Editors

United States Department, of Agriculture

Forest Service

Pacific Northwest Research Station

Research Note PNW-RN-463

Water Quality and Streamflow in the Caribou-Poker Creeks Research Watershed, Central Alaska, 1979

Jerry W. Hilgert and Charles W Slaughter

Abstract

Baseline data from 1979 are presented on precipitation, streamflow, occurrence of permafrost, and physical and chemical water quality in a subarctic, tiaga watershed. First- to third-order streams drain catchments embracing permafrost-underlain and permafrost-free landscapes in the undisturbed research watershed. The data are compared to those from a fourth-order stream impacted by placer mining; streams in the research watershed drain into the fourth-order stream slightly beyond the watershed border. These and subsequent baseline data sets will be used to compare natural conditions in undisturbed streams of the subarctic to conditions in streams impacted by resource management activities and to evaluate the impacts of such activities on stream ecosystems.

Keyword: Baseline data, water quality, streamflow, subarctic environment, Alaska (Caribou-Poker Creeks research watershed).

Introduction

The Caribou-Poker Creeks research watershed was established in 1969. Research in the watershed is directed toward understanding of environmental characteristics and processes in an undisturbed subarctic setting, and toward evaluating resource management techniques and their impacts on stream ecosystems. Water quality data were collected from 1971 through 1974 (Jinkinson and others 1973, Lotspeich and others 1976) and were reinitiated in 1978 (Hilgert and Slaughter 1983). Collection of baseline data has continued through 1986 with the purpose of accumulating a comprehensive data set against which post-treatment characteristics will be assessed.

Baseline water quality data are presented from eight sampling stations on Caribou and Poker Creeks and from a station recently established an the Chatanika River above its confluence with Poker Creek. The Caribou-Poker Creeks research watershed, located 49 km north of Fairbanks, encompasses 106 km^2 of the subarctic taiga of central Alaska (fig. 1). The setting and climate of this catchment are described by Koutz and Slaughter (1972), Reiger and others (1972), Slaughter and Long (1974), and Troth and others (1975).

JERRY W. HILGERT is an aquatic biologist and CHARLES W. SLAUGHTER is a research hydrologist, Institute of Northern Forestry, Pacific Northwest Research Station, 308 Tanana Drive, Fairbanks, Alaska 99701.

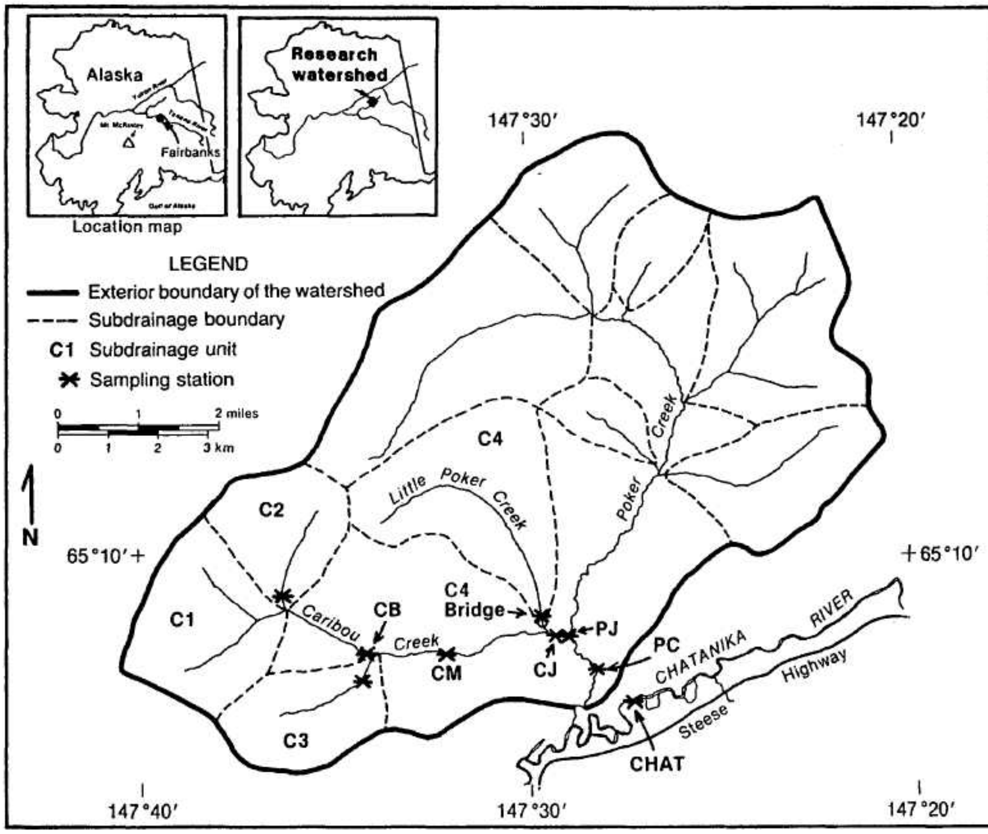

Figure 1—Caribou-Poker Creeks research watershed.

Subdrainages C2 and C3 were chosen for detailed monitoring because of their dissimi larity in the occurrence of permafrost. The C2 catchment has a relatively small percen tage of area underlain by permafrost (3 percent) and is characterized by south-facing slopes with relatively deep soils. Approximately 52 percent of the area is dominated by quaking aspen *{Populus tremuloides* Michx.), paper birch *{Betula papyrifera* Marsh.), and white spruce *(Picea glauca* (Moench) Voss); the remaining area is characterized by a black spruce *(Picea mariana* (Mill.) B.S.P.) and moss community. The C3 sub-drainage has a greater percentage of area underlain by permafrost (53 percent) because of its generally northeast aspect. Soils are shallow with approximately 99 per cent of the area overlain with a moss/lichen ground cover and a generally open, black spruce-dominated overstory. Striking dissimilarities between the two subdrainages have been documented on local climate (Slaughter and Long 1974) and hydrological response (Slaughter and Kane 1979). First comprehensive samples of water quality characteristics, taken in 1978, indicated possible variation in turbidity, temperature, and sediment production (Hilgert and Slaughter 1983).

The sampling site on the Chatanika River was chosen because it had been subjected to sedimentation and increased turbidity from placer mining on upstream tributaries during summer and fall 1979. By comparing higher order stations within the undisturbed research watershed to the Chatanika River station, we can determine whether sediment and turbidity are results of natural storm events or mining activities.

Characteristics of all subdrainages sampled are shown in table 1.

Table 1—Characteristics of subdrainages in Caribou-Poker Creeks research watershed and Chatanika River

Subdrainage	Area	Stream order at station	Dominant aspect	Permafrost	Stream length
	Square kilometer			Percent	Kilometer
C2	5.2	1	S	3.5	2.2
C3	5.7	1	NE	53.2	2.6
C4	11.4	1	SSE	18.8	5.0
CB	15.7	2	E	28.0	9.7
CM	23.1	2	E	28.0	11.3
CJ	43.8	2	E	28.0	19.0
PJ	61.3	3	S	30.5	29.6
PC	110	3	S	30.7	48.4
CHAT	738	5	W	40.0	1/113

1/ Estimated length of main channel; does not include tributaries.

Methods used in acquisition of samples and analysis of data are described in the first report presenting baseline data on Caribou-Poker Creeks (Hilgert and Slaughter 1983). The current report is built upon the first and upon work reported by Jinkinson and others (1973) and Lotspeich and others (1976).

Methods

Chemical and physical properties of the water and biological constituents were sampled throughout 1979 at eight stations: three first-order sites in separate streams (C2, C3, and C4), three second-order sites in Caribou Creek (CB, CM, CJ), a third-order site in Poker Creek (PJ), and a fourth-order site in the Chatanika River (CHAT) (table 2). Midway through the summer of 1979, we established a ninth station, below the confluence of Caribou and Poker Creeks (PC); that station completed a hypothetical "river continuum" (Vannote and others 1980).

Table 2—Water properties and biological constituents sampled in Caribou-Poker research watershed and Chatanika River, 1979

Chemical properties	Physical properties	Biological constituents
Alkalinity	Discharge	Periphyton:
pH	Temperature	Natural populations
Filterable:	Turbidity	Artificial substrates
NO_3-N, NH_3-N	Nonfilterable residue	Macroinvertebrates:
Kjeldahl-N	Specific conductance	Standing crop
ortho-P, total-P		Drift
Ca, Mg, Na, K, Mn, Fe, As, Cl, Si		

Samples of water quality were taken from April through November 1979. We attempted to take grab samples once each calendar week, but conditions often necessitated a change in sampling day. Ambient air and water temperatures at each site were measured with calibrated thermometers near midday while water quality was being sampled. Water samples for turbidity, pH, alkalinity, and specific conductance were kept cool and dark while being transported to the laboratory for measurement and for filtering for chemical determinations (American Public Health Association 1975). Two 125-ml samples were filtered through a rinsed Gelman MicroQuartz[1/] glass fiber filter (0.45 urn). One of the two 125-ml samples was then acidified to a pH of 2 and stored in the dark at 5°C until analyzed by atomic absorption spectrophotometry for dissolved sodium, potassium, calcium, magnesium, arsenic, iron, and manganese (American Public Health Association 1975). The other 125-ml sample was filtered as above, stored frozen, and analyzed for filterable nitrate, ammonia, Kjeldahl nitrogen, ortho-phosphorus, total phosphorus, chloride, and silica by the U.S. Environmental Protection Agency (Corvallis, Oregon) Chemical Lab using a Technicon Auto-Analyzer (U.S. Environmental Protection Agency 1976). A 500-ml grab sample was collected from each station and filtered through a tared Gelman MicroQuartz glass fiber filter (0.45 pm) for quantification of nonfilterable residue (total suspended sediment). Grab samples were collected because of the shallow nature (less than 30 cm) of the stream sites. Grab samples were collected at well-mixed sites from the center of each stream or from the mouth of each flume.

Results and Discussion

Streamflow

Discharge measurements at three stations are summarized in figure 2. Peak flows in C3 and CM occurred on July 6, and minor storms increased discharge on June 12 and July 27. Malfunction of the C2 water level recorder permitted only instantaneous discharge measurements, which were taken in the C2 flume when grab samples were taken. The instantaneous discharge measurements are plotted as "•" in figure 2. The relationship of C2 to C3 appears to be consistent with results from the 1978 field season (Hilgert and Slaughter 1983), when peak storm flows were much higher and more pronounced in C3 than in C2, and when base flow tended to be greater in C2 than C3. In the 1979 field season, C2 had much less flow than did C3 during the storm of July 6 but had higher base flow during the relatively dry months of August and September.

[1/] The use of trade, firm, or corporate names in this publication is for the information and convenience of the reader. **Such use does not** constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

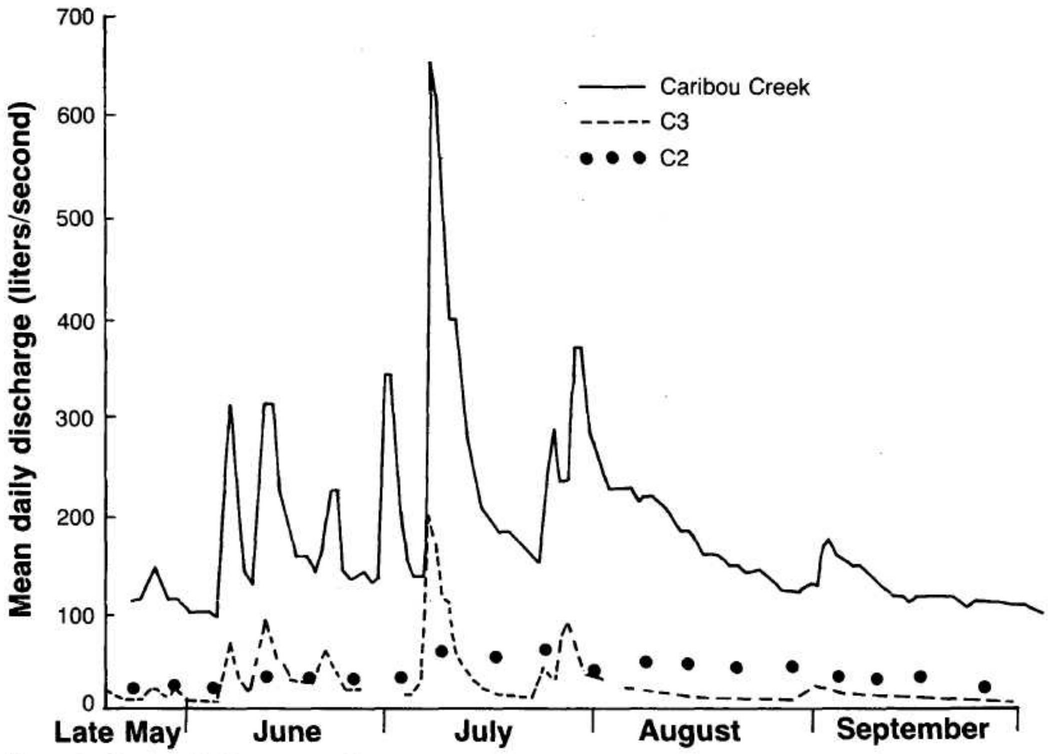

Figure 2—Mean daily discharge at C3 and Caribou Creek, and instantaneous point discharge at C2, May-September 1979.

Discharge during spring breakup[2/] at C3 was estimated hourly with time lapse photography (fig. 3). Breakup occurred from April 25 through May 15,1979, with an estimated discharge of 3.I6 x 10^8 liters in 23 days. This amount compares to a measured discharge of 3.67 x 10^8 liters during the ice-free season of May 16 through September 30, or 138 days. Kane and Slaughter (1972) estimated the discharge from C3 as 2.8 liters per second during the winter, when streams were covered with ice.

Discharge from C3 was estimated as 5.04 x 10^7 liters during the ice-covered season and 7.33 x 10^8 liters for the entire year. Approximately 50 percent of the annual discharge runs off during the ice-free season, 43 percent during breakup, and 7 percent during the winter. Future research efforts will strive to determine annual yields from each basin within the watershed and to determine a sediment budget for basins with gaged sampling stations.

2/ The term "breakup" refers to melting of ice cover and associated increase of discharge.

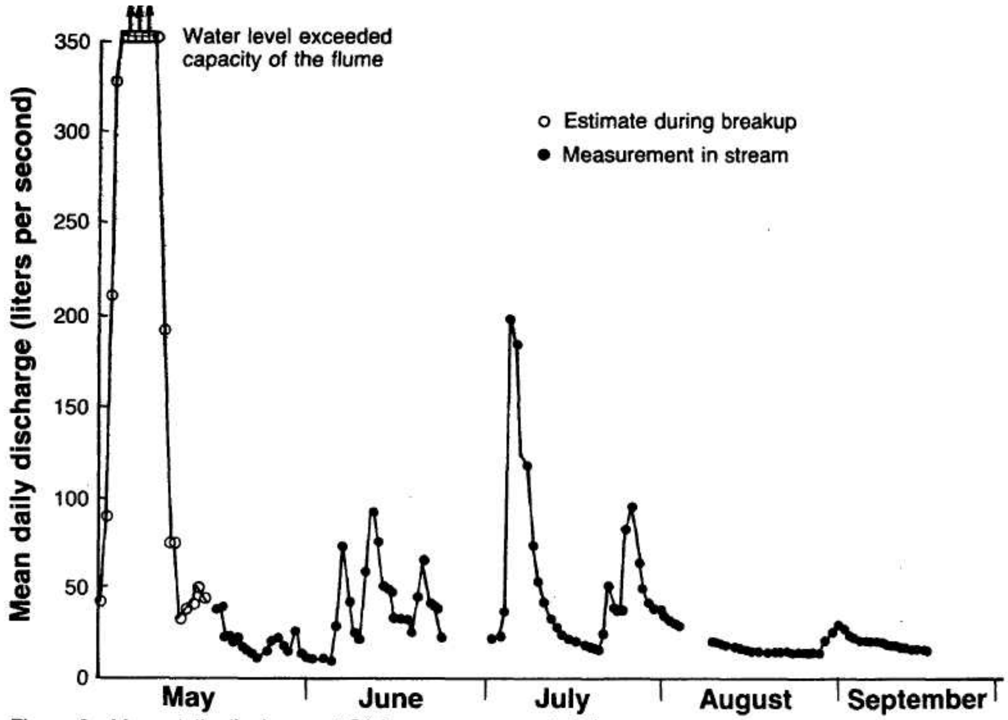

Figure 3—Mean daily discharge at C3 from measurements taken in the stream and from estimates during breakup, 1979

Temperature

Water and air temperatures measured at sampling stations throughout the season are shown in figure 4. Median water temperatures were lowest in streams draining C2 and C3 (table 3 and fig. 5). Water temperature appears to increase with higher stream order and larger basin area. Median water temperatures were greater in the downstream reaches of Caribou Creek than in the first-order streams of C2 and C3. In the first-order stream at C4-bridge,[a/] however, they appeared to be the same as in the second-order streams of CB and CM. The C4 basin has about twice the area as C2 and C3, and, although smaller than the CB or CM basin, has a lower percentage of its area (18 percent) underlain by permafrost. The stream reach is also longer (5.0 km in C4 as opposed to 2.2 km for C2 and 2.6 km for C3) and drains in a generally southeast direction (Lotspeich and Slaughter 1981). Poker Creek (third order) was warmer than Caribou Creek (second order), and the Chatanika River had the highest water temperature of the streams measured.

[3/] The only sampling station within C4 during the 1979 monitoring period was located at the bridge over Little Poker Creek. Since that time additional stations have been established within C4. To help the reader compare data for C4 in this report with data for C4 in subsequent reports, locations of the C4 sampling stations will be identified.

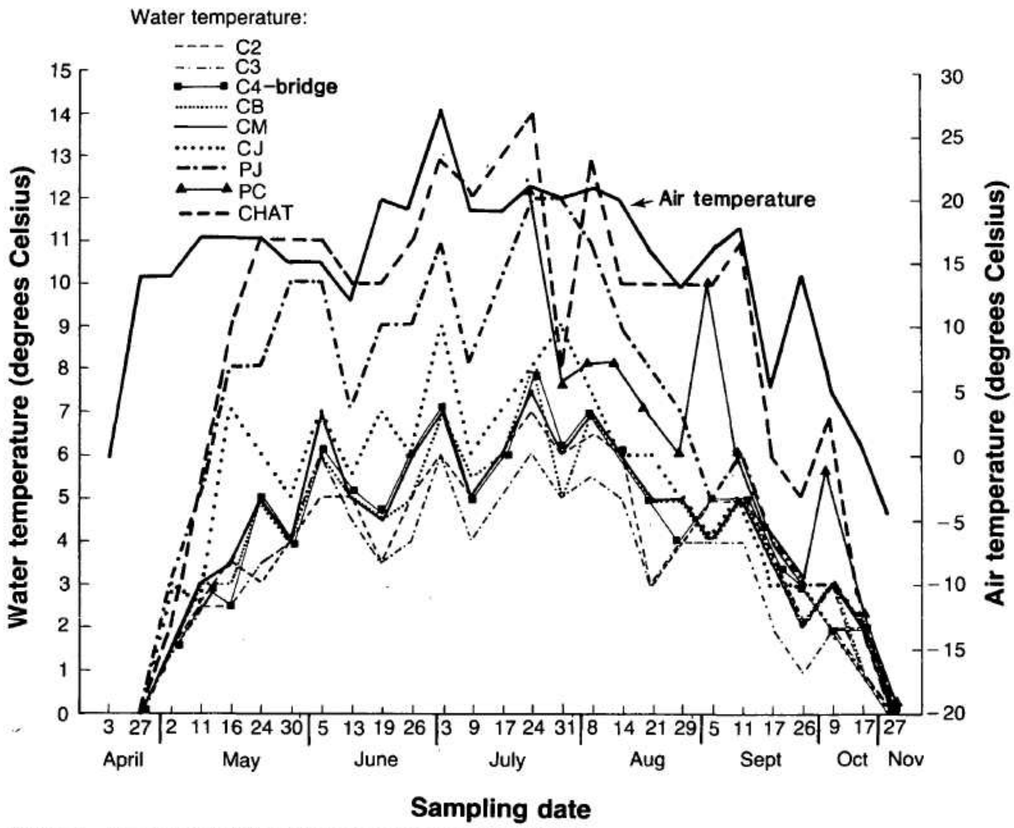

Figure 4—Median water temperature measured at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, and air temperature measured at the confluence of Caribou and Poker Creeks, 1979.

Table 3—Mean and median water temperature at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of observations	Mean	Median	Standard deviation
		Degrees Celsius		
C2	27	3.8	4.0	2.0
C3	26	3.4	4.0	1.8
C4-bridge	26	4.3	5.0	2.0
CB	27	4.1	5.0	2.2
CM	26	4.3	5.0	2.0
CJ	26	5.1	5.8	2.5
PJ	26	6.9	8.0	3.5
PC	13	6.1	6.0	3.3
CHAT	27	8.3	10.0	4.3

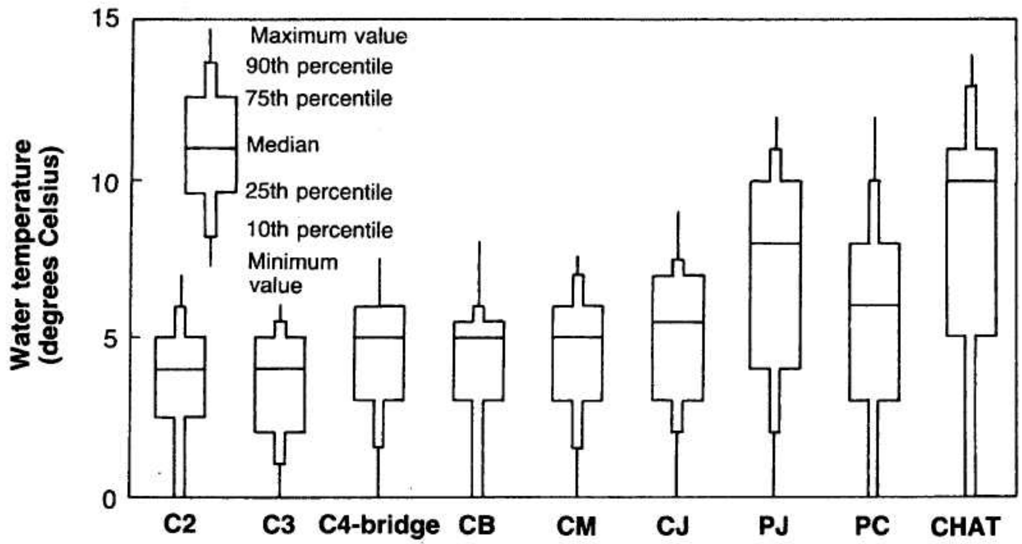

Figure 5—Summary statistics describing water temperature at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Relationships of interest are basin area to water temperature, and basin area underlain by permafrost to water temperature. When median water temperatures were correlated with basin area (fig. 6), there was a significant positive correlation (P< 0.05, r = 0.95, N = 7). This correlation is consistent with the "river continuum hypothesis" (Vannote and others 1980). The PC and CHAT sites were not included in this analysis. Measurements from PC represented only a portion of the season and were excluded. When the larger basin area of the Chatanika River was included, its warmer temperatures drove the correlation in a positive direction (P< 0.05, r = 0.84, N = 8), resulting in a curvilinear function instead of the linear function seemingly more typical of sites within the research watershed.

A greater proportion of area underlain by permafrost may coincide with lower water temperatures. The C2 and C3 basins have nearly equal drainage areas, yet C3 has a higher proportion of permafrost (53.2 percent) than C2 (3.5 percent). There was no apparent difference in the median water temperatures between the two sites (4.0 °C at both sites), but mean water temperatures during the ice-free season were lower in C3 than in C2. Median water temperature in Poker Creek (8.0 °C), however, appeared consistently higher than Caribou Creek (5.8 °C). The higher temperatures may reflect both the longer length of stream in Poker Creek (29.6 km) and its generally southerly-flowing direction as opposed to the shorter stream length (19.0 km) and easterly (more topographically shaded) flow of Caribou Creek (Bredthauer and Hoch 1979). Areas underlain by permafrost are nearly equal -in Caribou Creek (28.0 percent) and Poker Creek (30.5 percent). , ;

When water temperatures In low-order subarctic basins are modeled, components of the river continuum hypothesis are accounted for. stream length, width, direction of flow, and shading .by riparian vegetation. Characteristics of permafrost should also be considered.

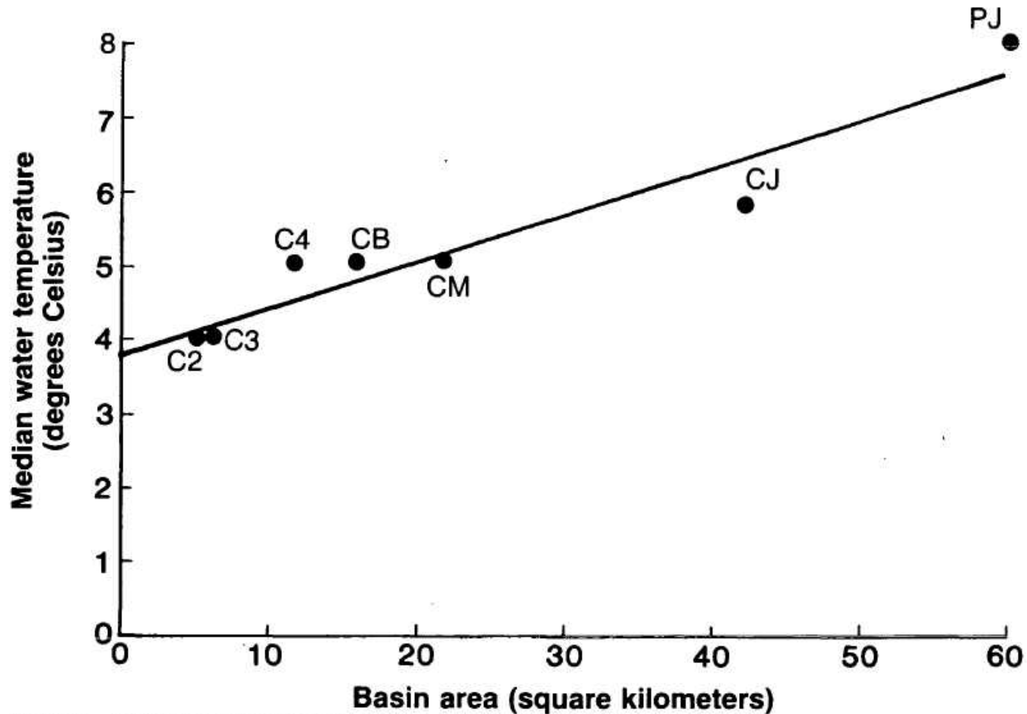

Figure 6—Correlation of median water temperatures for 1979 at some sampling stations in Caribou-Poker Creeks research watershed and basin area.

Turbidity

Mean and median turbidities for the 1979 sampling season presented in table 4 and summary statistics on turbidity are shown in figure 7. During spring breakup, melting and flushing do not occur simultaneously at all sites. The sites were in differing stages of breakup on April 27 and May 2: some locations were covered with thick ice and were not sampled, while other sites had substantial over-ice flow. The median rather than the mean is used as the comparative measure of central tendency. The median incorporates ice-free measurements but does not overemphasize the high breakup values from some sites. The mean values of some sites are much larger than the median, because of occasional high values during the breakup period, but are included for comparison. This procedure is followed for most water quality characteristics presented in this paper.

The Chatanika River had the highest median turbidity followed in descending order by the CJ, C3, C4-bridge, and PJ sites. Other sites had median turbidities near zero. First-order streams C3 and C4 appeared to have nearly equal median turbidities, whereas C2 had the same median turbidity (near zero) as second-order sites CB and CM. The PC site (below the confluence of Poker and Caribou Creeks) also had median turbidity of near zero; however, samples were collected only in the late summer and fall.

Because of the relatively higher proportion of basin underlain by permafrost in C3 than in C2, we assumed turbidity would be greater in C3 as a result of high humic staining from flows through the extensive moss cover (Hilgert 1979). Mean and median turbidities from C3 were indeed much higher in C3 than in C2, confirming observations from the 1978 sampling season.

Table 4—Mean and median turbidity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of observations	Mean	Median	Standard deviation
		- - - Formazin	turbidity units	- - -
C2	27	5.4	<0.1	11.7
C3	26	13.5	5.0	17.6
C4-bridge	26	4.4	5.0	2.0
CB	27	6.8	<.1	13.4
CM	25	7.9	<.1	14.7
CJ	26	10.5	8.0	12.5
PJ	26	9.3	3.0	13.8
PC	14	3.1	<.1	5.6
CHAT	27	18.4	18.0	21.9

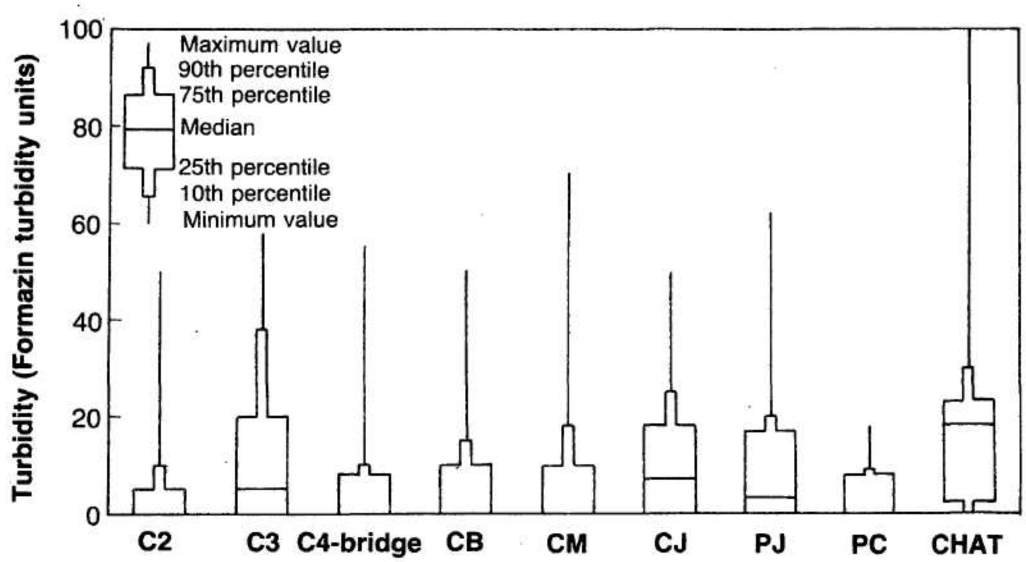

Figure 7—Summary statistics describing turbidity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

There is an apparent significant positive correlation ($P < 0.05$, $r = 0.85$, $N = 9$) of median turbidity to basin area. The Chatanika River, however, is impacted 50 km upstream of the research watershed by placer mining activities and cannot be considered an undisturbed system. The high turbidity values from CHAT and the large basin area tend to drive the correlation in a positive direction. When CHAT and partial-season data from PC are excluded from the analysis, the correlation coefficient becomes nonsignificant ($P > 0.05$, $r = -0.29$, $N = 7$).

When percent basin area underlain by permafrost is compared to median turbidity, a nonsignificant correlation coefficient ($P > 0.05$, $r = 0.42$, $N = 9$) results. When CHAT is excluded from the analysis, the correlation coefficient remains nonsignificant ($P > 0.05$, $r = 0.32$, $N = 8$). Comparison of first-order streams C2 and C3 draining basins of nearly equal size shows that the C3 site has consistently higher turbidity than C2, suggesting that turbidity in smaller streams may be related to proportion of permafrost and associated moss cover rather than to basin area. If substantiated by data from other subarctic watersheds, this concept could be valuable in comparing and predicting turbidities of similar-sized streams for impacts of pipeline, road, and trail construction.

Figure 8 shows turbidities by stream order. Turbidity was highest during spring breakup but also increased during storm events on June 13, July 9, and July 24. Turbidities were low in late August and September in the undisturbed (CJ and PJ) creeks. Fluctuations in turbidity of the Chatanika River reflect intermittent placer mining activity upstream. Water quality trends can be evaluated by comparing "background" turbidities of undisturbed Caribou and Poker Creeks to nearby streams.

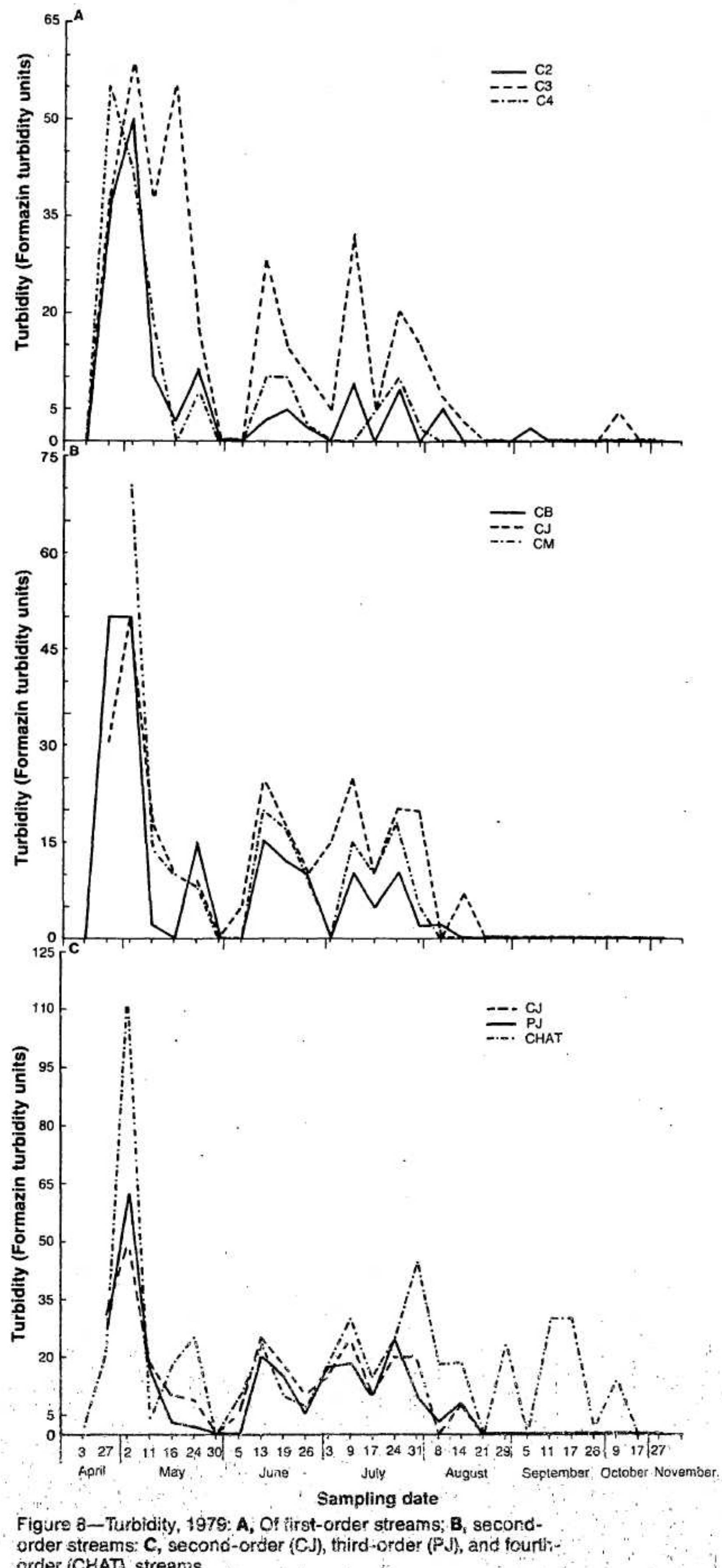

Figure 8—Turbidity, 1979: **A,** Of first-order streams; **B,** second-order streams: **C,** second-order (CJ), third-order (PJ), and fourth-order (CHAT), streams.

Nonfilterable Residue

Median concentrations of nonfilterable residue for the 1979 sampling season including residues collected from C2 and C3 by automated sampling[1] are presented in table 5. Among the first-order streams (C2, C3, and C4), C3 appeared to have the lowest median concentration (0.80 mg/liter). Concentrations of residue tended to increase slightly in a downstream direction toward CJ (1.20 mg/liter) and PJ (2.00 mg/liter), with the Chatanika River having the highest median value of 3.80 (fig. 9).

Because of the higher turbidities found in C3, we assumed C3 would have correspondingly higher concentrations of nonfilterable residue than C2. That was not the case, however: median concentration from C2 was only slightly higher than from C3. Because Caribou Creek had a higher mean turbidity than Poker Creek, we assumed CJ would have higher concentrations of nonfilterable residue. The CJ site, however, had lower concentrations than did PJ.

Subarctic systems having substantial variation in the occurrence of permafrost may lack an evident causal relationship of turbidity to concentration of nonfilterable residue during periods without storms. The dark-stained leachates from the thick moss layers on north-facing permafrost slopes may mask a direct turbidity-to-sediment relationship under the comparatively storm-free and low-discharge conditions sampled during 1979. Future monitoring may include more storm events, which would allow interbasin comparisons of water quality characteristics during periods of high discharge.

Table 5—Mean and median concentration of nonfilterable residue at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of obervations	Mean	Median	Standard deviation
		- - - -Milligrams per liter- - - -		
C2	189	1.71	1.00	2.30
C3	105	1.28	0.80	1.57
C4-bridge	26	2.01	1.60	1.97
CB	26	6.15	1.00	14.18
CM	24	1.25	1.10	1.11
CJ	26	1.90	1.20	2.58
PJ	26	3.25	2.00	4.17
PC	11	.67	0	1.01
CHAT	27	10.03	3.80	24.56

[1] Automated sampling is explained in the following section.

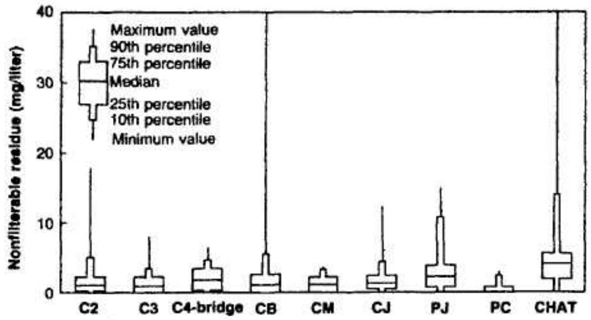

Figure 9—Summary statistics describing nonfilterable residue at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Concentrations of nonfilterable residue for first- and second-order streams are shown in figure 10 A and 10 B. Concentrations were highest during spring breakup. Concentrations in CB reached maximum on April 27, then appeared to respond in a manner similar to CM and CJ for the remainder of the 1979 season (fig. 10 B).

Concentrations of nonfilterable residue at higher order sites PJ, PC, and CJ are shown in figure 10 C. Concentrations during breakup peaked sooner in Poker Creek (May 2) than in Caribou Creek (May 11); however, the peak values appear similar. The earlier peak may be related to greater basin area and higher discharge in Poker Creek. Concentrations of residue in Poker Creek peaked again on July 9, September 17, and October 17 and were higher than in Caribou Creek. Concentrations appeared to be consistently higher in Poker Creek than in Caribou Creek from June 19 through July 24.

The Chatanika River site is not included on these figures. It tended to have much higher concentrations of residue than sites within the research watershed. The greater concentrations of nonfilterable residue taken in the fall at CHAT may have resulted from increased placer mining activity upstream combined with low streamflow.

These and previous data (Hilgert and Slaughter 1983) indicate that periods of highest sediment transport within the watershed occur during breakup and storm events. Future efforts to monitor concentrations of sediment should include these high-flow events.

Automated Sampling of Nonfilterable Residue

Automated sampling of nonfilterable residue from C2 and C3 began in summer 1979 to evaluate a wastewater sampler^/ for use in subarctic conditions. The advantage of an automated sampler is its battery-power capability, allowing continuous functioning in remote subarctic regions where electric line power is unavailable. Concentrations of nonfilterable residue were obtained from collections in up to 28 prewashed 500-ml bottles in the sampler. Samples can be composited up to 4 per bottle, or 4 bottles per sample. During periods of spring breakup, the devices were set to collect a single 500-ml water sample at 12-hour intervals. Later in the season, 2 samples taken 12 hours apart were composited into a "daily" sample.

5/ Model 1680 manufactured by Instrument Specialties Co. (ISCO), Lincoln Nebraska.

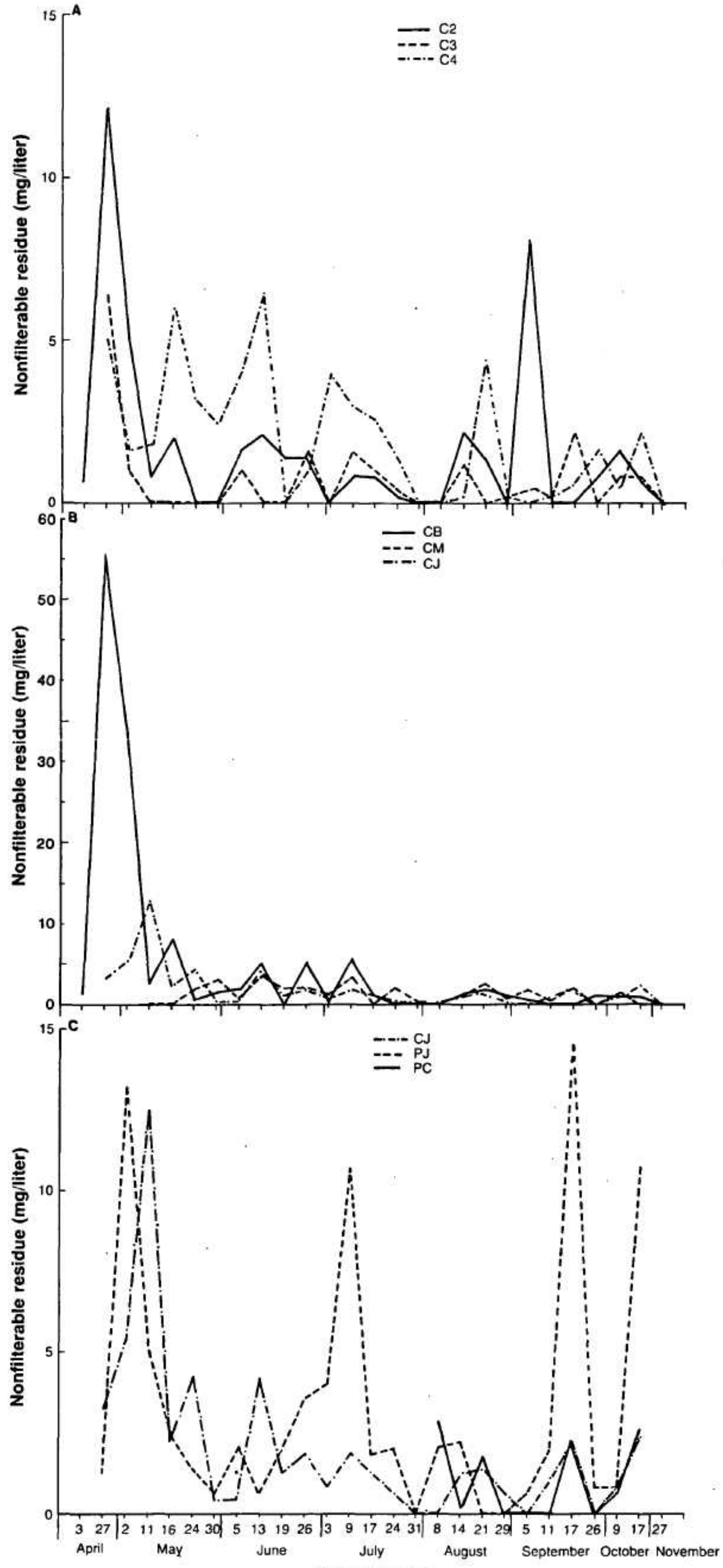

Figure 10—Concentration of nonfilterable residue, 1979: **A,** In first-order streams; **B,** second-order streams; **C,** second-order (CJ) and third-order (PJ and PC) streams.

Concentrations of nonfilterable residue taken from C2 by automated sampling are compared in figure 11 to those taken by grab sampling; a comparison for C3 is shown in figure 12. Generally, the residue level was low (< 10 mg/l) except for a few samples collected at breakup and during minor storms. Relationship of sediment to discharge for C3 is also shown in figure 12; the absence of high-discharge storm events throughout the season, however, precluded development of such relationships at high flows.

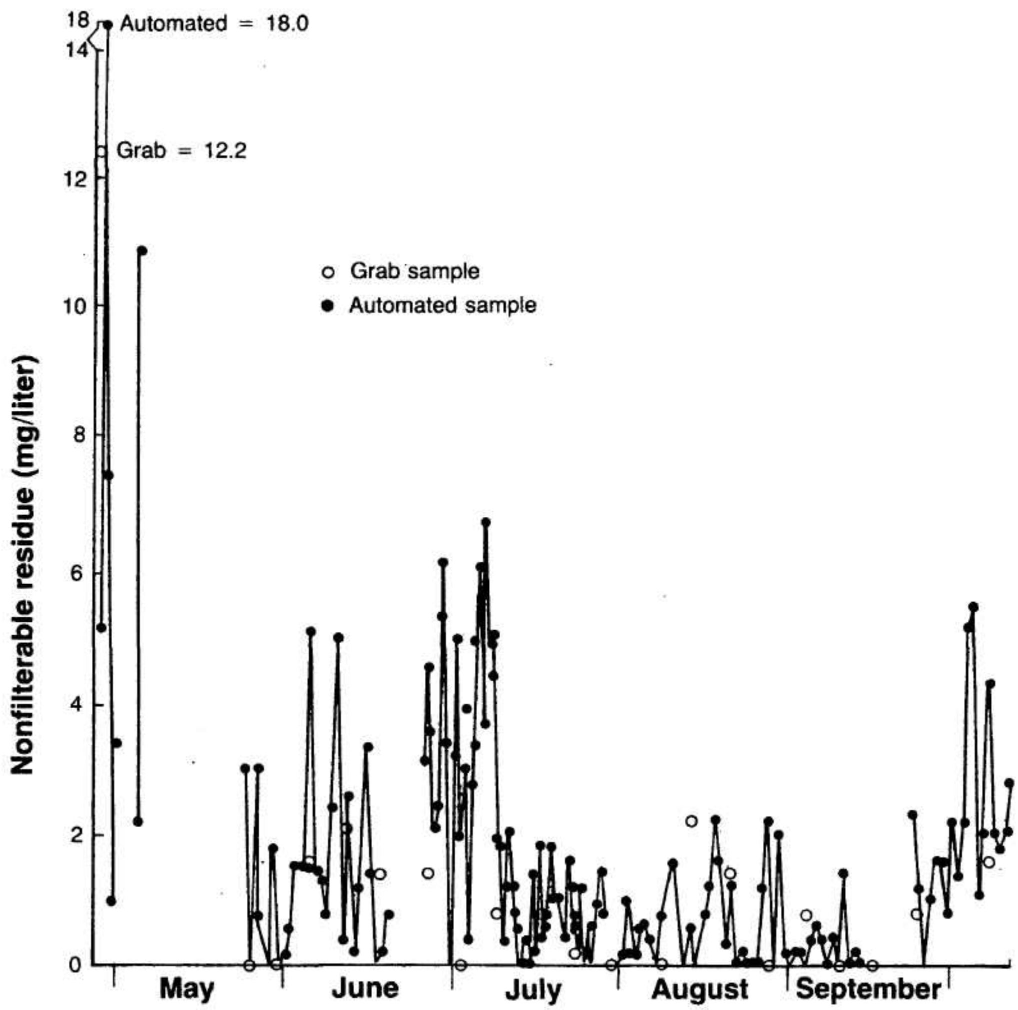

Figure 11—Concentration of nonfilterable residue from automated and grab sampling in C2, 1979. Values for grab samples duplicate those shown for C2 in figure 10A; they are repeated here for comparison with values from automated sampling.

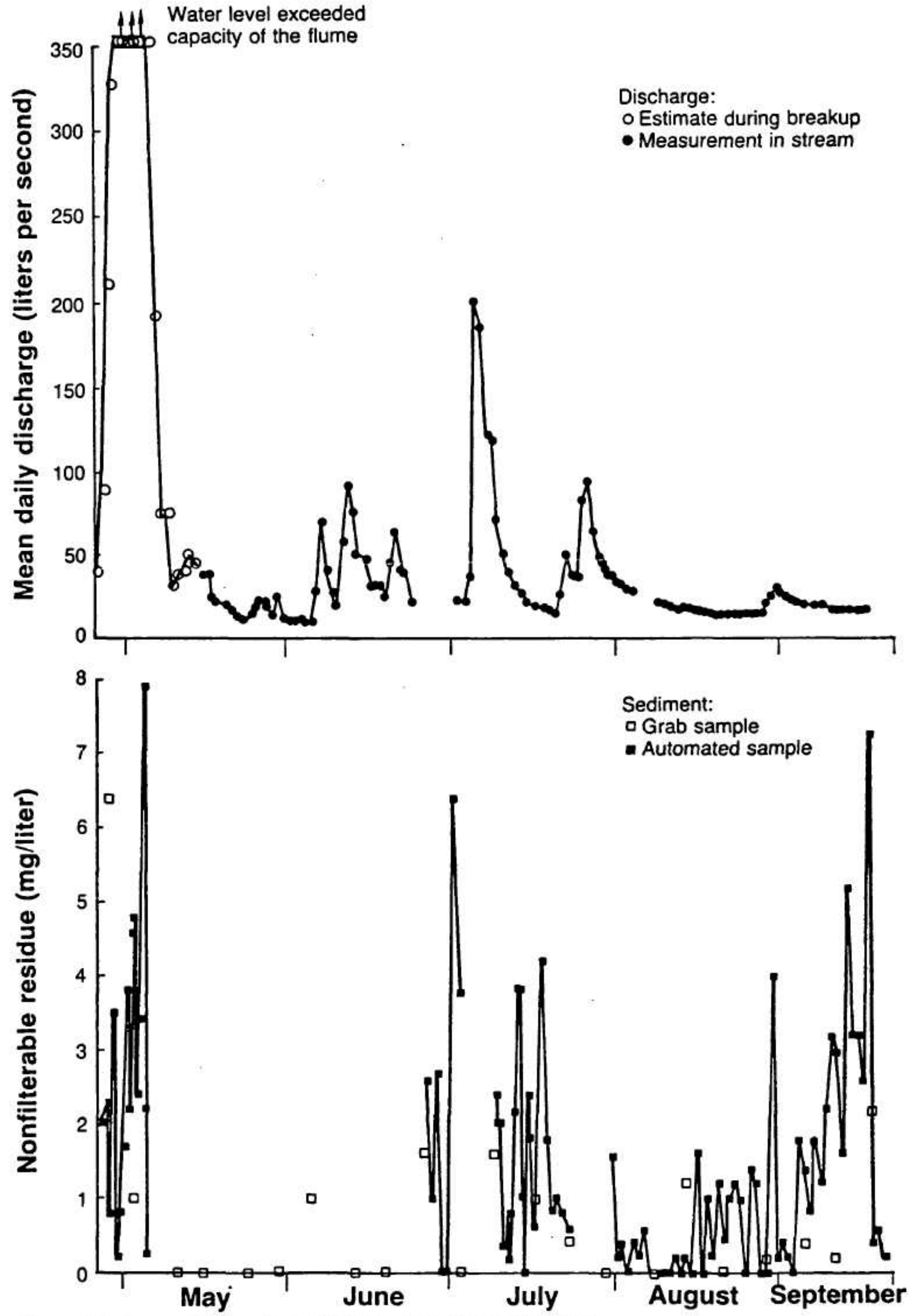

Figure 12—Concentration of nonfilterable residue from automated and grab sampling in C3, and relationship of discharge to sediment, 1979.

Automated sampling at C3 continued for 9 days during spring breakup, until a mechanical malfunction necessitated repair of the device. Samples were taken at 1 a.m. and 1 p.m. each day. Concentrations of nonfilterable residue appeared generally higher at the afternoon sampling times than at early morning (fig. 13). Time lapse photography taken at the flume (Slaughter and Hilgert 1979, Slaughter 1982) revealed that flow increased during the afternoon and decreased at night. Peak flows could not be determined because light levels in late afternoon were too low for photography. It appears that higher flows were accompanied by greater concentrations of residue. After April 29, discharge exceeded the capacity of the flume. A comparison of grab samples to automated samples taken throughout breakup would have been useful for evaluating techniques. Unfortunately, concurrent samples were not collected so that the devices could continue on the preprogrammed sampling schedule. In the future, automated samples will be taken at the same time as grab samples.

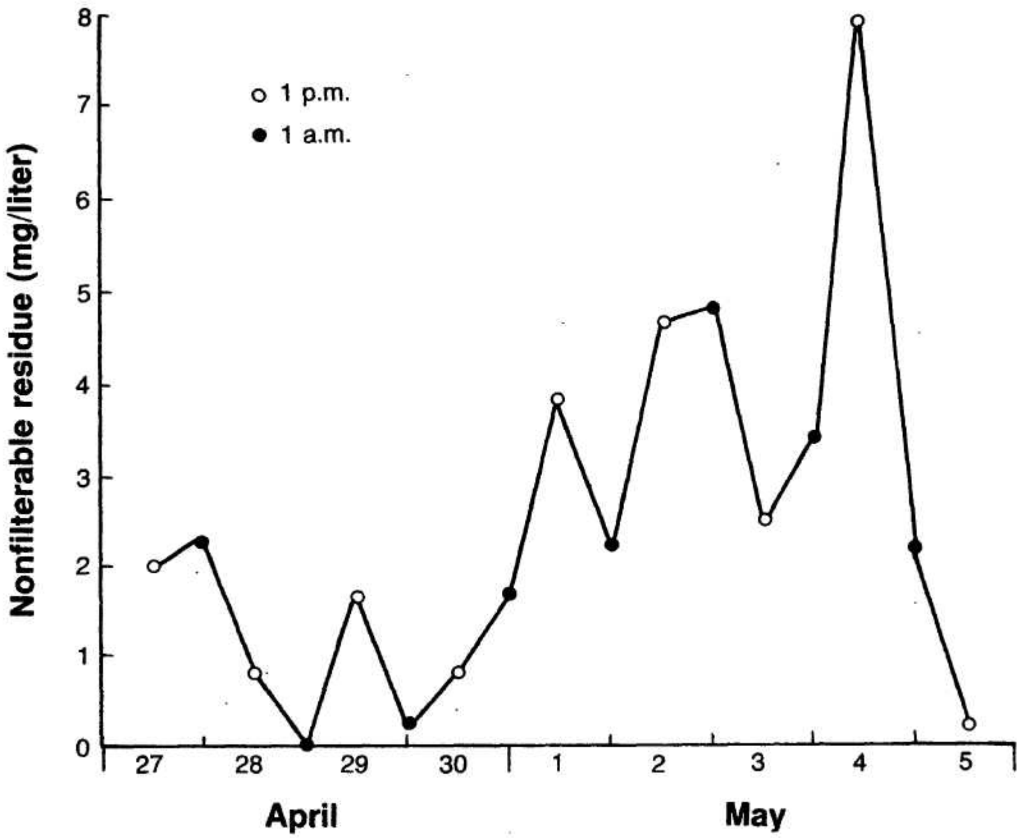

Figure 13—Concentration of nonfilterable residue taken by automated sampling in C3 during spring breakup, 1979.

A daily yield of residue at gaged stations at C3 can be estimated with the product of mean daily discharge and mean concentrations of nonfilterable residue, collected with automated samplers. This highest yield of residue occurred on July 10 and 11, following peak discharge on July 6. Unfortunately, the automated sampler failed during part of the storms on July 6 and on July 26; mean daily yield of nonfilterable residue for those days was 2.2 kg. Estimates of peak daily yields for storm events sampled throughout the season are given in table 6. To our knowledge, this is the first attempt to quantify residue on a continuous basis in subarctic headwaters.

Future efforts in the research watershed will be aimed toward achieving greater resolution of the relationships between discharge and residue concentration, particularly on the rising portion of the hydrograph, and expanding the coverage of baseline data to additional sites in the stream continuum. The use of a network of automated samplers coupled with continuous discharge measurement using flumes and water level recorders has the potential for obtaining accurate sediment loadings during breakup and high-discharge storm events.

Table 6—Estimated peak daily yield of nonfilterable residue collected with automated samplers at C3 during storm events

(In kilograms per day)

Date (1979)	Yield
7-11	13.7
7-18	7.2
8-1	5.2
8-31	8.9
9-14	7.5

Specific Conductance

Specific conductance appears to increase with stream order and basin size (fig. 14). Among the first-order streams, C4 had the highest median conductance (88 µmhos/cm) (table 7). Specific conductance of first-order streams declined during breakup (May 2) but then increased gradually until freeze-over (fig. 15 A). The C4 site had consistently greater specific conductance than C2, whereas lowest values occurred in C3.

In higher order streams, conductance was relatively low during breakup and gradually increased throughout the summer into winter (fig. 15 B and 15 C). Specific conductance increased from CB to CM to CJ and was highest in PJ and CHAT. Second-order (CB, QM, and CJ) and third-order (PJ) streams exhibited an apparent increase in specific conductance with increasing distance downstream.

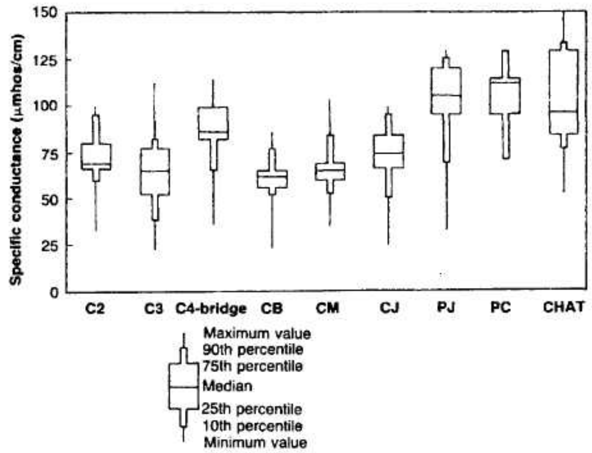

Figure 14—Summary statistics describing specific conductance at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Table 7—Mean and median specific conductance at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of observations	Mean	Median	Standard deviation
		- - - - - - µmhos/cm	- - - - - -	
C2	27	73.3	69.0	14.3
C3	26	65.1	66.0	19.0
C4-bridge	26	86.7	88.0	16.6
CB	27	62.0	62.0	12.2
CM	25	65.8	65.0	13.6
CJ	26	74.3	75.5	17.1
PJ	26	104.2	108.5	21.8
PC	13	107.8	112.0	15.5
CHAT	26	103.8	97.5	25.1

Increasing discharge was apparently accompanied by a reduction in specific conductance. The C3 stream had a significant negative correlation ($P < 0.05$, $r = -0.59$, $N = 23$) of specific conductance to discharge; CM had a slightly less significant negative correlation ($P < 0.05$, $r = -0.45$, $N = 23$), and C2 had a nonsignificant negative correlation ($P > 0.05$, $r = -0.26$, $N = 23$). This apparent inverse relationship of specific conductance to discharge is consistent with dilution as discharge increases.

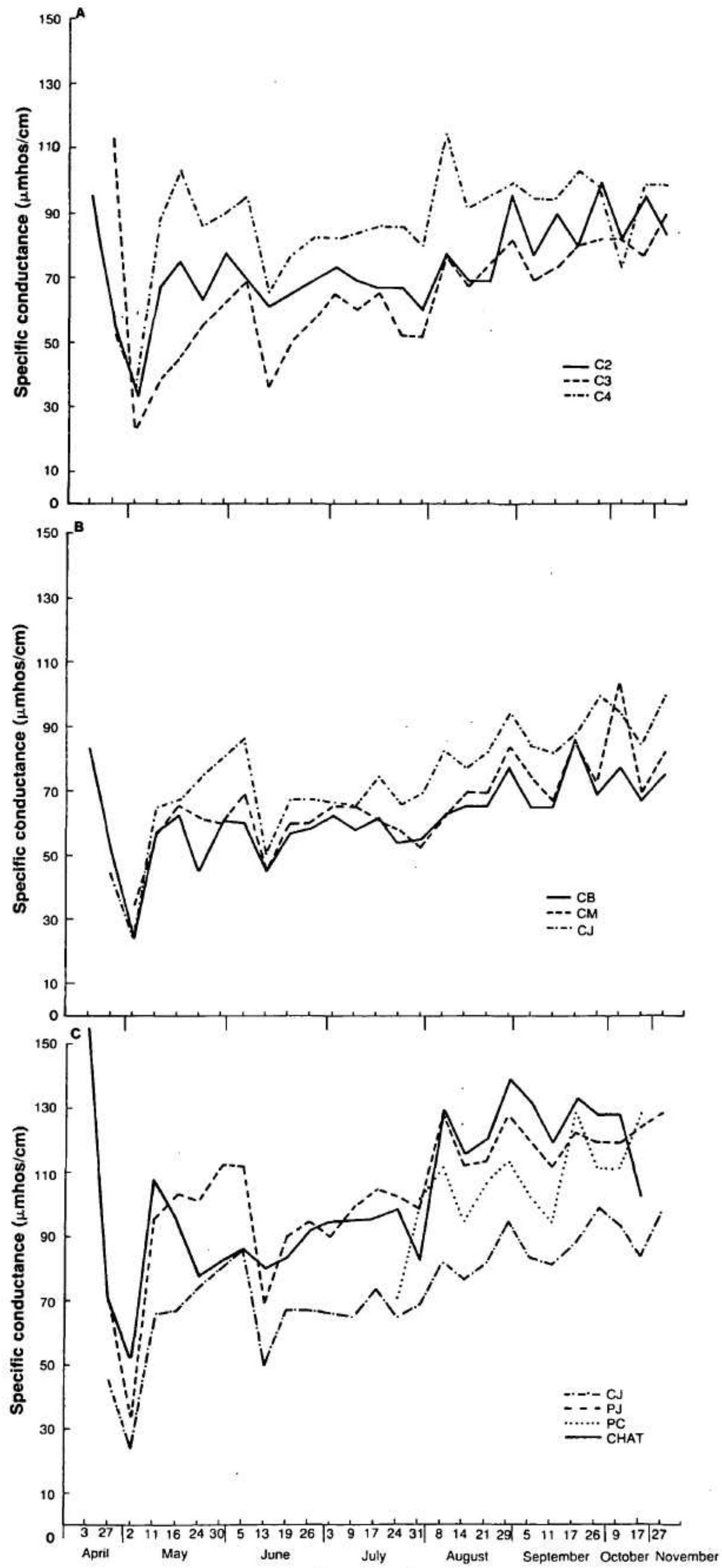

Figure 15—Specific conductance, 1979: **A,** Of first-order streams; **B,** second-order streams; **C,** second-order (CJ), third-order (PJ and PC), and fourth-order (CHAT) streams.

Figure 16 shows the specific conductance at several sites on a day with low discharge, September 11. The only sample taken from a thawing pingo (an ice-cored mound) in the north-facing area of Caribou Creek, near the CM station, had a specific conductance of 387 umhos/cm, a much higher value than at any other station within the watershed. Although the discharge contribution to Caribou Creek is small, the pingo runoff and several associated seeps from the surrounding slope may slightly increase stream conductivity.

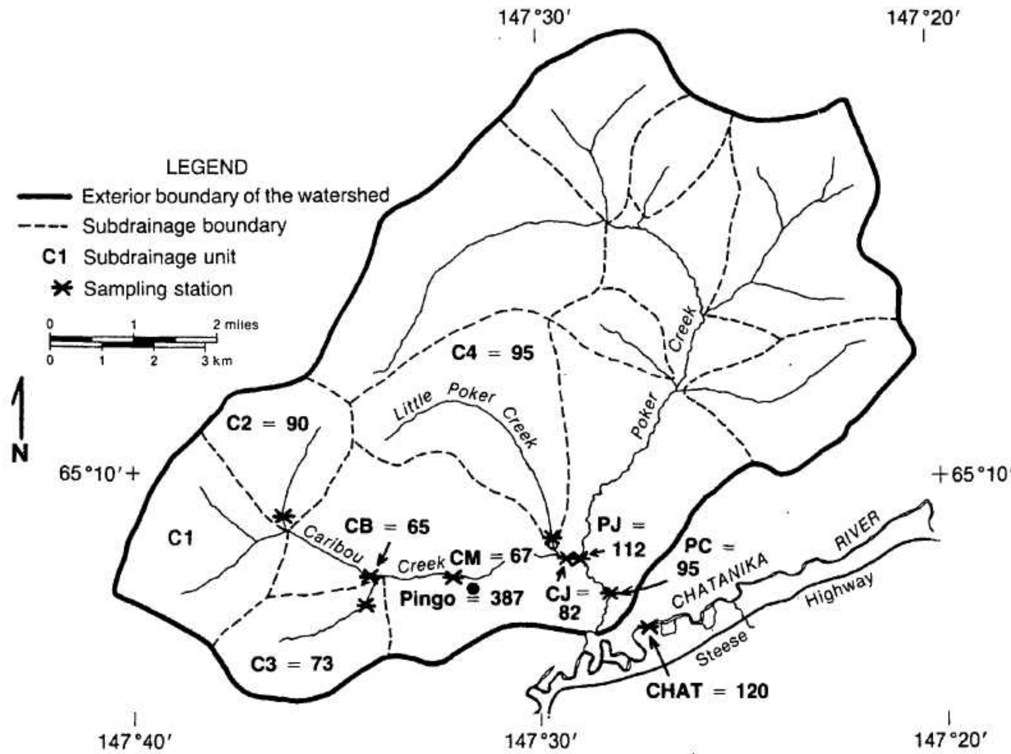

Figure 16—Specific conductance at selected sites on September 11, 1979.

Water Chemistry

pH and alkalinity. — The pH and alkalinity for CM is shown in fig. 17. Median pH at all sites was similar, ranging from 7.3 to 7.6 (table 8, fig. 18). The similarity was expected because of relatively homogeneous parent material and lack of any terrestrial disturbance that could alter pH. The C3 stream, however, was expected to have a slightly lower pH than C2 because its basin has a greater Sphagnum-dominated moss cover, which can increase soil and runoff acidity. A difference in pH between C2 and C3, however, was not apparent from these data.

Median bicarbonate alkalinity was highest in PJ, PC, and C4, and was lowest in C3. In the three stations having concurrent measurements of discharge and alkalinity, significant negative correlations! ($P < 0.05$, $N = 23$) were observed: $r = -0.473$ for G2, -0.732 for C3 and -0.624 for CM. The inverse relationship of alkalinity to discharge is consistent with a dilution effect with increasing discharge.

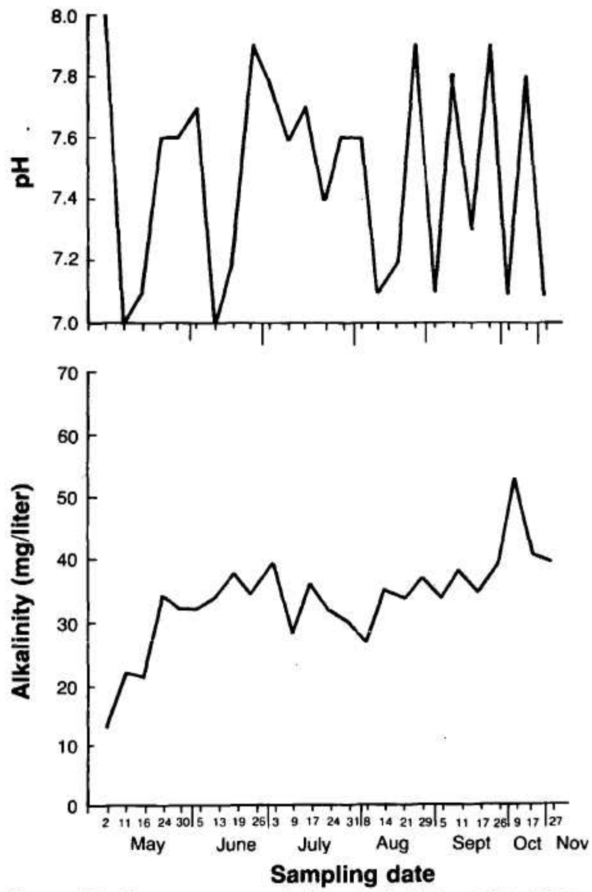

Figure 17—Measurements of pH and alkalinity at CM, 1979.

Table 8—Mean and median pH and alkalinity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979

Station	Number of observations	pH Mean	pH Median	pH Standard deviation	Alkalinity Mean	Alkalinity Median	Alkalinity Standard deviation
					- - - - -mg/liter - - - -		
C2	27	7.5	7.6	0.4	30.9	34.0	7.7
C3	26	7.4	7.3	.4	28.2	31.0	8.4
C4-bridge	26	7.4	7.5	.3	43.8	47.0	9.7
CB	27	7.4	7.3	.4	31.9	34.0	7.7
CM	26	7.4	7.3	.4	33.0	34.0	8.0
CJ	26	7.4	7.3	.4	39.4	42.0	10.2
PJ	26	7.4	7.4	.3	51.6	54.0	12.2
PC	13	7.5	7.4	.2	52.7	52.0	4.3
CHAT	26	7.4	7.4	.4	43.4	47.0	11.8

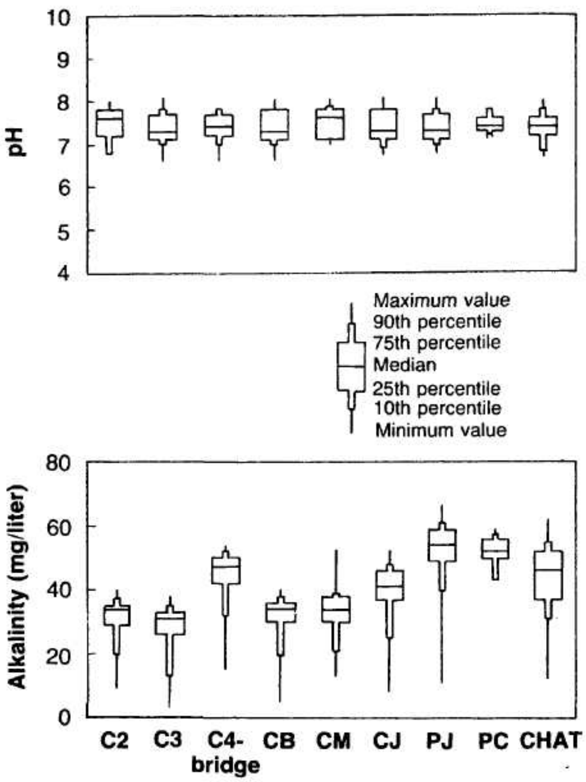

Figure 18—Summary statistics describing pH and alkalinity at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Nitrogen and phosphorus.—Median concentrations of dissolved Kjeldahl nitrogen, NH_3-N, NO3-N, and phosphorus compounds are summarized in table 9 and figure 19.

Table 9—Median concentrations of dissolved Kjeldahl nitrogen and phosphorus compounds at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979[1/]

Station and sample size	Kjeldahl-N		NH_3-N		NO_3-N		Total P		Available P	
C2, N=27	1.650	(0.306)	0.156	(0.086)	0.929	(0.543)	0.068	(0.174)	0.011	(0.176)
C3, N=26	1.715	(.310)	.146	(.063)	.744	(.439)	.067	(0.167)	.008	(.167)
C4-bridge, N=25	1.640	(.316)	.120	(.068)	.882	(.484)	.068	(0.120)	.000	(.125)
CB, N=27	1.590	(.319)	.085	(.072)	.738	(.416)	.062	(0.152)	.017	(.153)
CM, N=25	1.660	(.289)	.128	(.064)	.620	(.444)	.066	(0.123)	.000	(.126)
CJ, N=26	1.630	(.248)	.104	(.072)	.650	(.410)	.071	(0.142)	.013	(.147)
PJ, N=26	1.600	(.301)	.095	(.077)	.831	(.401)	.064	(0.149)	.004	(.149)
PC, N=13	1.720	(.349)	.189	(.074)	1.130	(.441)	.062	(0.010)	.000	(.015)
CHAT, N=26	1.625	(.309)	.111	(.069)	.607	(.447)	.068	(0.134)	.017	(.132)

1/ Standard deviations are shown in parentheses.

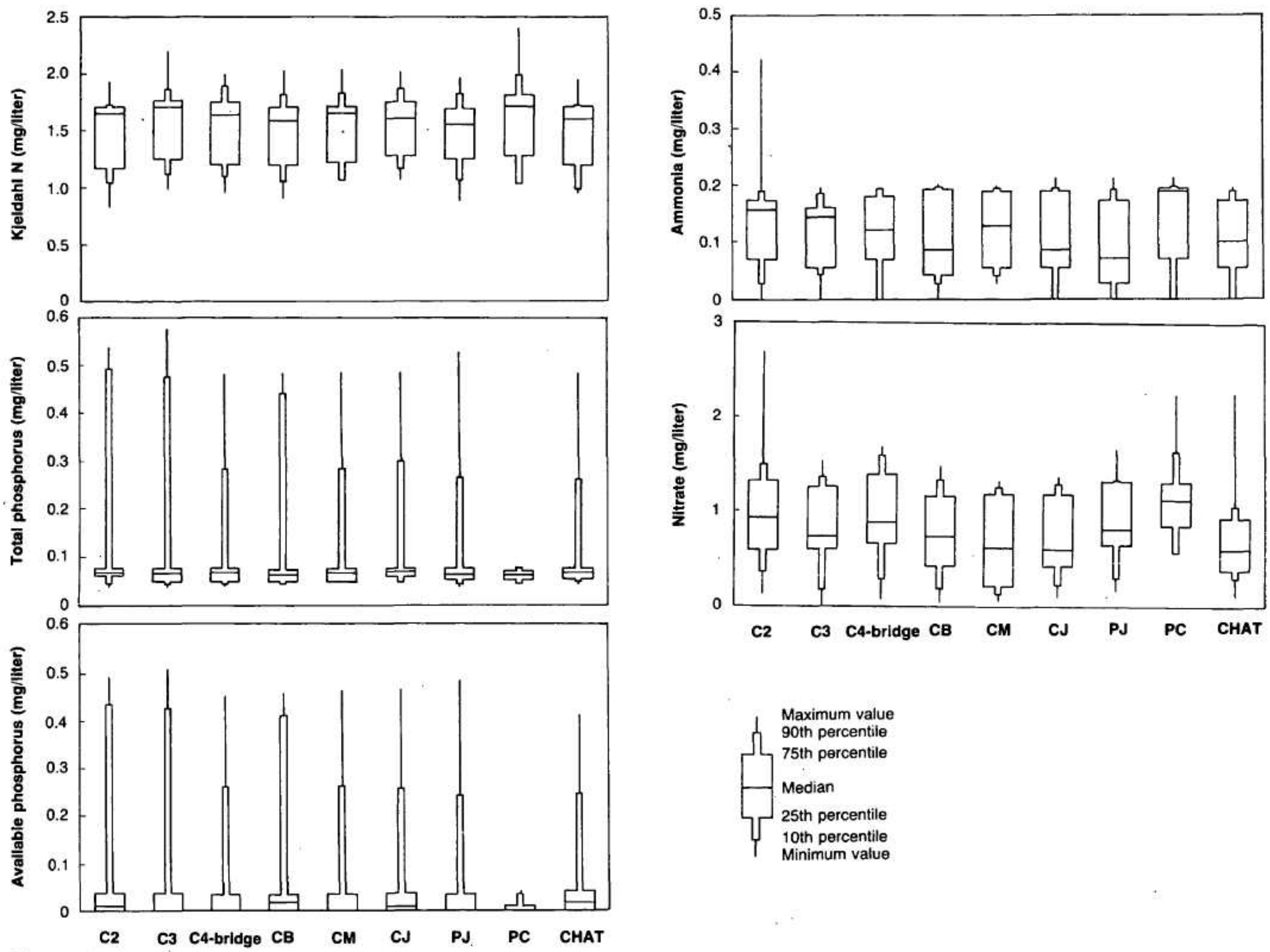

Figure 19—Summary statistics describing dissolved nitrogen and phosphorus compounds at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

The CM site is used in this report as a representative sampling point within the research watershed from which to examine the seasonality of chemical constituents. A historical data base of its chemical constituents and the continuous discharge record make CM a useful site for monitoring hydrochemical changes over the ice-free season. Median concentrations of Kjeldahl nitrogen in 1979 were highest during breakup (fig. 20). From a low of about 1 mg/liter in the spring, concentrations increased slightly, to 1.6 mg/liter, until just prior to freeze-up. A seasonal change is more pronounced in concentrations of NO_3-N and NH_3-N.

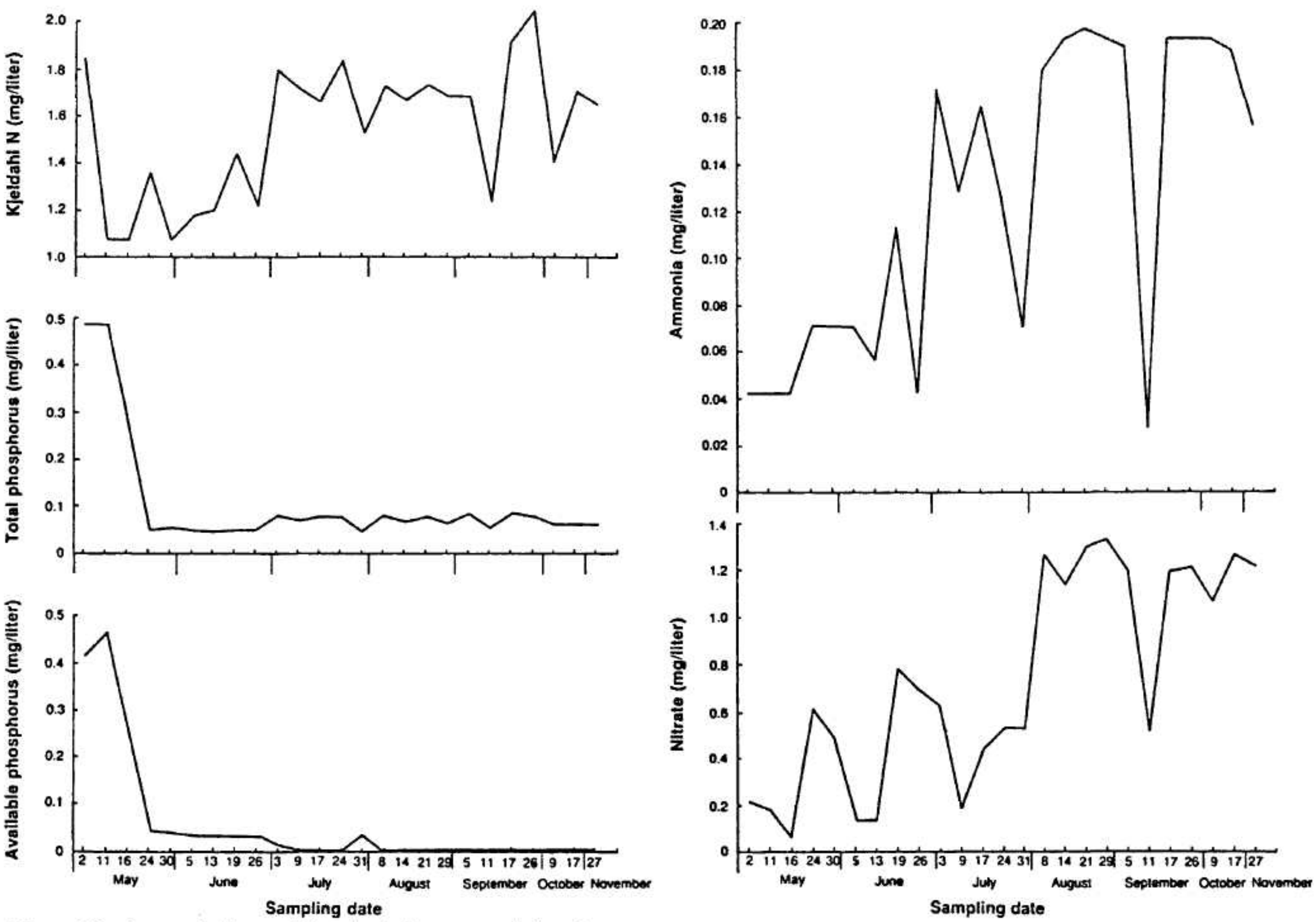

Figure 20—Concentrations of dissolved nitrogen and phosphorus compounds at CM, 1979.

Median concentrations of dissolved total phosphorus and Kjeldahl nitrogen appear similar at all sites sampled. There are slight variations in levels of nitrate, ammonia, and available phosphorus. Interpretation of these data is aided by ranking the sites from highest to lowest median concentration (table 10). Because sampling at PC did not begin until late summer, we did not include PC in the ranking. Its much lower number of observations and seasonal bias would be misleading in comparisons for the entire season. First-order sites G2, C3, and C4-bridge generally had higher concentrations of nitrogen compounds than did higher order sites. There was no apparent relationship of phosphorus to stream order. Ranking of sites by type of compound (table 11) suggest that dissolved phosphorus compounds are present in very concentrations throughout the watershed. Dissolved nitrogen compounds are also present in relatively low concentrations and exhibit a very weak but apparent relationship of decreasing levels with increased distance downstream.

Table 10—Ranking of sampling stations in Caribou-Poker Creeks research watershed and Chatanika River by median concentration of dissolved nitrogen and phosphorus compounds, 1979[1/]

Station	Kjeldahl-N	NH_3-N	NO_3-N	Total P	Available P
C2	3	1	1	3	4
C3	1	2	4	5	5
C4-bridge	4	4	2	4	7
CB	8	8	5	8	1
CM	2	3	7	6	8
CJ	5	6	6	1	3
PJ	7	7	3	7	6
CHAT	6	5	8	2	2

1/ 1 = highest concentration, 8 = lowest.

Table 11—Ranking of sampling stations in Caribou-Poker Creeks research watershed and Chatanika River by median **concentration of dissolved nitrogen compounds, dissolved phosphorus compounds, and dissolved nitrogen and phosphorus compounds combined, 1979**[1/]

Station	All nitrogen and phosphorus compounds	All nitrogen compounds	All phosphorus compounds
C2	1	1	1
C3	2	2	5
C4-bridge	3.5	3	6
CB	7.5	8	4
CM	6	4	8
CJ	3.5	5.5	1.5
PJ	7.5	5.5	7
CHAT	5	7	1.5

1/ 1=highest concentration, 8=lowest.

Growths of periphyton (attached algae) in the streams tend to be higher in sites further downstream in the research watershed (Hilgert 1984), especially in August and September. Uptake and incorporation of nitrogen and phosphorus compounds into the algal population, often described as a component process of "nutrient spiraling," can result in a decrease in dissolved nutrient levels along a river continuum. This relationship appears weak, however, at the sites sampled in the Caribou-Poker Creeks continuum.

Nitrogen-to-phosphorus ratios calculated from the 1978 field season (Hilgert and Slaughter 1983) were found to be overwhelmingly nitrogen dominated (phosphorus-limited). Values from the 1979 season also show consistent N-to-P ratios of approximately 25 to 1, verifying the observation from 1978 data that the Caribou-Poker Creeks river continuum is phosphorus-limited with respect to algal and aquatic plant production.

Dissolved ionic constituents.—Median concentrations of dissolved ionic constituents are given in table 12 and sites are ranked by concentration in table 13; summary statistics are shown in figure 21. An increase of median ionic concentrations apparently occurs from low-order to high-order streams, especially for dissolved calcium, magnesium, sodium, and manganese. The rank of C4, however, appears more representative of higher order sites. This position has been consistent with most of its other water quality characteristics, suggesting that C4 may represent a higher position in a hypothetical river continuum than just its basin area or relative discharge would suggest. Concentrations of silica, arsenic, and chloride appeared similar at all sites in the watershed, whereas iron levels tended to increase with stream order. When the ranks of all ionic constituents are totaled by site, sites can be ordered from highest to lowest concentrations: PJ > CHAT > CJ > C4-bridge > CB > C2 > CM > C3.

Table 12—Median concentration of dissolved ionic constituents at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979[1/]

Station	Ca	Mg	Na	Si	Fe	K	Mn	As	Cl
	mg/liter							ug/liter	mg/liter
C2, N=27	17.30 (2.59)	2.80 (0.64)	1.38 (0.25)	11.70 (3.78)	0.037 (0.040)	0.50 (0.15)	1.00 (0.84)	2.00 (1.16)	0.88 (0.42)
C3, N=26	18.95 (5.19)	1.50 (.60)	1.57 (.34)	10.65 (2.62)	.074 (.102)	.49 (0.24)	1.00 (7.84)	1.50 (1.72)	.72 (.43)
C4-bridge, N=25	28.50 (5.60)	2.70 (.49)	1.75 (.39)	11.70 (1.46)	.049 (.048)	.76 (0.12)	2.00 (1.12)	1.00 (1.26)	.81 (.33)
CB, N=27	17.00 (2.78)	2.10 (.44)	1.44 (.27)	12.15 (2.37)	.073 (.055)	.51 (0.14)	6.00 (4.45)	2.00 (1.63)	.75 (.90)
CM, N=25	18.40 (3.70)	2.00 (.44)	1.57 (.35)	12.70 (2.63)	.089 (.052)	.51 (0.15)	5.00 (1.98)	1.00 (1.51)	.70 (.36)
CJ, N=26	22.25 (5.45)	2.35 (.59)	1.62 (.35)	10.80 (1.88)	.121 (.062)	.64 (0.17)	6.00 (2.05)	2.00 (2.24)	.88 (.51)
PJ, N=26	31.15 (6.88)	3.60 (.81)	1.72 (.38)	11.45 (1.85)	.102 (.068)	.76 (0.15)	11.00 (6.08)	2.00 (2.19)	.86 (.43)
PC, N=13	28.90 (2.18)	3.50 (.27)	2.05 (.30)	12.30 (1.35)	.100 (.054)	.77 (0.41)	8.00 (1.66)	2.00 (1.03)	.75 (.30)
CHAT, N=26	28.65 (6.66)	4.35 (1.40)	1.69 (.36)	9.95 (2.41)	.241 (.135)	.75 (0.25)	9.00 (6.29)	1.50 (1.65)	1.05 (.51)

1/ Standard deviations are shown in parentheses.

Table 13—Ranking of sampling stations in Caribou-Poker Creeks research watershed and Chatanika River by median concentration of dissolved ionic constituents, 1979[1/]

Station	Ca	Mg	Na	Si	Fe	K	Mn	As	Cl	Total
C2	7	3	8	3.5	8	7	7.5	2.5	2.5	49
C3	5	8	5.5	7	5	8	7.5	5.5	7	58.5
C4-bridge	2	4	1	3.5	7	1.5	6	7.5	5	37.5
CB	8	6	7	2	6	5.5	3.5	2.5	6	46.5
CM	6	7	5.5	1	4	5.5	5	7.5	8	49.5
CJ	4	5	4	6	2	4	3.5	2.5	2.5	33.5
PJ	1	2	2	5	3	1.5	1	2.5	4	22
CHAT	3	1	3	8	1	3	2	5.5	1	27.5

1/ 1 = highest concentration, 8 = lowest.

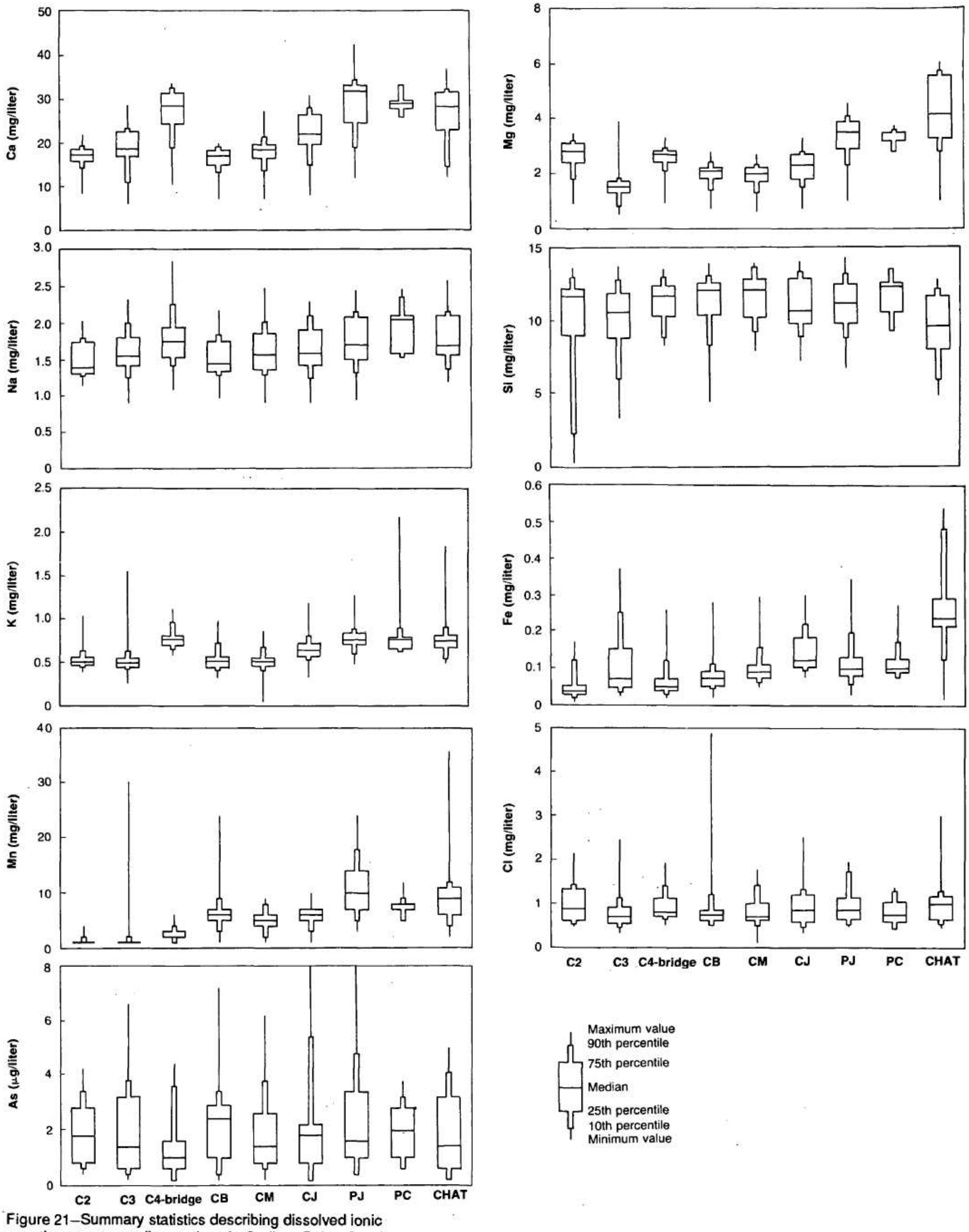

Figure 21—Summary statistics describing dissolved ionic constituents at sampling stations in Caribou-Poker Creeks research watershed and Chatanika River, 1979.

Concentrations of dissolved calcium, magnesium, sodium, and silica tended to increase from summer to freeze-up at CM (fig. 22). Potassium, manganese, chloride, and arsenic showed no apparent seasonal trends, whereas iron tended to decrease from summer to fall. Comparing rankings from these baseline data to rankings after treatment will aid in the assessment of water quality changes resulting from landscape manipulation. Logging or prescribed fire could change the rank relative to the pretreatment period. Comparing rankings of undisturbed basins to treated basins for the same year will also aid interpretation. Water quality characteristics most sensitive to landscape manipulation should exhibit the greatest change in ranking. Data from several years will be required to fully assess annual differences in relationships.

Conclusions

Physical and chemical water quality characteristics in samples collected in 1979 exhibited tendencies that appear consistent with those in a hypothetical river continuum. There appears to be a relationship of many water quality characteristics to basin size (or stream order), season, and the occurrence of underlying permafrost. When paired watersheds in this region of discontinuous permafrost are compared, the basins can yield drastically different results, evident in basins C2 and C3. Hydrologic response was much more pronounced in the permafrost-dominated C3 stream, as hypothesized in a previous study (Hilgert and Slaughter 1983). The difference in response of precipitation to discharge can impact the monitoring and interpretation of water quality characteristics related to discharge.

Annual discharge was estimated from gaged stream C3: approximately 43 percent occurred during the spring breakup, 7 percent during winter, and 50 percent during the ice-free season June through October.

Water temperature generally increased with basin size, consistent with a hypothetical stream continuum . Mean water temperature was slightly lower during the ice-free season in the C3 stream than in C2, possibly indicating a slight effect of permafrost dominance in the C3 basin.

Turbidity tended to increase with basin size; however, the C3 site had a much higher median turbidity than did C2. Highest turbidities occurred during breakup and storm flows, corresponding to increased concentrations of nonfilterable residue. Concentrations of residue increased slightly with basin area and were highest in the Chatanika River, just outside the research watershed; the river is impacted by placer mining activities upstream from the sampling site. Data indicate that concentrations of nonfilterable residue within the research watershed are typically very low, except during breakup and storm events.

Specific conductance, tended to increase with basin area and stream order, having low values during breakup and high discharge periods and gradually increasing through the summer. Runoff from a pingo within the watershed had higher specific conductance than did other sites but did not appear to have a substantial effect on specific conductance in Caribou Creek, into which it drains.

Among sites, pH appeared to be fairly consistent; however, alkalinity increased with stream order. Higher discharges were accompanied by lower alkalinity. Highest concentrations of nitrogen compounds tended to occur during the breakup period, were lowest in the summer, and increased slightly as the streams froze in the fall. Concentrations of total dissolved nitrogen and phosphorus did not appear related to stream order, and N-to-P ratios were generally 25 to 1, designated as phosphorus-limited with respect to aquatic plant growth.

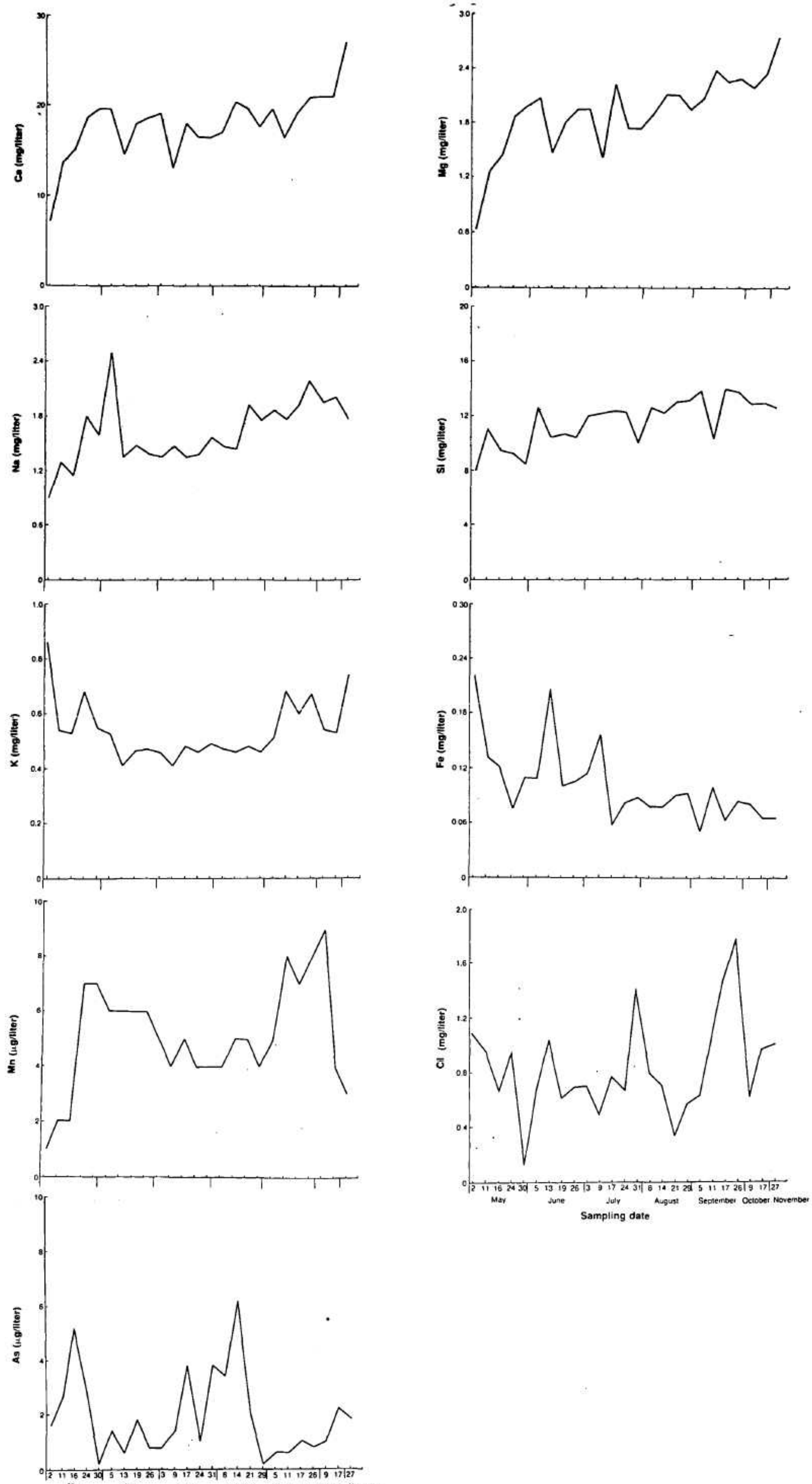

Figure 22—Median concentration of dissolved ionic constituents at CM, 1979.

There was an apparent increase in concentrations of dissolved calcium, magnesium, sodium, manganese, and iron with increasing stream order. Concentrations of dissolved calcium, magnesium, sodium, and silica tended to increase from summer months to freeze-up. A series of rankings of elements by site was developed for 1979.

Continuing efforts to monitor water quality characteristics should intensify sampling of storm events and spring breakup to better estimate sediment and chemical loadings, and should utilize an array of sites within the river continuum. Comparing rankings of sites by water quality characteristics described in baseline data to rankings after treatment will be valuable in assessing effects of landscape manipulation in the subarctic. Basins treated by logging or prescribed burning will likely change ranking because those treatments will change certain water quality characteristics. Several years of comprehensive data will be required to assess differences between years, differences that can result from annual variation in magnitude and timing of precipitation and in general climate.

Comparison of undisturbed sites within the Caribou-Poker Creeks research watershed to the Chatanika River and streams impacted by placer mining, road building, and timber harvesting will help resource managers assess and understand impacts of increased turbidity and concentration of sediment in the region. Thus, immediate benefits can be realized by continuing and expanding water quality monitoring, and long-term benefits will derive from studying effects of experimental landscape manipulations in the subarctic region.

Acknowledgments

This work was partially supported by the Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, under Inter-Agency Agreement EPA-79-D-X0557. The continued assistance of Mr. Eugene Culp, USDA Forest Service, Pacific Northwest Research Station, Institute of Northern Forestry, Fairbanks, Alaska, in both field and laboratory phases of this work is greatly appreciated. Ms. Michelle Abare and Mr. Steve Schoenheit assisted with sample collection and processing. Computer graphics and descriptive statistics were provided by the U.S. Environmental Protection Agency, Ambient Monitoring and Analysis Branch, Seattle, Washington, through the assistance and cooperation of Mr. Bruce Cleland. Dr. Mark Oswood, University of Alaska, Fairbanks, Alaska; Dr. F.B. Lotspeich, U.S. Environmental Protection Agency, Corvallis, Oregon; and Dr. Roy C. Sidle, USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Juneau, Alaska, reviewed the manuscript and provided useful criticism and comments.

English Conversions

Multiply	By	To obtain
kilometer (km)	0.621	mile
centimeter (cm)	.394	inch
meter (m)	3.281	foot
square kilometer (km^2)	.386	square mile
cubic meter (m^3)	35.320	cubic foot
kilogram (kg)	2.205	pound
milliliter (ml)	.338	fluid ounce
liter	.264	gallon
liter per second	.353	cubic feet per second
°C	$(\frac{9}{5}\ °C) + 32$	°F

Literature Cited

American Public Health Association. Standard methods for the examination of water and wastewater. Washington, DC; **1975.**1193 p.

Bredthauer, S.R.; Hoch, D. Drainage network analysis of a subarctic watershed. Spec. Rep. 79-19. Hanover, NH: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory; **1979. 9 p**

Hilgert, J.W. Upland stream quality in the Caribou-Poker Creeks Research Watershed. In: Proceedings, 30th Alaska Science Conference; 1979 September 19-21; Fairbanks, AK. Fairbanks, AK: American Association for the Advancement of Science, Alaskan Division, American Chemical Society; **1979:146.**

Hilgert, J.W.; Slaughter, C.W. Water quality and streamflow in the Caribou-Poker Creeks Research Watershed, central Alaska, 1978. Res. Note PNW-405. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1983. 36 p.**

Hilgert, J.W. Periphyton inventory and monitoring for water quality characterization in subarctic streams. In: LaBau, Vernon J.; Kerr, Calvin L, eds. Inventorying forest and other vegetation of the high latitude and high altitude regions: Proceedings of an international symposium, Society of American Foresters regional technical conference, 1984 July 23-26; Fairbanks, Alaska. SAF Publ. 84-11. Bethesda, MD: Society of American Foresters; **1984:** 271-279.

Jinkinson, W.M.; Lotspeich, F.B.; Mueller, E.W. Water quality of Caribou-Poker Creeks Research Watershed, Alaska. AERS Work. Pap. 24. College, AK:U. S. Environmental Protection Agency, Arctic Environmental Research Laboratory; **1973. 25 p.**

Kane, D.L.; Slaughter, C.W. Seasonal regime and hydrological significance of stream icings in central Alaska. In: The role of snow and ice in hydrology: Proceedings of the symposium; 1972 September; Banff, AB. [City and Province of publication unknown] Canada: Beauregard Press Ltd; UNESCO-WMO-IASH; **1972:** 528-554.

Koutz, F.R.; Slaughter, C.W. Geological setting of the Caribou-Poker Creeks Research Watershed, interior Alaska. Tech. Note. Hanover, N.H: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory; **1972.** 32 p.

Lotspeich, F.B.; Jackson, R.L.; Helmers, A.E. Climatology and water quality data, Caribou-Poker Creeks Research Watershed. AERS Work. Pap. 30 (CERL-014). College, Alaska. U. S. Environmental Protection Agency, Arctic Environmental Research Station; **1976. 41 p.**

Lotspeich, F.B.; Slaughter, C.W. Preliminary results on the structure and functioning of a taiga watershed. IWR-101. Fairbanks, AK: Institute of Water Resources, University of Alaska; **1981.** 94 p.

Reiger, S.; Furbush, C.E.; Schoephorster, D.B. [and others]. Soils of the Caribou-Poker Creeks Research Watershed. Tech. Rep. 236. Hanover, NH: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory; **1972.**11 p.

Slaughter, C.W. Snowmelt runoff estimation with time lapse photography. EOS. 63(8): 175; **1982.** Abstract.

Slaughter, C.W.; Hilgert, J.W. First-order streams during breakup. In: Proceedings, 30th Alaska Science Conference; 1979 September 19-21; Fairbanks, AK. American Association for the Advancement of Science, Alaskan Division, American Chemical Society; **1979.** Abstract.

Slaughter, C.W.; Kane, D.L. Hydrologic role of shallow organic soils in cold climates. In: Proceedings, Canadian hydrology symposium: 79-cold climate hydrology; 1979 May 10-11; Vancouver, BC. Ottawa, ON: National Research Council of Canada; **1979:** 380-389.

Slaughter, C.W.; Long, L.P. Upland climatic parameters on subarctic slopes, central Alaska. In: Climate of the Arctic: Proceedings, 24th Alaska Science Conference, 1973 August 15-17; College, AK. College, Alaska: Geophysical Institute; Fairbanks, AK: University of Alaska; **1974:** 276-280.

Troth, J.L; Deneke, F.J.; Brown, L.M. Subarctic plant communities and associated litter and soil profiles in the Caribou-Poker Creeks Research Watershed, interior Alaska. Res. Rep. 330. Hanover, NH: U.S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory; **1975. 25 p.**

U.S. Environmental Protection Agency. Methods for chemical analysis of water and wastewater. EPA-625-/6074-003a. Cincinnati, OH: U.S. Environmental Protection Agency, Environmental Research Center; **1976.** 298 p.

Vannote, R.L.; Minshall, G.W.; Cummins, K.W. [and others]. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences. 37: 130-37; **1980.**

The **Forest Service** of the U.S. Department of Agriculture is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.

The U.S. Department of Agriculture is an Equal Opportunity Employer. Applicants for all Department programs will be given equal consideration without regard to age, race-, color, sex, religion, or national origin.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

October 1987

U.S. Department of Agriculture
Pacific Northwest Research Station
319 S.W. Pine Street
P.O. BOX 3890
Portland, Oregon 97208

BULK RATE
POSTAGE
FEES PAID
USDA-FS
PERMIT No. G-40

Official Business
Penalty for Private Use, $300

do not detach label