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# Chemical and mechanical denudation rates in the Scott River catchment (Svalbard) during the summer season 2005

Denudacja chemiczna i mechaniczna w zlewni rzeki Scott (Svalbard) w sezonie letnim 2005

## ABSTRACT

Chemical and mechanical denudation rates were calculated i. a. for the Scott River (Scottelva) catchment (NW part of Wedel Jarlsberg Land – Svalbard). Runoff was recorded from 14th of July until 1st of September, 2005. Daily water samples were collected in order to determine the ion composition and suspended sediment. In the research period $5{,}120 \cdot 10^3$ $m^3$ of water outflowed, which-corresponded to 1,201 $dm^3 \cdot s^{-1}$ of average discharge, 506 mm of runoff index and 119 $dm^3 \cdot s^{-1} \cdot km^{-2}$ of specific runoff. The chemical denudation rate for the Scott River catchment was 0.24 to 0.70 $t \cdot km^{-2} \cdot day^{-1}$, 0.50 $t \cdot km^{-2} \cdot day^{-1}$ on average in the research period. The mechanical denudation rate for the Scott River catchment was 2.53 $t \cdot km^{-2} \cdot day^{-1}$ on average and changed in the range from 0.32 do 18.2 $t \cdot km^{-2} \cdot day^{-1}$.

**Key words**: denudation, hydrochemistry, glacier hydrology, Svalbard

## INTRODUCTION

Global climate changes in the European Arctic, such as slow temperature increase (Przybylak 2007) significantly influence the water circulation conditions. Glacial mass balance has in general been negative in Svalbard during the last 40 years, leading to a significant contribution to the water balance, at the level of 450 $mm \cdot year^{-1}$ on average (Killingtveit et al. 2003). The best documented result of water balance changes is recession of glaciers and related changes of landscape as well as conditions of energy and mass circulation. In the researches of fluvial transport of dissolved and suspended sediments, its structure and seasonal changeabil-

ity is the crucial index of changes taking place in the glacial environment. Results of those researches are the basis for calculations of the rate of chemical and mechanical denudation in glacierized and non-glacierized catchments (Barsch et al. 1994; Hodson and Ferguson 1999; Hodson et al. 2000; Pulina, Burzyk 2002; Bogen, Bønsnes 2003; Bukowska-Jania 2003; Krawczyk et al. 2003; Zajączkowski et al. 2004; Krawczyk and Petterson 2007; Strzelecki 2009; Rachlewicz 2009). Interpretation of actual climatic, hydrological and geomorphological processes taking place in the polar areas (including changes of the carbon cycle, removing the deposits, and their sedimentation within the valleys, fiords, and shelf areas) is possible as the result of the studies.

Studies of chemical and mechanical denudation of the Scott River were carried out during summer expeditions of Maria Curie-Skłodowska University research workers to Spitsbergen in 1987, 1988, 1989, 2002. The results of studies show the annual rate of the chemical denudation in the range from approx. 4 $t \cdot km^{-2} \cdot yr^{-1}$ to over 39 $t \cdot km^{-2} \cdot yr^{-1}$ (Krawczyk et al. 2008), however, the mechanical denudation was at the level of 70 $t \cdot km^{-2} \cdot yr^{-1}$ (Bartoszewski 1998). In 2005, the main purpose of hydrological and hydrochemical researches of the Scott River was evaluation of the load of outflowed sediments in the form of solutions and suspensions, concerning the share of the selected parts of the catchment and outflow dynamics.

## STUDY AREA

The study area was located on the coastal lowland reaching Recherche Fiord (Fig. 1). The ground surface in the coastal zone is built of Quaternary deposits of the thickness of a few meters: gravels, sands, clays, silts as well as Tertiary sandstones. The main block of rock massif (Bohlinryggen and Wijkanderberget) is formed by old metamorphic rocks of Hecla Hoek formation (Dallmann et al. 1990).

The main object of hydrological studies in the group of glacierized basins in the Bellsund region (Wedel Jarlsberg Land) is the Scott River (Scottelva) catchment ($77^{o}$ 33' N, $14^{o}$ 21' E) which carries waters to Recherche Fiord, the southern branch of Bellsund. The Scott River catchment, of 10.1 $km^2$ area, covers part of the coastal plain – Calypsostranda and partially glacierized mountain valley between the Bohlinryggen and Wijkanderberget massifs. In 2005 the glacier occupied 4.82 $km^2$ (Zagórski et al. 2008). The highest parts of the glacier reach 600 m a.s.l. and its front goes down to about 90 m a.s.l. The length of the glacier is 4 km, the width 1.1 – 1.8 km and the average inclination of the longer angle – $8^{o}$. The drainage system of Scott Glacier waters is formed by subglacial, inglacial and supraglacial underflows of various sizes. The Scott River starts from the marginal lake created in the terminal hollow between the current glacier front and the frontal moraine ridge. The waters from marginal slits, subglacial channel situated in

the SE part of glacier front and numerous supraglacial underflows flow down into the reservoir. Field researches conducted in 2005 in the forehead of the Scott Glacier showed that contribution of water outflow from the subglacial channel to the total outflow changes during the polar year and is about 50% on average. Along the ravine in frontal moraine ridge of the Scott River water discharges onto the outwash area where the river forms a vast glen system. The water gauge station was located 200 m above the outlet to the fiord in the central part of the ravine. The length of the river up to this point is 2.6 km and the average drop – 35‰. The water gauge station in the Scott River catchment supplied discharge summer season data since 1986 with interruption in 1991–1993, 1994–2000, and 2003–2004.

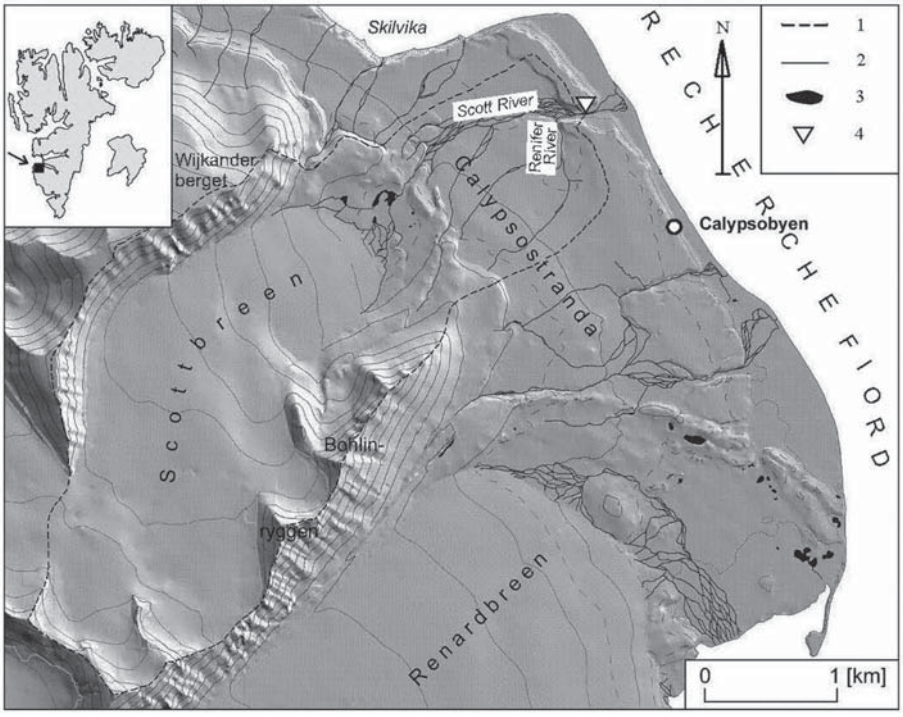


Fig. 1. Research area map (1 – watershed, 2 – river, 3– lake, 4 – water gauging station). The shade map made using the Digital Terrain Model (DTM) obtained from the aerial photograph from 1990 (Zagórski 2005)

## METHODS

Water stages of the Scott River were registered by limnigraph ASTER in the period of 14th July – 1st September, 2005. Measurements of water discharge and gauge data have allowed to calculate the rating curves and to determine the

amount of runoff. The hydrochemical researches carried out in the period of 14th July – 21st August, 2005 included everyday uptake of water samples from the Scott River current. Samples of water from the Scott River were taken three times using multi-points method and hydrochemical profiling was conducted nine times down the river in order to evaluate the diversity of physico-chemical indices in the control profile of the river. They included the waters from Scott Glacier forefield and tundra. Precipitation waters are collected in Calypsobyen into polyethylene container placed 1 m above the ground every 24 hours. The hydrochemical investigations were also carried out in Calypsostranda.

In the water samples there were measured suspended sediments (SS), its reaction and electrolytic conductivity. Water for further investigations was filtered using underpressure set trough the 0.45 μm cellulose–acetone filter. Basic measurements were made in the field laboratory in Calypsobyen. Filtered water in 12-ml polyethylene phials (non-acidified) and water in 125-ml HDPE bottles acidified with nitric acid (up to pH~ 2) were transported to the laboratory of the Department of Hydrography, Maria Curie-Skłodowska University in Lublin.

Water reaction and its electrolytic conductivity were measured using the meter WTW InoLab 1 firm compatible with the pH electrode Hanna Instrument and the conductometric electrode TetraC WTW. Electrolytic conductivity was determined from non-linear temperature correction up to 20°C taking into account the corrections according to the German standard DIN 38404. Concentrations of anions (sulphates, chlorides, nitrates, nitrites, bromides and fluorides) and cations (calcium, magnesium, sodium, potassium, ammonium) were determined by ion chromatography (Metrohm MIC 3, Switzerland); alkalinity was determined by titration method with hydrochloric acid in the presence of methyl orange indicator; the suspended sediments were determined by weight after filtration of 1 $dm^3$ water and drying. Silica and orthophosphates were determined using the photometer Hach DR/890. The monitoring determinations were made for calcium with the use of the versenian method.

For analysis there were used standard solutions produced by Merck and Accustandard and certified materials: CRM RAIN-97, SRM 1643e Trace Elements in Water, LMO CBE-WJ-03 water from oligotrophic Hańcza Lake.

Chemical and mechanical denudation in the Scott catchment was calculated on the basis of hydrometric and hydrochemical studies according to the following formula (Pulina 1999):

$$Dc = Q \cdot 0.0864 \cdot TDS/A$$
$$Dm = Q \cdot 0.0864 \cdot SS/A$$

where:

Dc – chemical denudation ($t \cdot km^{-2} \cdot day^{-1}$)

Dm – mechanical denudation ($t \cdot km^{-2} \cdot day^{-1}$)

Q – discharge ($m^3 \cdot s^{-1}$)
TDS – total dissolved solids ($mg \cdot dm^{-3}$)
SS – suspended sediments ($mg \cdot dm^{-3}$)
A – catchment area ($km^2$)

Mineral composition of suspended sediment samples was determined by diffraction (RTG) and thermal analysis (DTA). In the temperature range (20–1,000°C) – calcite, dolomite and organic substance (inflammable) were identified. The concentration of the remaining minerals (chlorite, muscovite/sericite, feldspars, quartz, iron oxides and hydroxides) was estimated from intensity of diffraction lines.

## RESULTS AND DISCUSSION

### Hydrology

Outflow from the Scott basin begins in the first decade of June and terminates in October (Bartoszewski 1998). The seasonal measured volumes of water flowing to the Recherche Fiord from the Scott River catchment ranged between 4,587 x $10^3$ $m^3$ (10th July – 31st August, 1986) and 9,122 x $10^3$ $m^3$ (7th July – 8th September, 1989). Average seasonal discharges varied from 956 $dm^3 \cdot s^{-1}$ (1988) to 1775 $dm^3 \cdot s^{-1}$ (1993). Specific discharge ranged from 94 to 175 $dm^3 \cdot s^{-1} \cdot km^{-2}$.

Figure 2 shows the discharges of the Scott River. Between 14th July – 1st September 5,120 x $10^3$ $m^3$ of water outflowed. The average discharge was 1,201 $dm^3 \cdot s^{-1}$, which corresponds to the runoff index 506 mm and the specific discharge 119 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Calculated values were alike those for Ebbaelva catchment (similar share of glacierized area) in the summer season of 1985 (Kostrzewski et al. 1989). They were also in the range of values for Glopbren catchment in the area of Liefdefjord, where runoff index was 700 mm in 1990 (Barsch et al. 1994).

Meteorological data from Calypsobyen show that the research period, July 14th – September 1st, 2005, was similar to the previous seasons (Bartoszewski et al. 2009). The average daily air temperature was 5.1°C. The highest temperature, 7.6°C, was on 28th of August and the lowest, 2.1°C, on 1st September (Fig. 3). The total seasonal precipitation was 56.7 mm, more than half of it, 29.4 mm, fell in the second half of August.

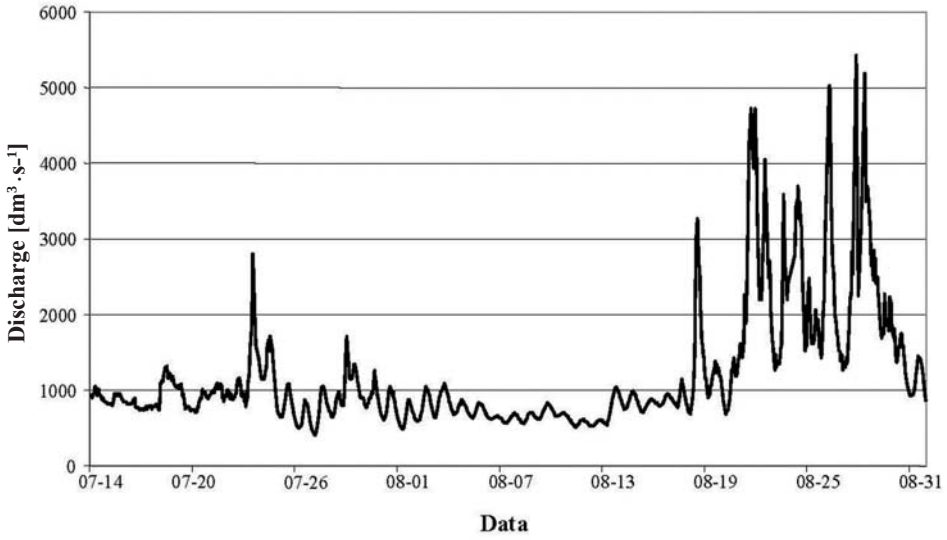


Fig. 2. Hourly values of the Scott River discharges in the summer season 2005

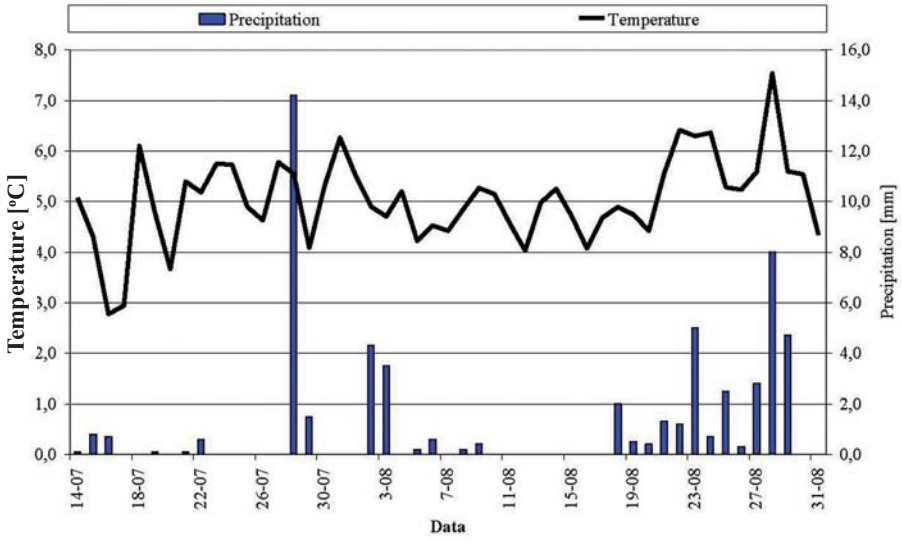


Fig. 3. Total precipitation and average air temperatures in the summer season 2005

At the moment of outflow registering start, most of snow cover in the coastal lowland vanished and the main component of runoff was proglacial waters from the lower and central parts of the Scott Glacier. July was dry (until 27th July), only

2.4 mm rain fell. The highest rainfall occurred on 28th July (14.2 mm). Until mid-August even discharge course with the characteristic (24-hour) rhythm due to the daily rhythm of glacier ablation was observed. Several days' long decrease of air temperature in the last decade of July resulted in decrease of ablation and drop of discharge up to the value 445 $dm^3 \cdot s^{-1}$ on 27th July. Increase of air temperature in the second half of August and several days' long period of higher precipitation caused intensive ablation of the Scott Glacier and discharge increase. The warmest day was 28th July (7.6ºC). The highest rainfalls occurred from 18th to 29th August (29.4 mm). The highest discharge value of 5,430 $dm^3 \cdot s^1$ was observed in the evening (9 p.m.) on 27th August.

**Water chemistry**

The obtained results represent properties of water taken up from various phases of hydrological cycle in the polar glaciated catchment. The collected material indicates large hydrochemical differentiation among individual phases of water circulation and confirms specific hydrochemical properties of waters of the glacier ablation origin (Wadham et al. 1998; Hodson et al. 2000; Yde et al. 2008).

Precipitation waters were characterized by slightly acidic reaction and low content of mineral substances from a few to several $mg \cdot dm^{-3}$. Chemistry of atmospheric precipitation was mainly shaped by marine aerosols which contributed to predominance of Na and Cl ions (Tab.1). Their concentration as well as bromine ion is connected with air masses. The highest values were recorded with air masses from the eastern direction carrying marine aerosols, the lowest ones from the western and northern directions of low marine aerosols concentration. This phenomenon is typical of the areas situated in the coastal zone of Spitsbergen (Krawczyk et. al 2003; Chmiel et. al 2007; Krawczyk et. al 2008). Assuming as the base characteristic relations of chloride concentrations to the other indices in sea water and linking obtained values to ions ratios in wet fall, participation of sea and continental ions which mould chemistry of precipitation waters was estimated. Weighted average mineralization value calculated as the sum of ions in precipitation collected in summer season 2005 was 11 $mg \cdot dm^{-3}$, where ions of sea origin were about 60%. The rest of the components were anthropogenic substance from near and far circulation and of geochemical origin less so (Chmiel et al. 2011).

The waters flowing within the Scott Glacier are characterized by large hydrochemical differentiation. In the upper part of the glacier they were characterized by low TDS of the order of a few $mg \cdot dm^{-3}$, slightly acidic reaction and the temperature below 0.5ºC (Tab. 2). Their physicochemical composition was close to precipitation waters with Na and Cl ions predominance. The other ions occurred in very low concentrations.

Significant changes of chemical composition of waters circulating within the glacier were observed in the sites of water contact with the eolian deposits. Then water TDS increased to several $mg \cdot dm^{-3}$ and the reaction to basic values. Such transformation of water physicochemical composition occurred mainly in the frontal zone of the glacier. Streams from subglacial drainage contained even up to a few $g \cdot dm^{-3}$ of the suspended sediments (SS). In the mineralogical composition of the SS Scott River quartz (~50%), dolomite (~20%) as well as calcite and muscovite/sericite (~10% each), were predominant. Plagioclase (albite) and chlorite (~4% each), iron oxides and hydroxides (~0.5%) were found in smaller amounts (Chmiel et al. 2009). Of these minerals calcite and dolomite are most readily soluble under natural conditions. Physical and chemical properties of waters outflowing from the glacier changed rapidly down the river, among others as the result of absorbing dioxide carbon from the atmosphere (Hodson et al. 2000; Krawczyk et al. 2008), and inflow of waters with the higher content of TDS from the non-glaciated zone. This was reflected in the chemical composition of waters in which the ions of $HCO_3$, Ca and Mg were predominant. TDS of waters in the area of the Scott Glacier forefield did not exceed 50 $mg \cdot dm^{-3}$ and their reaction increased even to over 9 pH units, the temperature was around $1^oC$. Increase in mineralization of waters flowing down the glacier was also observed in its forefield due to further dissolution of carbonates contained in the suspension and its mixing with more mineralized waters originating from the non-glaciarized zone.

The Scott River waters flowing from the gorge in the glacier frontal moraine were characterized by the TDS about 50 $mg \cdot dm^{-3}$ and in the sea estuary profile 80–90 $mg \cdot dm^{-3}$. $HCO_3$, Ca and Mg ions constituting over 85% of total ions were predominant there. The reaction of waters in this zone reached pH 9 units and in the estuary part of the Scott River was in the range 8.25–8.85. The temperature of flowing water was $2–3^oC$. Similar values and processes affecting formation of physicochemical composition of the Scott River waters were described based on the investigations carried out in the last century (Bartoszewski and Magierski 1989; Michalczyk and Magierski 1990). In the case of the SS, the amount of transported material decreased with the river course to several – several hundred $mg \cdot dm^{-3}$. Those values are lower by order of magnitude than the amount of suspended material observed in sub-glacial rivers. In the samples sites of the Scott River diversity of SS in cross-section was at the level of 83–104% of the value in the river current (the permanent water site). However, the diversity of TDS did not exceed 5% of the value in the cross-section of the Scott River.

Hydrochemical investigations of the Scott River waters in the estuary profile exhibited large dynamics of physicochemical characteristics (Tab. 1). This changeability is a result of meteorological conditions in the period of researches, particularly the quantity of atmospheric supply and temperature amplitude. On the basis of the conducted researches it is stated that due to the increase in discharge,

the decrease in ions concentration is observed. In the case of the Scott River, opposite reaction was observed in relation to suspended sediments and $NO_2$.

Table 1. Indices of physicochemical properties of rainfall and rivers in the period of 14th July – 01st September 2005 (values: average/standard deviation; min – max)

| **Index** | **Water samples sites** | | | | |
|---|---|---|---|---|---|
| | Rainfall Calypsobyen | Supraglacial stream of Scott Glacier | Scott River – glacier forefield | Renifer River – outlet | Scott River – outlet |
| Number of samples | 15 | 9 | 9 | 6 | 39 |
| SS mg· dm$^{-3}$ | - | -/-; <1–170 | -/-; 73–3750 | -/-; <1–17 | 251/215; 44–998 |
| pH | 5.49/0.39; 4.96–5.79 | -/-; 5.01–7.91 | 8.74/0.12; 8.51–8.89 | -/-; 8.19–8.35 | 8.51/0.17; 8.25–8.85 |
| COND µS·cm$^{-1}$ in 20$^{o}$C | 8.5/14.2; 3.5–56.6 | -/-; 3–25.7 | -/-; 47–75 | -/-; 164–233 | 93/7; 75–108 |
| Alkalinity meq·dm$^{-3}$ | < 0.05/ – ; <0.05–0.2 | -/-; <0.05–0.35 | -/-; 0.6–0.81 | -/-; 1.65–2.25 | 0.95/0.06; 0.80–1.05 |
| $Cl^-$ mg· dm$^{-3}$ | 4.9/7.6; 0.4–28.4 | -/-; 0.33–3.54 | -/-; 1.08–2.46 | -/-; 4.83–6.31 | 1.7/0.35; 1.1–2.6 |
| $NO_3^-$ mg· dm$^{-3}$ | 0.41/0.31; <0.01–1.2 | -/-; <0.01–0.13 | -/-; 0.03–0.06 | -/-; 0.31–0.58 | 0.07/0.04; 0.02–0.16 |
| $NO_2^-$ mg· dm$^{-3}$ | 0.005/0.004; 0.001–0.02 | -/-; 0.001–0.02 | -/-; 0.004–0.008 | -/-; 0.01–0.04 | 0.013/0.008; 0.002–0.046 |
| $SO_4^{2-}$ mg· dm$^{-3}$ | 1.1/1.0; 0.2–4.1 | -/-; 0.16–0.92 | -/-; 0.65–3.69 | -/-; 2.91–6.24 | 5.1/0.69; 3.2–6.2 |
| $PO_4^{3-}$ mg· dm$^{-3}$ | 0.02/0.04; <0.01–0.13 | -/-; <0.01–0.13 | -/-; 0.01–0.2 | -/-; 0.07–0.34 | 0.06/0.04; 0.02–0.3 |
| $F^-$ mg· dm$^{-3}$ | 0.002/0.001; <0.001–0.005 | -/-; 0.001–0.01 | -/-; 0.001–0.009 | -/-; 0.008–0.01 | 0.006/0.002; 0.001–0.007 |
| $Br^-$ mg· dm$^{-3}$ | 0.015/0.022; 0.001–0.084 | -/-; 0.001–0.01 | -/-; 0.002–0.005 | -/-; 0.003–0.011 | 0.004/0.001; 0.003–0.006 |
| $Ca^{2+}$ mg· dm$^{-3}$ | 0.6/0.52; 0.1–2.0 | -/-; 0.1–1.7 | -/-; 5.5–10.2 | -/-; 11.9–22.6 | 11.3/1.05; 7.4–13.4 |
| $Mg^{2+}$ mg· dm$^{-3}$ | 0.26/0.28; <0.1–1.1 | -/-; <0.1–0.8 | -/-; 1.7–2.8 | -/-; 5.1–7.7 | 2.9/0.41; 2.0–3.8 |
| $Na^+$ mg· dm$^{-3}$ | 2.48/3.83; 0.2–14.3 | -/-; 0.1–1.7 | -/-; 0.5–1.1 | -/-; 3.4–4.2 | 1.1/0.25; 0.6–1.7 |
| $K^+$ mg· dm$^{-3}$ | 0.16/0.41; <0.1–1.6 | -/-; <0.1–0.1 | -/-; <0.1–0.2 | -/-; 0.1–0.3 | 0.19/0.05; <0.1–0.3 |
| $NH_4^+$ mg· dm$^{-3}$ | 0.15/0.08; 0.03–0.35 | -/-; 0.02–0.47 | -/-; 0.02–0.11 | -/-; 0.05–0.32 | 0.17/0.13; 0.02–0.59 |
| $SiO_2$ mg· dm$^{-3}$ | 0.2/0.12; <0.1–0.4 | -/-; <0.1–0.3 | -/-; 0.1–0.4 | -/-; 0.7–1.2 | 0.45/0.28; <0.1–1.2 |

The water investigations in individual stages of the hydrological cycle showed mostly low content of substances of biogenic character. The contents of nitrate did not exceed 0.16 mg· $dm^{-3}$, nitrites – 0.045 mg· $dm^{-3}$, ammonium ions – 0.56 mg· $dm^{-3}$ and phosphates – 0.3 mg· $dm^{-3}$. In the case of ammonium, nitrate and phosphate ions, changes of the contents were quite accidental and did not exhibit significant response to supply conditions. The contents of nitrates in the non-glaciated watershed increased during the investigations, but slightly decreased in the Scott River waters. The silica content was also small.

**Ranges of chemical and mechanical denudation**

Chemical denudation in glacierized catchments has an important role to assess contemporary changes in the polar environment and to interpret historical transformations. In assuming the origin of physicochemical indices in the waters of glaciated areas of Spitsbergen, an important task is to divide the substance of geogenic and non-erosive origin (Hodson et al. 2000; Krawczyk et al. 2008; Yde et al. 2008). The early stages of forming physicochemical features of water take place already in the atmosphere. Substances which get to the ground with precipitation, especially salts of marine origin, determine the essential component of water outflow in the streams in Spitsbergen (Krawczyk 1994; Hodson et al. 2000; Krawczyk et al. 2003; Głowacki 2007; Krawczyk, Peterson 2007; Krawczyk et al. 2008).

To estimate water $TDS_{crustal}$ of the Scott River which is the effect of leaching natural minerals building the catchment, the value of mineralization calculated on the basis of ions was lessened by the level of substance provided with precipitation (Tab. 2). As the basis to such calculations, there were adopted ions ratios compared to chlorides in precipitation and equivalent values in the Scott River. Chlorides as the conservative indices are often used as the element of reference to estimate the intensity of water migration of elements. Calculated, on that basis, the average content of non-erosive ions provided from the atmosphere was 4.0 mg· $dm^{-3}$. This value is lower than the average levels of summer precipitation in 2005, which can point to, e. g., the decrease in the content of marine aerosols in the Scott catchment with a distance from the shore line.

Table 2. Content of atmospheric and geogenic component in the Scott River water, summer 2005

| Index | Average chemical composition of the Scott River water (meq·dm$^{-3}$) | Average chemical composition of precipitation in the Scott River catchment (meq· dm$^{-3}$) | Estimated index origin in the Scott River water (%) | |
|---|---|---|---|---|
| | | | From precipitation | From catchment – geogenic |
| Na | 0.048 | 0.044 | 92 | 8 |
| K | 0.005 | 0.002 | 40 | 60 |
| Mg | 0.242 | 0.01 | 4 | 96 |
| Ca | 0.565 | 0.012 | 2 | 98 |
| $NH_4$ | 0.009 | 0.004 | 44 | 56 |
| Cl | 0.048 | 0.048 | 100 | 0 |
| $SO_4$ | 0.106 | 0.01 | 9 | 91 |
| $NO_3$ | 0.001 | 0.004 | 100 | 0 |
| $HCO_3/CO_3$ | 0.95 | 0.025 | 3 | 97 |
| **Sum of ions (mg·L$^{-1}$)** | 82 | 4 | 5 | 95 |

TDS value counted from ions sum was also lowered by half the bicarbonate content of non-erosive origin (Hem 1985). Calculated on that basis mean 24-hour $TDS_{crustal}$ value was used to count chemical denudation (49 mg·dm$^{-3)}$, which gives 59.2% (range 57.6–59.7%) TDS total calculated from the sum of ions (82 mg·dm$^{-3}$).

Average diurnal values of transport of ions of geogenic origin in the Scott River during summer 2005 were 5.07 t, to is equivalent to the rate of chemical denudation of 0.50 t·km$^{-2}$. Diurnal variability of outflow of geogenic substances in the Scott River in the research period changed in the range from 2.430 t to 7.116 t, which is the equivalent of diurnal chemical denudation 0.24 t·km$^{-2}$ and 0.70 t·km$^{-2}$. These values were lower by 25% than the value of chemical denudation (0.65 t·km$^{-2}$) of the Scott River in the summer season 2002 (Krawczyk et al. 2008), with the outflow of 7,920·10$^3$ m$^3$ in 60 days and value of $TDS_{crustal}$ 50 mg·dm$^{-3}$. Chemical denudations values were a bit lower than in other study seasons in the Scott River (Bartoszewski and Magierski 1989; Bartoszewski and Repelewska-Pękalowa 1988) as the result of omitting the non-erosive substances in calculations. Much higher values of diurnal chemical denudation in the Scott River catchment are observed during thaw and intensive ablation supported by heavy precipitation.

The average daily transport of suspended sediments (SS) of the Scott River in the outlet profile in the summer season 2005 was 25.6 t, which corresponded to the level of mechanical denudation of 2.53 t·km$^{-2}$. Diurnal changeability of sus-

pended sediment transport in the research period was within the range 3.2–183.6 t (0.32–18.2 t·km$^{-2}$). Rapid decrease of suspended sediments transport from the glacier front to the measuring cross-section of the Scott River was observed. Outflow from the glacier was characterized by high index of mechanical denudation, on the basis of a single measurement on 19$^{th}$ of August; calculated diurnal transport of suspended sediment was at the level of 235 t. Index of diurnal mechanical denudation in relation to the glacier area and its direct catchment was at the level of 40 t·km$^{-2}$. In the outlet cross-section of the Scott River diurnal transport in that day was 23.5 t, which corresponded to the level of 4.1 t· km$^{-2}$ of mechanical denudation related to the glacier area and its direct catchment and mechanical denudation related to the whole area of the catchment at the level of 2.3 t·km$^{-2}$. Diurnal index of deposition of suspended sediments in the long profile of the Scott River was 211.5 t (approx. 90% of the material transported in the zone of the glacier front). Matelle (2006) observed almost 80%-decrease of the load of suspended sediments transported from the glacier in the valley of Linné.

Another situation was observed in the case of chemical denudation, when down the Scott River increase of TDS was stated, and as a result, the transported material as solutions increased. On the 19$^{th}$ of August, diurnal transport of solutions of geogenic origin ($TDS_{crustal}$) in the front of glacier was 0.63 t, which corresponded to chemical denudation from the direct catchment of the Scott Glacier at the level of 0.11 t·km$^{-2}$. In the outlet cross-section of the Scott River, the calculated diurnal transport of solution was 3.7 t, which corresponded to chemical denudation 0.37 t·km$^{-2}$. On the same day chemical denudation calculated for the next non-glacierized catchment of the Wydrzyca River was 0.25 t·km$^{-2}$ (Chmiel et al. 2011). Similar interactions were observed for glacierized catchment of the Bertram River on Svalbard (Strzelecki 2009).

Results of researches of bed load transport, conducted in the Scott River in the summer season of 2009 (Kociuba et al. 2010), when the average discharge was twice higher than in 2005, estimate it at the level of 3.3 kg per day. On the basis of results, while comparing the suspended sediment and solutions in 2005 and bed load material in 2009 (Kociuba et al. 2010) in the Scott River, it can be assumed that the transport in the form of bed load should constitute less than 1% of the total transport.

## CONCLUSIONS

Meteorological conditions and dynamics of runoff from the Scott River catchment in 2005 were comparable to average values. TDS of the Scott River water was approximately 80 mg·L, TSS 251 mg·L, with a pH of 8.25–8.85 at 2–3$^{o}$C, which were mainly $HCO_3$-Ca-Mg water. Carbonate mineral dissolution was due to rocks in the catchment containing minerals: calcite and dolomite.

The Scott River water TDS was shaped by products of atmospheric and marine origin. The proportion of products of atmospheric origin in the Scott River water was approximately 5.5%, of which aerosols of marine origin constituted over 4%. The Scott River water analysis revealed mostly low concentrations of biogenic nutrients which were mostly derived from the atmospheric origin.

The average daily chemical denudation of the Scott River between 14th July – 1st September 2005 was 0.50 $t \cdot km^{-2}$, however, the average level of diurnal mechanical denudation was 2.53 $t \cdot km^{-2}$. The suspended material dominates (>80%) in the structure of material outflow in the form of solutions and suspension of the Scott River. The share of mechanical denudation in the solution transport from the direct glacierized catchment of the Scott River exceeded 99% of the total suspended material outflow and in the form of solutions of geogenic origin. In the non-glacierized course of the Scott River chemical denudation was at the level of 0.2 $t \cdot km^{-2}$, however mechanical denudation – 0.02 $t \cdot km^{-2}$. The share of mechanical denudation in total transport of solutions and suspended material from the non-glacierized catchment of the Scott River did not exceed 10% of the total matter outflow.

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## STRESZCZENIE

Badania denudacji chemicznej i mechanicznej w zlewni rzeki Scott prowadzono w północnozachodniej części Ziemi Wedela Jarlsberga (Svalbard). W tym celu rejestrowano odpływ wody w okresie od 14 lipca do 1 września 2005 roku oraz pobierano próbki wody do analiz składu jonowego wody oraz oznaczeń zawiesiny. W okresie badań odpłynęło 5,120·103 $m^3$ wody, co odpowiada średniemu przepływowi 1 201 $dm^3 \cdot s^{-1}$, warstwie odpływu 506 mm i odpływowi jednostkowemu 119 $dm^3 \cdot s^{-1} \cdot km^{-2}$. Tempo denudacji chemicznej w okresie badań wynosiło od 0,24 do 0,70 $t \cdot km^{-2} \cdot doba^{-1}$, średnio 0,50 $t \cdot km^{-2} \cdot doba^{-1}$. Tempo denudacji mechanicznej wynosiło średnio 2,53 $t \cdot km^{-2} \cdot doba^{-1}$, przy zmienności w zakresie od 0,32 do 18,2 $t \cdot km^{-2} \cdot doba^{-1}$.

**Słowa kluczowe**: denudacja, hydrochemia, hydrologia glacjalna, Svalbard