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The Hydrology of Bayelva, Spitsbergen

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The hydrology of Bayelva, which is located to the northwestern part of Spitsbergen, was investigated during the period 1974-78. The river drains a catchment of 31.5 km^2, out of which 54 % are covered by glaciers. Additional studies were carried out on erosion and transport of suspended solids in the river. The major part of the runoff occurs during the months June to August. The snow melting usually starts in late May or early June, when air temperature rises above o°C. Mean annual runoff during the period was measured to $31.8 \times 10^6 m^3$, which during an average runoff period of 109 days/year gives 3.4 m^3/sec. Highest daily flood was measured to 32.2 m^3/sec. Annual sediment transport (suspended load) varies from 6,646 to 16,558 t, while highest observed concentration was 3,830 mg/l. The high variations may be explained by annual runoff volume, frequency of floods, amount of rainfall and rainfall intensity.

Introduction

As the human activities have increased considerably at the Spitsbergen archipelago during the last decade, and is expected to increase in the future, it is of common interest for the decision makers to get information on water balance and degration of the area. To get a reliable water supply has been a common problem for the major communities on the islands. In order to obtain some information on these topics, a small research project was initiated at Bayelva, Ny-Ålesund, in the northwestern part of Spitsbergen in 1973. During the project, which lasted six years, a number of problems not common in more temperate climates were encountered.

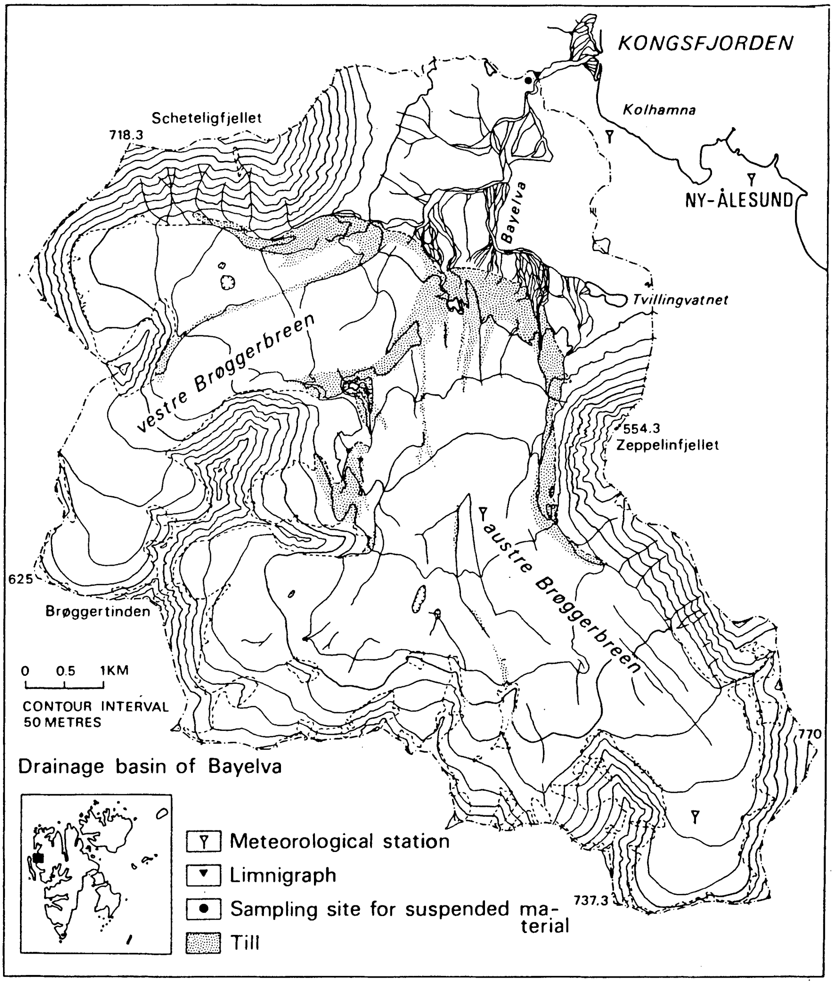

Fig. 1. Location map.

Catchment Description

Bayelva drains a catchment of 31.6 km^2, out of which 54% is covered by glaciers (Fig. 1). The mountains surrounding the glaciers consist of rocks from all geological periods, except the Triassic, Jurassic and Cretacious formations. Thus some of the formations are easily erodible. The area has undergone several orogenic periods; the latest one of Tertiary age. The present relief is characterised by glacial forms, and the dominant land forming agent today is the glacier, while the river and the periglacial denudation are only active during a very short period of the year. Frequent oscillations around the freezing-point only happen for a short time during the spring and the autumn. The permafrost reaches to a depth of approximately 150 metres outside the glaciers (Orvin 1944), while there might probably be a smaller permafrost-free area underneath the Austre Brøggersbre. During summertime the top layer of the permafrost is thawing, and the "active layer" is formed. The thickness varies, depending on the nature of the soil, and the air / water temperature. Soundings across the Bayelva varied from 0.5 to more than 1 m, respectively underneath the riverbed and the sandbanks in the river.

The climate of the area is strongly influenced by the North-Atlantic Current, from which a small branch is diverted to the north, causing a rather maritime climate on the west coast of Spitsbergen. The continentality increases towards the north and west. Annual precipitation ranges from 400 mm in the lower parts of the catchment to 1,000 mm in the higher areas. Annual temperture at Ny-Ålesund is −6°C, while the mean temperture in July is approximately +5°C.

Drainage Pattern

The major part of the runoff occurs during the months June to September. During the initial melt period in late May, the meltwater is trickling down into the snow where it refreezes, and superimposed ice is formed at the glacier surface as well as on the terrain outside the glacier. Simultaneously with the refreezing, energy which contributes to warm the snowcover and the ground below is released. Gradually the whole snowpack reaches the meltpoint and is saturated by water, and the horizontal runoff starts. The runoff during this early phase is highly influenced by the superimposed ice, which forms an impermeable layer on which the water flows away without penetrating down into the glacier. On the glacier surface, large depressions which are being filled with water during the initial phase of the melt season, are frequently found (Liestøl, Repp and Wold 1980).

As the melting increases and the superimposed ice disappears, the water percolates down into crevasses and holes in the glacier, and during the rest of the summer the runoff is a combination of englacial, subglacial, and surface-runoff on and outside the glacier.

Between the glacier front and the sea Bayelva flows in a braided pattern across two sandur plains before it is cutting through a rock sill and reaches the sea, where a delta is developing.

Approximately 0.5 km from the glacier front Bayelva is joined by a small tributary flowing from Tvillingvatn, a small lake 7-8 m deep, with an area of 0.03 km^2. As opposed to Bayelva, where the runoff stops shortly after the end of the melt season, the runoff from this small lake continues for several months, and probably during the whole winter. This assumption is confirmed by the extensive icelayers (0.5-1 m thick) deposited on the sandur during winter time, and also by the fact that the waterlevel in Tvillingvatn drops very little during the wintertime, even if water is abstracted for water supply to the community of Ny-Ålesund.

Hydrological Regime

Methodology

An automatic waterlevel recorder and a staff gauge was established where Bayelva cuts through the rock sill approximately 300 m from the sea. A major problem in flow monitoring at Spitsbergen is the lack of defined water courses and stable riverbed profiles. Numerous braided streams flowing across a sandur is a common feature. At Bayelva, however, all the small rivers unite to form one river flowing through the canyon cut down into the rock sill. Although the riverbed is covered by sand, gravel and pebbles, the profile is relatively stable. The stability of the riverbed was frequently checked by levelling, especially after floods.

An Ott current meter was used for calibrating the rating curve, which was only valid for the period after all snow and ice had disappeared, however. It was early realized that extensive ice layers form at the riverbed during early autumn when the water discharge and the temperature drops. Bottom freezing then starts, caused by heat loss to the permafrost below and to the air. During the spring the ice thickness increases due to the formation of superimposed ice, and ice thickness of more than one metre has been observed.

Consequently frequent discharge measurements were carried out during the period when the canyon was filled with ice, and an ice-reduction curve was established for use when converting waterlevels to discharges.

Two meteorological stations were etablished at different levels at Austre Brøggerbre in order to improve the knowledge about the relationship between runoff and various meteorological parameters, as well as providing the necessary parameters for the calibration of a runoff model. In addition there is a meteorological station in Ny-Ålesund, run by the Norwegian Meteorological Institute. A few precipitation gauges were established in the catchment, and the precipitation distribution registered during two short periods.

Runoff

Monthly runoff volumes are given in Table 1.

The bulk of the runoff is meltwater from ice and snow. Precipitation in the form of rain represents only one fifth of the total runoff. As can be seen from Table 1, the major part of the runoff usually occurs during July and August, while seven months of the year are almost completely dry, except for some spring flow and seepage from the active layer as mentioned earlier. Mean annual runoff during the whole observation period was measured to 31.8×10^6 m^3, which during an average runoff period of 109 days-year give 3.4 m^3/sec. Highest daily flood was measured to

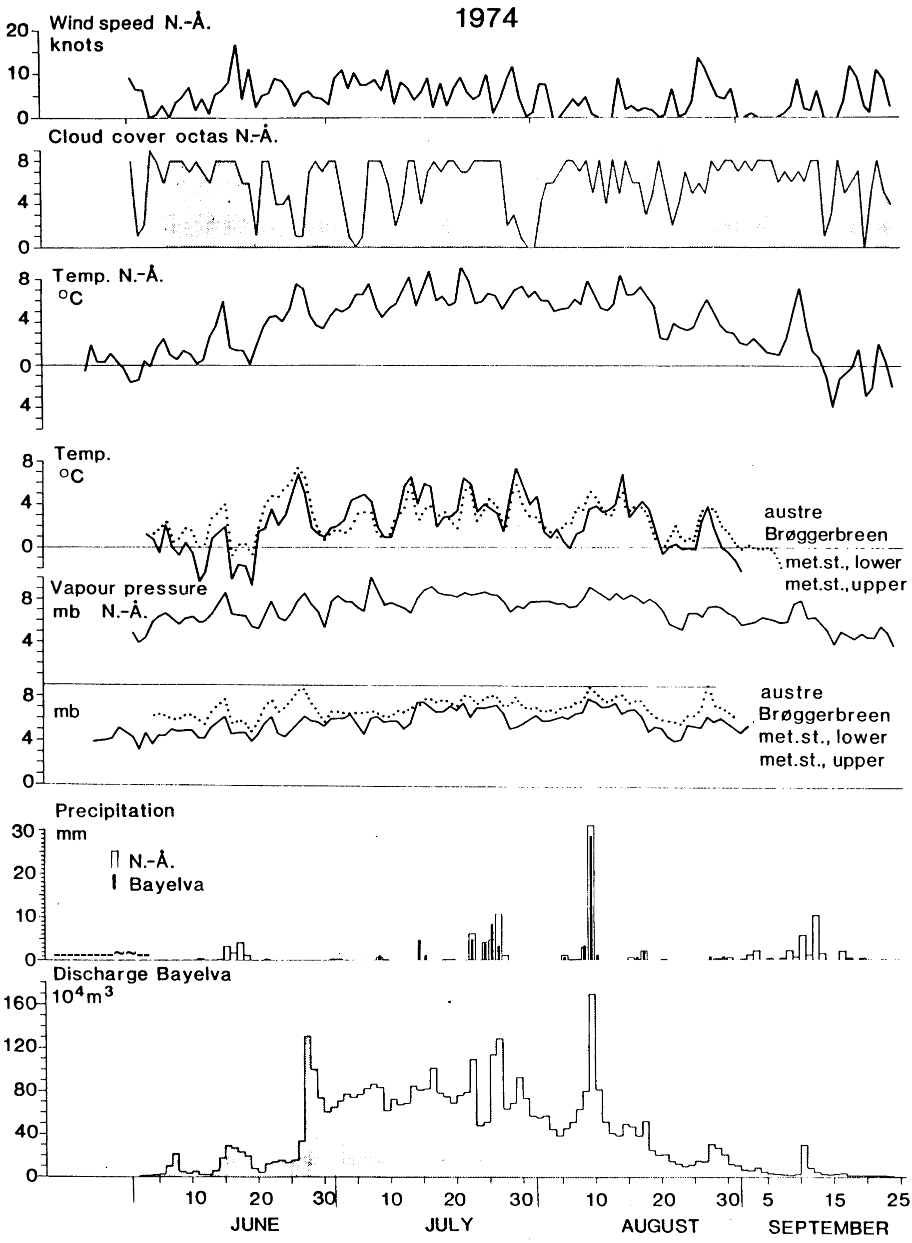

Fig. 2. Daily runoff compared to selected meteorological parameters, 1974.

32.2 m^3/sec. Daily runoff during 1974 compared to some meteorological parameters is shown in Fig. 2.

Table 1 – Monthly runoff volumes, Bayela 1974-78.
$10^4 m^3$

Year Runoff period	May	June	July	August	September	Total
1974 2/6-24/9		661	2409	1250	106	4426
1975 16/6-12/9		141	1480	1190	47	2858
1976 18/5-16/9	91	772	1307	1148	44	3362
1977 9/6-20/9		164	1171	882	89	2306
1978 24/5-19/9	31	1019	1020	814	61	2945
Mean	25	552	1477	1057	70	3180

Sediment Transport

Methodology

As the flow of the river through the canyon is rather turbulent, the socalled "momentary sampling" method was used for measuring the transport of suspended solids. The method as well as the laboratory analyses are well known (Liestøl 1967), and need no description. The method was tested by sampling at several verticals and found appropriate. The sampling frequency varied, depending on the discharge and the weather situation. During quickly rising and high waterlevels connected to rainfall the sampling was intensified. This sampling procedure is very important, since even a shortlasting high flood may account for most of the total sediment transport (the term "sediment transport" in this paper only includes inorganic particles in suspension).

I order to estimate the sediment transport during periods without any observations, the relationship between discharge and sediment transport was established by the computation of sediment rating curves whereafter the total transport during the whole melt season was calculated. More than 1,000 sediment samples made it possible to calculate separate rating curves for rising and falling waterlevel, as well as for different periods through the summer, based on characteristic changes in the runoff regime, *e.g.* when the riverbed is free from ice, when the catchment is free from snow, or during heavy rains and floods.

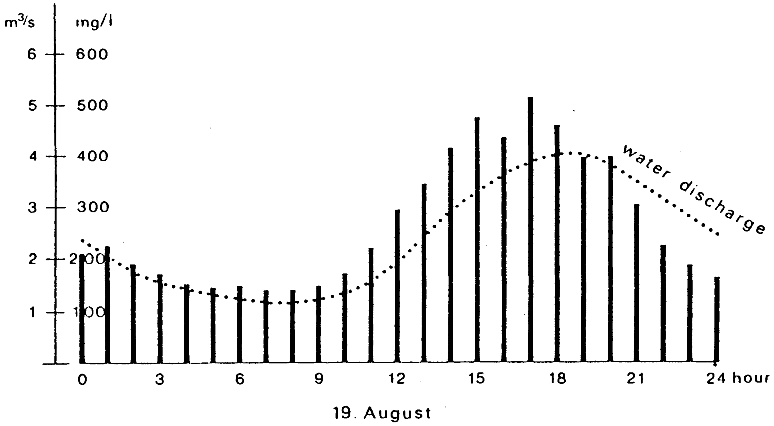

Fig. 3. Sediment concentration compared to discharge.

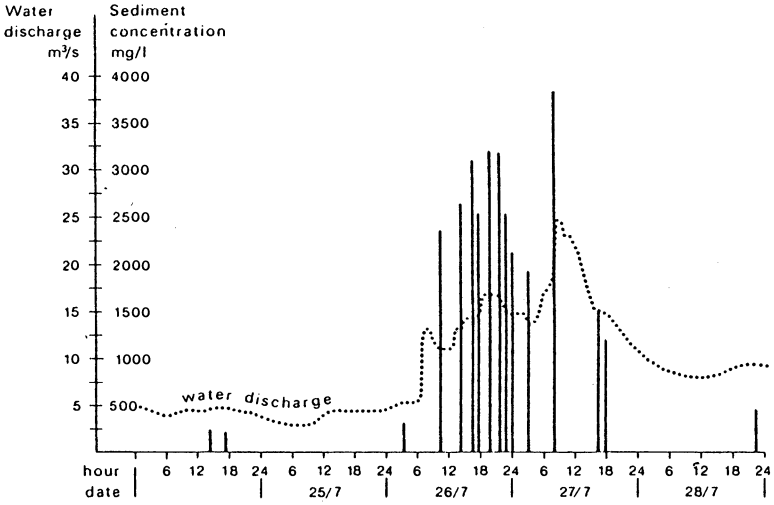

Fig.4. Sediment concentration compared to discharge during heavy rain.

Results

Sediment concentration in relation to discharge is illustrated in Figs. 3 and 4, showing respectively a typical situation where the sediment concentration reached its maximum a couple of hours before the runoff culmination, and an extreme situation where the concentration reached 3,800 mg/l. The first situation reveals that the sediment concentration is not clearly correlated to the discharge. It may be said that the sediment transport does not depend upon absolute discharge alone, but to a far greater degree upon the percent increase of discharge per interval of time.

Table 2 – Sediment transport, tons/year.

Year	Calculated by the equation $G \equiv 0.0534\ Q^{2.0392}$	Observed/ Calculated
1973 (incomplete)	1,043	792
1974	21,542	15,851
1975	10,281	16,558
1976	10,084	13,599
1977	6,033	6,646
Total	48,983	53,446

Several glaciologists have earlier called the attention to the nonexistant subglacial drainage at cold glaciers. The relatively great sediment transport measured in Bayelva, however, indicates a well developed and integrated network of subglacial streams and channels. The difference between temperate and cold, or subpolar glaciers, is only shown by the seasonal variations. At glaciers investigated in Norway, most of the erosion material produced during the winter is washed out early in the melt season (Liestøl 1967). Later in the summer less material is available, and the relationship discharge/sediment transport increases.

In Bayelva the opposite was registered during 1974. The sediment concentration increased during the summer, and reached its highest values in August. The main reason for this is the subglacial drainage system, which is poorly developed during the early summer, due to the superimposed ice blocking the drainage channels.

Most of the years, however, the sediment concentration is rather uniform throughout the runoff season, with the exception of the snow-melt period early in the summer, when the water is almost clear and free of sediment particles. This even access to erosion material is probably contributing to the relatively good correlation between discharge and sediment transport, as most of the sediment rating curves have correlation coefficients higher than 0.9.

The same reason probably also explains the rather good adjustment of only one rating curve valid for the whole runoff season. This fact is clearly shown by the annual transport values calculated by different methods (*i.e.* a number of rating curves), which differ very little from the observed values. The good agreement between measured and calculated transport should indicate that using sediment rating curves is a rather reliable method to calculate the annual total transport of suspended load. To calculate the transport separately for periods of rising and falling waterlevel seems to be unnecessary. This presupposes, however, that the samples, which are the basis for the calculation of the rating curves, are taken at both rising and falling waterlevels, and low waterlevels as well as high waterlevels are covered. On the other hand, a certain scepticism should be expressed against the uncritical use of sediment rating curves. One curve covering all the samples from 1973 to 1977 was calculated, whereafter the total annual sediment volumes

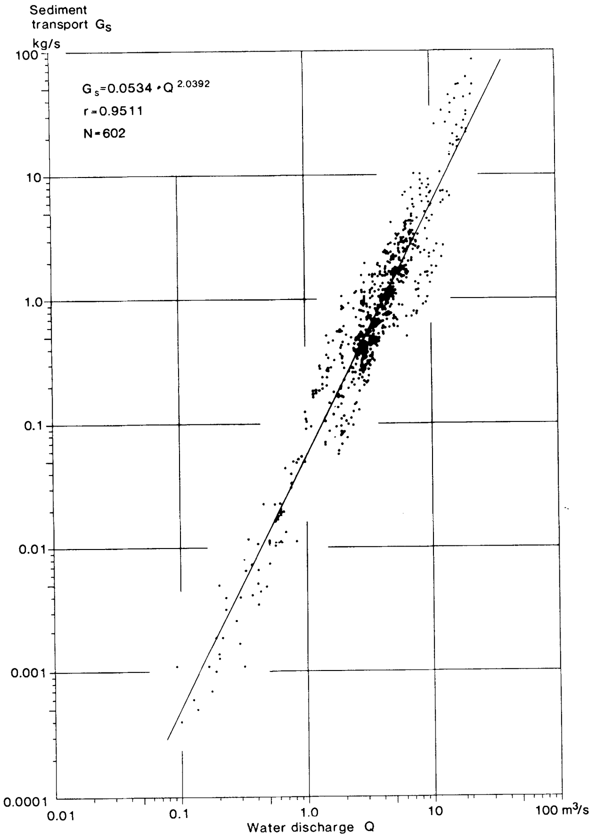

Fig. 5. Sediment rating curve covering the period 1974-78.

were calculated. As can be seen from Table 2 the annual deviations were substantial, primarily due to an underestimation of the transport at high discharges, as illustrated by Fig. 5.

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