WATER AND SUSPENDED SOLIDS DISCHARGE DURING SNOWMELT IN A DISCONTINUOUS PERMAFROST BASIN

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Abstract

For the 1985 snowmelt runoff season, discharge, specific conductance and total suspended solids are compared on Glenn Creek, a small, second-order, subarctic stream located near Fairbanks, Alaska, within the Yukon-Tanana-Upland physiographic province. The stream drains a 2.25-km^2 research watershed of which 70% is underlain by permafrost. Discharge was measured continuously, and specific conductance and total suspended solids concentration were measured at 2-hour intervals over the entire snowmelt season. Specific conductance decreased rapidly following initial streamflow and after 6 days reached a minimum, which held nearly constant for the remainder of the snowmelt runoff season. Suspended solids concentration was very low, less than 50 mg/l, over the entire rising limb of the seasonal snowmelt hydrograph and, with the exception of a small spike of 166 mg/l on the day of the peak discharge, remained low until the third day following the peak discharge. At that time, although discharge had dropped to 33% of the peak flow, a rapid flushing of the channel occurred, with solids concentration rising from less than 50 mg/l to 1337 mg/l in a single day. The flushing period lasted four days, during which time diurnal fluctuations in concentration were well defined, with peak values decreasing daily until on the fifth day the peak concentration was under 200 mg/l. By using water temperature data collected in 1983, the diurnal fluctuations in solids concentration and water temperature are shown to be consistent.

Résumé

Pendant la saison de la fonte des neiges en 1985, l'écoulement d'eau, la conductivité spécifique et la quantité de solides en suspension furent comparés pour Glenn Creek, un ruisseau subarctique de deuxième ordre près de Fairbanks, Alaska, dans la province physiographique du Yukon-Tanana-Upland. Ce ruisseau draine un bassin de 2,25 km^2 carrés dont 70% sont pergélisolés. Le débit fut mesuré en continu alors que la conductivité spécifique et la concentration de solides en suspension furent mesurés par intervalles de deux heures pendant toute la saison de la fonte des neiges. La conductivité spécifique baissa rapidement après le dégel initial du ruisseau et, après 6 jours, atteignit un minimum qui demeura presque constant pendant le reste de la saison. La concentration de solides en suspension fut très basse, moins de 50 mg/l, sur toute la courbe ascendante de l'hydrogramme de la saison; et, à l'exception d'une pointe de 166 mg/l le jour de l'écoulement maximum, elle resta à ce niveau jusqu'à trois jours plus tard. Alors, malgré une baisse jusqu'à 33% de l'écoulement maximum, un nettoiement rapide du lit du ruisseau se produisit avec un accroissment de la concentration des solides de moins de 50 mg/l jusqu'à 1337 mg/l en un seul jour. La période de nettoiement dura quatre jours pendant lesquels les fluctuations journalières de la concentration furent très nettement définies jusqu'à ce que, le cinquième jour, le niveau atteignit moins de 200 mg/l. Les fluctuations journalières de la concentration des solides et de la température de l'eau se montrèrent cohérentes par rapport à des données de 1983 sur la température de l'eau.

Introduction

The literature on suspended solids discharge in northern rivers has recently been reviewed by Clark et al. (1988) and Clark (1988). If our interest is limited to non-glacial northern rivers, a relatively large proportion of the studies can be discarded (for pro-glacial river studies see, for example, Gurnell, 1987). If our interest is further restricted to permafrost-dominated basins, there are relatively few studies reported. The studies that have been reported are, by necessity, regional in nature. For example, the studies on rivers of the High Arctic (McCann et al., 1972), where the basins are nearly devoid of vegetated soils and the streambeds are composed of coarse sediments, are not directly transferable to the moss-covered basins of Interior Alaska, where the streams run through the fine silts and clays of loess deposits. In Interior Alaska, Slaughter et al. (1983), working on Caribou Creek, examined the relationship of total suspended solids and rainfall-runoff. A search of the literature has not revealed any previous studies which have examined in detail the temporal relationship between water and suspended solids discharge during the snowmelt season in a nonglacial, vegetated, permafrost basin. This paper presents the total suspended solids concentration for one snowmelt runoff season on a small research watershed in Interior Alaska. The timing and variability of solids discharge are well documented, and influential factors are discussed.

Site description

Glenn Creek is a second-order stream located in a permafrost- dominated watershed 14 km north of Fairbanks, Alaska, at latitude 64°57'N, longitude 147°35'W at the southern edge of the Yukon-Tanana Uplands (Wahrhaftig, 1965). The watershed was selected by Dingman (1971) for detailed hydrological studies from 1964-1967 based on its size, accessibility, lack of recent human disturbance and apparent representativeness of the area. The gaged area of the watershed is 2.25 km^2 and is uniformly distributed between the peak elevation of 493 m and 250 m at the basin outlet. The average basin slope is 0.184 and ranges from near 0 to 0.6. About 30% of the basin is covered by birch-aspen-white spruce stands on moderately well-drained silt loams covered with up to 15 cm of organic soil. These are primarily located on south-facing slopes, and permafrost is not normally present. The remainder of the basin (70%) is covered by black spruce stands on the north- and west-facing slopes and the valley floor. These areas are generally underlain by permafrost and consist of poorly drained mineral soils overlain by a 30-to-45-cm-thick organic mat. The entire length of the stream is contained within the permafrost portion of the basin. The stream type ranges from diffuse flow patterns among tussocks to a single channel incised up to 2 m. Where the channel penetrates the organic mat, the streambed and banks consist of silts and clays. A detailed description of the vegetation and geology of the basin is given by Dingman (1971). In previous studies at Glenn Creek, rainfall-runoff relationships have been described in detail by Dingman (1966, 1971, 1973) and related to slope hydrology by Chacho and Bredthauer (1983). Kane et al. (1981) discussed the results of lysimeter studies during the snowmelt season.

Measurements

From 1978 to 1985, streamflow had been measured near the outlet of the basin with a Parshall flume (22.9 cm throat width) and F-1-type water level recorder. A stage-discharge curve was established for flows below the critical depth of the flume. The strip charts have been digitized and reduced to instantaneous discharge at 15-min intervals. A Campbell Scientific Instruments data logger was used to collect meteorologic data and water temperature, with the latter obtained by a thermistor installed at a fixed depth in the stream. The period of record varies from year to year; some years only the snowmelt runoff was measured, some years only the summer precipitation events were measured, and in a few years the entire runoff season was measured.

During the 1985 snowmelt runoff season an ISCO Model 1680 automatic water sampler was installed at the flume, with the intake nozzle fixed at 2 cm above the floor of the flume inlet. Samples were collected primarily at 2-hr intervals, with infrequent, short sampling periods of 3-4 hr. The samples were returned to the lab, where specific

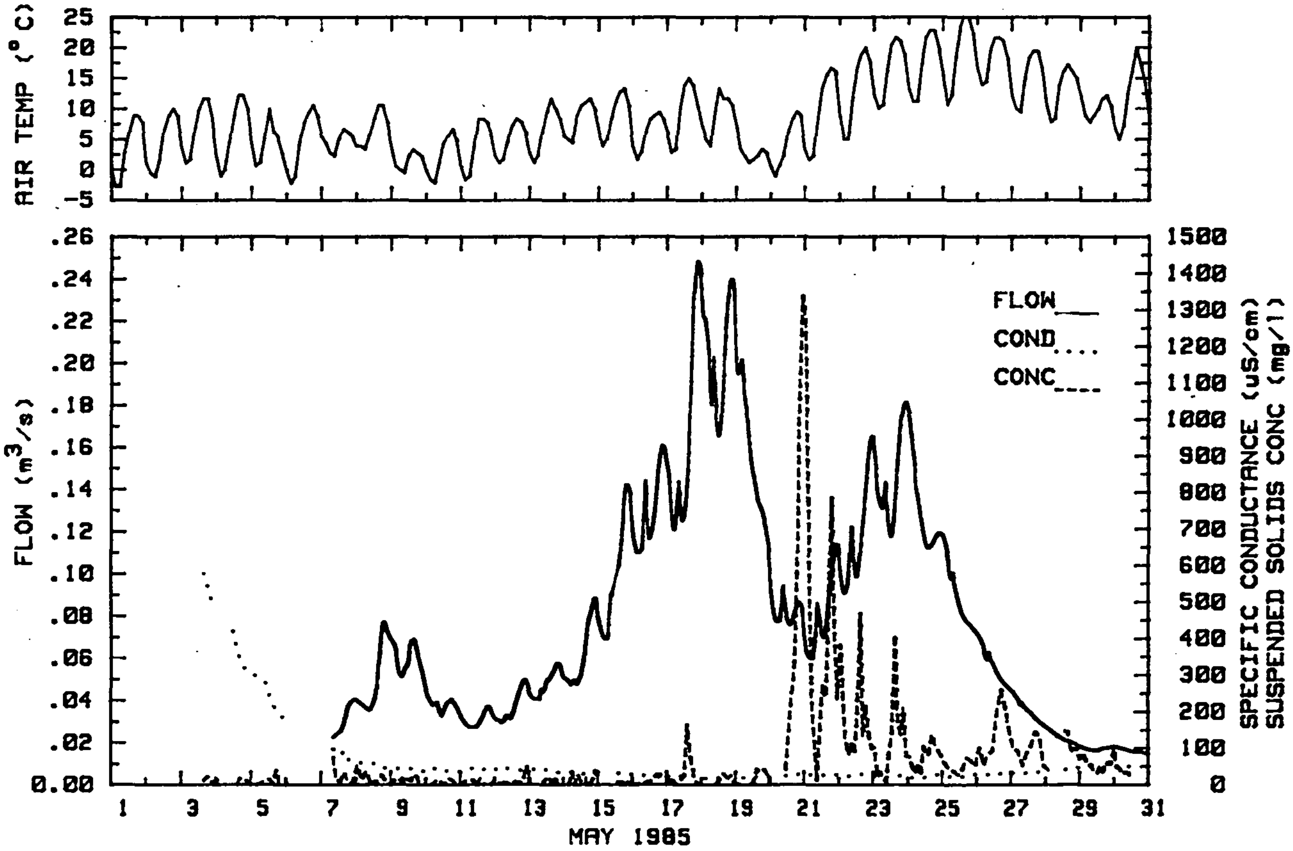

Figure 1. Air temperatures at Fairbanks, Alaska and discharge hydrograph, specific conductance and total suspended solids concentration for the 1985 snowmelt runoff season at Glenn Creek, Alaska.

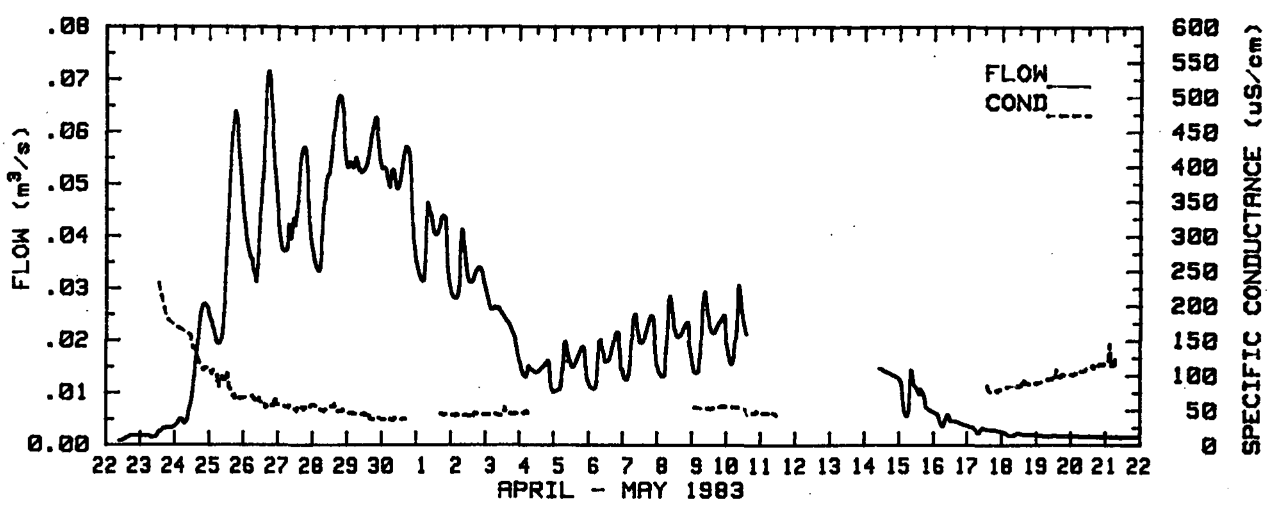

Figure 2. Discharge hydrograph and specific conductance for the 1983 snowmelt runoff season at Glenn Creek, Alaska.

conductance was measured using a Beckman Solu-bridge, and total solids concentration was determined by filtering the samples through pre-washed, tared Whatman #934-AH glass fiber filters, drying at 105°C and re-weighing. Based on the accuracy of the weighing balance the solids concentrations are accurate to about plus or minus 8 mg/l. No attempt was made to determine the organic or inorganic contents of the samples.

At the end of the summer, when air temperatures drop below freezing and rainfall events cease, water levels in Glenn Creek drop rapidly, and the stream usually freezes over by mid-October. Discharge ceases during the winter, evidenced by the flume freezing solid. However, the banks continue to drain, resulting in minor aufeis formation 0.5–1 m thick in the channel. At the initiation of snowmelt the ice was manually cleared from the flume and from a reach of the channel above and below the flume to assure free flow through the flume. The reach of the channel above the flume has been completely lined with sandbags to eliminate induced scour in the channel.

Clark et al. (1988) emphasized the complexity and variability in the relationship between discharge and sediment transport in northern basins where thermal mechanisms may play a dominant role. They further emphasized that a short-time-interval, systematic temporal sampling scheme may be required to adequately address the patterns of discharge and sediment transport during the snowmelt season. In the study reported here, discharge and water temperature were acquired at 15-min intervals, and specific conductance and suspended solids were sampled primarily at 2-hr intervals. This sampling design seemed adequate to resolve the diurnal variability in the sampled parameters.

Results

In 1985 the ice was cleared from the channel on 2-3 May, at which time a flow of 0.002 m /s was measured. During the first four days the channel was open, only spot stage measurements were made. The stage rose steadily until on 7 May, when the water stage recorder was put into operation, the discharge was 0.023 m /s. A continuous trace of the stage was obtained over the entire snowmelt season (Fig. 1). The air temperature data included in Figure 1 is from Fairbanks, Alaska, as these data were not available at the study site. Due to differences in elevation, the air temperatures at Glenn Creek are slightly cooler than in Fairbanks, consequently snowmelt at Glenn Creek lags the Fairbanks temperature record. Strong diurnal variation was evident throughout the snowmelt season except on the receding limbs of the seasonal hydrograph. The hydrograph is almost entirely snowmelt generated, except for small rainfall events on 7-9 May with a total of 4.6 mm and on 19 May with 1.5 mm and a larger event on 29 May of 4.1 mm, which for the purpose of this study marks the end of the snowmelt runoff season. The snowmelt runoff season lasted 28 days in which the peak discharge occurred 14 days after the initiation of streamflow. The small early-season peaks on 8-9 May are most likely due to the rain-on-snow events. The drop in discharge on 19-20 May corresponds to a drop in air temperatures, particularly night-time temperatures falling below freezing.

SPECIFIC CONDUCTANCE

The 1985 snowmelt runoff season specific conductance (SC) measurements (Fig. 1) were relatively high at the time of initial streamflow but decreased rapidly with a slight increase in discharge and within 6 days reached a minimum, which held nearly constant for the entire snowmelt season. The 1983 snowmelt runoff season also shows a similar relationship between discharge and SC (Fig. 2), with the lower initial SC attributed to a later start in sampling relative to initial streamflow. Generally SC is interpreted to indicate time of contact of components of runoff with solute-rich areas, either mineral or organic soils. The low SC during the majority of the snowmelt runoff season is indicative of the high proportion of the streamflow generated by snowmelt runoff on frozen ground with little infiltration and subsurface flow. The rising SC at the end of the snowmelt season

(Fig. 2) is indicative of stream discharge with a higher proportion of subsurface flow, and consequently longer contact time with basin soils, as thaw progresses and the basin soils drain to the stream channel.

The early-season high values of SC are not so easily explained. The high SC indicates that a large component of the very low discharge has had long contact time with the basin soils. It is too early in the season for snowmelt to infiltrate and drain to the channel. The initial streamflow most likely is generated by melt of snow contained within the channel banks. It is also too early, and discharge too low, for solutes that may be deposited in the aufeis within the channel to be released by melting and flushing. A possible explanation is that pockets of water remain unfrozen all winter beneath the channel ice and, with the winter- long contact with streambed soils, develop relatively high SC. This is consistent with observations, made at the time snow and ice was cleared from the channel for the operation of the flume, that the channel was not frozen solid to the streambed and that either a very shallow pool of water or saturated sediments were present. These observations are from a very short reach of channel that was deeply incised (>2 m) and filled with snow. The evidence of subsurface drainage (aufeis) and the insulating properties of the snow in the channel support the assumption of unfrozen water beneath the ice cover. Any such pockets of water would be flushed with the initial streamflow and rapidly exhausted or diluted as discharge increased. The unfrozen water pockets were not sampled and SC measurements were only made at the flume.

Suspended solids

The total suspended solids concentration (SSt) for the entire 1985 snowmelt runoff season is shown in Figure 1. Prior to 20 May, the SSt is very low, only exceeding 100 mg/l on 17 May, the day of the peak seasonal discharge. Significant SSt does not begin until 20 May, when a rise in concentration of less than 50 mg/l to 1337 mg/l occurred in a single day. Thus, significant SSt did not begin until 17 days after snowmelt runoff was first detected in the stream and lagged the discharge hydrograph peak by 3 days. The decline in the daily peak of SSt was rapid despite a rise in the discharge hydrograph to a secondary peak on 23 May.

At the beginning of the snowmelt runoff season, except for the short reach adjacent to the flume, which had been cleared of ice, it appeared that most of the flow took place on top of the snow and ice in the channel. This accounts for the early-season lack of suspended solids, as there was little contact of flowing water with the channel bed for melt and erosion to take place. The flow slowly melted through the ice cover as the melt season progressed. No observations were made of the ablation rate of the ice cover nor were water temperatures measured in 1985. Therefore there are no data to explain the timing of the sudden flushing of the channel which took place on 20 May (Fig. 1). Clark et al. (1988) reported that ice/freezing armoring of the channel may cause sediment transport to lag the hydrograph peak. This appears to be the case here, where flushing of the channel took place 3 days after the passage of the discharge hydrograph peak, when the flow had dropped to a near seasonal low of approximately 33 % of the peak flow. The timing of low flow and peak solids concentration appears to be a coincidence. However, it is of interest to note that the passage of the secondary discharge hydrograph peak on 23 May was also accompanied by a sudden, although much smaller, increase in SSt, which was also lagged by 3 days. The sudden availability of transportable solids on 20 May is most likely a function of the timing of ice cover ablation and thaw within the channel banks. The occurrence of the second SSt peak on 26 May is noted without explanation.

Mass curves for both water and suspended solids discharge in 1985, normalized by the snowmelt-season totals, are shown in Figure 3. The snowmelt runoff season lasted 28 days, with 90 % of the total snowmelt- season solids yield passing in a 10-day period. The significant solids discharge began after 60 % of the total snowmelt-season water yield had passed. During the following 4 days, 22 % of the total snowmelt-season water yield accounted for 71 % of the total solids yield. Over that 4-day period, daily solids yields of 27, 19, 13 and 12 % of the total snowmelt- season solids yield were measured. The second increase in SSt on 26 May accounted for only about 5 % of the total snowmelt-season solids yield. The two mass curves intersected at the 80 % point and were well matched over the remainder of the runoff season.

The plots of the hydrograph for the period during which significant solids discharge had taken place has been expanded in Figure 4 for closer inspection of the diurnal variability of the SSt. The occurrence of the double diurnal peaks in the snowmelt discharge hydrograph will not be addressed in this paper. As will be discussed below, they do not appear to directly affect SSt. However, this phenomenon occurs each year to varying degrees, and the timing of the peaks is generally consistent. The peak in SSt occurred on the first day of significant SSt and corresponded very closely with the late-day or second discharge peak. Also, the shape

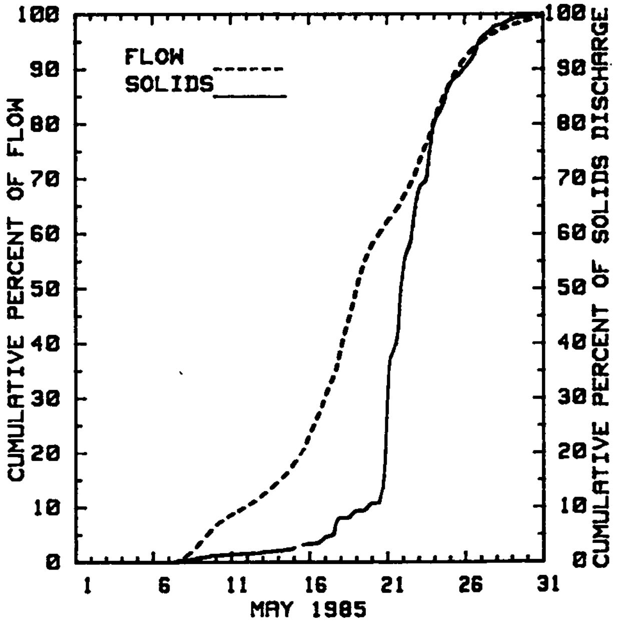

Figure 3. 1985 mass curves of water and total suspended solids discharge, normalized by the snowmelt season total.

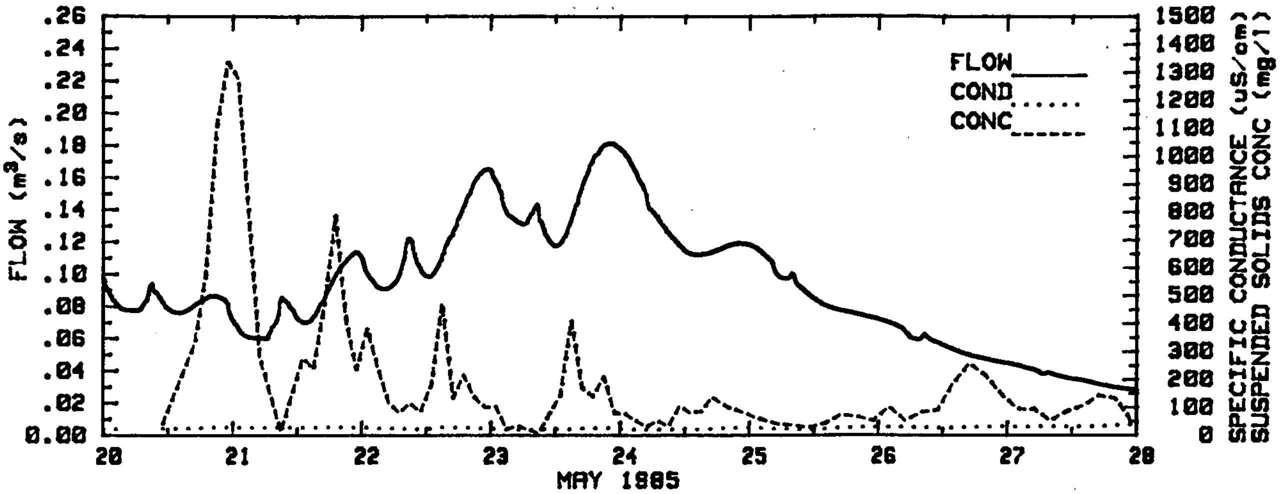

Figure 4. 1985 Glenn Creek discharge hydrograph and total suspended solids concentration for the 8-day period, 20-28 May, of significant suspended solids discharge.

of the concentration curve was nearly symmetrical, with SSt dropping close to 0 mg/l following the season-high peak. The SSt peak occurred 4 hrs earlier on the second day (21 May) and 4 hrs earlier again on the third day (22 May), at which point the timing of the daily peak remained consistent for the remainder of the snowmelt runoff season. After the first day the SSt peak preceded the second diurnal discharge peak until diurnal discharge fluctuations ceased. Also, after the first day of significant SSt, the symmetry of the SSt-versus-time curve disappeared, and multiple smaller concentration peaks accompanied the diurnal peak. The smaller peaks may be due to the release of snow or ice jams within the channel (Woo and Sauriol, 1981) or possibly may be associated with the same processes which produce the double diurnal discharge peaks. There is not enough information at this time to offer a full explanation.

Comparison of SSt to water temperature

To further investigate the diurnal fluctuations in SSt, it is of interest to compare SSt to water temperature. Unfortunately water temperatures were not obtained in 1985; however, they were measured in 1983. For lack of coincident data collection, the only comparison that can be made is that of 1983 water temperatures to 1985 SSt. The criteria for selection of an 8-day period in 1983 to compare to the 8-day period of significant solids discharge in 1985 was based on hydrograph characteristics, specifically the occurrence of strong double diurnal discharge peaks following the peak of the discharge hydrograph for the snowmelt runoff season. Inspection of the 1983 discharge hydrograph (Fig. 2) shows that the period from 4 May to 12 May meet these criteria. A comparison of the specific conductance values measured in both years (Fig. 1 and 2) also indicate a similarity in the source of streamflow. In addition, during both years the strong double diurnal discharge peaks developed on the rising limb of a secondary peak in the discharge hydrograph. The hydrographs for the selected 8-day periods in 1983 and 1985 are compared in Figure 5. Although there is a difference in magnitude, the general shape and timing of the discharge peaks are similar. Based on these similarities in the seasonal and daily discharge hydrographs, it is assumed that, for comparison purposes, the water temperatures of 20-28 May 1985 were similar to those measured on 4-12 May 1983.

The shape of the 1983 water temperature curves (Fig. 6) are consistent and, for the most part, follow what would be

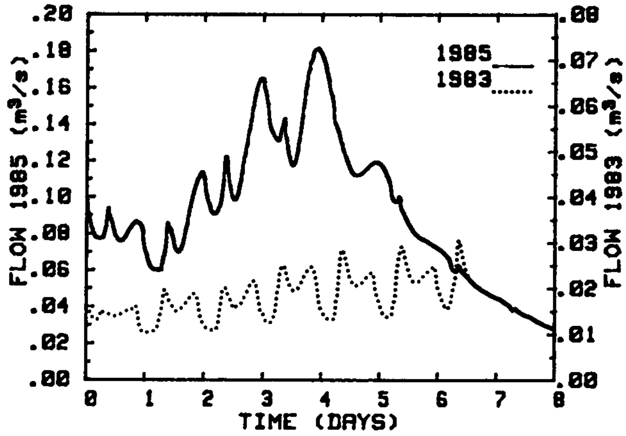

Figure 5. Comparison of 8-day hydrographs from 4-12 May 1983 and 20-28 May 1985 at Glenn Creek, Alaska.

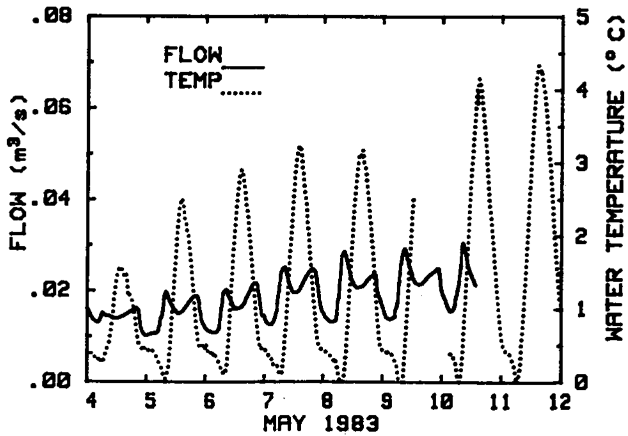

Figure 6. 1983 Glenn Creek discharge hydrograph and water temperature for the 8-day period, 4-12 May.

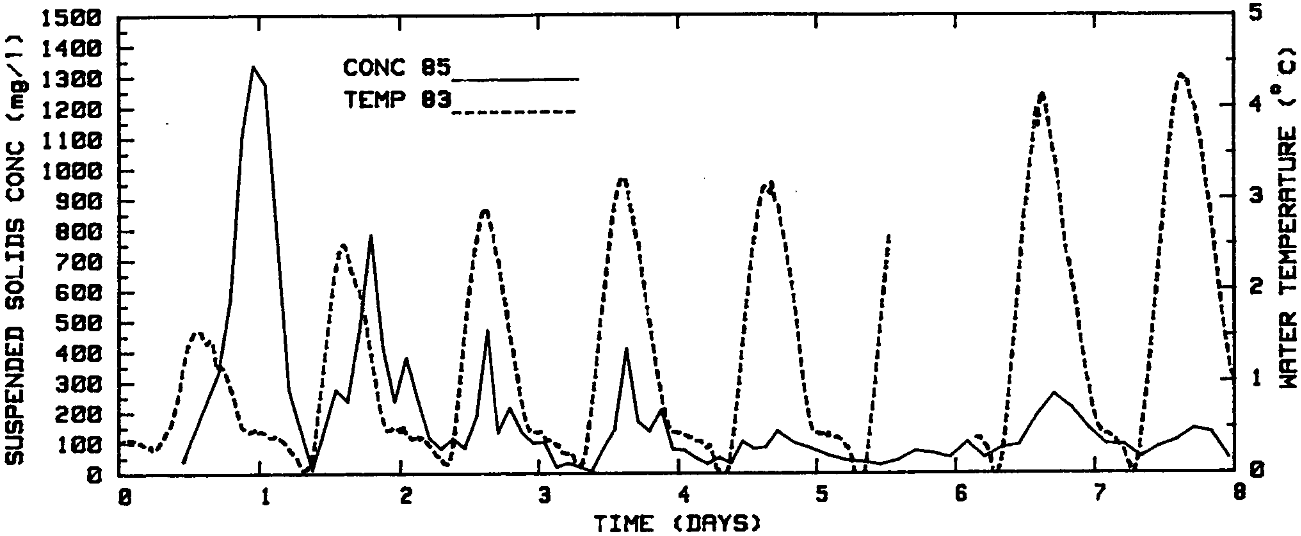

Figure 7. Comparison of 4-12 May 1983 water temperatures and 20-28 May 1985 total suspended solids concentration at Glenn Creek, Alaska.

expected for the snowmelt runoff period. Examination of this record does not present an obvious explanation for the drop in discharge (cause of the double diurnal discharge peak) at the time of the daily peak in water temperatures. Analysis of the discharge hydrographs is ongoing and will be reported in the future.

The 1985 SSt and 1983 water temperatures are compared in Figure 7. The timing of the water temperature peaks during the 8-day period was consistent. As discussed above, the timing of the SSt peaks gradually shifts over the first 3 days of this period, with the result that SSt initially lags the water temperature, but by the third day of solids discharge, the timing and general shape of the curves match very closely. The secondary peaks in SSt do not appear to be a function of water temperature changes. The apparent correlation between the general shape of the SSt curve and water temperature indicates that the timing of solids discharge during the snowmelt season is less a function of stream discharge and more a function of heat flow in the watershed, whether it be to melt through the ice cover and streambed within the channel banks or to thaw the watershed surface sufficiently for erosion and entrainment of solids by watershed runoff to take place. That does not necessarily mean that SSt in the stream is directly related to water temperature, only that it appears that the factors which influence water temperature also influence SSt. More detailed data collection is required to further address this relationship.

Summary and discussion

Data from one snowmelt runoff season shows that significant solids discharge did not begin until 60% of the total seasonal streamflow volume had passed. Solids discharge begins with a sudden flushing and rapidly diminishes within a 4-day period. The diurnal fluctuation of SSt appears to closely follow the diurnal fluctuations of water temperature. A complete data set showing the relationship between SSt and snowmelt runoff is presented but the existence of only one year of data and the lack of coincident data collection of related parameters raises many questions and leaves much of the observed phenomena unexplained.

The source of solids production during the snowmelt runoff season must play a major role in the timing of solids discharge. In this study only the total solids discharge was measured. The determination of organic and inorganic solids discharge may distinguish in-channel and watershed sources of solids production. In a permafrost-dominated basin where the thaw depth is very shallow during the snowmelt season, nearly all surface and subsurface runoff occurs in the upper organic soil layers (there may be localized areas where subsurface channels penetrate the organic soils and erode the underlying mineral soils). The stream channel is generally deeply incised, penetrating the organic soils, and the entire flow area is contained in the mineral soils. Therefore, high organic solids concentration would be indicative of a watershed source, and high sediment concentration would indicate an in-channel source.

Data collection must also be continued throughout the runoff season, not only to compare solids yield between the snowmelt and rainfall runoff seasons but to determine the effect of increased thaw depth on solids production. Studies at Glenn Creek are ongoing, and data collection was recently carried out over an entire runoff season. The results will be reported when sample reduction and data analysis are complete.

Acknowledgments

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