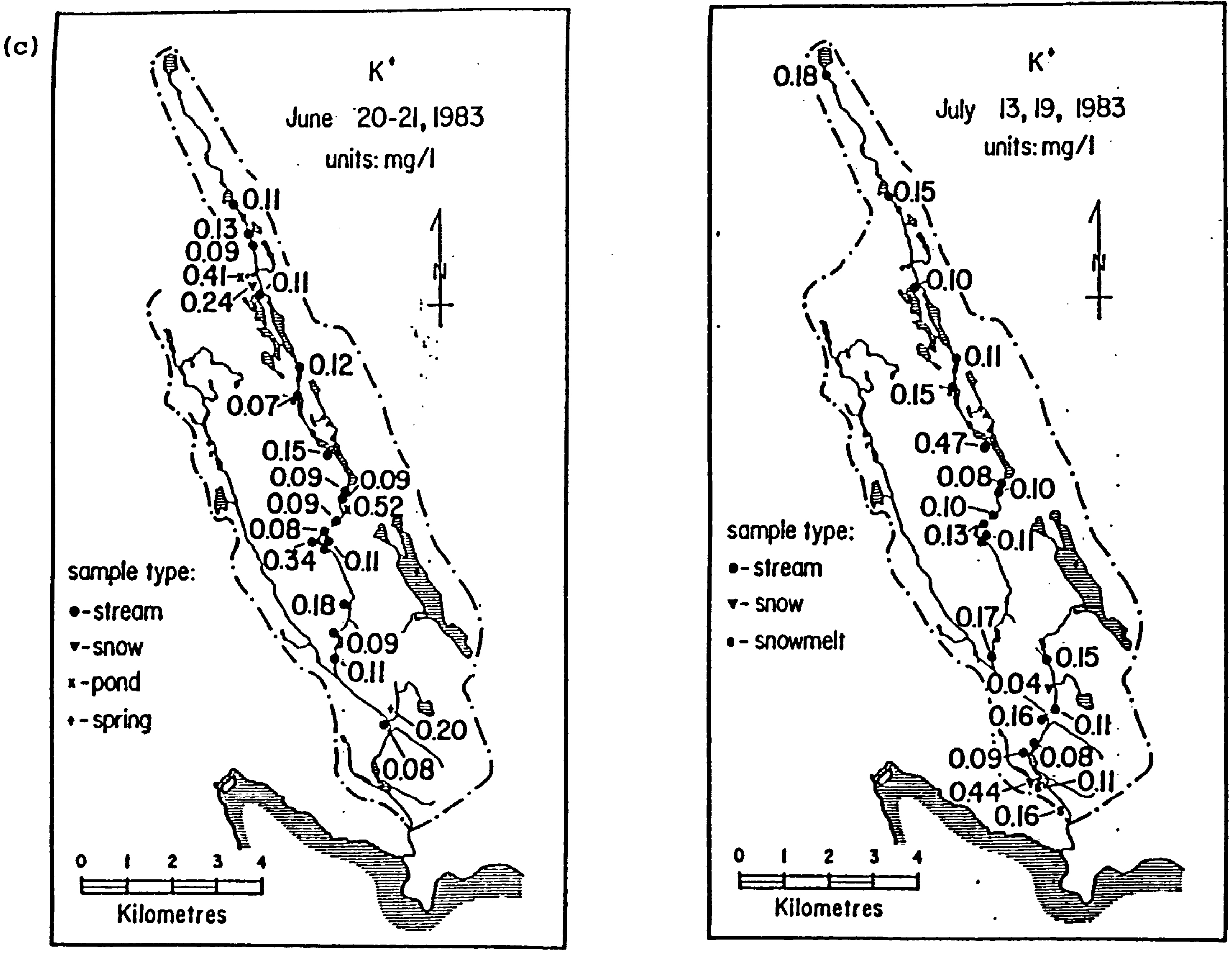


Figure 6.6: continued

(d)

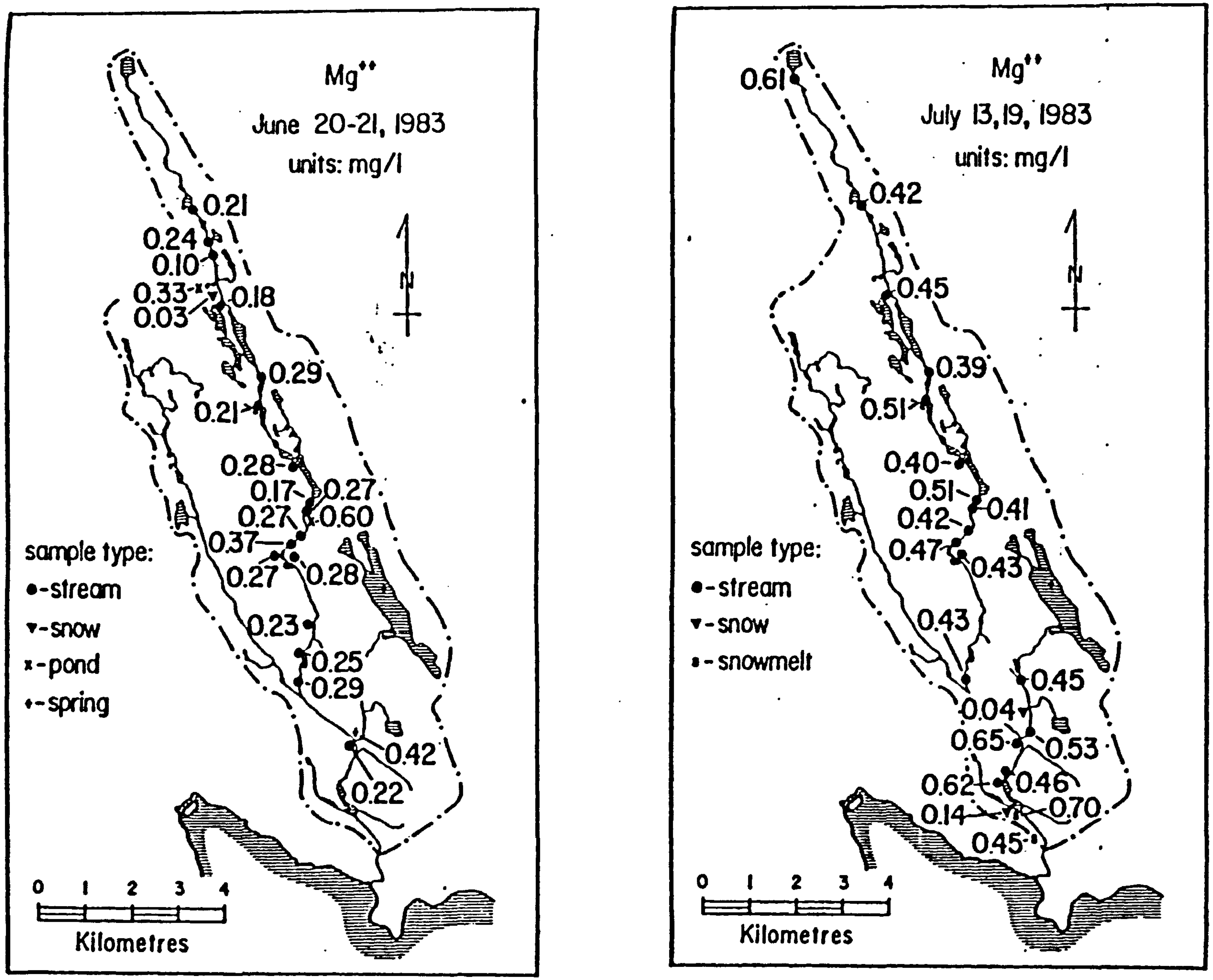


Figure 6.6: continued

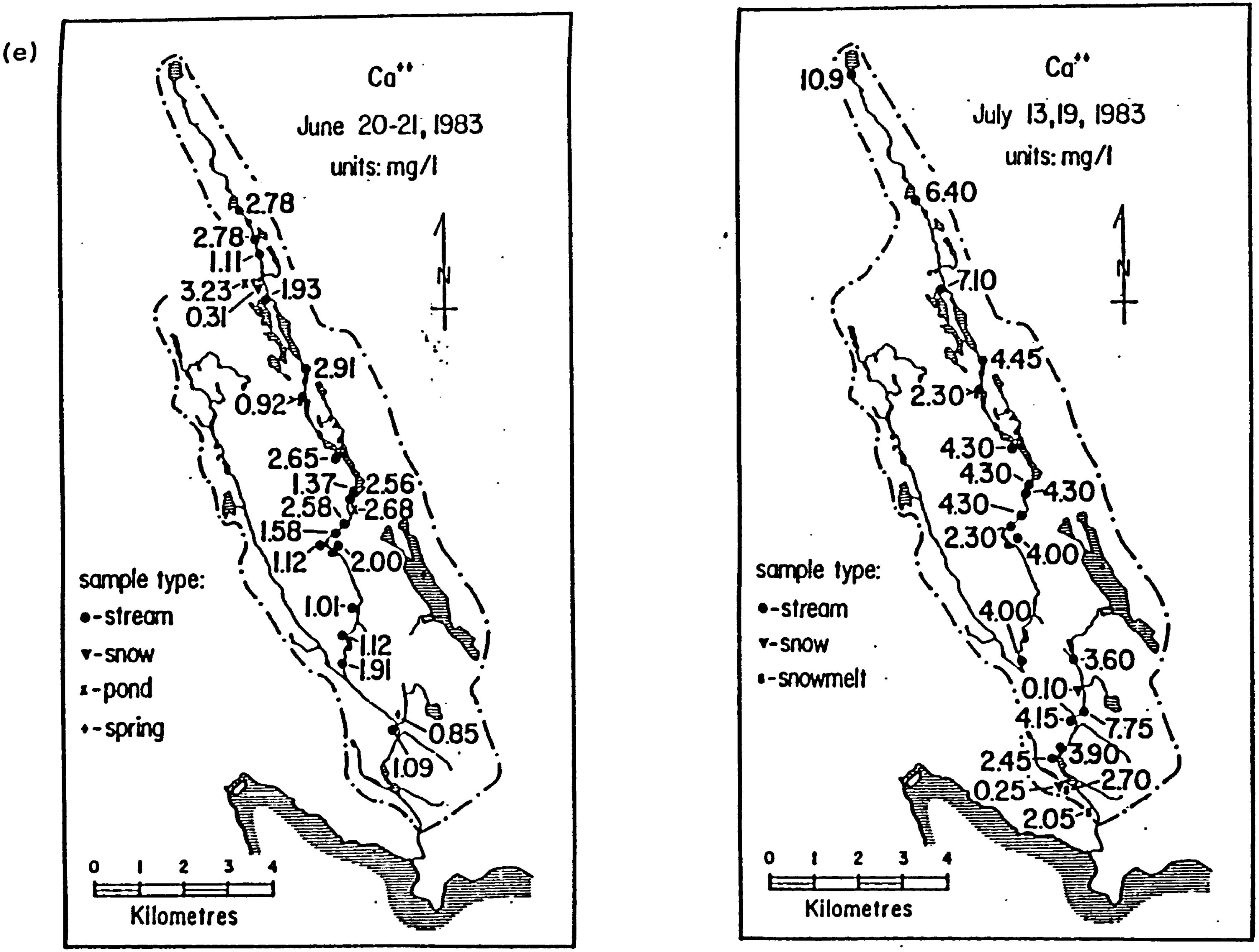


Figure 6.6: continued

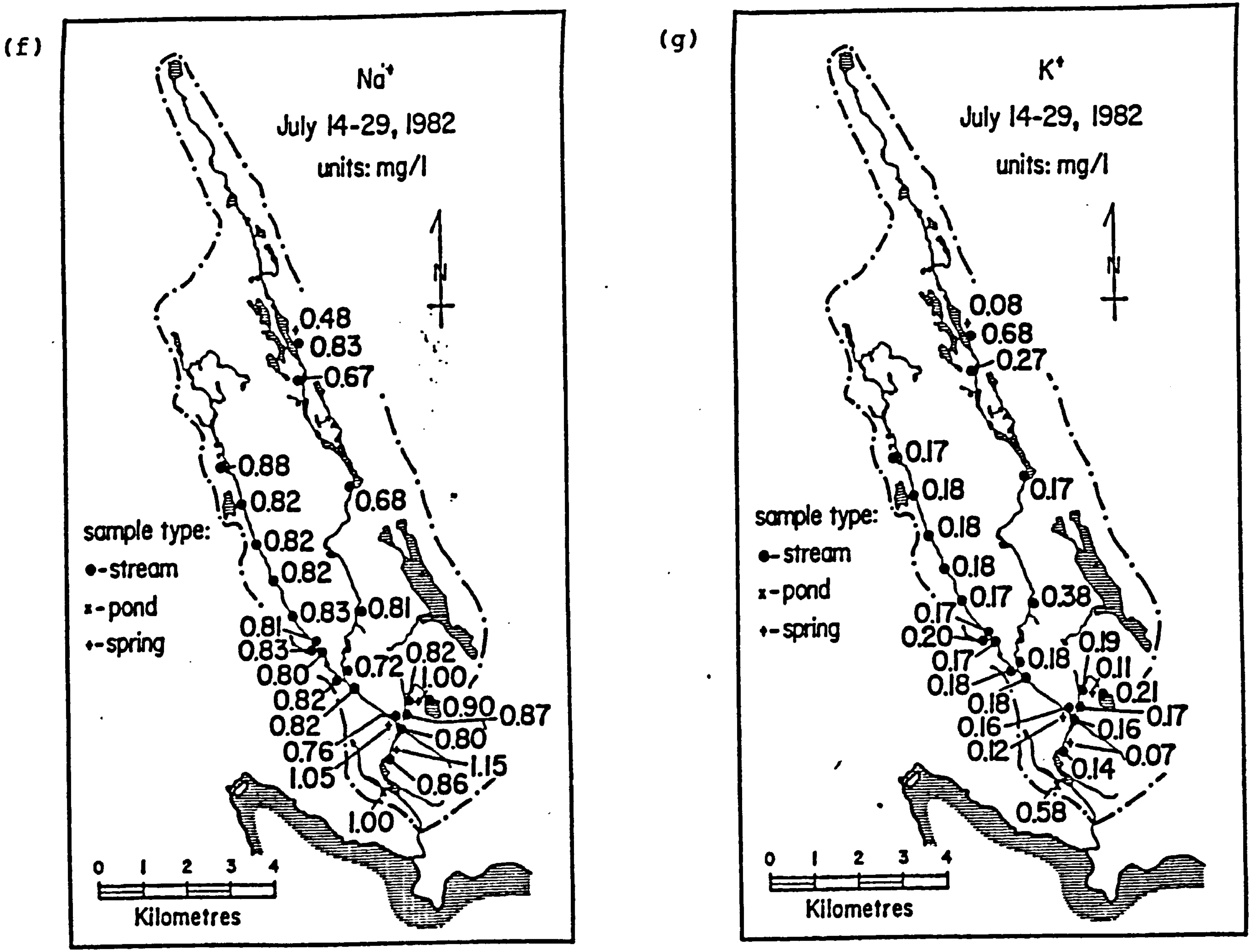
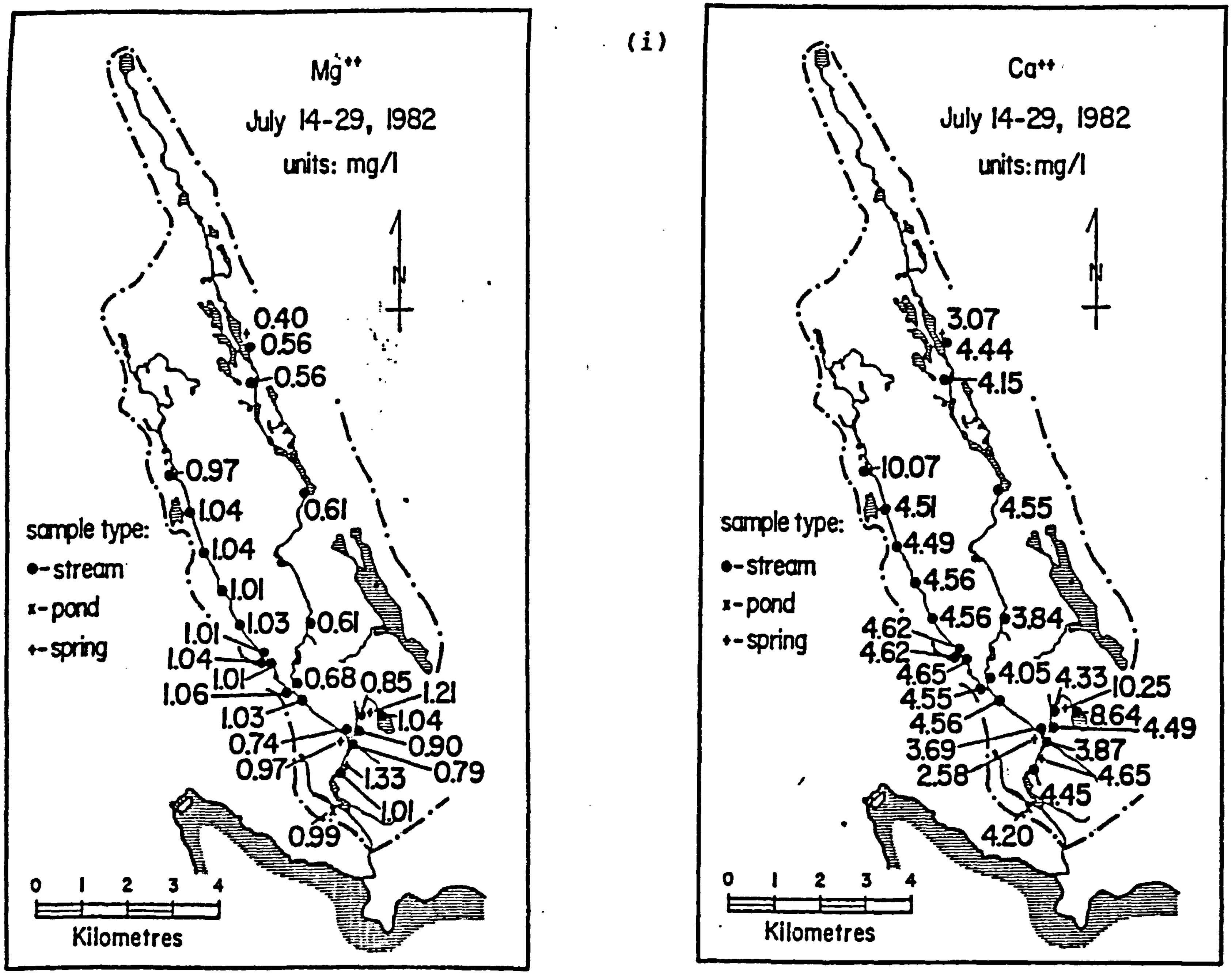


Figure 6.6: continued



(h)

(i)

Figure 6.6: continued

prefix B (e.g. B-24) for the 1983 samples and in Appendix III using the prefixes BP, CP and DP. The temporal variations shown by this series of figures appears to agree with those measured at the gauge site, that is, concentrations are generally higher during later summer which corresponds to periods of low flow. Table 6.4 summarizes the temporal variations; values for all of the constituents measured showed an increase between June 20-21 and July 13, 19, 1983. Values for pH were not determined on July 13 and 19 because of a problem with the meter.

The stream water chemistry changes in response to different sources of inflow. For much of the summer (to late July), most of the stream's discharge is probably related to snowmelt, either directly or by its displacement of groundwater. Later in the summer, most of the flow probably comes from groundwater. Other changes in stream chemistry may be linked to changes in the hydrogeology of the basin. For example, at the outlet of the lake at the extreme north end of the watershed was dry when visited on July 13, 1983. This indicates that the small lake was not contributing to the stream discharge at low flows. A sample taken from this lake on July 13 showed very high solute concentrations relative to the rest of the watershed (Figure 6.6 a-e). This may indicate stagnant water being concentrated by evaporation.

Spatially, there does not appear to be any obvious pattern to the ionic concentration data shown in Figures 6.6

Table 6.4: Comparison of chemical parameters averaged over the entire watershed between June 20,21 and July 13,19, 1983.

Parameter		June 20,21	July 13,19
EC (µS/cm)	$\bar{x}$	11.2	24.8
	s	2.5	4.2
	n	17	16
Na (mg/l)	$\bar{x}$	0.40	0.50
	s	0.08	0.10
	n	17	16
K (mg/l)	$\bar{x}$	0.12	0.14
	s	0.06	0.09
	n	17	16
Mg (mg/l)	$\bar{x}$	0.24	0.47
	s	0.06	0.07
	n	17	16
Ca (mg/l)	$\bar{x}$	1.85	4.35
	s	0.71	1.51
	n	17	16

a-e. Figure 6.7 illustrates this by showing no apparent relationship between electrical conductivity of stream samples and distance from the gauge at high flow (June 20-21) or low flow (July 13, 19). The geology of the watershed (Figure 1.5) does not appear to affect the distribution of solute concentrations. The drift material of the northern part of the watershed is largely composed of quartz-feldspar gneiss boulders, the same rock type as the exposed bedrock in the southern part of the watershed, so one would not expect any significant concentration variations due to geology.

6.2.2 Isotopic Hydrograph Separation

A total of 43 water samples from the Apex River watershed obtained during the summer of 1983 were analyzed for oxygen-18 in order to separate the hydrograph into new and old water components. A list of these analyses is given in Appendix IV. The hydrograph separation (Figure 6.8) is the result of the solution of the two mass balance equations (Equations 4.5 and 4.6). The basis of the solution is the assignment of oxygen-18 values and discharges to the appropriate variables in the equations using various assumptions or generalizations to estimate them. All of these values are illustrated in Figure 6.8.

Values for Q_T are from the mean daily discharge record from the Water Survey of Canada gauge near the outlet of the Apex River. The values for C_T come from averaging, on a

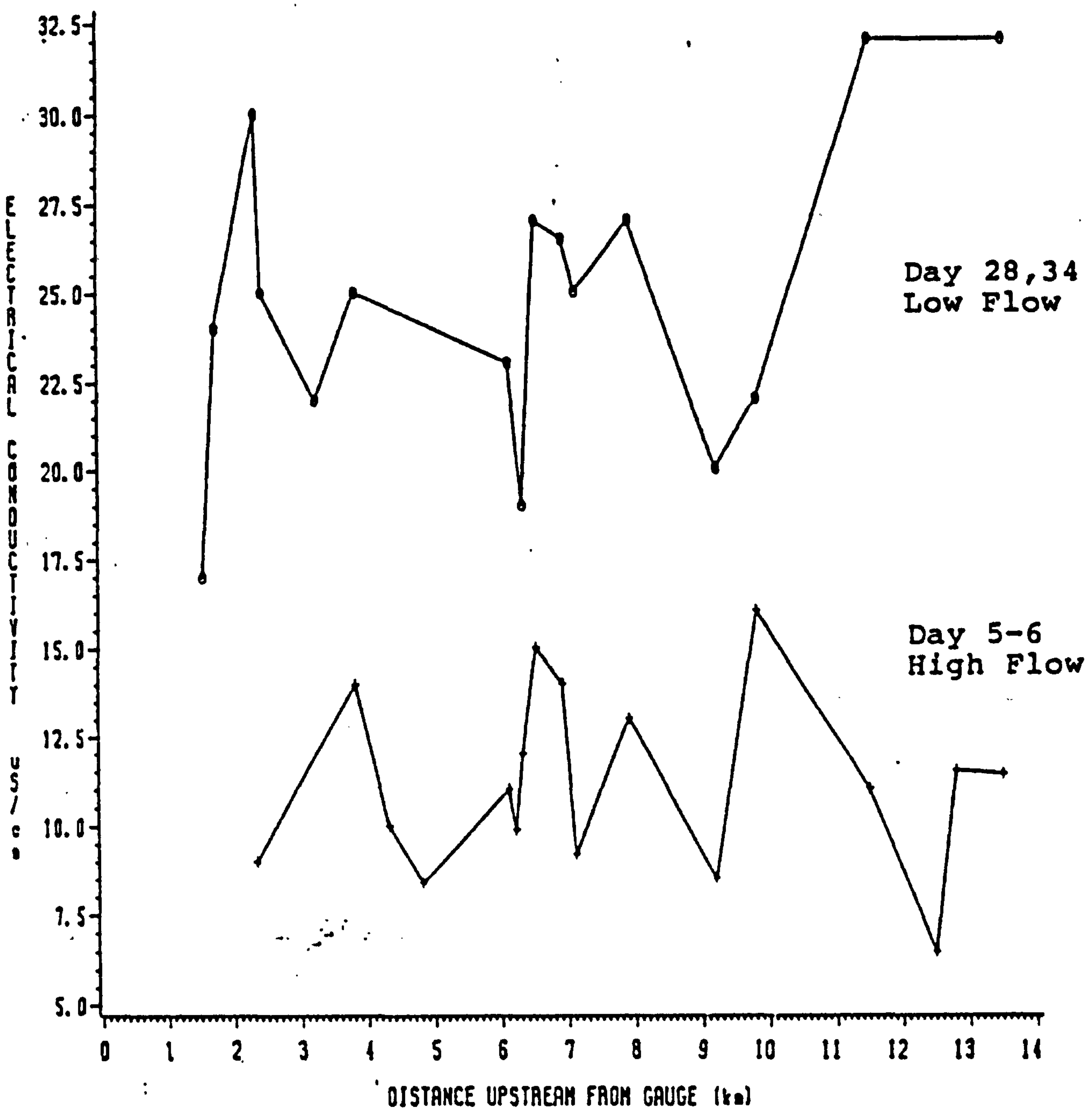


Figure 6.7: Variation of EC upstream from the gauge during different flow conditions.

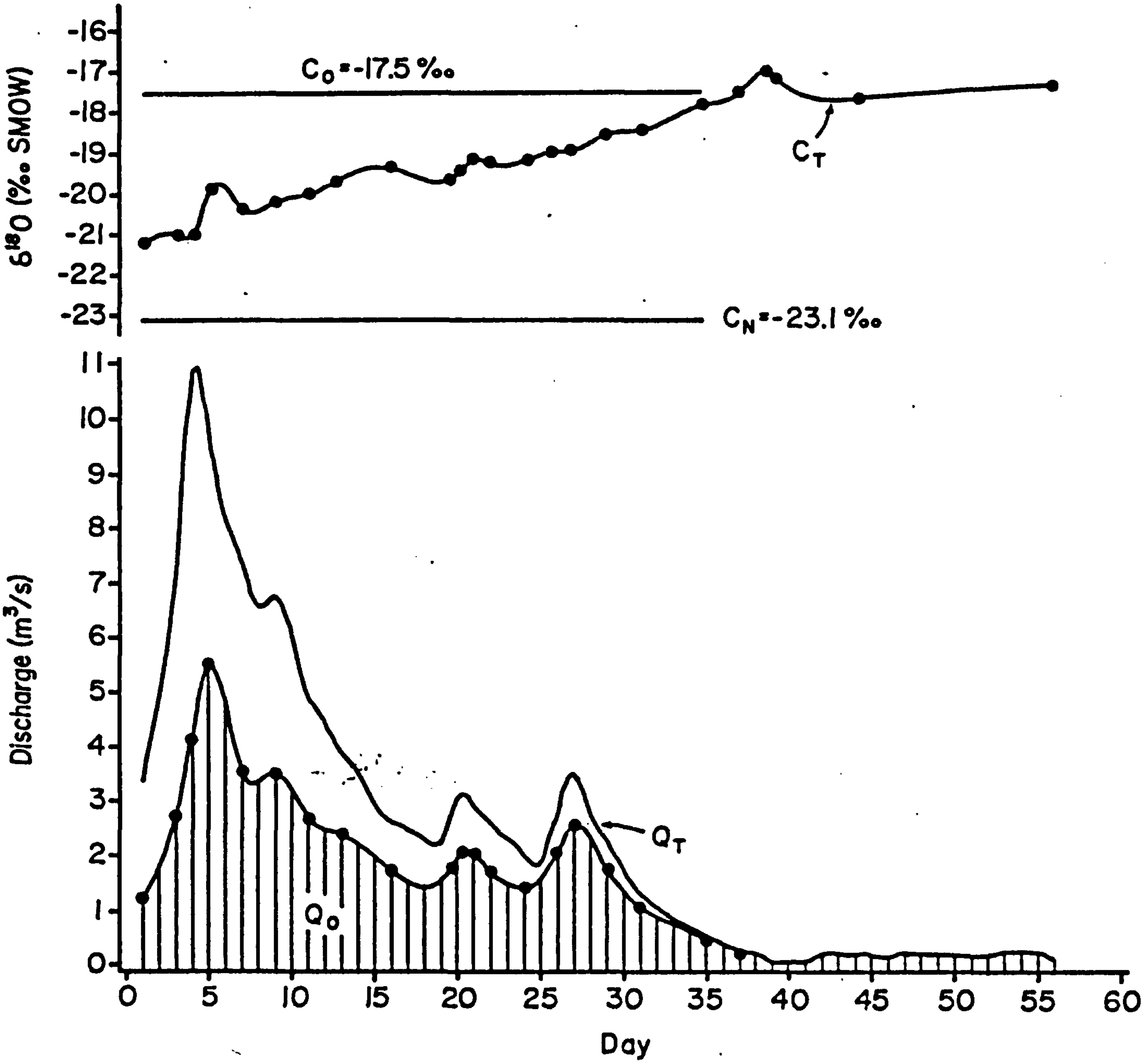


Figure 6.8: Isotopic hydrograph separation for the Apex River watershed 1983 showing the values used in the mass balance equations.

daily basis, stream water samples obtained at the gauge using the automatic sampler. C_O values are approximated using values obtained from the stream when baseflow was assumed to be the only input. This is a commonly used estimate (Sklash, 1978; Rodhe, 1981; 1983a,b; Hooper and Shoemaker, 1985) since it has been generally found that isotopic contents of groundwater samples are the same as those of low flow stream samples. One major advantage of using stream samples is that they are usually much more easily obtained and thus, more plentiful. In this particular case, much of the watershed consisted of exposed bedrock or large boulders making hand installation of piezometers or wells impossible. Another advantage of using baseflow samples over groundwater samples is that the baseflow samples represent an integrated sample of all low flow inputs upstream of the sample site while the groundwater may show variation from one site to another (Sklash <u>et al</u>., 1985).

To aid in determining the most accurate baseflow estimate for C_O, cluster analyses (SAS, 1982) were performed on the chemical and isotopic data; one using all of the chemical variables (EC, pH, Na, K, Mg, Ca), and another using only $\delta^{18}O$. Cluster analysis is a procedure used to group together large numbers of samples into smaller numbers of groups. Members of one group are more similar to each other than they are to members of another group. Schwartz (1979) used cluster analysis to determine the origin of streamflow in a watershed in northeastern Alberta by grouping streamwater samples from various times with muskeg water or groundwater samples.

The first cluster analysis (Figure 6.9; Appendix V) showed two distinct groups: one group consisted of samples at relatively high discharges which correspond to the period from Day 1 to about Day 35 of the discharge record; and, the other group was comprised of low flow samples from approximately Day 35 to the end of the study period (Day 56). On the basis of the 1983 discharge hydrograph, this second group appears to be baseflow. The average $\delta^{18}O$ for this period (Table 6.5) is similar to the value obtained from the groundwater spring sample analyzed. The second cluster analysis (Figure 6.10), using only oxygen-18 data, showed a grouping very similar to the first analysis. In this analysis, the two groups of stream samples were divided between Day 31 and Day 35. As a result of this cluster analysis, the $\delta^{18}O$ value for C_O was taken as the average of the same six samples noted as baseflow from the first cluster analysis.

Finally, the value for C_N was assumed to be a constant value and was obtained by averaging oxygen-18 contents of melted snow samples. Hooper and Shoemaker (1985) state that the use of snowcores ignores the contribution of any rain that falls during melt, however there was little evidence that $\delta^{18}O$ values of stream samples were significantly affected by rainfall (see Figure 6.8). Rodhe (1981;

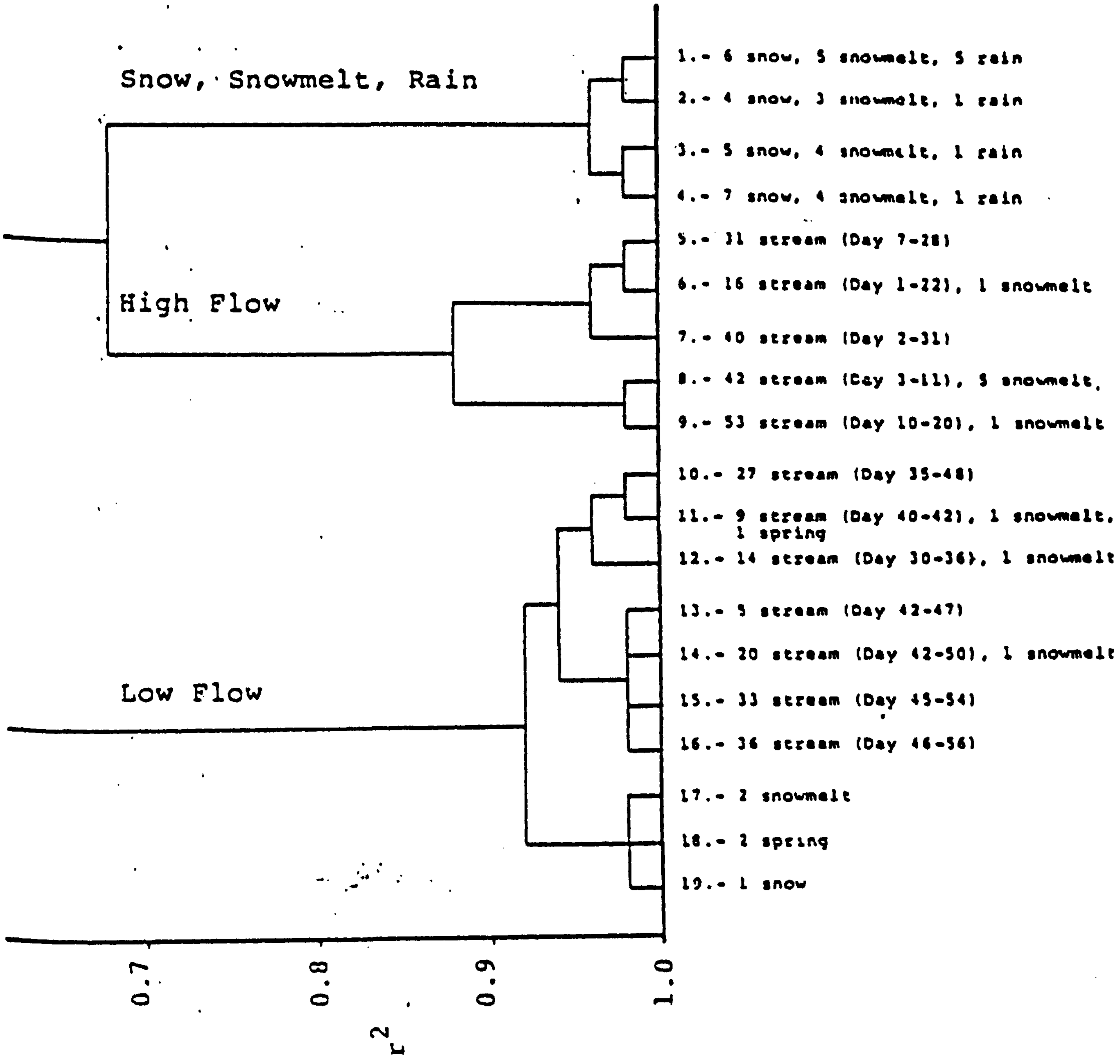


Figure 6.9: Results of the cluster analysis using the chemical variables.

Table 6.5: Summary of Oxygen-18 Values from Various Sources.

Source		$\delta^{18}O$ (‰)
Baseflow	$\bar{x}$	-17.5
	s	0.3
	n	6
High Flow	$\bar{x}$	-19.5
	s	0.9
	n	20
Snow	$\bar{x}$	-23.1
	s	0.6
	n	5
Snowmelt	$\bar{x}$	-24.5
	s	1.9
	n	4
Rain	$\bar{x}$	-18.0
	s	2.7
	n	7
Spring	$\bar{x}$	-17.9
	s	0.0
	n	1

NOTE: Baseflow period = Day 35 to Day 56
High flow period = Day 1 to Day 34.

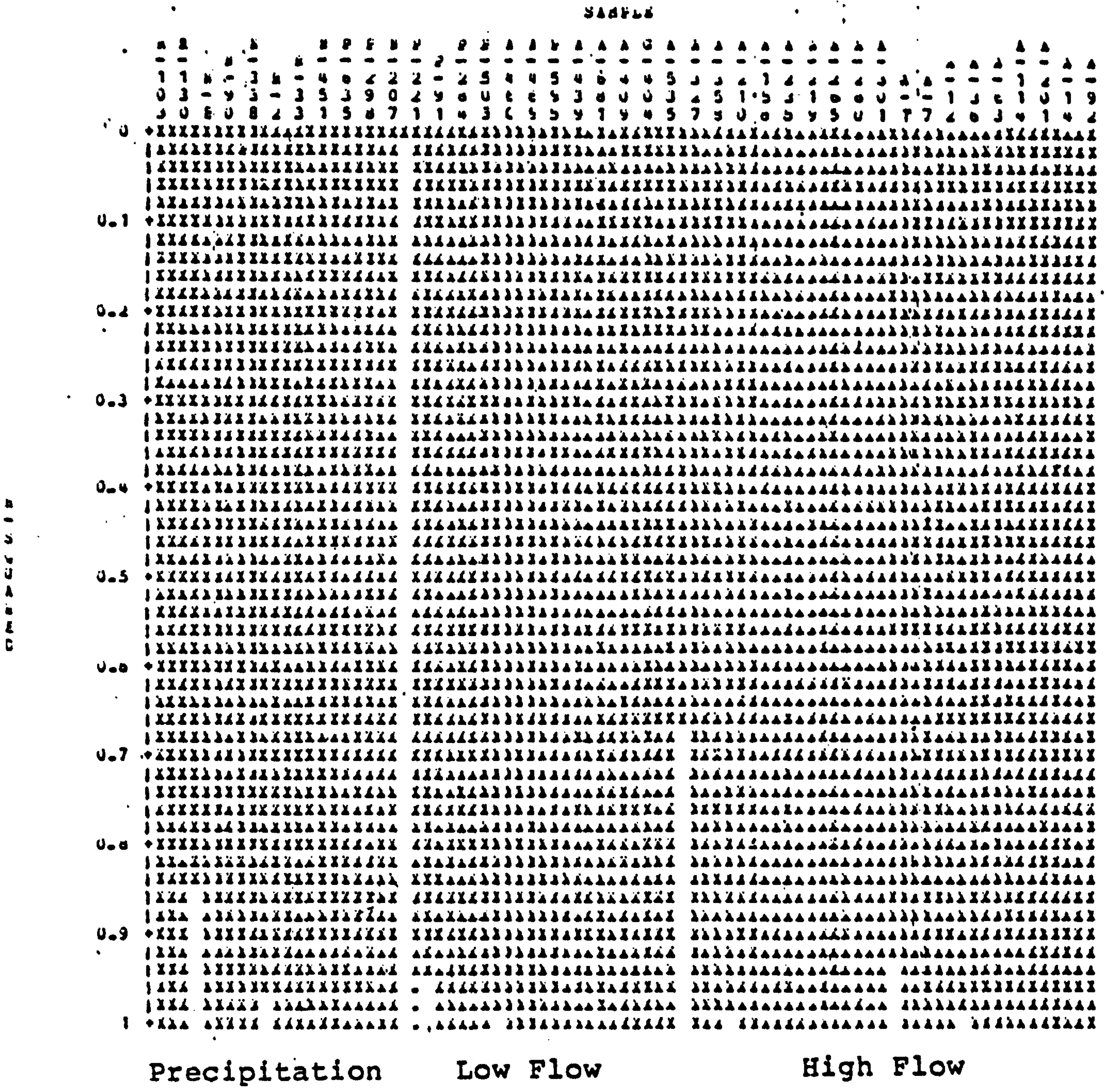


Figure 6.10: Results of the cluster analysis using the oxygen-18 data.

1983a,b) assumes that the isotopic content of snowcores is the same as that of snowmelt water. This assumption has been disputed by Hooper and Shoemaker (1985) who found that snowmelt samples were isotopically heavier in terms of D, than snowcore samples. Similarily, Krouse (1974; referenced in Steppuhn et al., 1975) noted an enrichment in $\delta^{18}O$ in melting snow.

The use of snow sample $\delta^{18}O$ for C_N should be considered valid for a number of reasons. First, snow samples were taken daily throughout the melt season. While they were not all analyzed owing to cost considerations, those that were, were spaced throughout the summer and included any effects of the isotopic content of rain falling on the snow. Secondly, since the normal summer rainfall intensities are light, the input of rainfall can be considered to be of minimal importance relative to the volume of water available from the snow on the ground during the first half of the field season. Finally, the trend of $\delta^{18}O$ of snowmelt samples from the Apex watershed is different from the trends found by Hooper and Shoemaker (1985) and Krouse (1974). The average $\delta^{18}O$ content of the snowmelt samples was depleted relative to that of the snow samples (Table 6.4). Since the meltwater is depleted in terms of $\delta^{18}O$, then the use of a constant value of $\delta^{18}O$ from snow samples would give a conservative solution to the hydrograph separation, that is, the separation could be considered a minimum estimate of the old water contribution.

Examination of the hydrograph separation (Figure 6.8) reveals several interesting points. First, the peak old water discharge is approximately 50% of the peak stream discharge, and occurs relatively soon after the peak stream discharge. Also, early in the season, the old water contributions are low relative to the total discharge but increase later in the season. A possible explanation for this occurrence is the gradual melting of the active layer which increases the contributing capacity of the subsurface. Early in the snowmelt season, the ground is still frozen up to the surface resulting in direct runoff as overland flow or flow along the vegetation-bedrock surface (Figure 6.11 a-b). Later in the summer, the active layer melting progresses, resulting in a larger contributing source for subsurface flow as well as a larger reservoir for storage of infiltrating snowmelt water. Also later in the summer, there is less snow left on the ground resulting in a higher proportion of old water in the total stream discharge. Rains, generally light in intensity, also are likely to infiltrate later in the summer when the active layer has the capacity to store it.

The overland flow shown in Figure 6.11 a-b is similar to that described by Dingman (1966; 1973) who noted overland flow and flow originating in stored water in vegetation migrating along the frozen ground surface in a discontinous permafrost watershed in Alaska. As in the studies by Woo (1976) and Lewkowicz and French (1982a), the overland flow

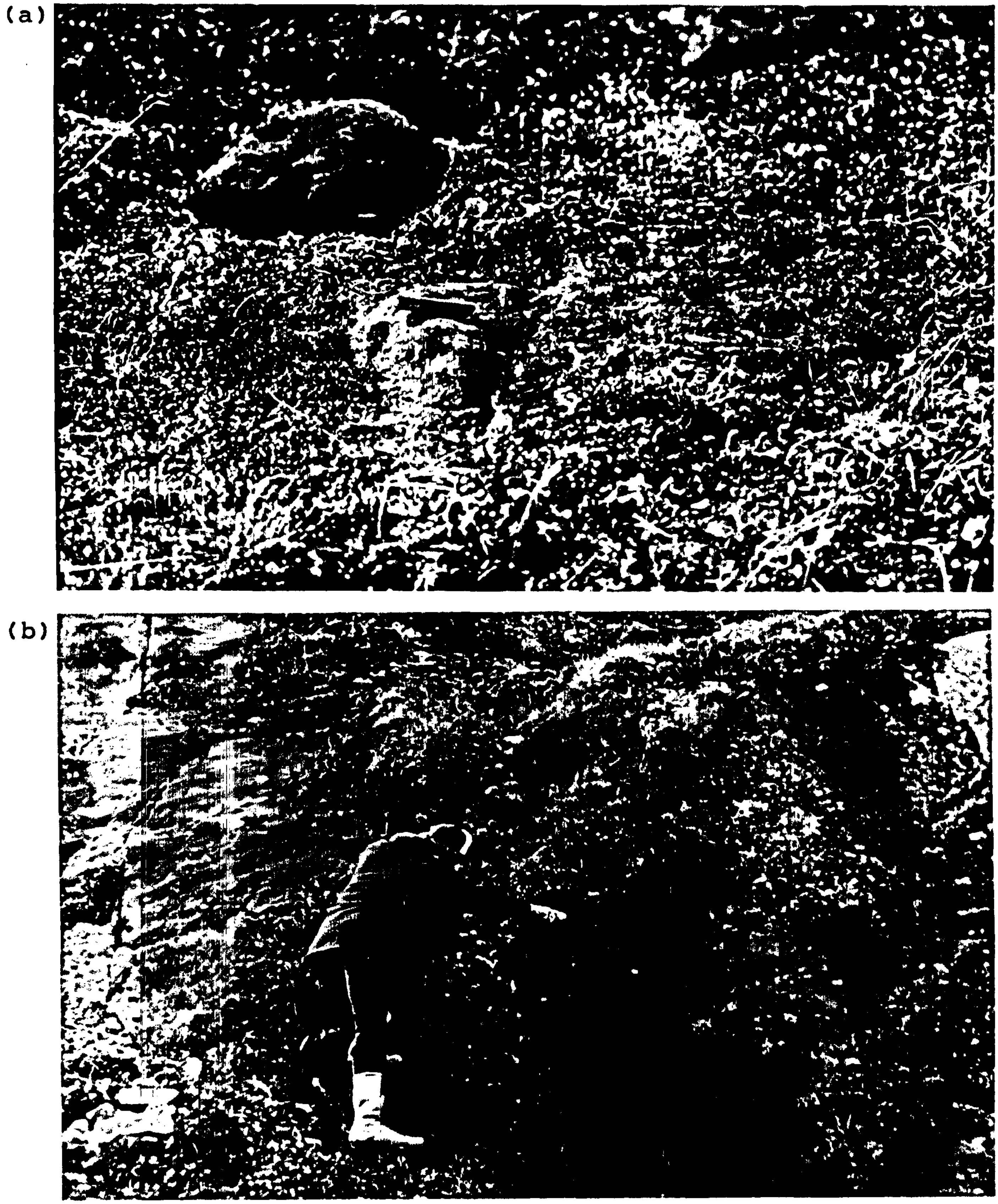


Figure 6.11: (a) Overland flow downslope of a large snow bank. (b) Flow along the vegetation-bedrock interface.

in the Apex watershed occurred downslope of substantial accummulations of snow.

Many northern researchers have presented evidence of groundwater discharge in permafrost areas, however no attempts have been made to quantify it (Brandon, 1963; Kalanin, 1968; Van Everdingen, 1974; See Chapter 3). Others have empahsized the role of subsurface flow (Lewkowicz and French, 1982a,b; Steer and Woo, 1983) however they tend to describe the subsurface flow as originating from infiltrating meltwaters. In light of the results presented here, it appears that "old" groundwater is a substantial contributor to the Apex River discharge, making up about 50% of the peak discharge and about 60% of the total stream discharge from June 16 to August 10, 1983. This "old" water is probably water which infiltrated into the active layer near the end of the previous summer. This presumption can be made based on the isotopic data in Table 6.5. The similarity of $\delta^{18}O$ values for rain and baseflow indicate a similar origin. Also, the estimated average $\delta^{18}O$ value for precipitation in the area from the literature (approximately -18‰, from Figure 4.5) is similar to the baseflow value.

A possible mechanism to explain the substantial groundwater contribution is similar to the displacement mechanism described for more temperate environments. Infiltrating meltwater displaces groundwater already in the melting active layer towards the stream. A similar displacement mechanism has been used to explain snowmelt runoff in non-permafrost zones (e.g. Dincer et al., 1970; Sklash and Farvolden, 1979; Rodhe, 1981; 1983a,b; Bottomley et al., 1985). Infiltration of meltwater into the frozen soil may provide more water to be displaced to the stream. Price and Hendrie (1983) have noted the ability of meltwater to infiltrate frozen soils.

This displacement mechanism contrasts with results reported by Steppuhn et al. (1975) and Krouse et al. (1978) who found no groundwater input in their snowmelt runoff studies in southern Canada. In the Steppuhn study, a channel formed by snowmelt runoff from a "snow patch" was analyzed for $\delta^{18}O$ as were other possible inputs such as spring discharge and snow. Their isotopic results revealed that virtually all of the channel's discharge was from snowmelt, which is not surprising since the watercourse is described as a meltwater channel. Krouse et al. (1978), on the other hand, do not dispute the results of Dincer et al. (1970), and Meiman et al. (1973) who suggest that a large amount of meltwater infiltrates. Rather, they explain their results showing little infiltration of meltwater as occurring because of the basin's high resistance to what Krouse et al. call "penetration" which is assumed to be infiltration. These results and explanation are puzzling since they describe one of the study basins as a well-drained agricultural watershed. It is highly likely, in view of the results of other isotopic studies of watersheds, that Krouse et al. (1978) and Steppuhn et al.

(1975) were measuring channelized overland flow from a melting snowbank rather than a perennial first order stream.

In general, the oxygen-18 data from the Apex River watershed are consistent with data in the literature. Michel (1976) stated that the $\delta^{18}O$ values for baseflow in streams in permafrost areas should be somewhere between the values for rain and snow, or the average of the year's precipitation. From Table 6.5 it can be seen that the baseflow values do lie between the measured rain and snow values. The $\delta^{18}O$ values for rain and snow taken from the Apex watershed average -20.6‰ which is very close to the estimate of -20‰ obtained using Dansgaard's (1964) plot of $\delta^{18}O$ content of precipitation versus mean annual air temperature (Figure 4.4). This estimate is obtained using a mean annual air temperature of -9.3°C for Frobisher Bay (Environment Canada, 1984). From the map of $\delta^{18}O$ distribution in precipitation (Figure 4.5), a value of between -20‰ and -18‰ (-18.5‰) is obtained for Frobisher Bay which is closer to the value of $\delta^{18}O$ for the baseflow of the Apex River (-17.5‰).

Temporally, the values of $\delta^{18}O$ in the stream do not deviate very much from the general trend of enrichment with time (Figure 6.8). The relationship between $\delta^{18}O$ in the stream and stream discharge (Figure 6.12) is very similar to some of the chemical constituents mentioned in Section 6.2.1, namely electrical conductivity, Mg and Ca (Figure 6.5).

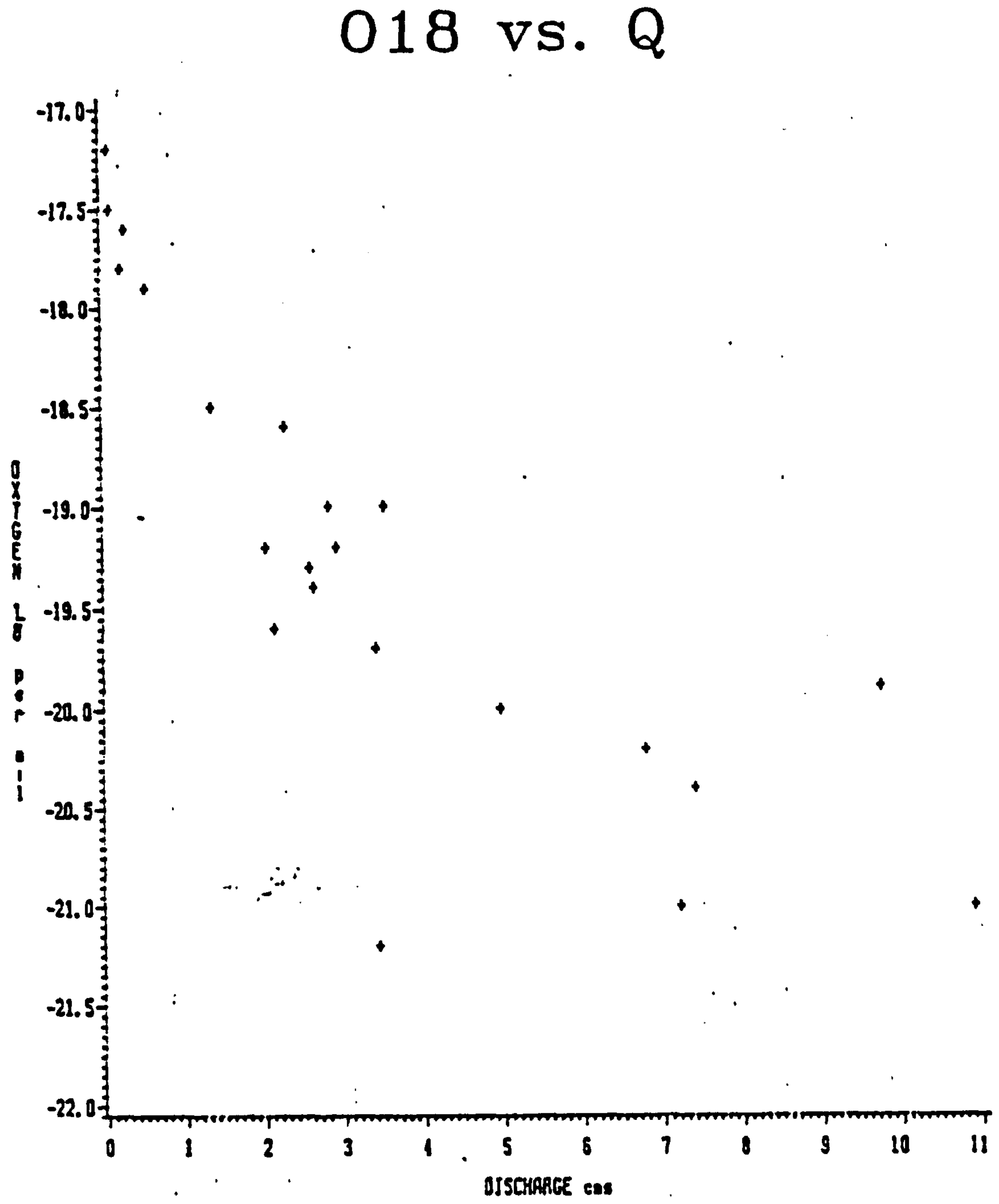


Figure 6.12: Relationship between $\delta^{18}O$ and discharge.

6.2.3 Chemical Hydrograph Separation

If one were to use chemical data to solve the mass balance equation (Equation 4.7), one would find that the various chemical species present in the water would not yield identical separations. The problem with chemical parameters is that they are not always conservative, that is, their concentrations change with increased contact time with geologic materials in the basin (Pilgrim _et_ _al_., 1979). Table 6.2 illustrates this response using electrical conductivity values. The EC of rain and snow are low because these waters have little or no contact with the watershed materials. The snowmelt has a higher EC as a result of coming in contact with basin material. Finally, the baseflow samples show a much higher EC due to their much longer contact time. Environmental isotopes, on the other hand, are considered to be conservative (e.g. Hooper and Shoemaker, 1985), that is, their concentrations in water do not change when the water interacts with basin materials on the time scale of normal hydrograph response which is on the order of hours or days (Pearce _et_ _al_., 1985). As a result, they are considered to be the most reliable tracers for hydrograph separations (e.g. Sklash _et_ _al_., 1976; Hermann and Stichler, 1980; Bottomley _et_ _al_., 1985). However, isotope analyses are expensive by comparison with major ion analyses or simple electrical conductivity measurements. Since much more chemical data can be gathered for a much lower cost than for isotopic data, as was the case in this study, it was attempted to determine if any of the chemical parameters were "conservative enough" to use for a reliable hydrograph separation.

To determine which chemical parameter was the most reliable, a predictive model was formulated on the assumption that the oxygen-18 solution was accurate. Using the hydrograph separation results in a rearranged mass balance equation (Equation 4.7), the concentration of a particular species in the stream water at a particular time can be predicted. Predicted concentrations at selected times during the study period can then be compared to the observed concentration values of stream water from corresponding times. The chemical parameter which shows the smallest difference between the predicted and observed values would then be considered the most conservative.

Chemical data consisting of electrical conductivity values and Mg and Ca concentrations were inserted in the rearranged mass balance equation. Na and K concentration data were not used in the model because they did not satisfy the criteria mentioned in Section 4.5 for their use as tracers.

The results of the model are illustrated in Figure 6.13 as plots of calculated values versus observed values. The 1:1 line on the plots represents the situation where the observed chemical data correlates exactly with the predicted values and, thus, will give a separation identical to the separation obtained with oxygen-18. It is likely, though,

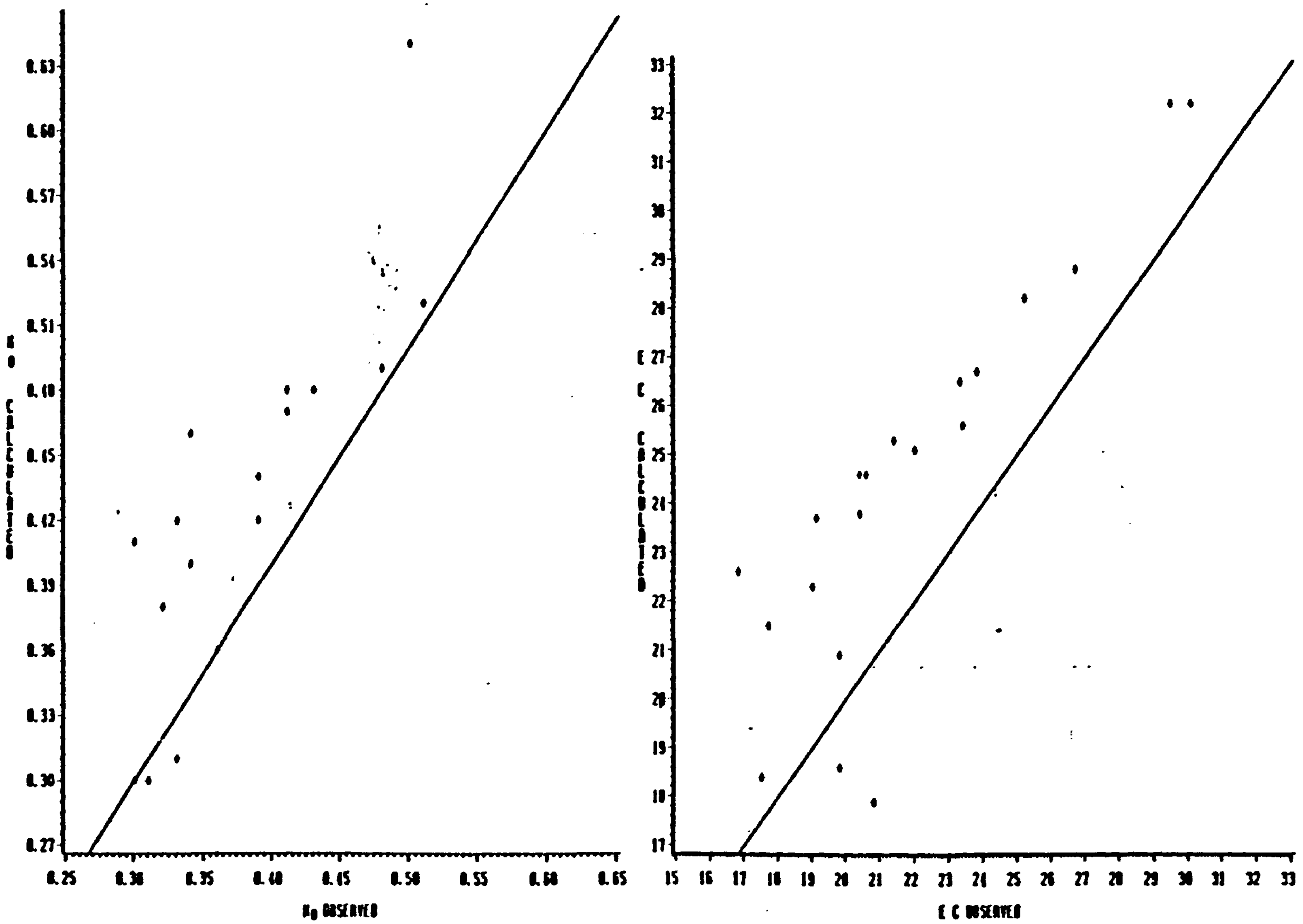


Figure 6.13: Results of predictive model.

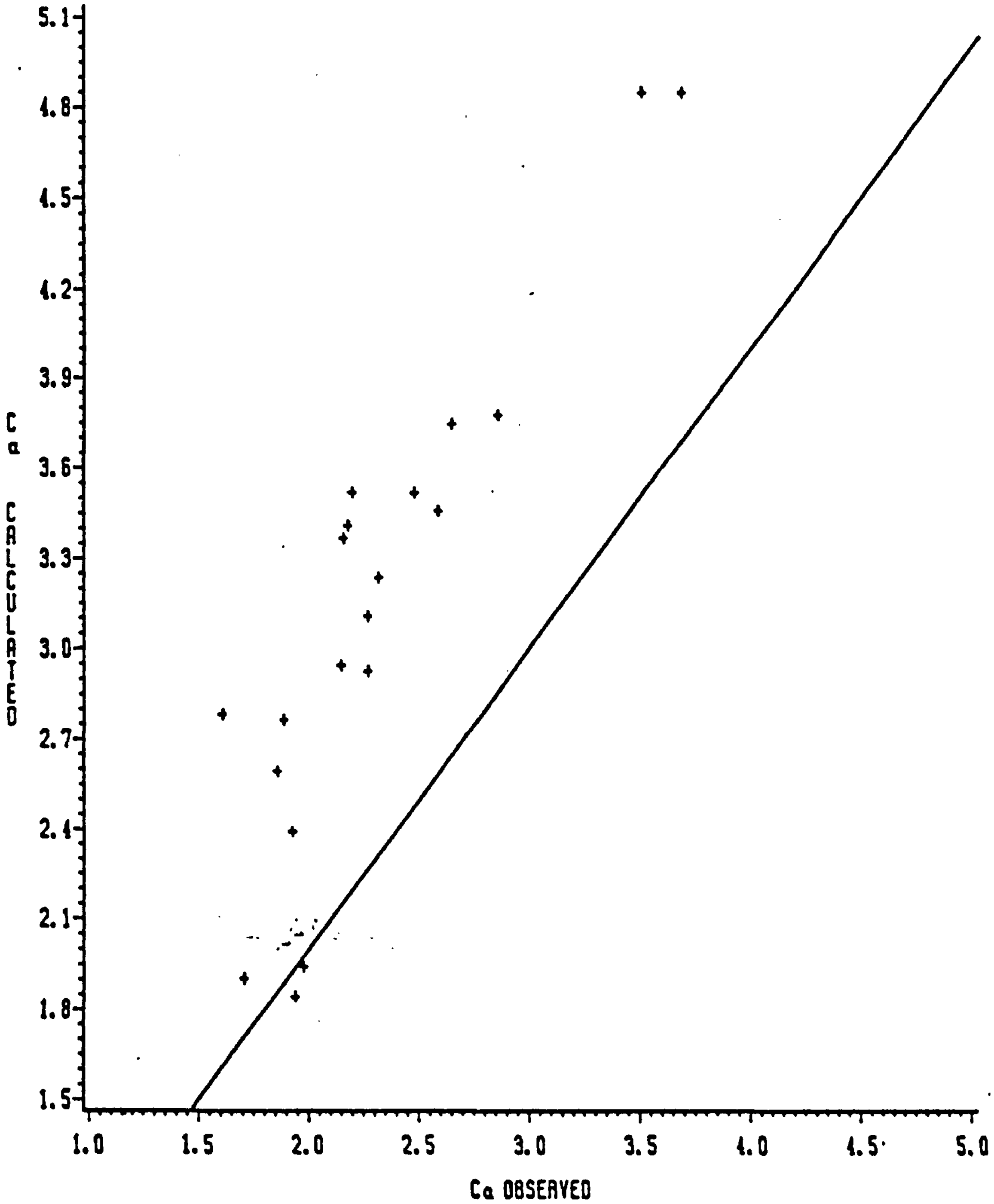


Figure 6.13: continued

that owing to the variability of the chemical species in water resulting from contact time relationships , the data will probably deviate from the 1:1 line. If the plotted data lies below the line (i.e. $C_{calc} < C_{obs}$), this indicates that the chemical parameter will underestimate the old water contribution relative to the oxygen-18 solution. If the points fall above the line, then the data will result in an overestimate of the old water contribution. From the results (Figure 6.13) it appears that electrical conductivity and Mg will yield the most accurate hydrograph separation relative to the oxygen-18 solution since the points plot nearest to the 1:1 line.

Another procedure for determining the best chemical parameter is illustrated in Figure 6.14. This procedure compares the hydrograph separations obtained from each of the chemical parameters (Figure 6.15 a-c) to the oxygen-18 solution. The bars represent the number of points on the respective hydrograph separations that differ from the oxygen-18 separation by a given percentage range of old water input. Since most of the bars are to the right of 0, this indicates that, in general, the ionic data underestimates the old water input relative to the oxygen-18 solution. Figure 6.14 indicates that Mg will give the most accurate hydrograph separation relative to the oxygen-18 solution, however the figure also shows that Mg consistently underestimates the old water contribution by an average of 10%.

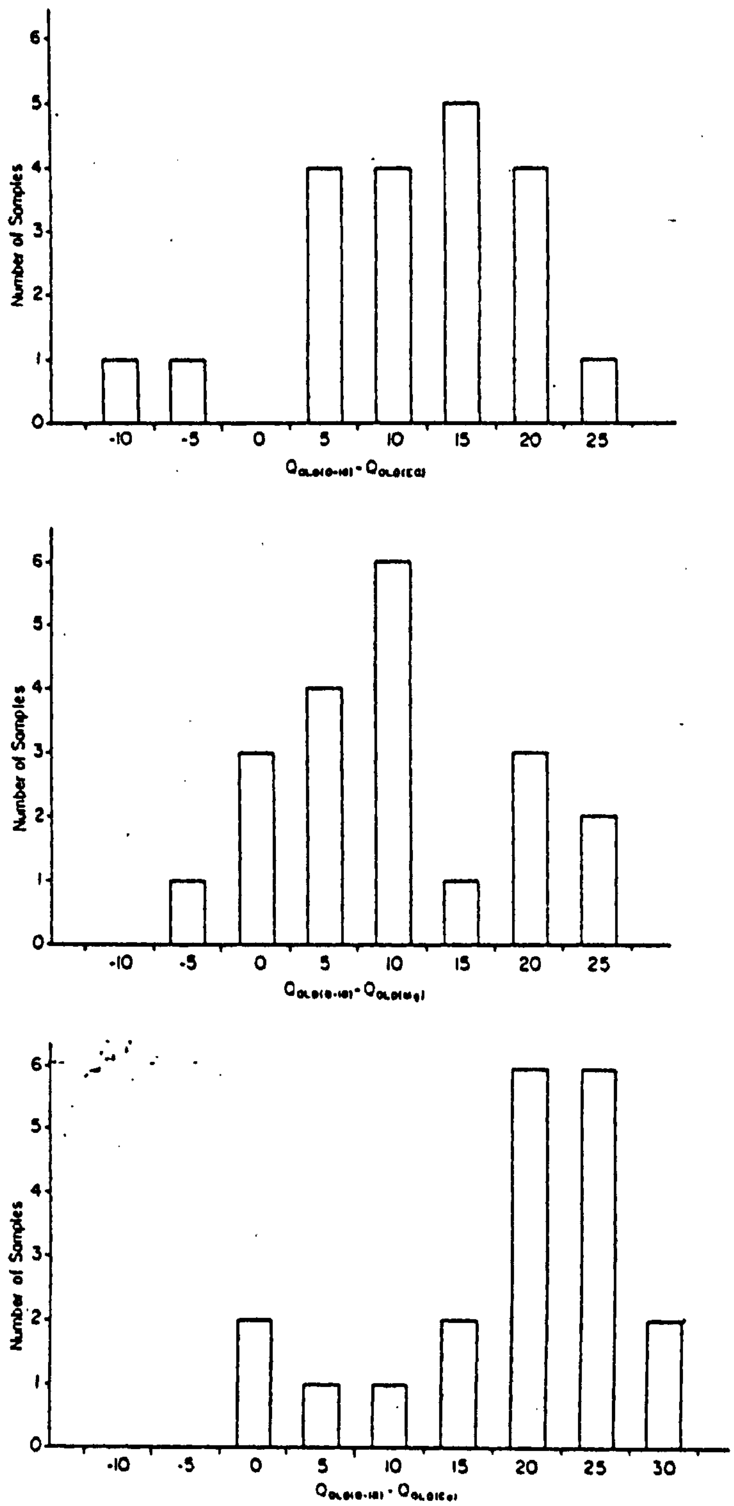


Figure 6.14: Bar graphs of difference in proportion of old water as calculated by EC, Mg, and Ca relative to $\delta^{18}O$.

The hydrograph separations illustrated in Figure 6.15 were produced using the same approach as for the oxygen-18 separation. Values of EC, Mg, and Ca for the various terms in the mass balance equation (Equation 4.7) were assigned using the same rationale that was used for the oxygen-18 solution.

This predictive model is essentially the same type of analysis done by Hooper and Shoemaker (1985). They compared oxygen-18 hydrograph separations with those based on major cations and anions (not specified) and found that silica (Si) was the most conservative chemical tracer for their particular watershed. They found that Si underestimated the proportion of old water by an average of about 4%.

Since all of the chemical parameters consistently underestimate old water contributions, it is necessary to examine the possibility that the oxygen-18 solution is incorrect. Since the Mg hydrograph separation was determined to be the most accurate relative to the $\delta^{18}O$ separation, the Mg solution will be used to examine the $\delta^{18}O$ solution.

The only source of error in the stream and baseflow samples is the analytical error for $\delta^{18}O$. Since this error is the same for all of the samples analyzed, it is assumed that these are accurate to within the analytical precision (see next section). This leaves the most likely source of error as the value of $\delta^{18}O$ used for C_N in the mass balance equation (Equation 4.7). C_N was estimated in this study as

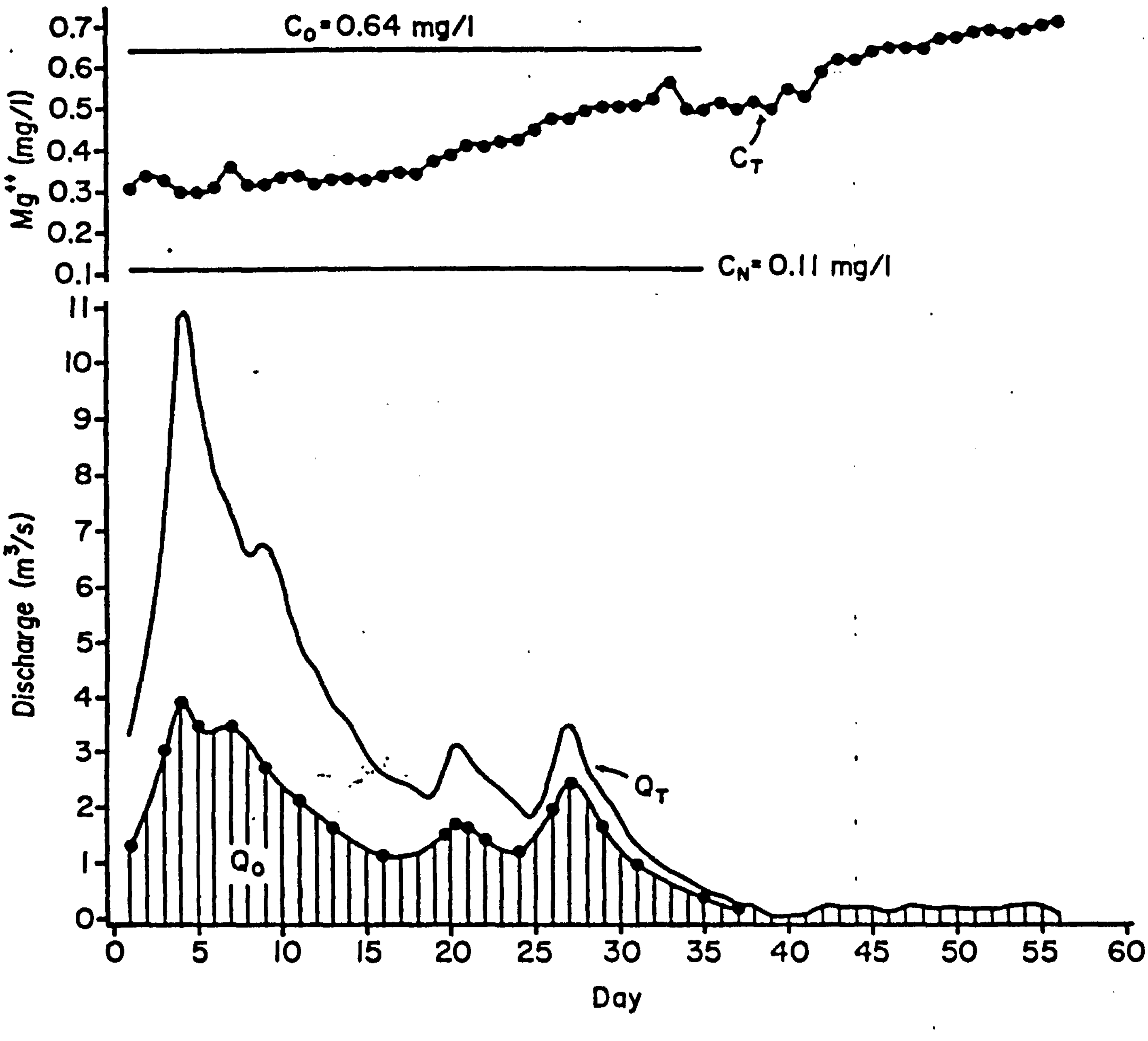


Figure 6.15(a): Hydrograph separation using Mg. (Day 1= June 1, 1983)

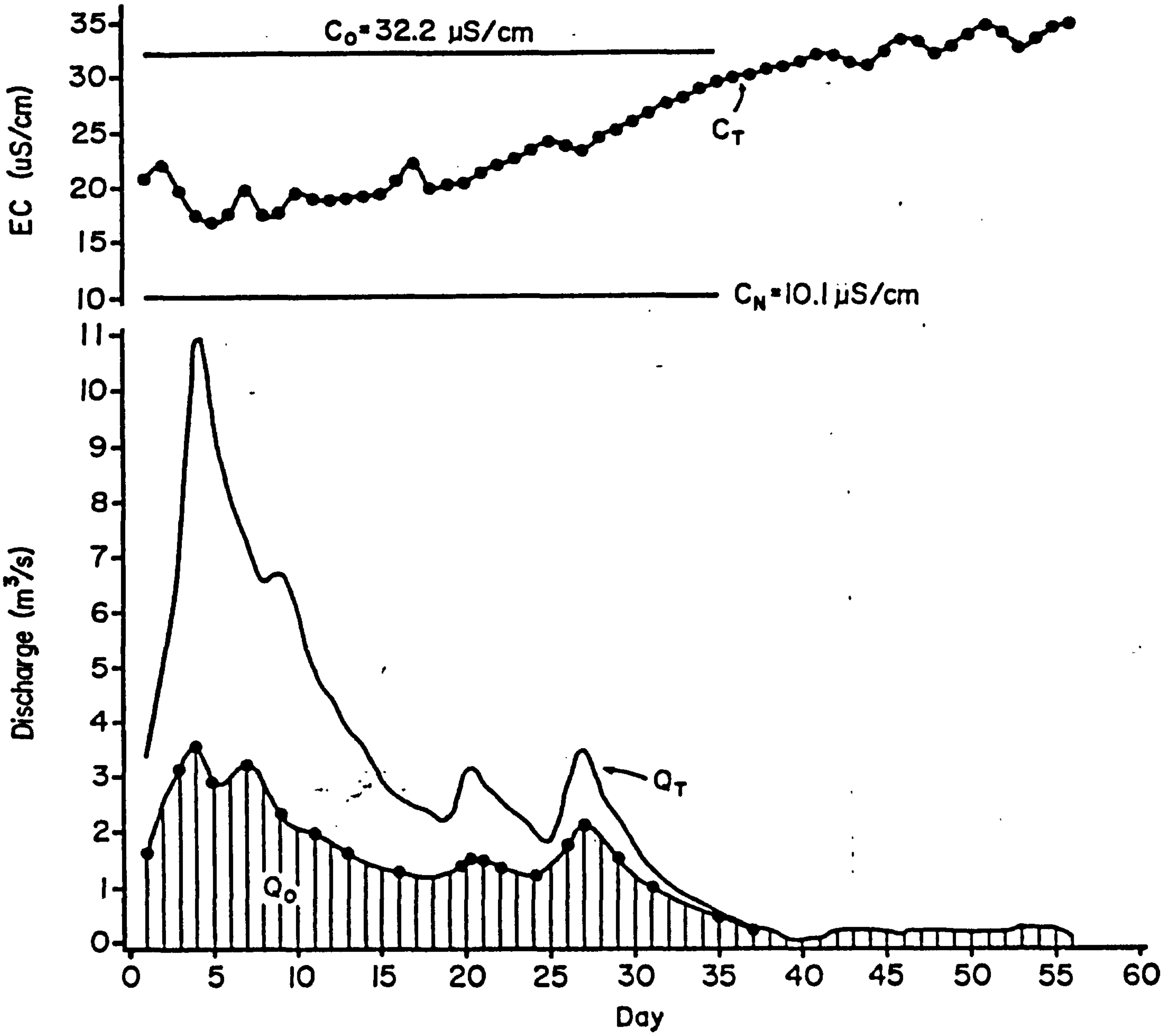


Figure 6.15(b): Hydrograph separation using EC. (Day 1= June 1, 1983)

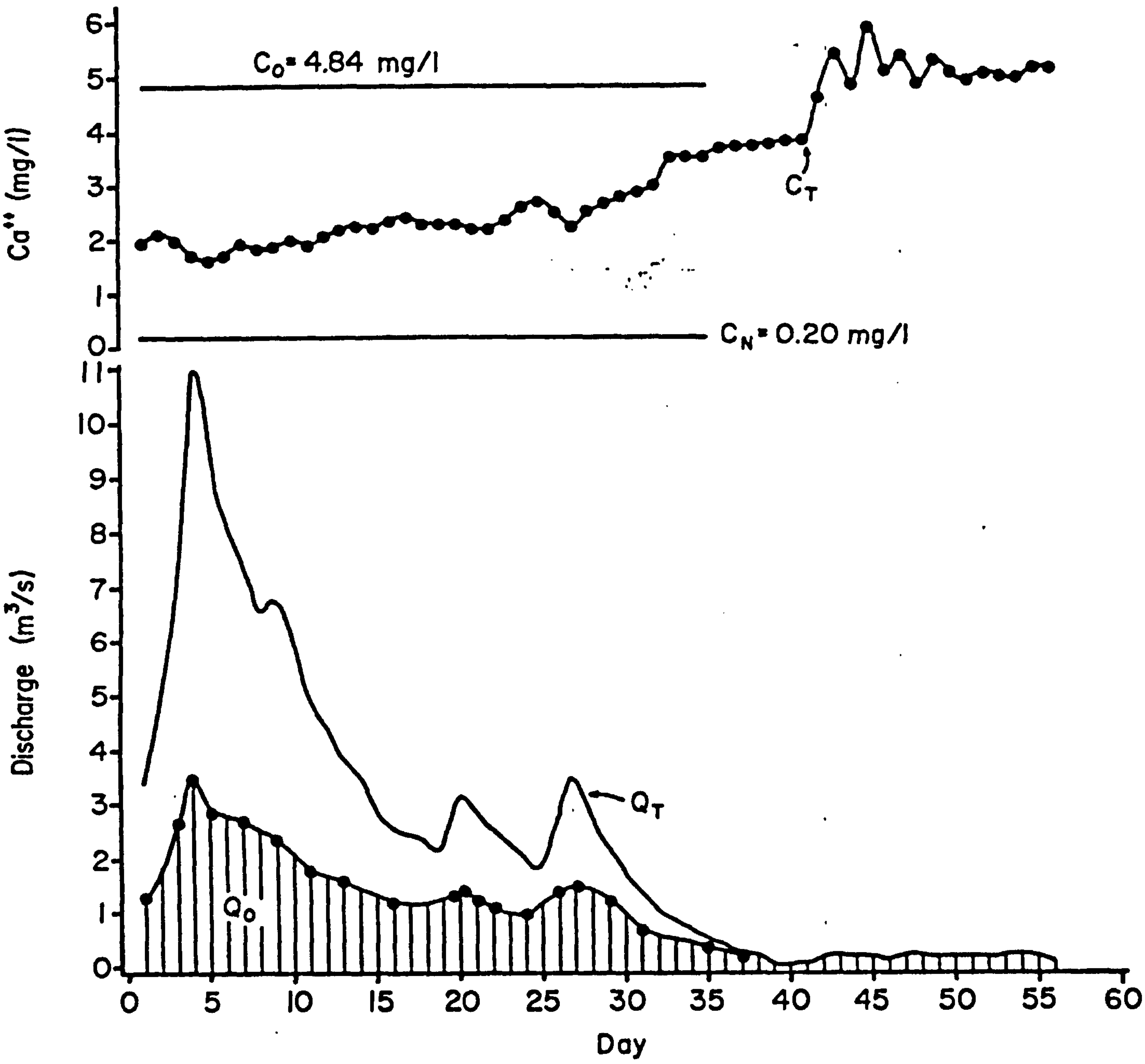


Figure 6.15(c): Hydrograph separation using Ca. (Day 1= June 1, 1983)

the average $\delta^{18}O$ of snow. According to a number of authors (e.g. Moser and Stichler, 1980; Hooper and Shoemaker, 1985), there is an enrichment of $\delta^{18}O$ in snowmelt water relative to snow samples. The average value obtained for snowmelt in this study is depleted in $\delta^{18}O$ relative to snow (Table 6.5), although the snowmelt value is based on only four samples. The use of more enriched $\delta^{18}O$ values for C_N in the mass balance equation would yield lower old water contributions.

To examine if the assumed value of C_N is correct, the calculated values of Q_O (and Q_N) from the Mg hydrograph separation are substituted into a rearranged mass balance equation to determine values of C_N necessary to make the $\delta^{18}O$ data match the Mg separation. The predicted C_N values are listed in Table 6.6. Four of the first five values are similar to the assumed value of C_N and this indicates that during the important peak flow period most of the points on the $\delta^{18}O$ and Mg hydrograph separations are similar. The rest of the values are consistent with what might be expected if enriched snowmelt water was the new water input. This may indicate a possible introduction of error by using the $\delta^{18}O$ content of snow as an estimate of C_N.

While the Mg solution points out certain limitations of the oxygen-18 solution, the oxygen-18 solution cannot be simply discarded in favour of the Mg separation. There is a characteristic of the Mg response that makes its solution suspect. The predicted C_N values of $\delta^{18}O$ (Table 6.6) calculated from the Mg hydrograph separation are not

Table 6.6: Values of $\delta^{18}O$ for C_N calculated from the Mg hydrograph separation (values are in ‰).

Day	C_N(calculated)	C_N(assumed)
1	-23.3	-23.1
3	-23.5	
4	-23.0	
5	-21.3	
7	-23.0	
9	-22.0	
11	-21.9	
13	-21.3	
16	-20.8	
20	-22.2	
20	-21.8	
21	-21.5	
22	-21.7	
24	-21.8	
26	-22.5	
27	-22.5	
29	-21.9	
31	-21.5	
35	-19.0	
37	-17.5	

consistent with other available data. For instance, rainstorms which occurred on Days 20 and 26-27 (Figure 6.4) had $\delta^{18}O$ values that were enriched relative to the snow or snowmelt samples ($\delta^{18}O_{Day\ 20}$=-14.7‰, $\delta^{18}O_{Day\ 26/27}$= -19.3‰). The expected response would be an enrichment of the overall C_N value, however Table 6.6 shows a depletion of the predicted $\delta^{18}O$ values of C_N on these days.

6.3 Sources of Error

6.3.1 Precision of the isotopic hydrograph separation

The main source of uncertainty in the isotopic hydrograph separation is the variation of $\delta^{18}O$ in groundwater and meltwater, relative to the estimates used in the mass balance equations. The variation of $\delta^{18}O$ in the stream water during baseflow (C_O) is ±0.4% . The variation about the mean value of $\delta^{18}O$ content of the snow samples (C_N) is within ±0.8‰. These variations were used to perform a sensitivity analysis on the calculated old water contribution. The results are listed in Table 6.7. From this table, the accuracy of the hydrograph separations is estimated to be within ±13%. This compares to values of ±15% obtained by Rodhe (1981) and ±10% by Hooper and Shoemaker (1985).

The analytical error for oxygen-18 is less than 0.2‰ (Payne and Halevy, 1968). Selected samples, approximately one in five, were analyzed twice as a check.

Table 6.7: Sensitivity analysis performed on measured data.

	C_0	C_N	C_T	Q_0/Q_T(%)
Day 1	-17.5	-23.1	-21.1	36
	-17.1	-22.3	-21.1	23
	-17.9	-23.9	-21.1	47
Day 5	-17.5	-23.1	-19.9	57
	-17.1	-22.3	-19.9	46
	-17.9	-23.9	-19.9	67
Day 35	-17.5	-23.1	-17.9	93
	-17.1	-22.3	-17.9	85
	-17.9	-23.9	-17.9	100

The measured values of C_0 and C_N (first line of each day) were varied by 0.4‰ and 0.8‰, respectively, to examine the change in proportion of old water.

The effect that rain events have on the snowmelt hydrograph separation depends on their isotopic content relative to that of the snow. If the $\delta^{18}O$ of the rain is the same as that of the snow, then the estimate of Q_O is correct because the rain has no effect on the isotopic content of the new water input. If the $\delta^{18}O$ of the rain is greater than that of the snow, then Q_O is overestimated (Rhode, 1981). During the hydrograph separation period, one of four rains analyzed was similar in $\delta^{18}O$ to the snow while the other three were more enriched in $\delta^{18}O$ than the snow. However, since the snow was analyzed periodically, any effect the $\delta^{18}O$ content of the rain had on the overall isotopic content of the new water component would show up in the $\delta^{18}O$ content of the snow.

6.3.2 Chemical analyses

About 75% of the 1983 samples were analyzed on the Varian AA-175 series atomic absorption spectrophotometer, while the rest were analyzed on the Instrumentation Laboratories IL-351. To check the reproducibility of the two machines, five samples werre analyzed for Ca and Mg on both machines. The results are tabulated in Table 6.8. From the table, Mg appears to compare quite well, while Ca appears to be slightly higher on the IL-351, although not significantly at the 99% level of significance when the results are subjected to a paired sample t-Test (Appendix IV)(Miller and Freund, 1977).

Table 6.8: Comparison of Ca and Mg analyses obtained using Varian AA-175 and Instrumentation Laboratories IL-351 atomic absorption spectrophotometers (values are in mg/l).

Sample	IL-351		AA-175	
	Ca	Mg	Ca	Mg
A-377	4.15	0.52	3.45	0.75
A-380	3.35	0.91	2.20	0.95
A-381	0.95	0.13	0.90	0.14
A-386	0.50	0.38	0.35	0.36
A-388	4.15	0.54	3.55	0.45

On both machines, quality control consisted of analyzing a bench standard (tap water in this case) with every batch of samples run. Usually, a sample analyzed in a previous batch was also analyzed and compared to its previous result.

All of the chemical data obtained during the study are presented in Appendices II and III. When performing mass balance calculations for hydrograph separation purposes, daily average values of EC, Mg and Ca were used. Anomalous values (e.g. "spikes" in Na on days 2, 7, and 17) were disregarded.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The following conclusions are derived from the data and field observations obtained during the summers of 1982 and 1983 in the Apex River watershed:

(i) "Old" groundwater is a major component of the snowmelt hydrograph, making up approximately 50% of the peak discharge and about 60% of the total stream discharge from June 16 to August 10, 1983.

(ii) The groundwater response must have been rapid. When calculated by $\delta^{18}O$ the peak groundwater discharge occurred about one day after the peak stream discharge. When calculated by EC, Mg and Ca, both peaks occurred on the same day.

(iii) Groundwater chemistry as determined from stream samples during baseflow is characterized by high ionic concentrations and enriched isotopic ratios, relative to the other sources that contribute to runoff. During snowmelt runoff, there is a dilution of the various chemical concentrations. The parameters which show the best inverse relationship with discharge are EC, Na, Mg, Ca and ^{18}O. There is no apparent relationship between K concentration and discharge probably because of the tendency of K to react with other solids in the water or to be taken up by vegetation.

(iv) The chemical and isotopic character of the waters which contribute to snowmelt runoff in the Apex River watershed can be summarized as follows (units: EC- µS/cm; Na, K, Mg and Ca- mg/l; $\delta^{18}O$-‰):

baseflow- EC=32.2, Na=0.59, K=0.12, Mg=0.64, Ca=4.84, $\delta^{18}O$=-17.5

snow- EC=8.1, Na=0.45, K=0.36, Mg=0.11, Ca=0.20 $\delta^{18}O$=-23.1

snowmelt- EC=15.8, Na=0.42, K=0.15, Mg=0.34, Ca=1.71, $\delta^{18}O$=-24.5

rain- EC=11.6, Na=0.39, K=0.32, Mg=0.24, Ca=0.40, $\delta^{18}O$=-18.0

springs- EC=40.7, Na=0.65, K=0.31, Mg=0.96, Ca=3.92, $\delta^{18}O$=-17.9

(v) Chemical concentrations throughout the watershed generally increase with time. Late in the summer, concentrations are relatively high because this period coincides with low stream discharge. Areally, there is no apparent pattern of chemical concentrations in the watershed.

(vi) Based on the hydrograph separation results, the mechanism responsible for the major old water input is probably a displacement of suprapermafrost groundwater from the melting active layer by infiltrating snowmelt and rain waters. Visual observation provided evidence of partial area overland flow in areas downslope of major accumulations of snow. Another mechanism delivering snowmelt water to the stream observed was interflow along the vegetation-bedrock interface. Overall, the streamflow is probably the result of some combination of the above mechanisms.

(vii) Mg was found to be the most conservative chemical parameter, relative to oxygen-18, for use in hydrograph separation. It did, however, consistently underestimate the old water contribution by an average of 10%.

(viii) On the basis of the historical hydrographs of the Apex River and Church's (1974a) classification, the flow regime of the Apex River can be classified as arctic nival.

(ix) The peak flow frequency analysis yielded results similar to those of comparably sized watersheds in southern Canada.

(x) The flow duration curves are difficult to interpret because of incomplete discharge data. The steep central section of the curve suggests an impermeable watershed, with overland flow dominating the streamflow. This interpretation is not consistent with the findings of the isotope and chemical hydrograph separations.

(xi) The recession analysis is also difficult to compare to other watersheds. The recession limb is fed by snowmelt (directly or indirectly) not by groundwater as in more temperate watersheds. The reservoir coefficient for the Apex River is larger than those of southern watersheds and smaller than those of other permafrost basins. The long recessions are likely a result of the increased storage capacity of the thawing active layer during the summer.

(xii) Graphical techniques for hydrograph separation are not suitable for use in watersheds dominated by a prolonged snowmelt runoff.

7.2 Recommendations

This work raises interesting possibilities regarding applications of this type of study and further research ideas:

(i) The fact that Mg was determined to be the most conservative chemical parameter in the Apex River watershed does not suggest that this will necessarily be the case in other watersheds. Similar studies should be done on each basin studied to determine the best parameter.

(ii) Further studies should be directed at smaller permafrost watersheds underlain by unconsolidated material. This would facilitate more complete coverage areally, and would also permit the monitoring of the progressive melting of the active layer. "Easy" installation of shallow wells, piezometers and seepage meters would also be possible, yielding information which could be used to better identify the mechanisms responsible for streamflow.

(iii) Isotope analyses are rather expensive. It would have been possible to improve the resolution of the hydrograph separation if more samples could have been analyzed. It is suggested that future studies have sufficient funding to perform a reasonable number of isotope analyses.

(iv) Future studies should also consider analyzing some samples for tritium, especially if piezometer samples are available. This will aid in determining the origin of the groundwater. The use of long-term isotopic data will aid in determining the residence time of the groundwater.

(v) An interesting future study might be to determine the effects of groundwater discharge on streams in permafrost regions in light of various scenarios that indicate a global warming trend. Higher temperatures would likely lead to greater active layer thicknesses, resulting in a larger contributing capacity of the subsurface.

(vi) A study such as this one has potential applications in environmental studies such as those concerned with acid rain research. Isotopic and chemical hydrograph separation data can be combined with historical discharge data such as flow frequency and flow duration to predict the magnitude and duration of future acidic input episodes.

(vii) This type of study also has applications in studies of non-point source pollution. An example of this type of situation is pollution from mine tailings. A study such as this could aid in identifying the route taken by pollutants to reach the stream and in determining remedial measures.

8. REFERENCES

Abdul, A. S. and Gillham, R. W. 1984. Laboratory studies of the effects of the capillary fringe on streamflow generation. Water Resources Research, 20, pp. 691-698.

Anderson, J. C. 1974. Permafrost-Hydrology studies at Boot Creek and Peter Lake watersheds, N.W.T. In Permafrost Hydrology-Proceedings of Workshop Seminar, Canadian National Committee, International Hydrological Decade, Environment Canada, Ottawa, pp. 39-44.

Attanayake, P. M. 1983. A field investigation of the groundwater ridging hypothesis. Unpublished M.Sc. Thesis. University of Windsor, 202 p.

Betson, R. P. 1964. What is watershed runoff? Journal of Geophysical Research, 69, pp. 1541-1551.

Beven, K. 1978. The hydrological response of headwater and sideslope areas. Hydrological Sciences Bulletin, 23, pp. 419-437.

Bird, V. B. 1967. The physiography of Arctic Canada, with special reference to the area south of Parry Channel. Johns-Hopkins Press, Baltimore, MD, 336 p.

Blackadar, R. G. 1967. Geological reconnaissance, southern Baffin Island. District of Franklin. Geological Survey of Canada Paper 66-47, 32 p.

Blake, W. Jr. 1966. End moraines and deglaciation chronology in northern Canada, with special reference to southern Baffin Island. Geological Survey of Canada Paper 66-26, 31 p.

Bottomley, D. J. 1974. Sources of stream flow and dissolved constituents in a small Precambrian Shield watershed. Unpublished M.Sc. Thesis. University of Waterloo, 191 p.

Bottomley, D. J., Craig, D., and Johnston, L. M. 1985. Neutralization of acid runoff by groundwater discharge to streams in Canadian Precambrian Shield watersheds. Journal of Hydrology, 75, pp. 1-26.

Brandon, L. V. 1963. Evidences of groundwater flow in permafrost regions. Proceedings: Permafrost International Conference, pp. 176-177.

Brown, J., Dingman, S. L., and Lewellen, R. I. 1968. Hydrology of a drainage basin on the Alaskan coastal plain. Research Report 240, United States Army Cold Regions Research and Engineering Laboratory, Hanover, NH, 18 p.

Brown, R. J. E. 1970. Permafrost in Canada. University of Toronto Press. 234 p.

Brown, R. J. E. 1974. Distribution and environmental relationships of permafrost. In Permafrost Hydrology-Proceedings of Workshop Seminar. Canadian National Committee, International Hydrological Decade, Environment Canada, Ottawa, pp. 1-6.

Brown, R. J. E., Johnston, G. H., MacKay, J. R., Morgenstern, N. R., and Shilts, W. W. 1981. Permafrost distribution and terrain characteristics. In Permafrost Engineering Design and Construction, Edited by G. H. Johnston. John Wiley & Sons, Toronto, pp. 31-72.

Burt, T. P., and Williams, P. J. 1976. Hydraulic conductivity in frozen soils. Earth Surface Processes, 1, pp. 249-360.

Cherry, J. A., Fritz, P., Bottomley, D. J., Farvolden, R. N., Sklash, M. G., and Weyer, K. U. 1975. Storm runoff studies in upstream basins using oxygen-18. Proceedings of the Canadian Hydrology Symposium, Winnipeg, pp. 552-560.

Church, M. 1974a. Hydrology and permafrost with reference to northern North America. In Permafrost Hydrology-Proceedings of Workshop Seminar. Canadian National Committee, International Hydrological Decade, Environment Canada, Ottawa, pp. 7-20.

Church, M. 1974b. On the quality of some waters on Baffin Island, Northwest Territories. Canadian Journal of Earth Sciences, 11, pp. 1676-1688.

Cogley, J. G., and McCann, S. B. 1975. Subsurface runoff characteristics of an Arctic nival catchment: Mecham River, Cornwallis Island. Proceedings of the Canadian Hydrology Symposium, Winnipeg, pp. 282-288.

Craig, H. 1961. Standards for reporting concentrations of deuterium and oxygen-18 in natural waters. Science, 133, pp. 1833-1834.

Crouzet, E., Hubert, P., Olive, P., and Siwertz, E. 1970. Le tritium dans les mesures d'hydrologie de surface. Determination experimentale du coefficient de ruissellement. Journal of Hydrology, 11, pp. 217-229.

Dansgaard, W. 1964. Stable isotopes in precipitation. Tellus, 16, pp. 436-468.

Dincer, T., Payne, B. R., Florkowski, T., Martinec, J., and Tongiorgi, E. 1970. Snowmelt runoff from measurements of tritium and oxygen-18. Water Resources Research, 6, pp. 110-124.

Dingman, S. L. 1966. Characteristics of summer runoff from a small watershed in central Alaska. Water Resources Research, 2, pp. 751-754.

Dingman, S. L. 1973. Effects of permafrost on stream flow characteristics in the discontinuous permafrost zone of central Alaska. In Permafrost: the North American Contribution to the Second International Conference, National Academy of Sciences, Washington, DC, pp. 447-452.

Drever, J. I. 1982. The geochemistry of natural waters. Prentice-Hall, Inc., Englewood Cliffs, NJ, 388 p.

Dunne, T. 1978. Field studies of hillslope flow processes. In Hillslope Hydrology, Edited by M. J. Kirkby, John Wiley and Sons, Toronto, pp. 249-290.

Dunne, T., and Black, R. D. 1970a. An experimental investigation of runoff production in permeable soils. Water Resources Research, 6, pp. 478-490.

Dunne, T., and Black, R. D. 1970b. Partial area contributions to storm runoff in a small New England watershed. Water Resources Research, 6, pp. 1296-1311.

Dunne, T., and Leopold, L. B. 1978. Water in environmental planning. W. H. Freeman & Co., San Francisco, CA 818 p.

Dunne, T., Moore, T. R., and Taylor, C. H. 1975. Recognition and prediction of runoff producing zones in humid regions. Hydrological Sciences Bulletin, 20, pp. 305-327.

Durum, W. H. 1953. Relationship of the mineral constituents in solution to streamflow, Saline River near Russel, Kansas. Transactions American Geophysical Union, 34, pp. 435-442.

Duysings, J. J. H. M., Verstraten, J. M., and Bruynzeel, L. 1983. The identification of runoff sources of a forested lowland catchment: a chemical and statistical approach. Journal of Hydrology, 64, pp. 357-375.

Environment Canada 1984. Principal station data. Frobisher Bay A. Atmospheric Environment Service PSD-48.

Ferris, P. F. 1975. Effect of man's northern developments on the hydrologic cycle (abstract). Proceedings of the Canadian Hydrology Symposium, Winnipeg, p. 732.

Fontes, J. Ch. 1980. Environmental isotopes in groundwater hydrology. In Handbook of environmental isotope geochemistry. Edited by P. Fritz and J. Ch. Fontes, Elsevier Scientific Publishing Co., Amsterdam, pp. 75-140.

Foster, I. D. L. 1978. A multivariate model of storm-period solute behaviour. Journal of Hydrology, 39, pp. 339-353.

Freeze, R. A. 1972a. Role of subsurface flow in generating surface runoff, 1. Baseflow contributions to channel flow. Water Resources Research, 8, pp. 609-623.

Freeze, R. A. 1972b. Role of subsurface flow in generating surface runoff, 2. Upstream source areas. Water Resources Research, 8, pp. 1272-1283.

Freeze, R. A. 1974. Streamflow generation. Reviews of Geophysics and Space Physics, 12, pp. 627-647.

Fritz, P., Cherry, J. A., Weyer, K. U., and Sklash, M. G. 1976. Runoff analyses using environmental isotopes and major ions. In Interpretation of Environmental Isotope and Hydrochemical Data in Groundwater Hydrology-Proceedings of an Advisory Group Meeting, International Atomic Energy Agency, Vienna, pp. 111-130.

Gat, J. R. 1980. The isotopes of hydrogen and oxygen in precipitation. In Handbook of Environmental Isotope Geochemistry, Edited by P. Fritz and J. Ch. Fontes, Elsevier Scientific Publishing Co., Amsterdam, pp. 21-47.

Gillham, R. W. 1984. The effect of capillary fringe on water-table response. Journal of Hydrology, 67, pp. 307-324.

Glover, B. J., and Johnson, P. 1974. Variations in the natural chemical concentration of river water during flood flows, and the lag effect. Journal of Hydrology, 22, pp. 303-316.

Gray, D. M., and Wigham, J. M. 1970. Runoff-Rainfall-General. In Handbook on the principles of hydrology, Edited by D. M. Gray, National Research Council, Ottawa, pp. 7.1-7.24.

Hare, F. K., and Thomas, M. K. 1979. Climate Canada. 2nd edition. John Wiley & Sons, Toronto, 230 p.

Health and Welfare Canada 1981. Results of water analysis, raw water tank, Frobisher Bay, November 9,1981. 1 p.

Hebert, P. 1982. Course notes. The Arctic Environment. University of Windsor field course.

Hem, J. D. 1959; 1970. Study and interpretation of the chemical characteristics of natural water (Two editions). United States Geological Survey Water-Supply Paper 1473. 363 p.

Hermann, A., and Stichler, W. 1980. Groundwater-runoff relationships. Catena, 7, pp. 251-263.

Hewlett, J. D. 1969. Tracing storm baseflow to variable source areas on forested headwaters. Technical Report Number 2, School of Forest Resources, University of Georgia, Athens, GA.

Hewlett, J. D., and Hibbert, A. R. 1967. Factors affecting the response of small watersheds to precipitation in humid areas. Proceedings of the International Symposium on Forest Hydrology, Edited by W. E. Sopper and H. W. Lull, pp. 275-290.

Hewlett, J. D., and Nutter, W. L. 1970. The varying source area of streamflow from upland basins. Proceedings of the Symposium on Interdisciplanary Aspects of Watershed Management, pp. 65-83.

Hoefs, J. 1973. Stable isotope geochemistry. Springer-Verlag, New York, 140 pp.

Holecek, G. R., and Noujaim, A. A. 1975. Separation of the surface and subsurface flow from snowmelt by the use of radioactive tracers. Publication Numero 117 de L'Asociation Internationale des Science Hydrologques, Symposium de Tokyo, pp. 497-505.

Holtan, H. N., and Overton, D. E. 1963. Analyses and application of simple hydrographs. Journal of Hydrology, 1, pp. 250-264.

Hooper, R. P., and Shoemaker, C. A. 1985. A comparison of chemical and isotopic hydrograph separation. Submitted to Water Resources Research.

Horton, R. E. 1933. The role of infiltration in the hydrologic cycle. Transactions American Geophysical Union, 14, pp. 446-460.

Ingenkamp, P. 1984. Groundwater seepage into an arctic stream during snowmelt recession. Unpublished B.A.Sc. thesis, University of Windsor. 53 p.

Kalanin, G. P. 1968. Global Hydrology (translated from Russian, 1971). Israel Program for Scientific Translations Ltd. 310 p.

Kobayashi, D. 1985. Separation of the snowmelt hydrograph by stream temperatures. Journal of Hydrology, 76, pp. 155-162.

Krouse, H. R. 1974. Stable isotopes in the study of snow and ice resources. Proceedings of the Conference on Advanced Concepts and Techniques in the Study of Snow and Ice Resources. American Committee for the International Hydrological Decade and the National Academy of Sciences, Washington DC.

Krouse, H. R., Holecek, G., and Steppuhn, H. 1978. Detecting snow water in streamflow by D/H and $^{18}O/^{16}O$ abundances in two western Canadian basins. In Stable Isotopes in the Earth Sciences. New Zealand Department of Scientific and Industrial Research Bulletin 220, pp. 87-95.

Kunkle, G. R. 1965. Computation of groundwater discharge to streams during baseflow by use of specific conductance. United States Geological Survey Profesional Paper 525C, pp. C202-C208.

Lewkowicz, A. G., and French, H. M. 1982a. The hydrology of small runoff plots in an area of continuous permafrost, Banks Island, N.W.T. Proceedings of the 4th Canadian Permafrost Conference, Calgary, pp. 151-162.

Lewkowicz, A. G., and French, H. M. 1982b. Downslope water movement and solute concetrations within the arctic layer, Banks Island N.W.T. Proceedings of the 4th Canadian Permafrost Conference, Calgary, pp. 163-172.

Linsley, R. K., Kohler, M. A., and Paulhus, J. L. H. 1958. Hydrology for engineers. McGraw-Hill, Toronto, 340 pp.

Martinec, J. 1975. Subsurface flow from snowmelt traced by tritium. Water Resources Research, 11, pp. 496-497.

Martinec, J. 1977. Snowmelt hydrographs from spatially varied input. Third International Hydrology Symposium, Colorado State University, Fort Collins, CO, pp. 100-111.

Martinec, J. 1985. Time in hydrology. In Facets of Hydrology Volume II, Edited by J. C. Rodda. John Wiley and Sons, pp. 249-290.

Martinec, J., Siegenthaler, U., Oeschger, H., and Tongiorgi, E. 1974. New insights into the run-off mechanism by environmental isotopes. Proceedings of the Symposium on Isotope Techniques in Groundwater Hydrology. International Atomic Energy Agency, Vienna. pp. 129-142.

Maxwell, J. B. 1980. The climate of the Canadian Arctic Islands and adjacent waters (two volumes). Environment Canada. Atmospheric Environment Service Climatological Studies Number 30.

McCann, S. B., and Cogley, J. G. 1972. Hydrological observations on a small Arctic catchment, Devon Island. Canadian Journal of Earth Sciences, 9, pp. 361-365.

Meiman, J. R., Friedman, I., and Hardcastle, K. 1973. Deuterium as a tracer in snow hydrology. Proceedings of the Banff Symposia on the role of snow and ice in hydrology, pp. 39-48.

Meyboom, P. 1961. Estimating ground-water recharge from stream hydrographs. Journal of Geophysical Research, 66, pp. 1203-1214.

Michel, F. A. 1977. Hydrogeologic studies of springs in the central Mackenzie Valley, North-West Territories, Canada. Unpublished M.Sc. Thesis, University of Waterloo, 185 p.

Michel, F. A. 1982. Isotope investigations of permafrost waters in northern Canada. Unpublished Ph.D. Thesis, University of Waterloo, 448 p.

Miller, I., and Freund, J. E. 1977. Probability and statistics for engineers. Prentice-Hall, Inc., Englewood Cliffs, NJ, 529 p.

Mook, W. G., Groeneveld, D. J., Brouwn, A. E., and Van Ganswijk, A. J. 1974. Analysis of a run-off hydrograph by means of natural ^{18}O. Proceedings of the Symposium on Isotope Techniques in Groundwater Hydrology. International Atomic Energy Agency, Vienna, pp. 145-153.

Moser, H., and Stichler, W. 1980. Environmental isotopes in ice and snow. In Handbook of Environmental Isotope Geochemistry, Edited by P. Fritz and J. Ch. Fontes. Elsevier Scientific Publishing Co., Amsterdam, pp. 141-178.

Mosley, M. P. 1979. Streamflow generation in a forested watershed, New Zealand. Water Resources Research, 15, pp. 795-806.

Mosley, M. P. 1982. Subsurface flow velocities through selected forest soils, South Island, New Zealand. Journal of Hydrology, 55, pp. 65-92.

Nakamura, R. 1971. Runoff analysis by electrical conductance of water. Journal of Hydrology, 14, pp. 197-212.

Newbury, R. W. 1974. River hydrology in Permafrost areas. In Permafrost Hydrology-Proceedings of Workshop Seminar. Canadian National Committee, International Hydrological Decade, Environment Canada, Ottawa, pp. 31-38.

Newbury, R. W., Cherry, J. A., and Cox, R. A. 1969. Groundwater-streamflow systems in the Wilson Creek Experimental Watershed, Manitoba, Canada. Canadian Journal of Earth Sciences, 11, pp. 964-975.

O'Brien, A. L. 1980. The role of groundwater in stream discharges from two small wetland controlled basins in eastern Massachusetts. Groundwater, 18, pp. 359-365.

Payne, B. R., and Halevy, E. 1968. Environmental isotopes. In Guidebook on nuclear techniques in hydrology. International Atomic Energy Agency Technical Report Series Number 91, Vienna, pp. 5-14.

Pearce, A. J., Stewart, M. K., and Sklash, M. G. 1985. Storm runoff generation in humid headwater catchments, I: Where does the water come from? Submitted to Water Resources Research.

Pilgrim, D. H., Huff, D. D., and Steele, T. D. 1978. A field evaluation of surface and subsurface runoff. 2. Runoff processes. Journal of Hydrology, 38, pp. 319-341.

Pilgrim, D. H., Huff, D. D., and Steele, T .D. 1979. Use of specific conductance and contact time relations for separating flow components in storm runoff. Water Resources Research, 15, pp. 329-339.

Pinder, G. F., and Jones, J. F. 1969. Determination of the ground-water component of peak discharge from the chemistry of total runoff. Water Resources Research, 5, pp. 438-445.

Price, A. G., and Hendrie, L. K. 1983. Water motion in a deciduous forest during snowmelt. Journal of Hydrology, 64, pp. 339-356.

Ragan, R. M. 1968. An experimental investigation of partial area contributions. International Association of Scientific Hydrology (Berne) Publication 76, pp. 241-249.

Rainwater, F. H., and Thatcher, L. L. 1960. Methods for collection and analysis of water samples. United States Geological Survey Water Supply Paper 1454.

Raudkivi, A. J. 1979. Hydrology. Pergamon Press, New York, 479 p.

Rodhe, A. 1981. Spring flood: meltwater or groundwater? Nordic Hydrology, 12, pp. 21-30.

Rodhe, A. 1983a. Groundwater contribution to streamflow in Swedish forested till soil as estimated by oxygen-18. International Symposium on Isotope Hydrology in Water Resources Development, Vienna 12-16 September, 1983. International Atomic Energy Agency, Vienna, 15 p.

Rodhe, A. 1983b. Groundwater contribution to streamflow in the Lake Gardsjon area. In Water Movements in Moraines. Swedish Natural Science Research Council, Committee for Hydrology, 34 p.

Sangal, B. P., and Kallio, R. W. 1977. Magnitude and frequency of floods in southern Ontario. Inland Waters Directorate Technical Bulletin Series Number 99, Fisheries and Environment Canada, 336 p.

SAS 1982. SAS User's Guide: Statistics. SAS Institute Inc., Cary, North Carolina. 584 p.

Schwartz, F. W. 1979. Interim report on a hydrogeological investigation of the Muskeg River Basin, Alberta. Prepared for the Alberta Oil Sands Environmental Research Program by the University of Alberta, Department of Geology, 104 p.

Sibul, U. 1969. Water resources of the Big Otter Creek drainage basin. Ontario Water Resources Commission. Water Resources Report 1, 91p.

Singh, T., and Kalra, Y. P. 1975. Specific conductance method for in situ estimation of total dissolved solids. Journal of the American Water Works Association, 67, pp. 99-100.

Sklash, M. G. 1978. The role of groundwater in storm and snowmelt runoff generation. Unpublished Ph.D. thesis. University of Waterloo. 261 p.

Sklash, M. G. 1983. Final report on the feasibility of using environmental isotopes for streamflow hydrograph separations in the APIOS calibrated watersheds. Industrial Research Institute, University of Windsor, IRI 16-15, 75 p.

Sklash, M. G., and Farvolden, R. N. 1979. The role of groundwater in storm runoff. Journal of Hydrology, 43, pp. 45-65.

Sklash, M. G., and Farvolden, R. N. 1980. Groundwater response during runoff events. Proceedings of the Symposium on Watershed Management, Boise ID, July 21-23, 1980. American Society of Civil Engineers, pp. 743-754.

Sklash, M. G., and Farvolden, R. N. 1982. The use of environmental isotopes in the study of high-runoff episodes in streams. In Isotope Studies of Hydrologic Processes Edited by E. C. Perry and C. W. Montgomery, Northern Illinois University Press, pp. 65-73.

Sklash, M. G,. and Wilson, B. A. 1982. An investigation of the groundwater ridging hypothesis for storm runoff generation. Proceedings of the Canadian Hydrology Symposium on Hydrological Processes of Forested Areas Fredericton, N.B. pp. 575-596.

Sklash, M. G., Farvolden, R. N., and Fritz, P. 1976. A conceptual model of watershed response to rainfall, developed through the use of oxygen-18 as a natural tracer. Canadian Journal of Earth Sciences, 13, pp. 271-283.

Sklash, M. G., Stewart, M. K., and Pearce, A. J. 1985. Storm runoff generation in humid headwater catchments, II: A case study of hillslope and low order stream response. Submitted to Water Resources Research.

Squires, C. A. 1984. The late Foxe deglaciation of the Burton Bay area, southeastern Baffin Island, N.W.T. Unpublished M.A. thesis, University of Windsor, 115p.

Steer, P., and Woo, M. K. 1983. Measurement of slope runoff in a permafrost region. Canadian Geotechnical Journal, 20, pp. 361-365.

Steppuhn, H., Krouse, H. R., and Erickson, D. E. L. 1975. Contributions to runoff from a melting prairie snow patch as traced by oxygen-18. Presented at the 43rd Annual Meeting, Western Snow Conference, 14 p.

Stumm, W., and Morgan, J. J. 1970. Aquatic Chemistry. Wiley-Interscience, New York, 583 p.

Toler, L. G. 1965. Use of specific conductance to distinguish two baseflow components in Econfina Creek, Florida. United States Geological Survey Professional Paper 525C, pp. C202-C208.

Tolstikhin, N. I., and Tolstikhin, O. N. 1976. Groundwater and surface water in the permafrost region. Inland Waters Directorate, Water Resources Branch, Fisheries and Environment Canada, Technical Bulletin Number 97, 25 p.

U. S. Environmental Protection Agency 1974. Methods for chemical analysis of water and wastes. Environmental Monitoring and Support Laboratory, Cincinnati, OH, 298 p.

U. S. Forest Service 1961. Soil moisture as a source of base flow from steep mountain watersheds, by J.D. Hewlett. Research Paper SE 132, 11 p.

Van Everdingen, R. O. 1974. Groundwater in permafrost regions of Canada. In Permafrost Hydrology-Proceedings of Workshop Seminar. Canadian National Committee, International Hydrological Decade, Environment Canada, Ottawa, pp. 83-94.

Varian Techtron 1971. Analytical Methods for Flame Spestroscopy. Varian Techtron Inc.

Viessman, W. Jr., Knapp, J. W., Lewis, G. L., and Harbaugh, T. E. 1977. Introduction to Hydrology. Harper and Row, New York, 704 p.

Visocky, A. P. 1970. Estimating the ground-water contribution to storm runoff by the electrical conductance method. Groundwater, 8(2), pp. 5-11.

Voronokov, P. P. 1963. Hydrochemical basis for segregating local runoff and a method of separating its discharge hydrograph. Soviet Hydrology, 4, p. 409.

Vreeland, J. C., Beven, K. J., and Hornberger, G. M. 1985. Shenandoah watershed study: groundwater contributions to streamflow. Submitted to Water Resources Research.

Walker, E. R., and Lake, R. A. 1975. Runoff in the Canadian Arctic archipelago. Proceedings, Twenty-fourth Alaska Science Conference, pp. 374-378.

Ward, R. C. 1982. The fountains of the deep and the windows of heaven: Perplexity and progress in explaining the response of rivers to precipitation. University of Hull, 30 p.

Williams, J. R., and van Everdingen, R. O. 1973. Groundwater investigations in permafrost regions of North America: A review. In Permafrost- the North American Contribution to the Second International Conference, National Academy of Sciences, Washington, DC, pp. 435-446.

Wilson, B. A. 1981. An investigation of the groundwater ridging theory for large groundwater contributions to streams during storm runoff events. Unpublished M.A.Sc. thesis. University of Windsor. 94 p.

Woo, M. K. 1976. Hydrology of a small Canadian high arctic basin during the snowmelt period. Catena, 3, pp. 155-168.

Woo, M. K., and Marsh, P. 1978. Analysis of error in the determination of snow storage for small high arctic basins. Journal of Applied Meteorology, 17, pp. 1537-1541.

Woo, M. K., and Steer, P. 1982. Occurrence of surface flow on arctic slopes, sourthwestern Cornwallis Island. Canadian Journal of Earth Sciences, 19, pp. 2368-2377.

Woo, M. K., and Steer, P. 1983. Slope hydrology as influenced by thawing of the active layer, Resolute, N.W.T. Canadian Journal of Earth Sciences, 20, pp. 978-986.

Zekster, I. S. 1963. Role of artesian water in feeding large rivers as exemplified by the middle and lower reaches of the Neman River. Soviet Hydrology, 1, p. 94.

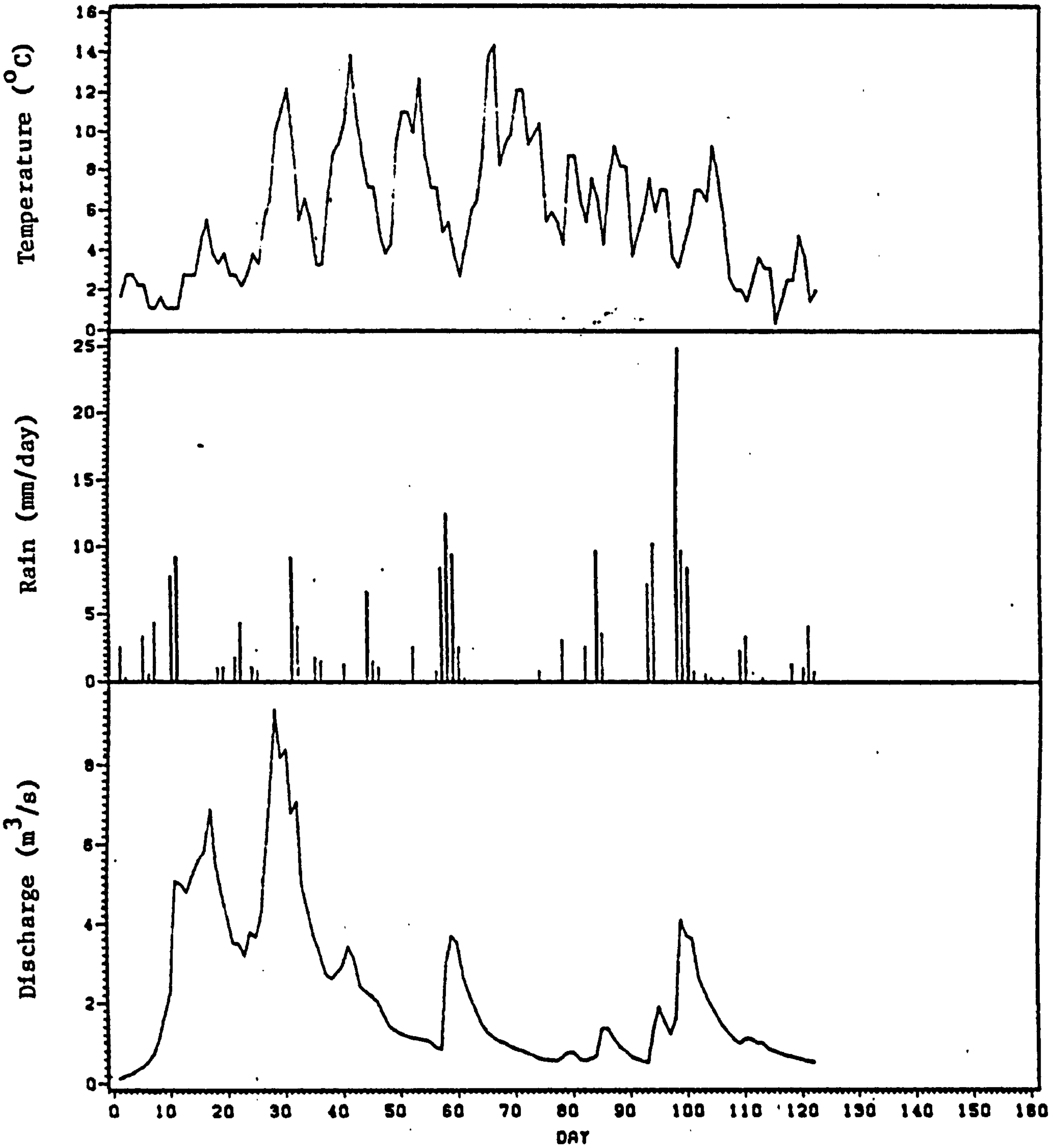
Zeman, L. J., and Slaymaker, H. O. 1975. Hydrochemical analysis to discriminate variable runoff source areas in an Alpine basin. Arctic and Alpine Research, 7(4), pp. 341-351.

APPENDIX I

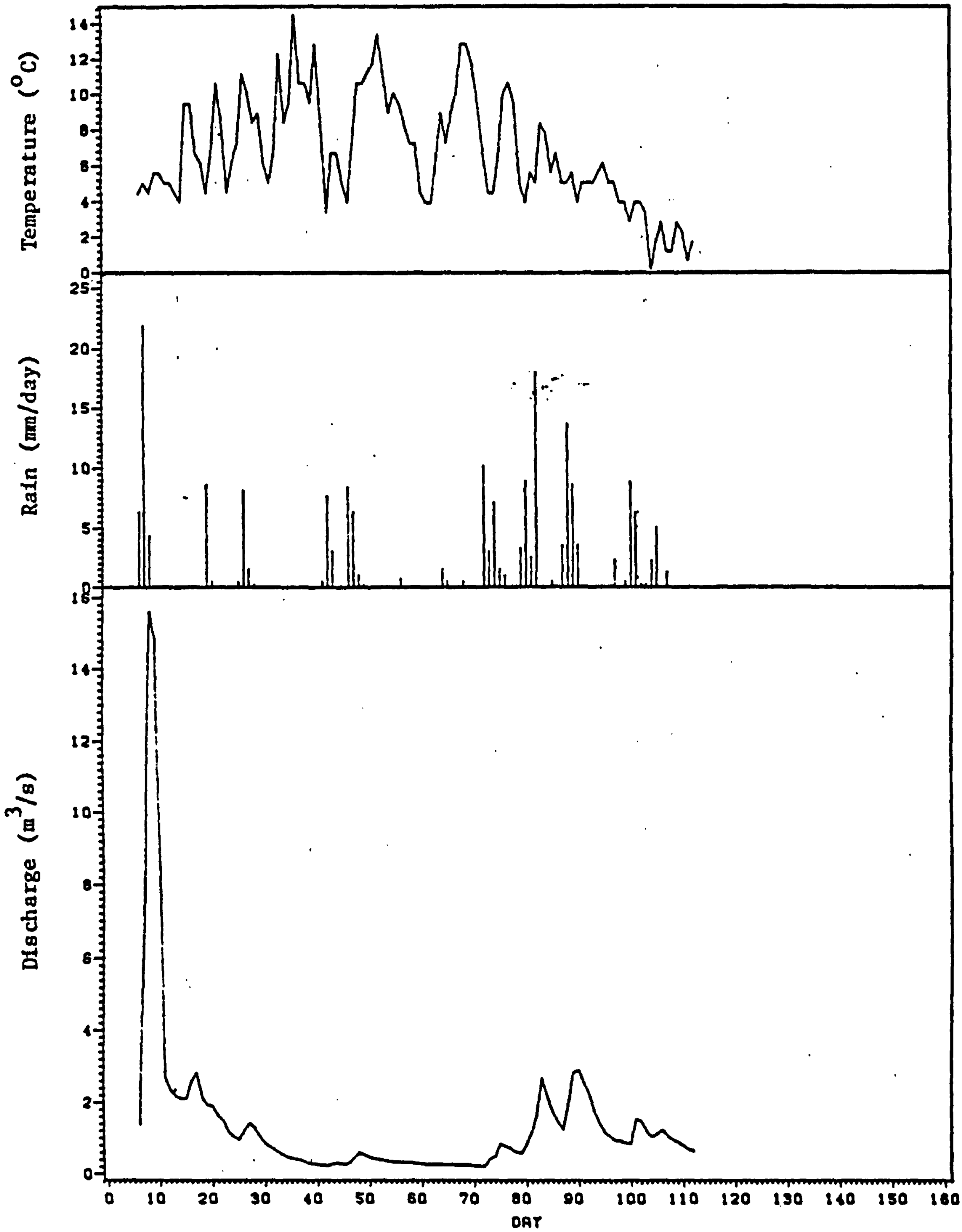
Historical Hydrographs, Temperature and Precipitation Data for the Apex River watershed 1973-1983.

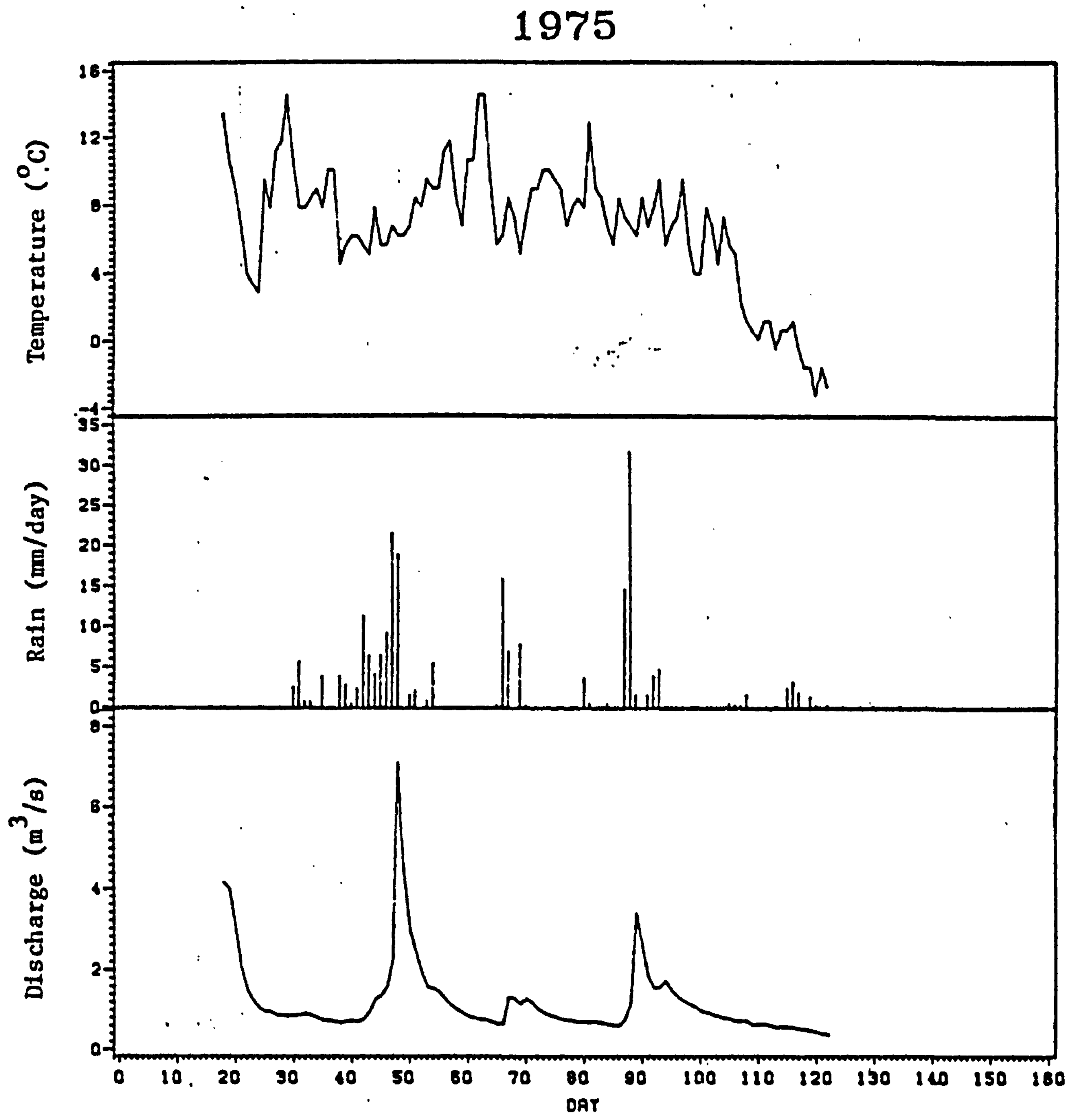
NOTES: For all plots Day 1= June 1.
Discharges are mean daily flows.
Temperatures are mean daily air temperatures.

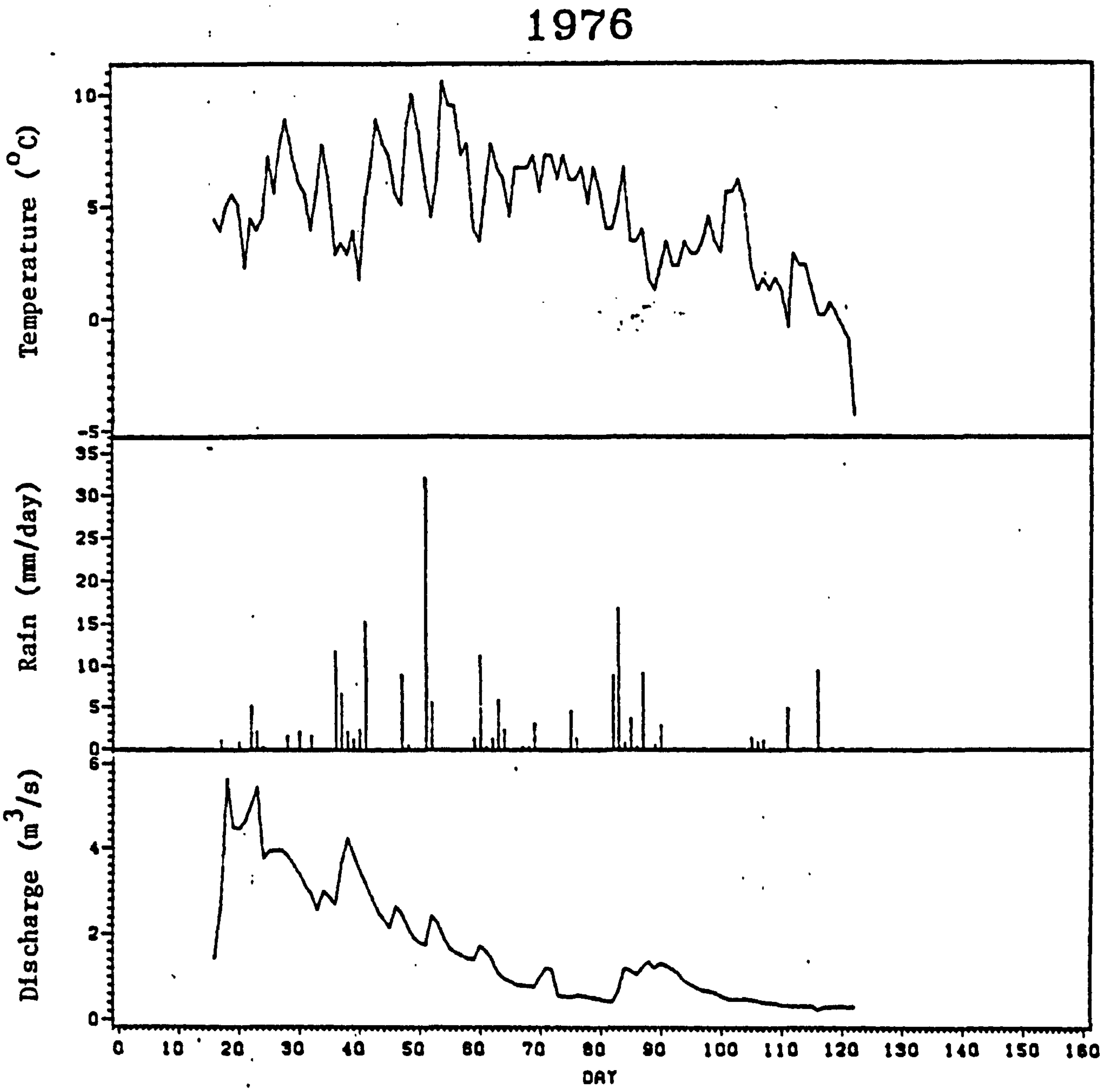
1973

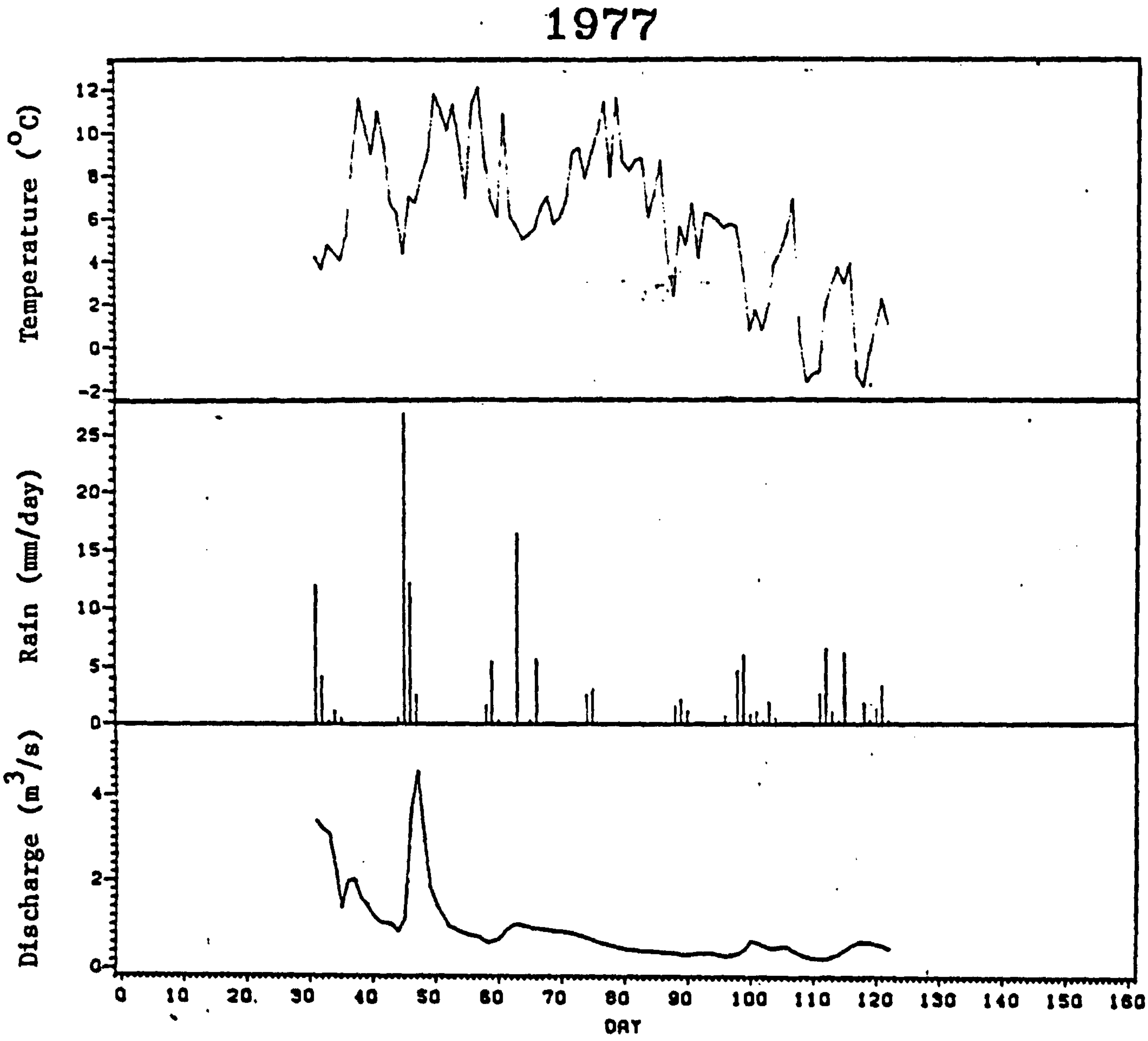

Temperature (°C)
0
2
4
6
8
10
12
14
16
Rain (mm/day)
0
5
10
15
20
25
Discharge (m³/s)
0
2
4
6
8
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY

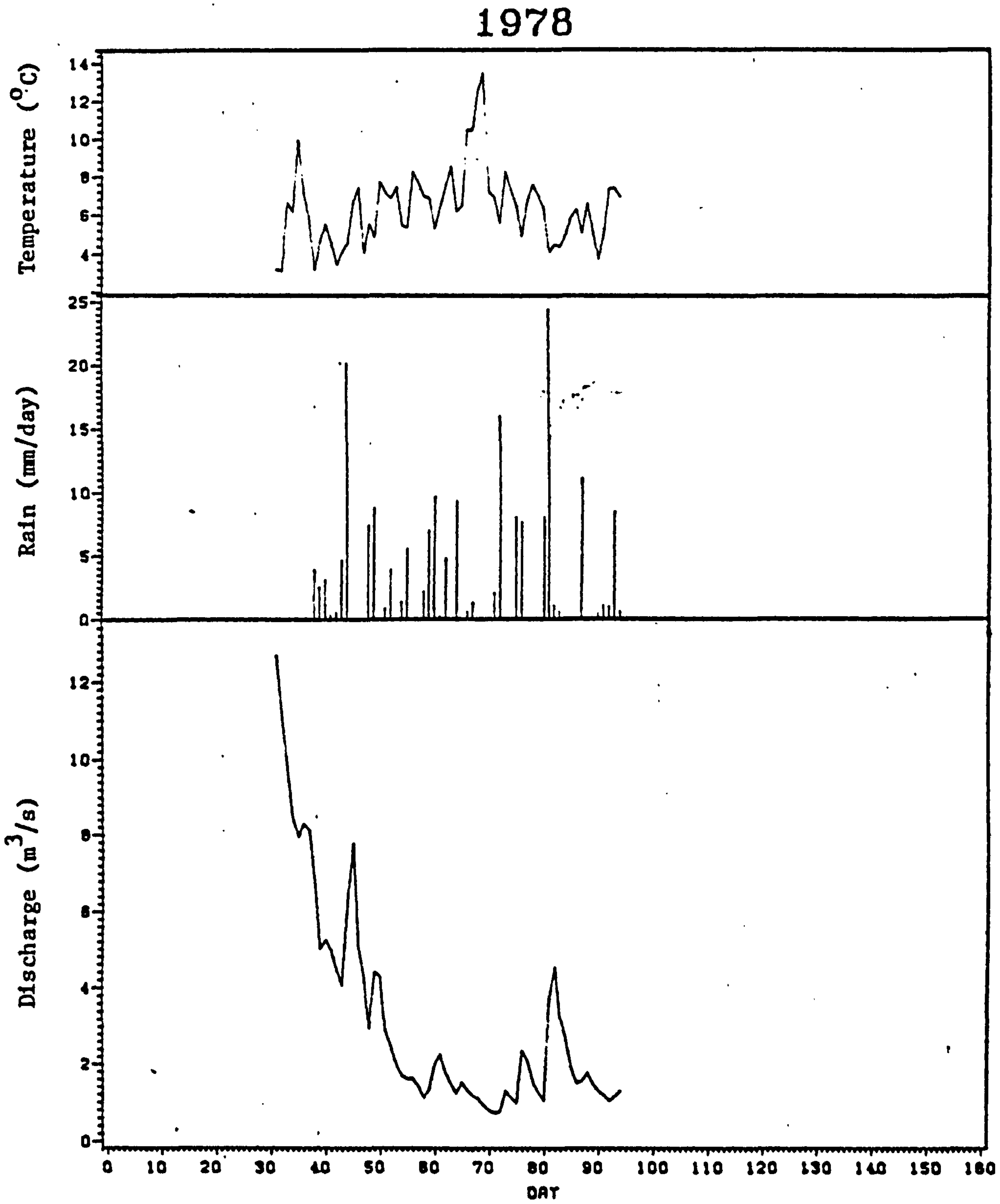
1974

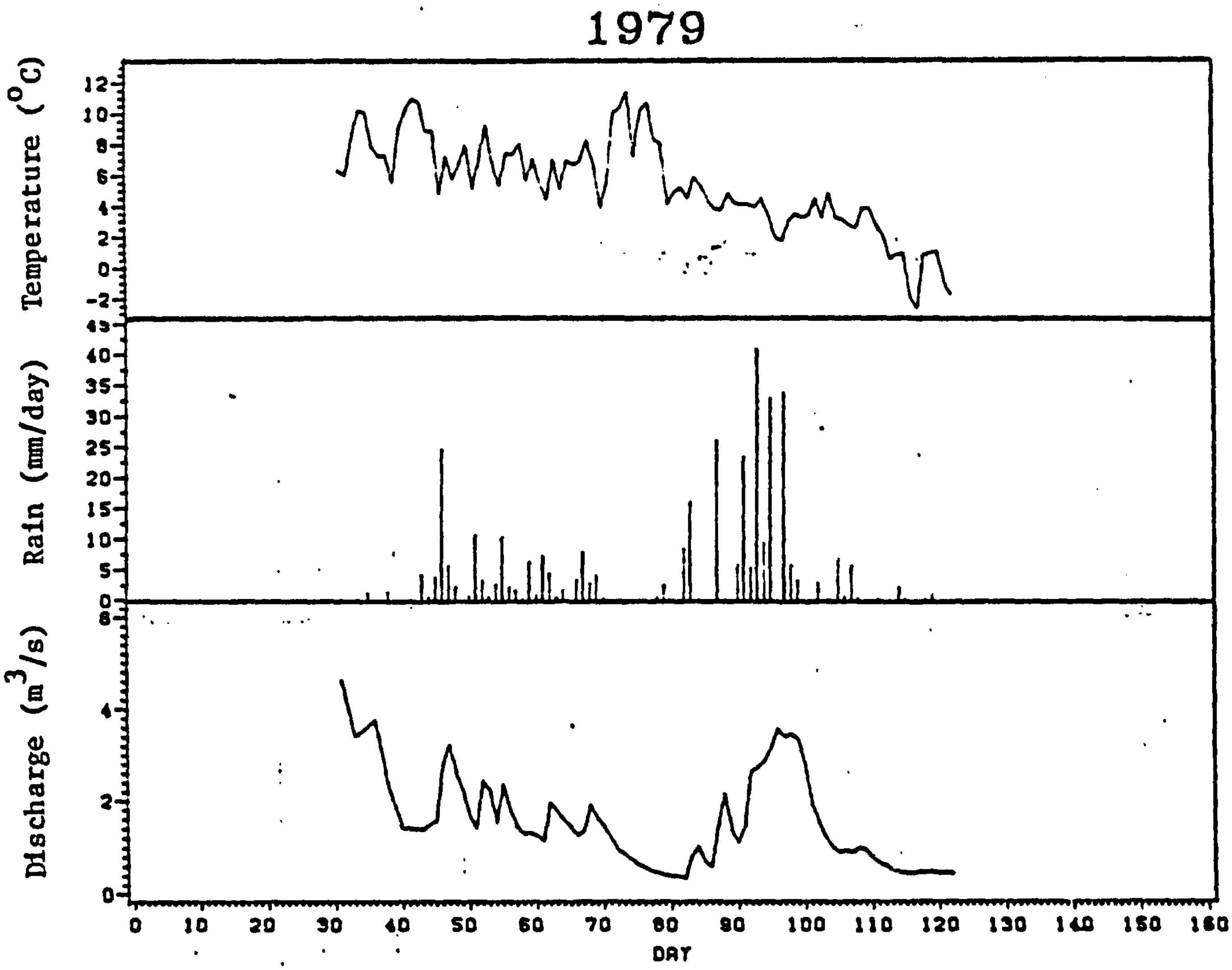

Temperature (°C)
0
2
4
6
8
10
12
14
Rain (mm/day)
0
5
10
15
20
25
Discharge (m³/s)
0
2
4
6
8
10
12
14
16
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY

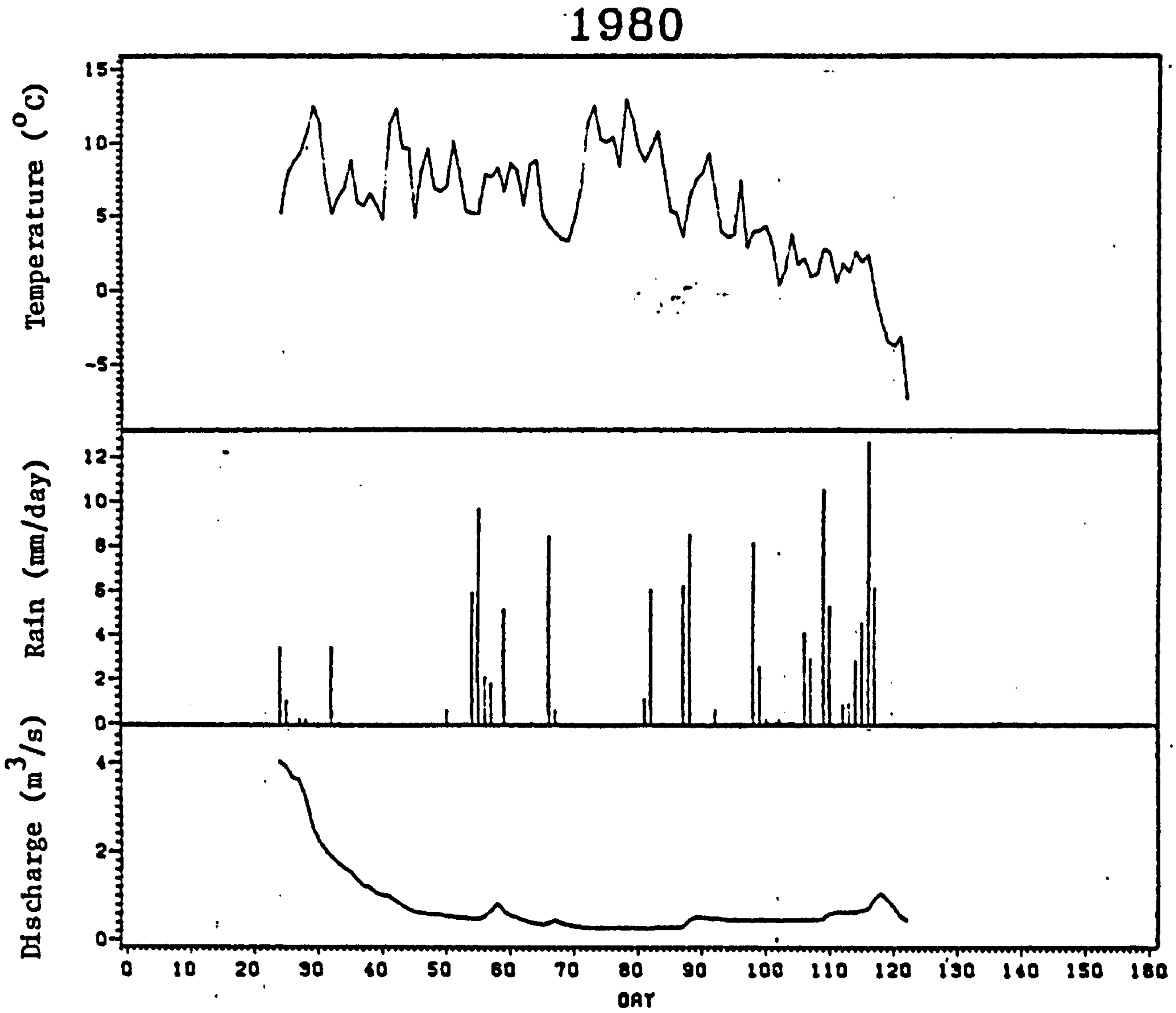

1975
Temperature (°C)
16
12
8
4
0
-4
Rain (mm/day)
35
30
25
20
15
10
5
0
Discharge (m^3/s)
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY

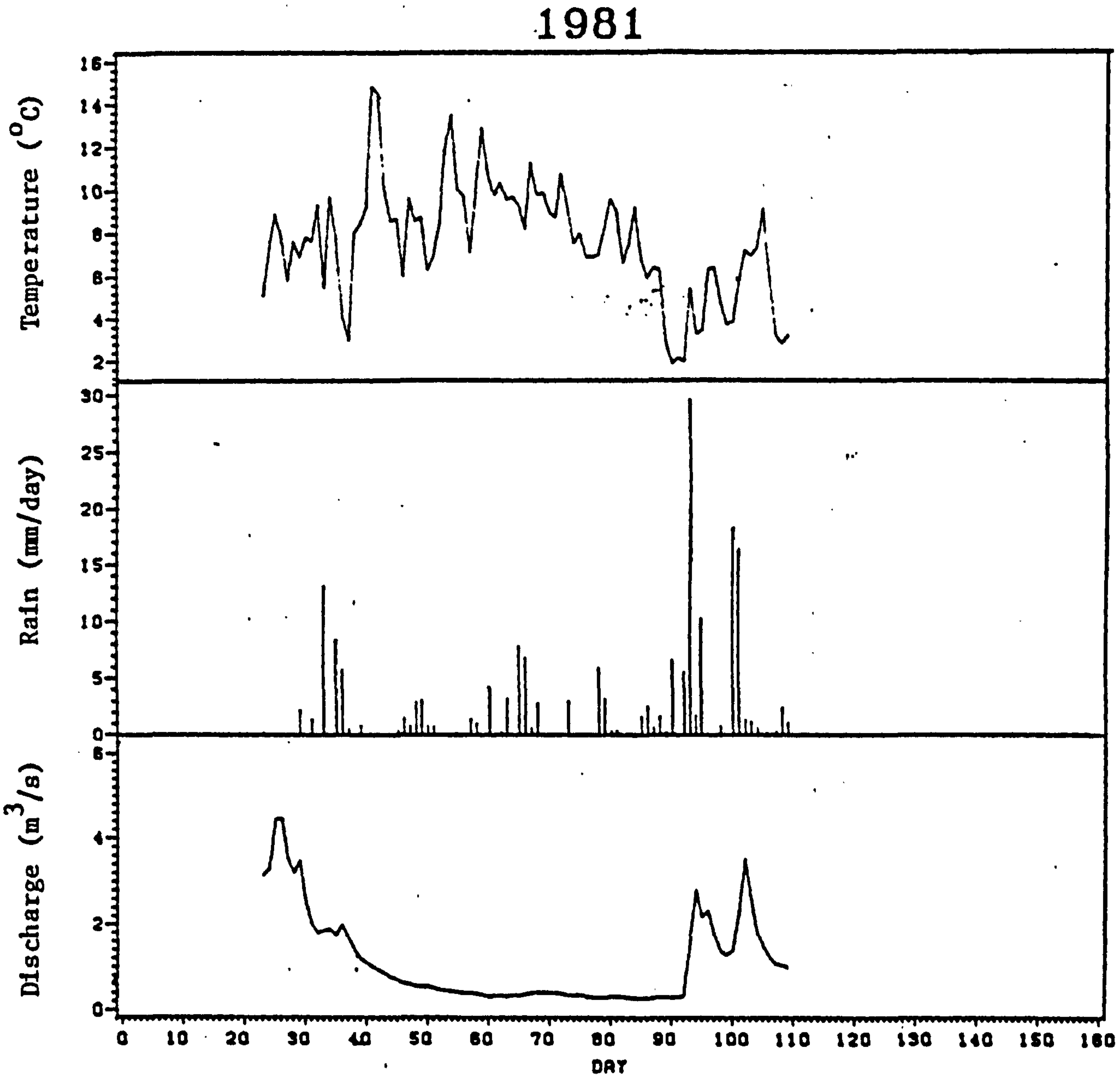

1976
Temperature (°C)
10
5
0
-5
Rain (mm/day)
35
30
25
20
15
10
5
0
Discharge (m³/s)
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY


1977
Temperature (°C)
12
10
8
6
4
2
0
-2
Rain (mm/day)
25
20
15
10
5
0
Discharge (m³/s)
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY

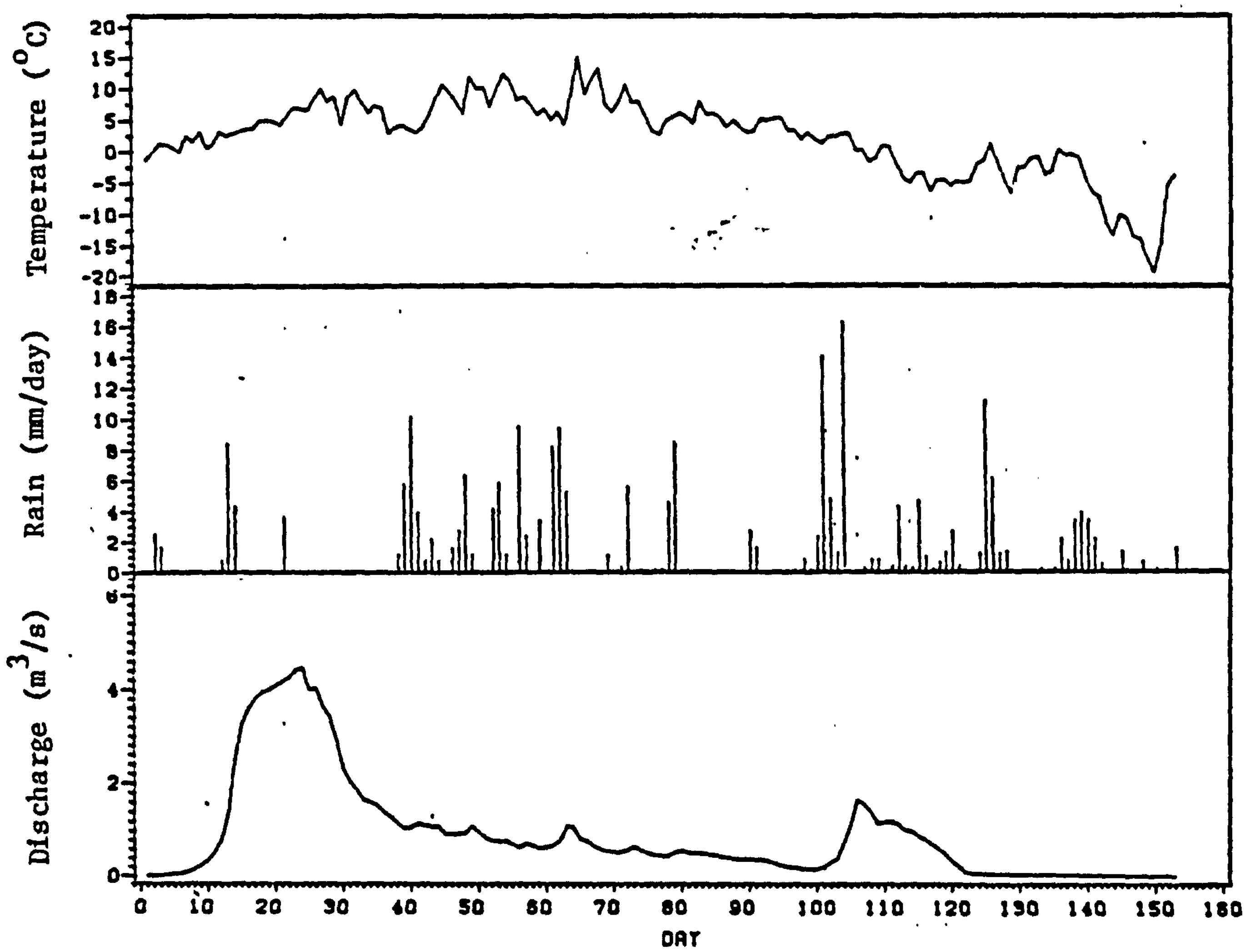

1978
Temperature (°C)
14
12
10
8
6
4
Rain (mm/day)
25
20
15
10
5
0
Discharge (m³/s)
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY

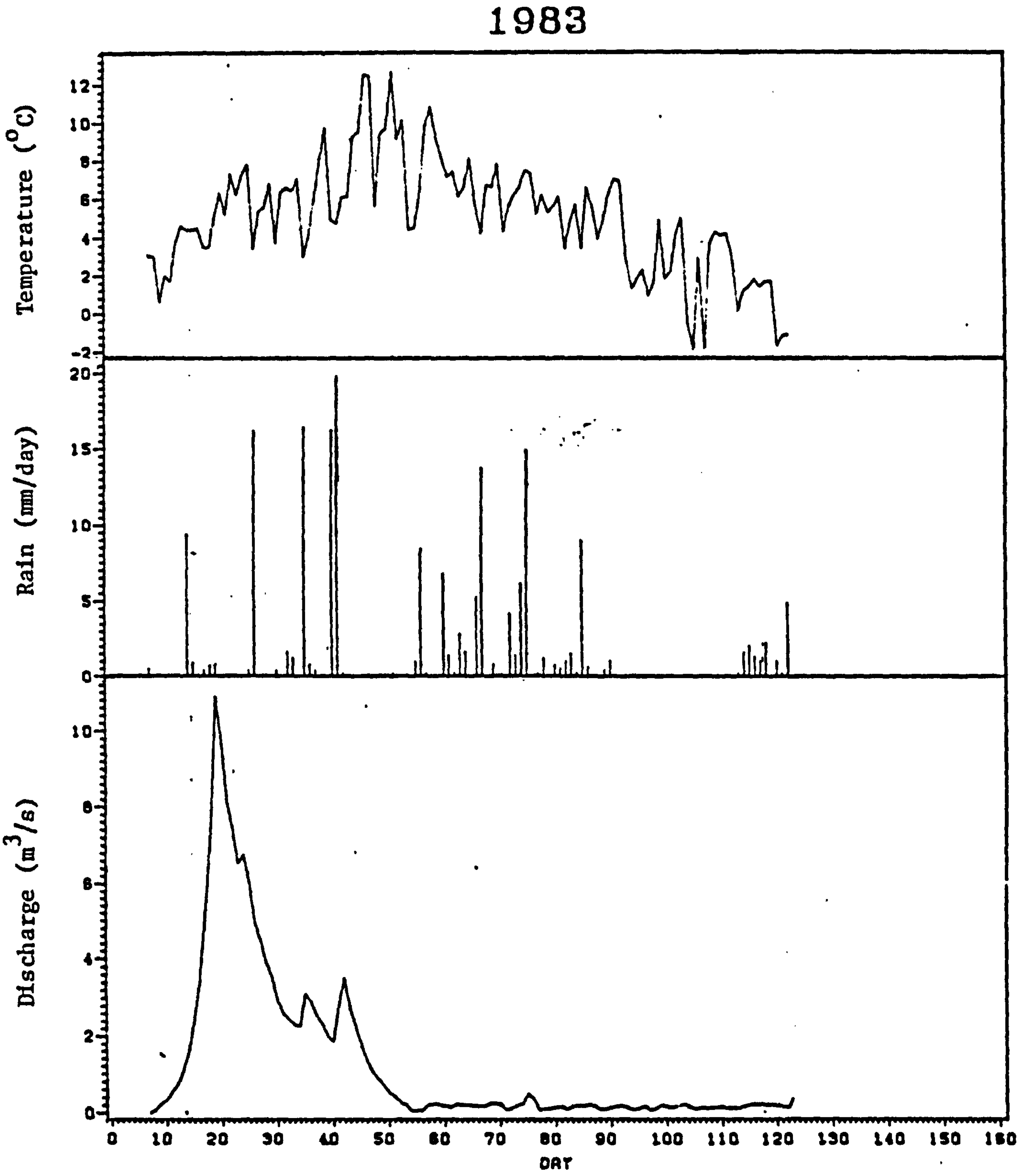

1979
Temperature (°C)
12
10
8
6
4
2
0
-2
Rain (mm/day)
45
40
35
30
25
20
15
10
5
0
Discharge (m³/s)
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY


1980
Temperature (°C)
15
10
5
0
-5
Rain (mm/day)
12
10
8
6
4
2
0
Discharge (m³/s)
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY


1981
Temperature (°C)
16
14
12
10
8
6
4
2
Rain (mm/day)
30
25
20
15
10
5
0
Discharge (m³/s)
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY

1982


Temperature (°C)
20
15
10
5
0
-5
-10
-15
-20
Rain (mm/day)
18
16
14
12
10
8
6
4
2
0
Discharge (m³/s)
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY


1983
Temperature (°C)
12
10
8
6
4
2
0
-2
Rain (mm/day)
20
15
10
5
0
Discharge (m³/s)
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
DAY

APPENDIX II

Chemical Data for the Apex River Watershed 1983.

NOTES: Sample Type: 1= stream at gauge
2= rain
3= snowmelt
4= spring
5= snow
6= stream tributary
7= pond

Units: EC= μS/cm
pH= pH units
Na, K, Mg, Ca= mg/l
TEMP= °C

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP.
A-1	1	1	830616	1435	20.0	6.4	0.47	0.12	0.31	1.93	.
A-3	1	2	830617	905	19.0	6.2	0.48	0.12	0.32	1.95	.
A-5	1	2	830617	1425	25.0	6.4	1.65	0.11	0.36	2.23	.
A-6	1	3	830618	225	21.5	6.4	0.53	0.11	0.35	2.01	.
A-7	1	3	830618	1340	18.0	6.3	0.48	0.10	0.31	1.92	2
A-11	1	4	830619	150	17.5	6.2	0.44	0.10	0.31	1.69	.
A-12	1	4	830619	1350	.	.	0.43	0.09	0.29	1.71	.
A-13	1	5	830620	200	15.5	6.2	0.40	0.11	0.20	1.48	.
A-14	1	5	830620	1400	16.0	6.3	0.43	0.10	0.32	1.63	.
A-15	1	5	830620	2200	17.0	6.4	0.41	0.10	0.30	1.50	.
A-16	1	6	830621	0	17.0	6.4	0.41	0.10	0.29	1.48	.
A-17	1	6	830621	200	17.0	6.4	0.40	0.10	0.29	1.62	.
A-18	1	6	830621	400	17.5	6.3	0.41	0.11	0.31	1.52	.
A-19	1	6	830621	600	17.5	6.4	0.41	0.10	0.32	1.62	.
A-20	1	6	830621	800	17.5	6.4	0.41	0.10	0.31	1.63	.
A-21	1	6	830621	1000	18.0	6.4	0.41	0.09	0.30	1.65	.
A-22	1	6	830621	1200	18.0	6.5	0.46	0.09	0.32	1.77	.
A-23	1	6	830621	1400	18.0	6.5	0.41	0.09	0.32	1.77	.
A-24	1	6	830621	1600	18.0	6.4	0.41	0.10	0.33	1.68	.
A-25	1	6	830621	1800	18.0	6.6	0.42	0.09	0.32	1.63	.
A-26	1	6	830621	2000	18.0	6.5	0.46	0.09	0.32	1.79	.
A-27	1	6	830621	2200	18.0	6.5	0.39	0.09	0.32	1.74	.
A-28	1	7	830622	0	19.0	6.5	0.41	0.10	0.33	1.83	.
A-29	1	7	830622	200	23.0	6.6	1.44	0.10	0.33	1.95	.
A-30	1	7	830622	400	22.0	6.5	0.79	0.12	0.39	2.00	.
A-31	1	7	830622	600	23.0	6.5	1.42	0.10	0.35	2.04	.
A-32	1	7	830622	800	24.0	6.6	1.05	0.12	0.60	2.39	.
A-35	1	7	830622	1230	19.0	6.2	0.44	0.11	0.34	1.96	.
A-36	1	7	830622	1430	18.5	6.4	0.43	0.11	0.33	1.83	.
A-37	1	7	830622	1630	18.0	6.4	0.43	0.11	0.33	1.53	.
A-38	1	7	830622	1830	18.0	6.4	0.43	0.11	0.32	1.83	.
A-39	1	7	830622	2030	17.0	6.4	0.43	0.11	0.32	1.74	.
A-40	1	7	830622	2230	16.5	6.4	0.40	0.11	0.31	1.72	.
A-41	1	8	830623	30	16.5	6.6	0.40	0.11	0.31	1.74	.
A-42	1	8	830623	230	16.5	6.4	0.40	0.11	0.31	1.76	.
A-43	1	8	830623	430	16.5	6.4	0.40	0.11	0.32	1.85	.
A-45	1	8	830623	830	17.0	6.4	0.41	0.11	0.32	1.76	.
A-46	1	8	830623	1030	17.0	6.5	0.41	0.10	0.32	1.87	.
A-48	1	8	830623	1215	18.0	6.2	0.41	0.10	0.32	1.91	4
A-49	1	8	830623	1415	18.0	6.2	0.40	0.10	0.32	1.96	.
A-50	1	8	830623	1615	18.0	6.0	0.43	0.16	0.34	1.76	.
A-51	1	8	830623	1815	18.0	6.2	0.41	0.11	0.31	1.76	.
A-52	1	8	830623	2015	20.0	6.0	0.42	0.11	0.32	1.78	.
A-53	1	8	830623	2215	18.0	5.9	0.40	0.11	0.31	1.61	.
A-54	1	9	830624	15	17.0	6.0	0.40	0.10	0.31	1.65	.
A-55	1	9	830624	215	19.0	6.0	0.39	0.10	0.32	1.76	.
A-56	1	9	830624	415	18.0	6.1	0.39	0.10	0.32	1.76	.
A-57	1	9	830624	615	18.0	6.1	0.43	0.13	0.33	1.87	.
A-58	1	9	830624	815	17.5	6.1	0.40	0.10	0.32	1.89	.
A-59	1	9	830624	1015	18.0	6.1	0.39	0.10	0.32	1.89	.
A-62	1	9	830624	1130	18.0	6.0	.	.	.	.	5
A-63	1	9	830624	1330	17.5	6.2	0.46	0.10	0.33	1.91	.
A-64	1	9	830624	1530	17.0	6.2	.	.	.	.	.
A-65	1	9	830624	1730	17.0	6.2	0.35	0.10	0.32	1.89	.
A-66	1	9	830624	1930	17.0	6.2	.	.	.	.	.
A-67	1	9	830624	2130	18.0	6.1	0.35	0.10	0.31	1.85	.

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP
A-68	1	9	830624	2330	18.5	6.3	.	.	.	.	.
A-69	1	10	830625	130	18.5	6.4	0.39	0.10	0.32	1.96	.
A-70	1	10	830625	330	19.0	6.3	.	.	.	.	.
A-71	1	10	830625	530	19.0	6.4	0.40	0.10	0.33	2.00	.
A-72	1	10	830625	730	19.0	6.2	.	.	.	.	.
A-73	1	10	830625	930	20.0	6.5	0.42	0.09	0.34	2.02	.
A-76	1	10	830625	1120	21.0	6.1	.	.	.	.	6
A-77	1	10	830625	1320	20.5	6.3	0.42	0.09	0.34	1.98	.
A-78	1	10	830625	1520	20.0	6.4	.	.	.	.	.
A-79	1	10	830625	1720	19.0	6.5	0.44	0.10	0.34	2.00	.
A-80	1	10	830625	1920	19.0	6.4	.	.	.	.	.
A-81	1	10	830625	2120	19.5	6.3	0.44	0.10	0.34	2.00	.
A-82	1	10	830625	2320	20.0	6.4	.	.	.	.	.
A-83	1	11	830626	120	19.0	6.4	0.43	0.10	0.35	1.94	.
A-84	1	11	830626	320	19.0	6.4	.	.	.	.	.
A-85	1	11	830626	520	19.0	6.4	0.42	0.10	0.35	1.90	.
A-86	1	11	830626	720	19.0	6.4	.	.	.	.	.
A-87	1	11	830626	920	18.5	6.2	0.44	0.09	0.35	1.99	.
A-88	1	11	830626	1120	19.0	6.3	.	.	.	.	4
A-92	1	11	830626	1500	24.0	6.7	0.41	0.09	0.34	1.87	.
A-93	1	11	830626	1700	19.0	6.8	.	.	.	.	.
A-94	1	11	830626	1900	18.0	6.7	0.40	0.09	0.33	1.76	.
A-95	1	11	830626	2100	17.0	6.8	.	.	.	.	.
A-96	1	11	830626	2300	17.5	6.8	0.40	0.09	0.33	1.74	.
A-97	1	12	830627	100	18.0	6.7	.	.	.	.	.
A-98	1	12	830627	300	18.0	6.6	0.40	0.09	0.32	1.93	.
A-99	1	12	830627	500	19.0	6.6	.	.	.	.	.
A-100	1	12	830627	700	18.5	6.6	0.40	0.09	0.32	2.00	.
A-101	1	12	830627	900	19.0	6.4	.	.	.	.	.
A-102	1	12	830627	1100	18.5	6.6	0.41	0.09	0.32	2.01	.
A-105	1	12	830627	1130	19.0	6.5	.	.	.	.	4
A-106	1	12	830627	1330	19.0	6.4	0.41	0.09	0.32	2.06	.
A-107	1	12	830627	1530	19.0	6.4	.	.	.	.	.
A-108	1	12	830627	1730	19.0	6.4	0.44	0.11	0.32	2.09	.
A-109	1	12	830627	1930	19.0	6.5	.	.	.	.	.
A-110	1	12	830627	2130	19.0	6.5	0.43	0.10	0.32	2.14	.
A-111	1	12	830627	2330	19.0	6.5	.	.	.	.	.
A-112	1	13	830628	130	19.0	6.3	0.42	0.09	0.33	2.08	.
A-113	1	13	830628	330	19.0	6.5	.	.	.	.	.
A-114	1	13	830628	530	18.0	6.5	0.42	0.10	0.33	2.14	.
A-115	1	13	830628	730	19.0	6.5	.	.	.	.	.
A-116	1	13	830628	930	19.0	6.6	0.41	0.09	0.33	2.14	.
A-118	1	13	830628	1130	19.0	6.4	.	.	.	.	4
A-119	1	13	830628	1330	19.0	6.5	0.41	0.09	0.33	2.16	.
A-120	1	13	830628	1530	19.0	6.6	.	.	.	.	.
A-121	1	13	830628	1730	19.0	6.5	0.41	0.09	0.33	2.16	.
A-122	1	13	830628	1930	19.5	6.6	.	.	.	.	.
A-123	1	13	830628	2130	19.0	6.6	0.42	0.10	0.33	2.18	.
A-124	1	13	830628	2330	19.5	6.5	.	.	.	.	.
A-125	1	14	830629	130	19.5	6.5	0.41	0.09	0.33	2.24	.
A-126	1	14	830629	330	19.0	6.5	.	.	.	.	.
A-127	1	14	830629	530	19.0	6.5	0.43	0.09	0.34	2.24	.
A-128	1	14	830629	730	19.0	6.3	.	.	.	.	.
A-129	1	14	830629	930	19.0	6.5	0.40	0.09	0.33	2.24	.
A-132	1	14	830629	1130	20.0	6.3	.	.	.	.	6
A-133	1	14	830629	1330	19.5	6.3	0.40	0.08	0.33	2.21	.

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP
A-134	1	14	830629	1530	19.0	6.5	.	.	.	.	.
A-135	1	14	830629	1730	19.0	6.4	0.42	0.09	0.33	2.21	.
A-136	1	14	830629	1930	15.0	6.4	.	.	.	.	.
A-137	1	14	830629	2130	19.0	6.4	0.41	0.09	0.33	2.10	.
A-138	1	14	830629	2330	15.0	6.4	.	.	.	.	.
A-139	1	15	830630	130	15.0	6.4	0.40	0.09	0.33	2.16	.
A-140	1	15	830630	330	15.0	6.4	.	.	.	.	.
A-141	1	15	830630	530	19.0	6.4	0.39	0.09	0.33	2.24	.
A-142	1	15	830630	730	19.0	6.4	.	.	.	.	.
A-143	1	15	830630	930	19.0	6.4	0.39	0.09	0.33	2.14	.
A-144	1	15	830630	1145	20.0	6.7	.	.	.	.	4
A-145	1	15	830630	1345	20.0	6.6	.	.	.	.	.
A-146	1	15	830630	1545	15.5	6.6	0.40	0.09	0.32	2.16	.
A-147	1	15	830630	1745	19.5	6.5	.	.	.	.	.
A-148	1	15	830630	1945	15.5	6.5	.	.	.	.	.
A-149	1	15	830630	2145	19.5	6.5	0.39	0.09	0.33	2.21	.
A-150	1	15	830630	2345	20.0	6.5	.	.	.	.	.
A-151	1	16	830701	145	20.0	6.5	.	.	.	.	.
A-152	1	16	830701	345	20.0	6.5	0.40	0.09	0.34	2.30	.
A-153	1	16	830701	545	20.0	6.5	.	.	.	.	.
A-154	1	16	830701	745	20.0	6.5	.	.	.	.	.
A-155	1	16	830701	930	24.0	6.6	0.40	0.08	0.34	2.30	4
A-156	1	16	830701	1130	20.0	6.6	.	.	.	.	.
A-157	1	16	830701	1330	21.0	6.4	.	.	.	.	.
A-158	1	16	830701	1530	20.5	6.4	0.40	0.09	0.34	2.30	.
A-159	1	16	830701	1730	20.0	6.4	.	.	.	.	.
A-160	1	16	830701	1930	20.0	6.4	.	.	.	.	.
A-161	1	16	830701	2130	21.0	6.3	0.50	0.09	0.34	2.33	.
A-163	1	17	830702	130	25.0	6.3	.	.	.	.	.
A-164	1	17	830702	330	25.0	6.4	1.23	0.10	0.35	2.50	.
A-165	1	17	830702	530	25.0	6.5	.	.	.	.	.
A-166	1	17	830702	730	25.0	6.4	.	.	.	.	.
A-167	1	17	830702	930	25.0	6.5	1.23	0.09	0.36	2.52	.
A-171	1	17	830702	1250	20.0	6.2	0.40	0.09	0.34	2.24	7
A-172	1	17	830702	1450	20.0	6.4	.	.	.	.	.
A-173	1	17	830702	1650	19.5	6.4	.	.	.	.	.
A-174	1	17	830702	1850	15.5	6.4	0.39	0.09	0.34	2.21	.
A-175	1	17	830702	2050	20.0	6.4	.	.	.	.	.
A-176	1	17	830702	2250	20.0	6.4	.	.	.	.	.
A-177	1	18	830703	50	20.0	6.4	0.40	0.09	0.34	2.24	.
A-178	1	18	830703	250	20.0	6.4	.	.	.	.	.
A-179	1	18	830703	450	20.0	6.4	.	.	.	.	.
A-180	1	18	830703	650	20.0	6.4	0.39	0.09	0.35	2.30	.
A-181	1	18	830703	850	20.0	6.3	.	.	.	.	.
A-182	1	18	830703	1050	20.0	6.3	0.40	0.09	0.35	2.28	.
A-183	1	18	830703	1400	20.0	6.3	0.39	0.09	0.34	2.28	7
A-184	1	18	830703	1600	20.0	6.4	.	.	.	.	.
A-185	1	18	830703	1800	19.5	6.4	.	.	.	.	.
A-186	1	18	830703	2000	15.5	6.4	0.39	0.08	0.33	2.18	.
A-187	1	18	830703	2200	19.5	6.4	.	.	.	.	.
A-188	1	19	830704	0	15.5	6.4	.	.	.	.	.
A-189	1	19	830704	200	20.0	6.4	0.40	0.09	0.35	2.25	.
A-190	1	19	830704	400	20.0	6.4	.	.	.	.	.
A-191	1	19	830704	600	20.0	6.4	.	.	.	.	.
A-192	1	19	830704	800	20.0	6.4	0.42	0.09	0.39	2.24	.
A-193	1	19	830704	1000	20.0	6.4	.	.	.	.	.

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP
A-194	1	19	830704	1200	20.0	6.4	.	.	.	.	.
A-195	1	19	830704	1600	.	.	0.44	0.09	0.38	2.26	10
A-196	1	19	830704	1800	23.0	6.8	.	.	.	.	.
A-197	1	19	830704	2000	20.0	6.8	.	.	.	.	.
A-198	1	19	830704	2200	20.0	6.5	0.43	0.09	0.38	2.26	.
A-199	1	20	830705	0	20.0	6.4	.	.	.	.	.
A-201	1	20	830705	400	20.0	6.4	0.50	0.09	0.39	2.30	.
A-202	1	20	830705	600	21.0	6.4	.	.	.	.	.
A-203	1	20	830705	800	21.0	6.2	0.47	0.09	0.40	2.20	.
A-204	1	20	830705	1000	21.0	6.2	0.45	0.09	0.40	2.26	.
A-205	1	20	830705	1200	21.0	6.2	0.50	0.09	0.40	2.24	.
A-208	1	20	830705	1430	20.0	5.9	0.44	0.09	0.39	2.24	6
A-209	1	20	830705	1630	20.0	5.8	0.43	0.09	0.39	2.24	.
A-210	1	20	830705	1830	20.0	5.9	0.44	0.09	0.36	2.26	.
A-211	1	20	830705	2030	20.0	6.0	0.44	0.08	0.39	2.26	.
A-212	1	20	830705	2230	20.0	6.0	0.45	0.09	0.38	2.26	.
A-213	1	21	830706	30	21.0	6.0	0.43	0.08	0.42	2.20	.
A-214	1	21	830706	230	21.0	6.0	0.44	0.08	0.42	2.16	.
A-215	1	21	830706	430	21.5	6.0	0.44	0.08	0.41	2.20	.
A-216	1	21	830706	630	21.0	6.0	0.44	0.08	0.41	2.18	.
A-217	1	21	830706	830	21.5	6.1	0.44	0.08	0.41	2.18	.
A-218	1	21	830706	1030	21.5	6.1	0.44	0.08	0.41	2.18	.
A-219	1	21	830706	1230	21.5	6.0	0.45	0.08	0.41	2.18	.
A-220	1	21	830706	1430	21.0	6.1	.	.	.	.	.
A-224	1	21	830706	1630	.	.	.	.	.	.	7
A-225	1	21	830706	1830	22.0	6.5	.	.	.	.	.
A-226	1	21	830706	2030	21.5	6.5	0.45	0.08	0.41	2.02	.
A-227	1	21	830706	2230	21.5	6.5	.	.	.	.	.
A-228	1	22	830707	30	22.0	6.4	0.46	0.08	0.41	2.14	.
A-230	1	22	830707	430	22.0	6.5	0.44	0.08	0.41	2.14	.
A-231	1	22	830707	630	22.0	6.5	.	.	.	.	.
A-232	1	22	830707	830	22.0	6.5	0.45	0.08	0.42	2.16	.
A-233	1	22	830707	1030	22.0	6.5	.	.	.	.	.
A-234	1	22	830707	1200	22.0	6.5	.	.	.	.	6
A-235	1	22	830707	1400	22.0	6.5	0.45	0.08	0.41	2.16	.
A-236	1	22	830707	1600	22.0	6.5	.	.	.	.	.
A-237	1	22	830707	1800	22.0	6.5	0.45	0.08	0.41	2.16	.
A-238	1	22	830707	2000	22.0	6.5	.	.	.	.	.
A-239	1	22	830707	2200	22.0	6.5	0.46	0.09	0.41	2.16	.
A-240	1	23	830708	0	22.0	6.5	.	.	.	.	.
A-241	1	23	830708	200	22.0	6.6	0.46	0.09	0.41	2.25	.
A-242	1	23	830708	400	22.5	6.6	.	.	.	.	.
A-243	1	23	830708	600	23.0	6.6	0.46	0.08	0.43	2.14	.
A-244	1	23	830708	800	23.0	6.6	.	.	.	.	.
A-245	1	23	830708	1000	23.0	6.6	0.45	0.08	0.43	2.31	.
A-248	1	23	830708	1200	23.0	6.4	.	.	.	.	6
A-249	1	23	830708	1400	23.0	6.4	.	.	.	.	.
A-250	1	23	830708	1600	22.5	6.6	.	.	.	.	.
A-251	1	23	830708	1800	22.5	6.6	0.46	0.08	0.42	2.44	.
A-252	1	23	830708	2000	22.5	6.6	.	.	.	.	.
A-253	1	23	830708	2200	22.5	6.6	0.47	0.08	0.42	2.43	.
A-255	1	24	830709	200	23.0	6.6	0.50	0.09	0.43	2.53	.
A-256	1	24	830709	400	23.5	6.6	.	.	.	.	.
A-257	1	24	830709	600	23.5	6.6	0.44	0.08	0.42	2.62	.
A-258	1	24	830709	800	24.0	6.5	.	.	.	.	.
A-259	1	24	830709	1000	24.0	6.6	0.36	0.10	0.44	2.60	.

SAMPLE	TYPE	DAY	DATE	TIME	TC	PH	NA	K	MG	CA	TEMP
A-260	1	24	830709	1200	23.5	6.6	.	.	.	.	.
A-261	1	24	830709	1400	23.5	6.6	0.47	0.09	0.43	2.60	.
A-262	1	24	830709	1600	23.0	6.6	.	.	.	.	.
A-263	1	24	830709	1800	23.0	6.6	0.47	0.09	0.42	2.52	.
A-264	1	24	830709	2000	23.0	6.6	.	.	.	.	.
A-265	1	24	830709	2200	23.5	6.6	0.46	0.09	0.43	2.57	.
A-266	1	25	830710	0	24.0	6.6	.	.	.	.	.
A-267	1	25	830710	200	24.0	6.6	0.47	0.09	0.45	2.66	.
A-268	1	25	830710	400	24.5	6.6	.	.	.	.	.
A-269	1	25	830710	600	24.5	6.7	0.47	0.09	0.45	2.70	.
A-270	1	25	830710	800	24.5	6.7	.	.	.	.	.
A-271	1	25	830710	1000	24.5	6.7	0.47	0.08	0.45	2.70	.
A-272	1	25	830710	1600	24.0	6.7	0.47	0.09	0.45	2.62	8
A-273	1	25	830710	1800	24.0	6.7	0.47	0.08	0.45	2.62	.
A-274	1	25	830710	2000	24.0	6.7	0.47	0.09	0.45	2.70	.
A-275	1	25	830710	2200	24.0	6.7	0.46	0.08	0.45	2.70	.
A-276	1	26	830711	0	24.0	6.7	0.47	0.09	0.45	2.70	.
A-277	1	26	830711	200	24.0	6.7	0.47	0.08	0.46	2.70	.
A-278	1	26	830711	400	24.5	6.7	0.47	0.08	0.46	2.70	.
A-279	1	26	830711	600	24.5	6.6	0.48	0.09	0.50	2.57	.
A-280	1	26	830711	800	24.5	6.8	0.48	0.08	0.50	2.52	.
A-281	1	26	830711	1000	24.0	6.6	0.45	0.08	0.50	2.52	.
A-282	1	26	830711	1200	24.0	6.6	0.49	0.07	0.49	2.44	7
A-286	1	26	830711	1400	23.0	6.2	0.50	0.08	0.49	2.31	.
A-287	1	26	830711	1600	22.5	6.2	0.45	0.07	0.46	2.22	.
A-288	1	26	830711	1800	23.0	6.2	.	.	.	.	.
A-289	1	26	830711	2000	22.5	6.2	0.48	0.07	0.46	2.27	7
A-290	1	26	830711	2200	25.0	6.5	0.48	0.07	0.47	2.24	.
A-291	1	27	830712	0	22.5	6.6	0.45	0.09	0.47	2.24	.
A-292	1	27	830712	200	23.0	6.6	0.45	0.08	0.46	2.20	.
A-294	1	27	830712	600	23.0	6.6	0.49	0.07	0.48	2.17	.
A-295	1	27	830712	800	23.0	6.6	0.45	0.08	0.46	2.13	.
A-296	1	27	830712	1000	23.0	6.6	0.50	0.08	0.46	2.20	6
A-301	1	27	830712	1200	24.0	6.4	0.45	0.07	0.48	2.22	.
A-302	1	27	830712	1400	23.5	6.4	0.50	0.08	0.46	2.20	.
A-303	1	27	830712	1600	24.0	6.5	0.50	0.09	0.48	2.15	.
A-304	1	27	830712	1800	23.5	6.5	0.45	0.07	0.47	2.22	.
A-305	1	27	830712	2000	23.5	6.5	0.45	0.08	0.46	2.20	.
A-306	1	27	830712	2200	23.0	6.6	0.48	0.09	0.46	2.20	.
A-307	1	28	830713	0	22.5	6.5	.	.	.	.	.
A-308	1	28	830713	200	24.5	6.5	0.49	0.09	0.50	2.44	.
A-309	1	28	830713	400	25.0	6.6	0.49	0.09	0.50	2.49	.
A-310	1	28	830713	600	25.0	6.6	0.49	0.09	0.50	2.57	.
A-311	1	28	830713	800	25.5	6.6	0.49	0.08	0.50	2.52	.
A-312	1	28	830713	1000	24.5	6.6	0.45	0.08	0.51	2.52	8
A-313	1	28	830713	1200	24.5	6.6	.	.	.	.	.
A-314	1	28	830713	1400	24.5	6.6	0.45	0.08	0.50	2.46	.
A-315	1	28	830713	1600	24.0	6.6	.	.	.	.	.
A-316	1	28	830713	1800	24.5	6.6	0.50	0.09	0.49	2.41	.
A-317	1	28	830713	2000	25.0	6.6	.	.	.	.	.
A-318	1	28	830713	2200	25.0	6.6	0.50	0.08	0.49	2.52	.
A-319	1	29	830714	0	25.0	6.6	.	.	.	.	.
A-320	1	29	830714	200	25.0	6.6	.	.	.	.	.
A-322	1	29	830714	600	26.0	6.6	0.51	0.09	0.51	2.69	.
A-323	1	29	830714	800	26.0	6.6	.	.	.	.	.
A-324	1	29	830714	1000	26.0	6.7	0.51	0.09	0.51	2.63	.

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP
A-325	1	29	830714	1200	25.0	7.2	-	-	-	-	10
A-326	1	29	830714	1400	25.0	7.2	-	-	-	-	-
A-327	1	29	830714	1600	24.5	7.2	0.52	0.11	0.50	2.61	-
A-328	1	29	830714	1800	24.5	7.1	-	-	-	-	-
A-329	1	29	830714	2000	25.0	7.1	-	-	-	-	-
A-330	1	29	830714	2200	25.0	6.9	0.51	0.11	0.50	2.83	-
A-331	1	30	830715	0	25.0	7.0	-	-	-	-	-
A-332	1	30	830715	200	25.0	7.0	-	-	-	-	-
A-333	1	30	830715	400	26.0	7.0	0.51	0.12	0.51	2.74	-
A-334	1	30	830715	600	26.0	7.0	-	-	-	-	-
A-335	1	30	830715	800	26.5	7.0	-	-	-	-	-
A-336	1	30	830715	1000	26.5	6.9	0.51	0.10	0.51	2.83	-
A-339	1	30	830715	1200	27.0	7.3	0.53	0.25	0.50	2.81	11
A-340	1	30	830715	1400	26.0	7.0	-	-	-	-	-
A-341	1	30	830715	1600	26.0	6.9	-	-	-	-	-
A-342	1	30	830715	1800	25.5	6.8	0.53	0.12	0.51	2.66	-
A-343	1	30	830715	2000	26.0	6.6	-	-	-	-	-
A-344	1	30	830715	2200	26.0	6.7	-	-	-	-	-
A-345	1	31	830716	0	26.0	6.7	0.53	0.11	0.50	2.61	-
A-346	1	31	830716	200	27.0	6.7	-	-	-	-	-
A-348	1	31	830716	600	27.0	6.7	0.53	0.14	0.51	2.89	-
A-349	1	31	830716	800	27.0	6.4	-	-	-	-	-
A-350	1	31	830716	1000	27.0	6.3	-	-	-	-	-
A-351	1	31	830716	1200	27.0	6.5	0.52	0.11	0.52	2.93	-
A-355	1	31	830716	1400	27.0	6.9	-	-	-	-	-
A-356	1	31	830716	1600	26.5	6.9	-	-	-	-	-
A-357	1	31	830716	1800	26.5	6.8	-	-	-	-	-
A-358	1	31	830716	2000	26.0	6.8	0.53	0.10	0.51	2.78	-
A-359	1	31	830716	2200	26.5	6.6	-	-	-	-	-
A-360	1	32	830717	0	26.5	6.8	-	-	-	-	-
A-361	1	32	830717	200	27.0	6.8	-	-	-	-	-
A-362	1	32	830717	400	27.3	6.8	0.55	0.13	0.53	3.01	-
A-363	1	32	830717	600	27.5	6.9	-	-	-	-	-
A-364	1	32	830717	800	28.0	6.8	-	-	-	-	-
A-365	1	32	830717	1000	28.0	6.9	-	-	-	-	-
A-368	1	32	830717	1200	28.0	6.4	0.54	0.10	0.53	2.98	14
A-369	1	32	830717	1400	28.0	6.5	-	-	-	-	-
A-370	1	32	830717	1600	28.5	5.7	-	-	-	-	-
A-371	1	32	830717	1800	27.0	5.7	-	-	-	-	-
A-372	1	32	830717	2000	27.0	5.6	-	-	-	-	-
A-373	1	32	830717	2200	27.5	5.7	0.54	0.10	0.52	2.93	-
A-374	1	33	830718	0	27.5	5.7	-	-	-	-	-
A-375	1	33	830718	200	27.5	5.7	-	-	-	-	-
A-377	1	33	830718	600	28.5	5.9	0.53	0.10	0.75	3.45	-
A-378	1	33	830718	800	28.0	5.6	-	-	-	-	-
A-379	1	33	830718	1000	28.5	5.8	-	-	-	-	-
A-387	1	33	830718	1200	28.0	6.1	-	-	-	-	13
A-388	1	33	830718	1400	28.0	6.0	0.55	0.13	0.45	3.55	-
A-389	1	33	830718	1600	23.0	6.3	-	-	-	-	-
A-390	1	33	830718	1800	28.0	6.4	-	-	-	-	-
A-391	1	33	830718	2000	28.0	6.6	-	-	-	-	-
A-392	1	33	830718	2200	29.0	6.4	0.54	0.13	0.50	3.50	-
A-393	1	34	830719	0	28.5	6.5	-	-	-	-	-
A-394	1	34	830719	200	28.5	6.5	-	-	-	-	-
A-395	1	34	830719	400	29.0	6.5	-	-	-	-	-
A-396	1	34	830719	600	29.0	6.9	0.54	0.14	0.50	3.50	-

SAMPLE	TYPE	DAY	DATE	TIME	TC	PH	NA	K	MG	CA	TURB
A-397	1	34	830719	600	29.0	6.8	.	.	.	.	.
A-398	1	34	830719	1300	29.5	6.6	.	.	.	.	.
A-399	1	34	830719	1700	29.0	4.3	.	.	.	.	.
A-400	1	34	830719	2100	28.5	6.1	0.54	0.12	0.50	3.50	.
A-401	1	35	830720	100	29.0	6.0	.	.	.	.	.
A-402	1	35	830720	500	29.5	7.2	.	.	.	.	.
A-403	1	35	830720	900	29.0	5.5	.	.	.	.	.
A-409	1	35	830720	1130	30.0	6.4	0.55	0.13	0.55	3.50	13
A-410	1	35	830720	1330	29.5	6.3	.	.	.	.	.
A-411	1	35	830720	1530	30.0	6.2	.	.	.	.	.
A-412	1	35	830720	1730	29.5	6.2	.	.	.	.	.
A-414	1	35	830720	2130	29.0	6.1	0.55	0.12	0.45	3.50	.
A-415	1	35	830720	2330	30.0	6.3	.	.	.	.	.
A-416	1	36	830721	130	30.0	6.0	.	.	.	.	.
A-417	1	36	830721	330	30.5	5.4	.	.	.	.	.
A-418	1	36	830721	530	30.0	6.4	0.56	0.11	0.50	3.65	.
A-420	1	36	830721	930	30.0	5.7	.	.	.	.	.
A-421	1	36	830721	1130	30.0	5.8	.	.	.	.	.
A-424	1	36	830721	1330	29.0	5.6	0.56	0.12	0.50	3.65	.
A-425	1	36	830721	1530	30.0	5.5	.	.	.	.	.
A-426	1	36	830721	1730	29.5	5.8	.	.	.	.	.
A-427	1	36	830721	1930	30.0	5.8	.	.	.	.	.
A-428	1	36	830721	2130	30.0	5.6	0.56	0.12	0.55	3.70	.
A-429	1	36	830721	2330	30.0	5.7	.	.	.	.	.
A-430	1	37	830722	130	30.0	5.7	.	.	.	.	.
A-431	1	37	830722	330	30.0	5.8	.	.	.	.	.
A-432	1	37	830722	530	30.0	5.8	0.55	0.11	0.55	3.65	.
A-433	1	37	830722	730	29.5	5.8	.	.	.	.	.
A-434	1	37	830722	930	30.0	6.0	.	.	.	.	.
A-437	1	37	830722	1130	31.0	5.4	.	.	.	.	10
A-438	1	37	830722	1330	30.0	5.4	.	.	.	.	.
A-439	1	37	830722	1530	30.0	5.8	0.55	0.16	0.50	3.70	.
A-440	1	37	830722	1730	30.0	5.7	.	.	.	.	.
A-442	1	37	830722	2130	30.0	5.6	.	.	.	.	.
A-443	1	37	830722	2330	30.5	5.4	0.56	0.11	0.45	3.70	.
A-444	1	38	830723	130	30.5	5.7	.	.	.	.	.
A-445	1	38	830723	330	30.5	5.6	.	.	.	.	.
A-446	1	38	830723	530	30.5	5.3	.	.	.	.	.
A-447	1	38	830723	730	30.5	5.3	0.56	0.10	0.50	3.65	.
A-448	1	38	830723	930	30.0	5.6	.	.	.	.	.
A-449	1	38	830723	1130	30.5	5.3	.	.	.	.	.
A-452	1	38	830723	1330	30.0	5.4	0.56	0.11	0.50	3.65	12
A-453	1	38	830723	1530	30.0	5.2	.	.	.	.	.
A-454	1	38	830723	1730	30.5	5.2	.	.	.	.	.
A-455	1	38	830723	1930	31.0	5.4	.	.	.	.	.
A-456	1	38	830723	2130	31.0	5.4	0.57	0.11	0.55	3.80	.
A-457	1	38	830723	2330	31.5	5.4	.	.	.	.	.
A-458	1	39	830724	130	31.5	5.6	.	.	.	.	.
A-459	1	39	830724	330	31.5	5.4	.	.	.	.	.
A-460	1	39	830724	530	30.0	5.6	0.56	0.11	0.50	3.70	.
A-461	1	39	830724	730	31.0	5.4	.	.	.	.	.
A-462	1	39	830724	930	30.5	5.6	.	.	.	.	.
A-463	1	39	830724	1130	30.5	5.3	.	.	.	.	11
A-465	1	39	830724	1330	30.5	6.2	0.56	0.11	0.50	3.70	.
A-466	1	39	830724	1530	30.0	6.1	.	.	.	.	.
A-467	1	39	830724	1730	30.5	6.1	.	.	.	.	.

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP
A-469	1	39	830724	2130	31.0	5.8	0.57	0.11	0.50	3.80	.
A-470	1	39	830724	2330	31.5	5.4	.	.	.	.	.
A-471	1	40	830725	130	32.0	5.5	.	.	.	.	.
A-472	1	40	830725	330	31.5	5.4	.	.	.	.	.
A-473	1	40	830725	530	31.5	5.6	0.56	0.11	0.55	3.85	.
A-474	1	40	830725	730	30.5	5.5	.	.	.	.	.
A-475	1	40	830725	930	30.5	5.2	.	.	.	.	.
A-476	1	40	830725	1130	30.5	5.5	.	.	.	.	.
A-478	1	40	830725	1330	30.5	5.4	0.58	0.12	0.55	3.70	10
A-479	1	40	830725	1530	30.5	5.7	.	.	.	.	.
A-480	1	40	830725	1730	31.0	5.9	.	.	.	.	.
A-481	1	40	830725	1930	31.5	6.0	.	.	.	.	.
A-482	1	40	830725	2130	32.0	5.6	0.57	0.11	0.55	3.85	.
A-483	1	40	830725	2330	32.5	5.6	.	.	.	.	.
A-484	1	41	830726	130	32.5	6.0	.	.	.	.	.
A-485	1	41	830726	330	32.0	6.0	.	.	.	.	.
A-486	1	41	830726	530	32.0	5.7	0.56	0.11	0.50	3.90	.
A-487	1	41	830726	730	31.5	5.8	0.57	0.11	0.55	3.70	.
A-488	1	41	830726	930	31.5	5.8	.	.	.	.	.
A-489	1	41	830726	1130	31.5	5.7	0.56	0.11	0.55	3.70	.
A-490	1	41	830726	1330	31.5	5.7	0.57	0.11	0.55	3.75	.
A-491	1	41	830726	1530	31.5	5.9	0.57	0.11	0.50	3.80	10
A-493	1	41	830726	1730	31.5	5.9	0.57	0.11	0.50	3.75	.
A-495	1	41	830726	2130	32.5	6.3	0.57	0.12	0.55	3.90	.
A-496	1	41	830726	2330	32.5	6.2	0.56	0.12	0.55	3.90	.
A-497	1	42	830727	130	33.0	6.3	0.57	0.12	0.60	3.70	.
A-498	1	42	830727	330	32.5	6.0	0.56	0.11	0.55	3.70	.
A-499	1	42	830727	530	32.0	6.0	0.58	0.11	0.55	3.50	.
A-500	1	42	830727	730	32.0	5.6	0.57	0.10	0.55	3.55	.
A-501	1	42	830727	930	32.5	5.6	0.57	0.11	0.55	3.50	.
A-505	1	42	830727	1130	31.0	5.6	0.57	0.15	0.61	4.30	8
A-506	1	42	830727	1330	31.0	5.7	0.57.	0.14	0.61	5.95	.
A-507	1	42	830727	1530	31.5	5.6	.	.	.	.	.
A-508	1	42	830727	1730	31.0	5.6	0.56	0.14	0.61	6.75	.
A-509	1	42	830727	1930	31.5	5.6	0.55	0.12	0.62	5.35	.
A-510	1	42	830727	2130	31.5	5.8	0.57	0.12	0.63	5.05	.
A-511	1	42	830727	2330	32.0	5.6	0.57	0.14	0.63	4.90	.
A-512	1	43	830728	130	32.0	5.8	0.56	0.13	0.62	4.75	.
A-513	1	43	830728	330	32.5	5.7	0.57	0.12	0.62	5.05	.
A-514	1	43	830728	530	32.0	5.9	0.57	0.13	0.66	6.90	.
A-515	1	43	830728	730	31.5	5.9	0.56	0.12	0.61	4.60	.
A-516	1	43	830728	930	31.0	6.0	.	.	.	.	.
A-517	1	43	830728	1130	31.0	6.0	0.56	0.12	0.62	7.75	.
A-519	1	43	830728	1330	32.5	6.2	0.56	0.36	0.61	4.45	11
A-520	1	43	830728	1530	29.5	5.7	.	.	.	.	.
A-521	1	43	830728	1730	30.0	5.6	0.57	0.17	0.62	4.45	.
A-523	1	43	830728	2130	30.0	6.0	0.57	0.13	0.62	4.90	.
A-524	1	43	830728	2330	31.0	6.0	.	.	.	.	.
A-525	1	44	830729	130	31.0	6.2	0.57	0.13	0.63	4.90	.
A-526	1	44	830729	330	31.0	6.0	.	.	.	.	.
A-527	1	44	830729	530	31.0	6.1	0.57	0.12	0.63	4.90	.
A-528	1	44	830729	730	31.0	6.1	.	.	.	.	.
A-529	1	44	830729	930	31.0	6.2	0.56	0.13	0.62	4.60	10
A-531	1	44	830729	1200	31.0	6.0	0.57	0.10	0.61	4.60	.
A-532	1	44	830729	1400	30.0	6.0	.	.	.	.	.
A-533	1	44	830729	1600	30.0	6.0	.	.	.	.	.

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP
A-534	1	44	830729	1600	31.0	5.9	-	-	-	-	-
A-535	1	44	830729	2000	31.5	5.8	0.57	0.13	0.62	4.90	-
A-536	1	44	830729	2200	32.0	5.8	-	-	-	-	-
A-537	1	45	830730	0	32.0	5.6	-	-	-	-	-
A-538	1	45	830730	200	32.0	5.6	-	-	-	-	-
A-539	1	45	830730	400	32.5	5.4	0.58	0.13	0.65	5.05	-
A-540	1	45	830730	600	-	-	0.58	0.14	0.65	7.60	-
A-541	1	45	830730	800	32.0	5.5	0.58	0.12	0.63	5.50	-
A-542	1	45	830730	1000	31.5	5.8	-	-	-	-	-
A-545	1	45	830730	1200	32.0	7.4	0.59	0.19	0.64	7.10	-
A-546	1	45	830730	1400	32.0	7.3	0.59	0.14	0.63	4.75	-
A-547	1	45	830730	1600	32.0	7.2	0.58	0.13	0.63	5.05	-
A-548	1	45	830730	1800	32.5	7.2	0.58	0.13	0.64	4.90	-
A-550	1	45	830730	2200	33.5	7.2	0.58	0.13	0.66	6.10	-
A-551	1	46	830731	0	34.0	7.2	0.59	0.12	0.66	5.50	-
A-552	1	46	830731	200	34.0	7.2	0.59	0.13	0.66	5.05	-
A-553	1	46	830731	400	34.0	7.1	0.59	0.12	0.65	5.05	-
A-554	1	46	830731	600	34.0	7.1	0.58	0.12	0.66	5.35	-
A-555	1	46	830731	800	33.0	7.2	0.59	0.11	0.64	5.05	-
A-558	1	46	830731	1000	33.0	6.7	0.60	0.12	0.64	4.90	5
A-559	1	46	830731	1200	32.5	6.4	-	-	-	-	-
A-560	1	46	830731	1400	32.5	6.4	0.56	0.12	0.64	4.75	-
A-561	1	46	830731	1600	32.0	6.2	-	-	-	-	-
A-562	1	46	830731	1800	32.5	6.2	0.58	0.11	0.64	4.60	-
A-563	1	46	830731	2000	33.0	6.2	-	-	-	-	-
A-564	1	46	830731	2200	33.5	6.5	0.56	0.12	0.66	4.90	-
A-565	1	47	830801	0	33.0	6.6	-	-	-	-	-
A-566	1	47	830801	200	34.5	6.6	0.56	0.12	0.66	4.90	-
A-567	1	47	830801	400	34.0	6.6	-	-	-	-	-
A-568	1	47	830801	600	34.0	6.7	0.59	0.12	0.66	4.90	-
A-569	1	47	830801	800	33.0	6.6	-	-	-	-	-
A-570	1	47	830801	1000	33.0	6.6	0.59	0.11	0.64	4.90	-
A-571	1	47	830801	1200	33.0	6.7	-	-	-	-	-
A-572	1	47	830801	1400	33.0	6.4	-	-	-	-	11
A-574	1	47	830801	1730	33.0	3.4	0.59	0.13	0.65	6.75	-
A-575	1	47	830801	1930	31.5	3.0	-	-	-	-	-
A-577	1	47	830801	2330	32.0	5.2	0.55	0.11	0.64	5.05	-
A-578	1	48	830802	130	33.0	5.2	-	-	-	-	-
A-579	1	48	830802	330	33.0	5.2	-	-	-	-	-
A-580	1	48	830802	530	33.0	5.4	0.59	0.11	0.66	5.05	-
A-581	1	48	830802	730	32.0	5.6	-	-	-	-	-
A-582	1	48	830802	930	32.5	5.6	-	-	-	-	-
A-583	1	48	830802	1130	31.0	5.7	0.59	0.15	0.64	4.60	9
A-584	1	48	830802	1330	30.5	5.7	0.59	0.14	0.64	4.60	-
A-585	1	48	830802	1530	31.0	6.1	0.55	0.14	0.64	4.60	-
A-586	1	48	830802	1730	31.5	6.0	-	-	-	-	-
A-587	1	48	830802	1930	32.0	6.1	0.60	0.13	0.64	4.75	-
A-588 —	1	48	830802	2130	32.0	6.5	0.59	0.14	0.65	4.90	-
A-589 —	1	48	830802	2330	32.0	6.4	0.60	0.13	0.66	5.05	-
A-590	1	49	830803	130	32.5	6.5	0.60	0.13	0.66	5.05	-
A-591	1	49	830803	330	33.0	6.4	0.60	0.13	0.66	5.05	-
A-592	1	49	830803	530	33.5	6.6	0.59	0.11	0.66	6.55	-
A-593	1	49	830803	730	33.0	6.7	0.59	0.10	0.67	5.05	-
A-594	1	49	830803	930	32.0	6.2	0.55	0.11	0.66	4.90	-
A-597	1	49	830803	1130	33.0	5.1	-	-	-	-	6
A-598	1	49	830803	1330	32.0	5.2	0.60	0.10	0.66	5.05	-

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TEMP
A-599	1	49	830803	1530	32.0	5.3	.	.	.	.	.
A-600	1	49	830803	1730	32.5	5.8	0.60	0.12	0.66	5.05	.
A-601	1	49	830803	1930	32.5	5.2	.	.	.	.	.
A-602	1	49	830803	2330	33.5	5.2	0.61	0.12	0.66	5.05	.
A-603	1	50	830804	130	33.5	5.4	.	.	.	.	.
A-604	1	50	830804	330	33.5	5.0	0.60	0.11	0.66	5.20	.
A-605	1	50	830804	530	34.0	5.4	.	.	.	.	.
A-606	1	50	830804	730	33.0	5.8	0.60	0.12	0.66	5.05	.
A-607	1	50	830804	930	33.0	5.3	.	.	.	.	.
A-609	1	50	830804	1130	34.0	6.3	.	.	.	.	.
A-610	1	50	830804	1330	33.0	6.7	0.60	0.12	0.66	4.90	.
A-611	1	50	830804	1530	33.0	6.8	.	.	.	.	.
A-612	1	50	830804	1730	33.5	7.0	.	.	.	.	.
A-613	1	50	830804	1930	34.0	7.0	0.61	0.13	0.67	4.90	.
A-614	1	50	830804	2130	35.0	7.0	.	.	.	.	.
A-615	1	50	830804	2330	34.5	7.1	.	.	.	.	.
A-616	1	51	830805	130	35.0	7.1	0.61	0.12	0.68	4.90	.
A-617	1	51	830805	330	35.0	7.1	.	.	.	.	.
A-618	1	51	830805	530	35.0	7.1	.	.	.	.	.
A-619	1	51	830805	730	35.0	7.1	0.61	0.12	0.70	4.80	.
A-620	1	51	830805	930	35.0	7.1	.	.	.	.	.
A-621	1	51	830805	1130	33.5	7.2	.	.	.	.	9
A-622	1	51	830805	1330	33.5	7.2	0.60	0.12	0.67	5.20	.
A-623	1	51	830805	1530	34.0	7.2	.	.	.	.	.
A-624	1	51	830805	1730	34.0	7.1	0.60	0.12	0.66	4.80	.
A-625	1	51	830805	1930	34.5	7.2	.	.	.	.	.
A-626	1	51	830805	2330	35.5	7.2	0.60	0.13	0.70	5.05	.
A-627	1	52	830806	130	35.0	7.2	0.62	0.13	0.71	5.05	.
A-628	1	52	830806	330	35.0	7.2	0.61	0.12	0.71	5.05	.
A-629	1	52	830806	530	35.5	7.2	0.62	0.15	0.75	4.90	.
A-630	1	52	830806	730	35.0	7.2	0.59	0.11	0.70	5.05	.
A-631	1	52	830806	930	34.0	7.2	0.60	0.11	0.67	4.90	.
A-632	1	52	830806	1130	34.5	7.2	0.59	0.12	0.69	4.90	.
A-633	1	52	830806	1330	34.5	7.2	0.60	0.13	0.68	4.90	.
A-637	1	52	830806	1530	34.0	7.3	0.66	.	0.66	5.05	.
A-638	1	52	830806	1730	32.0	7.3	.	.	.	.	.
A-639	1	52	830806	1930	32.0	7.3	0.60	0.14	0.66	5.05	.
A-640	1	52	830806	2130	32.0	7.3	0.60	0.13	0.68	5.05	.
A-641	1	52	830806	2330	32.5	7.2	0.60	0.13	0.66	5.05	.
A-642	1	53	830807	130	33.0	7.2	0.59	0.12	0.66	5.05	.
A-643	1	53	830807	330	32.5	7.2	0.60	0.12	0.66	5.05	.
A-644	1	53	830807	530	32.5	7.2	0.59	0.10	0.66	5.05	.
A-645	1	53	830807	730	32.5	7.2	0.59	0.12	0.70	5.05	.
A-646	1	53	830807	930	32.5	7.2	0.60	0.11	0.68	4.90	.
A-647	1	53	830807	1130	32.5	7.2	.	.	.	.	.
A-648	1	53	830807	1330	32.5	7.2	0.59	0.11	0.69	4.90	.
A-649	1	53	830807	1530	32.5	7.2	0.60	0.11	0.68	4.90	.
A-650	1	53	830807	1730	32.0	7.2	0.60	0.10	0.68	4.80	.
A-651	1	53	830807	1930	32.0	7.2	.	.	.	.	.
A-652	1	53	830807	2330	32.0	7.2	0.61	0.11	0.66	4.90	.
A-653	1	54	830808	130	32.0	7.2	0.60	0.11	0.60	4.90	.
A-654	1	54	830808	330	32.5	7.2	0.61	0.11	0.68	4.90	.
A-655	1	54	830808	530	33.0	7.2	0.61	0.11	0.69	5.05	.
A-656	1	54	830808	730	33.0	7.2	0.67	0.15	0.75	4.45	.
A-657	1	54	830808	930	33.0	7.2	0.61	0.12	0.66	5.05	8
A-658	1	54	830808	1130	33.5	6.6	0.62	0.25	0.66	5.05	.

SAMPLE	TYPE	DAY	DATE	TIME	SC	PH	NA	K	MG	CA	TEMP
A-659	1	54	830808	1330	33.5	7.1	0.62	0.17	0.70	4.90	.
A-660	1	54	830808	1530	33.5	7.2	.	.	.	.	.
A-661	1	54	830808	1730	33.5	7.2	.	.	.	.	.
A-662	1	54	830808	1930	34.0	7.2	0.61	0.12	0.68	4.90	.
A-663	1	54	830808	2130	34.0	7.2	0.62	0.12	0.71	4.90	.
A-664	1	54	830808	2330	34.0	7.3	0.62	0.12	0.69	5.05	.
A-665	1	55	830809	130	34.0	7.2	0.62	0.16	0.70	5.05	.
A-666	1	55	830809	330	34.0	7.3	0.61	0.12	0.70	5.05	.
A-667	1	55	830809	530	35.0	7.2	0.62	0.11	0.70	5.05	.
A-668	1	55	830809	730	34.0	7.3	0.62	0.13	0.69	5.05	.
A-669	1	55	830809	930	34.5	7.3	0.61	0.12	0.70	5.05	.
A-670	1	55	830809	1130	34.5	7.3	.	.	.	.	10
A-671	1	55	830809	1330	35.0	7.0	0.61	0.12	0.71	5.05	.
A-672	1	55	830809	1530	34.0	6.8	0.60	0.11	0.70	5.05	.
A-673	1	55	830809	1730	34.0	6.8	0.62	0.13	0.73	5.05	.
A-674	1	55	830809	1930	34.0	6.8	.	.	.	.	.
A-675	1	55	830809	2330	35.0	6.8	0.61	0.14	0.71	5.35	.
A-676	1	56	830810	130	35.0	6.6	0.64	0.31	0.71	5.05	.
A-677	1	56	830810	330	35.0	6.8	0.62	0.11	0.71	5.20	.
A-678	1	56	830810	530	35.0	6.8	0.61	0.11	0.71	5.20	.
A-679	1	56	830810	730	34.5	6.8	0.63	0.13	0.73	5.05	.
A-680	1	56	830810	930	34.5	6.8	0.61	0.11	0.70	5.05	.
A-681	1	56	830810	1130	34.5	6.8	0.63	0.13	0.72	4.90	.

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA
A-4	2	3	830618	1110	-	-	0.41	0.07	0.24	0.62
A-91	2	11	830626	1500	7.3	6.0	0.15	0.12	0.08	0.43
A-169	2	17	830702	1255	31.0	5.6	-	-	-	-
A-206	2	20	830705	1430	9.0	5.8	0.21	0.11	0.05	0.34
A-221	2	21	830706	1430	12.0	6.0	0.52	0.39	0.32	1.19
A-283	2	26	830711	1200	9.0	5.4	-	-	-	-
A-284	2	26	830711	1330	8.1	5.1	0.25	0.17	0.14	0.43
A-285	2	26	830711	1330	8.1	5.1	0.30	0.16	0.14	0.42
A-297	2	27	830712	1000	6.0	5.9	-	-	-	-
A-298	2	27	830712	1200	2.8	5.6	0.12	0.11	0.03	0.05
A-492	2	41	830726	2000	36.5	5.8	-	-	-	-
A-502	2	42	830727	1000	9.0	5.3	-	-	-	-
A-503	2	42	830727	930	8.1	5.4	0.84	0.02	0.05	0.35
A-544	2	45	830730	1000	8.3	4.6	-	-	-	-
A-557	2	46	830731	815	12.0	4.6	-	-	-	-
A-595	2	49	830803	1130	9.0	5.2	0.94	-	0.01	0.13
A-634	2	52	830806	1400	9.9	6.4	-	-	-	-
A-635	2	52	830806	1430	7.7	6.2	0.30	0.34	0.14	0.23
A-636	2	52	830806	1430	7.7	6.2	0.42	-	0.29	0.11
A-33	3	7	830622	1230	17.0	6.2	0.48	0.25	0.60	1.63
A-60	3	9	830624	1130	7.8	6.2	0.23	0.11	0.18	0.40
A-74	3	10	830625	1130	31.0	6.4	0.69	0.17	1.03	2.56
A-89	3	11	830626	1130	21.0	6.1	0.61	0.13	0.72	1.23
A-103	3	12	830627	1145	3.7	6.6	0.32	0.18	0.08	0.00
A-130	3	14	830629	1130	2.4	5.8	0.15	0.02	0.04	0.00
A-168	3	17	830702	1255	14.0	6.2	0.35	0.09	0.44	1.08
A-222	3	21	830706	1530	220.0	7.0	2.20	0.60	0.42	30.00
A-240	3	23	830708	1100	28.0	6.3	0.61	0.09	0.57	2.26
A-299	3	27	830712	1030	43.0	6.2	0.90	0.29	1.94	3.51
A-337	3	30	830715	1100	9.0	6.8	0.29	0.25	0.19	0.06
A-352	3	31	830716	1205	5.1	6.4	0.23	0.15	0.13	0.26
A-366	3	32	830617	1100	3.7	5.2	0.16	0.10	0.09	0.15
A-381	3	33	830718	1100	7.0	5.1	0.39	0.14	0.14	0.90
A-405	3	35	830720	1145	7.6	6.6	0.41	0.21	0.12	0.75
A-423	3	36	830721	1300	9.5	5.2	0.25	0.29	0.20	1.15
A-435	3	37	830722	1100	8.5	5.0	0.24	0.17	0.16	0.75
A-450	3	38	830723	1230	13.5	4.5	0.37	0.36	0.25	1.50
A-464	3	39	830724	1130	10.0	3.8	0.37	0.27	0.23	1.00
A-477	3	40	830725	1135	13.0	4.4	0.36	0.11	0.24	1.45
A-504	3	42	830727	1000	11.0	4.4	0.41	0.36	0.19	1.00
A-518	3	43	830728	1145	15.0	4.6	0.40	0.12	0.29	2.05
A-530	3	44	830729	1000	33.0	5.1	0.88	0.14	0.70	4.00
A-543	3	45	830730	1000	18.0	5.0	0.49	0.12	0.37	5.05
A-556	3	46	830731	830	43.0	6.6	0.76	0.12	0.83	5.80
A-573	3	47	830801	1500	17.0	6.3	0.60	0.09	0.30	1.90
A-596	3	49	830803	1100	16.5	5.4	0.53	0.16	0.29	2.20
A-608	3	50	830804	930	17.0	3.8	0.60	0.10	0.30	2.20
A-2	4	1	830616	1435	14.0	6.0	0.84	0.15	0.31	1.18
A-380	4	33	830718	1100	32.0	5.2	0.80	0.11	0.95	2.20
A-382	4	33	830718	1300	48.0	5.8	0.82	0.27	0.97	4.90
A-383	4	33	830718	1300	46.0	5.7	0.52	0.33	0.93	5.45
A-384	4	33	830718	1300	51.0	5.8	-	0.85	1.13	4.95
A-404	4	35	830720	1145	33.0	6.5	-	0.20	0.60	2.10
A-407	4	34	830719	1300	32.0	6.7	-	-	-	-
A-8	5	3	830618	1740	2.3	5.3	0.13	0.03	0.02	0.18
A-9	5	3	830618	1740	2.3	5.2	0.25	0.15	0.02	0.10

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA
A-10	5	3	830618	1740	2.6	5.1	0.15	0.04	0.02	0.06
A-34	5	7	830622	1230	5.6	6.1	0.46	0.14	0.04	0.04
A-47	5	8	830623	1230	10.5	5.6	0.36	0.44	0.03	0.10
A-61	5	9	830624	1130	12.0	5.4	0.96	0.32	0.06	0.09
A-75	5	10	830625	1130	10.0	6.2	0.95	0.38	0.07	0.07
A-90	5	11	830626	1130	5.3	6.0	0.39	0.17	0.06	0.09
A-104	5	12	830627	1145	9.0	6.2	0.67	0.31	0.11	0.20
A-117	5	13	830628	1135	14.0	6.1	1.07	0.95	0.07	0.09
A-131	5	14	830629	1130	12.5	5.8	1.14	0.67	0.10	0.14
A-170	5	17	830702	1255	12.0	5.5	1.00	1.00	0.08	2.06
A-207	5	20	830705	1430	40.0	5.4	3.50	3.30	0.46	0.23
A-243	5	21	830706	1530	12.0	7.2	0.61	0.53	0.06	0.00
A-247	5	23	830708	1100	11.5	5.9	0.79	0.71	0.10	0.12
A-300	5	27	830712	1630	4.0	6.2	0.43	0.36	0.16	0.00
A-338	5	30	830715	1100	5.7	6.2	0.45	0.27	0.11	0.09
A-353	5	31	830716	1205	7.0	6.2	0.44	0.39	0.11	0.00
A-354	5	31	830716	1205	7.0	6.2	0.42	0.37	0.08	0.05
A-367	5	32	830717	1100	13.0	5.7	0.46	0.41	0.12	0.00
A-386	5	33	830718	1100	18.0	5.2	.	1.21	0.36	0.35
A-406	5	35	830720	1145	5.8	6.2	1.01	1.21	0.29	0.10
A-436	5	37	830722	1140	10.0	4.2	0.50	0.45	0.18	0.10
A-451	5	38	830723	1230	10.0	4.0	0.75	1.09	0.22	0.00

SAMPLE	TYPE	DAY	DATE	TIME	EC	PH	NA	K	MG	CA	TREE
B-1	6	5	830620	930	11.0	6.2	0.38	0.11	0.13	1.93	1
B-3	6	5	830620	1100	6.5	5.6	0.28	0.09	0.19	1.11	1
B-4	6	5	830620	1120	11.5	6.2	0.41	0.13	0.24	2.78	1
B-5	6	5	830620	1245	11.4	6.5	0.38	0.11	0.21	2.78	2
B-7	6	5	830620	1450	16.0	6.3	0.45	0.12	0.29	2.91	2
B-8	6	5	830620	1545	8.5	5.6	0.33	0.07	0.21	0.92	1
B-6	7	5	830620	1320	22.0	6.1	0.55	0.41	0.33	4.23	10
B-2	5	5	830620	930	3.8	5.2	0.40	0.24	0.03	0.31	6
B-9	6	6	830621	945	13.0	6.4	0.47	0.15	0.28	2.05	4
B-10	6	6	830621	1030	9.2	6.0	0.30	0.09	0.17	1.37	3
B-12	6	6	830621	1045	14.0	6.4	0.40	0.09	0.27	2.56	1
B-13	6	6	830621	1115	15.0	6.4	0.40	0.09	0.27	2.58	2
B-14	6	6	830621	1135	12.0	6.4	0.49	0.06	0.37	1.58	1
B-15	6	6	830621	1315	11.0	6.4	0.41	0.11	0.26	2.00	1
B-16	6	6	830621	1320	9.9	5.8	0.61	0.34	0.27	1.12	3
B-17	6	6	830621	1430	8.4	5.6	0.43	0.18	0.23	1.01	7
B-18	6	6	830621	1435	10.0	5.4	0.41	0.09	0.25	1.12	7
B-19	6	6	830621	1500	14.0	6.2	0.39	0.11	0.29	1.91	3
B-21	6	6	830621	1540	9.0	6.4	0.33	0.06	0.22	1.09	4
B-11	7	6	830621	1036	17.0	5.8	0.46	0.52	0.60	2.68	9
B-20	4	6	830621	1515	13.0	5.6	0.57	0.20	0.42	0.85	2
B-25	6	28	830713	1115	17.0	6.8	0.74	0.09	0.64	2.45	6
B-26	6	28	830713	1115	24.0	6.9	0.46	0.06	0.46	3.90	9
B-27	6	28	830713	1140	25.0	6.6	0.58	0.11	0.53	7.75	10
B-29	6	28	830713	1150	22.0	7.0	0.45	0.15	0.45	3.60	5
B-22	3	28	830713	1030	13.0	6.0	0.73	0.16	0.45	2.05	10
B-23	3	28	830713	1045	22.0	6.4	1.02	0.11	0.70	2.70	8
B-24	5	28	830713	1045	4.5	6.2	0.41	0.44	0.14	0.25	6
B-28	5	28	830713	1145	1.3	6.0	0.08	0.04	0.04	0.10	6
B-30	6	34	830719	1400	63.0	.	0.51	0.16	0.61	10.90	12
B-31	6	34	830719	1405	32.0	.	0.46	0.35	0.42	6.40	11
B-32	6	34	930719	1410	32.0	.	0.40	0.10	0.45	7.10	14
B-33	6	34	830719	1435	22.0	.	0.37	0.11	0.39	4.45	6
B-34	6	34	830719	1455	20.0	.	0.33	0.15	0.51	4.30	16
B-35	6	34	830719	1525	27.0	.	0.63	0.47	0.40	4.30	15
B-36	6	34	830719	1600	25.0	.	0.49	0.08	0.51	4.30	12
B-37	6	34	830719	1610	26.5	.	0.41	0.10	0.41	4.30	12
B-38	6	34	830719	1625	27.0	.	0.41	0.10	0.42	4.30	14
B-39	6	34	830719	1630	19.0	.	0.52	0.13	0.47	2.30	11
B-40	6	34	830719	1645	23.0	.	0.43	0.11	0.43	4.00	14
B-41	6	34	830719	1605	25.0	.	0.50	0.17	0.43	4.00	15
B-42	6	34	830719	1620	30.0	.	0.66	0.16	0.65	4.15	16

APPENDIX III

Chemical Data for the Apex River Watershed 1982.

NOTES: Sample Type: 1= stream at gauge
2= rain
3= snowmelt
4= spring
5= snow
6= stream tributary
7= pond

Units: Na, K, Mg, Ca= mg/l

OBS	SAMPLE	TYPE	DAY	DATE	TIME	NA	K	MG	CA
1	AP-1	1	1	820707	1636	0.89	0.27	0.90	8.19
2	AP-4	1	2	820708	1948	0.84	0.18	1.06	4.55
3	AP-5	1	2	820708	2149	0.75	0.17	1.06	8.74
4	AP-6	1	2	820708	2348	0.71	0.19	0.85	4.97
5	AP-7	1	3	820709	148	0.80	0.26	1.03	7.59
6	AP-8	1	3	820709	2022	0.66	0.15	0.82	4.08
7	AP-9	1	3	820709	2222	0.69	0.16	0.79	4.21
8	AP-10	1	4	820710	22	0.72	0.19	0.85	4.43
9	AP-11	1	4	820710	222	0.70	0.17	0.77	4.43
10	AP-12	1	4	820710	422	0.65	0.15	0.79	4.37
11	AP-13	1	4	820710	622	0.74	0.17	0.92	4.77
12	AP-14	1	4	820710	822	0.70	0.18	0.73	4.26
13	AP-15	1	4	820710	1022	0.73	0.16	0.97	4.68
14	AP-16	1	4	820710	1222	0.73	0.17	0.83	4.92
15	AP-17	1	4	820710	1422	0.72	0.17	0.92	4.64
16	AP-18	1	4	820710	1622	0.79	0.18	0.88	4.50
17	AP-22	1	4	820710	1730	0.69	0.21	0.76	4.17
18	AP-23	1	4	820710	1930	0.64	0.15	0.97	4.22
19	AP-24	1	4	820710	2130	0.66	0.17	0.76	4.30
20	AP-25	1	4	820710	2330	0.71	0.17	0.92	4.08
21	AP-26	1	5	820711	130	0.69	0.16	1.03	4.26
22	AP-27	1	5	820711	330	0.64	0.14	0.72	4.32
23	AP-28	1	5	820711	530	0.69	0.16	0.73	4.10
24	AP-29	1	5	820711	730	0.67	0.18	0.84	4.10
25	AP-30	1	5	820711	930	0.68	0.15	0.75	4.22
26	AP-31	1	5	820711	1130	0.66	0.14	0.71	4.17
27	AP-32	1	5	820711	1330	0.69	0.14	0.77	4.26
28	AP-33	1	5	820711	1530	0.78	0.17	0.84	4.59
29	AP-35	1	5	820711	2015	0.65	0.14	0.77	4.18
30	AP-36	1	5	820711	2215	0.74	0.17	0.77	3.95
31	AP-37	1	6	820712	15	0.64	0.14	0.76	4.20
32	AP-38	1	6	820712	215	0.65	0.14	0.77	4.22
33	AP-39	1	6	820712	415	0.65	0.14	0.77	4.18
34	AP-40	1	6	820712	615	0.68	0.16	0.71	4.16
35	AP-41	1	6	820712	815	0.71	0.16	0.92	4.28
36	AP-42	1	6	820712	1015	0.68	0.16	0.80	4.30
37	AP-43	1	6	820712	1215	0.71	0.16	0.90	4.33
38	AP-44	1	6	820712	1415	0.65	0.15	0.79	4.18
39	AP-45	1	6	820712	1615	0.66	0.13	0.72	4.20
40	AP-47	1	6	820712	1712	0.64	0.13	1.03	4.23
41	AP-48	1	6	820712	1912	0.64	0.13	0.83	3.83
42	AP-49	1	6	820712	2112	0.63	0.13	0.86	3.88
43	AP-50	1	6	820712	2312	0.68	0.15	0.95	4.29
44	AP-51	1	7	820713	112	0.65	0.14	0.85	3.92
45	AP-52	1	7	820713	312	0.66	0.19	0.99	4.00
46	AP-53	1	7	820713	512	0.66	0.15	0.90	4.22
47	AP-54	1	7	820713	712	0.65	0.15	0.73	4.10
48	AP-55	1	7	820713	912	0.68	0.15	0.94	4.38
49	AP-56	1	7	820713	1112	0.65	0.14	0.99	4.20
50	AP-57	1	7	820713	1312	0.65	0.13	0.74	4.35
51	AP-58	1	7	820713	1512	0.69	0.16	0.79	4.25
52	AP-61	1	7	820713	1718	0.65	0.14	0.90	4.25
53	AP-62	1	7	820713	1918	0.67	0.14	0.73	4.12
54	AP-63	1	7	820713	2118	0.65	0.14	0.86	4.12
55	AP-64	1	7	820713	2318	0.70	0.16	1.01	4.45
56	AP-65	1	8	820714	318	0.67	0.16	0.75	4.50

OBS	SAMPLE	TYPE	DAY	DATE	TIME	NA	K	MG	CA
57	AP-66	1	8	820714	718	0.73	0.17	0.97	4.13
58	AP-67	1	8	820714	1118	0.71	0.16	0.76	4.47
59	AP-68	1	8	820714	1518	0.69	0.15	0.73	4.29
60	AP-69	1	10	820716	1440	0.70	0.18	0.77	4.36
61	AP-70	1	10	820716	1840	0.68	0.15	0.88	4.32
62	AP-71	1	10	820716	2240	0.68	0.16	0.84	4.50
63	AP-72	1	11	820717	240	0.71	0.17	1.01	4.60
64	AP-73	1	11	820717	640	0.68	0.15	0.90	4.17
65	AP-74	1	11	820717	1040	0.68	0.16	0.84	4.52
66	AP-75	1	11	820717	1645	0.70	0.17	0.77	4.48
67	AP-76	1	11	820717	1845	0.67	0.15	0.88	4.47
68	AP-77	1	11	820717	2045	0.69	0.19	0.77	4.82
69	AP-78	1	11	820717	2245	0.68	0.16	0.84	4.56
70	AP-79	1	12	820718	45	0.71	0.17	0.97	4.67
71	AP-80	1	12	820718	245	0.69	0.16	0.90	4.43
72	AP-81	1	12	820718	445	0.73	0.17	0.81	4.76
73	AP-82	1	12	820718	645	0.71	0.16	0.99	4.66
74	AP-83	1	12	820718	845	0.68	0.16	0.86	4.61
75	AP-84	1	12	820718	1045	0.69	0.16	0.82	4.41
76	AP-85	1	12	820718	1245	0.72	0.26	0.80	4.48
77	AP-86	1	12	820718	1445	0.68	0.16	0.82	4.45
78	AP-88	1	12	820718	1610	0.68	0.16	1.17	4.58
79	AP-89	1	12	820718	2010	0.67	0.14	0.86	4.52
80	AP-90	1	13	820719	10	0.69	0.16	0.82	4.41
81	AP-91	1	13	820719	410	0.72	0.16	1.10	4.76
82	AP-92	1	13	820719	810	0.69	0.14	0.84	4.43
83	AP-93	1	13	820719	1210	0.68	0.14	0.86	4.54
84	AP-94	1	13	820719	1630	0.73	0.16	0.79	4.35
85	AP-95	1	14	820720	30	0.69	0.16	0.82	4.31
86	AP-96	1	14	820720	830	0.67	0.14	0.90	4.50
87	AP-98	1	19	820725	1425	0.71	0.18	0.85	4.78
88	AP-99	1	19	820725	1825	0.73	0.17	0.86	4.81
89	AP-100	1	19	820725	2225	0.73	0.20	0.95	10.88
90	AP-101	1	20	820726	225	0.73	0.17	1.05	4.75
91	AP-102	1	20	820726	625	0.74	0.17	0.88	4.81
92	AP-103	1	20	820726	825	0.70	0.18	0.88	10.69
93	AP-104	1	20	820726	1025	0.78	0.19	0.90	4.72
94	AP-105	1	20	820726	1225	0.73	0.17	0.90	4.67
95	AP-106	1	20	820726	1530	0.74	0.17	0.86	4.76
96	AP-107	1	20	820726	1930	0.75	0.18	0.88	4.91
97	AP-108	1	20	820726	2130	0.72	0.17	0.86	4.79
98	AP-109	1	20	820726	2330	0.76	0.18	1.24	8.19
99	AP-110	1	21	820727	130	0.71	0.17	0.95	5.00
100	AP-111	1	21	820727	330	0.73	0.18	0.99	4.73
101	AP-112	1	21	820727	530	0.73	0.17	0.90	4.79
102	AP-113	1	21	820727	730	0.71	0.17	0.90	11.28
103	AP-114	1	21	820727	930	0.77	0.18	1.04	4.72
104	AP-115	1	21	820727	1130	0.74	0.17	0.92	4.93
105	AP-116	1	21	820727	1330	0.73	0.18	0.97	4.96
106	AP-118	1	21	820727	1520	0.75	0.17	0.88	4.84
107	AP-119	1	21	820727	1920	0.73	0.16	0.92	4.71
108	AP-120	1	21	820727	2320	0.75	0.17	0.90	4.90
109	AP-121	1	22	820728	320	0.68	0.15	1.03	4.72
110	AP-122	1	22	820728	720	0.70	0.17	0.90	4.63
111	AP-123	1	22	820728	1120	0.73	0.16	0.88	4.63
112	AP-124	1	22	820728	1555	0.69	0.15	1.01	4.65

OBS	SAMPLE	TYPE	DAY	DATE	TIME	NA	K	MG	CA
113	AP-125	1	22	820728	1955	0.69	0.15	0.97	4.68
114	AP-126	1	22	820728	2355	0.72	0.16	1.01	4.70
115	AP-127	1	23	820729	355	0.69	0.17	0.88	4.75
116	AP-128	1	23	.	555	0.69	0.16	0.99	4.72
117	AP-129	1	23	820729	755	0.72	0.16	0.99	4.60
118	AP-130	1	23	820729	955	0.73	0.17	0.88	4.65
119	AP-131	1	23	820729	1155	0.69	0.14	1.13	4.67
120	AP-132	1	23	820729	1355	0.69	0.15	1.13	4.70
121	AP-134	1	23	820729	1555	0.69	0.15	1.10	4.77
122	AP-135	1	23	820729	1755	0.74	0.18	0.99	4.85
123	AP-136	1	23	820729	1955	0.68	0.18	1.13	4.83
124	AP-137	1	23	820729	2155	0.68	0.19	1.13	4.88
125	AP-138	1	23	820729	2355	0.73	0.18	1.08	4.83
126	AP-139	1	24	820730	155	0.73	0.17	1.06	4.80
127	AP-140	1	24	820730	355	0.69	0.15	1.19	4.85
128	AP-141	1	24	820730	555	0.72	0.16	1.08	4.78
129	AP-142	1	24	820730	755	0.71	0.14	1.01	4.77
130	AP-143	1	24	820730	955	0.71	0.15	1.01	4.75
131	AP-144	1	24	820730	1155	0.70	0.17	1.01	4.73
132	AP-145	1	24	820730	1355	0.70	0.17	1.12	4.83
133	AP-147	1	24	820730	1555	0.74	0.17	0.99	4.88
134	AP-148	1	24	820730	1755	0.68	0.17	1.19	4.85
135	AP-149	1	24	820730	1955	0.70	0.21	1.17	4.90
136	AP-150	1	24	820730	2155	0.72	0.16	1.10	4.82
137	AP-151	1	24	820730	2355	0.69	0.15	1.04	4.83
138	AP-152	1	25	820731	155	0.70	0.17	1.08	4.83
139	AP-153	1	25	820731	355	0.70	0.16	1.06	4.83
140	AP-154	1	25	820731	555	0.69	0.15	0.97	4.77
141	AP-155	1	25	820731	755	0.71	0.15	1.01	4.75
142	AP-156	1	25	820731	955	0.69	0.15	1.03	4.73
143	AP-157	1	25	820731	1155	0.69	0.15	1.13	4.78
144	AP-158	1	25	820731	1355	0.73	0.15	0.99	9.24
145	AP-160	1	25	820731	1600	0.69	0.15	1.15	4.73
146	AP-161	1	25	820731	2000	0.69	0.17	1.13	4.78
147	AP-162	1	26	820801	1	0.69	0.20	1.19	4.83
148	AP-164	1	26	820801	800	0.74	0.15	1.24	4.68
149	AP-165	1	26	820801	1200	0.74	0.15	1.22	4.78

```
 OBS    SAMPLE    TYPE    DAY    DATE     TIME     NA      K       MG      CA

   1    SN-1       5       2    820708    1545    0.77    0.84    0.17    0.20
   2    AP-19      2       4    820710    1700    0.35    0.20    0.06    0.55
   3    AP-34      2       5    820711    1943    0.32    0.44    0.07    0.65
   4    AP-20      4       5    820711    1555    0.72    0.05    0.49    1.19
   5    AP-21      4       5    820711    1605    0.84    0.06    0.99    5.94
   6    BP-1       4       8    820714       .    1.03    0.46    1.46    2.98
   7    BP-3       4       8    820714       .    0.83    0.14    0.65    1.97
   8    BP-6       4       8    820714       .    0.57    0.13    0.13    1.53
   9    BP-16      4       8    820714       .    0.42    0.18    0.31    1.73
  10    BP-15      7       8    820714       .    0.63    0.25    0.58    5.00
  11    BP-18      7       8    820714       .    0.64    0.27    0.54    5.27
  12    BP-9       6       8    820714       .    1.00    0.91    0.56    3.67
  13    BP-10      6       8    820714       .    0.60    0.18    0.56    3.18
  14    BP-13      6       8    820714       .    0.83    0.76    0.56    3.67
  15    BP-22      4       9    820715       .    0.48    0.08    0.40    3.07
  16    BP-29      4       9    820715       .    1.05    0.12    0.97    2.58
  17    BP-20      7       9    820715       .    0.83    0.68    0.56    4.44
  18    BP-23      7       9    820715       .    0.67    0.27    0.56    4.15
  19    BP-24      6       9    820715       .    0.69    0.17    0.61    4.55
  20    BP-25      6       9    820715       .    0.81    0.39    0.61    3.84
  21    BP-26      6       9    820715       .    0.72    0.18    0.68    4.05
  22    BP-28      6       9    820715       .    0.76    0.16    0.74    3.69
  23    BP-30      6       9    820715       .    0.80    0.16    0.79    3.87
  24    SN-5       5      20    820726       .    0.40    0.29    0.03    0.36
  25    SN-6       5      20    820726       .    0.35    0.22    0.03    0.18
  26    SN-7       5      20    820726       .    0.18    0.29    0.05    0.05
  27    SN-8       5      20    820726       .    0.19    0.25    0.03    0.15
  28    SN-9       5      20    820726       .    0.43    0.43    0.05    0.15
  29    SN-10      5      20    820726       .    0.43    0.50    0.03    0.09
  30    SN-11      5      20    820726       .    0.31    0.29    0.10    0.22
  31    SN-12      5      20    820726       .    0.33    0.52    0.10    0.13
  32    SN-13      5      20    820726       .    0.26    0.07    0.02    0.07
  33    SN-14      5      20    820726       .    0.29    0.07    0.03    0.16
  34    SN-15      5      20    820726       .    0.44    0.20    0.09    0.20
  35    SN-16      5      20    820726       .    0.90    1.16    0.11    0.35
  36    AP-117     2      21    820727    1500    0.23    0.36    0.06    0.45
  37    SN-17      5      22    820728       .    0.30    0.09    0.05    0.09
  38    SN-18      5      22    820728       .    0.29    0.07    0.04    0.11
  39    SN-19      5      22    820728       .    0.37    0.05    0.03    0.15
  40    SN-20      5      22    820728       .    0.40    0.09    0.03    0.18
  41    SN-21      5      22    820728       .    0.38    0.26    0.11    0.20
  42    SN-22      5      22    820728       .    0.39    0.23    0.09    0.13
  43    SN-23      5      22    820728       .    0.45    0.21    0.13    0.16
  44    SN-24      5      22    820728       .    0.42    0.21    0.11    0.22
  45    SN-25      5      22    820728       .    0.38    0.12    0.08    0.22
  46    SN-26      5      22    820728       .    0.29    0.08    0.06    0.24
  47    CP-3       4      22    820728       .    1.15    0.07    1.33    4.65
  48    CP-7       4      22    820728       .    1.00    0.11    1.21   10.25
  49    CP-11      4      22    820728       .    1.27    0.26    1.22    4.18
  50    CP-1       7      22    820728       .    1.00    0.58    0.99    4.20
  51    CP-5       7      22    820728       .    0.90    0.21    1.04    8.64
  52    CP-10      7      22    820728       .    0.92    0.18    1.06    8.28
  53    CP-2       6      22    820728       .    0.86    0.14    1.01    4.45
  54    CP-4       6      22    820728       .    0.87    0.17    0.90    4.49
  55    CP-6       6      22    820728       .    0.82    0.19    0.85    4.33
  56    CP-8       6      22    820728       .    0.82    0.21    0.81    4.22
```

OBS	SAMPLE	TYPE	DAY	DATE	TIME	NA	K	MG	CA
57	CP-9	6	22	820728	.	0.81	0.19	0.81	4.20
58	DP-1	4	23	820729	.	1.16	0.16	1.51	4.22
59	DP-6	4	23	820729	.	0.95	0.19	0.85	2.13
60	DP-9	4	23	820729	.	1.08	0.08	1.26	10.07
61	DP-20	4	23	820729	.	1.06	0.26	1.13	3.51
62	DP-2	7	23	820729	.	1.07	0.24	1.26	9.00
63	DP-3	7	23	820729	.	1.02	0.19	1.03	4.11
64	DP-4	7	23	820729	.	1.00	0.04	0.99	4.16
65	DP-5	7	23	820729	.	1.05	0.21	1.19	4.98
66	DP-8	7	23	820729	.	0.87	0.11	0.74	3.09
67	DP-10	7	23	820729	.	0.88	0.17	0.97	10.07
68	DP-11	6	23	820729	.	0.82	0.18	1.04	4.51
69	DP-12	6	23	820729	.	0.82	0.18	1.04	4.49
70	DP-13	6	23	820729	.	0.82	0.18	1.01	4.56
71	DP-14	6	23	820729	.	0.83	0.17	1.03	4.56
72	DP-15	6	23	820729	.	0.81	0.17	1.01	4.62
73	DP-16	6	23	820729	.	0.83	0.20	1.04	4.62
74	DP-17	6	23	820729	.	0.80	0.17	1.01	4.65
75	DP-18	6	23	820729	.	0.82	0.18	1.06	4.55
76	DP-19	6	23	820729	.	0.82	0.18	1.03	4.56
77	AP-146	2	24	820730	1530	0.50	0.32	0.07	0.23
78	AP-159	2	25	820731	1545	0.69	0.19	0.09	0.20

APPENDIX IV

Isotope Data for the Apex River Watershed 1983.

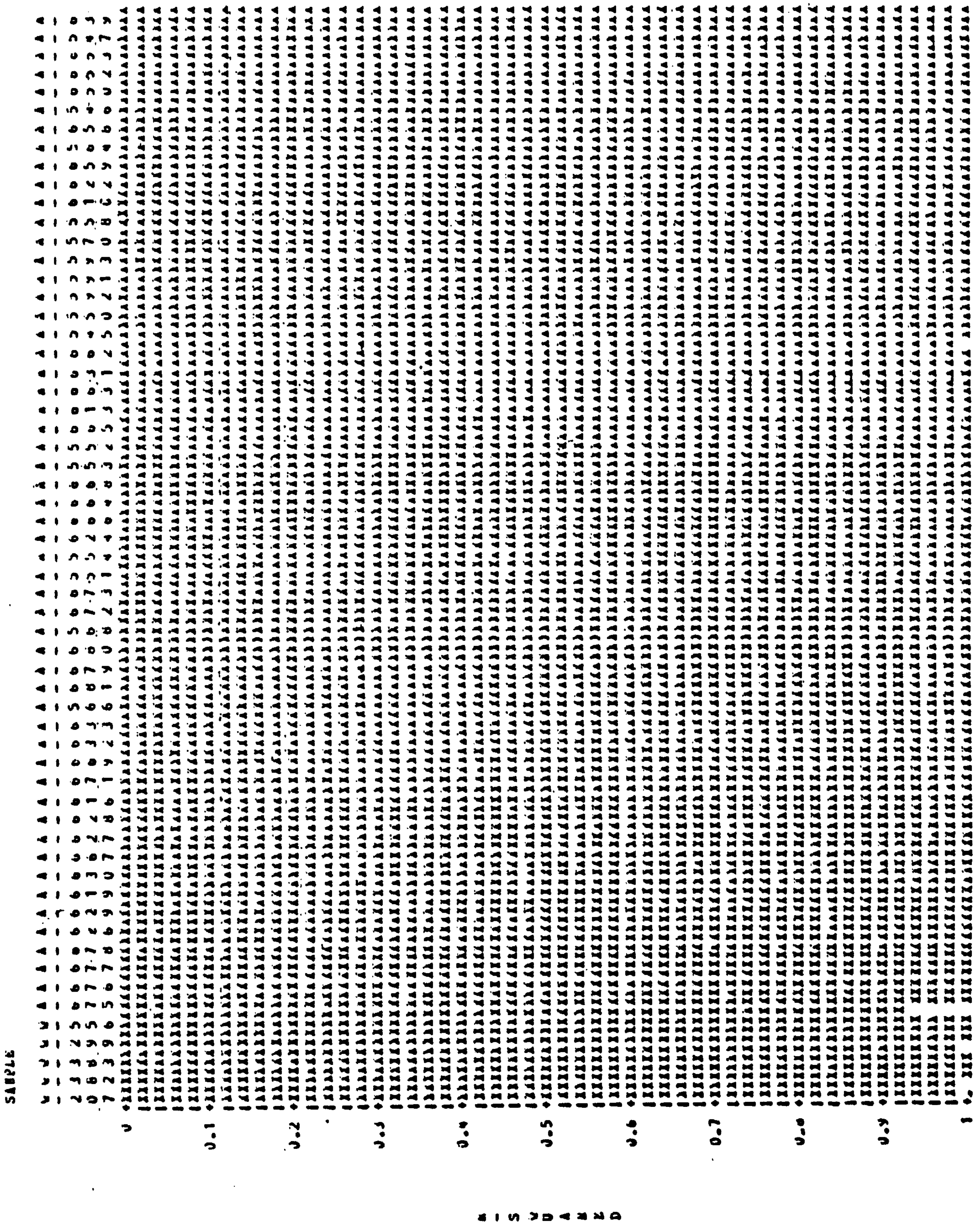
NOTES: Sample Type:
1= stream at gauge
2= rain
3= snowmelt
4= spring
5= snow

Units: $\delta^{18}O$=‰ SMOW

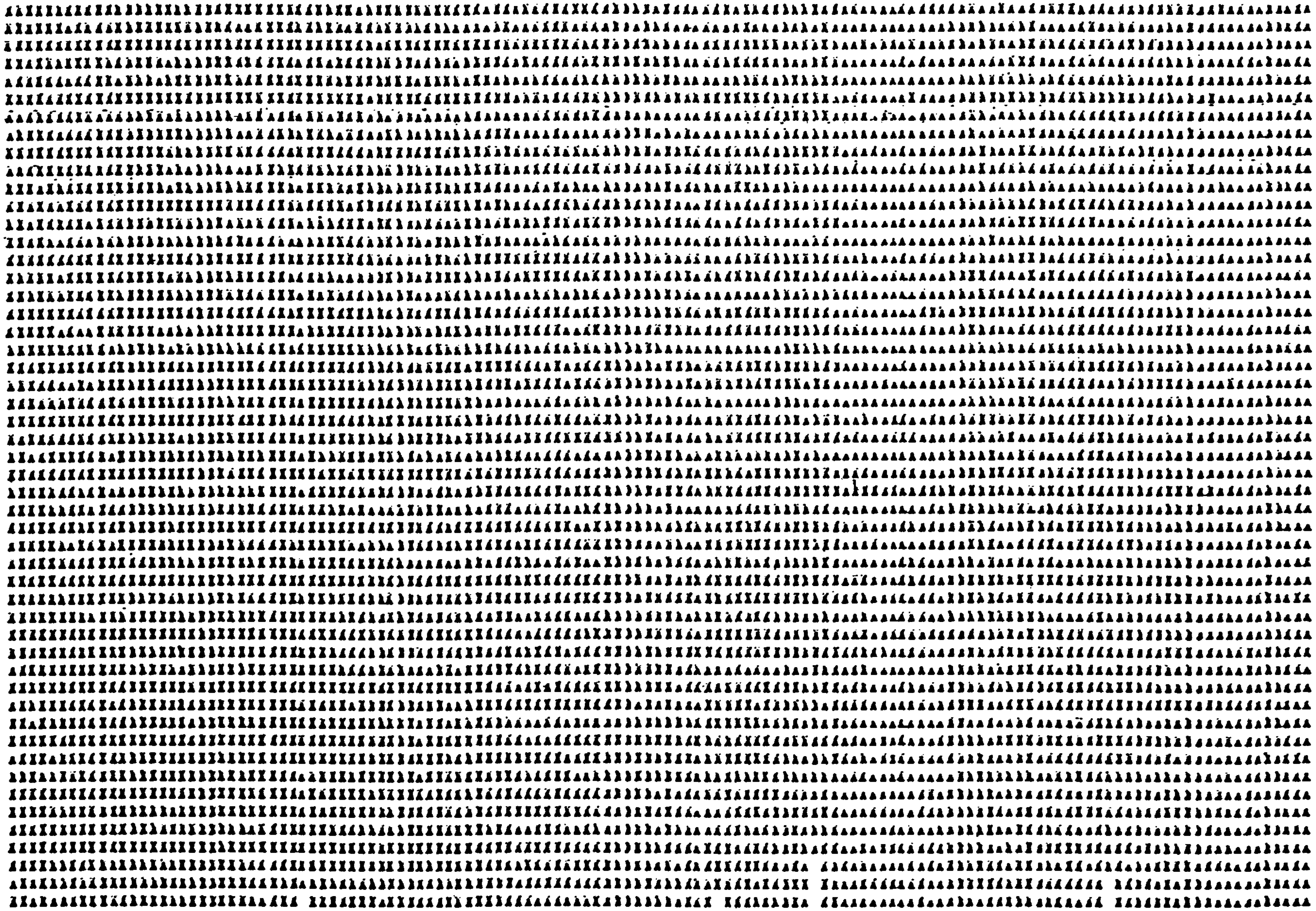
```
                                   SAS

  OBS      SAMPLE      TYPE      DAY      DATE       TIME       C18

    1      A-1           1         1     830616      1435      -21.2
    2      A-2           3         1     830616      1435      -22.6
    3      A-7           1         3     830618      1340      -21.0
    4      A-8           5         3     830618      1740      -23.6
    5      A-12          1         4     830619      1350      -21.0
    6      A-14          1         5     830620      1400      -19.9
    7      A-36          1         7     830622      1430      -20.4
    8      A-33          3         7     830622      1230      -22.6
    9      A-63          1         9     830624      1330      -20.2
   10      A-92          1        11     830626      1500      -20.0
   11      A-91          2        11     830626      1500      -16.4
   12      A-90          5        11     830626      1130      -23.6
   13      A-103         3        12     830627      1145      -26.8
   14      A-114         1        13     830628       530      -19.7
   15      A-130         3        14     830629      1130      -26.8
   16      A-158         1        16     830701      1530      -19.4
   17      A-201         1        20     830705       400      -19.7
   18      A-210         1        20     830705      1630      -19.5
   19      A-207         5        20     830705      1430      -22.3
   20      A-219         1        21     830706      1230      -19.2
   21      A-221         2        21     830706      1430      -14.7
   22      A-235         1        22     830707      1400      -19.3
   23      A-265         1        24     830709      2200      -19.2
   24      A-280         1        26     830711       800      -19.0
   25      A-284         2        26     830711      1330      -16.4
   26      A-301         1        27     830712      1200      -19.0
   27      A-298         2        27     830712      1200      -22.2
   28      A-327         1        29     830714      1600      -18.6
   29      A-338         5        30     830715      1100      -23.5
   30      A-358         1        31     830716      2000      -18.5
   31      A-409         1        35     830720      1130      -17.9
   32      A-404         4        35     830720      1145      -17.9
   33      A-439         1        37     830722      1530      -17.6
   34      A-451         5        38     830723      1230      -22.6
   35      A-460         1        39     830724       530      -17.1
   36      A-469         1        39     830724      2130      -17.3
   37      A-503         2        42     830727       930      -16.6
   38      A-535         1        44     830729      2000      -17.8
   39      A-595         2        49     830803      1130      -17.2
   40      A-635         2        52     830806      1430      -22.1
   41      A-681         1        56     830810      1130      -17.5
```

APPENDIX V

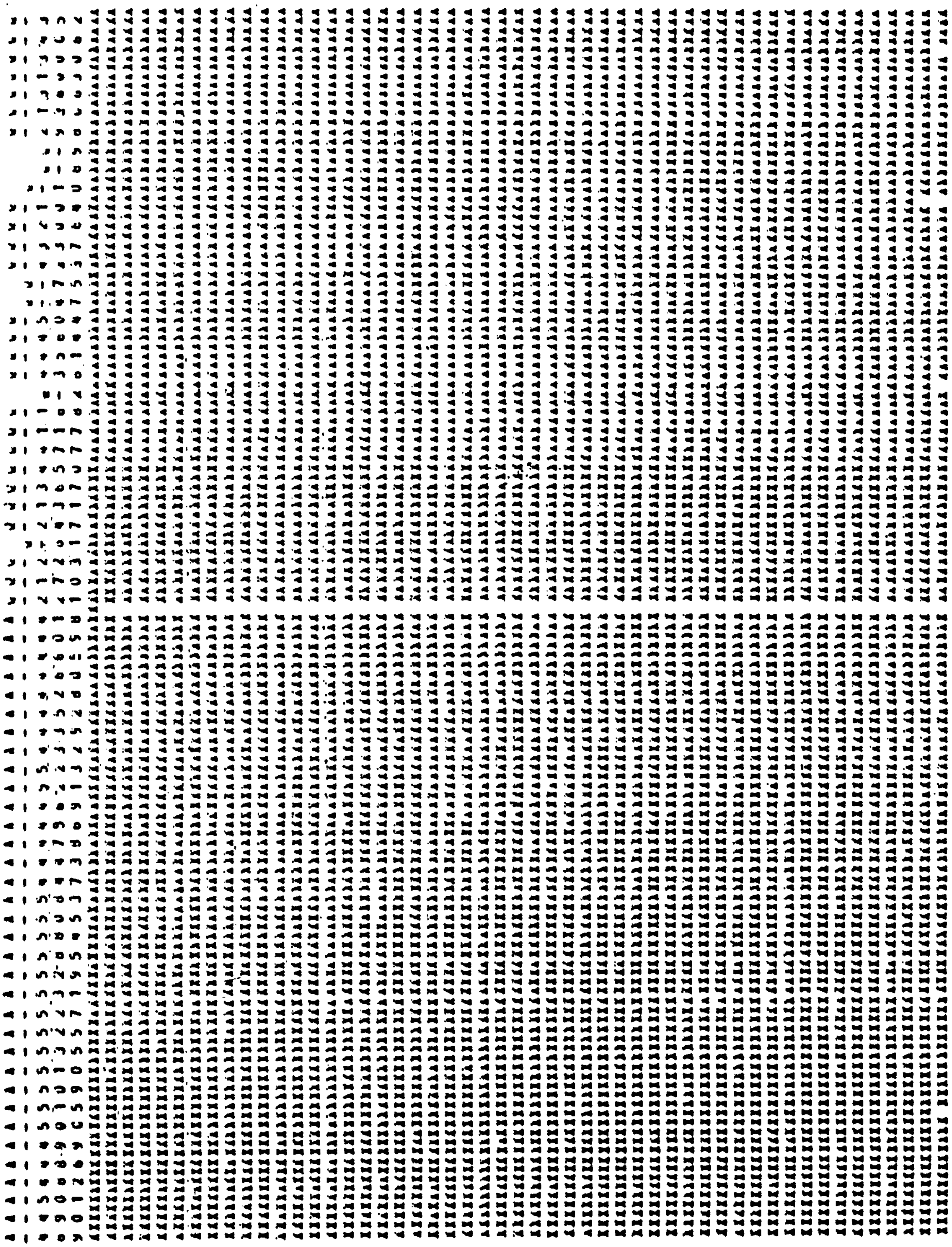
Computer Output of Cluster Analysis of Water Samples Using Chemical Variables. (Refer to Figure 6.9)


SAMPLE
DISTANCE
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

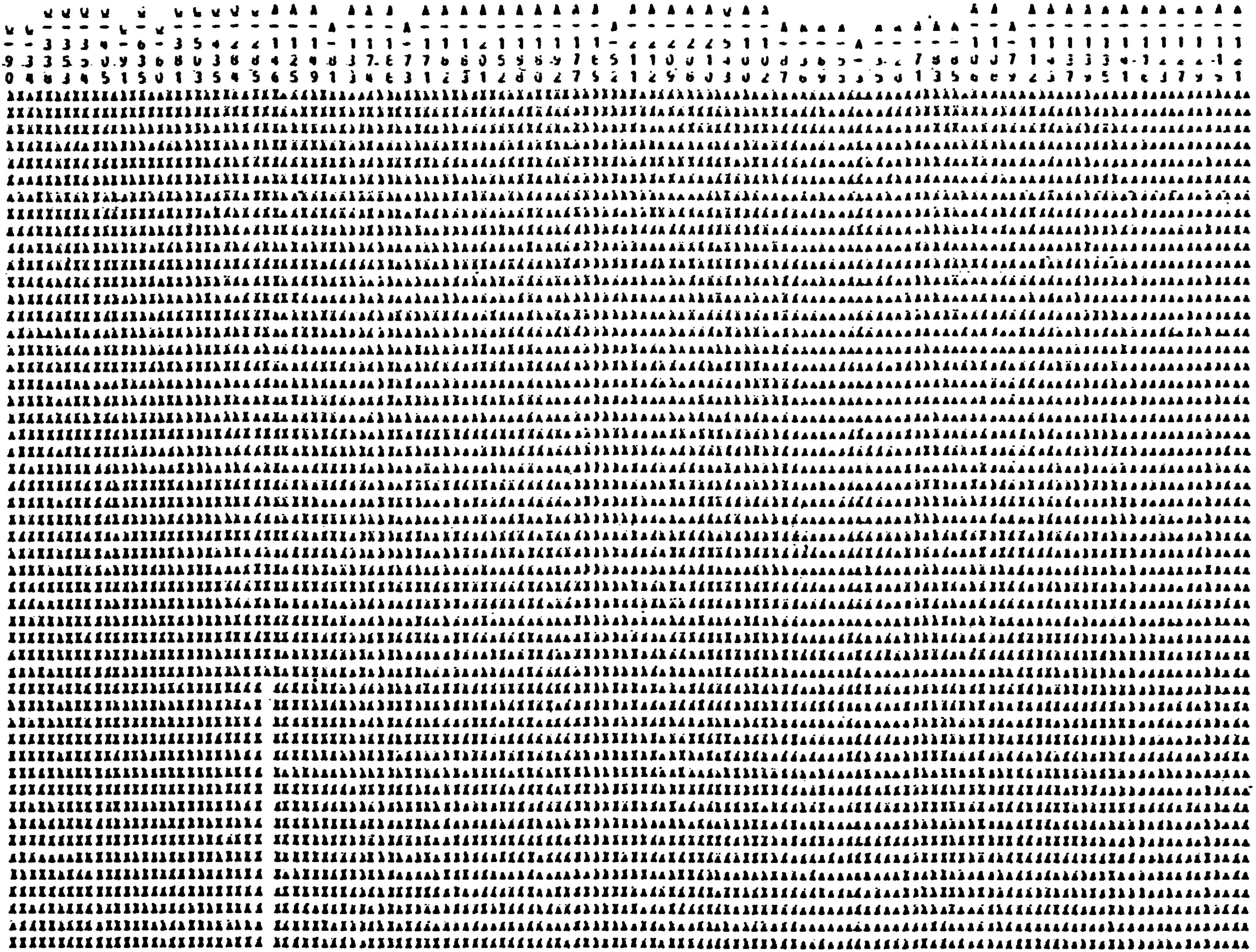
```
SAMPLE

A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A A   A A A A A A A A A
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - A - - - - - - - - -
6 6 6 6 6 5 6 6 6 6 6 5 6 6 6 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 6 5 6 5 6 6 5 5 5 5 5 3 3 4 3 4 3 4 3 3 3 3 3 3 3 2 - 3 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 5 5 5 4 5 5 8 9 8 8 9 1 6 0 3 4 7 9 1 1 1 0 6 6 0 0 0 7 0 0 1 1 8 7 0 9 2 9 1 6 4 5 3 3 7 6 4 7 8 9 9 9 9 9 9 7 8
0 4 5 1 3 8 8 6 9 4 6 5 2 5 7 7 4 6 5 0 5 0 2 9 1 7 8 1 2 3 0 0 6 0 2 4 4 6 8 4 7 8 7 0 0 4 2 4 2 8 1 6 9 3 8 6 4 0 7 8 5 6 1 3 3 7
```



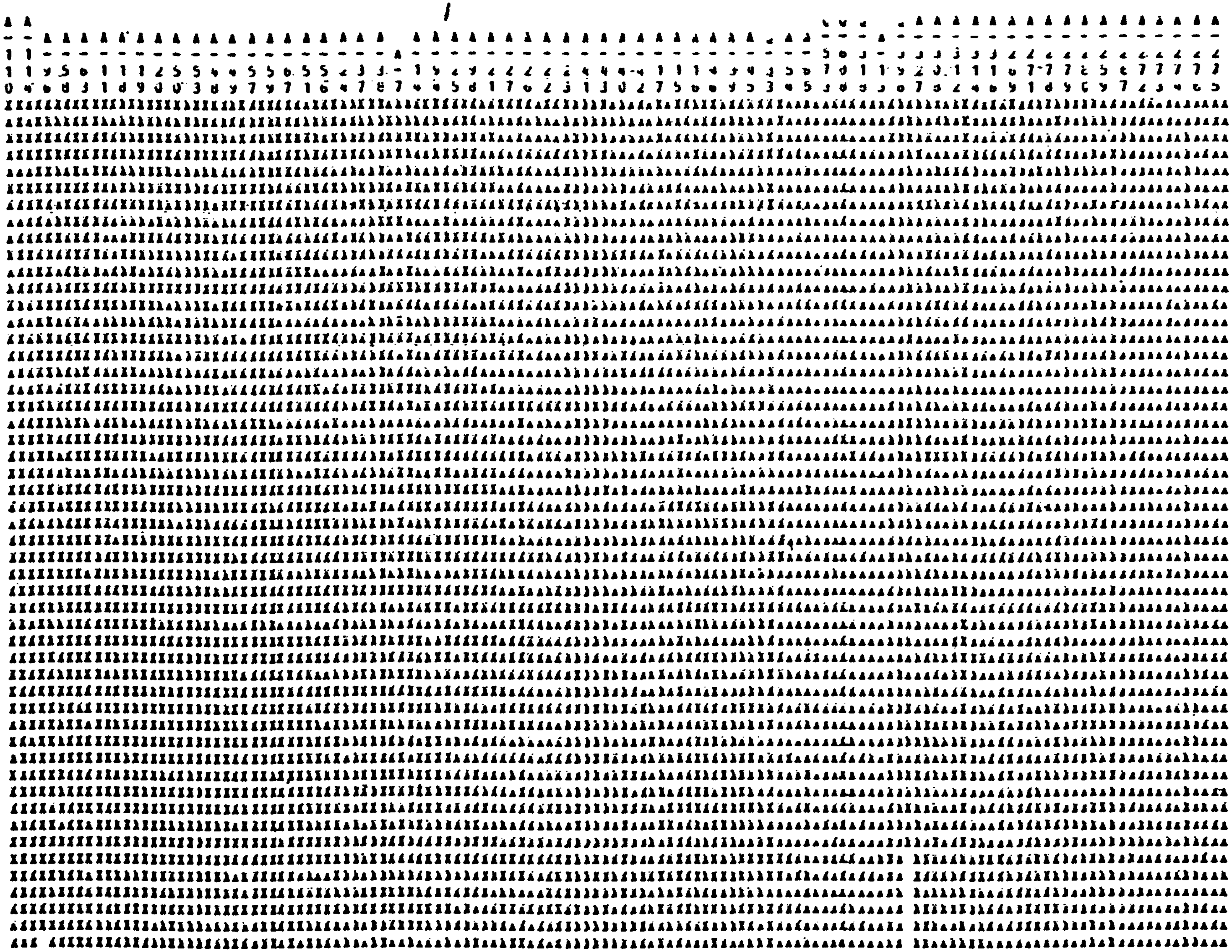
SAMPLE



SAMPLE



SAMPLE



```
SAMPLE

A A A A     A A A A A A A   A A A A A A A A A A A A A   A   A A A A A A A A       A A A A A A A A A A A A     A A A A A A A A A A A
- - - - A A - - - - - - -   - - - - - - - - - - - - -   - A - - - - - - - -   A A - - - - - - - - - - - - A A - - - - - - - - - - -
2 1 2 2 - - 3 3 3 3 3 3 3 A 1 1 3 3 3 2 3 3 3 2 2 2 2 A 2 - 2 2 2 1 2 2 2 1 A - - 2 2 2 2 2 2 2 2 2 2 2 2 - - 2 2 3 2 2 2 2 2 2 2 2
7 5 6 8 3 9 0 0 3 4 5 2 2 - 6 6 1 4 3 9 1 0 1 1 1 1 1 - 2 6 1 1 1 6 0 0 0 5 - 7 3 4 2 3 3 3 3 3 3 6 9 5 5 2 3 4 5 0 5 9 4 9 6 5 6 5
7 5 1 2 2 2 1 3 3 5 8 2 4 5 4 7 1 2 6 0 0 9 8 7 6 5 9 6 6 9 3 4 6 1 3 4 5 6 1 7 0 1 6 0 9 4 3 7 7 9 1 1 3 9 1 5 4 6 2 0 3 5 6 5 3 7
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
```

```
SAMPLE

A A A A A
- - - - -
2 2 3 3 3
6 6 0 0 0
1 5 2 4 5
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
XXXXXXXXX
```

APPENDIX VI

Paired Sample t-test Comparing Chemical Analyses Obtained from the Two Atomic Absorption Spectrophotometers.

(Refer to Table 6.8)

Paired Sample t-test (refer to data in Table 6.6)

For Ca : $n=5$
$x=0.53$
$s=0.40$

$$t= \frac{0.53-0}{0.40/ 5} =2.963$$

$t_{0.99}=3.474$

Since $t_{calc}<t_{0.99}$,

values of Ca are not significantly different at the 99% level of significance.

For Mg : $n=5$
$x=0.034$
$s=0.107$

$$t= \frac{0.034-0}{0.107/ 5} =0.710$$

$t_{0.95}=2.132$

Since $t_{calc}<t_{0.95}$,

values of Mg are not significantly different at the 95% level of significance.

VITA AUCTORIS

MILAN MITCH OBRADOVIC
Born March 6, 1960 in Windsor, Ontario, Canada.

EDUCATION

1973-1978	J. L. Forster S. S., Windsor, Ontario. Graduated with OSSHGD.
1978-1982	University of Windsor, Windsor, Ontario. Graduated with a B.A.Sc. in Geological Engineering.
1982-1986	University of Windsor, Windsor, Ontario. Graduated with a M.A.Sc. in Geological Engineering.