RIVER REGIMES

OF

NORTHERN ONTARIO

by

PETER DAVID diCENZO

A Research Paper

Submitted to the Department of Geography

in Fulfilment of the Requirements

of Geography 4C6

McMaster University

April 1984

ABSTRACT

The period of observation necessary to obtain representative mean monthly values for precipitation, temperature, and streamflow is about fifteen years. At present there is a paucity of meteorological and streamflow records of such length. This makes hydrological investigations in northern Ontario difficult.

River regimes of northern Ontario are found to exhibit general characteristics. More specifically, runoff peaks occur in spring due to snowmelt, and secondary fall peaks occur due to rainfall. The regimes can be classified into four types based upon qualitative comparisons of annual flow response patterns. River regimes in northern Ontario exhibit spatial variation. Rivers to the northwest have lower flow magnitude due to decreased precipitation, and tend to have flow "buffered" by the many small lakes located there. Rivers to the southeast have more pronounced spring melt peaks resulting from greater winter snow accumulation. Fall contributuion to total annual runoff increases to the northwest. The colder winter conditions of northern Ontario is reflected in a tendency of winter contribution to annual yield to decrease towards the northwest.

Seasonal runoff is affected by meteorological conditions. Temperature has a marked effect on spring streamflow as rising temperature causes snowmelt. Summer flow reflects the effects of both temperature and precipitation. Precipitation has a pronounced effect on fall runoff. Winter runoff is dominated by baseflow only as temperatures are low and precipitation is snow which accumulates until spring.

An attempt to produce equations for predicting seasonal monthly flow was unsuccessful. Meteorological stations are too sparsely distributed to provide representive data necessary for producing such equations. There is a need to increase the meteorological and streamflow station network in northern Ontario to enable a more comprehensive study of the hydrologic processes.

ACKNOWLEDGEMENTS

I am greatly indebted to my advisor, Dr. Ming-Ko Woo for his assistance, encouragement, and friendship in the preparation of this work. I would also like to acknowledge the guidance of Dr. S.B. McCann over the year.

The assistance of Mr. Ric Hamilton in the presentation of the material was most appreciated.

I am also most grateful to Drs. W.R. Rouse, J.J. Drake, and M.J. Webber for their support during my time in the department.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

1:1 INTRODUCTION

Northern Ontario comprises wilderness environment which has scarcely been affected by man. The population of this region is sparse and unevenly distributed (Hutton and Black, 1975; Woo and Waylen, 1983). The economy of northern Ontario is strongly resource oriented. Mining, forest industries, fur trapping, commercial fishing, recreation and tourism are established industries within the region (Hutton and Black, 1975).

Several rivers in northern Ontario have potential for generating hydroelectricity (Woo and Waylen, 1983). Proposed hydroloelectric development of these rivers, and the resultant effects on the environment, may affect the economy and social nature of the region. Investigation of river regime in the region should enable general hydrologic characteristics to be established. Such characteristics will aid in environmental impact studies of proposed hydroelectric projects.

1:2 RIVER REGIME

River regime can be defined as the systematic variation in streamflow due to the seasonality of water gains and losses (Beckinsale, 1969). Thus, regimes are influenced by the seasonal pattern of snowmelt, rainfall, evapotranspiration, and flow regulations. For rivers with natural flow, short or long-term changes in local climate affect the annual runoff response pattern (Weyman, 1975). Also important are such factors as vegetation, soil type, catchment area, drainage density, geology, physiography, mean land slope, and land use practices (Hely and Olmstead, 1962; Lull and Sopper, 1966; Mustonen, 1967; Gregory and Walling, 1968; Gray, 1970). The sum of all factors that transform a portion of precipitation into direct runoff is known as "hydrologic depth" (Woodruff and Hewlett, 1970). The spatial variation of river regime reflects a response to the spatial changes in the above factors.

To determine the flow regime, runoff must be quantified. Flow rates, minimum and maximum flow events, flood magnitudes, and mean flows are commonly considered (Beckinsale, 1969; Gregory and Walling, 1973). Runoff is often converted into water depth per unit area of the watershed to enable a direct comparison with precipitation and to facilitate the comparison of runoff from two or more watersheds.

Flow patterns can be examined over arbitrary time intervals. Court (1962) uses the term "half flow interval" to refer to the time period in which one quarter to three quarters of annual flow occurs. Sopper and Lull (1965) compare seasonal contribution to total annual runoff for streams in northeastern United States. Mustonen (1967) starts the hydrologic year in spring when the ground in Finland is nearly saturated, and subsequently divides the year into three seasons according to meteorological conditions.

Graphical representation of runoff parameters over time, either as absolute values or dimensionless ratios, provide informative summary of flow pattern. Regime diagrams of mean monthly flow are frequently examined for peaks and low flows (Beckinsale, 1969).

It is often required to regionalize the flow regime by establishing several general characteristics that can be extended spatially rather than temporally (Riggs, 1973). Spatial variation in flow characteristics are considered to be the result of interactions between meteorological factors and basin conditions (Gregory and Walling, 1973), or as chance variation due to sampling (Riggs, 1973).

Knowledge of streamflow regime and its spatial variation are important for the planning of residential, industrial, or hydroelectrical projects. These projects require information on the availability of water and an assessment of the risks involved due to floods and droughts.

1:3 PREVIOUS STUDIES

Streamflow in northern Ontario has not been studied extensively; however, a few investigations have provided valuable information with respect to regime and runoff processes in this region. As in most Canadian watersheds, runoff is dominated by snowmelt and rainfall events (Hutton and Black,1975; Woo and Waylen, 1983). Other processes affecting streamflow include lake storage and runoff regulation (OWRC, 1975).

Although peak annual runoff events for many basins result directly from spring breakup and snowmelt, peak flows in summer and fall due to rainfall events can sometimes exceed spring peaks (OWRC, 1975; Woo and Waylen, 1983). Furthermore, some basins exhibit annual flood peaks due to snowmelt in some years, while in other years peak flow is due to rainfall. In general, snowmelt events dominate peak floods in the southeast, and rainfall becomes progressively more important in peak flow generation to the north and northwest (Woo and Waylen, 1983).

The Ontario Water Resources Commission (1975) analysed seven-day low flows and demonstrated that minimum streamflows are most frequent in March and early April before spring melt begins. Secondary low flows occur during summer before the "fall rainy season".

1:4 THESES OBJECTIVES

Due to the scarcity of regime studies in northern Ontario, it is the objective of this study to improve our understanding of flow response patterns in this region. More specifically, the objectives are:

(1) to determine the number of years of record required to obtain representative mean monthly values for precipitation, temperature and streamflow

(2) to establish general characteristics of northern Ontario river regimes

(3) to classify regime types on the basis of general characteristics

(4) to examine spatial variation of regimes in the region

(5) to assess the meteorological effects on seasonal runoff.

CHAPTER II

STUDY AREA AND DATA SOURCES

2:1 STUDY AREA

Northern Ontario comprises two major physiographic regions, the Hudson Bay Lowland and the Canadian Shield. The Canadian Shield is mainly composed of Precambrian igneous and metamorphic crystalline rock. Topographically, the shield reaches a maximum elevation of about 500 m in its upland area. Pleistocene glaciation, during which ice moved from the north and northeast, created an irregular relief with rocky parallel ridges separating depressions which are subsequently occupied by muskegs and narrow lakes. The effects of glaciation were particularly marked in the area west of Lansdown House and Pickle Crow (Brown, 1968).

The Hudson Bay Lowland is flat with a maximum elevation of approximately 150 m where it meets the shield (Hutton and Black, 1975). The lowland lacks any noticeable relief except for the raised beach ridges near the coast, and south of Winisk where there are two areas with Precambrian outliers (Brown, 1968). The underlying bedrock is mainly Paleozoic limestones and shales. Surficial materials include such recessional ice features as morraines, eskers, and kames which provide local relief.

Much of the surface, however, is covered by poorly drained marine clay and glacial lake deposits. As a result, extensive peat bogs capped by muskeg have developed (Hutton and Black, 1975).

Most rivers in the region drain northward or northeastward toward Hudson and James Bays. Many of these rivers originate in the shield and cross the lowland in approximately parallel courses, leaving large tracts of wetlands between the major river channels. The higher parts of the shield area can have good drainage but the depressions are often poorly drained. Drainage in the lowland tends to be extremely poor, though local drainage of peat plateaus and palsas can be good (Brown, 1968).

Northern Ontario has a boreal climate except for a narrow strip fringing Hudson Bay which has arctic climatic conditions (Woo and Waylen, 1983). The regional climate is modified to a large extent by Hudson Bay and its sea ice (Hutton and Black, 1975; Rouse and Bello, 1983). Characteristically, the region has harsh winters with mean January temperatures of about $-25^{\circ}C$ in the lower Severn basin, and of about $-18^{\circ}C$ in extreme southeastern Moose basin. Summers are generally cool with temperatures of about $13^{\circ}C$ at the coast and $18^{\circ}C$ inland to the southeast (Hutton and Black, 1975). Annual precipitation decreases northwestward from 800 mm near the Quebec border to about 500 mm at the Manitoba border (Woo and Waylen, 1983).

Snowfall is most important between November and April, and snowmelt usually begins towards the end of April (Hutton and Black, 1975).

2:2 DATA SOURCES

Streamflow records were obtained from the Historical Streamflow Summary (Water Survey of Canada) for ten rivers which drain into James and Hudson Bays. These rivers provide a southeast-northwest "transect". Rivers with natural flow and drainage areas ranging from 2020-7950 km^2 were selected so that flow responses would better reflect the local environmental control. These stations provide records ranging from nine to twenty-nine years in length (table 2:1).

Initially, data from fifteen meteorological stations were obtained from the Monthly Record of Meteorological Observations in Canada, Atmospheric Environment Services. Weather stations located as close as possible to the streamflow gauging stations were selected to increase the representativeness of the data with respect to the watershed. Five stations were found to be unusable because many years with incomplete data were encountered.

Figure 2:1 shows a map of the study area including the positions of gauging and meteorological stations from which data were obtained. Table 2:1 lists the corresponding gauging stations, with respective drainage area and length of record, and meteorological stations.

Table 2:1 A list of streamflow gauging stations and meteorological stations in the study area; and basin area and length of record for gauging stations.

NUMBER SHOWN IN FIGURE 2:1	RIVER	BASIN AREA (km)	LENGTH OF RECORD (years)
1	Kabinakagami	3780	29
2	Shekak	3290	29
3	Nagagami	2410	29
4	Pagwachuan	2020	11
5	Little Current	5360	10
6	Pineimuta	4900	12
7	Pipestone	5960	12
8	Fawn	4350	10
9	Ashweig	7950	12
10	Severn	4010	9

SYMBOL SHOWN IN FIGURE 2:1	METEOROLOGICAL STATION
A	Moosonee
B	Kapuskasing
C	Hornepayne
D	Geraldton
E	Armstrong
F	Ears Falls
G	Red Lake
H	Lansdown House
I	Trout Lake
J	Island Lake (Manitoba)

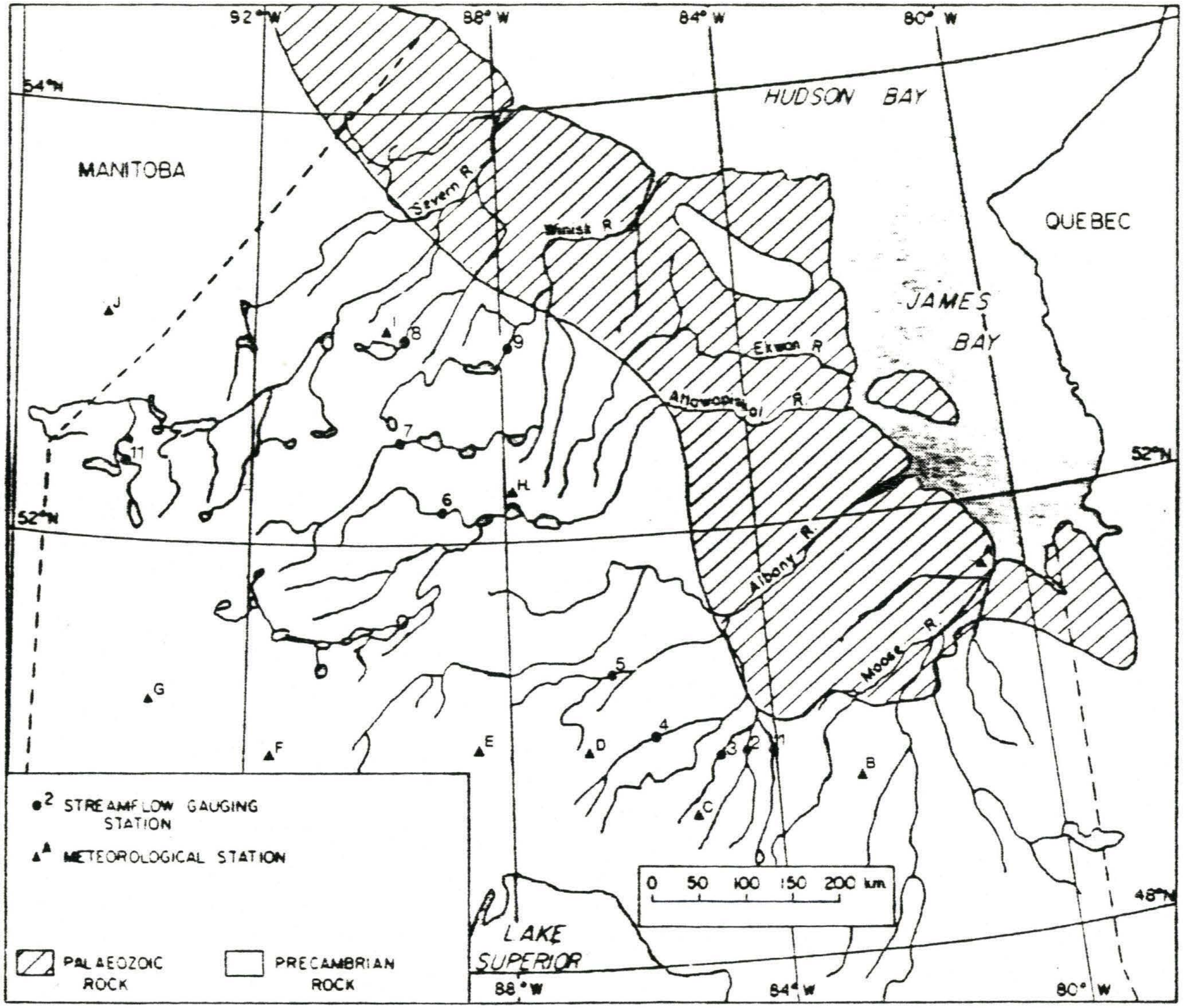

Figure 2.1 Major rivers in the study area, northern Ontario, Canada. Also shown are streamflow gauging stations and meteorological stations which provide data for this study.

CHAPTER III

METHODS

To provide a standardized measure of runoff from different watersheds and to enable direct comparison with precipitation received by the catchments, streamflow data were converted from cubic meters per second to millimeters per area. Precipitation records from before 1977 had to be changed from inches to millimeters to be compatible with other data. Air temperature was also standardized in degrees Centigrade.

To quantify the runoff of the ten rivers included in this study, mean monthly streamflows and the ninety-percent confidence intervals around the means were calculated. Mean values of runoff, precipitation and temperature were calculated:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (3:1)$$

where $\bar{x}$ is the mean value for the variable x and n data were used to obtain the mean.

The confidence interval was obtained as:

$$C.I. = \overline{x} - t_{n-1,\alpha/2}\frac{S}{\sqrt{n}} < \overline{x} < \overline{x} + t_{n-1,\alpha/2}\frac{S}{\sqrt{n}} \quad (3:2)$$

where C.I. is the confidence interval at the $1-\alpha$ confidence level (C.L.), n is the sample size, S is the standard deviation of the sample, $\overline{x}$ is the sample mean, and $t_{n-1},\alpha/2$ is the "t-disribution" value with n-1 degrees of freedom, and significance level α.

The period of record over which the means are calculated will affect the reliability and representativeness of the value (Haan, 1977). Binnie (1892, reprinted in Gregory and Walling, 1978) showed that as many as thirty years of data may be required to derive a mean value to within an accuracy of ±2 percent. Unfortunately, most stations in northern Ontario do not have such long records.

To determine the reliability of the mean values from the records of various durations, two meteorological stations with long records were chosen on the basis of location. Kapuskasing and Trout Lake were examined because they provided over twenty-five years of data, and because they are located at the opposite ends of the southeast-northwest transect. Analyses of these stations may bracket the conditions for the whole region.

Initially, the three year mean monthly temperatures with ninety-percent confidence intervals for the two weather stations were calculated. Then two more years of data were added and a new set of means and confidence intervals were calculated. This procedure was repeated until the entire length of record was exhausted. The analysis produced a trend in which the confidence intervals decrease and the means stabilize as the data size increases. This trend was used to determine the number of years of data required to obtain reliable means. Similarly, precipitation data for Kapuskasing was analysed.

Twenty-nine years of runoff record for Kabinakagami River was analysed using the same approach. This river is located at the southeastern part of the region. Unfortunately, similar analysis could not be applied to any river in the northwest because they all have short records.

When a criterion for determining the minimum requirement for n in equation 3.1 was established, the longterm mean monthly runoff and the corresponding confidence intervals for ten stations were computed. These mean values were used to produce regime diagrams. The regime diagrams are graphical plots of mean monthly runoff over the hydrologic year which begins with the spring freshet.

Spatial variation of regime is analysed in two ways. Firstly, regime diagrams for various rivers are compared qualitatively. Secondly, cumulative seasonal contribution to total annual runoff for eight rivers along the southeast-northwest transect are calculated, starting from April. Seasons are defined according to the monthly variation in the hydrographs. Winter is the low flow season, separated from the spring which arrives as the hydrograph shows a sharp rise. Spring is the high flow season due to snowmelt. It continues until the hydrograph exhibits a sharp decrease. Summer is the period of low flow which continues until the secondary rise in the hydrograph occurs. Fall is the months of October and November during which the secondary peak in the hydrograph diminishes.

For all the rivers selected, runoff of each season was regressed against precipitation and temperature using as many years of data as was available. The regression equations were derived as:

$$\hat{y}_i = b_0 + b_1 x_{1i} + b_2 x_{2i} \qquad (3:3)$$

where $\hat{y}$ an estimate of the mean monthly flow within the season, b's are regression coefficients, x_{1i} is the corresponding mean monthly precipitation, and x_{2i} is the corresponding mean monthly temperature.

To test the regression coefficients for significance, "t-ratios" were calculated and compared with tabulated critical values of "t". The "t-ratios were calculated as:

$$t^* = \frac{t^* b_i}{\sqrt{S.D.}} \qquad (3:4)$$

where $t^* b_i$ is the "t-ratio" for b_i, b_i is the value of regression coefficient, and S.D. is the standard deviation of coefficient.

To indicate the strength of the regression relationship, the coefficient of multiple correlation was calculated:

$$R^2 = 1 - \frac{SS(ERR)}{SS(TOT)} \qquad (3:5)$$

where R^2 is the coefficient of determination, SS(TOT) is the original variation in the dependent variable, and SS(ERR) is the error variation after the best fit equation has been obtained.

To test if the regression equation is significant and usable for prediction purposes, "F-statistics" were calculated and compared with tabulated critical values for "F". The "F-statistics" were calculated as:

$$F = \frac{SS(REG)/df_1}{SS(RES)/df_2} \qquad (3:6)$$

where "F" is the calculated "F-statistic",
SS(REG) is the variance due to the regression,
df_1 is the degrees of freedom of regression,
SS(RES) is the variance due to the residual, and
df_2 is the degrees of freedom of the residual

Results of this analysis will indicate the degree to which the climatic variables affect the magnitude of runoff within a given season. The relation of runoff with climate variables is also investigated graphically by comparing the plots of mean monthly discharge, precipitation, and temperature against time.

In carrying out all the above analyses, the computer package MINITAB was used.

CHAPTER IV
DATA ANALYSIS AND RESULTS

4:1 DATA RELIABILITY

The period of observation necessary to obtain representative mean monthly values for precipitation, temperature, and streamflow was determined by plotting monthly means, with ninety-percent confidence intervals, against the length of observation. Means and their decreasing confidence intervals tend to stabilize at about fifteen years of record. This is indicated in the analyses of the region to the southeast with Kapuskasing temperature data, and to the northwest using Trout Lake temperature records (figures 4:1 and 4:3). Analyses of Kapuskasing precipitation records, and streamflow data for the Kabinakagami river produce the same trends (figures 4:2 and 4:4).

The paucity of streamflow data in the study area necessitates the inclusion of six rivers even though they yielded only nine to twelve years of streamflow data. This is less than the minimum period of observation needed for truly representative means. However, the runoff records are approaching a level of stability and are considered to be useful in this study.

4:2 RIVER REGIMES AND SPATIAL VARIATION

The regimes of ten northern Ontario rivers are quantified and represented diagramatically in figures 4:5–4:7. Qualitative comparisons of the regimes enable the cognition of general characteristics. All rivers exhibit runoff peaks in spring due to snowmelt, and a secondary peak in fall due to rainfall.

The regimes can be classified into four types (figure 4:8 and table 4:1). Type I regimes show a marked spring peak, low summer flow, a distinct fall peak, and low winter flow. This regime type is typical of the southeast where there is much precipitation. Large snow accumulation over the winter months produces considerable spring melt events with peak flows occuring during May. Late summer rainfall results in fall runoff peaks.

Type II regimes are similar to Type I regimes, exhibiting snowmelt peaks in May, and rainfall induced peaks in the fall. The major difference is that the summer low flow is "buffered" to such an extent by lake storage so that the fall runoff peaks are not as pronounced. This regime type is characteristic of the northwest where there are many small lakes. The magnitude of runoff in the northwest is relatively less than in the southeast due to lower annual precipitation.

Type III regimes are modified forms of Type II regimes. The major difference between them is that the spring melt peak occurs in June rather than in May. There is no apparent spatial trend related to the positioning of the basins along the northwest portion of the transect. Further study is required to explain this difference.

Type IV regimes exhibit reduced peak flow due to large lake storage effects. The annual peak is delayed till July. This regime classification is based on the Fawn river regime (figure 4:7b). Fawn River is gauged immediately below the outlet of Big Trout Lake. The large water storage capacity of the lake diminishes the influences of snowmelt and rainfall events upon the flow regimes.

Cumulative seasonal contribution to total annual runoff has been examined on a spatial basis (figure 4:9). The Ashweig, Severn, and Fawn Rivers are not included in the examination. The Ashweig and Severn Rivers are too far removed from the transect, and the Fawn River regime is not responsive to seasonal changes due to lake storage effects. The hydrologic year is divided into four seasons. Spring is from April through June, summer is from July through September, fall is the months of October and November, and winter is between December and March. Data from the Kettle River (Manitoba) has been included to extend the transect of rivers past the Ontario border. This will help in the establishment of spatial trends within the region.

Rivers to the southeast of, and including, the Pagwachuan exhibit seasonal flow characteristics different from those to the northwest. Rivers to the southeast have more than fifty-percent of their total annual runoff occuring during the spring season. Summer contribution amounts to about twenty-percent. In contrast, the rivers to the northwest have only about forty-percent of their total annual flow discharged in spring, but summer contribution is about thirty-percent.

Fall contribution to total annual runoff tends to increase from the southeast towards the northwest of the region. Conversely, winter contribution to annual yield tends to decrease towards the northwest, reflecting the colder winter conditions of northern Ontario.

4:3 METEOROLOGICAL EFFECTS ON SEASONAL RUNOFF

Figure 4:10 illustrates the change in monthly runoff corresponding to change in monthly precipitation and temperature for the Nagagami river. As the spring temperatures rise above $0^{\circ}C$, snowmelt begins. Low flow occurs in the summer when the snow is melted. Temperatures are high and rainfall moderate so that runoff is minimized by evaporation and evapotranspiration processes. The increase in precipitation at the end of the summer causes a rise in streamflow. With the onset of winter, runoff decreases to a minimum and the snowfall accumulates as storage to be released in the following spring.

Regression analysis of seasonal runoff against precipitation and temperature has been done to investigate the meteorological effects on streamflow. Analyses for the Kabinakagami, Shekak, and Nagagami rivers have produced reasonable results. Table 4:2 lists the regression statistics for these rivers. Analyses of the other rivers proved to be unsuccessful. Meteorological stations are too sparsely distributed to provide representive data for these basins. Appendix I contains the analytical results for these watersheds.

Results of the analyses show that during spring, the regression coefficient for temperature and regression constant are statistically significant, while the coefficient for precipitation is not. This finding indicates that temperature has a pronounced affect on runoff. This is reasonable as rising spring temperatures cause snowmelt to occur. Baseflow is also found to contribute to streamflow.

During the summer period, the coefficients for both precipitation and temperature are found to be statistically significant, while the regression constant is not. This indicates that baseflow is no longer a significant factor in basin runoff. It appears that both precipitation and temperature significantly affect summer streamflow.

Fall runoff response is significantly affected by rainfall, but not by temperature. This is indicated by the significance of the precipitation coefficient. It appears, because the regression constant is significant, that baseflow again becomes a contributing factor to basin runoff.

Baseflow dominates during the winter and neither precipitation nor temperature are significant variables affecting streamflow. Temperatures are below freezing and the only precipitation is snow. Winter runoff, as indicated by the regression statistics, is the result of baseflow only.

An attempt was made to produce predictive equations for seasonal monthly flow. Insignificant variables in the spring and fall regressions were removed, and discharge was regressed against the significant variable only. Summer regression equations were considered as they were, with both variables in the equations already being significant. Winter equations were not considered, as neither variable was found to be significant during this season.

The predictive equations are of poor quality (table 4:3 lists the regression statistics). The low R^2 values indicate a very weak relationship between the dependent and independent variables. The "F-statistic" shows, except for the Kabinakagami river in fall and the Shekak river in spring, that the equations are significant; however, the low

"F-values" indicate that the predicted flow produced by these equations is not much better than the sample mean. The "F-values" for the Kabanakagami and Shekak rivers, in fall and spring repectively, show that these equations are insignificant; i.e., the predicted values obtained from these equations are no better than the sample means itself.

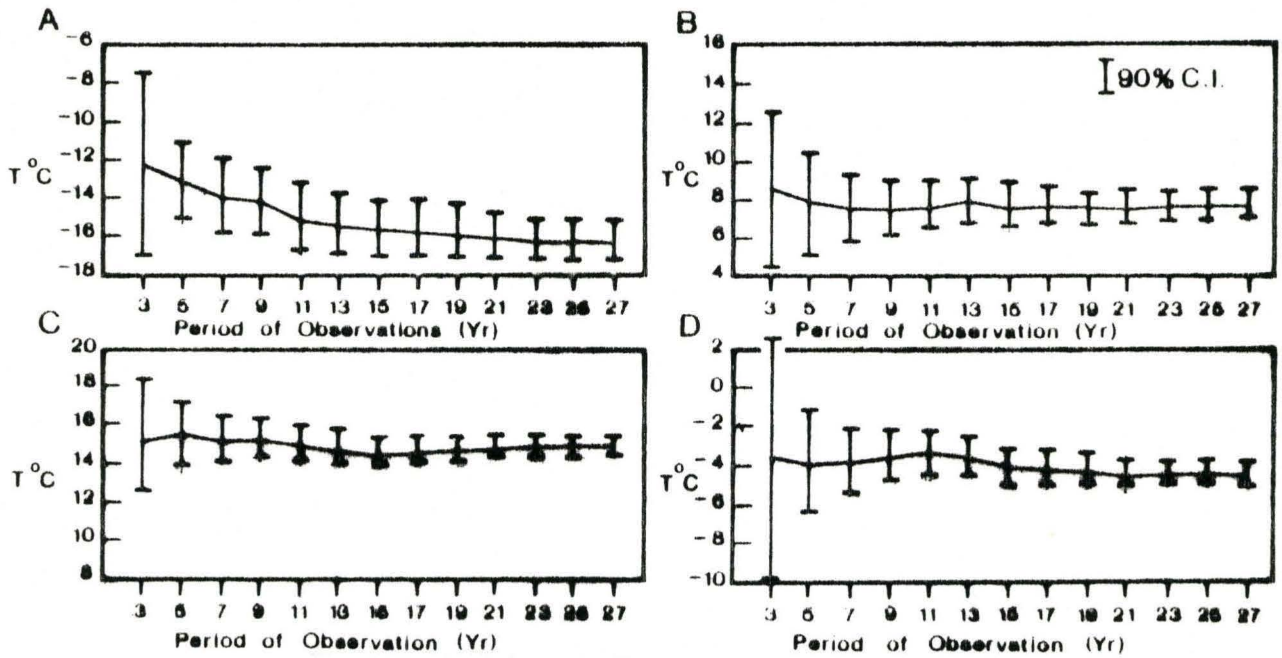

Figure 4:1 Changing values of means and confidence intervals as length of record increases. Temperature data for Kapuskasing for (a) February (b) May (c) August and (d) November.

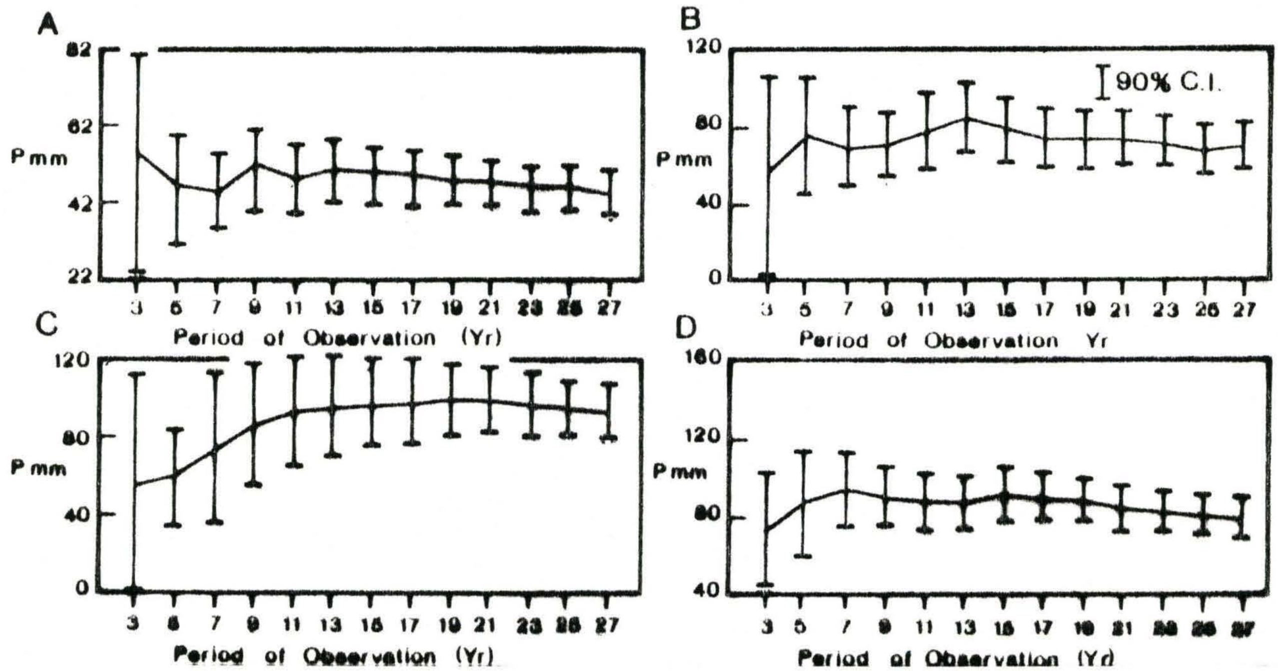

Figure 4:2 Changing values of means and confidence intervals as length of record increases. Precipitation data for Kapuskasing for (a) February (b) May (c) August and (d) November.

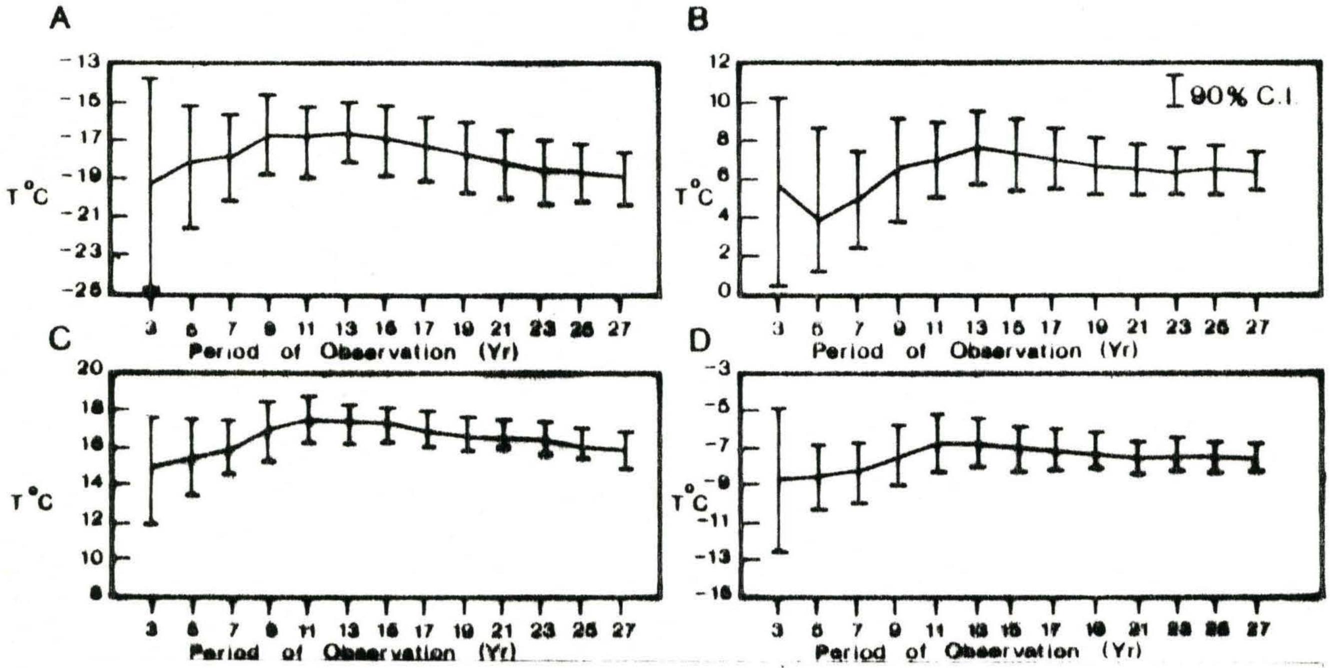

Figure 4:3 Changing values of means and confidence intervals as length of record increases. Temperature data for Trout Lake for (a) February (b) May (c) August and (d) November.

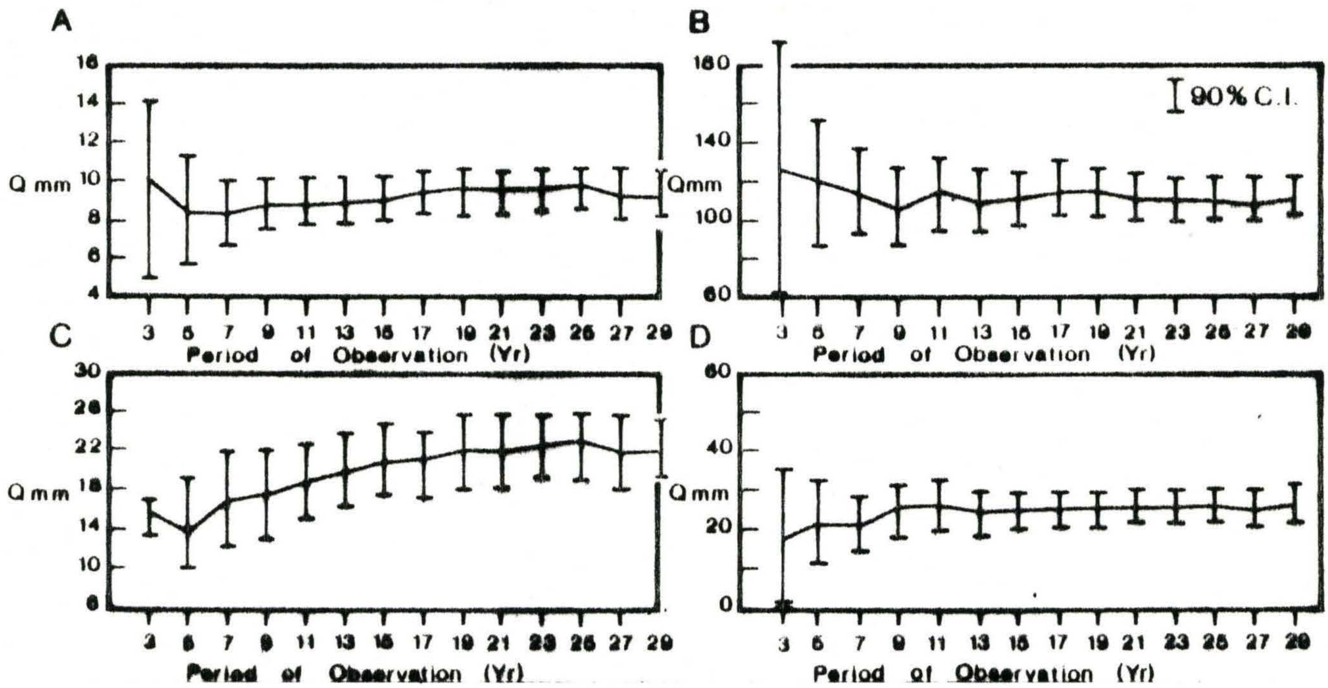

Figure 4:4 Changing values of means and confidence intervals as length of record increases. Runoff data for the Kabinakagami river for (a) February (b) May (c) August and (d) November.

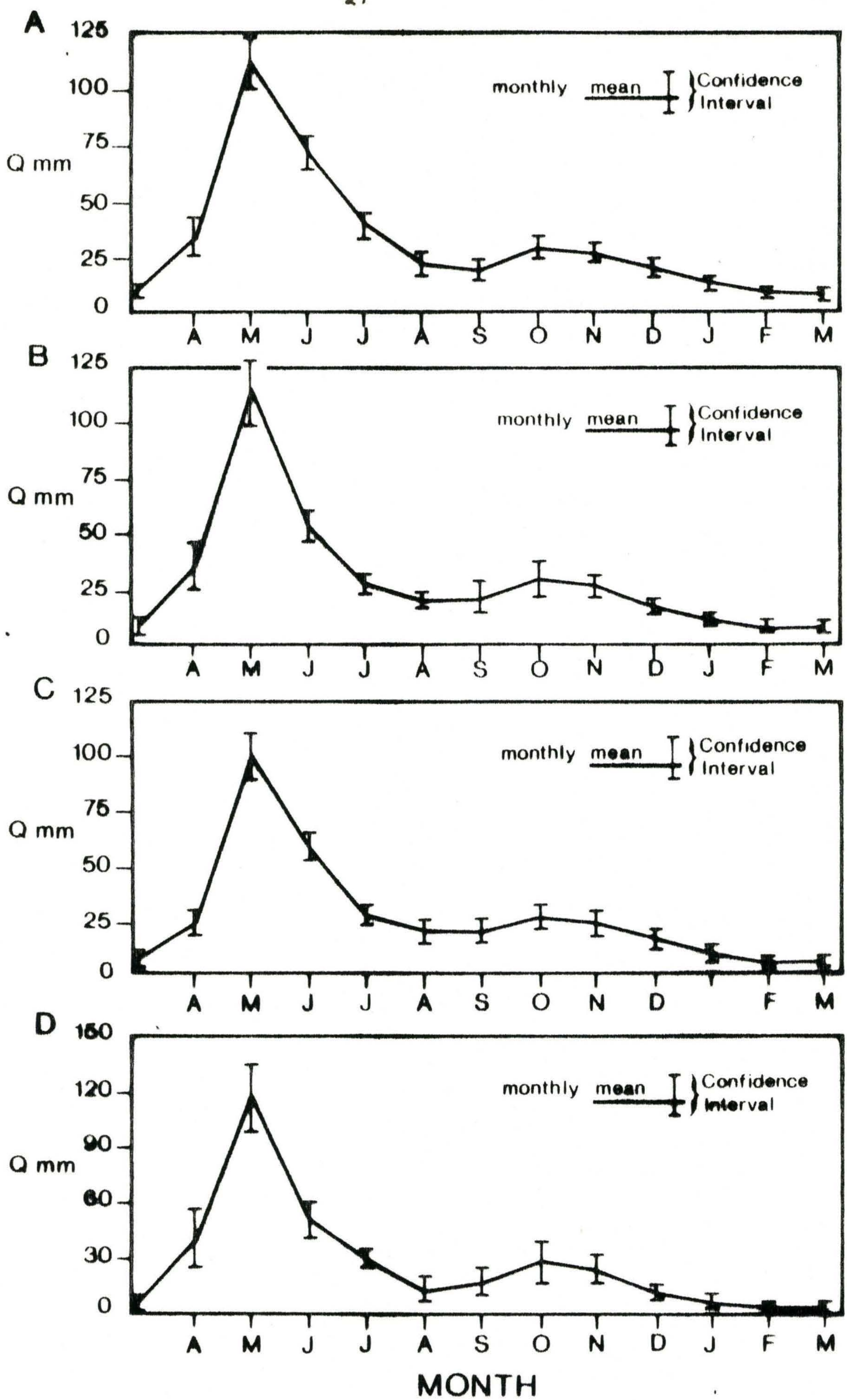

Figure 4:5 Streamflow regime for the (a) Kabinakagami (b) Shekak (c) Nagagami and (d) Pagwachuan rivers.

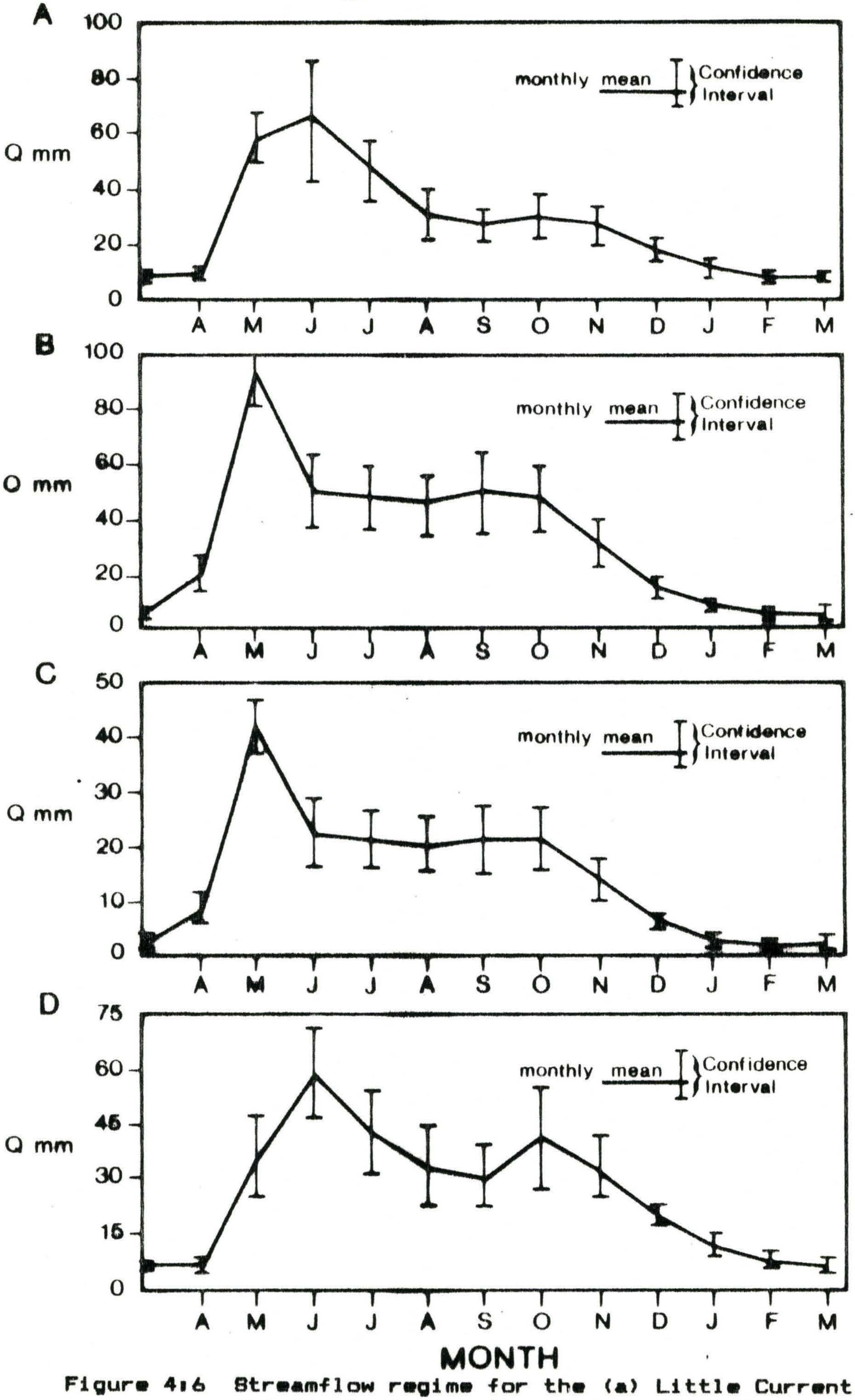

Figure 4:6 Streamflow regime for the (a) Little Current (b) Pineimuta (c) Pipestone and (d) Ashweig rivers.

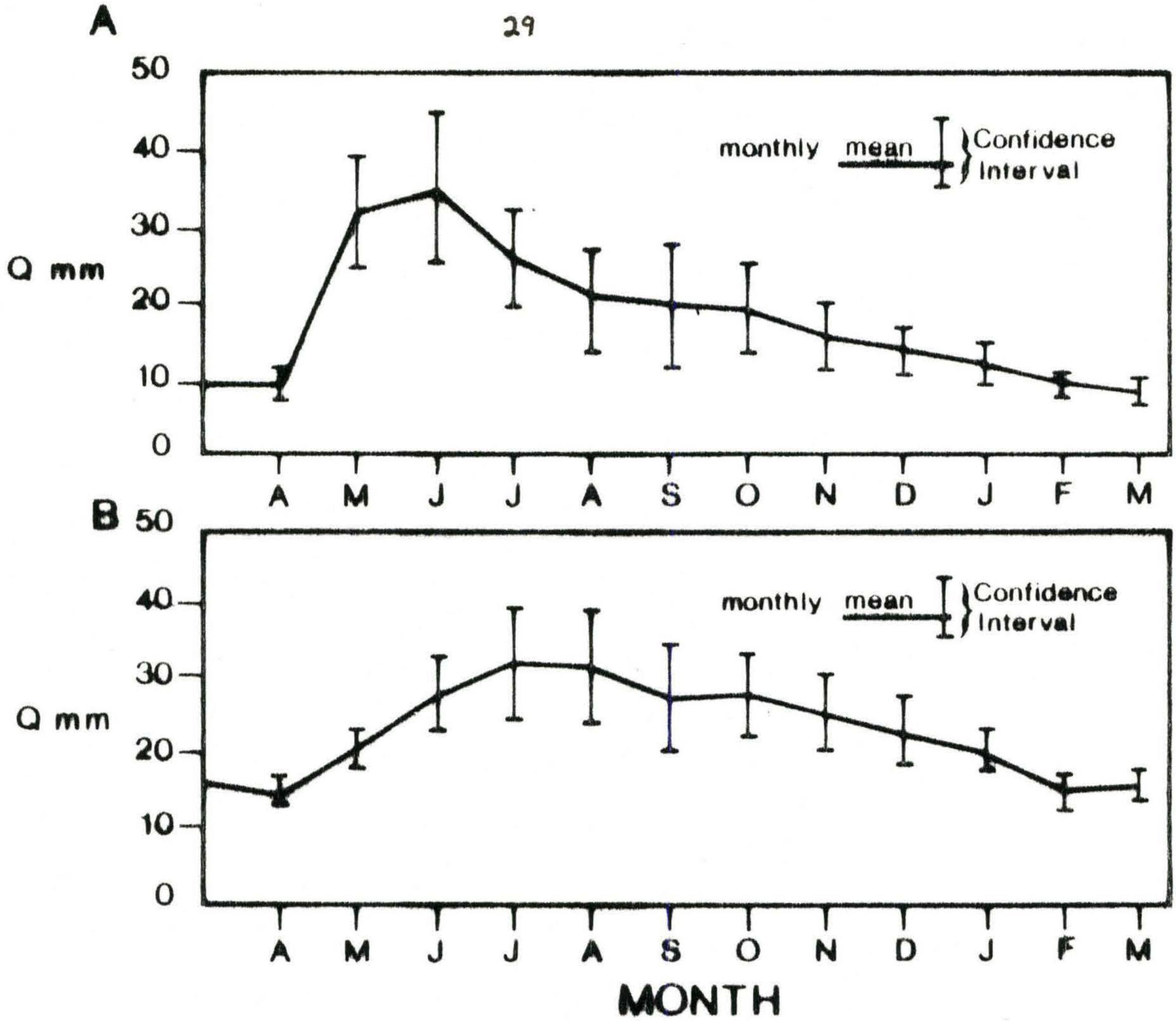

Figure 4:7 Streamflow regime for the (a) Severn and (b) Fawn rivers.

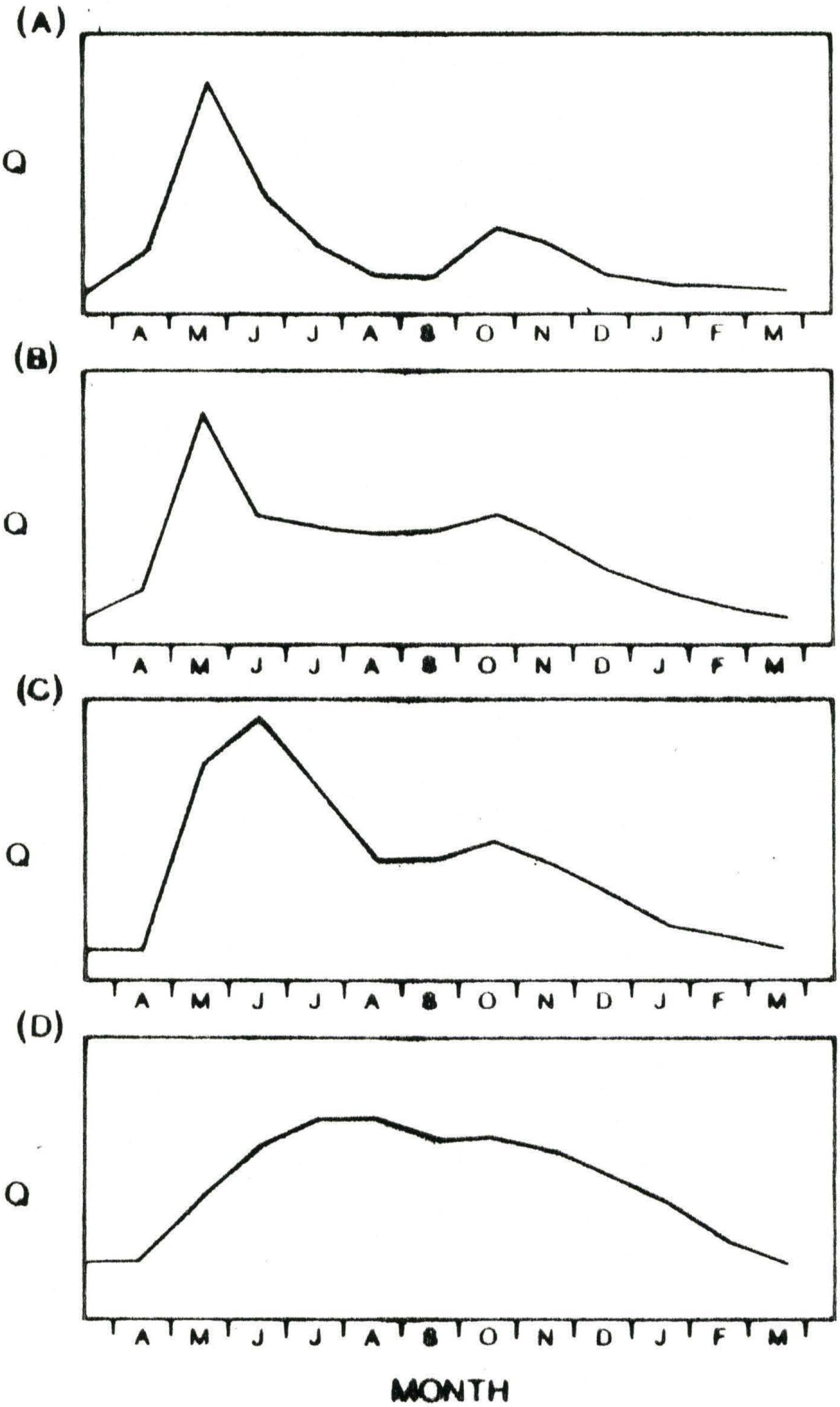

Figure 4:8 Characteristic northern Ontario regime types; (a) TYPE I (b) TYPE II (c) TYPE III and (d) TYPE IV.

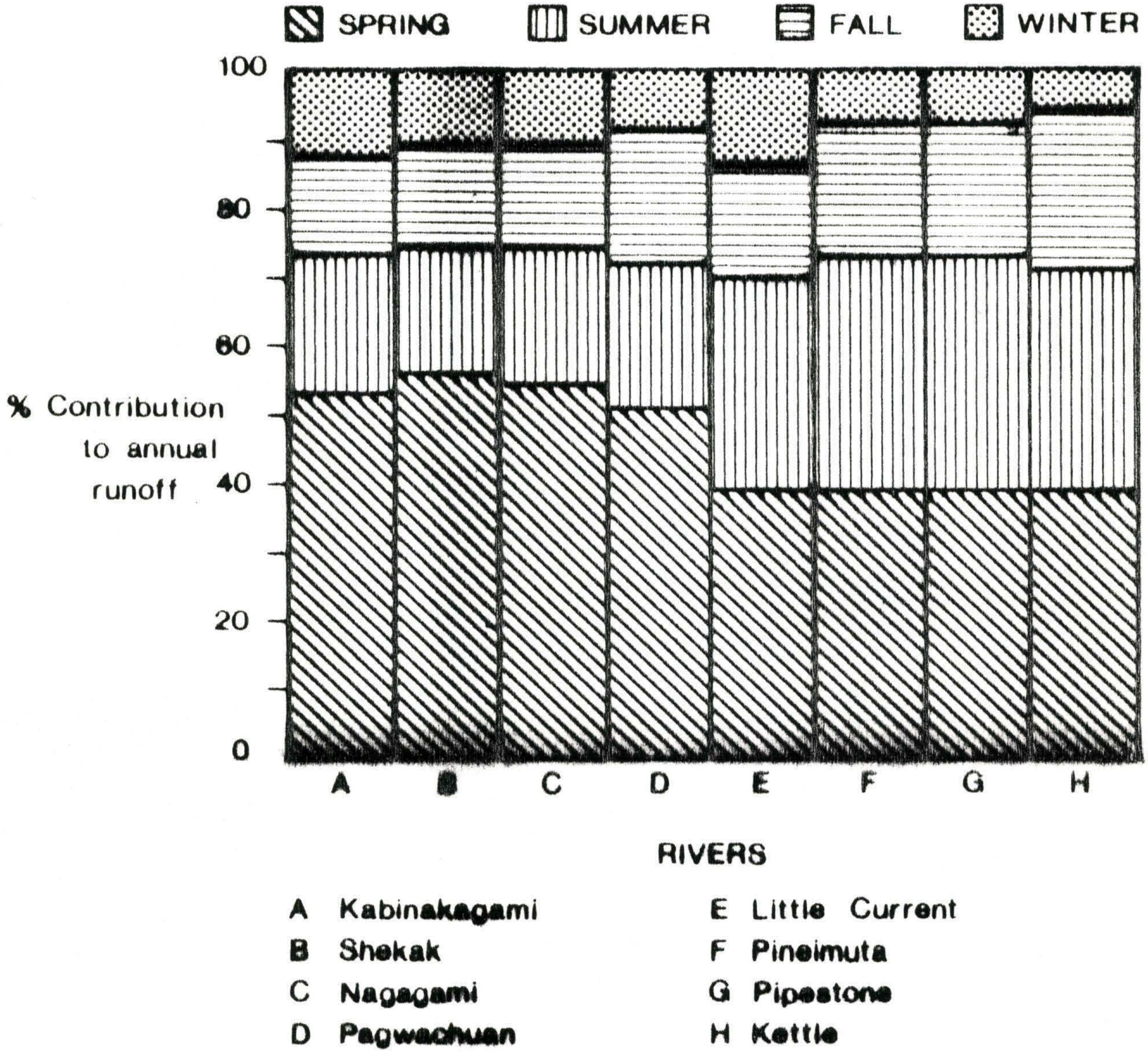

Figure 4:9 Cumulative seasonal contribution to the annual runoff of selected areas.

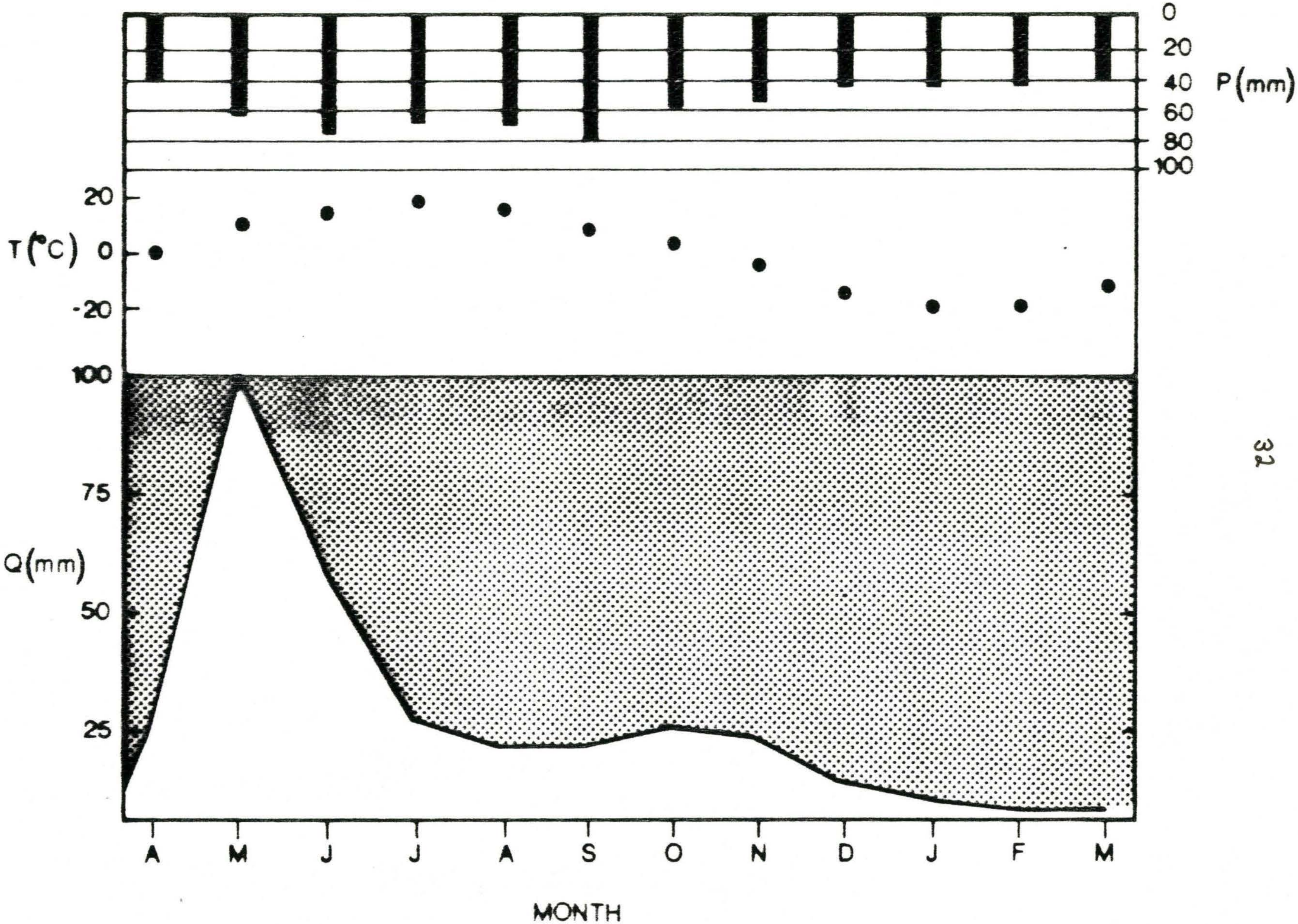

Figure 4:10 Nagagami river runoff compared with Hornepayne meteorological data.

RIVER CLASSIFICATION	
RIVER	TYPE
Kabinakagami	TYPE I
Shekak	TYPE I
Nagagami	TYPE I
Pagwachuan	TYPE I
Little Current	TYPE III
Pineimuta	TYPE II
Pipestone	TYPE II
Ashweig	TYPE III
Severn	TYPE III
Fawn	TYPE IV

Table 4:1 Classification of selected northern Ontario rivers into characteristic type.

Table 4:2 Regression coefficients and statistics for runoff of selected rivers against precipitation and temperature.

RIVER	METEOROLOGICAL STATION	SEASON	b_0	b_1	b_2	$t^* b_0$	$t^* b_1$	$t^* b_2$	df	R^2 (%)	F	
Kabinakagami	Kapuskasing	Spring	38.4	.177	2.87	3.40	1.19	3.39	57	23.5	8.77	**
Kabinakagami	Kapuskasing	Summer	-7.8	.152	1.53	-1.1	3.70	3.14	57	33.0	14.0	**
Kabinakagami	Kapusaksing	Fall	17.8	.152	.33	2.73	1.91	.63	37	9.5	1.94	
Kabinakagami	Kapuskasing	Winter	10.3	.046	-.01	3.01	1.46	-.06	77	2.7	1.09	
Shekak	Hornepayne	Spring	50.0	.081	1.55	4.14	.47	1.60	57	6.3	1.91	
Shekak	Hornepayne	Summer	-3.8	.184	.822	-.57	5.00	2.06	57	31.5	13.1	**
Shekak	Hornepayne	Fall	17.5	.156	.196	3.57	2.18	.40	37	11.4	2.83	
Shekak	Hornepayne	Winter	8.76	.034	.023	4.56	1.79	.20	77	4.0	1.61	
Nagagami	Hornepayne	Spring	39.2	.027	2.59	4.10	.20	3.38	57	19.4	6.88	**
Nagagami	Hornepayne	Summer	-1.6	.120	1.05	-.27	3.65	2.95	57	24.6	9.30	**
Nagagami	Hornepayne	Fall	14.0	.178	.160	3.04	2.66	.35	37	16.0	3.53	*
Nagagami	Hornepayne	Winter	8.30	.034	.049	3.83	1.57	.39	77	3.2	1.28	

** significant at 99 %
* significant at 95 %

Table 4:3 Regression coefficients and statistics of prediction equations for seasonal monthly flow of selected rivers.

RIVER	METEOROLOGICAL STATION	SEASON	b_0	b_1	b_2	$t^* b_0$	$t^* b_1$	$t^* b_2$	df	R^2 (%)	F
Kabinakagami	Kapuskasing	Spring	48.3	3.20	——	6.33	4.00	——	58	21.6	16.0 **
Kabinakagami	Kapuskasing	Summer	-7.8	.152	1.53	-1.1	3.70	3.14	57	33.0	14.0 **
Kabinakagami	Kapuskasing	Fall	18.1	.147	——	2.81	1.88	——	38	8.5	3.53
Shekak	Hornepayne	Spring	54.0	1.68	——	6.31	1.88	——	58	5.7	3.51
Shekak	Hornepayne	Summer	-3.8	.184	.822	-.57	5.00	2.06	57	31.5	13.1 **
Shekak	Hornepayne	Fall	16.1	.144	——	2.86	2.11	——	38	10.4	4.4 *
Nagagami	Hornepayne	Spring	40.5	2.65	——	6.06	3.73	——	58	19.4	13.9 **
Nagagami	Hornepayne	Summer	-1.6	.120	1.08	-.27	3.65	2.95	57	24.6	9.3 **
Nagagami	Hornepayne	Fall	14.2	.176	——	3.14	2.66	——	38	15.7	7.1 *

** significant at 99 %
* significant at 95 %

CHAPTER V

CONCLUSION

It is found that the period of observation necessary to obtain representative mean monthly values for precipitation, temperature and streamflow is about fifteen years. Many meteorological and streamflow stations within the region lack complete records of such length. This paucity of data makes hydrological and meteorological investigations difficult.

River regimes of northern Ontario possess several general characteristics. More specifically, all rivers exhibit peak runoff in spring due to snowmelt, and a secondary peak in the fall due to rainfall. Four types of regimes can be recognized based on qualitative comparisons of their flow response patterns. There is a spatial variation in the flow regimes. Rivers to the southeast exhibit more pronounced spring melt peaks due to greater winter snow accumulation. Flow magnitude is also greater as a result of increased annual precipitation. Rivers to the northwest tend to have their summer low flow buffered by the effects of the many small lakes which occur there. Fall contribution to annual runoff tends to increase from the southeast to the northwest. The colder winter conditions of northwestern Ontario leads to a lower winter contribution to total annual flow.

Seasonal runoff is affected by meteorological conditions. Temperature is related to snowmelt and therefore has a pronounced effect on the spring freshet. Both precipitation and temperature have marked effects on runoff during the summer. Fall streamflow tends to increase in response to increased precipitation. The low winter temperatures cause the precipitation to fall mainly as snow. As a result, winter runoff is dominated by baseflow.

An attempt to produce equations to predict seasonal monthly streamflow was unsuccessful. Meteorological stations are too sparsely located to provide representative data for the watersheds. There is a great necessity to increase the meteorological and streamflow station network in northern Ontario. Proposed hydroelectrical development of northern Ontario rivers may have significant effects on the environment, economy, and social nature of the region. Without a broader data base and increased research, it will be difficult to assess the impact that proposed development will have on the area.

REFERENCES

Atmospheric Environment Service, 1952-79, MONTHLY RECORD OF METEOROLOGICAL OBSERVATIONS IN CANADA. Environment Canada.

Beckinsale, R.P., 1969, RIVER REGIMES. from Physical Hydrology, edited by R.J. Chorley, Methuen and Co. Ltd., London.

Brown, R.J.E., 1968, PERMAFROST INVESTIGATIONS IN NORTHERN CANADA. N.R.C. of C., Ottawa, Technical Paper No.291 of the Div. of Building Research.

Gray, D.M., 1970, PRICIPLES OF HYDROLOGY. National Research Council of Canada.

Gregory, K.J., and Walling, D.E., 1968, THE VARIATION OF DRAINAGE DENSITY WITHIN A CATCHMENT. Bulletin Int. Assoc. Sci. Hydrology, 13, 61-68.

Gregory, K.J., and Walling, D.E., 1973, DRAINAGE BASIN FORM AND PROCESS. Edward Arnold Pub. Ltd., London, 458p.

Haan, C.T., 1977, STATISTICAL METHODS IN HYDROLOGY. The Iowa State Press, Ames, Iowa, 378p.

Hely, A.G., and Olmstead, F.H., 1962, SOME RELATIONS BETWEEN STREAMFLOW CHARACTERISTICS AND THE ENVIRONMENT IN THE DELAWARE RIVER REGION. U.S. Geological Survey Professional Paper, 417-A.

Hutton, C.L.A., and Black, W.A., 1975, ONTARIO ARCTIC WATERSHED. Information Canada, Ottawa, 107p

Lull, H.W., and Sopper, W.E., 1966, FACTORS THAT INFLUENCE STREAMFLOW IN THE NORTHEAST. Water Resources Research, Vol.2, No.3., 371-379.

Mustonen, S.E., 1967, EFFECTS OF CLIMATOLOGIC AND BASIN CHARACTERISTICS ON ANNUAL RUNOFF. Water Resources Research, Vol.3, No.1, 123-130.

O.W.R.C., 1975, GENERAL CHARACTERISTICS OF STREAMFLOWS. Water Resources Report 11a, Ministry of the Environment, Water Resources Branch, Government of Ontario.

Riggs, H.C., 1973, REGIONAL ANALYSIS OF STREAMFLOW CHARACTERISTICS. Techniques of Water-Resources Investigations of the United States Geological Survey, Book 4, Chapter B3.

Rouse, W.R., and Bello, R.L., THE ADVECTIVE INFLUENCE OF HUDSON AND JAMES BAYS ON CLIMATE IN THE HUDSON BAY LOWLANDS. TASO Report No.3, McMaster University, Hamilton.

Sopper, W.E., and Lull, H.W., 1965, STREAMFLOW CHARACTERISTICS OF PHYSIOGRAPHIC UNITS IN THE NORTHEAST. Water Resources Research, Vol.1, No.1, 115-124.

Water Survey of Canada, 1979, HISTORICAL STREAMFLOW SUMMARY. Inlands Waters Directorate, Water Resources Branch, Water Survey of Canada.

Weyman, D.R., 1975, RUNOFF PROCESSES AND STREAMFLOW MODELLING. Oxford University Press.

Woo, M.K., and Waylen, P.R., PREDICTION OF ANNUAL FLOODS IN NORTHERN ONTARIO BASINS. TASO Report No.2, McMaster University, Hamilton.

Woodruft, J.F., and Hewlett, J.D., 1970, PREDICTING AND MAPPING THE AVERAGE HYDROLOGIC RESPONSE FOR EASTERN UNITED STATES. Water Resources Research, Vol.6, No.5, 1312-1326.

APPENDIX I

Regression coefficients and statistics for runoff of selected rivers against precipitation and temperature.

RIVER	METEOROLOGICAL STATION	SEASON	b_0	b_1	b_2	$t^* b_0$	$t^* b_1$	$t^* b_2$	df	R^2 (%)	F
Ashweig	Trout Lake	Spring	19.0	.024	.790	3.82	.23	1.78	33	6.5	2.21
Ashweig	Trout Lake	Summer	24.0	.022	-.40	3.53	.45	-.9	33	2.7	.45
Ashweig	Trout Lake	Fall	18.4	.016	.527	3.72	.20	1.40	21	2.3	1.27
Ashweig	Trout Lake	Winter	.565	.048	-.08	.38	2.02	-1.3	45	7.2	2.82
Pipestone	Trout Lake	Spring	17.2	.035	.736	3.39	.45	1.68	33	6.7	2.26
Pipestone	Trout Lake	Summer	23.7	.028	-.44	3.34	.78	-.94	33	3.7	.63
Pipestone	Trout Lake	Fall	13.5	.077	.385	3.22	1.37	1.07	21	7.8	1.98
Pipestone	Trout Lake	Winter	1.81	.021	-.06	1.36	1.08	-.93	45	.1	.99
Pineimuta	Lansdown House	Spring	38.2	.087	1.67	3.41	.50	1.72	33	12.9	2.44
Pineimuta	Lansdown House	Summer	55.8	.061	-1.2	3.50	.76	-1.1	33	4.5	.78
Pineimuta	Lansdown House	Fall	30.3	.171	.764	3.23	1.36	.94	21	14.6	1.79
Pineimuta	Lansdown House	Winter	4.10	.044	-.13	1.40	1.03	-.99	45	.1	1.03

** significant at 99 %
* significant at 95 %

Regression coefficients and statistics for runoff of selected rivers against precipitation and temperature.

RIVER	METEOROLOGICAL STATION	SEASON	b_0	b_1	b_2	$t^* b_0$	$t^* b_1$	$t^* b_2$	df	R^2 (%)	F
Severn	Trout Lake	Spring	13.1	.089	1.23	2.85	1.15	2.95	24	30.6	6.74 *
Severn	Trout Lake	Summer	10.8	.117	.126	1.31	1.83	.23	24	6.6	1.93
Severn	Trout Lake	Fall	23.6	-.10	.592	5.25	-1.3	1.64	15	7.7	1.71
Severn	Trout Lake	Winter	7.26	.004	-.20	2.22	.07	-1.6	33	1.8	1.32
Pagwachuan	Geraldton	Spring	50.1	.170	.866	3.11	.70	.54	30	5.3	.84
Pagwachuan	Geraldton	Summer	-1.4	.108	.878	-.12	1.46	1.28	30	10.7	1.80
Pagwachuan	Geraldton	Fall	2.95	.415	.814	.32	2.97	1.28	19	28.4	5.93 *
Pagwachuan	Geraldton	Winter	7.62	.003	.065	2.71	.10	.48	41	.7	0.14
Little Current	Geraldton	Spring	22.3	-.04	3.66	2.40	-.35	3.87	27	32.0	9.96 **
Little Current	Geraldton	Summer	5.52	-.01	2.23	.44	-.13	2.99	27	19.4	4.5
Little Current	Geraldton	Fall	13.9	.243	.542	2.10	2.41	1.12	17	22.9	3.83 *
Little Current	Geraldton	Winter	10.7	.006	-.04	2.92	.15	-.21	37	.1	.03

** significant at 99 %
* significant at 95 %