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Hydrology of the mouth section of the Ebbaelva and the Petuniabukta, Billefjorden, central Spitsbergen

ABSTRACT: The observations made on the Ebbaelva and measurements of water stages and discharge provide the basis of determination of runoff variations and amount for its catchment. The results of simultaneous measurements of suspended sediment load are used for calculating the magnitude of denudation. The present article, whilst covering the above aspects, describes thermal properties of the Petuniabukta waters as well as considers whether inland water can desalt them.

Key words: Arctic, Spitsbergen, hydrology.

Introduction

The Petuniabukta is the northern extremity of Billefjorden which is turn, is a northern branch of Isfjorden. Adjoining the bay to the east occurs the Ebbaelva catchment originating from the Ebbabreen and Bertrambreen that represent the western branch of the Mittag-Lefflerbreen.

Over a period between 1 July and 1 August 1987 fieldwork was carried out, including observations of water stages, measurements of discharge and suspended sediment load on the Ebbaelva, those of soil infiltration capacities, and production of depth-temperature profiles of the Petuniabukta.

The objective of this study is to provide answers to the following questions: what is the amount of runoff?, what are its variations?, how fast is the rate of denudation?, is there enough river-delivered water to desalt the bay waters?

Hydrological characteristics of the Ebbaelva catchment

The river catchment is of the type where a glacier terminates on land and does not reach the sea. Its surface area is 51.4 sq km. Bastionfjellet, lying at 984 m a.s.l. is the highest landmark, whereas the mouth located at about 0.75 m a.s.l. (tide height) is the lowest-lying portion. A water-gauging station was installed in the Ebbaelva mouth section at a distance of about 150 m from the bay coast beyond the extent of the action of tides.

The measurement of flow velocity was accomplished at 1-metre intervals by means of a hydrometric current meter. Water flowed at the highest velocities in the course of the thalweg. At the highest recorded stages the velocities ranged from 1.7 m per sec at the surface to 1.6 m per sec at the bed, whereas they were 0.6 to 0.5 m per sec, respectively, at the lowest stages. Thus, velocity differences in vertical river profiles were insignificant. This is of considerable importance if water is sampled for suspended load content.

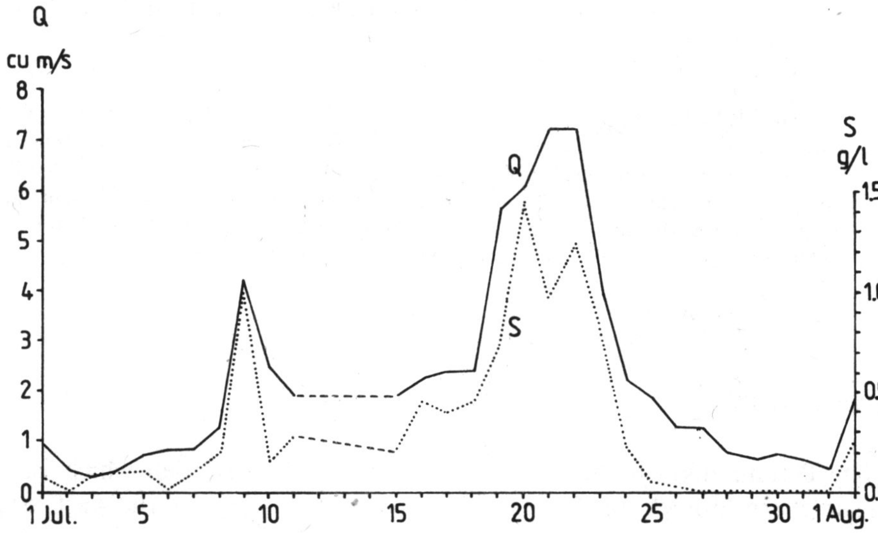

Fig. 1. Variations of discharge (Q) and suspended load (S)

Figure 1 shows variations of discharge and suspended sediment load. The maximum and minimum discharges were 7.26 and 0.32 cumecs, respectively. Thus, the coefficient of irregular extreme discharge is 23. Over the period between 1 July and 1 August the average discharge was 2.3 cumecs, thereby yielding the average unit gross flow of 44.7 l/s/Km^2. For maximum and minimum discharges it was 141.2 and 6.2 l/s/Km^2, respectively. The resulting values given on the graph indicate that the summer was exceptionally cold. The discharge values were low, as opposed to those recorded from 27 June to 23 July 1986.* The average discharge approximated then 8 cumemecs and so it was greater than the maximum discharge recorded during the summer months 1987.

Extremely slight variation of discharge was observed day after day or on a given day. The diurnal water level fluctuations were indiscernible, even on days with a lot of bright sunshine. Therefore measurements were made once throughout the 24-hour period. Stages and discharges were simultaneously measured during 10 days. The curve equation that is derived from the resulting data takes the form:

$$Q = 5.140 - 20.487\,H + 16.480\,H^2$$

where Q is the discharge in cumecs and H is the water stage in m.

The total runoff was 6 million cu m. Because of low precipitation, waters derived from the melting of glaciers and the thawing of frozen ground and snow covers are largely its component parts. The runoff rate for the entire catchment area was 117 mm.

The daily measurement of suspended load was accomplished by filtering a river water sample of 1 dcm^3 volume. Its amount varied from trace quantities to 1.43 g/dcm^3.

The correlation between the suspended load and discharge values allows their relationship to be established. It is described by the following equation:

$$S = 0.1826\,Q - 0.1035, \qquad R = 0.93$$

where S is the suspended load in g/dcm^3, Q is the discharge in cumecs and R is the coefficient of correlation.

In the case of the average suspended load of 0.31 g/dcm^3 the total monthly quantity of material carried in suspension is about 1.850.000 kg, thereby resulting in the volume of 900 m^3. The denudation rate can be calculated by dividing this volume by the catchment area. The resulting estimate is 0.0175 mm per month. If it is assumed that rivers remain active for about three months throughout the year, the annual denudation rate of 0.05 mm can be estimated. In case there is a markedly wet year, the rate can be several times faster.

Variations of groundwater runoff

Over a period between 6 July and 24 July 1987 the measurement of runoff from the active layer (the thawing layer) was made. Measuring operations were performed at a distance of 0.5 km to the south of the

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*) Results by Associate Profesor Alfred Kaniecki of the Institute of Physical Geography, the Adam Mickiewicz University, *personal communication*.

Ebbaelva mouth. A catchment area* was delimited in the field. Its surface area was estimated as 0.0135 sq km by the use of the tachometric technique. The catchment lies within the zone of marine terraces. Its highest point is situated at the altitude of 8.1 m a.s.l. The surface is covered with a several-cm-thick layer of soil that is underlain by terrace deposits, i.e. stones, gravels, as well admixed sands and fine fractions. In the catchment there are two shallow water basins a few tens of centimetres in depth from where runoff occurs through an erosional cut.

At the initial stage of the measurement on a stream draining the catchment runoff from it was 1.2 l/sec. Because of the total absence of precipitation, this figure gives an indication of groundwater runoff. Throughout the 24-hour period no runoff variations of importance were observed. Consequently, the catchment was gradually drained with time, *i.e.* runoff figures were as follows: 0.9 l/sec on 9 July, 0.2 l/sec on 15—20 July, trace amounts on 23 July and the total runoff cessation on 24 July (Fig. 2). This is indicative of complete depletion of water reserves in the active (thawing) layer.

In addition, water and air temperatures were measured. Their variations are concurrent, *i.e.* a rise of air temperature. However, no relationship was established between an increase in runoff and a rise of air and water temperatures. After runoff cessation, the measurement of the depth of the frozen ground was made, thereby yielding a figure of 68 cm for three excavated holes.

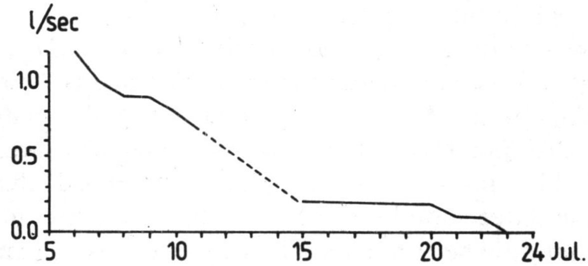

Fig. 2. Variations of runoff in l/sec

In order that infiltration conditions might be determined, the infiltration rate was estimated for the soil itself and its substratum. The mean values resulting from six measurements are 0.0075 and 0.5077 cm/sec, respectively. Thus, it can be inferred that a direct supply of precipitation into groundwater is slow. Yet, because of high hydraulic conductivity, there exist

*) Here I am indebted to Dr. Andrzej Mizgajski of the Institute of Physical Geography, the Adam Mickiewicz University.

extremely favourable conditions for subsurface runoff derived from the melting of ice in the active layer.

In infiltration capacity being equal to water absorption capacity for stony-gravelly particles is taken as 0.25, water reserves found in the layer above the frozen ground can be estimated. They are 2295 cu m as a result of 13500 $m^2 \times 0.68$ m$\times$ 0.25. At the average discharge values of 0.6—0.9 l/sec the useful life of the catchment should last for 1.5 to 3 months. These figures confirm the reliability of the resulting estimates. The maximum runoff, *i.e.* 1.2 l/sec, results in groundwater runoff of the order of 90 l/sec/Km^2. This exceptionally high value, which averages 3 l/sec/Km^2 for Poland, gives an indication of possible high groundwater runoff reaching some river sections in the Polar Regions. This holds for measurable items, as well as the contribution to total runoff.

Thermal properties of the Petuniabukta waters

The temperature of Petunia Bay waters was measured by the use of a thermometer with scale divisions reaching 50 m of depth and exceeding 0°C.

The temperature of surface water ranged from 0.5 to 4.6°C, depending on the bay water circulation, tides and insolation changes. Temperature profiles of the Petuniabukta were produced for Skottehytta-Petuniahytta, Skottehytta-Elzabreen and Elzabreen-Ebbaelva, mouth. Figure 3 illustrates the resulting data.

In the case of three profiles thermal stratification is similar *i.e.* the pattern of more or less parallel isotherms remains undisturbed. The zone of water temperature transition to a negative range of values lies at the depth of 19—22 m, depending on the measuring point. Great thickness of the water layer immediately at the bottom at the temperature of below 0°C is due to the presence of the frozen ground beneath the bay bottom. The bottom surface itself remains unfrozen in a semi-liquid strate, which is indicated by sediment samples.

Figure 4 shows five selected temperature profiles. As a result of changing interactions between waves, tides and currents, each of profiles 1, 2 and 3 is based on two thermoclines. The maximum temperature gradient approaches 1.2°C per metre (profile 1). Minimum temperatures were not recorded at the bottom as merely those over 0°C could be read off. However, the temperature of the water layers immediately at the bottom can be estimed to be higher than −1.6°C at salinity values exceeding 30‰. Such temperature values are assigned to water freezing at such salinity values. Thus the hypolimnion temperature gradient is scarcely 0.05°C per metre in the deepermost portions of the bay. This is indicative of stability of thermal stratification in the zone immediately at the bottom.

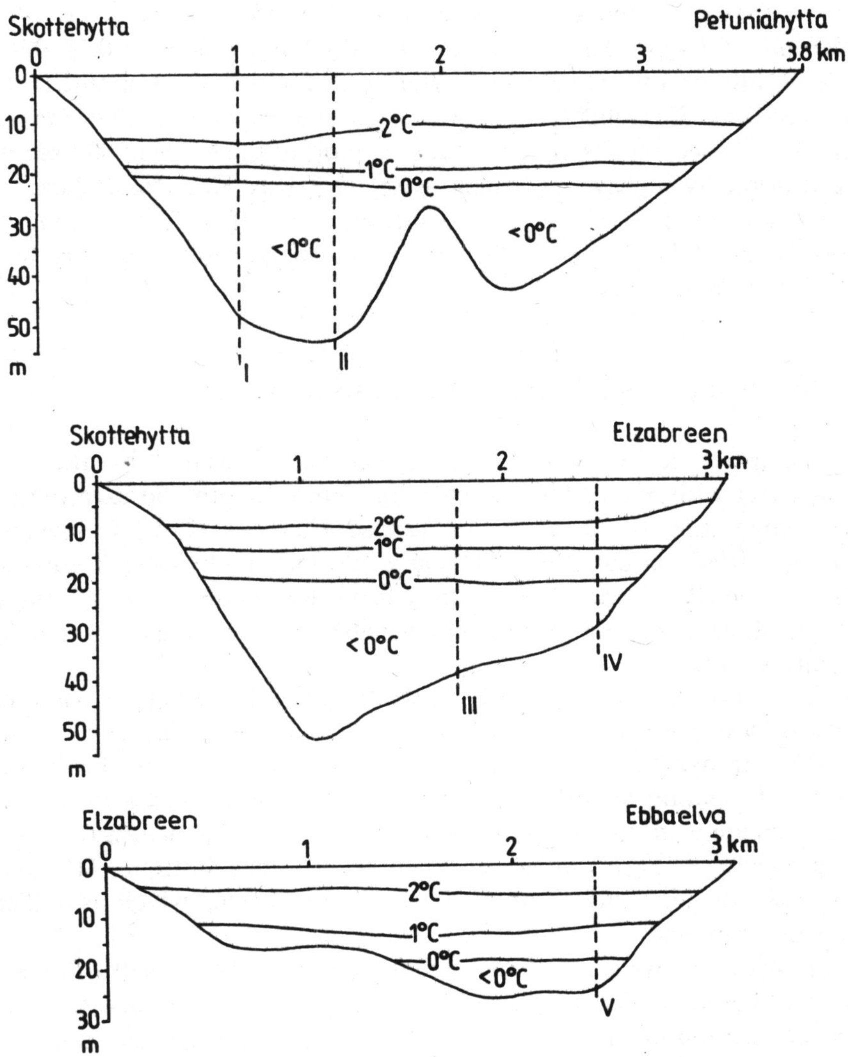

Fig. 3. Temperature profiles of the Petuniabukta (I—V: profiles shown in Fig. 4)

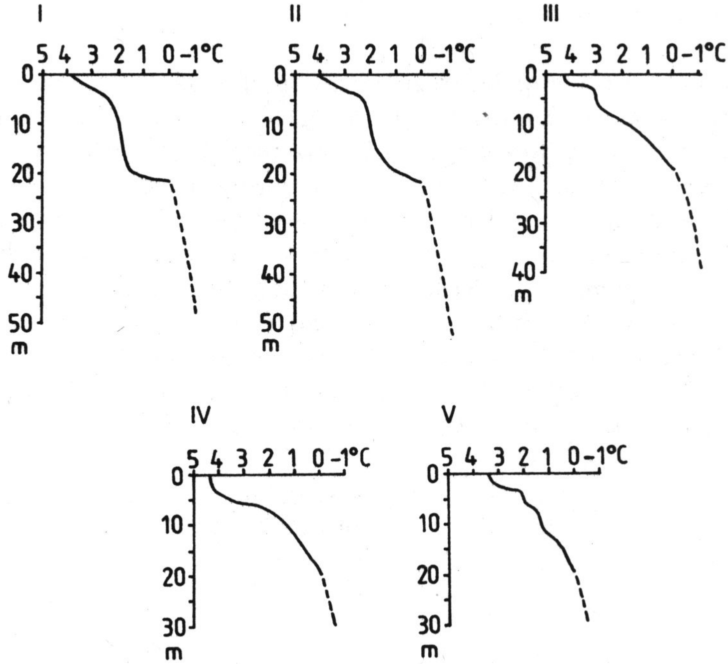

Fig. 4. Temperature profiles (for location *see* Fig. 3)

Possible desalination of the Petuniabukta waters by inland waters

In order that it may be established whether inland waters have an effect on desalination of the Petuniabukta waters, the volume of the stored bay waters and that of inland waters entering the bay have been estimated. Promontories from which the orientation of the bay shores changes from meridional into parallel are recognized as the bay limits. The surface area is 18.28 sq km while the waters retained within these limits are 0.4591 cu km in volume at the average depth of 25.1 m. In case the unit gross flow is identical for catchments adjacent to the Ebbaelva catchment, *i.e.* 44.7 l/ses/Km^2, the runoff to the Petuniabukta approximates 7 m^3/sec, thereby resulting in 18 million cu m per month. This value makes up scarcely 4 per cent of the bay water volume but account should be taken of runoff into and from the bay due to tides and currents. In the discussion of this type of circulation it has been suggested that inland waters have practically no effect on desalination of the Petuniabukta waters.

Concluding remarks

Observations of the polar regions are useful as there are still many unsolved problems concerning the hydrological cycle. In addition, there are few studies presenting long-term fieldwork results. It seems necessary to conduct research in the same catchments during subsequent years as the regime of rivers in the Polar Regions may be determined then. Also of considerable importance is the identification of the whole hydrological cycle, *i.e.* from the beginning of discharge variation till the end. Contributions from snow, glacier ice, frozen ground and precipitation can also be determined. It is extremely difficult to make such an attempt because of technical limitations. In order that the initial and final phases of runoff can be measured, hydrologists will have to pass there at least one winter season.

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Streszczenie

Między 1.07. i 2.08.1987 roku przeprowadzono badania terenowe w ujściowym odcinku Ebbaelva i w Petuniabukta. Wykonano obserwacje stanów wody rzeki, pomiary przepływów i zawiesiny, określono warunki filtracyjne gruntów oraz wykonano przekroje głębokościowo-termiczne przez zatokę.

Średnia wielkość przepływu w analizowanym okresie wynosiła 2,3 m^3/sek, przepływ maksymalny 7,26 m^3/sek, zaś minimalny 0,32 m^3/sek. Na podstawie uzyskanych wielkości obliczono odpływy jednostkowe. Wynoszą one odpowiednio: 44,7 l/sek/km^2,141,2 l/sek/km^2, 6,2 l/sek/km^2. Równoczesne pomiary stanów i przepływów pozwoliły na określenie zależności między nimi. Wyraża się ona wzorem: $Q = 5{,}140 - 20{,}487\ H + 16{,}480\ H^2$, gdzie: Q — przepływ w m^3/sek, H — stany wody w m. Na tle zmienności przepływów przedstawiono zróżnicowanie ilości zawiesiny fig. 1, której zawartość w wodzie wahała się od wartości śladowych do 1,43 g/dcm^3. Określono zależność między przepływami a ilością zawiesiny, która wyraża się wzorem: $S = 0{,}1826\ Q - 0{,}1035$, gdzie S — zawiesina w g/dcm^3, Q — przepływ w m^3/sek. Na podstawie kubatury zawiesiny dopływającej do zatoki w ciągu miesiąca oszacowano wielkość denudacji. Wynosi ona 0,05 mm/rok.

Figura 2 przedstawia wyniki pomiarów odpływu z warstwy czynnej (odmarzającej). Ustalono, że maksymalny odpływ jest rzędu 90 l/sek/km^2. Fakt ten świadczy o możliwości dużego zasilania podziemnego pewnych odcinków rzek strefy polarnej, zarówno w wielkościach wymiernych jak i udziału w odpływie całkowitym.

Badania termiki wód Petuniabukta wskazują, że występuje niezaburzony, w przybliżeniu równoległy układ izoterm — fig. 3. Przejście temperatur wody w zakres ujemny występuje na głębokości 19—22 m. Duża miąższość występującej przy dnie warstwy wody o temperaturze poniżej 0°C jest efektem zmarzliny zalegającej pod dnem. Fig. 4. obrazuje profile termiczne rozkładu temperatur w pionach pomiarowych. Określony z nich gradient temperatury w strefie hypolimnionu wynosi zaledwie 0,05°C/m. Świadczy to o stabilności strefy przydennej.

Korelując dopływające do Petuniabukta wody (7 m^3/sek) z kubaturą wód zatoki (0,4591 km^3) ustalono, że wody lądowe nie mają wpływu na wysładzanie zatoki Petuniabukta.