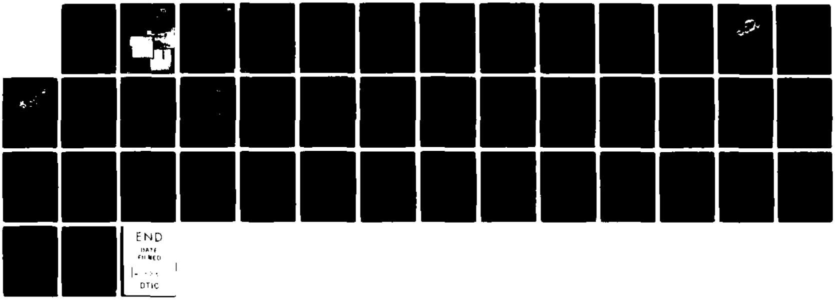
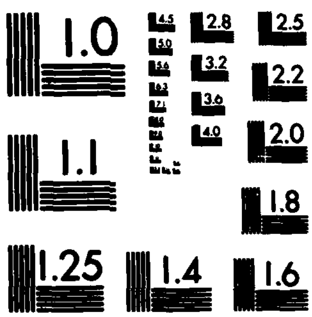
AD-A122 402 HYDROLOGY AND CLIMATOLOGY OF THE CARIBOU-POKER CREEKS RESEARCH WATERSHED ALASKA(U) COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH R K HAUGEN ET AL. OCT 82 1/1

UNCLASSIFIED CRREL-82-26 F/G 8/8 NL



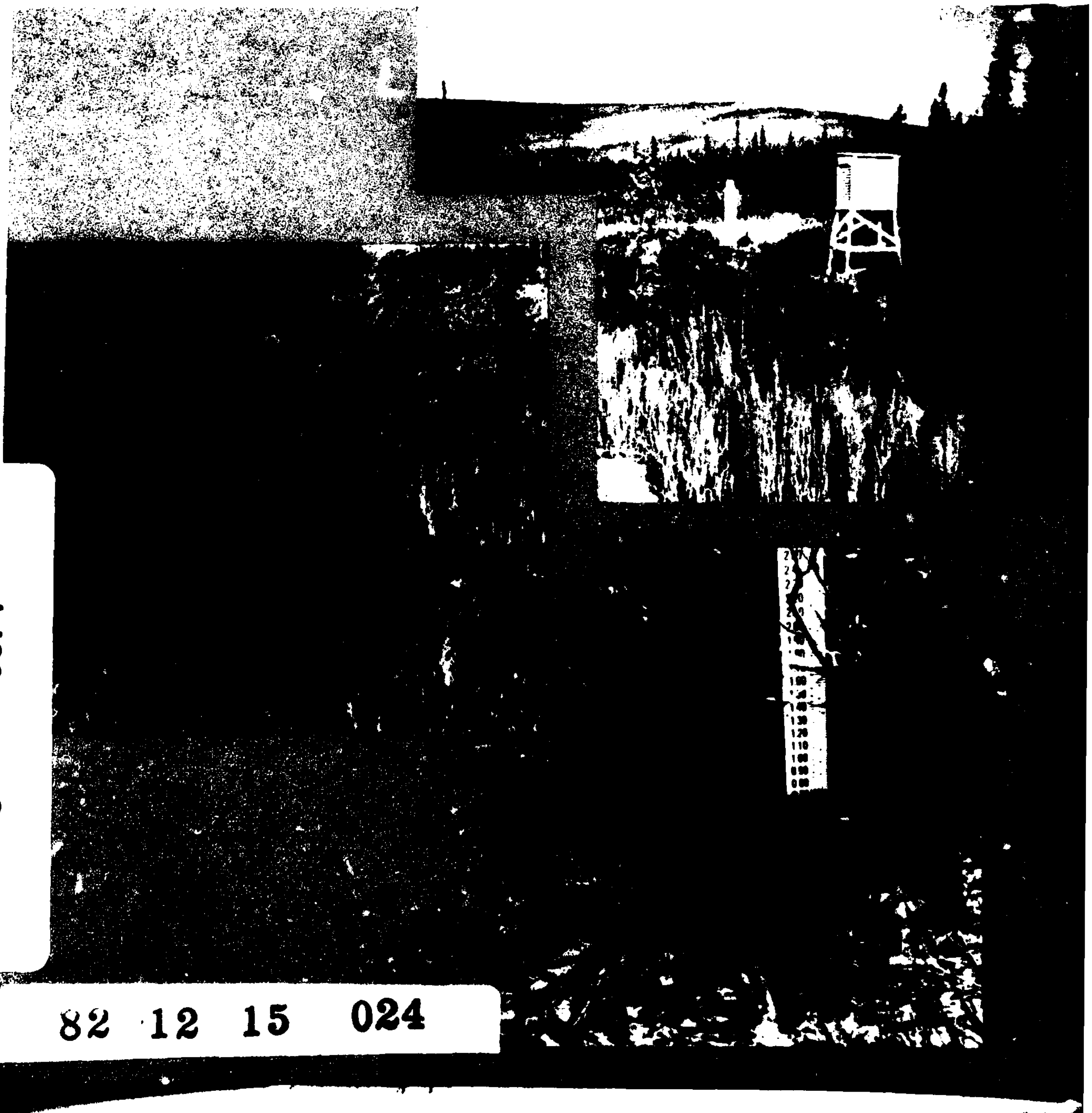


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

CRREL REPORT 82-26

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Hydrology and climatology of the Caribou–Poker Creeks Research Watershed, Alaska



CRREL Report 82-26

October 1982

Hydrology and climatology of the Caribou–Poker Creeks Research Watershed, Alaska

R.K. Haugen, C.W. Slaughter, K.E. Howe and S.L. Dingman

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CRREL Report 82-26	2. GOVT ACCESSION NO. AD-A122 402	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HYDROLOGY AND CLIMATOLOGY OF THE CARIBOU-POKER CREEKS RESEARCH WATERSHED, ALASKA		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R.K. Haugen, C.W. Slaughter, K.E. Howe and S.L. Dingman		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03766		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS CWIS 31003
11. CONTROLLING OFFICE NAME AND ADDRESS Office of the Chief of Engineers Washington, D.C.		12. REPORT DATE October 1982 13. NUMBER OF PAGES 42
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Climate
Cold Regions
Hydrology
Permafrost
Runoff

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Caribou-Poker Creeks Research Watershed is a small (101.5-km²) drainage basin located 48 km northwest of Fairbanks, Alaska. Elevations within the watershed range from 210 to 826 m, and approximately 28% of its area is underlain by permafrost. Climatic differences between the watershed and Fairbanks are primarily due to the higher elevation of the watershed. Generally the watershed climatic sites are warmer in winter and cooler in summer than Fairbanks. Within the watershed the greatest temperature contrasts exist in winter, when the valley-bottom sites are beneath the regional air temperature inversion, and the higher sites are above it. From May through September the total precipitation averages 270 mm, 1.47 times that received at Fairbanks. The annual precipitation is about 1.7 times

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (cont'd)

that of Fairbanks. The historical precipitation record at Fairbanks indicates that summer precipitation was below the long-term normal in eight of the eleven years of watershed measurements (1969–1980); no climatic extremes occurred during this period.

An analysis of annual streamflow data showed an inconsistency of baseflow recessions from year to year. The runoff-rainfall ratio for individual summer storms averaged 0.35 for Caribou Creek. Comparisons of spot discharge measurements of predominantly permafrost and non-permafrost subwatersheds showed that permafrost-dominated watersheds have a much "flashier" response to precipitation than non-permafrost watersheds. A comparison of the annual flow distribution of the watershed indicated that Caribou Creek has lower summer and higher winter discharges per unit area than the Chena or Salcha Rivers. The temporal variability of the flow of Caribou Creek is low compared with small- and moderate-sized streams in New England.

PREFACE

This report was prepared by Richard K. Haugen, Geographer, Earth Sciences Branch, Research Division, Cold Regions Research and Engineering Laboratory (CRREL); Dr. Charles W. Slaughter, Hydrologist, Institute of Northern Forestry, U.S. Forest Service, Fairbanks, Alaska; Karen E. Howe, Hydrologist, Earth Sciences Branch, Research Division, CRREL; and Dr. S. Lawrence Dingman, Associate Professor of Water Resources, University of New Hampshire.

The results reported are based on investigations sponsored over a period of 11 years under the U.S. Army Corps of Engineers Cold Regions Hydrology Program under Work Unit CWIS 31003, *Watershed Studies in Cold Regions*. Technical review of this report was performed by Edward Chacho, Alaska Projects Office (AKPO), CRREL, and Dr. C.T. Dyrness, Institute of Northern Forestry.

Report investigations were conducted in cooperation with the Interagency Hydrology Committee for Alaska. The U.S. Army Meteorological Support Team based at Ft. Wainwright was responsible for gathering and reducing much of the climatic data. The U.S. Geological Survey Fairbanks Office assisted in collecting streamflow data.

The authors thank the following individuals for their suggestions and assistance over the course of the study and the period of analysis: Dr. Terry McFadden, Chief, AKPO; Ed Clark, former Chief, AKPO; Dr. Jerry Brown, Chief, Earth Sciences Branch, Research Division, CRREL; and Stephen Bredthauer, formerly with the Alaska District, Corps of Engineers, and former project leader for the Watershed Studies in Cold Regions Project. They also thank Douglas Kane, Fleetwood Koutz, James Gilchrist, Eugene Culp, Philip Delp, James Crowley and Pat Quinn, all of AKPO, for technical support in field investigations; Robert D. Lamke, Chief, Hydrology Section, USGS Anchorage Office, for assisting with streamflow data; Timothy Pangburn of CRREL for calculating storm runoff volumes; and Gary DeCoff of CRREL for computer programming.

CONTENTS

ILLUSTRATIONS

TABLES

HYDROLOGY AND CLIMATOLOGY OF THE CARIBOU–POKER CREEKS RESEARCH WATERSHED, ALASKA

R.K. Haugen, C.W. Slaughter, K.E. Howe and S.L. Dingman

INTRODUCTION

Few studies of hydrologic processes and parameters in the North American Subarctic (the region of discontinuous permafrost) were conducted prior to the 1960s. An increasing need for basic hydrological information in the Subarctic and Arctic was apparent by the late 1960s, partially due to increasing oil and gas exploration and development and to the unprecedented Fairbanks flood of August 1967. Dingman's studies (1966a, b, 1971, 1973) of hydrologic processes in the 1.8-km² Glenn Creek basin 11 km north of Fairbanks provided the first documented data on upland precipitation-runoff relationships in subarctic Alaska and indicated a need for continuing investigations of cold regions hydrology.

The Research Coordination Subcommittee of the Inter-Agency Hydrology (formerly Technical) Committee for Alaska agreed on the need for complete catchment studies in the permafrost-dominated uplands of central Alaska and established the Caribou-Poker Creeks Research Watershed in 1969 with the participation of 13 Federal and state agencies (Slaughter 1971). The commitee indicated that studies of both "undisturbed" settings and the effect of landscape modification on hydrologic regimens were desirable.

There is evidence that the watersheds of interior Alaska have precipitation–runoff characteristics that differ from catchments of similar size in more temperate regions. For instance, Dingman (1971) found that Glenn Creek streamflow responded rapidly to rainstorms except when the basin was very dry, but that it had very slow recessions compared with temperate streams of similar size. His analysis of flow hydrographs and physical characteristics of the basin suggested two principal sources of runoff: 1) overland flow originating in a source area of variable size in the valley bottom, where the water table is at the ground surface, giving rise to rapid initial stream response to precipitation input, and 2) delayed flow through the moss and the soil organic layer on the valley floor and sides underlain by permafrost, resulting in prolonged recessions. Ford's examination (1973) of 1970–71 precipitation and streamflow data for Caribou Creek revealed that 1) the stream began to rise an average of two hours after rainfall began, 2) the length of time between the beginning of rainfall and the beginning of hydrograph rise was not related to antecedent moisture condition, and 3) the duration of hydrograph rise was an average of four hours longer than the duration of the precipitation that produced that rise. The first two conclusions were identical to those of Dingman

(1971) concerning Glenn Creek, while the third differs, probably because the travel time is longer in the larger Caribou Creek basin.

The purpose of this report is to further our understanding of rainfall-runoff relationships in the Alaskan Subarctic by examining the eleven-year data record from the Caribou-Poker Creeks Research Watershed. Precipitation-runoff characteristics, such as recessions, streamflow generation, precipitation response, and discharge-antecedent moisture relationships, are of primary interest. The available data record also allows the opportunity to examine year-to-year or longer trends in precipitation, air temperature and streamflow.

SETTING

The Caribou-Poker Creeks Research Watershed is in the Yukon-Tanana Uplands of central Alaska, at 65°10′ N latitude and 147°30′ W longitude, 48 km north of Fairbanks (Fig. 1). The basin is shown on U.S. Geological Survey 1:63,360 topographic maps (Livengood A-1 and A-2 quadrangles).

Wahrhaftig (1965) described the Yukon-Tanana Uplands as

> rounded even-topped ridges with gentle side slopes.... In the western part these ridges trend northeast to east; they have ridge-crest altitudes of 1,500-3,000 feet [457-914 m] and rise 500-1,500 [152-457 m] above adjacent valley floors....Valleys in the western part are generally flat, alluvium floored and 1/4-1/2 mile [0.4-0.8 km] wide to within a few miles of headwaters.... Most streams in the western part follow courses parallel to the structural trends of the bedrock....Drainage divides are very irregular.

Elevations in the watersheds range from 210 to 826 m. The drainage pattern is dendritic, and stream channels in the subdrainages are generally steep-walled and narrow, while the main channels are wider, often with alternating pools and riffles (Bredthauer and Hoch 1979).

The total area of the Caribou-Poker Creeks Research Watershed is 101.5 km². Runoff from 41.7 km² is measured at the Poker Creek gage and runoff from 23.8 km² is measured at the Caribou Main gage, which is located well upstream from the confluence of the two streams. The remainder of the area is drained by Caribou Creek downstream of the Caribou Main gage (Fig. 2).

The watershed above the Caribou Main gage is divided into four subwatersheds: C-1, C-2 and C-3, which are discrete subdrainages, and a small area labeled "C above gage." The ungaged portion of the watershed contains the subdrainage

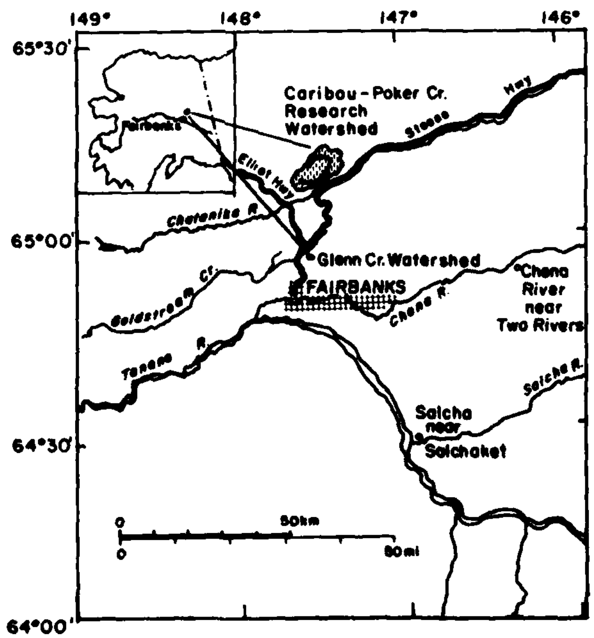


Figure 1. Location of Caribou-Poker Creeks and Glenn Creek watersheds.

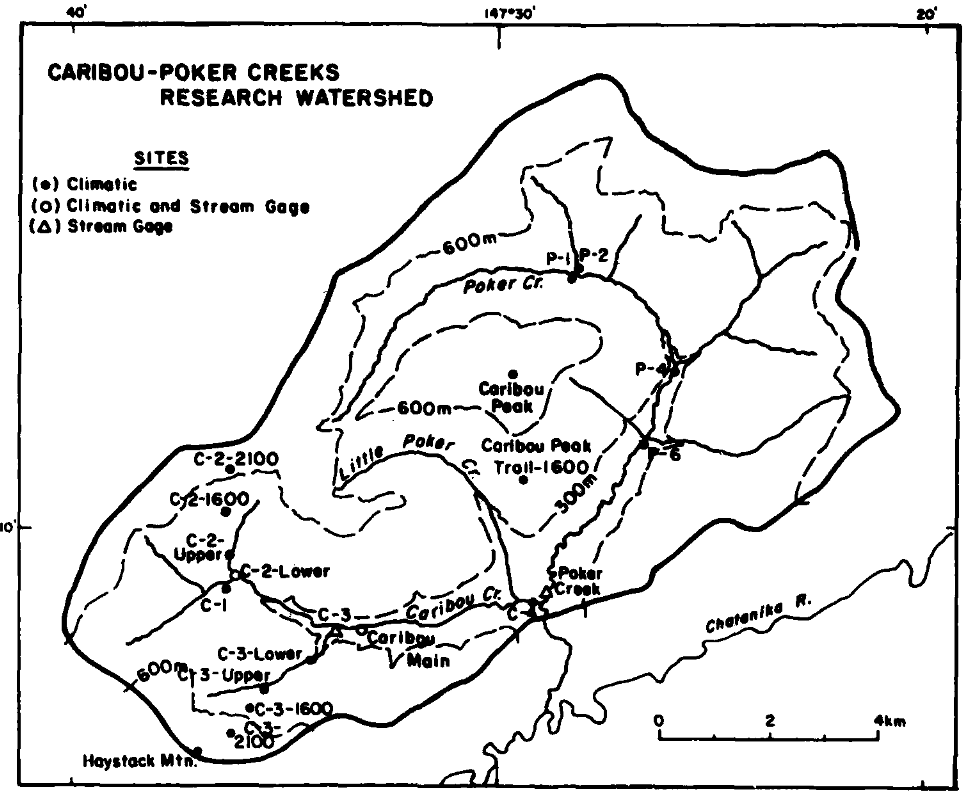


Figure 2. Climatic and stream gage sites.

Table 1. Physical hydrologic characteristics of the Caribou-Poker Creeks Research Watershed. (After Lotspeich and Slaughter 1981.)

Basin	*Area (km²)*	*Aspect*	*Elevation (m)*	*Total stream length* (km)*	*Drainage density (km/km²)*	*Area below elevation of 305 m (%)*	*Area between elevations of 305 and 488 m (%)*	*Area between elevations of 488 and 640 m (%)*	*Area above elevation of 640 m (%)*	*Area underlain by permafrost (%)*
Caribou-Poker	101.5	-	226–826	48.4	0.77	8.2	34.2	32.5	24.1	30.7
Poker	59.8	S	726–826	29.6	0.80	7.8	31.3	33.5	25.9	30.5
Caribou	41.7	E	226–770	19.0	0.73	9.8	39.9	23.8	21.5	28.0
C-1	6.7	E	325–738	3.5	0.86	0.0	40.8	43.4	15.8	26.1
C-2	5.2	S	323–738	2.2	0.70	0.0	29.0	38.0	33.0	3.5
C-3	5.7	NE	274–770	2.6	0.73	0.1	39.5	51.4	9.1	53.2
C-4	11.4	SSE	226–686	5.0	0.70	5.9	27.3	50.9	15.9	18.8
Caribou Main	23.8	E	256–770	11.1	0.93	3.0	41.0	39.0	17.0	23.8
C above gage	4.9	SE	256–640	2.8	†	14.0	58.5	21.5	6.0	14.5
P-1	14.8	ENE	360–773	5.8	0.63	0.0	15.8	34.3	52.8	37.8
P-2	6.7	S	360–826	4.0	0.96	0.0	10.0	16.9	62.0	6.9
P-4	11.1	SW	293–825	7.7	1.11	0.1	41.4	30.5	27.5	14.2
P-6	7.0	NW	271–755	3.9	0.89	0.2	37.1	42.7	18.5	17.8

* From Rieger et al. (1972); all other data are from USGS topographical maps.
† No data available.

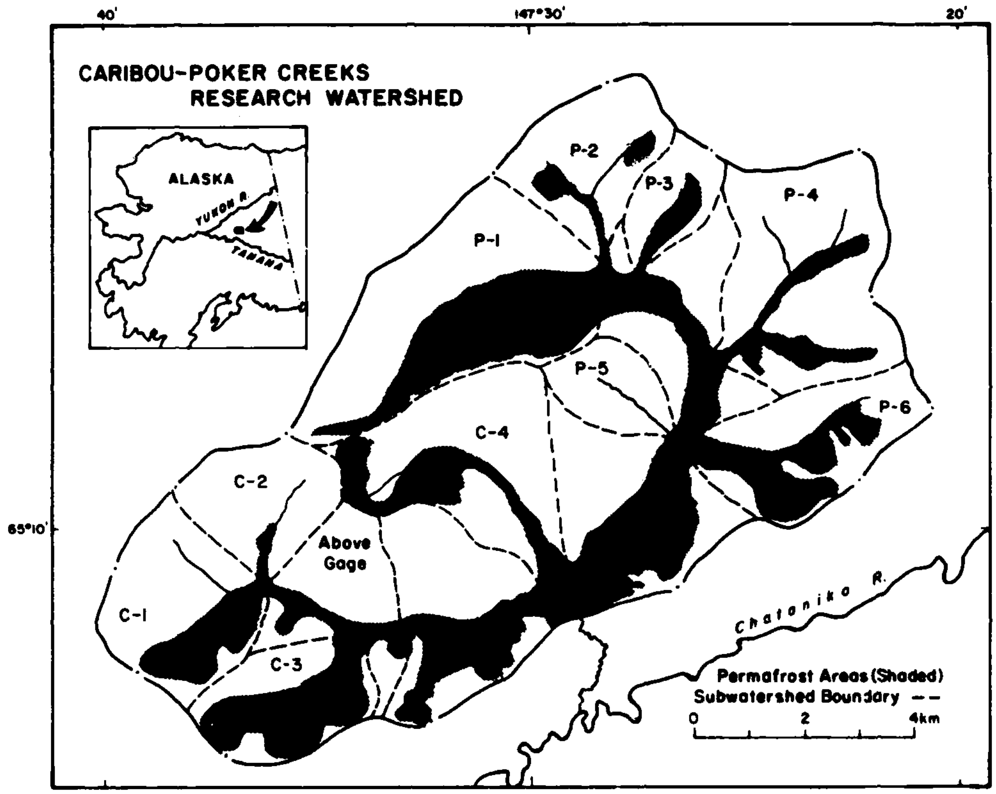


Figure 3. Permafrost areas, subwatersheds and stream channels.

C-4. Permafrost underlies 23.8% of the gaged portion of the Caribou Creek watershed (Fig. 3).

The Poker Creek watershed is divided into six subwatersheds, all of which are measured at the Poker Creek gage. Permafrost underlies 30.5% of the Poker Creek drainage (Fig. 3). Table 1 presents physical hydrologic information for the entire watershed and includes information about the subdrainages.

Geology and soils

The Caribou-Poker Creeks Research Watershed is underlain by mica schist of the Birch Creek Formation. A thin cap of loess mantles the area, but because the loess is derived from the floodplains of streams draining the area, there is no sharp boundary between it and the weathered schist below it (Rieger et al. 1972). Soils in this unglaciated area are poorly developed silt loams, which may contain various amounts of sand or gravel. They are generally thin, and the gravel or shattered bedrock reaches to within a few feet of the surface.

Seven soil series have been identified in the watershed (Fig. 4, Table 2)(Rieger et al. 1972). In general they can be grouped into two categories: 1) permafrost-underlain soils, which tend to be poorly drained, have a high moisture content, and develop ice-rich layers and 2) moderately well drained, permafrost-free soils.

Permafrost soils are generally found on north-facing slopes and valleys beneath black spruce stands. Their low annual soil temperatures result in reduced decomposition rates of organic matter. As a result, litter and organic material accumulates on the surface, allowing moss and lichen communities to develop. This thick ground cover insulates the mineral soil, leading to lower soil temperatures and further development of organic soils, which are generally 20-50 cm thick (Slaughter and Kane 1979). Moderately well drained silt loams are found under birch, aspen and white spruce stands on south-facing slopes. They have a thin veneer of organic soil that usually does not exceed 15 cm (Slaughter and Kane 1979).

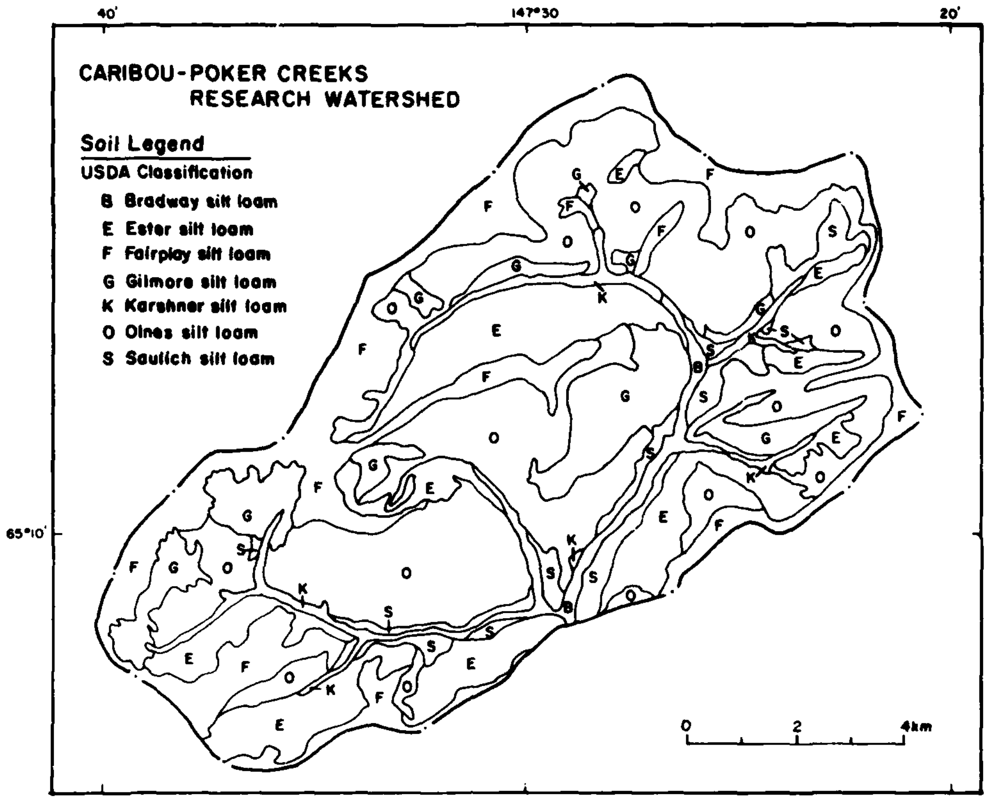


Figure 4. Soils of the watershed.

Table 2. Properties of soils of the Caribou-Poker Creeks Research Watershed. (After Rieger et al. 1972.)

Soil series	*USDA texture*	*Drainage*	*Permafrost*	*Location*	*Percentage of watershed*
Bradway	Stratified silt loam and loamy sand	Poorly drained	Shallow	Flood plain	1.89
Ester	Silt loam	Poorly drained	Shallow	Steep north-facing slopes	19.09
Fairplay	Silt loam and gravelly silt loam	Moderately well drained; somewhat poorly drained	None	High ridges above tree line	21.94
Gilmore	Silt loam, gravelly silt loam and very gravelly silt loam	Well drained	None	South-facing slopes	11.52
Karshner	Stratified silt loam, silt loam, very gravelly silt loam and very gravelly loamy sand	Poorly drained	Shallow	Narrow floodplains bordering upper courses of streams	1.71
Olnes	Silt loam and very gravelly silt loam	Well drained	None	South-facing slopes	39.48
Saulich	Silt loam	Poorly drained	Shallow	Foot slopes of hills	4.37

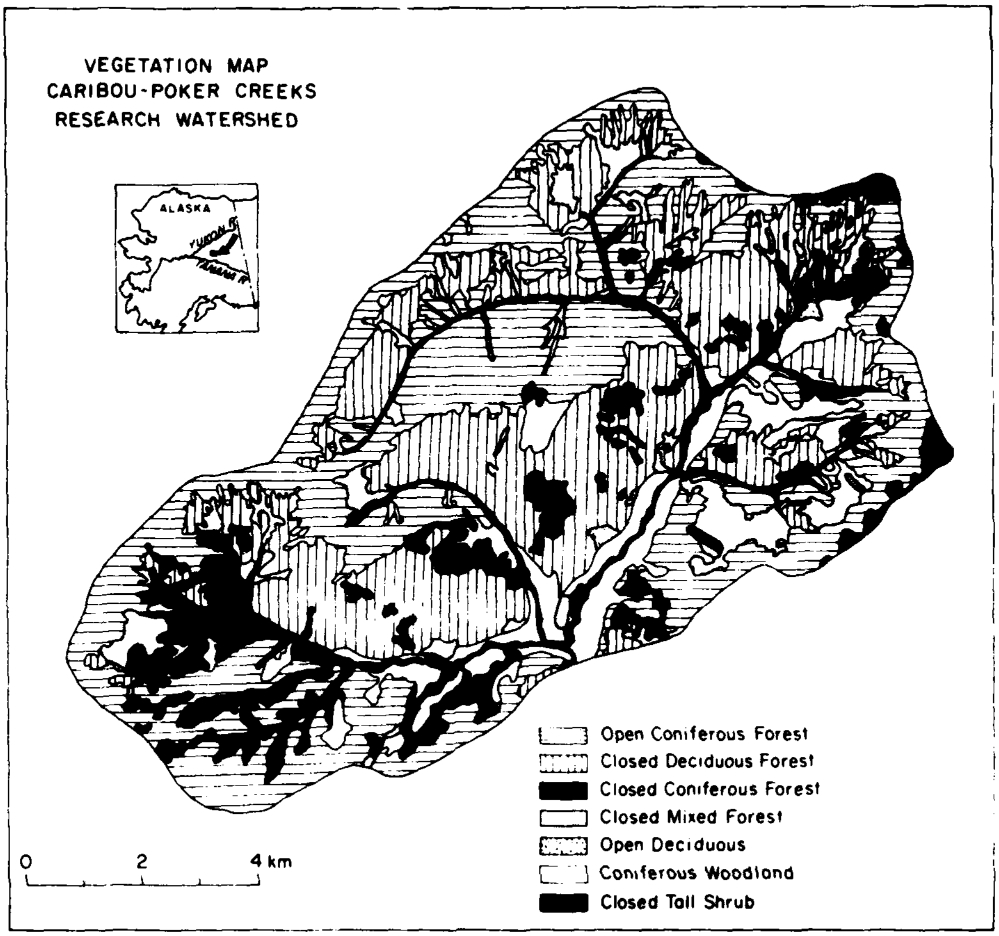


Figure 5. Vegetation of the watershed.

Vegetation

Figure 5 is a vegetation map of the Caribou-Poker Creeks Research Watershed based on a unified statewide system for classifying vegetation in Alaska (Viereck and Dyrness 1980). Under this system the watershed falls within the Interior Alaska Forest (Taiga) designation.

Spetzman (1963) classified the region that includes the watershed as "moderately well mixed evergreen and deciduous forest," and the Alaska Land Use Planning Commission (1973) categorized the area as "upland spruce-hardwood forest." This type is described as a fairly dense interior forest, with black spruce typically growing on north-facing slopes and poorly drained flat areas. Aspen, birch, alder and occasionally white spruce grow on south-facing slopes and well-drained soils. The white spruces average 12-24 m in height and up to 40 cm in diameter, and the aspens and birches average 15 cm in height.

Fire scars are found on some older trees within the basin, and charred old stumps are common. The undergrowth and ground cover consist of thick spongy moss and low brush on cool, moist slopes, grasses and forbs on dry slopes, and dense brush of willow, alder and dwarf birch in open forests near tree line at approximately 600 m.

CLIMATE

The watershed lies in the "Interior" climatic division of Alaska, a region of pronounced continentality that is characterized by large diurnal and annual temperature variations, low annual precipitation, low cloudiness and low humidity. The Fairbanks 30-year normals (U.S. Department of Commerce 1973) show that January is typically the coldest month, with a mean temperature of -24.4°C, while July, the warmest month, has a mean of 17.1°C. The annual precipitation at Fairbanks averages 285 mm, over half of which occurs in the months of June, July and August (U.S. Department of Commerce 1980). Annual snowfall averages 1692 mm, with an average accumulation of 175–300 mm per month during October through January. Snow commonly covers the ground from October to mid-April; the average duration of snow cover in the Fairbanks area is about 214 days. The length of the frost-free period at Fairbanks averages 97 days, extending from May 24 to August 29 (U.S. Department of Commerce 1973).

Due both to its distance from the ocean and to the numerous topographic barriers, the watershed is usually isolated from maritime air masses. The low temperatutes that occur during the winter stem from intense radiational cooling caused by long periods of darkness. During these months, strong temperature inversions are common. Bilello (1966) showed that surface-based inversions are present during more than 40% of the winter in Fairbanks; at Caribou Creek, inversions have been noted throughout the winter (Ford 1973). During the summer, cool air flows into the valley bottoms at night, also creating a localized inverted air-temperature gradient.

Air temperature

The analysis of air-temperature regimes for the watershed is based on records obtained at watershed stations during 1975–1979 and the long-term records from Fairbanks. The temperature records obtained from 30-day recording thermographs installed in standard shelters are often discontinuous due to instrument stoppages, especially during the winter (Table A1). However, enough continuity exists to permit the missing data to be reconstructed for various sites, so that five-year mean values could be computed. The development of coherent temperature records for all the sites was done using an algorithm developed by S.I. Outcalt.[1] It is based on the assumption that any temperature regime can be abstracted into a periodic time series with only three parameters: the mean station temperature, the amplitude of the thermal regime, and the phase angle of the annual temperature curve.

However, when records are missing for several months, the station mean and amplitude can be estimated from the mean monthly temperatures for the warmest and coldest months (TMAX, TMIN). The analytical estimates of freezing and thawing degree-days follow from these relationships:

$$
\begin{aligned}
TM &= (TMAX + TMIN)/2 \\
TA &= (TMAX - TMIN)/2 \\
A &= ARCOS\,(-TM/TA) \\
TS &= TM + TA[SIN(A)/\,A] \\
TW &= TM - TA\,[SIN(A)/(\pi - A)] \\
SD &= 365\,(A/\pi) \\
WD &= 365[(\pi - A)\,\pi] \\
DDT &= TS \cdot SD \\
DDF &= TW \cdot WD
\end{aligned}
$$

where

TM = station mean (°C)
TA = amplitude (°C)
A = phase angle (radians)
TS = mean summer temperature (°C)
TW = mean winter temperature (°C)
SD = length of summer (days)
WD = length of winter (days)
DDT = thawing degree-days
DDF = freezing degree-days.

The results of this procedure are summarized in Table 3. The observed and estimated Fairbanks records are included for comparison with those of the watershed sites. The estimated values for the watersheds are close to the observed values, which are the means of 1–5 years of record. The greatest differences between observed and estimated values are for January. This is probably because January has the poorest data representation for all the months, and the missing data are for the coldest Januarys, when recorder failure was most common. January is the coldest month at Fairbanks, and if all the data were available, harmonic analysis would probably indicate that this is also true for the watershed. Therefore, the estimated rather than the observed values are likely to be more representative of the true mean temperature.

Estimated and observed values for the watersheds indicate that these sites are generally warmer in winter and cooler in summer than Fairbanks. The highest winter temperatures occur at the highest elevations; the coldest watershed site is Caribou Main, which is in a confined valley and is the lowest of all the watershed climatic stations. July temperatures are relatively uniform throughout the watershed but are con-

[1]Personal communication, University of Michigan, 1981.

Table 3. Synthesized 1975-1979 mean values of January and July air temperatures (°C) and freezing and thawing degree-days for Caribou-Poker Creeks Research Watershed.

Station	January		July		Degree-days		Mean annual temperature
	Observed	*Estimated*	*Observed*	*Estimated*	*Freezing*	*Thawing*	
Caribou Peak	-11.5	-17.0	13.9	12.5	2147	1319	-2.3
Caribou Main	-22.6	-22.9	13.1	13.0	3071	1269	-4.9
Caribou Peak Trail-1600	-10.2	-14.8	14.4	12.5	1811	1382	-1.2
C-1	-13.1	-19.6	12.4	11.8	2605	1192	-3.9
C-2-Lower	-15.4	-19.9	13.4	12.3	2621	1242	-3.8
C-2-Upper	-13.2	-18.6	11.8	11.0	2481	1093	-3.8
C-2-1600	-11.4	-16 5	13.5	11.8	2091	1242	-2.3
C-2-2100	-10.8	-16.1	12.3	12.6	2003	1367	-1.7
C-3-Lower	-18.1	-21.2	12.5	12.7	2808	1255	-4.3
C-3-Upper	-13.5	-18.8	13.5	11.8	2487	1206	-3.5
C-3-1600	-10.9	-16.9	11.9	11.6	2177	1209	-2.7
C-3-2100	-10.2	-17.0	13.0	11.2	2200	1150	-2.9
C-4	-18.1	-20.5	12.2	12.8	2685	1282	-3.8
P-1	-17.2	-22.1	13.5	13.2	2930	1319	-4.4
P-2	-17.2	-21.5	11.4	12.5	2875	1223	-4.5
P-4	-12.5	-17.7	12.9	12.3	2281	1289	-2.7
Haystack Mt.	-12.4	-17.7	12.9	11.2	2321	1128	-3.3
Fairbanks*	-24.4	-24.2	16.0	17.1	3084	1799	-3.5

*Thirty-year average.

siderably lower than at Fairbanks. Estimated mean freezing and thawing degree-days exhibit the same relationships described for January and July temperatures (Table 3).

Mean annual temperatures for the watershed sites range from -1.2°C at Caribou Peak Trail to -4.9°C at Caribou Main. Most of the sites that have a mean annual temperature of -3.0°C or lower are within the permafrost boundaries shown in Figure 3. The warmest sites are those on the south-facing slopes at intermediate elevations between the valley bottoms and the peaks.

The temperature differences with elevation were not the same in winter and summer (Fig. 6). The January 1978 temperature in the C-3 subwatershed exhibited a clear elevational gradient from -15.6°C at C-3-Lower to -8.7°C at Haystack Mt., whereas the July temperatures varied by only 1.1°C between the two sites. The July 1978 temperatures for Haystack Mt. and Caribou Main were nearly the same: 13.2° and 12.8°C, respectively. Viewing the temperature difference

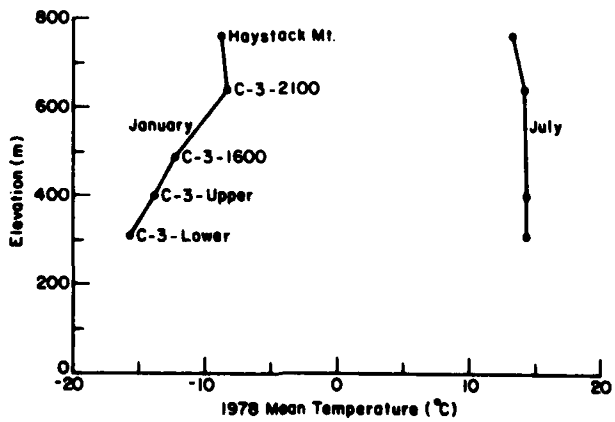


Figure 6. Slope profile of C-3 subwatershed showing vertical gradients of 1978 January and July mean air temperatures.

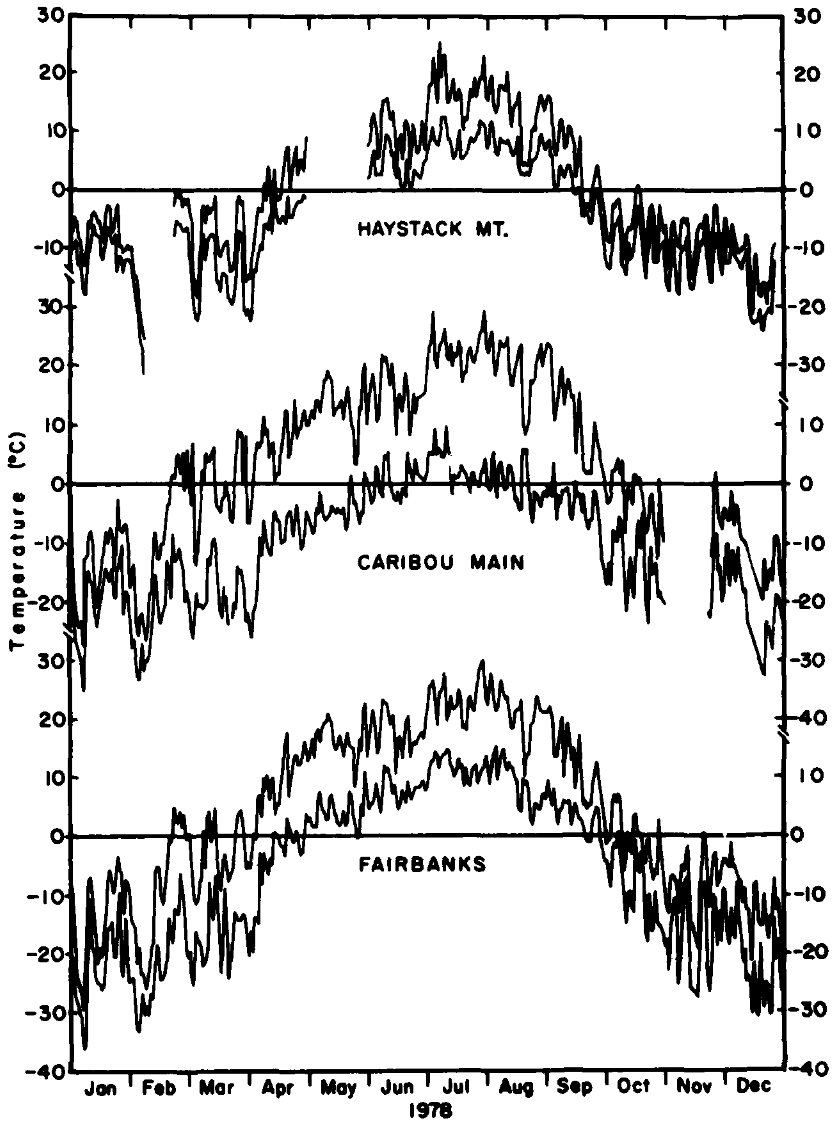


Figure 7. Daily maximum and minimum air temperature envelopes for Haystack Mt., Caribou Main and Fairbanks, 1978.

between these sites as illustrated in Figure 7 suggests the reason for the winter-summer differences. At the Caribou Main site, daily minimum temperatures dropped below the freezing point on nearly half the nights of the summer season. In contrast, freezing temperatures occurred only once at Fairbanks and never at Haystack Mt. during the same period. Winter temperatures at the high elevation site, Haystack Mt., are higher in winter than either Caribou Main or Fairbanks and show a smaller daily range.

Precipitation

The 30-year normal annual precipitation (1941-1970) at Fairbanks is 285 mm, of which 184 mm (65%) falls during the unfrozen season, May-September (U.S. Department of Commerce 1980). It is generally believed that summer precipitation in the interior of Alaska results from isolated storm cells that develop randomly in response to the heating of the land surface during the day. These convective showers would be expected to occur most frequently in the after-

Table 4. Total number of days with measurable precipitation,* May-September 1976–79.

Station	1976	1977	1978	1979
Caribou Peak	38	-†	57	57
C-3-2100	-	58	50	54
C-3-1600	-	49	56	-
Caribou Main	-	-	48	53
Fairbanks	31	49	52	54

*At least 0.25 mm.
†No data.

Table 5. Summer precipitation (mm), May-September 1976–79.

Station	Elevation (m)	1976	1977	1978	1979
Caribou Peak	773	139	-*	298	201
C-3-2100	637	-	309	246	194
C-2-2100	616	-	472	223	-
C-3-1600	488	-	311	218	174
Caribou Main	264	126	366	191	220
Fairbanks	133	127	232	141	152

*No data.

noon. However, Santeford (1976) has shown that most summer precipitation events occur in the morning at Fairbanks and were otherwise scattered randomly throughout the 24-hour period, indicating that some of the summer precipitation at Fairbanks has other causes, possibly occasional intrusions of maritime air.

Precipitation has been recorded at various sites within the Caribou-Poker Creeks Research Watershed since 1969 (Table A2). Prior to 1974, precipitation was measured at C-2-2100, C-3-2100 and Caribou Main with Belfort weighing-bucket recording rain gages with one-week revolving drums. The weekly totals were also measured in standard eight-inch rain gages, located with each recording gage. Since 1974, precipitation has been recorded only on a daily basis, and the Caribou Peak, C-3-1600, P-1 and P-4 stations were added to record precipitation at various elevations. Measurements are still being recorded at all the stations except P-1 and P-4, which were terminated in 1978.

Table 4 is a comparison of the number of summer days with measurable precipitation in Fairbanks and in the Caribou-Poker Creeks Research Watershed. It is apparent that the numbers are similar for Fairbanks and the various stations in the watershed. The 30-year mean for Fairbanks is 49 days (U.S. Department of Commerce 1977).

Although the number of summer precipitation events appears to be relatively uniform, this does not imply that the duration or intensity of precipitation is the same. A comparison of the total summer precipitation at the watershed sites and at Fairbanks is shown in Table 5. With the exception of the Caribou Main station in 1976, all the watershed stations had higher totals than did Fairbanks, and some are nearly double that of Fairbanks.

For the Chena River basin Santeford (1976) found an orographic, or elevational, gradient in the precipitation totals for both winter and summer. The Chena basin ranges in elevation from 133 m at Fairbanks to over 1220 m and has an estimated mean annual precipitation of 518 mm, approximately 1.7 times that of Fairbanks. The 518 mm corresponds closely to the mean annual precipitation observed at Caribou-Poker Creeks Research Watershed. Although the Caribou-Poker Creeks Research Watershed is smaller in area and elevational range than the Chena basin, elevational trends in precipitation amounts can be identified (Table 5).

Precipitation within the Caribou-Poker Creeks Research Watershed is usually of low intensity and high areal variability for a given storm. As a result, measurements of precipitation vary from station to station, with generally increasing precipitation with elevation (Table 5). This variability, and the often discontinuous record, makes computation of precipitation volumes entering the watershed for any storm difficult. Since precipitation volumes entering the watershed are necessary to analyze hydrologic relationships such as precipitation-runoff, a method to estimate summer watershed precipitation using station records was devised.

Since precipitation increases with elevation, the watershed was divided into three elevation zones: less than 305 m, 305-640 m, and greater that 640 m, representing respectively, the valley bottoms, the slopes, and the subalpine areas of the watershed. The proportion of watershed area in each elevational range is shown in Table 6. Stations within each zone were used to determine precipitation for that zone only. To determine the total watershed precipitation for any storm, an average value for each elevational range was computed from the station measurements within the zone. These values were multiplied by the percent of watershed area within that range and then totaled. When only one pre-

Table 6. Elevation ranges for determining precipitation volume at the Caribou-Poker Creeks Research Watershed.

	Elevation zones (m)		
	< 305	305-640	>640
Caribou Creek watershed (23.8 km²)			
Percentage of total area	3.0	80.0	17.0
Station(s) within zone	Caribou Main	C-2-2100 C-3-1600 C-3-2100	Caribou Peak
Poker Creek watershed (59.8 km²)			
Percentage of total area	8.0	65.0	26.0
Station within zone	P-4	P-1	Caribou Peak

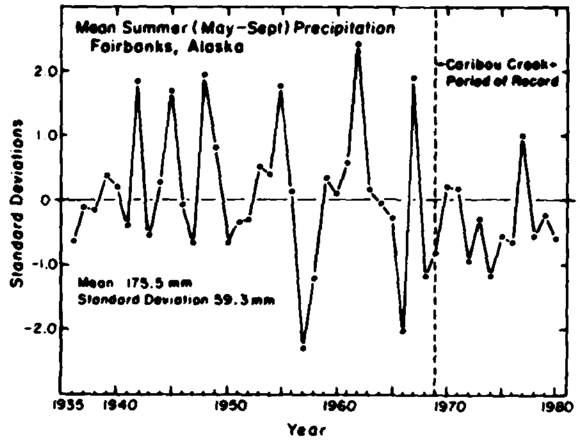


Figure 8. Mean and standard deviations of summer precipitation at Fairbanks, 1936-1980.

cipitation measurement was available, it was assumed that that amount of precipitation fell on the entire watershed, and the value was multiplied by the watershed area to obtain a total volume.

The average ratio of precipitation at the watershed to that at Fairbanks for the summer season (May-September) was 1.47 to 1. This ratio was used to estimate monthly precipitation volumes for months when no watershed measurements were available.

Although the Caribou-Poker Creeks Research Watershed was established in 1969, most precipitation records are reasonably continuous only since 1976. This is too short a time to permit an evaluation of year-to-year variations. Therefore, the Fairbanks record beginning in 1936 was examined to provide some insight into long-term summer precipitation variations (Fig. 8). This record indicates that summer precipitation totals during the 1969-1980 period were generally below normal, and the year-to-year variations were, with one exception, within one standard deviation of the normal mean value. As can be seen in Figure 8, the variations were considerably greater prior to 1969. Therefore, it must be assumed that the 1969-1980 precipitation and runoff records for the Caribou-Poker Creeks Research Watershed do not include an adequate sampling of either the driest or wettest summers experienced in the Fairbanks area since 1936 and generally reflect relatively dry conditions.

HYDROLOGY

Annual and monthly runoff

Figures 9 and 10 are annual hydrographs of recorded and estimated mean daily flows for Caribou Creek (1969-1980) and Poker Creek (1970-1978). Mean daily flow values are usually very high in May due to snowmelt runoff. The highest mean daily flow recorded at Caribou Creek was on 11 May 1975, with a flow of 2.83 m³/s. Poker Creek's highest mean daily flow was 5.66 m³/s, recorded on 12 May 1975.

Monthly precipitation and discharge volumes were calculated for the watersheds (Fig. 11). Monthly discharge volumes were computed by estimating the area under a plot of mean daily flow (m³/s) vs time (days) for any specified period of time. The precipitation volumes were determined as previously described; Fairbanks values were converted when monthly precipitation values were lacking for the watershed.

Figures 11 shows certain runoff trends. The greatest monthly discharge volumes occurred in Caribou Creek in May of most years and in Poker Creek in May every year except 1978. Following snowmelt runoff, the volumes generally fell off rapidly, and June discharge volumes were usually much smaller than May volumes. Winter flows, which were in part estimated by the USGS, were low and fairly constant; flows began to increase at the start of the thaw period.

During a few years the recorded flow deviated

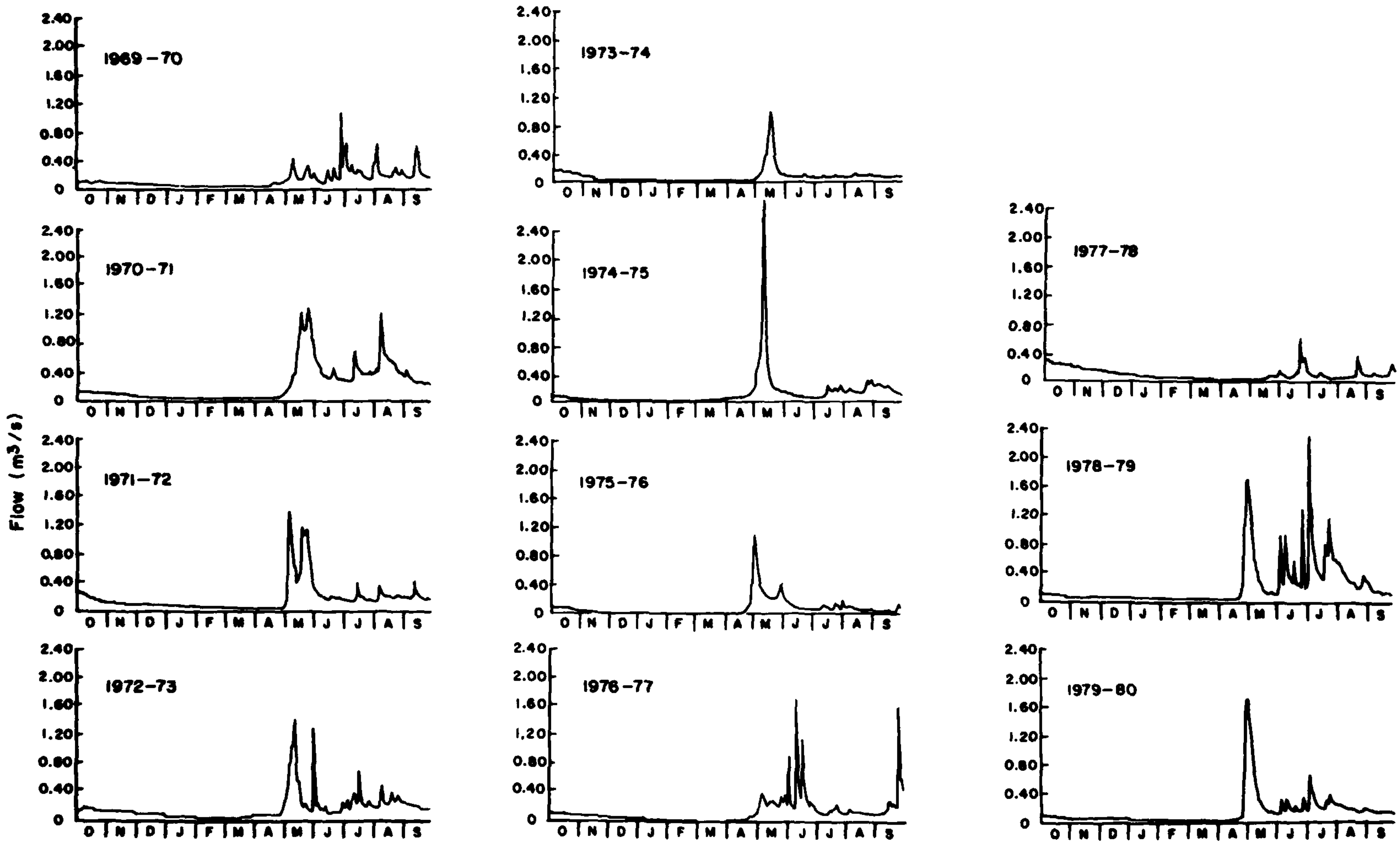


Figure 9. Annual hydrographs for Caribou Creek, 1969-1980.

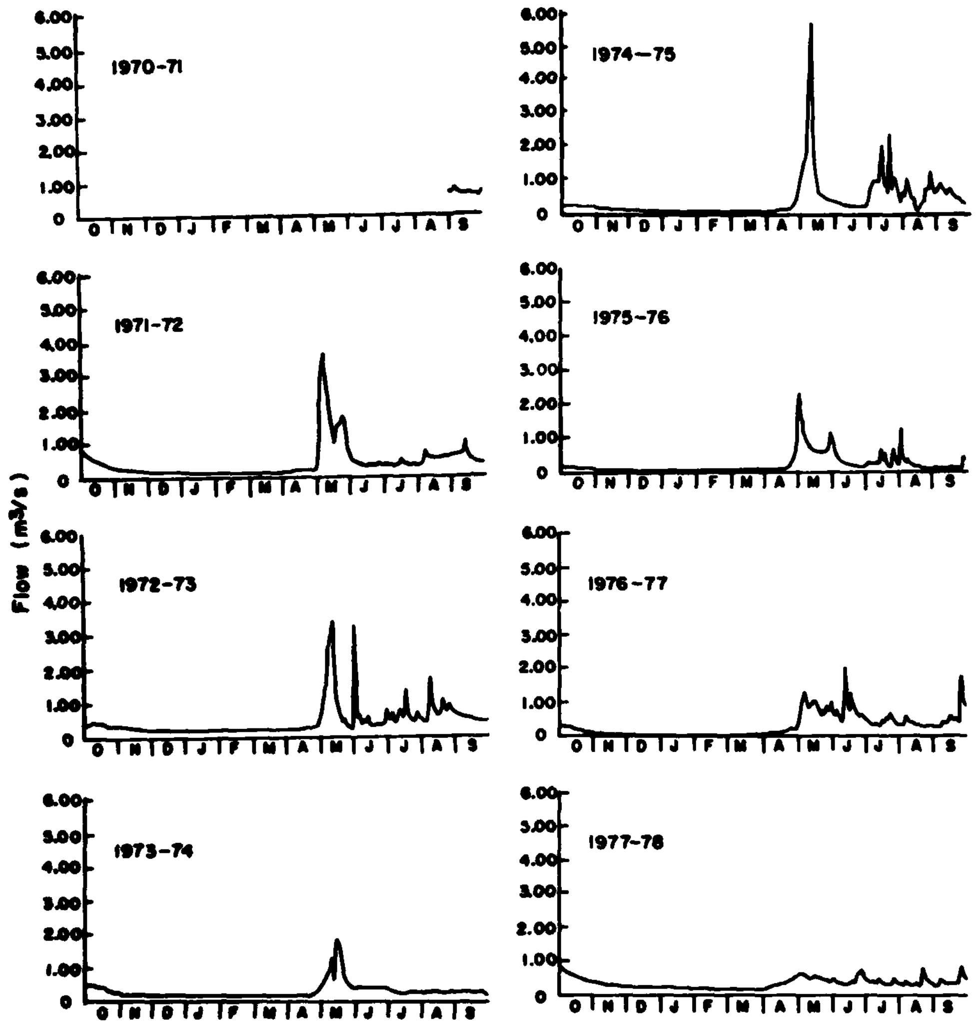


Figure 10. Annual hydrographs for Poker Creek, 1970-1978.

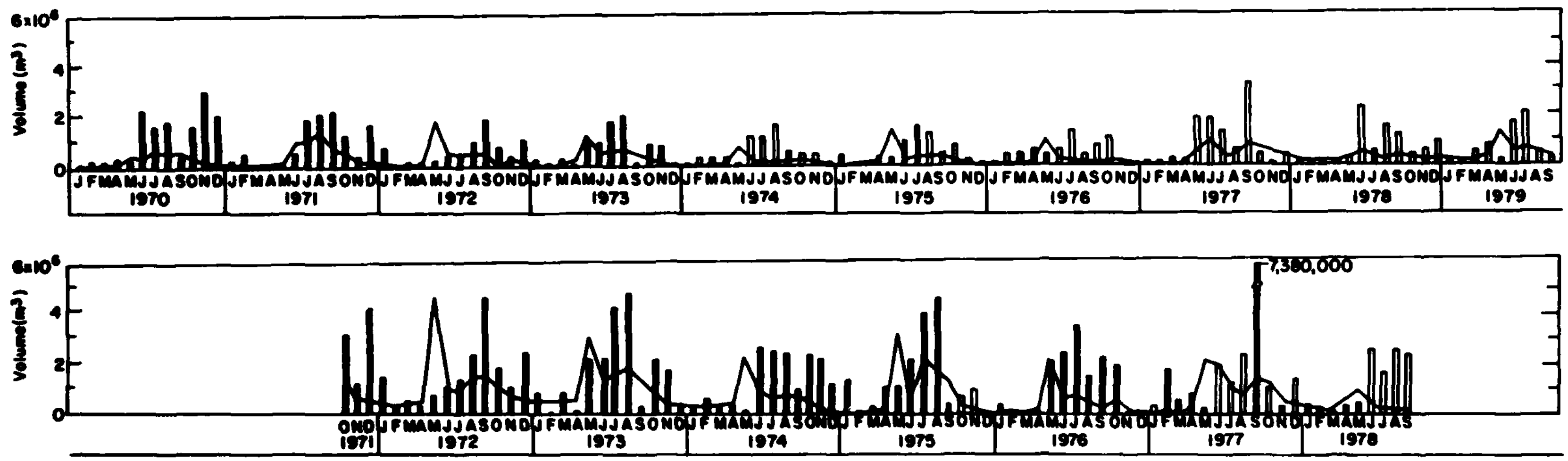


Figure 11. Monthly precipitation and discharge volumes at Caribou Creek (top) and Poker Creek (bottom). The black bars are precipitation volumes extrapolated from Fairbanks data; the white bars are precipitation volumes calculated from Caribou-Poker Creeks Research Watershed data. The curves are monthly discharge volumes.

Table 7. Mean monthly temperatures at Caribou Creek, 1969–79.

	1969	*1971*	*1972*	*1973*	*1974*	*1975*	*1976*	*1977*	*1978*	*1979*
September										
Caribou Main	-	-	-	-	-	*-2.1**	-	4.3	4.2	2.5
C-1	-	4.1	4.3	4.6	6.5	*2.5*	5.7	3.8	5.9	-
C-2-Lower	-	4.0	3.4	*2.9*	-	4.3	-	3.3	6.2	4.0
C-2-Upper	-	2.4	-	3.6	4.5	-	5.2	*1.6*	5.3	-
C-2-2100	-	3.7	*2.6*	-	-	-	8.2	8.7	5.9	6.9
C-3-Lower	-	3.8	3.2	7.0	7.3	-	-	3.7	8.6	5.4
C-3-Upper	-	-	-	-	7.5	-	-	*2.2*	4.3	-
C-4	-	-	-	-	-	*3.8*	-	4.0	6.0	4.7
October										
Caribou Main	-	-	-	-	-	*-14.3*	-4.4	-6.2	-8.2	-5.7
C-1	-2.5	-5.6	-5.8	*-8.4*	-7.8	-7.5	-7.0	-6.8	-7.1	-
C-2-Lower	-	-5.2	-	-7.9	*-8.9*	-	-7.1	-5.2	-5.6	-
C-2-Upper	-	-5.4	-2.8	-6.2	-	-4.6	-	-5.7	-5.7	*-7.1*
C-2-2100	-	-3.8	-	-	-	-	-	-4.2	*-4.8*	*-0.5*
C-3-Lower	-	-5.7	-2.8	-10.0	*-10.1*	-	-	-7.5	-7.1	-3.3
C-3-Upper	-	-	-	-	*-11.2*	-	-	-8.8	-	-
C-4	-	-	-	-	-	-5.0	-	-6.6	-6.3	*-7.6*
November										
Caribou Main	-17.3	-	-	-	-	*-30.2*	-	-22.3	-12.0	-11.9
C-1	-16.3	-	-15.4	-19.6	-	-21.6	-8.2	*-21.7*	-	-
C-2-Lower	-	-18.8	-	-	-14.0	*-23.2*	-6.0	-21.7	-13.1	-
C-2-Upper	-16.9	-	-	-	-	*-21.5*	-10.1	-21.4	-14.8	-8.8
C-2-2100	-	-	-	-	-	-	-3.3	*-15.2*	-9.1	-5.4
C-3-Lower	-	*-19.3*	-	-	-	-	-	-	-12.5	-9.5
C-3-Upper	-	-	-	-	-	-	-	*-24.1*	-10.6	-
C-4	-	-	-	-	-	*-25.0*	-	-20.1	-12.3	-8.4
December										
Caribou Main	-	-	-	-	-	*-43.7*	-	-11.6	-14.9	-27.9
C-1	-	-	-18.5	-17.5	*-26.3*	-	-18.9	-24.9	-	-
C-2-Lower	-	-	-	-16.2	-22.6	-	-18.3	-22.6	-	*-22.7*
C-2-Upper	-	-	-	-	*-24.7*	-	-18.9	-23.9	-	-
C-2-2100	-	-	-	-	-	-	-14.9	-17.1	-12.9	*-18.7*
C-3-Lower	-	-21.3	-	-18.2	*-24.2*	-	-	-	-16.3	-23.9
C-3-Upper	-	-	-	-	*-24.2*	-	-17.5	-	-	-
C-4	-	-	-	-	-	-	-	-	-16.1	*-22.4*

*Values in italics are the lowest mean monthly temperatures recorded at that station for that month for the period of record.

from what appears to be normal for the watersheds. In 1971 the largest monthly volume of runoff at Caribou Creek occurred in August. The previous late winter and spring was a period of very little precipitation, which caused the May runoff volume to be lower than average. Summer precipitation, which caused the August peak, was quite high.

Caribou Creek had one period when there was no measurable flow (from 11 December 1975 to 4 April 1976). This observation was made by USGS hydrologists during routine winter visits. They made observations at only one stream reach, so there may have been flow throughout this period in other stream reaches within the watershed.

The conditions that caused the stream to freeze completely that winter were a combination of low precipitation the preceding fall and extremely low temperatures. The mean monthly temperatures recorded at the Caribou Main station for September-December 1975 were the lowest recorded at that station for those months during the entire period of record (Table 7). Of the fourteen mean monthly temperatures that were recorded at stations throughout the watershed from September through December 1975, nine were the lowest mean monthly tempera-

Table 8. Mean monthly hydrologic response, precipitation and runoff for Caribou Creek, May-September 1970-1979.

Month	Avg. HR	Avg. precip. (mm)	Avg. runoff (m^3)
May	2.79	21.5	920,000
June	0.73	51.7	508,000
July	0.37	56.4	467,000
Aug	0.41	54.1	495,000
Sept	0.77	47.8	425,000

tures recorded at that station for the entire period of record. Heavy aufeis formed downstream from the gaging station that winter, suggesting that due to unusually low temperatures, the channel was completely frozen or that flow was restricted beneath the ice. This condition is common along small, shallow channels in areas where winter streamflow is sustained by groundwater.

Average monthly values of the hydrologic-response ratio HR (the monthly discharge divided by the monthly precipitation) were computed to quantify the variability of summer streamflow responses. Table 8 gives the average (1970-1979) HR values for each summer month at Caribou Creek. Snowmelt runoff generally persists into June, and since the soil-moisture deficit is satisfied by then, much of the precipitation runs off. After that, the HR values decrease due to increased evapotranspiration and soil-moisture deficits. The decrease of evapotranspiration in September then causes the HR values to increase.

Individual storms

Precipitation and corresponding runoff volumes were calculated to determine the HR values for individual summer storms in the Poker and Caribou creeks watersheds. The data for 20 storms at Caribou Creek and 13 storms at Poker Creek are summarized in Tables 9 and 10, respectively.

The runoff volumes for individual storms were estimated by plotting the mean daily flows for each summer on semi-logarithmic paper and extrapolating the recession limbs of individual storms as straight lines to an arbitrary value, 0.028 m^3/s (1 ft^3/s), assumed to be the value of flow that would be sustained by sources other than storm precipitation (Fig. 12). This is equivalent to assuming that the flow following a peak

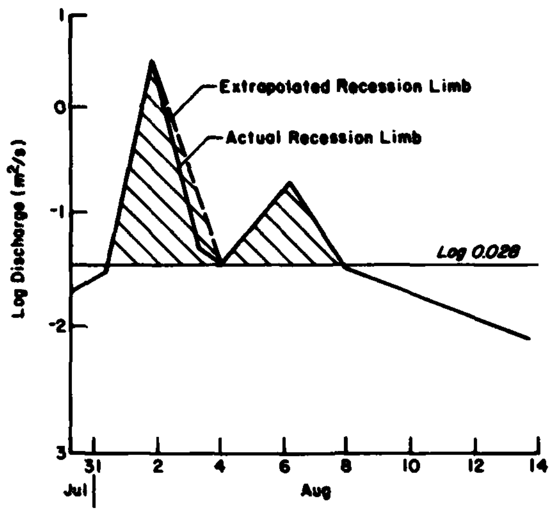


Figure 12. Method of calculating storm discharge.

decreases exponentially with time. After the streamflow contributions from each storm were arbitrarily separated by this procedure, a computer program was used to compute the runoff volume for each. To minimize errors, no multi-peaked or complex storm events were included in the analysis.

HR values for individual storms were calculated from these runoff volumes and from precipitation volumes, which were computed from the total daily precipitation measurements. The HR values for Caribou Creek range from 0.09 for the 21-24 July 1979 storm to 0.79 for the 11-14 June 1977 storm (Table 9). The average value for the 20 storms studied at Caribou Creek was 0.35. The HR values for Poker Creek range from 0.07 for the 4 June 1977 storm to 2.04 for the 25 June 1977 storm (Table 10). The average HR value for 13 storms at Poker Creek was 0.49. The two HR values greater than 1 are not meaningful and are probably due to the sparse precipitation data available for this watershed (Table A2).

Regression equations for HR as a function of antecedent discharge q_i were calculated for each watershed. Antecedent discharge, the flow immediately before storm hydrograph rise, is a general indicator of basin wetness. The regression equations showed that the relationship between HR and q_i is not significant at the 0.05 probability level. Ford's analysis (1973) produced the same results. This led him to suggest that there is no relationship between basin antecedent moisture conditions and hydrologic response. He noted that other factors, such as evapotranspiration, infiltration capacity of the soil,

Table 9. Precipitation, runoff and hydrologic response for 20 summer storms at Caribou Creek, 1977–79.

Storm period	Precipitation (mm) Caribou Main	C-2-2100	C-3-2100	C-3-1600	Caribou Peak	Total*	Precipitation (m^3)	Runoff (m^3)	HR	Antecedent discharge (m^3/s)
25–27 May '77	6.6	12.2	-	-	-	12.0	286,000	189,000	0.66	0.017
30 May '77	6.3	8.9	-	-	-	8.8	210,000	37,700	0.18	0.043
3–4 June '77	10.9	19.0	24.9	-	-	21.6	513,000	186,000	0.36	0.021
11–14 June '77	25.1	13.7	28.2	25.5	-	22.6	537,000	424,000	0.79	0.011
18 June '77	16.5	17.8	15.3	20.3	17.3	17.7	423,000	243,000	0.57	0.068
26 June '77	8.4	8.4	5.1	-	13.2	7.9	187,000	102,000	0.55	0.024
18 July '77	17.0	57.0	9.7	17.8	19.0	26.3	625,000	121,000	0.19	0.009
10–11 Sept '77	6.6	32.5	43.2	-	6.1	31.5	750,000	134,000	0.18	0.005
15–17 June '78	5.9	7.3	7.7	6.3	5.3	7.1	169,000	18,100	0.11	0.002
21–24 June '78	24.4	31.5	43.6	34.8	29.6	35.1	835,000	176,000	0.21	0.006
25–27 June '78	9.6	21.1	16.6	11.5	12.5	15.5	370,000	111,000	0.30	0.046
11–14 July '78	6.9	9.4	13.2	10.4	20.1	12.4	294,000	38,900	0.13	0.003
18–22 Aug '78	52.3	37.3	55.0	60.2	38.0	48.8	1,160,000	196,000	0.17	0.001
5–6 June '79	34.0	-	14.5	7.9	23.9	14.1	336,000	94,700	0.28	0.005
10–12 June '79	19.3	-	17.3	18.3	26.2	19.2	458,000	93,300	0.20	0.009
19–21 June '79	8.2	-	6.4	8.9	2.6	6.9	163,000	64,400	0.40	0.011
25–26 June '79	3.8	-	5.6	6.1	5.6	5.7	137,000	62,200	0.45	0.010
21–24 July '79	21.3	-	17.8	15.3	8.9	15.5	368,000	34,400	0.09	0.013
25–27 July '79	9.7	-	18.8	14.8	9.9	15.4	367,000	271,000	0.74	0.035
27–30 Aug '79	16.1	-	19.6	-	17.8	19.2	457,000	168,000	0.37	0.008

*Adjusted for elevational differences as explained in the text.

Table 10. Precipitation, runoff and hydrologic response for 13 summer storms at Poker Creek, 1977–78.

Storm period	Precipitation (mm) P-4	P-1	Caribou Peak	Total*	Precipitation (m^3)	Runoff (m^3)	HR	Antecedent discharge (m^3/s)
30 May '77	2.3	-	-	2.3	138,000	194,000	1.41	0.447
4 June '77	12.7	-	-	12.7	759,000	54,100	0.07	0.269
18 June '77	3.6	-	17.3	10.5	628,000	527,000	0.84	0.447
25 June '77	0.8	-	4.6	2.7	162,000	331,000	2.05	0.214
13–14 June '77	9.9	-	17.5	13.7	819,000	89,900	0.11	0.037
21–22 June '77	3.8	-	24.3	14.1	843,000	244,000	0.29	0.138
4–5 Aug '77	12.7	-	-	12.7	759,000	147,000	0.19	0.043
15–16 June '78	4.0	6.1	5.3	5.7	341,000	226,000	0.66	0.02
11–13 July '78	8.7	9.7	20.1	12.3	736,000	77,600	0.11	0.03
20–26 July '78	12.7	22.6	7.6	17.9	1,070,000	175,000	0.16	2.75
4–7 Aug '78	15.5	16.3	8.7	14.3	855,000	65,900	0.08	2.95
13–17 Aug '78	11.5	11.7	11.6	11.7	700,000	94,300	0.14	2.75
5–6 Sept '78	15.2	16.8	16.8	16.7	999,000	281,000	0.28	-

*Adjusted for elevational differences as explained in the text.

rainfall intensity and storm duration, affect hydrologic response.

Stepwise multiple regression was also performed to clarify the relationships between antecedent discharge, rainfall and runoff volumes. This analysis provided the opportunity to see whether there was a significant relationship between rainfall and runoff volumes. The R value for this regression is 0.39, which is not significant at the 0.05 probability level.

Dingman (1971, 1973) used q_i as an index of watershed wetness in Glenn Creek; he found a significant correlation between HR and q_i for summer storms. His studies and others (e.g. Kane et al. 1981) strongly suggest that the partial- and variable-source-area concepts of streamflow generation, in which only portions of the catchment contribute overland flow, are as applicable in the Subarctic as they are in humid temperate regions. Where these processes operate, watershed wetness must exert a strong control on the amount of runoff resulting from individual storms.

Thus, the fact that no relation between q_i and HR was detectable in the data for Caribou and Poker creeks is presumably not because the partial- and variable-source-area processes are not operating. Rather, it is probably due to a combination of three factors. First, mean daily discharge data are not precise enough to use in identifying the discharge at the time a runoff-producing storm begins. Second, there are many periods for which gage-height records are lacking, and the reported values are estimates based on water level observations, water temperature and climatic data. In addition, the mean daily flows for the periods for which gage-height records exist are classified at best as "fair" by the U.S. Geological Survey (Appendix A). Finally, it is possible that the relation between the discharge and the percentage of the watershed contributing streamflow is "flat," i.e., there is only a relatively small change in contributing area with discharge, as Dunne et al. (1975) found on some watersheds they studied.

The role of antecedent wetness in determining watershed response to rainfall is critical in watershed modeling. Clearly, more detailed studies will be required to understand the nature of this role in Caribou-Poker Creeks and other subarctic watersheds.

Baseflow recessions

In an attempt to understand runoff processes in central Alaska, hydrograph recessions have been examined at Glenn Creek (Dingman 1971) and Caribou-Poker Creeks (Ford 1973). Dingman and Ford both estimated the recession limbs of hydrographs from individual summer storms. They calculated recession constants for the storms and compared them to recession constants for basins in the contiguous United States. This comparison led them to conclude that recessions in central Alaska are more drawn out in time and the drainage occurs more slowly than in similar-sized basins in the contiguous United States.

Analysis of streamflow recessions has generally been considered to be a means of identifying distinctive geological-soil characteristics of watersheds, because it is usually assumed that the drainage of a watershed following a runoff-producing event is controlled solely by the hydraulic characteristics of the watershed, especially those that affect groundwater movement and storage. These characteristics are generally considered to change little with time, or to change in ways that consistently reflect the sequential dominance of streamflow contributions from various sources, such as overland flow, interflow, and groundwater. The basis for the "classical" interpretation of recessions is generally that the watershed behaves like a linear reservoir, i.e., one in which the rate of drainage is a linear function of the amount of water remaining in storage. This assumption has persisted, in spite of the fact that 1) there is little theoretical or empirical support for the idea and 2) it can be readily shown that other inputs or outputs in the watershed (condensation and unmeasured precipitation, groundwater recharge, and evapotranspiration) cause deviations from linearity (Dingman 1973, Federer 1973). It is becoming increasingly apparent that these inputs and outputs occur regularly and cannot be ignored.

The conditions in the fall and winter at Caribou-Poker Creeks should be ideal for determining the true recession characteristics, because 1) all the sources of input are frozen, 2) evapotranspiration is negligible, and 3) groundwater is likely to be the sole source of streamflow. The recession curves (Fig. 13) show that streamflow persisted through most winters. The flows tended to converge to between 0.05 and 0.10 m^3/s by the end of the season.

In general, though, the recession characteristics varied widely. The 1 October flows for 1974, 1975, and 1976 (curves F, G and H) were nearly identical, yet the subsequent recessions were very dissimilar. In the 1974-75 season the recession decay constant was about 0.019/day until December, when it dropped nearly to zero; a total of 24 mm of water ran off during that winter. In 1975-76 the recession constant was twice as high (0.042/day), and only 7.8 mm ran off before flow ceased altogether in mid-December. In 1976-77 the recession constant was close to the initial 1974-75 value (0.017/day), but it did not change; 22 mm of water ran off that winter.

Clearly, interpreting the winter hydrograph recessions of Caribou Creek is not straightforward, particularly because no streamflow measurements or gage-height obervations are available for these periods. However, even measured flow

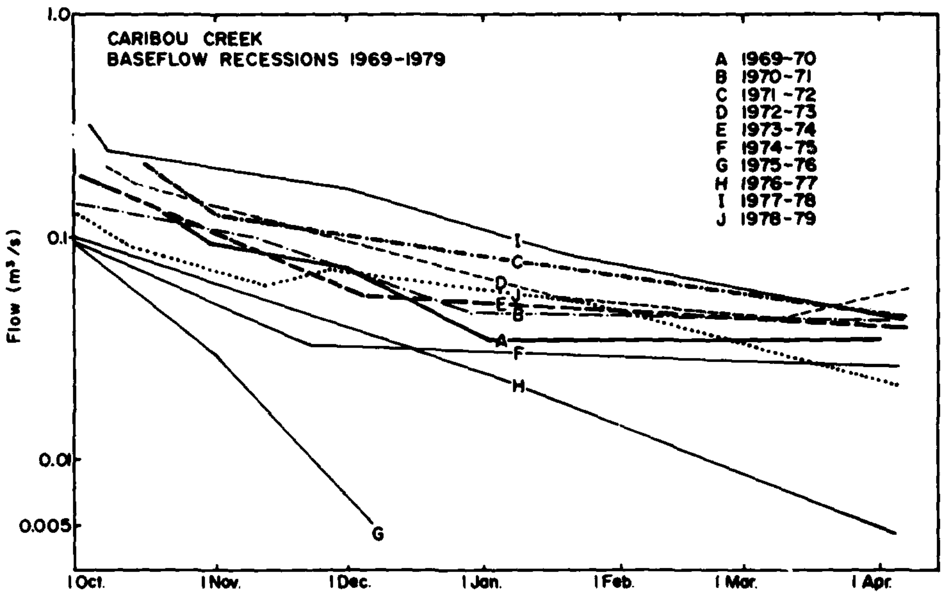


Figure 13. Baseflow recession curves for Caribou Creek, 1969–1979.

data might not reflect the basin hydrologic characteristics, because subchannel freezing, which might vary considerably from year to year, could significantly affect winter discharges. In any case, the interpretation of recessions, classical or otherwise, must await more detailed information on subchannel conditions and other hydrologic characteristics.

Spatial flow variability

Studies of runoff generation in interior Alaska (Dingman 1971, 1973, Kane et al. 1981) suggest that the extent of permafrost exerts a strong control on the open-water-season hydrologic response of small watersheds. Kane et al. (1981) studied the differences in runoff processes between permafrost-underlain and permafrost-free soils in Glenn Creek and found that permafrost-underlain soils contributed the major portion of spring runoff. During winter the organic layer over these soils provides a moisture supply for vertical transport upward to the snowpack, increasing its water equivalent. The organic mat becomes dessicated over the winter, so during snowmelt, water from the snowpack may be used to satisfy its moisture deficit instead of becoming runoff (Santeford 1978, Slaughter and Kane 1978, Kane et al. 1981).

In permafrost areas the poorly drained mineral soils under this mat often cause ice-rich conditions to develop in the vicinity of streams and valley bottoms. The ice restricts drainage, so that once the organic mat moisture deficit is satisfied, water in these areas moves downslope through the mat to the stream.

On the other hand, soils in permafrost-free areas are moderately well drained (even when frozen), so water can infiltrate them once the organic mat moisture deficit has been satisfied. No overland flow will occur until the infiltration capacity of these soils is exceeded. Kane et al. (1981) observed no overland flow on permafrost-free, south-facing slopes, indicating that this rarely occurs (Dingman 1971). As a result, permafrost-free soils contribute little to runoff during snowpack ablation.

Discharge measurements taken at the outlets of subwatersheds C-2 and C-3 approximately once a week from May through October in 1969 and 1970 allow comparisons of summer runoff from permafrost- vs nonpermafrost-underlain areas (Appendix A). Permafrost and poorly drained soils are widespread in C-3 and nearly absent in C-2 (Table 11). The entire main channel of C-3 is underlain by permafrost, while only the lowest portion of the main channel of C-2 is situated in permafrost (Fig. 3). These differences should be reflected in the response to snowpack ablation (Kane et al. 1981) and precipitation (Slaughter and Kane 1979).

Figure 14 shows the cumulative frequency distributions for the instantaneous discharge mea-

Table 11. Geomorphological and soils data for subwatersheds C-2 and C-3, Caribou Creek and Glenn Creek.

	*C-2**	*C-3**	*Caribou Creek*	*Glenn Creek†*
Drainage area (km²)	5.2	5.54	23.8	1.81
Aspect	South	Northeast	East	Northwest
Elevation range (m)	323-738	274-770	256-770	257-493
Relief ratio**	0.155	0.133	—	0.79
Elongation ratio**	0.97	0.76	0.68	0.51
Drainage density (km/km²)	4.72	3.57	0.93	1.64
Predominant soil series	Gilmore (well drained)	Ester (poorly drained)	Olnes (well drained)	—
Area underlain by permafrost (%)	3.5	53.2	23.8	68.5

*Data from Bredthauer and Hoch (1979).
†Data from Dingman (1971).
**See Bredthauer and Hoch (1979) for definitions.
††Calculated from aerial photographs by Bredthauer and Hoch (1979). (Table 1 values were calculated from USGS topographic maps.)

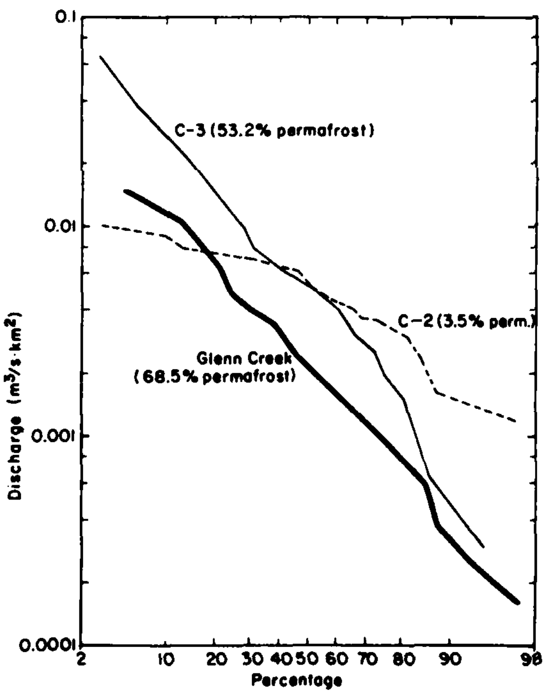


Figure 14. Cumulative frequency distributions of spot measurements at C-2 and C-3 (1969 and 1970) and Glenn Creek (1964).

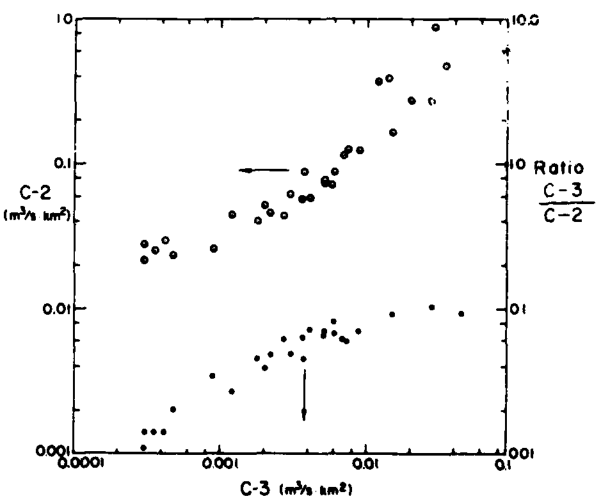


Figure 15. Comparison of concurrent flows on C-2 and C-3 for spot measurements, 1969 and 1970. The closed circles represent the flows on C-2 vs the concurrent flows on C-3; the open circles represent the ratio of concurrent flows (C-3/C-2) vs flows on C-3.

Table 12. Means and coefficients of variation of the monthly stream flow per watershed area for Caribou Creek, Chena River near Two Rivers, Chena River at Fairbanks and Salcha River near Salchaket, 1969–79.

	Caribou Creek (23.8 km²)		*Chena River near Two Rivers (2437 km²)*		*Chena River at Fairbanks (5130 km²)*		*Salcha River near Salchaket (5620 km²)*	
	Mean ($m^3/s \cdot km^2$)	*Coefficient of variation*	*Mean ($m^3/s \cdot km^2$)*	*Coefficient of variation*	*Mean ($m^3/s \cdot km^2$)*	*Coefficient of variation*	*Mean ($m^3/s \cdot km^2$)*	*Coefficient of variation*
June	0.0094	49	0.0143	62	0.0123	44	0.0166	42
July	0.0084	50	0.0096	44	0.0094	29	0.0115	30
August	0.0080	74	0.0109	62	0.0099	43	0.0112	35
September	0.0076	41	0.0107	50	0.0096	33	0.0105	32
October	0.0065	65	0.0057	33	0.0060	43	0.0048	25
November	0.0038	47	0.0029	24	0.0033	36	0.0023	26
December	0.0026	50	0.0019	32	0.0023	35	0.0016	38
January	0.0021	38	0.0013	39	0.0017	29	0.0012	42
February	0.0017	41	0.0010	40	0.0014	29	0.0009	44
March	0.0016	38	0.0009	44	0.0013	23	0.0008	50
April	0.0026	50	0.0016	50	0.0021	33	0.0017	65
May	0.0196	54	0.0235	57	0.0197	42	0.0226	43
Mean	0.0063	29	0.0075	32	0.0067	27	0.0073	23

surements on C-2 and C-3. For comparison, a similar number of instantaneous discharge measurements for May through October 1964 on Glenn Creek are also plotted (Dingman 1971).

Although the median discharge values for C-2 and C-3 are virtually identical, differences in their distributions reflect important differences in the behavior of the two watersheds. C-3 and Glenn Creek have higher peak flows and lower base flows than C-2. The values for C-3 range over almost three orders of magnitude, while those for C-2 cover only one order of magnitude suggesting that C-3 is much "flashier" in its response to precipitation (Slaughter and Kane 1979). Figure 15 further illustrates this contrast: when flows are generally high, C-3 has instantaneous rates as much as ten times higher than the approximately concurrent flows on C-2; when flows are low, discharges on C-3 are as little as 25% of those on C-2.

It is generally believed that the distributions of high flows are controlled largely by climate, topography and vegetative cover, while the difference of low-flow characteristics are controlled chiefly by drainage-basin geology (Searcy 1959). However, Dingman's (1978) studies in New Hampshire indicated that climate may also have a significant influence on the distribution of low flows. Since climatic conditions are similar in subwatersheds C-2 and C-3, differences in response characteristics may be related to 1) percentage of permafrost, 2) watershed size, 3) watershed shape, 4) characteristics of the drainage networks, 5) watershed slope, and 6) soils and land use. Table 12 contains pertinent geomorphological and soils data for subwatersheds C-2, C-3 and Caribou and Glenn creeks watersheds. The difference in size between subwatersheds C-2 and C-3 is minor (0.5 km²) and cannot be responsible for the major contrast reflected in Figure 14. The relief ratio (an index of basin slope), the elongation ratio (an index of basin shape), and the drainage density (an index of the drainage efficiency of the stream network) are all lower for C-3. This would cause C-3 to be less flashy than C-2, which is the opposite of what was observed.

Thus, most of the differences in response between C-2 and C-3 appear to be attributable to the percentage of permafrost in the two watersheds. The plots of the data for Glenn Creek, with 68.5% permafrost, are essentially parallel to those for C-3, in spite of the considerably lower relief ratio and drainage density of Glenn Creek. Response differences between C-2 and C-3 indicate that the variable-source-area process may be operating as suggested by Dingman (1971) for Glenn Creek. If so, the restricted drainage due to permafrost results in more widespread saturated and nearly saturated zones and thus more overland flow in C-3, as reflected in Figure 14. To the extent that Hortonian overland flow occurs, the more widespread poorly drained soils in C-3 may also result in more overland flow to the channel. The widespread permafrost on slopes and beneath the channel in C-3 may result in much smaller groundwater contributions and lower base flows than in C-2, as shown in Figure 14.

This apparent dependence of streamflow response on permafrost area may be different in larger watersheds with considerably different slopes or land use characteristics. In larger basins, even if permafrost is extensive, it may be absent or at great depths beneath their main channels, so that groundwater contributions sustain significant base flows. However, Anderson (1970) did not see such effects, even in the Salcha River near Salchaket or the Chena River at Fairbanks. Their drainage areas are 5620 and 5130 km^2, respectively, considerably larger than Poker and Caribou creeks. Only in the Tanana River at Big Delta (3500 km^2) and the Chisana River at Northway Junction (8500 km^2) were significant base flows sustained by groundwater.

This analysis suggests that the hydrologic response of small watersheds in central Alaska is strongly controlled by permafrost. When permafrost underlies a significant portion of a watershed and is present beneath most stream channels, the streamflow peaks in response to rainstorms will be relatively high, and the base flows between storms will be relatively low. Watersheds with little permafrost will have lower peaks and higher sustained base flows per unit area. This suggests that mapping the permafrost in ungaged watersheds would provide useful clues to their behavior.

Temporal flow variability

Mean monthly flow values for Caribou Creek, the Chena River near Two Rivers and at Fairbanks, and the Salcha River near Salchaket are graphed in Figure 16 and listed in Table 12, along with coefficients of variation of mean monthly flow, to illustrate similarities and differences in flow patterns between these central Alaskan rivers. As shown in Table 12, monthly streamflow variability tends to be highest during the spring and summer and lowest in the fall and winter, when streamflow is also low. On the three smaller watersheds the highest flow variability coefficients are for the summer months, probably in response to individual storms. High streamflow variability in April and May, reflecting snowmelt runoff, is evident for all four watersheds. The two smaller watersheds, Caribou Creek and Chena near Two Rivers, show higher mean flow variability that the larger Chena at Fairbanks and Salcha watersheds.

Figure 16 shows that Caribou Creek, the smallest river, has lower summer flows and higher winter flows per unit area than the other rivers. The lower summer flows probably reflect the fact that the mean elevation, and hence the mean precipitation, of Caribou Creek is lower than those of the others; the higher winter flows suggest that Caribou Creek may have more storage per unit area.

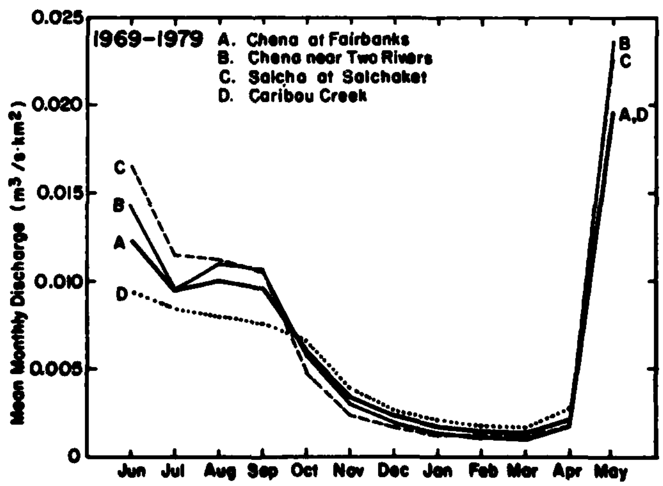


Figure 16. Mean monthly discharge per watershed area for the Chena River at Fairbanks, the Chena River near Two Rivers, the Salcha River near Salchaket and Caribou Creek, 1969–1979.

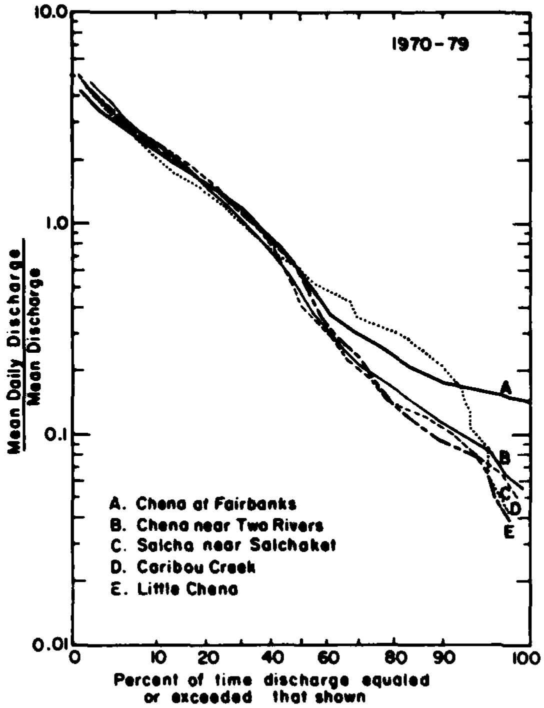


Figure 17. Flow-duration curves of the ratio of mean daily discharge to mean discharge for the Chena River at Fairbanks, the Chena River near Two Rivers, the Salcha River near Salchaket, Caribou Creek and the Little Chena River at Fairbanks, 1970–1979.

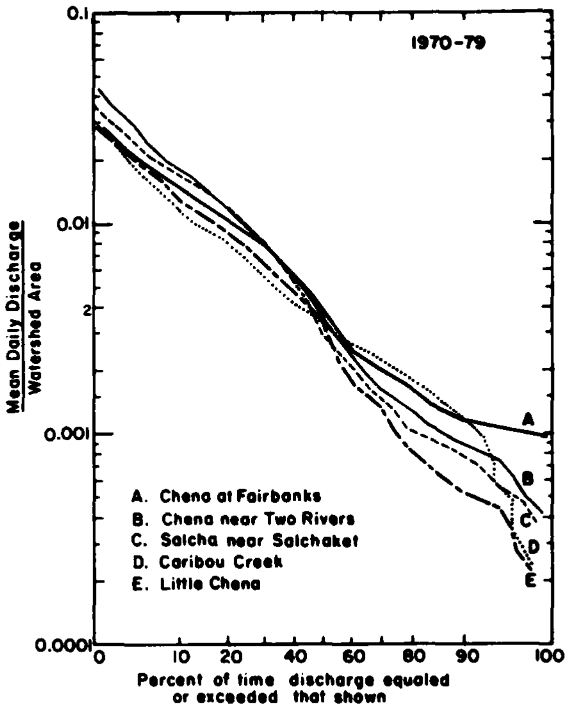


Figure 18. Flow-duration curves of the mean daily discharge per watershed area for the Chena River near Two Rivers, the Chena River at Fairbanks, the Salcha River near Salchaket, Caribou Creek and the Little Chena River at Fairbanks, 1970–1979.

For comparative purposes, flow-duration curves of mean daily discharge of Caribou Creek, the Chena River at Fairbanks and near Two Rivers, the Salcha near Salchaket and the Little Chena were plotted in two ways: 1) as discharge per unit area ($m^3/s \cdot km^2$) and 2) as the ratio of daily discharge to mean discharge (Figs. 17 and 18). Duration curves of mean daily discharge often approximate straight lines when plotted on logarithmic/probability paper (i.e. the distributions are approximately log-normal), and the slopes of the lines are measures of the time variability of the flows. Thus, a drainage basin with a limited capacity for storage of groundwater and surface water and with relatively steep slopes will have a steeper flow-duration curve than a basin containing permeable geologic formations, widespread lakes and swamps, and low slopes. Drainage-basin size may be inversely related to the slopes of flow-duration curves, since larger basins tend to have more channels and groundwater storage per unit area because of the characteristics of channel networks and because larger basins tend to have more opportunities for interception of regional groundwater flow patterns. Based on the streamflow measurements in subwatersheds C-2 and C-3 one would also expect that basins with relatively large areas underlain by permafrost would have considerably more variable flows than those with little permafrost.

The curves for the Chena River at Two Rivers (2437 km^2) and the Salcha River near Salchaket (5620 km^2) are virtually identical (Figs. 17 and 18). The curves for the Chena River at Fairbanks (5130 km^2) and Caribou Creek (23.8 km^2) are also virtually identical to the others at high flows but deviate markedly from them and from each other at low flows in ways that suggest significant storage effects. Because the drainage basin of Caribou Creek is more than an order of magnitude smaller than the others, this effect is unexpected. Furthermore, groundwater probably does not contribute significantly to the flow of Caribou Creek because of the basin geology (Koutz and Slaughter 1972) and because the ma-

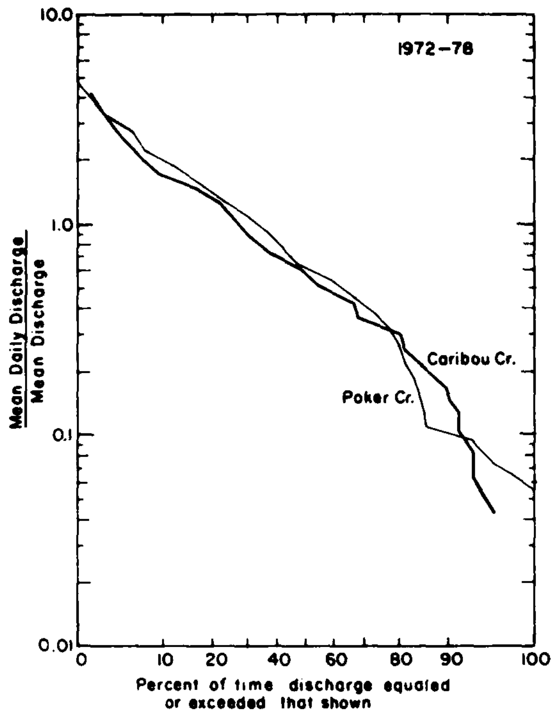


Figure 19. Flow-duration curves of the ratio of mean daily discharge to mean discharge for Caribou and Poker creeks, 1972–1978.

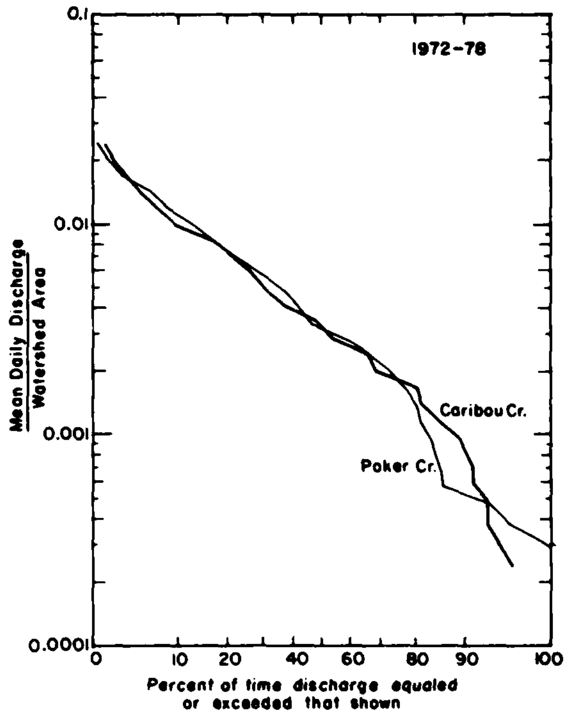


Figure 20. Flow-duration curves of the mean daily discharge per watershed area for Caribou and Poker creeks, 1972–1978.

jor streams in the basin are underlain by permafrost at shallow depths (Bredthauer and Hoch 1979).

The flow-duration curves for Caribou and Poker creeks (59.9 km^2) for 1972–1978 (Figs. 19 and 20) do not show striking dissimilarities, which is not surprising in view of their similarities in geology, permafrost coverage, vegetation, topography and climate. The larger basin may have higher extreme low flows, perhaps reflecting somewhat greater groundwater contributions. However, all interpretations of the flow-duration curves for Poker and Caribou creeks must be tempered by the fact that gage-height records for both are lacking for much of each water year, and flows for those periods that tend to be the periods of lowest and highest flows are estimates. It is thus probable that some of the similarities of the curves of Poker and Caribou creeks to each other and to other streams in the region are artifacts, and it is possible that some of the dissimilarities are due to errors of measurement.

To compare the flow-duration curves from central Alaska streams with those for streams in more temperate areas, a "variability index" is computed. This index, as defined by Lane and Lei (1950), is proportional to the standard deviation of the logarithms of the daily flows. Lane and Lei computed this value for a large number of streams in the north-central and northeastern United States and found values ranging from 0.15 to 1.09 $\log_{10}$ units. For the periods of record on the Chena and Salcha rivers (1949–1979 in both cases) the values are 0.43 and 0.55, respectively; these are near the center of the values listed by Lane and Lei.

Published flow-duration data for streams with drainage areas in the range of Poker and Caribou creeks are rare, and very few are included in Lane and Lei's extensive list. However, Dingman (1981) has studied the ratio of the mean daily flow exceeded 5% of the time to that exceeded 95% of the time for small to moderate-sized basins in New Hampshire and Vermont. For basins larger than 30 km^2, this ratio ranged from about 19 to 80, while for smaller streams it ranged from 20 to 630. The corresponding value for Caribou Creek is close to 35, indicating a relatively low variability when compared to Dingman's sample.

In summary, the flow-duration curves of Poker and Caribou creeks are very similar to those of other, considerably larger central Alaskan streams, although their low flows may be unusually high for basins of their size. The flow-duration curves for larger central Alaskan streams have variabilities much like those of streams from the north-central and northeastern United States, while the variability of Poker and Caribou creeks appears low when compared with small and moderate-sized streams in New England.

SUMMARY AND CONCLUSIONS

An analysis of 11 years of climatic data revealed that the Caribou-Poker Creeks Research Watershed precipitation record does not represent any extremely wet or dry years and thus may not reflect any years of abnormally high or low streamflow. Annual precipitation values at the watershed were, with one exception, within one standard deviation of the normal mean value. Precipitation values were compared with the Fairbanks record, and it was found that the watershed received more precipitation than Fairbanks, due primarily to its higher elevation. Watershed precipitation can be estimated from Fairbanks values by multiplying mean annual values by 1.7 or summer values by 1.47.

Streamflow response to summer storms does not seem to depend on antecedent discharge, although the relationship could be masked by the use of mean daily (rather than hourly) flow values and by inadequate gage height information. Average hydrologic response values (storm runoff divided by storm rainfall) for summer storms were 0.35 for Caribou Creek and 0.49 for Poker Creek. Instantaneous discharge measurements on subwatersheds C-2 (3.5% permafrost) and C-3 (53.2% permafrost) indicated that permafrost-underlain areas are flashier in response to precipitation than nonpermafrost areas. The north-facing, predominantly permafrost-underlain areas of the watershed contribute more overland flow to streams during snowmelt and greater runoff as a result of summer precipitation than moderately well drained permafrost-free slopes. Glenn Creek (68.5% permafrost) behaves in a similar manner to C-3, suggesting that permafrost strongly controls streamflow response in central Alaska.

Mean monthly discharge values and flow-duration curves of mean daily discharge for Caribou Creek, the Chena at Fairbanks and near Two Rivers, the Salcha near Salchaket, and the Little Chena were used to compare temporal flow variability among central Alaskan streams. Caribou Creek has higher winter flows and lower summer flows than the other rivers, suggesting that its basin has greater storage capacity per unit area than the other rivers, even though its basin is an order of magnitude smaller than the others. Mean annual flow variability is similar to that of the Chena River at Fairbanks and the Salcha River near Salchaket but is relatively low when compared to similar-sized streams in northern New England.

SELECTED BIBLIOGRAPHY

Anderson, G.S. (1970) Hydrologic reconnaissance of the Tanana Basin, central Alaska. U.S. Geological Survey Hydrologic Investigations HA-319.

Benson, C.S. (1967) A reconnaissance snow survey of interior Alaska. UAGR-190, Geophysical Institute, University of Alaska, College, Alaska.

Benson, C.S. (1969) The seasonal snow cover of arctic Alaska. The Arctic Institute of North America, Research Paper 51, Washington, D.C.

Benson, C.S. (1979) Studies on the seasonal snow cover of the Caribou-Poker Creeks Research Watershed during the winters of 1974/75 and 1975/76. In *Proceedings of 30th Alaska Science Conference*, Alaska Division, American Association for the Advancement of Science, Fairbanks, Alaska.

Bilello, M.A. (1966) Survey of arctic and subarctic temperature inversions. CRREL Technical Report 161. AD 645597.

Bilello, M.A. (1974) Air masses, fronts and winter precipitation in central Alaska. CRREL Research Report 319. AD 780696.

Bredthauer, S.R. (1977) Caribou-Poker Creeks Research Watershed: Basic data report, 1 January 1974 through 31 December 1974. Inter-Agency Technical Committee for Alaska. Also CRREL Technical Note (unpublished).

Bredthauer, S.R. (1979) Snowmelt runoff from a subarctic watershed. In *Proceedings of 30th Alaska Science Conference*, Alaska Division, American Association for the Advancement of Science, Fairbanks, Alaska.

Bredthauer, S.R. and D. Hoch (1979) Drainage network analysis of a subarctic watershed: Caribou-Poker Creeks Research Watershed, interior Alaska. CRREL Special Report 79-19. ADA 073595.

Brown, J., S.L. Dingman, R.I. Lewellen (1968) Hydrology of a drainage basin on the Alaskan coastal plain. CRREL Research Report 240. ADA 671005.

Burns, L.E. and D. Hawkins (1979) Statistical analyses of the chemical composition of waters from the Poker-Caribou Creeks Research Watershed. In *Proceedings of 30th Alaska Science Conference,* Alaska Division, American Association for the Advancement of Science, Fairbanks, Alaska (abstract).

Carlson, R.F. (1972) Development of a conceptual hydrologic model for a subarctic watershed. Institute of Water Resources, University of Alaska, Report No. IWR-28, Fairbanks, Alaska.

Dingman, S.L. (1966a) Hydrologic studies of Glenn Creek drainage basin near Fairbanks, Alaska. CRREL Special Report 86. AD 631948.

Dingman, S.L. (1966b) Characteristics of summer runoff from a small watershed in central Alaska. *Water Resources Research,* vol. 2, p. 751-754.

Dingman, S.L. (1971) Hydrology of the Glenn Creek Watershed, Tanana River Basin, central Alaska. CRREl Research Report 297. AD 732410.

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, D.C., p. 447-453.

Dingman, S.L. (1981) Elevation: A major influence on the hydrology of New Hampshire and Vermont, U.S.A. *Hydrological Sciences Bulletin,* vol. 26, no. 4, p. 399-413.

Dunne, T., T.R. Moore and C.H. Taylor (1975) Recognition and prediction of runoff-producing zones in humid regions. *Hydrological Sciences Bulletin,* vol. 20, no. 3, p. 305-327.

Environmental Data Service (1972) Climatological data, Alaska. U.S. Dept. of Commerce, National Oceanic and Atmospheric Administration.

Federer, C.A. (1973) Forest transpiration greatly speeds steamflow recession. *Water Resources Research,* vol. 9, p. 1599-1604.

Feulner, A.J., J.M. Childers and V.W. Norman (1971) Water resources of Alaska. Open-file report, Alaska District, Water Resources Division, U.S. Geological Survey, Anchorage, Alaska.

Fitzgibbon, J.E. and T. Dunne (1980) Snowmelt prediction in a subarctic drainage area. *Nordic Hydrology,* vol. 11, no. 5, p. 243-254.

Ford, T.R. (1973) Precipitation-runoff characteristics of the Caribou Creek research watershed near Fairbanks, Alaska. Unpublished M.S. thesis, University of Alaska, College, Alaska.

Freeman, T.G. (1970) Summary of snow survey measurements for Alaska. USDA Soil Conservation Service and Alaska Soil Conservation District.

Hall, F.R. (1968) Baseflow recessions—A review. *Water Resources Research,* vol. 4, no. 5, p. 973-983.

Hamilton, T.D. (1965) Alaskan temperature fluctuations and trends—An analysis of recorded data. *Arctic,* vol. 18, p. 105-117.

Hare, F.K. (1971) Snow-cover problems near the Arctic tree-line of North America. Report of the Kevo Subarctic Research Station, vol. 8, p. 31-40.

Haugen, R.K., M.J. Lynch and T.C. Roberts (1971) Summer temperatures in interior Alaska. CRREL Research Report 244. AD 733317.

Haugen, R.K. and J. Brown (1979) Climatic and dendroclimatic indices in the discontinuous permafrost zone of the central Alaska Uplands. In *Proceedings of the Third International Conference on Permafrost, 1978,* Edmonton, Alberta, Canada, National Research Council of Canada, vol. 1, p. 393-398.

Helmers, A.E. and C.T. Cushwina (1973) Research opportunities and needs in the Taiga of Alaska. USDA, Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-2, Portland, Oregon.

Hershfield, D.M. (1965) On the spacing of rain gages. International Association of Hydrological Sciences, Symposium on Design of Hydrological Networks, Publication No. 67, p. 72-79.

Hershfield, D.M. (1973) The frequency of freeze-thaw cycles. *Journal of Applied Meteorology,* vol. 13, p. 7.

Hewlett, J.D. and A.R. Hibbert (1967) Factors affecting the response of a small watershed to precipitation in humid regions. In *Forest Hydrology,* (William E. Sopper and Howard W. Lull, eds.), Oxford: Pergamon Press, p. 275-290.

Hilgert, J. (1979) Upland stream quality in the Caribou-Poker Creeks Research Watershed. In *Proceedings of 30th Alaska Science Conference,* Alaska Division, American Association for the Advancement of Science, Fairbanks, Alaska, p. 146 (abstract).

Hobgood, T.W. and C.W. Slaughter (1974) Caribou-Poker Creeks Research Watershed: Basic data report, 1 April 1970 through 31 December 1970. Inter-Agency Technical Committee for Alaska. Also CRREL Technical Note (unpublished).

Interagency Committee on Water Resources (1964) Guidance Memorandum No. 1, Subject:

Comprehensive Plan for Collection of Hydrologic Data in Alaska. Interagency Committee on Water Resources, Subcommittee on Hydrology, Washington, D.C.

Inter-Agency Technical Committee for Alaska (1979) Alaska ten-year comprehensive plan for climatologic and hydrologic data. Third edition.

Jinkinson, W.M., F.B. Lotspeich and E.W. Mueller (1973) Water quality of the Caribou-Poker Creeks Research Watershed, Alaska. Working Paper No. 24, Arctic Environmental Research Laboratory, U.S. Enviromental Protection Agency, College, Alaska.

Johnson, P.R. and C.W. Hartman (1969) *Environmental atlas of Alaska.* Institute of Arctic Environmental Engineering and Institute of Water Resources, University of Alaska, College, Alaska.

Jorgenson, T. and C.W. Slaughter (1981) Vegetation of the Caribou-Poker Creeks Research Watershed, central Alaska: Revised mapping and preliminary geogotanical analysis. USDA Pacific Northwest Forest and Range Experimental Station, Research Note.

Kane, D.L. and C.W. Slaughter (1972) Seasonal regime and hydrological significance of stream icings in central Alaska. *International Symposium on the Role of Snow and Ice in Hydrology,* Banff, Alberta, UNESCO/WMO/IAHS Publication, p. 528-540.

Kane, D.L., S.R. Bredthauer and J. Stein (1981) Subarctic snowmelt runoff generation. *Proceedings of the Specialty Conference on the Northern Community,* Seattle, Washington, p. 591-601.

Knisel, W.G. (1963) Baseflow recession analysis for comparison of drainage basins and geology. *Journal of Geophysical Research,* vol. 68, no. 12, p. 3649-3653.

Koutz, F.R. and C.W. Slaughter (1972) Geologic setting of the Caribou-Poker Creeks Research Watershed, interior Alaska. Unpublished memo, CRREL.

Koutz, F.R. and C.W. Slaughter (1973) Equivalent latitude (potential insolation) and a permafrost environment: Caribou-Poker Creeks Research Watershed, interior Alaska. CRREL Technical Note (unpublished).

Kunkle, G.R. (1962) The baseflow-duration curve, a technique for the study of groundwater discharge from a drainage basin. *Journal of Geophysical Research,* vol. 67, no. 4, p. 1543-1554.

Lane, E.W. and K. Lei (1950) Streamflow variability. *American Society of Civil Engineers Transactions,* vol. 115, p. 1084-1134.

Lotspeich, F.B., R.L. Jackson, and A.E. Helmers (1976) Climatological and water quality data, Caribou-Poker Creeks Research Watershed. Arctic Environmental Research Laboratory Working Paper No. 30, (CERL No. 14), U.S. Environmental Protection Agency, College, Alaska.

Lotspeich, F.B. and C.W. Slaughter (1981) Preliminary results on structure and functioning of a taiga research watershed. Institute of Water Resources, University of Alaska, Fairbanks, Alaska.

Luthin, J.N. and G.L. Guymon (1974) Soil moisture-vegetation-temperature relationships in central Alaska. *Journal of Hydrology,* vol. 23, no. 3/4, p. 233-246.

Miller, J.F. (1963) Probable maximum precipitation and rainfall-frequency data for Alaska for areas to 400 square miles, duration to 24 hours, and return periods from 1 to 100 years. U.S. Weather Bureau, Technical Paper No. 47.

Nordenson, T.J. (1968) Preparation of coordinated precipitation, runoff and evaporation maps. World Meteorolgical Organization International Hydrologic Decade, Report No. 6.

Pielke, R. and P. Mehring (1976) Use of mesoscale climatology in mountainous terrain to improve the spatial representation of mean monthly temperatures. *Monthly Weather Review,* vol. 105, p. 108-112.

Rieger, S., C.E. Furbush, D.B. Schoephorster, H. Summerfield and L.C. Geiger (1972) Soils of the Caribou-Poker Creeks Research Watershed, Alaska. CRREL Technical Report 236. AD 744451.

Santeford, H.S. (1976) A preliminary analysis of precipitation in the Chena Basin, Alaska. National Oceanic and Atmospheric Administration Technical Memorandum NWS AR-15, Anchorage, Alaska.

Santeford, H.S. (1978) Snow-soil interaction in interior Alaska. *Proceedings, Modeling of Snow Cover Runoff* (S.C. Colbeck and M. Ray, eds.), CRREL, Hanover, N.H., p. 311-318.

Searcy, J.K. (1959) *Flow-duration curves,* U.S. Geological Survey Water Supply Paper 1542-A.

Slaughter, C.W. (1970a) Caribou-Poker Creeks Research Watershed, Basic data report, period ending December 1969. IATCA and CRREL Technical Note (unpublished).

Slaughter, C.W. (1970b) Caribou-Poker Creeks Research Watershed, Basic data report, 1 January-31 March 1970. Inter-Agency Technical Committee for Alaska. Also, CRREL Technical Note (unpublished).

Slaughter, C.W. (1970c) A subarctic research watershed. *EOS: Transactions, American Geophysical Union,* vol. 52, no. 5, p. 434 (abstract).

Slaughter, C.W. (1971) Caribou-Poker Creeks Research Watershed: Background and current status. CRREL Special Report 157. AD 726373.

Slaughter, C.W. (1972) Caribou-Poker Creeks Research Watershed: Summary of hydrologic data, 1970 water year (1 October 1969–30 September 1970). CRREL Technical Note (unpublished).

Slaughter, C.W. (1977) Circumpolar subarctic research basins. PNW Regional Meeting, American Geophysical Union, Portland, Oregon (abstract).

Slaughter, C.W., T.G. Freeman and G.L. Audsley (1974) Cooperation in water resources programs: Alaska's example. *Water Resources Bulletin*, vol. 10, no. 4, p. 802–812.

Slaughter, C.W. and A. Helmers (1974) An expanding role for subarctic watershed research. *Water Resources Bulletin*, vol. 10, no. 2, p. 256–264.

Slaughter, C.W., T.W. Hobgood and C.D. Carver (1975) Caribou-Poker Creeks Research Watershed: Basic data report, 1 January 1972 through 31 December 1972. CRREL Technical Note (unpublished).

Slaughter, C.W. and H.S. Santeford (1975) High latitude research basins as settings for circumpolar environmental studies. In *Proceedings, Circumpolar Conference on Northern Ecology*. National Research Council of Canada, Ottawa, Ontario, p. IV-57 - IV-68.

Slaughter, C.W. and S.R. Bredthauer (1977) Caribou-Poker Creeks Research Watershed: Basic data report, 1 January 1973 through 31 December 1973. Inter-Agency Technical Committee for Alaska. Also, CRREL Technical Note (unpublished).

Slaughter, C.W. and F.B. Lotspeich (1977) Caribou-Poker Creeks Research Watershed. *Arctic Bulletin*, vol. 2, no. 10, p. 182–188.

Slaughter, C.W. and J.W. Hilgert (1978) Upland stream system quality in the Taiga. PNW Regional Meeting, American Geophysical Union, Tacoma, Washington (abstract).

Slaughter, C.W. and D.L. Kane (1979) Hydrologic role of shallow organic soils in cold climates. In *Canadian Hydrology Symposium 79—Cold Climate Hydrology Proceedings*. National Research Council of Canada, p. 380-389.

Spetzman, L.A. (1963) Terrain study of Alaska, Part V: Vegetation. In *Engineering Intelligence Study*, EIS 301, U.S. Dept. of Army, Office of the Chief of Engineers, Washington, D.C.

Streter, N.A. (1969) Aspects of winter temperatures in interior Alaska. *Arctic*, vol. 22, no. 4, p. 403–412.

Trabant, D. and C.S. Benson (1972) Field experiments on the development of depth hoar. In *Studies in mineralogy and Precambrian geology*. Geological Society of America Memoir 135, p. 309–322.

Troth, J.L., F.J. Deneke and L.M. Brown (1975) Subarctic plant communities and associated litter and soil profiles in the Caribou Creek Research Watershed, interior Alaska. CRREL Research Report 330. AD 009063.

U.S. Department of Commerce (1973) Monthly normals of temperature, precipitation, and heating and cooling degree-days, 1941–1970. National Oceanic and Atmospheric Adminstration, Asheville, North Carolina.

U.S. Department of Commerce (1975–1978) Climatological data: Annual summary, Alaska. National Oceanic and Atmospheric Administration, Asheville, North Carolina.

U.S. Department of Commerce (1977) Comparative climatic data through 1976. National Oceanic and Atmospheric Administration, Asheville, North Carolina.

U.S. Department of Commerce (1980) Local climatological data annual summary with comparative data, Fairbanks, Alaska. National Oceanic and Atmospheric Administration, Asheville, North Carolina.

U.S. Geological Survey (1969–1980) Water resources data for Alaska. U.S.G.S. Water Resources Division, Anchorage, Alaska.

U.S. Soil Conservation Service (1972) *National Engineering Handbook*. SCS Hydrology, Section 4, Washington, D.C.

Viereck, L.A. and C.T. Dyrness (1980) A preliminary classification systems for vegetation of Alaska. USDA Pacific Northwest Forest and Range Experiment Station, General Technical Report PNW-106.

Vogel, T.C. and C.W. Slaughter (1972) A preliminary vegetation map of Caribou-Poker Creeks Research Watershed, interior Alaska. CRREL Technical Note (unpublished).

Wahrhaftig, C. (1965) Physiographic divisions of Alaska. U.S. Geological Survey Professional Paper 482.

APPENDIX A: STATION HISTORIES.

Table A1. Station history of air temperature measurements.

Caribou Main (264 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969											X	X
1970												
1971				X	X	X	X	X	X	X	X	
1972						X	X	X	X			
1973			/		X	X	X	X	X	X	X	X
1974	X	X	X	X	X	X	X	X	X	X		
1975								/	/	/	X	/
1976	/	X	X	/	/	X	X	X	X	X	X	
1977	/		/	/	X	/	X	/	X	X	/	/
1978	/	X	X	X	X	/	X	X	X	X	/	/
1979	/	/	/	X	X	X	X	X	X	X	/	/

C-2-2100 (616 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1971						X	X	X	X	X	X	X
1972							X	X	X			
1973												
1974												
1975												
1976									/	/	X	X
1977	X		/	/	/	X	/	/	X	X	/	/
1978	X	X	X	/	X	X	X	X	X	X	X	X
1979	X	/	X		X	X	X	/		X	X	/

C-1 (325 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969										X	X	X
1970	/	X	X									
1971			X	X	/	X	X	X	X	X		
1972							X	X	X	X	X	X
1973	X	X	X	X	X	X	X	X	X	X	X	X
1974	X	X	X	X	X	X		X	X	/		X
1975							/	X	X	/	/	
1976			/	/	X	/		/	X	/	/	X
1977	/		/	/	X	X	/	/	X	X	/	X
1978	X	X	X	X	X	X	X	X	X	X		

C-2-UPPER (381 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969										X	X	X
1970												
1971							X	X	X	X	X	
1972						X	X	X	X	X	/	/
1973				X	X	X	X	X	X	X		
1974			X	/	X	X	X	X	X	X	X	X
1975							/				/	
1976			/	/	X	/	X	X	X	X	X	/
1977	X			/	X	/	X	/	X	/	/	/
1978	/	X	/	X	X	X	X	X	X	/	X	

C-2-LOWER (323 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969										X	X	X
1970	X	X	X									
1971		X	X	X	/	X	X	X	X	X	X	
1972				X	X	X	X	X	X	X		
1973		/	/						X	/		X
1974	/		X	X	X	X	/	X				X
1975								X	/	/	/	
1976							/				/	/
1977	/		/	/	/	/	X	/	X	X	/	/
1978	X	X	X	/	/	/	X	X	X	X	/	
1979	/		X	X	/			/	/	/	X	X

C-3-LOWER (298 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969										X	X	X
1970	X	X	X									
1971		X	X	X	X	X	X	X	X	X	X	X
1972	X	X	X	X	X	X	X	X	X	X		
1973		X	X			X	X	X	X	X		X
1974	X		X	X	X	/		X	X	X		X
1975												
1976	/	/	X	/	X	X	X	X		/	/	/
1977	X			/	X	X	/		X	X		
1978	X	/	/	X	X	X	X	X	X	X	X	X
1979	X	/	/	X	X	X	/	/	X	X	X	X

X - Data recorded.
/ - Only some data recorded for the month.
Blank - No data recorded for the month.

Table A1. (Cont.)

C-2-1600 (484 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969							X	X	X	X	/	X
1970	X	X	X									
1971		X	X	X	X	X	X	/	X	X		
1972							X	X				
1973												
1974												
1975												
1976										X	X	X
1977	X			X		X	X	X	X	X	X	X
1978		X	X	X	X					X	X	
1979	X							X	X			

C-3-1600 (488 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969							X	X	X	/	/	X
1970	X	X	X									
1971		X	X	X	X	X	X	X	X	X	X	X
1972						X	X	X				
1973												
1974												
1975												
1976									X	/	/	X
1977	X			/	/	X	X	/	X	/	/	X
1978	X		X	X	X							
1979					X	X	X	X				

C-3-2100 (637 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1971					/	X	/	X		X	X	X
1972							X	X	X	X		
1973				X		X	X	/				
1974	X		X	X	X	X		X	X	X		X
1975												
1976								/	X	/	/	
1977	/		/	/	/	X	X	/	X	/	/	/
1978	X	X	X	X		X	X	X	X	X	X	X
1979	X	X	/	X				/	X	X	X	X

Caribou Peak Trail-1600 (488 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1975							X	X	X	X	X	/
1976	/	/	X	/			/	X	X			
1977				/		X	/	/	X	X	/	/
1978	X	X	X	X	X	X	X	X	X	/	X	

C-3-UPPER (381 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1976												X
1977				/	/	/	X	/	X	X	/	/
1978	/	/	/	X	X	/	/	/	/		/	

P-1 (360 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1975									/	X	/	/
1976	/	X	/	/	/	X	/	X	X			
1977				/	X	X		/	/	/	/	/
1978	/	X	X	/	X	X	/	X	X	X	/	

C-4 (226 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1975								X	X	/	/	
1976	/	/	X	X			X	X	X	X	X	/
1977	X			/	/			/	X	/	/	
1978	/	X	X	X	X	X	X	X	X	X	X	/
1979		/	/	/				/	/	/	/	/

P-2 (360 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1975										/	/	/
1976	/	/	X				X	X	X	X	X	
1977	/			/	X	X	X		/	/	/	/
1978	X											

Table A1. (Cont.)

Caribou Peak (773 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1969						X	X	X	X	X	X	X
1970	X	X	X									
1971	/	X	X	X	/	X	X	/				/
1972		X		X	X		X	X	X			
1973												
1974												
1975							/	/	X	X	/	X
1976	/	X	X	X	/	X	X		X	X	X	X
1977	X			/		X	/		X	/	/	
1978	X	X	X	X	X	X	X	X	X	X	X	X
1979	X	X	/	X	X	/		/	X	X	X	X

P-4 (293 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1976								/	/			
1977	X			/	/	/	/	/	/	X	/	/
1978	X	X	X	X	X	X	/	X	X	/	/	

Table A2. Station history of precipitation measurements.

Caribou Main (264 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1974					X	X	X	/		X	X	X
1975								X	X	X	X	/
1976	X	X	/	/	X	X	X	X	X	X	X	
1977	X		X	/	X	X	X	X	/	/	/	/
1978	X	X	X	X	X	X	X	X	X	X	X	X
1979	X	X	X	X	X	X	X	X	X	X	/	X

C-3-2100 (637 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1974	/				X	X	X	X	/	/		
1975												
1976										X	/	X
1977	X		/	/		X	X	X	X	/	/	/
1978	/	X	X	X	X	X	X	X	X	X	/	X
1979	X	X	X	X	X	X	X	X	/	/	/	/

C-2-2100 (616 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1974	X	X	X	X	X	/	/					
1975									/	X	/	/
1976	X	X	/			X	X	X	X	X	X	/
1977	X		X	/	/	X	X	/	/	X	X	X
1978	X	X	X	X	X	X	X	X	/	X	X	/
1979	X	X	X		/			/	/	/	/	X

Caribou Peak (773 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1975							/	X	X	X	/	/
1976	/			X	X	X	X	X	X	X	X	/
1977			/	/		/	/		/	X	/	
1978	X	X	X	X	X	X	X	X	X	X	X	X
1979	/	X	X	X	X	X	X	X	X	/	/	X

C-3-1600 (488 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1976									/	X	X	X
1977	X			/	X	/	X	X	X	/	/	/
1978	X	X	X	X	X	X	X	X	X	X	X	X
1979	X	X	X		X	X	X	/	/			

P-1 (360 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1975										/	/	/
1976			X									
1977				/	/			X	/	/	X	X
1978	X	X	X	X	X	X	X	X	X	X	X	/

P-4 (293 m)

	J	F	M	A	M	J	J	A	S	O	N	D
1976	X	/	/	X	/		X	/				
1977	X			/	/	X	/	/	/			
1978	/					/	X	X	X	X	/	

X - Data recorded.
/ - Only some data recorded for the month.
Blank - No data recorded for the month.

Discharge

Daily discharge measurements were taken at the Caribou Main and Poker Creek gages with Stevens A-35 water-stage recorders during the open water season. The gages did not operate during some periods of extreme cold and when the streams were frozen. During the frozen season U.S. Geological Survey personnel visited the stations approximately three times: in early winter, in mid-winter and in early spring prior to breakup. They drilled holes through the ice and measured water levels; this information was used in conjunction with water temperature and rating curves to estimate daily discharge. Instantaneous discharge measurements were taken on C-2 and C-3 from May-October 1969 and 1970. The measurements were taken within a few hours of each other and can be considered to be random samples of the streamflow for those summers.

The accuracy of the measurements on Caribou Creek, as rated by U.S.G.S. personnel, ranged from poor (over 8% probable error) to fair (95% of the flows are thought to be within 15% of the true value). All measurements on Poker Creek were rated poor. Station histories of Poker and Caribou Creek are presented in Table A3.

Table A3. Stream gage station history.

Caribou Creek

Period of record: October 1969 - present

Year*	Period when gage was not operating
1969-70	15 Oct.-17 June
1970-71	1 Oct.- 2 May
1971-72	14 Oct.- 9 May
1972-73	6 Oct.-11 May
1973-74	1 Oct.- 9 June
1974-75	1 Oct.- 1 July
1975-75	Only occasional records for entire year
1976-77	1 Oct.- 1 June, 8 June- 7 July, 17 July-15 August
1977-78	7 Oct.-23 May
1978-79	1 Oct.-24 May
1979-80	

Poker Creek

Period of record: September 1971 - September 1978

1970-71	1 Oct.-31 August
1971-72	14 Oct.- 2 May
1972-73	1 Oct.-31 May
1973-74	1 Oct.-19 August
1974-75	1 Oct.- 1 July
1975-76	1 Oct.-10 July
1976-77	1 Oct.- 7 July
1977-78	5 Oct.-28 June

* 1 October-30 September

A facsimile catalog card in Library of Congress MARC format is reproduced below.

Haugen, R.K.
Hydrology and climatology of the Caribou-Poker Creeks Research Watershed, Alaska / by R.K. Haugen, C.W. Slaughter, K.E. Howe and S.L. Dingman. Hanover, N.H.: U.S. Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1982.
v, 42 p., illus., 28 cm. (CRREL Report 82-26.)
Prepared for Office of the Chief of Engineers by Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory under CWIS 31003.
Bibliography: p. 25.
1. Climate. 2. Cold regions. 3. Hydrology. 4. Permafrost. 5. Runoff. I. Slaughter, C.W. II. Howe, K.E. III. Dingman, S.L.

(see next card)

Haugen, R.K.
Hydrology and climatology ...
1982 (Card 2)

IV. United States. Army. Corps of Engineers. V. Army Cold Regions Research and Engineering Laboratory, Hanover, N.H. VI. Series: CRREL Report 82-26.

☆U.S. GOVERNMENT PRINTING OFFICE: 1982 – A-2294/269

DAT

ILM