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HYDROLOGIC STUDIES OF THE GLENN CREEK DRAINAGE BASIN NEAR FAIRBANKS, ALASKA

by

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PREFACE

This report was prepared by S. Lawrence Dingman, research geologist, for the Environmental Research Branch, Dr. R. W. Gerdel, Chief. The work was performed as a project of the Research Division, J. A. Bender, Chief.

Dr. Gerdel provided valuable guidance in the planning of this project. Gilberto M. Font-Jimenez collected most of the data during the summer months. F. F. Kitze, Chief, and Pvts. Harley Natvig and Henry Galle, of the USA CRREL Alaska Field Station, aided the project by collecting discharge and precipitation data during September and October. Discussions with Dr. Jerry Brown, USA CRREL, concerning many aspects of this study were very valuable. Pvt. George Wolfel assisted in analyzing portions of the data.

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SUMMARY

A detailed hydrologic study of Glenn Creek, which drains an area of 0.7 mi^2 lying 8 miles north of Fairbanks, Alaska, was begun in June, 1964. The soil beneath the lower portions of this area is perennially frozen to within a few feet of the surface, and a thick mat of mosses covers much of the surface of the watershed. During the period June-October, rainfall, runoff, dissolved and suspended sediment concentrations, and air and water temperatures were measured. The following observations and tentative conclusions are based on the first summer's study of Glenn Creek and its drainage basin: 1) relationships comprising at-a-station hydraulic geometry are similar to those for larger streams in other areas; 2) the lag time between rainfall and peak storm discharge is much longer for Glenn Creek than for similar-sized streams in mid-latitude regions; 3) hydrograph recessions are drawn out in time relative to those for similar-sized streams in mid-latitude regions; 4) base flow was low in early and mid-summer, rose to a peak in late summer, and very gradually diminished thereafter, accounting for most of the flow in September and October; 5) direct runoff must occur largely as interflow; 6) about 24% of the rain which fell appeared as runoff; 7) the fraction of rainfall appearing as direct runoff varied from 3% to 30%, and showed no seasonal trends; 8) the suspended and dissolved sediment concentrations of Glenn Creek are within the ranges reported for larger streams in the area; 9) suspended sediment yield was roughly five times as large as dissolved sediment yield for June-October. A number of years of study will be required to confirm these preliminary conclusions and to determine the representativeness of the observations.

HYDROLOGIC STUDIES OF THE GLENN CREEK DRAINAGE BASIN NEAR FAIRBANKS, ALASKA - PRELIMINARY REPORT

by

S. Lawrence Dingman

Introduction

There are few quantitative hydrologic data for central Alaska. Streamflow measurements on a regular basis were begun in 1951, and gaging stations are widely scattered. Only recently have any analyses of these data been possible (U. S. Geological Survey and Alaska Department of Highways, in press). Furthermore, the analyses have been limited to streams draining areas of 500 mi^2 or larger, as there are virtually no data for smaller areas. Very little is known about rainfall-runoff relations in the area because precipitation stations are also widely scattered.

Hydrologic events in large drainage areas can to a large extent be rationally synthesized from knowledge of the events occurring in small constituent watersheds. Thus it was decided that an efficient way to learn about the hydrology of central Alaska would be to study closely a "typical" drainage basin small enough for reasonably detailed analysis, yet large enough so that the effects of extremely local conditions would be minimized.

Two physical characteristics of central Alaska would seem to preclude direct application of quantitative hydrologic information from mid-latitude areas: 1) it is an area of discontinuous permafrost; and 2) much of its land surface is covered by a thick sponge-like mat of mosses and lichens.

The specific objectives of this study are 1) to determine rainfall-runoff relations; 2) to establish a water balance statement for the basin; 3) to determine the sequence of break-up and freeze-up events and their influences on runoff and other processes; 4) to obtain information as to the production of stream-borne sediment.

This preliminary report gives the results of the first summer's observations. A period of study of 5 years or more is anticipated in order to satisfactorily fulfill the above objectives.

Location

Choice of an area for study depended on size, accessibility, and typicalness. It was decided that an area of about 1 to 5 mi^2 would allow detailed analysis, yet would eliminate very local effects. After examining several possibilities, the drainage basin of Glenn Creek, near Fox, Alaska (about 8 miles north of Fairbanks), was selected (Fig. 1). Its area is about 0.7 mi^2, somewhat smaller than originally planned. It is easily accessible from Fairbanks via the Steese Highway, and is adjacent to the USA CRREL permafrost tunnel project facilities. The area is virtually undisturbed by man.

A general view of the basin from the ground is shown as Figure 2, and oblique aerial photographs as Figure 3. The basin ranges in elevation from about 850 ft a.s.l. to about 1600 ft a.s.l. Glenn Creek flows northwesterly, and there are marked differences in vegetation and permafrost conditions between the northeast- and southwest-facing slopes. Parts of the northeast-facing slope are underlain by

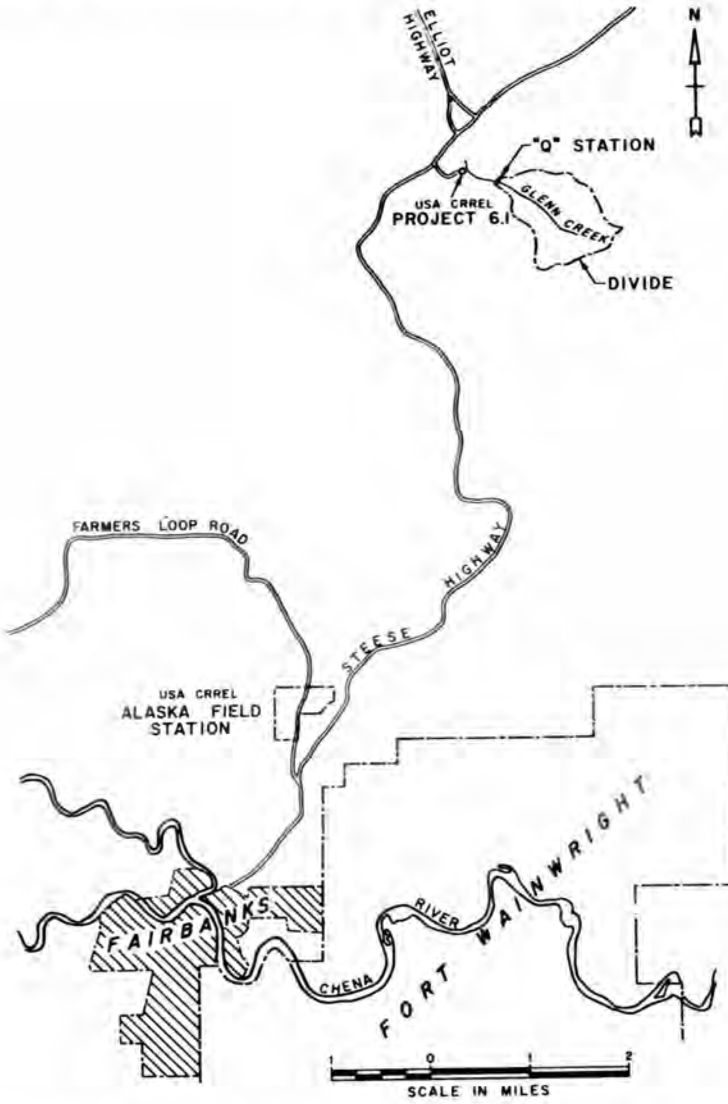

Figure 1. Location of Glenn Creek watershed.

permafrost having a thin seasonal thaw zone, though present evidence suggests that the permafrost pinches out before reaching the divide. This slope is largely forested with black spruce, with some birches and a ground cover of thick mosses and lichens. The southwest-facing slope is apparently free of permafrost, and is covered by a forest of tall birch and aspen above a floor much like the organic duff of a temperate forest, and generally without a thick moss mat. In the valley bottom small willows and grasses and sedges predominate, with larger alders toward the upper reaches. Perennially frozen ground is present within 3 ft of the surface in this portion of the basin.

Schists of the Precambrian Birch Creek formation underlie the entire basin. These are mantled by silts which were originally wind-deposited (loess), but which have been largely or wholly reworked subsequently (Péwé, 1958; Dement, 1962).

Figure 2. View of Glenn Creek drainage basin showing typical vegetation. The stream channel is visible in the foreground.

The soils of the area, mapped by Rieger, Dement and Sanders (1963), consist of silt loams of three series, with differences controlled largely by drainage characteristics and slope aspects.

Average annual precipitation in the vicinity of Fairbanks is approximately 12 in., with about 7 in. of this falling as rain between April and October. Evaporation as measured in a class-A pan at College, 8 miles to the west, is of the order of 14 in. annually. Watson (in Rieger, Dement and Sanders, 1963) reports that potential evapotranspiration determined by the Thornthwaite method is about 13 in. during the three summer months. These rainfall and evapotranspiration figures are discussed later in this report.

Methods of data collection and analysis

Rainfall. Rainfall was measured approximately daily for the period 1 to 24 June in a nonrecording rain gage located about $\frac{1}{4}$ mile below the gaging station. From 24 June to 26 August it was measured in a similar gage about $\frac{1}{8}$ mile below the gaging station, at a location which will be referred to as the Moss Site. A weighing type recording rain gage was installed on 26 August at the Moss Site. All rain gages were equipped with Alter wind shields. The Moss Site gages were installed according to instructions in U. S. Weather Bureau Circular B, 10th edition (1955).

Runoff. Runoff was measured on an approximately daily basis by one of two methods. Most measurements were made by a Price-type pygmy current meter attached to a rod. A straight reach of channel free from major obstructions was selected for the measuring site, referred to as the Q-Station. The reach was cleared of channel vegetation, and a board installed over the channel, level and at right angles to it. This guide board was marked and provided with nails so that the current meter rod could be accurately placed at 0.1-ft intervals across the channel (see Fig. 4).

Figure 3. Glenn Creek watershed.

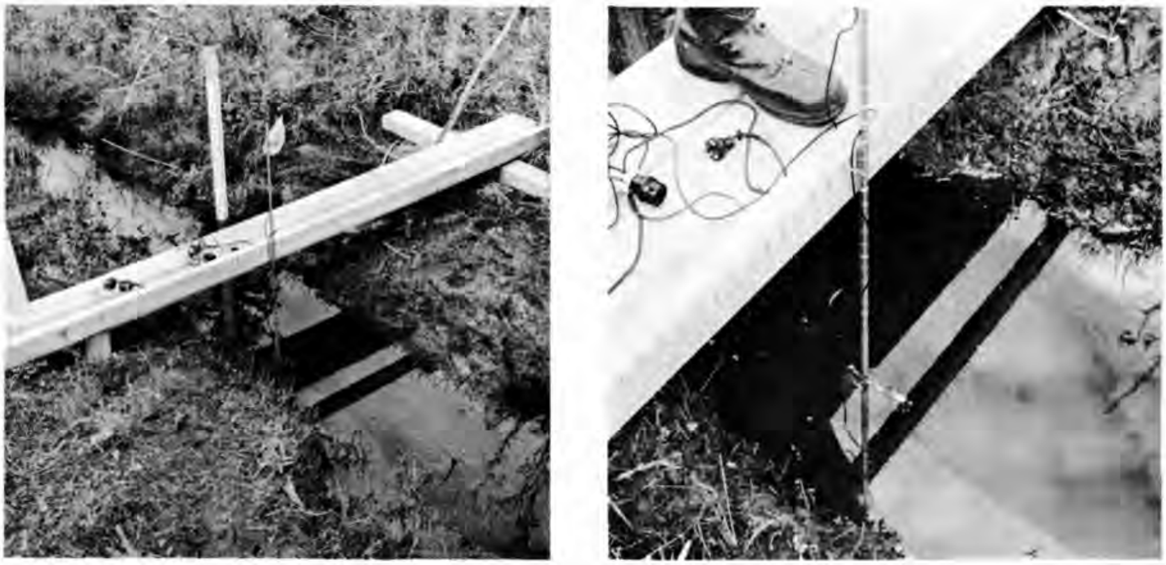

Figure 4. Q-Station.

To make a discharge measurement, a plumb bob was used to locate the edges of the water relative to the markings on the guide board. The current meter, which could be adjusted to any position on the rod, was placed in the channel at the point closest to the left bank at which the water was deep enough to cover the meter at its lowest position (0.2 ft above the channel bottom). With the current meter extending directly upstream from the rod, the location of the rod in the cross section, the depth of water at that point, and the rate of rotation of the current meter cups (which is directly related to flow velocity) were noted. Velocity read at 0.6 of the depth at any point along the cross section is close to the average velocity at that point (see Corbett, et al., 1943). Measurements were made at 0.1-ft increments across the channel, and discharges in each increment (width x depth x velocity) were summed to determine total discharge. Because of the small depths of flow often encountered, it was not always possible to take velocity readings at 0.6 of the flow depth, especially near the banks. Thus, discharge computed by this method is probably a few percent greater than actual discharge.

Because of this discrepancy, a second method was employed to measure discharge when flows were very low. The flow was temporarily diverted through a flume (see Fig. 5) into a bucket of known volume, and the time required to fill the bucket was noted. Generally, five such measurements were made for each discharge determination, and the results averaged. Comparison of the volumetric and current-meter methods showed good agreement. Discharge measurements by both methods were made to the nearest 0.01 ft^3/sec.

A staff gage was installed immediately downstream from the guide-board, so that a rating curve (discharge vs stage) could be developed. When established, the rating curve was used for occasional discharge estimates (Fig. 7). This was especially useful in conjunction with a peak stage gage, also installed in the measuring reach. It was found that organic debris floating on the stream would adhere to this peak stage gage; a line of debris was left at the peak stage after flow descended. Readings on it were graphically related to staff gage readings, and discharge at the peak was then determined from the rating curve.

Figure 5. Flume used in volumetric discharge determinations.

Field investigations disclosed no apparent means whereby water could flow from the basin without passing the Q-Station.

Air temperature. Air temperature was measured by maximum-minimum thermometers in a standard U. S. Weather Bureau shelter about $\frac{1}{4}$ mile below the Q-Station. Average daily temperature was computed by averaging the maximum and minimum temperature readings for a given day. However, readings were made at about 0800 hours, so that the maximum and minimum temperatures read do not correspond to those of the calendar day (0000-2400 hours). An attempt was made to correct this by assuming that the minimum temperature read at 0800 occurred during the current calendar day and the maximum occurred during the previous day. When this was done, a simple linear regression analysis was carried out to determine the relation between daily temperatures at Glenn Creek (T_{GC}) and those at Fairbanks International Airport (T_F). The regression equation was

$$T_{GC} = -20.7 + 1.30\ T_F,$$

with a correlation coefficient of .988 (significant at less than the .001 level) and a standard error of estimate of 1.27 Fahrenheit degrees. This relation can be used to fill the gaps in the temperature record at Glenn Creek with reasonable certainty. The elevation of the Glenn Creek station is about 750 ft a. s. l. and that of the Fairbanks Airport is about 430 ft a. s. l.

Water temperature. Water temperature was measured with a Weston dial thermometer, which was read to the nearest centigrade degree. Measurements were made in the vigorously flowing portion of the stream with the sensing element shielded from the sun. Water temperature was read at each discharge measurement and each time a suspended or dissolved sediment sample was taken.

Soil moisture. Soil moisture was determined by the standard procedure of collecting the sample in a sampling spoon, immediately transferring it to a sealed can, and later weighing the sample before and after oven-drying. Samples from the top few inches of the soil were taken at the Moss Site on a weekly basis.

Moss moisture. Moss moisture was determined in the same manner as soil moisture. Samples were taken by inverting a sharp-edged can over the moss, pressing it into the moss, and then using a knife to free the sample. An effort was made to prevent compression of the moss, so that each sample was of known volume and surface area.

Moss samples were taken from two plots at the Moss Site. Each plot was marked as a 10-ft square over a typical moss-covered area (Fig. 6), and a 1-ft grid system set up. One sample was collected from beneath the same grid coordinates on each plot, so that temporal variations (variations due to rainfall and evaporation) could be compared with spatial variations (variations between the two plots).

Depth of active layer. Depth of thaw was measured by a graduated steel probing rod. Measurements were taken on a weekly basis at the moss plots and across the channel at the Q-Station, and irregularly when exploring in the drainage basin.

Dissolved solids. Concentration of material dissolved in Glenn Creek and in other bodies of water in the basin was determined by the residue-on-evaporation method (see Rainwater and Thatcher, 1960). Samples of 700 to 1000 ml were taken by submerging polyethylene bottles. An effort was made to minimize inclusion of suspended organic and inorganic material during collection. Immediately after collection, about 10 drops of chloroform were added per liter of sample to inhibit bacterial and algal activity. The samples were tightly sealed and shipped to USA CRREL, where they were stored at 40F until analyzed.

Electrical conductivity, pH, and residue upon evaporation were determined in the laboratory. Conductivity was measured by a conductivity bridge (Industrial Instruments IGB2) and corrected to 25C. The pH was determined with a Beckman pH meter as a matter of information only, as pH so measured does not necessarily correspond to pH in situ. The procedure used to determine residue on evaporation is outlined in Appendix A.

Suspended sediment concentration. A DH-48 suspended sediment sampler (see Subcommittee on Sedimentation, Inter-Agency Committee on Water Resources, 1959) was used to collect samples for determination of suspended sediment concentration. This instrument consists of a nozzle designed to admit flowing water and suspended material in the proportions in which they are present in the stream, and a removable bottle in which the sample is collected. The sampler is lowered in the stream at a constant rate until bottom is reached, then immediately reversed and raised at a constant rate. When the sampler touches bottom, the nozzle is $3\frac{1}{2}$ in. above the bed, so that sediment traveling close to the bed is not sampled. This method allows one to obtain a sample with the average concentration of suspended sediment for the column of water sampled. For each determination, one sample was taken in the center of the stream. Samples (700-1000 ml) were transferred to polyethylene bottles and shipped to USA CRREL to be analyzed. Analysis was by a filtration method, described in Appendix B.

Summer 1964 weather

Table I shows monthly precipitation and average monthly temperature and departures from normal for Fairbanks International Airport for May through October 1964, as published in U. S. Weather Bureau Local Climatological Data reports. The average temperature for May 1964 was the lowest ever recorded, but the five summer months were somewhat warmer than the 30-year normals. It was shown that average daily temperatures at Glenn Creek correlate well with

Figure 6. Left (above) and right Moss Plots.

Table I. Precipitation and temperature, Fairbanks International Airport, May - October 1964.

	Average temp (°F)	Departure from normal (°F)	Total precipitation (in.)	Departure from normal (in.)
May	38.6	-8.5	0.97	+0.37
June	60.1	+1.7	1.33	-0.06
July	59.7	0	1.28	-0.56
August	56.5	+2.2	2.37	+0.17
September	44.9	+1.3	0.85	+0.25
October	28.3	+2.1	0.53	-0.32

those at Fairbanks Airport. However, records presented later in this report show significantly greater monthly precipitation for Glenn Creek. Because of the local nature of the summer storms in the area, it is impossible to say whether precipitation at Glenn Creek was greater or less than normal.

Without data for a number of years, it is presently impossible to determine how these deviations from the normal (30-year) climate, particularly the very cold May, may have influenced the hydrologic variables measured on Glenn Creek.

Hydraulic geometry

The term "hydraulic geometry" was coined by Leopold and Maddock (1953) to refer to variations in stream width, average depth, average velocity, and sediment concentration that accompany changes in discharge. An extensive discussion of the subject can be found in Leopold, Wolman and Miller (1964).

The present discussion is limited to the variations in hydraulic characteristics which occur with discharge changes at Q-Station. Variations accompanying downstream changes in discharge were not investigated.

Stage-discharge relation. Figure 7 shows the relation between discharge and stage (water level measured on a staff gage as an arbitrary datum) at Q-Station. The form of these curves is typical of those for larger streams (Linsley, Kohler and Paulhus, 1949, p. 213). It is immediately apparent from Figure 7 that a significant shifting of the rating curve took place in the course of the summer. Discharge measurements 1 through 45 (10 June through 25 July) define one curve, measurements 61 through 89 (17 August through 25 September) define another, and measurements 46 through 60 (27 July through 15 August) are transitional between the two.

For a given discharge, the later curve shows a higher stage than the earlier curve, suggesting a silting up at the measuring section. To check this, cross sections were plotted using data taken during discharge determinations; some of these are shown in Figure 8. No significant change in the cross section occurred through 25 July, and its form for this period is represented by the section for 11 July. The section for 27 July, however, shows a silting of 0.05 to 0.1 ft across the channel. Curves of 4 August and 27 August show further silting. Calculations showed an average of 0.3 ft of sediment deposited at the cross section between 25 July and 27 August.

Cross sections subsequent to 27 August show a deepening of the channel, especially near the left bank. The last section, made on 25 September, shows that the channel had been scoured nearly to its original depth.

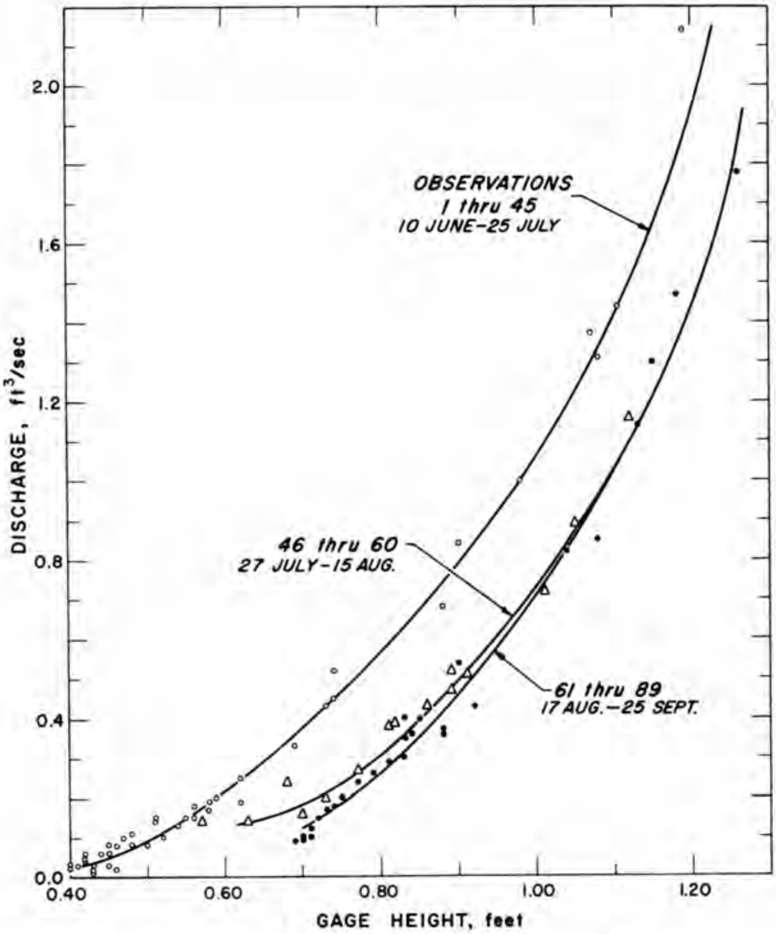

Figure 7. Stage-discharge relation at Q-Station.

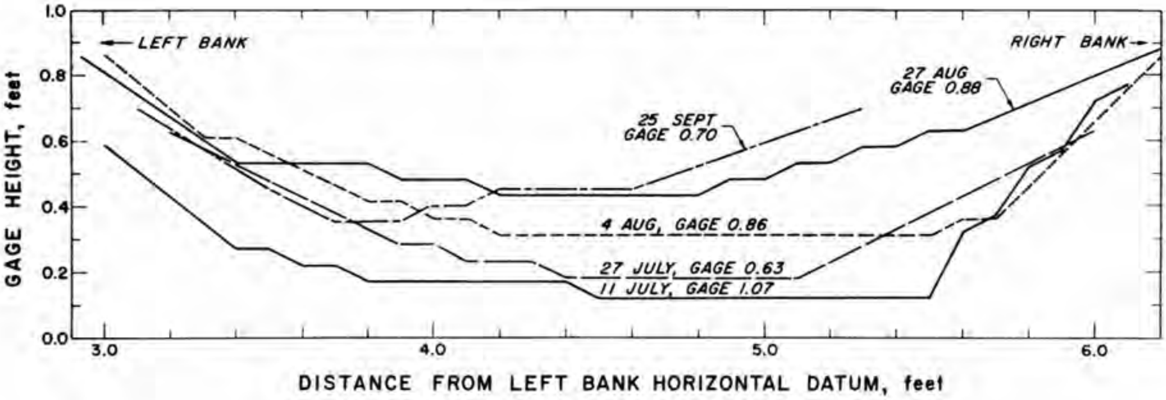

Figure 8. Channel cross-sections at Q-Station, showing changes with time due to scour and fill.

Causes for this scour and fill can be suggested. Investigations of the channel above Q-Station have disclosed an extensive thermokarst area (see Hopkins and Karlstrom, 1958, p. 141). This feature is discussed in detail later in this report. Briefly, it is a region extending about 100 yards along the stream course where the stream flows in a trench 2 to 10 ft deep. This probably is due to the fairly recent thawing of a buried ice mass, causing collapse of the thick moss mat and allowing water and sun to melt the frozen ground thus exposed. Apparently significant thawing of this frozen ground did not take place until the end of July, at which time Glenn Creek began to carry the released sediment. Before the end of July, Glenn Creek had occasional high concentrations of suspended sediment, but average flow, and hence average suspended sediment concentration (see Fig. 19), was lower during this period than subsequently. Deposition occurred at the Q-Station because it was located at a relatively wide reach of the channel. Immediately after 27 August, flows and flow velocities were near their highest levels for several days, and scouring began at Q-Station. Average flow velocities in this period reached 0.6 ft/sec and above at Q-Station, thus entering for the first time the range of velocities capable of eroding unconsolidated silts and clays (see Sundborg, 1956, Fig. 13).

Width, depth, and velocity vs discharge. Figures 9, 10, and 11 are plots of width, average depth, and average velocity respectively vs discharge. Straight lines have been fitted by eye to points on two of these graphs for discharges greater than 0.2 ft^3/sec. Because of the changes in channel geometry, separate symbols are used for measurements 1-45, 46-60, and 61-89.

The exponent is about 0.35 for the depth-discharge relation and about 0.50 for the velocity-discharge relation. These are slightly lower and higher, respectively, than the values given for streams in the continental United States by Leopold, Wolman and Miller (1964, Table 7-5). It is difficult to estimate a best fit line for the width-discharge relation, but as the sum of the three exponents must equal unity (width x depth x velocity = discharge) the exponent is about 0.15, roughly in the middle of the range of values given by Leopold, Wolman and Miller. For a given discharge, velocity is roughly 30% higher and depth 30% lower for measurements 61-89 as compared to measurements 1-45, and measurements 46-60 are transitional between the two groups. The breakdown of the width-discharge and depth-discharge relations, and to some extent the velocity-discharge relation, at low flows is probably due largely to the fact that only a few current meter readings are made at low flows, and those only in the center of the channel, and also to a backwater effect caused by a channel constriction a few feet below Q-Station.

While the relationships just discussed only represent measurements at one point on one small stream, they provide some insight into the behavior of the stream and may provide a basis for extrapolation when considering the installation of a weir or other structure, or for estimating sediment transport capacity or competence. They may also be of interest in comparing this stream to others in Alaska and in other parts of the world. The consistency of the relationships indicates that the various measurements were reasonably accurate. Another element of hydraulic geometry, the relation between discharge and suspended sediment concentration, will be considered later in this paper.

Hydrograph analysis

Plots of discharge vs time are shown on Figures 12-16. Actual discharge measurements are represented by circles on the graph; an "E" adjacent to a circle indicates that the discharge was estimated from staff gage observations. Estimates of peak discharge are represented by bars at the peak discharge, extending over the time period within which the peak occurred. The smooth curve (hydrograph) connecting the points is drawn taking into account periods of rainfall, and is believed to be a good representation of actual discharges at any time. When more uncertainty exists, particularly at times of rise and times of peak, the hydrograph is dashed.

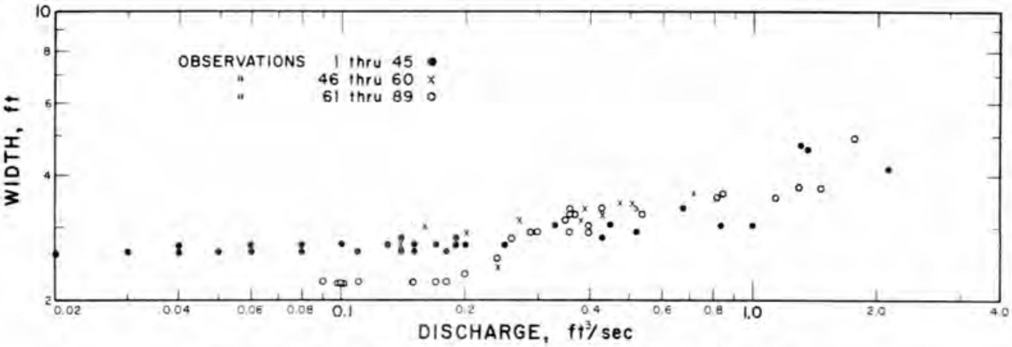

Figure 9. Width vs discharge at Q-Station.

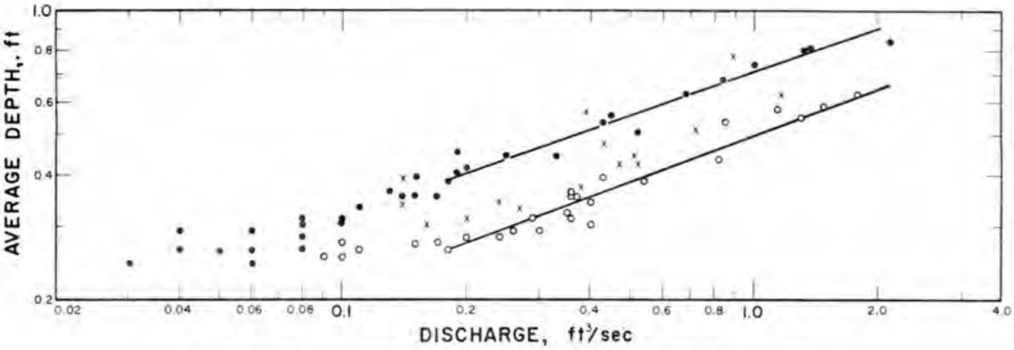

Figure 10. Depth vs discharge at Q-Station.

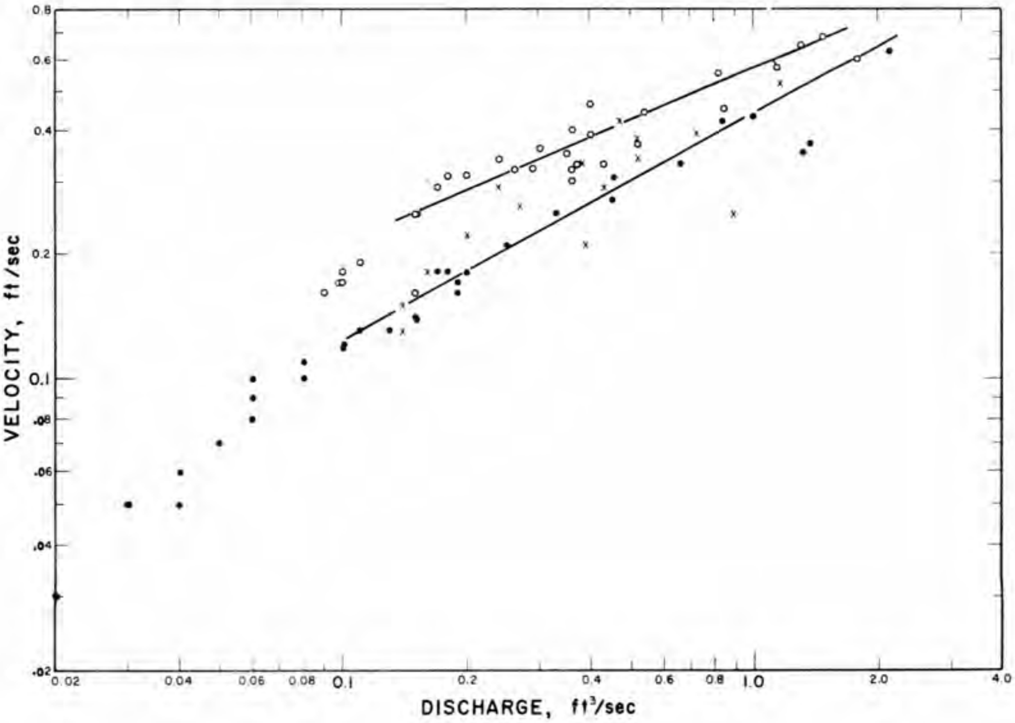

Figure 11. Velocity vs discharge at Q-Station.

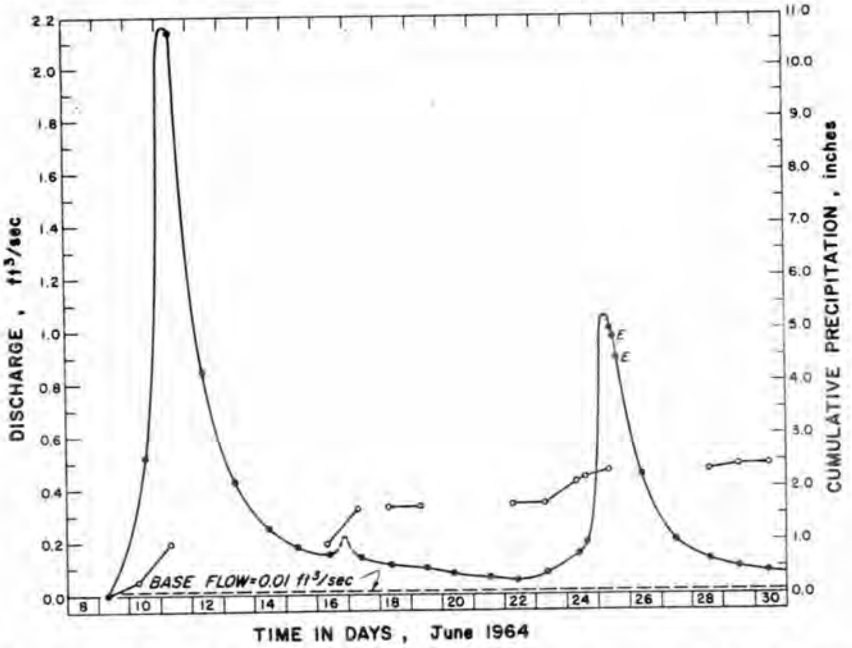

Figure 12. Glenn Creek hydrograph and cumulative precipitation, June 1964. E denotes estimates from stage-discharge relations.

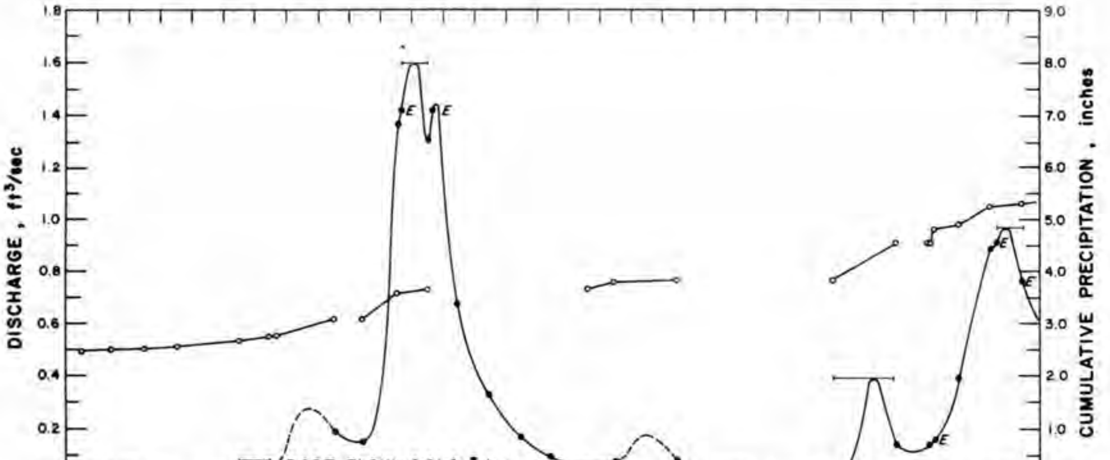

Figure 13. Glenn Creek hydrograph and cumulative precipitation, July 1964. E denotes estimates from stage-discharge relation, horizontal bars are estimates of peak discharges from peak stage gage.

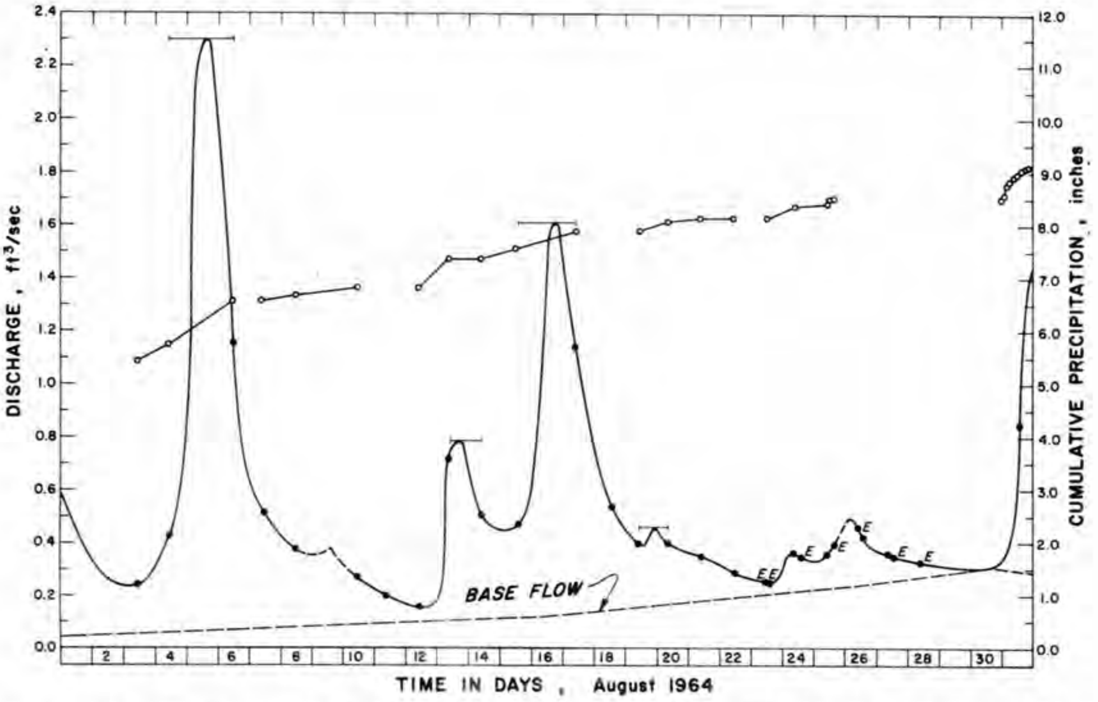

Figure 14. Glenn Creek hydrograph and cumulative precipitation, August 1964. E denotes estimates from stage-discharge relation, horizontal bars are estimates of peak discharges from peak stage gage.

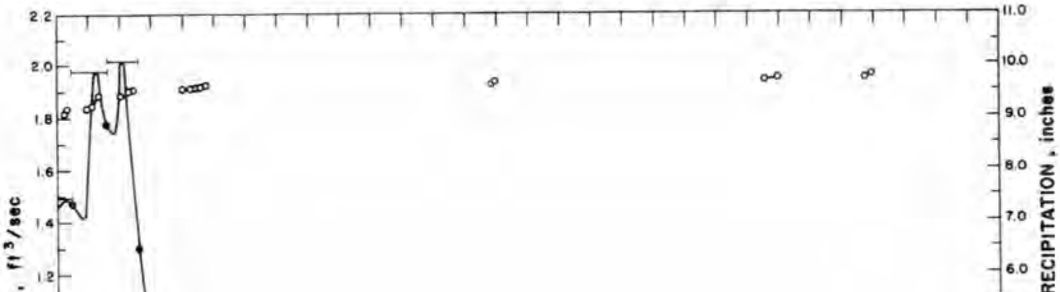

Figure 15. Glenn Creek hydrograph and cumulative precipitation, September 1964. E denotes estimates from stage-discharge relation, horizontal bars are estimates of peak discharges from peak stage gage.

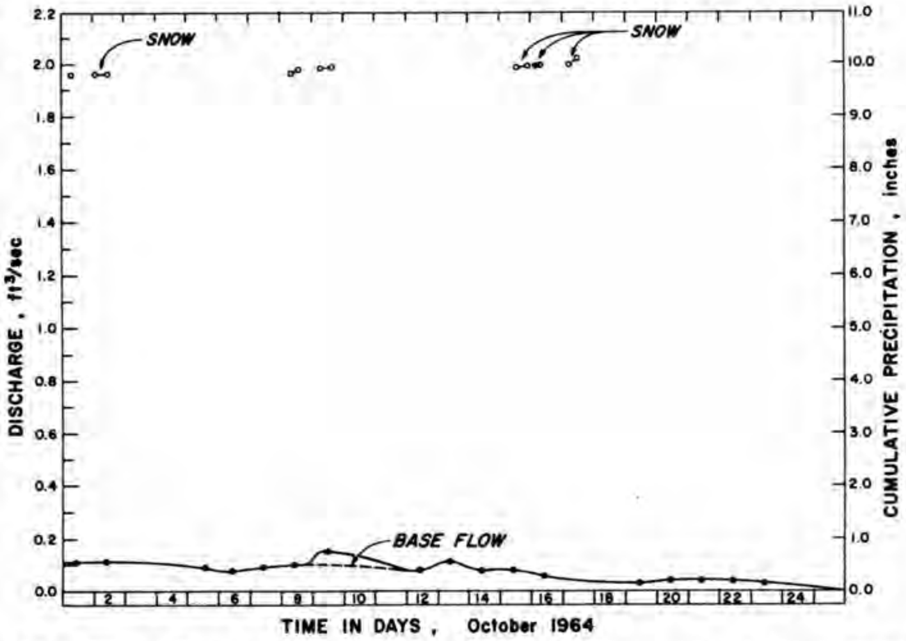

Figure 16. Glenn Creek hydrograph and cumulative precipitation, October 1964. Freeze-up occurred on 25 October.

In examining a hydrograph, it is important to separate "surface" runoff (runoff directly related to a given storm) from base flow, or ground water discharge into the stream. In the basin of Glenn Creek, there is probably no surface runoff in the sense of overland flow, as more than half the area of the basin is covered by a highly permeable carpet of mosses about 1 ft thick. Preliminary laboratory measurements show a vertical permeability of about 1 cm/sec and it is unlikely that overland flow would take place here. The remainder of the basin has a surface much like the organic duff on the floor of a temperate hardwood forest. Such a surface is known to be highly permeable, and comparison with areas in New England suggests that true overland flow occurs rarely, if at all. In early spring, rain falling or snow melting on still frozen ground of this type may run off as overland flow.

Thus, direct runoff from a storm must occur almost exclusively as interflow. While little is known about the effects of frost on the permeability of the moss, it might be surmised that deeper penetration of rain water becomes possible as the moss thaws from the top down, so that lag times (time from center of mass of effective rainfall to peak runoff) would increase over an unknown period beginning in spring, while percent of rainfall running off directly should tend to decrease. However, as mentioned later, no such trends were noted in the data.

Hydrograph timing. The lack of a runoff recorder and, for most of the summer, a recording rain gage precludes a satisfactory analysis of the timing of runoff relative to rainfall for Glenn Creek. However, if estimates of the times of occurrence of peak runoff on 31 August and 1 and 2 September are at all accurate and representative, lag times for Glenn Creek are much larger than for areas of similar size in more temperate areas. Engman (1964) found that the most consistent measure of lag time (the measure with the smallest variation from storm to storm) for small basins in northern Vermont was time from occurrence of the center of mass of a limited "block" of rainfall to the occurrence of the associated hydrograph peak. Using this measure, lag times for Glenn Creek for the above storms were 12 to 18 hours. Engman (1964, table 2) found an average lag time of about 2 hours for a basin of 3.25 mi^2 area in northern Vermont, and even basins up to 42 mi^2 had average lag times of less than 6 hours.

An analysis of the recessions of Glenn Creek hydrographs, discussed more fully later, also suggests that lag times are unusually large compared to streams of the same size in temperate areas. If no rainfall excess occurs after the peak runoff the recession portion of a hydrograph can be closely approximated by an equation of the form

$$q_t = q_p \exp(-ct) \tag{1}$$

where q_t is discharge at any time $\underline{t}$, q_p is peak discharge, and $\underline{c}$ is a positive constant. The average value of $\underline{c}$ for Glenn Creek is 0.027 hr^{-1} (standard deviation .005 hr^{-1}), a very low value when compared with values given by Holtan and Overton (1963, Table 1). The constant $\underline{c}$ can be related to lag time if duration of rainfall excess is known (Holtan and Overton, 1963, p. 260), and estimates for the three storms using this relationship give lag times of about 13 hours.

Table II shows values of the recession constant for six simple recessions (recessions during which no significant rainfall occurred) for Glenn Creek. If conjectures about the influence of thaw depth on lag times (which are inversely related to recession constants) are correct, these constants should decrease from spring to late summer. However, no evidence of a trend is discernible, and it must be presumed for the present that other influences are predominating.

Table II. Recession constants, $\underline{c}$.

Recession	Avg $\underline{c}$ (hr^{-1})	Std Dev $\underline{c}$
11-16 June	0.025	0.009
25-28 June	0.023	0.011
13-17 July	0.035	0.004
17-19 Aug	0.035	0.003
26-28 Aug	0.025	0.004
8-14 Sept	0.021	0.003
Average	0.027	0.005

Thus, presently there is a strong indication that lag times for small basins in central Alaska are very large compared with similar-sized areas in the continental United States. More work must be done to establish this and to determine the extent of any seasonal variations.

Separation of base flow. Separation of base flow is always to some extent arbitrary, and there seemed to be no reason for choosing any one method of separation from the several that are in common use. Instead, the hydrographs were examined for any clues as to the magnitude of base flow, using the following lines of reasoning. It was first noted that the permeabilities of the soil materials covering the basin (below the moss and highly organic zones) are low (about 1.4×10^{-4} cm/sec to 4.2×10^{-4} cm/sec, see Rieger, Dement, and Sanders, 1963, Table 6), and there are no areas of relatively coarse alluvium adjacent to the stream to provide fluctuating bank storage during a storm. Thus the response of ground water flow to rainfall should be slow and of limited magnitude.

With these considerations in mind, the positions of the asymptotes to the recession portions of the hydrographs were estimated. These are represented by the dashed curves in Figures 12-16, which are taken as the approximate hydrographs of base flow. On this basis, base flow was constant at 0.01 ft^3/sec through June until late July, when it began to rise toward a peak of 0.30 ft^3/sec in late August. Thereafter, it declined until mid-September, after which time very little rain fell and stream flow became virtually all base flow, fluctuating around 0.1 ft^3/sec until freeze-up on 25 October.

This estimate of base flow is supported by examining the recession portions of individual storm hydrographs. In an attempt to estimate the constant $\underline{c}$ in eq 1, measured discharges for several recessions were plotted against time on semi-logarithmic paper (Fig. 17). It is obvious that $\underline{c}$, which should depend largely on the surface (or immediate subsurface) drainage characteristics of a basin, and hence on its fairly constant physical characteristics, shows a considerable change over the summer. However, if the base flow, estimated as above, is subtracted from the total flow, the curves in Figure 18 are produced, in which $\underline{c}$ does become nearly constant from storm to storm as expected.

The generalizations presented here concerning base flow on Glenn Creek are probably applicable to basins of similar size and geology in the area, but larger basins may have streams which are incised through aquifers, or which flow in extensive permeable alluvium, so that base flow conditions would be very different.

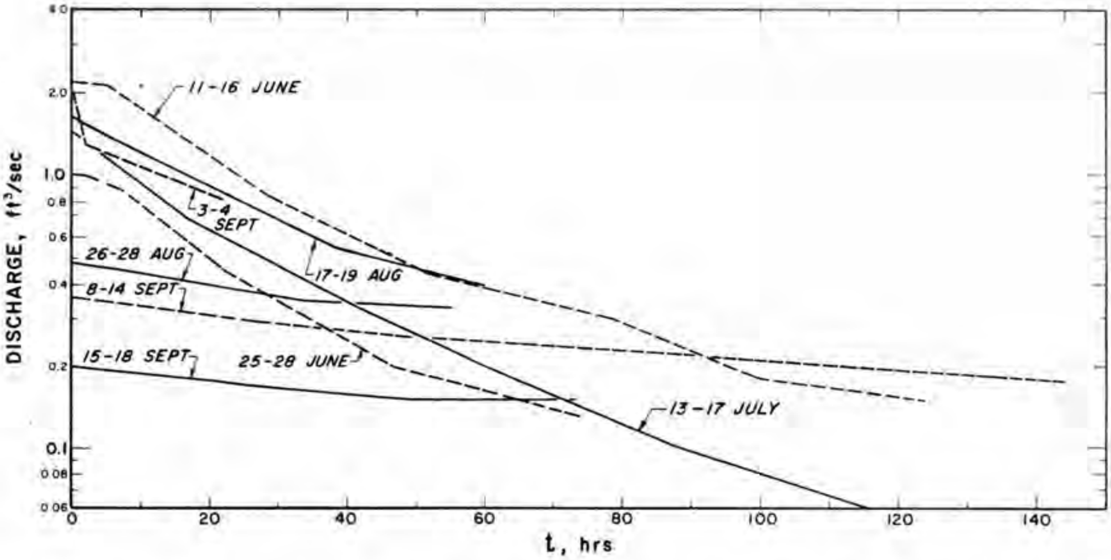

Figure 17. Measured discharge vs time for eight hydrograph recessions.

Recession analysis. Some aspects of the analysis of the recession portions of individual storm hydrographs have already been mentioned. The importance of the constant $\underline{c}$ in eq 1 has been discussed by Holtan and Overton (1963), who showed that it is related to basin lag times as well as being a determinant of peak discharge and general hydrograph shape. Table II shows average values of $\underline{c}$ for storm hydrographs which had recessions during which no rain fell. As noted earlier, this value is very low when compared to drainage basins of a similar size in the conterminous United States (Holtan and Overton, 1963, Table 1), $1/c = 37$ hours being required for discharge to fall from a given value to $1/e = 0.37$ of that

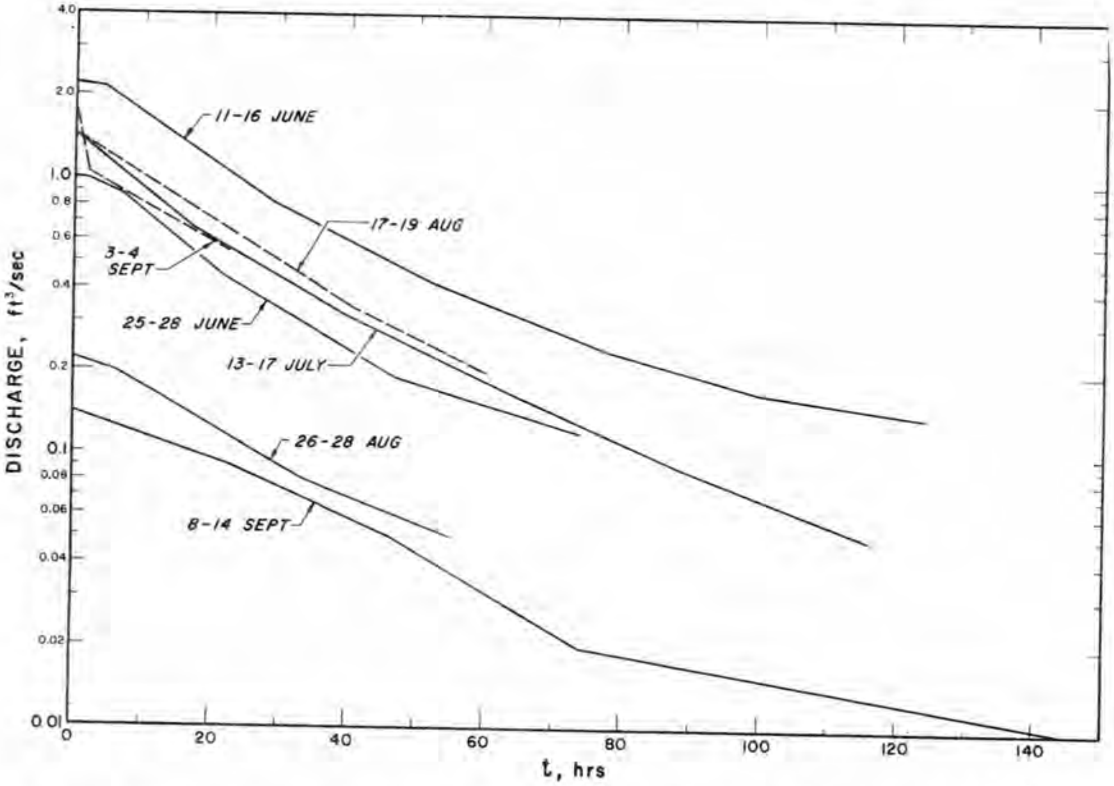

Figure 18. Measured discharge less base flow for seven hydrograph recessions.

value. Qualitatively, hydrographs for Glenn Creek should have smaller peak discharges and longer time bases for a storm of a given amount of excess precipitation and given duration.

Water balance

A general water balance statement is:

input - change in storage = output

over a stated period of time. Enumerating the elements in each term of such a statement,

$$R + C - (\Delta SM + \Delta SS) = ET + Q \qquad (2)$$

where R is rainfall, C is condensation, ΔSM is change in soil moisture, ΔSS is change in surface storage, ET is evapotranspiration, and Q is stream runoff.

Rainfall and streamflow were the only items of eq 2 which were measured during the summer of 1964. However, the water contents of the moss and top layers of the soil were measured at two plots at the Moss Site. There were no trends in these data through the summer, and no indication of significant changes between the beginning and end of the summer. Therefore, while there are no data for other parts of the basin, it can be approximated that

$$\Delta SM = 0 = \Delta SS$$

for the period of time considered. Making the further assumption that C is negligibly small, we have

$$R - Q = ET. \tag{3}$$

Table III shows volumes of runoff and percent of rainfall running off for several periods covering the entire summer. The periods are of varying length, determined by the occurrences of major storms followed by several consecutive days of no rain, when it was presumed that streamflow was largely base flow. Using time divisions thus determined minimizes the amount of guesswork involved in extending recession curves from one storm into the period when runoff from a subsequent storm is occurring.

Table III. Runoff. (Basin area = 0.67 mi^2 = 18,700,000 ft^2.)

From	To	Total runoff ft^3	in.	%	Base flow ft^3	in.	%	Storm runoff ft^3	in.	%	Rainfall in.
9 June 1000	22 June 1000	408,000	.26	15	11,200	.01	0.6	397,000	.25	15	1.69
22 June 1000	4 July 2400	191,000	.12	14	10,900	.01	1.2	180,000	.11	13	.86
4 July 2400	25 July 1000	408,000	.26	20	17,600	.01	0.8	391,000	.15	19	1.28
25 July 1000	12 Aug 1200	792,000	.51	17	125,000	.08	3	667,000	.43	14	3.01
12 Aug 1200	23 Aug 1600	547,000	.35	27	188,000	.12	9	359,000	.23	18	1.31
23 Aug 1600	30 Aug 1800	214,000	.14	39	165,000	.11	31	48,300	.03	8	.36
30 Aug 1800	14 Sept 2000	824,000	.53	48	306,000	.20	18	518,000	.33	30	1.11
14 Sept 2000	17 Sept 1000	38,200	.02	33	34,600	.02	33	3,600	.002	3	.06
17 Sept 1000	24 Oct 2400	284,000	.18	70	280,000	.18	70	4,000	.002	0.8	.26*
9 June 1000	24 Oct 2400	3,706,200	2.37	24	1,138,000	.74	8	2,567,900	1.63	16	9.94

*Includes one snowfall of 0.01 in., which is assumed to have melted. Subsequent snows (15 Oct and later) not included.

Runoff volumes were determined by measuring the areas under the hydrographs with a planimeter. The figure for total runoff for the summer was also independently determined by estimating average discharges for each day, multiplying this by the number of seconds in a day, and adding total daily discharges. There was less than 1% difference between the two figures.

However, there are several possible sources of error in the rainfall-runoff figures. The first, of course, is the estimation involved in drawing the hydrograph between the measured points. A second error enters because the actual area of the basin is not known very accurately, so that conversion from cubic feet to inches is uncertain. Another error source arises because the area distribution of rainfall is not known (comparison of the records for Glenn Creek, Fairbanks, and College, Alaska, shows that areal variations may be large), and greater or less amounts of rain may have fallen than were recorded. There is also the possibility that unmeasured runoff was occurring from the basin by some unknown route. In the future, these sources of error will be largely eliminated, but until then the values in Table III must be considered provisional.

Assuming the figures to be roughly correct, Table IV compares "actual" evapotranspiration to 1964 class-A pan evaporation at College, Alaska, 10-year average pan evaporation at College, and potential evapotranspiration calculated by the method of Thornthwaite and Mather (1957). It is apparent that "actual" evapotranspiration is about half the pan evaporation and Thornthwaite potential evapotranspiration.

Table IV. Monthly water balance for Glenn Creek watershed.

Month	Rainfall (in.)	Runoff (in.)	"Actual" ET (in.)	1964 pan evap (in.)	Avg pan evap (in.)	Thornthwaite Pot. ET (in.)
June	2.45	0.41	2.04	5.59	5.46	4.5
July	2.90	0.40	2.50	3.90	4.62	4.5
August	3.75	0.89	2.86	2.88	2.97	3.4
September	0.68	0.59	0.09	1.29	1.23	1.6
October	0.26	0.10	0.16	0.01	0.10	0
Total	10.04	2.39	7.65	13.67	14.38	14.00

This discrepancy indicates either that pan evaporation, even applying a standard coefficient of 0.7, and the Thornthwaite method do not provide good estimates of actual evapotranspiration or that evapotranspiration does not take place at the potential rate on the Glenn Creek basin. Because observations suggest that there is ample water available to plants in the basin at all times, the first alternative seems most likely at present. However, Sanderson (1950) found that the Thornthwaite method provided a good estimation of actual evapotranspiration (measured in a lysimeter beneath a cover of grass) at Norman Wells, N. W. T., Canada (at the same latitude as Fairbanks).

Few data have been published concerning rainfall-runoff relations for central Alaska. Duncan (1963, p. 281) reported that "studies indicated that about 60% of the rain recorded at precipitation stations appeared as runoff at stream gaging stations" for the Yukon River drainage basin. A large discrepancy exists between this figure and the 24% found for Glenn Creek. It is rather difficult to evaluate this difference - the figures for the Yukon are supported by their use in computer programs which were successful in synthesizing past floods, yet it seems unlikely that the figures for Glenn Creek are off by a factor of 2.

It is apparent from Table III that there are no well defined trends in percent of rainfall running off directly as the summer advances, so that here again any influence of increasing depth of thaw is obscured. Furthermore, total runoff percents do not reflect any influence of beginning and end of tree growth (transpiration), which should take place in mid-June and mid-August, respectively.

Establishment of the magnitudes of the various elements of the water balance statement for central Alaska is important in the development of the water resources of the region, and it is obvious that further work is required on this problem.

Sediment transport

Stream-borne sediment is usually considered in three categories: suspended load, bed load, and dissolved load. The term "bed load" applies to sediment that moves by sliding, rolling, or saltating on or very near the bed. Because of the difficulty in measuring bed load and suspended load close to the bed, no data on these were collected. However, the generally small size of the particles (clay to fine sand) in the overburden in the basin makes it likely that most of the non-dissolved load is in suspension.

Suspended load. Concentration of the suspended material in the stream was measured on 15 occasions at discharges ranging from 0.02 to 1.78 ft^3/sec. These concentrations are plotted against discharge in Figure 19, and define the least squares regression equation

$$PPM = 372\ Q^{1.38} \tag{4}$$

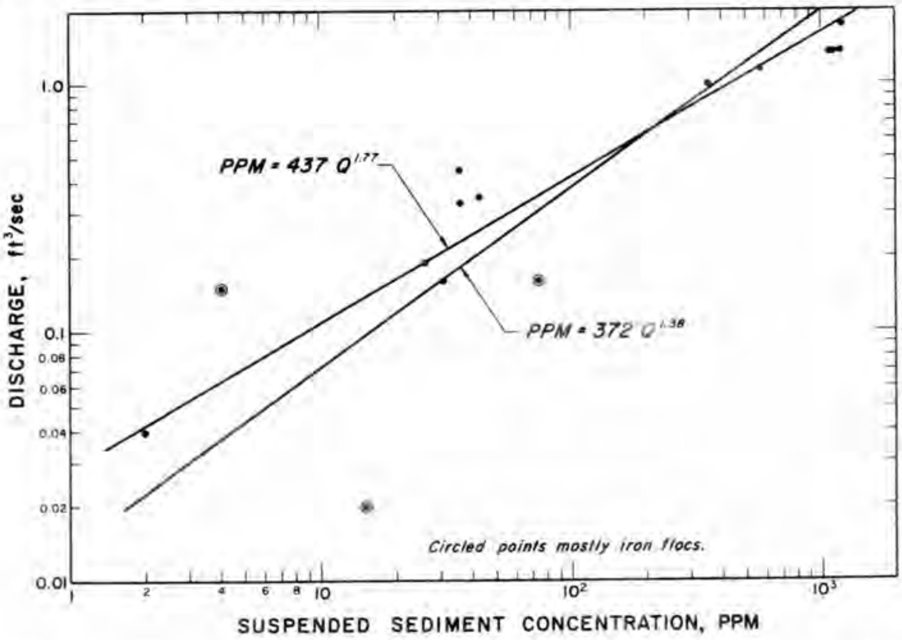

Figure 19. Relation between suspended sediment concentration and discharge.

with a correlation coefficient of 0.88 (significant at less than 0.001 level), where PPM is sediment concentration in parts per million and Q is discharge in ft³/sec. In three of the samples, the filtered residue was largely a bright red stain rather than sediment grains, suggesting the presence of colloidal iron. If these are eliminated, the exponent in eq 4 becomes 1.77. For most streams the value of the exponent in eq 4 lies between 1 and 2 (Leopold, Wolman and Miller, 1964, p. 220).

Plots of similar data for five streams in central Alaska showed fairly wide scatter, with exponents lying between 1.3 and 2.3. For the Chena River, which drains an area of 1980 mi² similar in topography, geology, and climate to the basin of Glenn Creek, recorded suspended sediment concentrations range from 6 to 800 ppm. This range is roughly the same as for Glenn Creek, and suggests that the presence of an actively degrading thermokarst region along the stream course has not altered the sediment transport regime of Glenn Creek appreciably. Some of the higher concentrations in Glenn Creek may, however, be due to this active degradation.

Using relationship 4 with Q equal to average daily discharge, the weight of suspended sediment transported past Q-Station was calculated for each day. Approximately 32 tons of suspended sediment were transported between 10 June and 24 October.

Because of the small amounts of suspended material collected, no grain size determination was possible.

Dissolved load. Twenty-one determinations of total dissolved solids were carried out for the summer of 1964. When plotted against conductivity, the least-squares relationship

$$S_D = 2.7 + 0.73\,\mu \qquad (5)$$

was defined, where S_D is dissolved solids (residue on evaporation) in milligrams per liter and μ is conductivity in micromhos at 25C (see Fig. 20). According to Hem (1959, p. 40), the regression coefficient in relations such as eq 5 "has a value

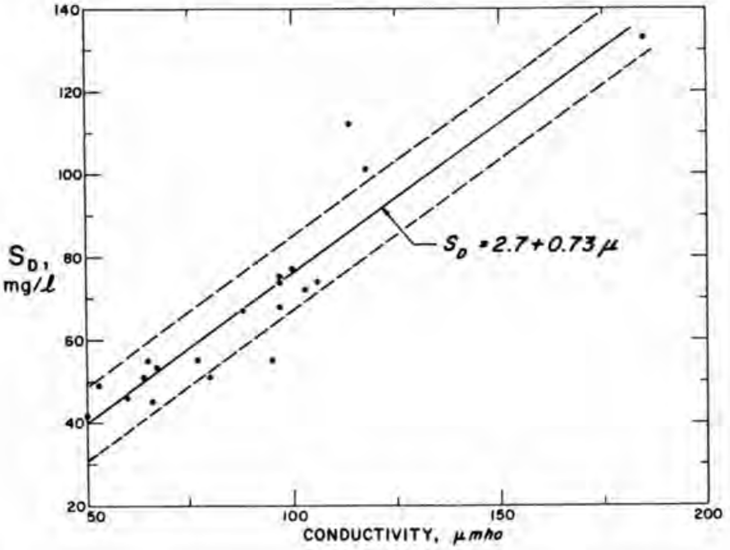

Figure 20. Relation between dissolved solids concentration and conductivity. Dashed lines show one standard error of estimate.

between 0.55 and 0.75 unless the water has an unusual composition." No attempt was made to determine the elements present in solution, but the percents of metallic ions present are probably close to the averages for the Chena and Salcha Rivers, shown in Table V.

Table V. Average percent dissolved solids*.

	SiO_2	Fe	Ca	Mg	Na	K
Salcha River	10.2	0.10	21.3	5.8	2.4	1.6
Chena River	12.6	0.08	10.3	5.9	2.7	1.4

*Calculated from data in U. S. G. S. Water Supply Papers 1466, 1486, and 1570.

Recorded total dissolved solids concentrations for the Salcha and Chena Rivers are between 6.3 and 161 ppm, and those for Glenn Creek fall within this range.

Figure 21 shows parts per million dissolved solids plotted against discharge, with a curve fitted to the points by eye. Using this curve and the average daily discharge, daily discharge of dissolved material was calculated. This added up to about $6\frac{1}{2}$ tons for the period 10 June to 24 October.

Moss water contents

In an attempt to discover something about the water-handling properties of the Sphagnum and associated mosses and lichens, which form the ground cover for much of the basin, the two Moss Plots were set up (Fig. 6). This attempt was largely unsuccessful, as an analysis of variance showed that the variations between the samples taken at the two plots were greater than the daily variations, which would be attributed to rainfall, evaporation, and flow of water through the moss. Even for individual plots, no coherent pattern relating moss moisture to rainfall and evaporation was discernible. This lack of pattern was probably due largely to the influence of microrelief and to the very high permeability of the moss (around 1 cm/sec). Future work will be directed toward evaluating the infiltration and water transmitting characteristics of the surface of the basin.

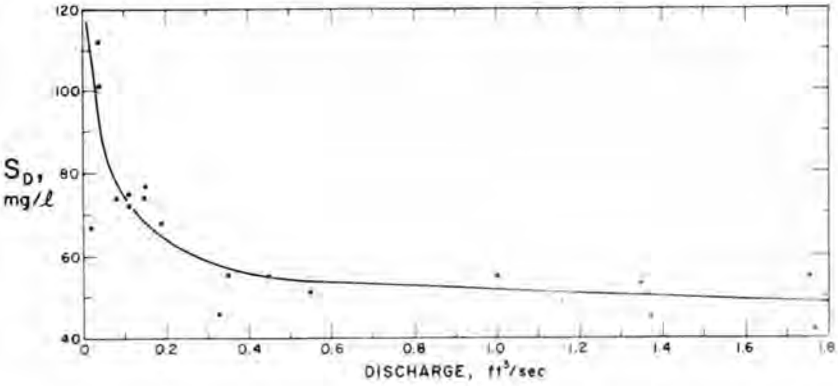

Figure 21. Relation between dissolved solids concentration and discharge.

Thermokarst features

Beginning about 500 yards above Q-Station and extending upstream for roughly 100 yards is an active thermokarst area. Two general views of the area are shown in Figure 22. It is obvious that this reach has been the site of extensive degradation, and the channel now flows 2 to 10 ft below the general level of the valley floor. The moss mat has collapsed where the erosion has taken place, and many of the trees show no response to their changed orientation, indicating that much of the degradation occurred within the past year or so. In many places the stream is visible at the bottom of the depression where the moss mat has been breached, but in others it is not visible and flows 6 ft or more back under the banks. In a few places, the moss mat has collapsed but is not breached; the person in Figure 23 is standing on such a "bridge," and the stream is flowing beneath him. When examined on 23 August, the banks of the depression were frozen within a few inches of their surface, and the water temperature in the stream was 43F, about 3F cooler than measured at Q-Station the same day.

Immediately below this eroded area is a roughly circular deposit of silt, clay, and organic material about 50 ft in diameter (Fig. 24). Similar deposits are present along the stream course for about 50 ft downstream.

The most reasonable explanation for these features would seem to be that a mass of ground ice has melted and allowed the moss mat and surrounding soil to collapse. While no remnants of this ground ice were visible in the walls of the depression, Péwé (in Hopkins and Karlstrom, 1958, p. 127) mentions that "large masses of clear ice occur... in the creek valley bottoms north of the Tanana River." Examples of such ice can be seen in the walls of the USA CRREL permafrost tunnel, about $\frac{1}{4}$ mile below Q-Station.

No evidence of these features is apparent on airphotos taken in the summer of 1962, but this may be due to the small scale of the photos (about 1 to 20,000). While it is certain that this erosion has begun quite recently, it is not possible presently to fix its beginning more precisely; nor is it possible to pinpoint the events which triggered the rapid melting of the ice mass.

Summary and conclusions

The following observations and tentative conclusions are based on the first summer's study of Glenn Creek and its drainage basin: 1) relationships comprising at-a-station hydraulic geometry are similar to those for larger streams in other areas; 2) the lag time between rainfall and peak storm discharge is much longer for Glenn Creek than for similar-sized streams in mid-latitude regions; 3) hydrograph recessions are drawn out in time relative to those for similar-sized

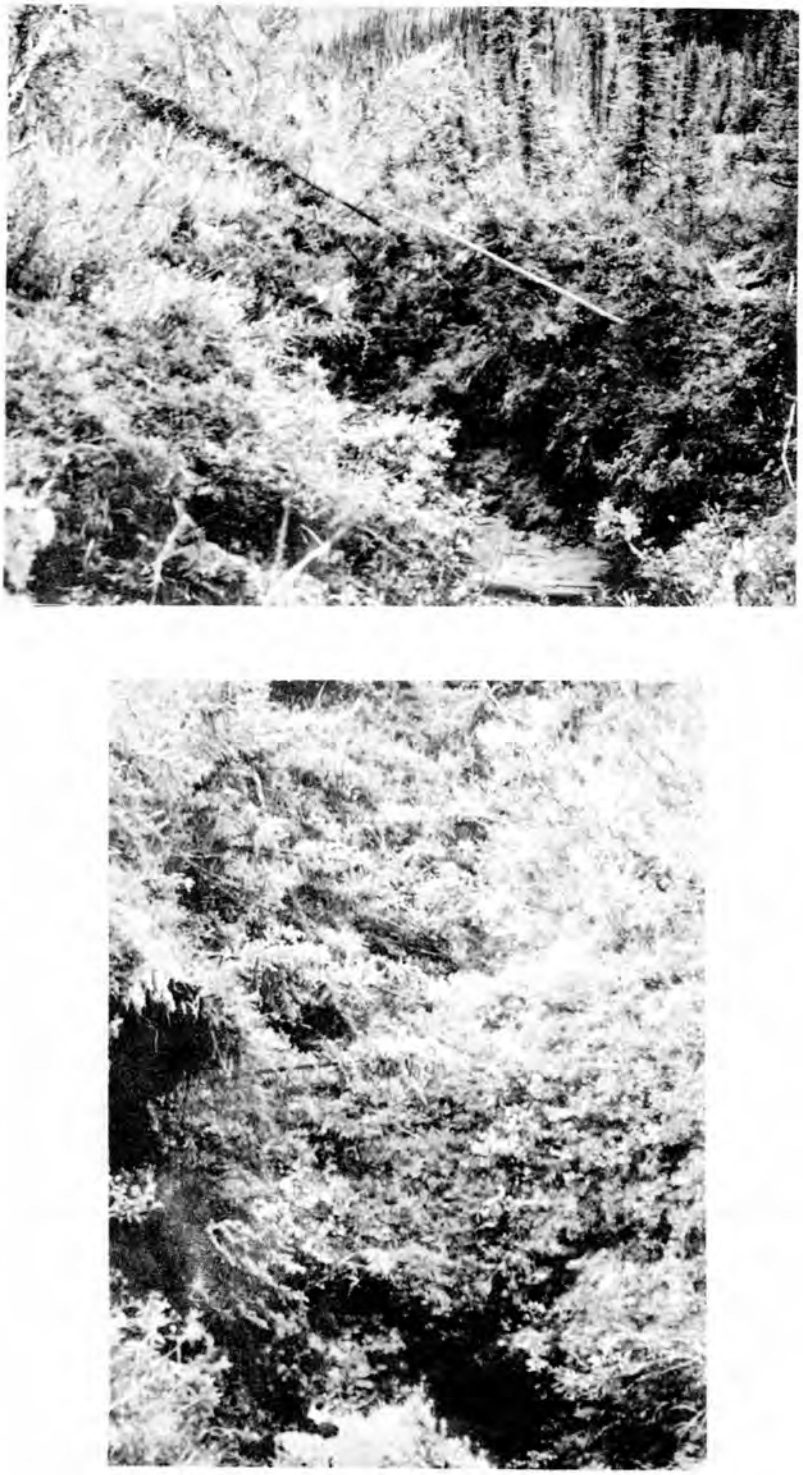

Figure 22. Thermokarst area.

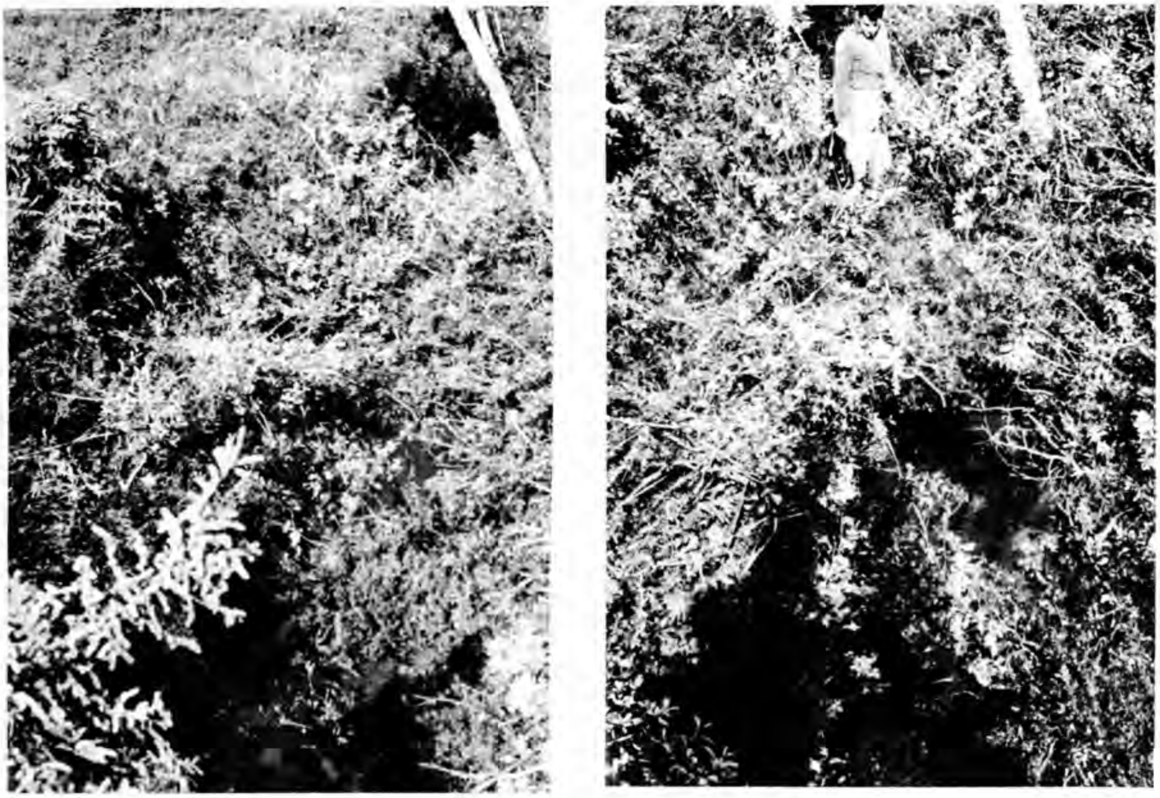

Figure 23. Thermokarst area.

streams in mid-latitude regions; 4) base flow was low in early and mid-summer, rose to a peak in late summer, and very gradually diminished thereafter, accounting for most of the flow in September and October; 5) direct runoff must occur largely as interflow; 6) about 24% of the rain which fell appeared as runoff; 7) the fraction of rainfall appearing as direct runoff varied from 3% to 30%, and showed no seasonal trends; 8) the suspended and dissolved sediment concentrations of Glenn Creek are within the ranges reported for larger streams in the area; 9) suspended sediment yield was roughly five times as large as dissolved sediment yield for June-October. A number of years of study will be required to confirm these preliminary conclusions and to determine the representativeness of the observations.

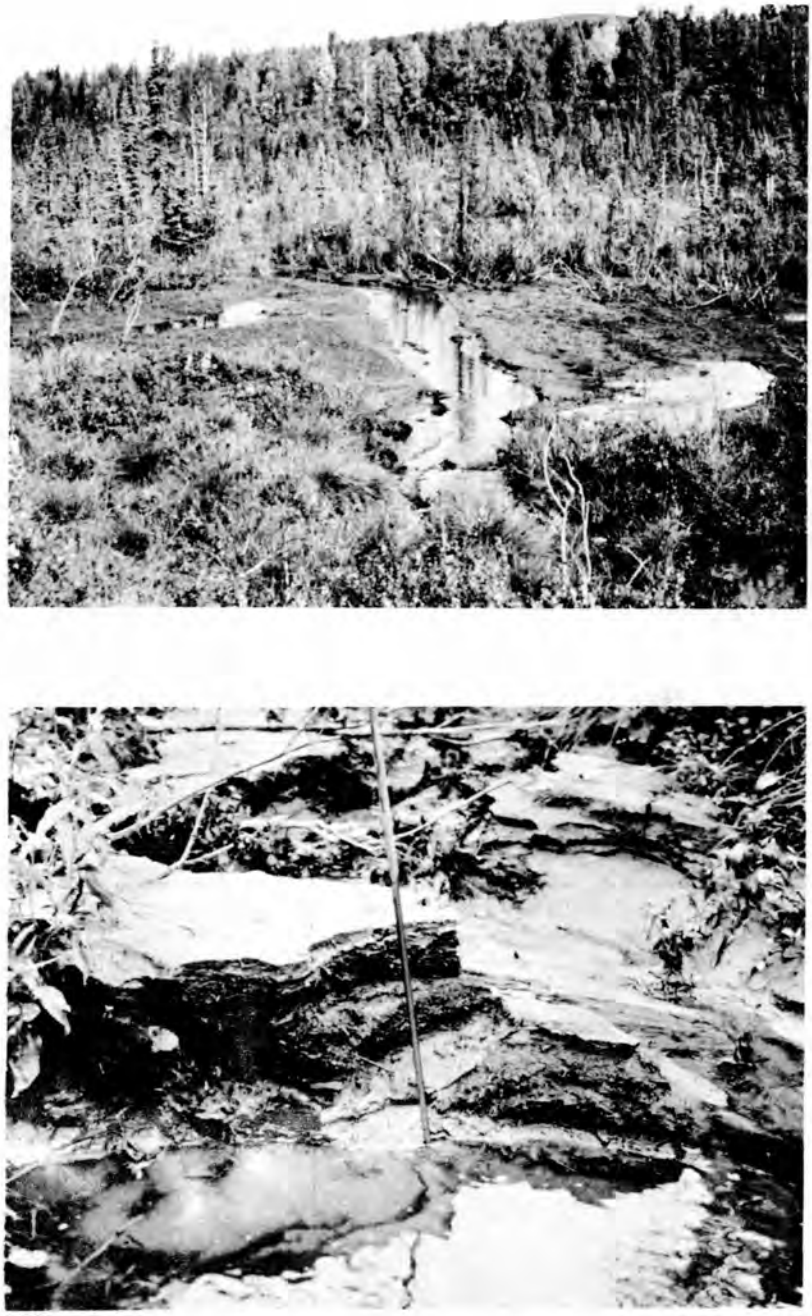

Figure 24. Deposit below thermokarst area.

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APPENDIX A: PROCEDURE FOR DETERMINATION OF RESIDUE ON EVAPORATION

1. Sample filtered through No. 1 filter paper
2. 100 ml of filtrate pipetted and transferred to beaker
3. 10 ml 30% H_2O_2 added to each beaker to oxidize organic material
4. Beakers placed on steam plate and allowed to evaporate
5. When 10-15 ml remained in beaker, beaker removed from heat and sample transferred to tared aluminum weighing dish
6. Beaker rinsed with distilled water, rinse added to sample
7. Samples placed in 105C oven, evaporated to dryness (at least 5 hours)
8. Weighing dishes with residue weighed to .00002 g after cooling in desiccator

Remarks:

Several runs were carried out using distilled water to determine residue due to picking up ions from filter paper and due to impurities in H_2O_2. This amount is the correction indicated in the calculation.

Calculation: (items in parentheses are weights in grams)

$$\text{mg/l} = \frac{(\text{DISH + RESIDUE}) - (\text{DISH}) - (\text{CORRECTION})}{1\ \text{g/ml} \times 100\ \text{ml}} \times 10^4$$

APPENDIX B: PROCEDURE FOR DETERMINATION OF CONCENTRATION OF SUSPENDED SEDIMENT

1. Samples weighed in tared polyethylene bottles

2. Samples thoroughly agitated, poured into beakers

3. Bottles rinsed, rinse added to sample

4. 2 drops concentrated HCl added to each beaker (700-1000 ml) as flocculent; left to settle until liquid clear (20 hours)

5. Supernatant liquid decanted by siphon until about 100 ml remained

6. 10 ml 30% H_2O_2 added to each beaker to oxidize organic material

7. Beakers covered, placed on steam table until liquid color disappeared and visible organic material largely gone (additional H_2O_2 added as necessary)

8. Beakers removed from heat, samples filtered through tared No. 1 filter paper

9. Filter paper with suspended material placed on watch glass and dried in 105C oven

10. Filter paper plus suspended material weighed to 0.00002 g after cooling in desiccator.

Remarks:

Several tests were carried out to determine loss of weight from filter paper after oven drying as compared to air dry condition. This loss of moisture from the paper itself is the correction indicated in the calculation.

Calculation: (items in parentheses are weights in grams)

$$\text{PPM} = \frac{(\text{PAPER + SEDIMENT}) - (\text{PAPER}) - (\text{CORRECTION})}{(\text{SAMPLE + BOTTLE}) - (\text{BOTTLE})} \times 10^6$$