



# Polar hydrology

Norwegian Water Resources and Energy  
Directorate's work in Svalbard

*Monica Sund*

2  
2008

R  
E  
P  
O  
R  
T



# **Polar hydrology**

Norwegian Water Resources and Energy  
Directorate's work in Svalbard

Monica Sund

## **Report nr 2 -2008**

### **Polar hydrology – Norwegian Water Resources and Energy Directorate's work in Svalbard**

**Published by:** Norwegian Water Resources and Energy Directorate

**Author:** Monica Sund

**Print:** NVEs hustrykkeri

**Number printed:** 50

**Cover photo:** Waterfall in Eskerdalen (Sverre Husebye, NVE)

#### **Other photographs used in this report are from:**

John Brittain (JB)

Sverre Husebye (SH)

Lars-Evan Pettersson (LEP)

Kjell Repp (KR)

Monica Sund (MS)

**English correction:** Miriam Jackson

**Abstract:** The report introduces with a general description of the climate and hydrological conditions as a background for information on NVE's work in Svalbard. The hydrological stations that NVE has operated in Svalbard since 1989 are treated, as well as examples of the collected data (from the stations). The climatic conditions in Svalbard introduce special challenges regarding the establishment and the operation of hydrological stations. Short overviews of the different projects where NVE has been involved are given. Finally, publications by NVE personnel and by external authors where data from NVE's stations used, are listed.

**Subject words:** polar, hydrology, arctic, Svalbard, Spitsbergen, water balance, discharge, sediment

Norwegian Water Resources and Energy Directorate  
Middelthunsgate 29  
Postboks 5091 Majorstua  
N-0301 OSLO

Telephone: 22 95 95 95

Telefax: 22 95 90 00

Internett: [www.nve.no](http://www.nve.no)

April 2008

# Contents

<b>Preface.....</b>	<b>5</b>
<b>Abstract .....</b>	<b>6</b>
<b>1 Introduction.....</b>	<b>7</b>
<b>2 Background – Svalbard.....</b>	<b>8</b>
2.1 Infrastructure.....	8
2.2 Climate .....	9
2.2.1 General circulation .....	9
2.2.2 Air temperature .....	9
2.2.3 Precipitation .....	10
2.3 Permafrost .....	11
2.4 Runoff .....	11
2.5 Glaciers .....	13
2.6 Groundwater and springs.....	14
<b>3 Hydrological monitoring stations .....</b>	<b>16</b>
3.1 History .....	16
3.2 Bayelva 400.1 .....	16
3.3 Isdammen 400.2 .....	18
3.4 Tvillingvatn 400.3, 400.8, 400.10, 400.11, 400.12.....	19
3.5 Londonelva 400.4 .....	22
3.6 De Geerdalen 400.5.....	24
3.7 Steintippdalen 400.6 .....	25
3.8 Endalselva 400.7 .....	26
3.9 Diesetelva 400.9 .....	26
3.10 Parameter tables for runoff stations.....	27
3.11 Other runoff measurements in Svalbard.....	30
<b>4 Method and instrumentation .....</b>	<b>31</b>
4.1 Method.....	31
4.1.1 Water discharge monitoring .....	31
4.1.2 Suspended sediment monitoring .....	32
4.2 Technical aspects of runoff instrumentation in polar areas.....	34
<b>5 Data from the hydrological stations.....</b>	<b>35</b>
5.1 Runoff and discharge.....	35
5.1.1 Bayelva .....	35
5.1.2 De Geerdalen.....	37
5.1.3 HBV model.....	38
5.2 Sediment load.....	38
5.2.1 Bayelva .....	38
5.2.2 Londonelva .....	39
5.2.3 Endalen and Isdammen .....	40
<b>6 Studies.....</b>	<b>42</b>
6.1 Water balance.....	42

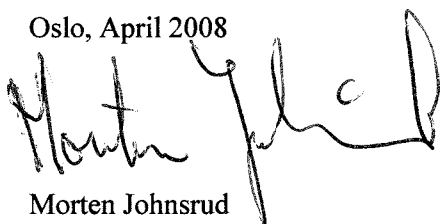
6.2	Erosion and sediment transport .....	43
6.3	Physical and chemical conditions in Tvillingvatn .....	43
6.4	Water supply in Ny-Ålesund.....	43
6.5	The Bayelva compound crump weir .....	44
6.5.1	Design and construction.....	44
6.5.2	Weir design .....	44
6.5.3	Construction.....	45
6.6	Evaluation of the technical aspects of the watercourse in Elvesletta, Longyearbyen .....	45
6.7	Environmental impacts of road construction between Longyearbyen and Sveagruva.....	46
6.8	Hydrographical mapping in Nordenskiöld Land .....	47
6.9	Ecosystems .....	48
<b>7</b>	<b>Future view .....</b>	<b>49</b>
	<b>References .....</b>	<b>50</b>
	<b>Appendix .....</b>	<b>55</b>
<b>1</b>	<b>Svalbard related publications by NVE personnel.....</b>	<b>56</b>
<b>2</b>	<b>External publications including NVE's Svalbard data.....</b>	<b>60</b>
<b>3</b>	<b>Reference marks at NVEs hydrological stations .....</b>	<b>62</b>

# Preface

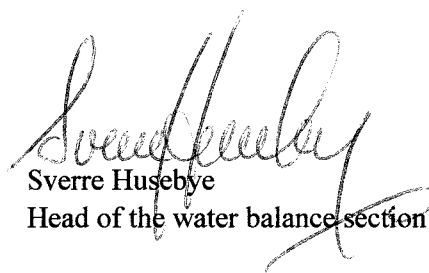
Norwegian Water Resources and Energy Directorate (NVE) is responsible for hydrological management in Norway, which also includes the Svalbard archipelago.

This report is a presentation of the work that has been carried out during the years 1989 – 2005 by NVE in Svalbard. It is mainly based on already published work, but contains also references to external work. The principal project has been the Polar Hydrology programme financed by the Norwegian Hydrology Committee, but one of the objectives of the report is also to cover other parts of the project to achieve an overview. The main task is to compile the Svalbard knowledge and publications by NVE personnel, and not to present a complete reference on Polar Hydrology.

Oslo, April 2008



Morten Johnsrud  
Head of the Hydrology department



Sverre Husebye  
Head of the water balance section

# Abstract

The report introduces with a general description of the climate and hydrological conditions as a background for information on NVE's work in Svalbard. The hydrological stations that NVE has operated in Svalbard since 1989 are treated, as well as examples of the collected data (from the stations). The climatic conditions in Svalbard introduce special challenges regarding the establishment and the operation of hydrological stations. Short overviews of the different projects where NVE has been involved are given. Finally, publications by NVE personnel and by external authors where data from NVE's stations used, are listed.

# 1 Introduction

Hydrological data from Arctic regions are sparse, and Svalbard is no exception. The first regular monitoring station was set up in 1989, and even today there are only five stations with continuous recording.

The Hydrology Department of the Norwegian Water Resources and Energy Directorate (NVE) is responsible for the collection and archiving of hydrological records in Norway, including the Arctic archipelago Svalbard. Although the general hydrological data from mainland Norway are good, as a result of the extensive development of hydropower, similar data from Svalbard are sparse.

In 1989 the Hydrology Department at NVE initiated a long-term monitoring programme of research and management of arctic hydrology as part of the responsibility of being the institution responsible for the administration of Norwegian water resources. Monitoring in arctic hydrology comprises surface runoff, water balance, erosion, sediment transport, sedimentation and water temperature.

The need of reliable and accurate hydrological data is important for management of the environment and water resources. Such data are extremely scarce in Arctic regions. The main reason is due to the extreme climate conditions, but also a lesser need of commercial data from these areas. However, the latter may or indeed has changed already. The possible utilisation of water-related commercial enterprises such as fish farming in polar regions, reliable water supply for increased tourism and permanent habitation, and the general need for a better understanding of cold climate hydrology as a small but significant factor for better insight into the global environment, all require reliable basic hydrological data. Reliable water supplies have been a common problem for the arctic communities. It is of common interest for policy-makers to acquire information on water balance and degradation of the area.



**Figur 1 Aerial view of southern part of Spitsbergen**



## 2 Background – Svalbard

Svalbard is an archipelago situated between latitudes 74° and 81° N, and longitudes 10° and 35° E (Figur 2). Spitsbergen is the largest island of the island group with an area of approximately 39,000 km<sup>2</sup>. The total area of Svalbard is about 63,000 km<sup>2</sup>, of which 60 % is covered by glaciers. The highest peak in Svalbard is Newtontoppen (1713 m a.s.l.). The distance to the North Pole is about 1780 km and thus Svalbard is quite unique in this way as no other localities at these latitudes, are so easily accessible.



Figur 2 Map Svalbard (without Bjørnøya). Grey areas indicate glaciers

### 2.1 Infrastructure

Longyearbyen is the largest community in Svalbard with about 2000 inhabitants, followed by the Russian community Barentsburg inhabited by approximately 500 people. Very few people live permanently in Sveagruva but about 240 commute weekly or every second week from either Longyearbyen or the mainland. Ny-Ålesund has about 25 permanent inhabitants but in the busiest summer season the population can be several times this. In addition, there are smaller meteorological, research and trapper stations.

Most facilities, banks etc. that are expected in a modern community can be found in Longyearbyen. The infrastructure in Longyearbyen has changed considerably over the last few decades, from a pure mining company town towards a more normal community with a mix of mining activities in the last nearby mine, research activities and tourism. Ny-Ålesund has changed totally from a company town via a small community for data acquisition to a modern settlement with facilities to support research activities in several fields. Barentsburg, however, still has mining as the main activity.

There is no road connection between the communities and travel is thus by aircraft, helicopter, boat or snowmobile.

Before the first commercial airport opened in Longyearbyen in 1976 the only access to the archipelago was by boat. During winter the ice conditions could prevent contact for

months at a time. In addition to the airport in Longyearbyen, shorter runways in Sveagruva and Ny-Ålesund are operated by smaller Dornier aircrafts. The use of icebreakers also makes visits by ship possible during the winter.

## **2.2 Climate**

### **2.2.1 General circulation**

The prevailing warm and cold sea currents are factors of great importance to the climate in Svalbard (Hanssen-Bauer et al., 1990). The North Atlantic Current, a continuation of the North Atlantic current, reaches the west coast of Spitsbergen and gives a milder climate than is common in other areas at the same latitude.

Usually the west coast is free of ice during summer, while the east coast of Svalbard is influenced by colder Siberian currents. Frequent pack-ice here can make access difficult even in summer. The general circulation is determined by the low-pressure system near Iceland, and relatively high pressures over Greenland and the Arctic Ocean.

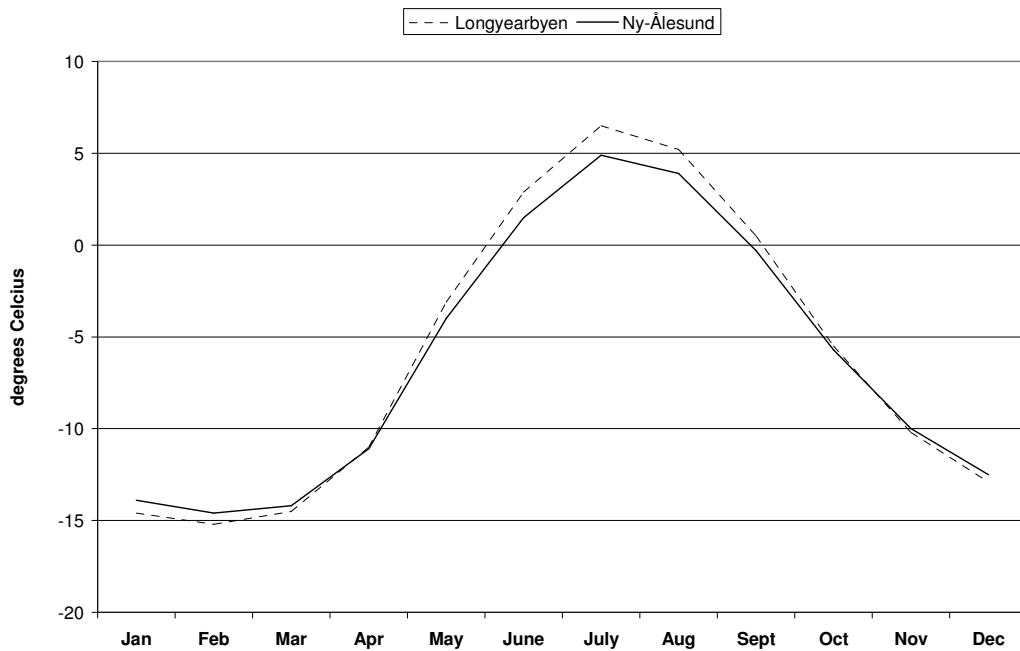
Between Iceland and Norway the prevailing winds are westerly or south-westerly, resulting in the transport of mild air from lower latitudes towards Svalbard. Variation in the extent of air masses and sea ice causes great fluctuations in weather. The largest variations occur in winter, when the contrast in temperature between the warm and cold air masses is largest (Hanssen-Bauer et al., 1990).

### **2.2.2 Air temperature**

In the lower areas of Spitsbergen, Longyearbyen and Ny-Ålesund, the mean annual air temperature is about -6 °C. Considering the latitude, the air temperature is characterised by relatively high mean values (Fig. 3) and large fluctuations (Hisdal, 1985).

The mean winter temperatures in Longyearbyen and Ny-Ålesund are similar, while the mean summer temperature in Ny-Ålesund corresponds with Isfjord radio, both being located close to the open western ocean. Summer temperatures in Longyearbyen, situated more inland are 1 – 2 °C higher.

The tendency for a more continental climate during winter may be explained by freezing of the fjords. January-March is normally the coldest part of the year. However, there may still be occasional periods of mild weather and even above zero temperatures. Summer temperatures are characterised by a marked uniformity. Minimum temperatures of several degrees below 0 °C, however, occur throughout the summer, and only rarely do maximum temperatures reach above 15 °C (Hanssen-Bauer et al., 1990).



**Fig. 3 Monthly mean temperature for the period 1961-1990 based on data from the Norwegian Meteorological Institute**

There are large differences in temperature between clear and overcast days in the period October to April, while this variation is minor between May and September. Fog is common in coastal regions and the maximum frequency is reached in June-July (Fig. 4). From June to October 50 % or more days are usually overcast, while December and April normally have the greatest number of clear days.



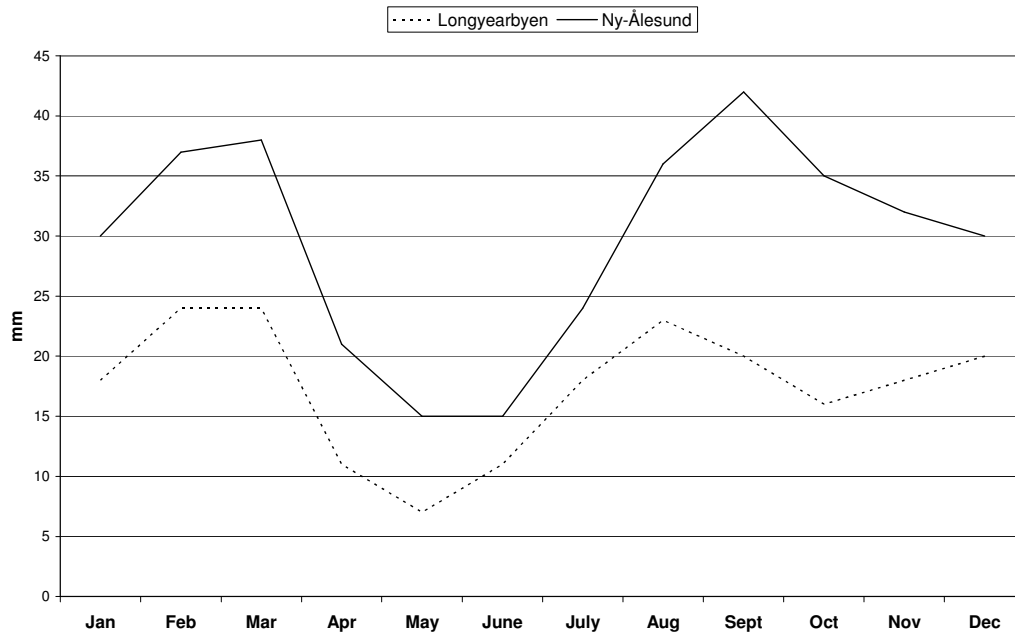
**Fig. 4 Sea fog creeping in at Hotellneset, Longyearbyen (MS)**

In Longyearbyen the midnight sun can be seen from 20<sup>th</sup> April to 22<sup>nd</sup> of August, while the polar night lasts from about 27<sup>th</sup> October to the 16<sup>th</sup> of February.

### 2.2.3 Precipitation

Precipitation measurements have been carried out by the Norwegian Meteorological Institute since 1911 in Green Harbour, since 1916 in Longyearbyen and since 1950 in Ny-

Ålesund (Fig. 5) (Førland et al., 1997). Precipitation is generally low in Svalbard. Recordings of mean annual precipitation at the meteorological stations in Spitsbergen vary between 190- 525 mm for the period 1961-1990 (Førland et al., 1997). The precipitation inland in the higher south-eastern areas, however, can be up to 1200 mm per year (Hagen et al., 1993). Local topographic variations cause large differences in precipitation. Minimum monthly values occur in April- June while most meteorological stations have maxima both in August and February-March (Hansen-Bauer et al., 1990). Evaporation measurements are almost non-existent, but a few measurements were done by the Norwegian Institute of Technology (now called the Norwegian University of Science and Technology).



**Fig. 5 Monthly mean precipitation for the period 1961-1990 based on data from the Norwegian Meteorological Institute**

## 2.3 Permafrost

Most of the land area in Svalbard has permafrost due to a mean annual air temperature of less than  $-6^{\circ}\text{C}$ . Permafrost depth depends on several factors of the landscape and climate, such as snow cover, glaciers, soil and vegetation and slope aspect (orientation of surface slope). Permafrost is maintained by sub-zero air temperatures, while geothermal heat flux thaws the ice from below. A gradient of  $1^{\circ}\text{C}/40\text{ m}$  has been measured in several boreholes. Permafrost depths between 100 m close to the sea and up to 500 m in the mountains have been measured (Liestøl, 1976, 1980). However, taliks (unfrozen patches) can be found under many glaciers.

## 2.4 Runoff

The snowmelt in the Arctic is very intense, and a major part of the runoff is from snowmelt early in the season (Fig. 6). This is most pronounced in rivers with none or small glacier-covered areas. In Svalbard river runoff occurs mainly during the months June to September. Apart from this the rivers are frozen, except from a few rivers fed by

springs. The snow melting from glacier-free areas is normally completed in early July. After this, the runoff depends on the glacier coverage of the catchments and rainfall, this is scarce. Comparisons between heavily glaciated areas and areas with lower glacier coverage indicate a different runoff pattern during the summer. The largest floods normally occur in the late summer, caused by heavy rainstorms and glacier melting. The runoff in central parts of Spitsbergen, however, generally seems to be little influenced by rain. The rain floods (Fig. 6) vary in magnitude from year to year, if they occur at all, while the snowmelt floods in early summer are more stable in magnitude. Some high flood discharges are caused by the emptying of ice- or snow-dammed lakes early in the season, or when glacier-dammed lakes are emptied (Pettersson, 1994). The runoff season usually ends abruptly in September-October when the temperature drops below zero.



**Fig. 6 Snow melting on Osbornebreen (MS)**



**Fig. 7 Bayelva flooding (LEP)**

Due to Svalbard's position close to the terminus of the North Atlantic Current and to the influence of transported mild air, precipitation can fall as rain in winter. Occasionally this can cause runoff in low areas, but usually the water freezes quickly and creates icing (ice accumulation at the surface during the winter).

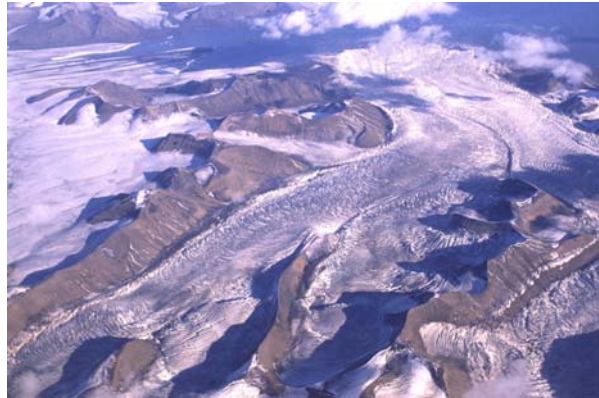
When the runoff season starts there is often a lot of surface water on top of the ice at the riverbeds. Variations in temperature in spring cause freezing of the water and hence superimposed ice.

The results from hydrometric and glaciological measurements, supported by an approximate evaluation of the height dependence of the runoff, indicate that the mean runoff in Spitsbergen ranges between 300-350 mm in the low-laying areas around Isfjorden to 1200-1500 mm in front of many glaciers (Pettersson, 1994).

The runoff from catchments with glaciers depends on the mass balance status of the glaciers, and does not necessarily represent precipitation in the area. By definition glaciers with negative mass balance release more water than they receive as snow or rain. In this way the negative mass balance of glaciers has an important impact upon the hydrology and runoff in glacier catchments. The Bayelva catchment is a good example and the extra runoff due to negative mass balance is calculated as 200 mm/year.

## 2.5 Glaciers

More than half of the total area of the Svalbard archipelago is covered by glaciers, and very few river basins are completely glacier-free. Most of the glaciers are polythermal, which means that parts of the ice are temperate, with temperatures at or close to the pressure melting point and other parts are frozen to the bed. Surging glaciers are widespread in Svalbard (Fig. 8), which is one of few locations in the world with this phenomenon. Surges are characterised by cyclical instabilities related to internal changes in the glacier system rather than climate change. Due to an ice-flux that is smaller than the balance flux in the accumulation area, the glaciers build up and the surface gradient increases. When a critical, unknown value is reached, a surge is initiated, causing a large ice flux from the higher to the lower parts of the glacier. This increase in velocity is followed by heavy crevassing of the glacier surface. Usually, this also results in an advance of the glacier front. In glaciers terminating in the sea, tide-water glaciers, the result is enhanced iceberg production. When the glacier terminates on land the area is subject to increased melting of ice, as large amounts of ice have been relocated to below the equilibrium line of the glacier.



**Fig. 8 Nuddbreen, to the left, is in its quiescent phase, while the heavily crevassed Vindeggbreen to the right is surging (MS)**

The glaciers in Svalbard have a non-surging, quiescent phase, of 30-500 years, which is interrupted by a rather short surge phase lasting up to about 10 years. However, the surplus melting after a surge can last for decades. The emptying of glacier dammed lakes can also give a large contribution to runoff locally. The gain or the loss of freshwater locked up in Svalbard glaciers has implications both locally and for global sea level (Hagen et al., 2003). The total surface runoff from Svalbard glaciers due to melting of snow and ice is found to be approximately 800 mm per year. Iceberg calving constitutes about 16 % of the surface runoff, and is estimated to be about  $4 \text{ km}^3 \pm 1 \text{ km}^3$  or about 110 mm annually, but there are variations due to surges. The 1970 surge of Hinlopenbreen caused calving of  $2 \text{ km}^3$  ice in one single year (Liestøl, 1973). The impacts on hydrology are to a great extent related to seasonal variation in runoff. There are significant runoff variations through the melt season, as well as winter discharge from tidewater glaciers.

Ice features called icing, aufeis or naled ice can be found in front of many land terminating glaciers. They occur when water from the temperate parts of the glacier drains from the glacier during winter, and are evidence of a polythermal glacier.



The mass balance of some glaciers e.g. Kongsvegen, Austre Brøggerbreen and midre Lovénbreen are monitored by the Norwegian Polar Institute each year.

## 2.6 Groundwater and springs

Groundwater springs (Fig. 9) and the occurrence of subpermafrost groundwater have been described from several places in Svalbard (Orvin, 1944; Liestøl, 1976). Trollosen in southern Spitsbergen is one of the most well known springs. As well as many of the other springs, Trollosen is characterized as a karst spring (Lauritzen, 1993).

Due to the permafrost there is usually no groundwater flow below the active layer (1-2 m). However, there is groundwater flow from temperate part of glaciers and taliks under lakes or directly to the sea.



Fig. 9 The Jotunkjeldene hot springs in Bockfjorden (MS)

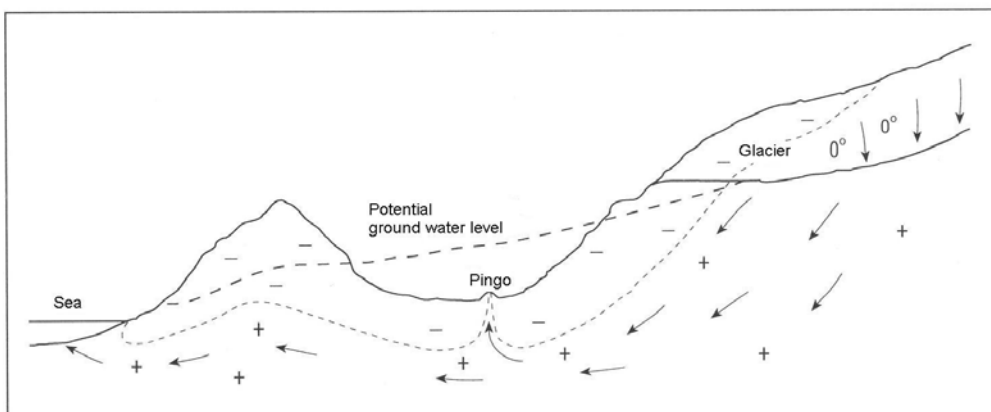


Fig. 10 Water flow in ground with permafrost. The dotted line indicates the 0-isotherm. Based on Liestøl 1976.

Polythermal glaciers develop temperate parts as the meltwater soaks the surface snow and firn in the accumulation area. The meltwater then refreezes releasing latent heat, which warms the glacier ice to 0 °C (or pressure melting point). In the ablation area of the glacier the snow cover is often thin, and most meltwater drains off the ice surface. Refreezing and warming is thus less effective here. The taliks under the glaciers allow the subglacial water to drain into groundwater reservoirs below the permafrost (Fig. 10). This water is probably the most important source for groundwater recharge. The permafrost forms an impermeable barrier for the groundwater, and artesian groundwater may develop in lower areas and form pingos. Icings generally indicate groundwater discharge points in permafrost areas (Haldorsen and Lauritzen, 1993). Pingos indicate taliks in valleys (Fig. 10). They evolve as artesian water under the permafrost, which finds its way through a local unfrozen patch and water will thus flow as a small spring all year round. Pingos have traditionally been used as a source of water supply in polar regions, and in Adventdalen some huts have been built on top of pingos.



## 3 Hydrological monitoring stations

### 3.1 History

The first systematic runoff measurements in Svalbard were started at Bayelva, close to Ny-Ålesund in 1974 (Repp, 1988). Regular and continuous recording of runoff have been operated by NVE in Bayelva since 1989. Stations were later established in other catchments. There is one with a natural profile in the valley De Geerdalen and three related to the water supply in Longyearbyen (Fig. 11). The order of the NVE station numbers is given by time of establishment.

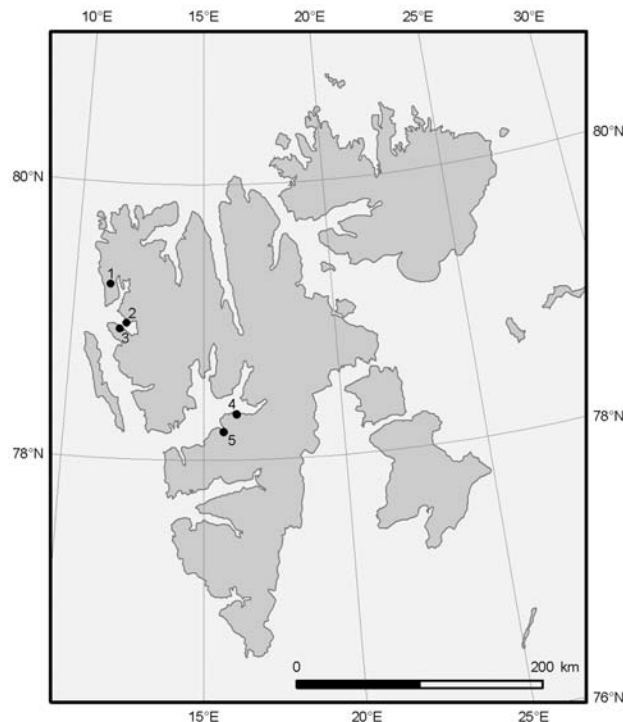
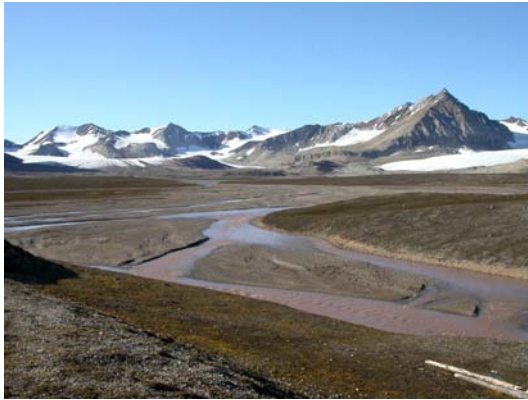


Fig. 11 Location of NVE's hydrological monitoring stations: 1: Diesetelva, 2: Londonelva, 3: Bayelva and Tvillingvatn 4: De Geerdalen, 5: Isdammen, Steintippdalen and Endalselva

### 3.2 Bayelva 400.1

Bayelva (Figur 12) is situated on Brøggerhalvøya, due west of Ny-Ålesund. The catchment area (Figur 123) is 30.9 km<sup>2</sup> of which 54 % is covered by the glaciers Austre Brøggerbreen and Vestre Brøggerbreen. The mountains surrounding the glaciers consist of rock from all geological periods, except the Triassic, Jurassic and Cretaceous formations. Some of the formations are very easily eroded.

The present relief is characterised by glacial forms, and the glaciers are presently the dominant land-forming agent, while the rivers and the periglacial denudation are active only during a short period of the year (Repp, 1988). The permafrost reaches a depth of about 150 m below surface in the weir site area (Orvin, 1944). Soundings across Bayelva have shown that the active layer varies between 0.5 m and 1.5 m underneath the riverbed and the banks, respectively (Repp, 1988).



**Figur 12 Brøggerbreane and Bayelva upstream of the station (JB)**



**Fig. 13 Bayelva catchment. Location of station marked with a red dot (Bogen & Bønsnes, 2003)**

In order to obtain some information on water balance and degradation of the area, a small project was initiated in 1973. Repp started the hydrological measurements in Bayelva, measuring over the period from 1974 to 1978. An automatic water level recorder and a staff gauge was established where Bayelva cuts through a rock sill approximately 300 m from the sea. In spite of the often undefined water courses found in Svalbard, the braided rivers unite to form one river flowing through a canyon cut down into the rock sill. Two meteorological stations were established at different levels at Austre Brøggerbreen in addition to the one in Ny-Ålesund. A few precipitation gauges were also established in the catchment.

In 1988 NVE reinitiated the discharge measurements and the river profile of Bayelva was stabilised by a large compound crump weir, designed and built by NVE. It was built slightly further upstream from Repp's station and was considered a pioneer project as it was not only the northernmost but also the first crump weir built in permafrost. The cost was about 1 million Norwegian 1988-kroner. As the river profile is constantly changing there followed several problems, mainly due to the large amounts of sediment and ice build-up, but most were solved the following year. Greenland, USA and Canada followed both the building engineering and the scientific experiences with great interest. This weir gave suitable conditions for water level measurements, thus enabling the determination of the water discharge in Bayelva. Water temperature measurements are also carried out.

Bayelva was the first site where NVE established an automatic suspended sediment monitoring station. The sediment production in Bayelva represents mainly production from glacial erosion, slumping and mud-flows from ice-cored moraines and fluvial erosion along the river channels. A passive acoustic sensor for monitoring of the bed load was installed in Bayelva in 2000 (Bogen and Møen, 2003). In 2004 water conductivity measurements were initiated at this station.



**Fig. 14 Bayelva station in spring (MS)**

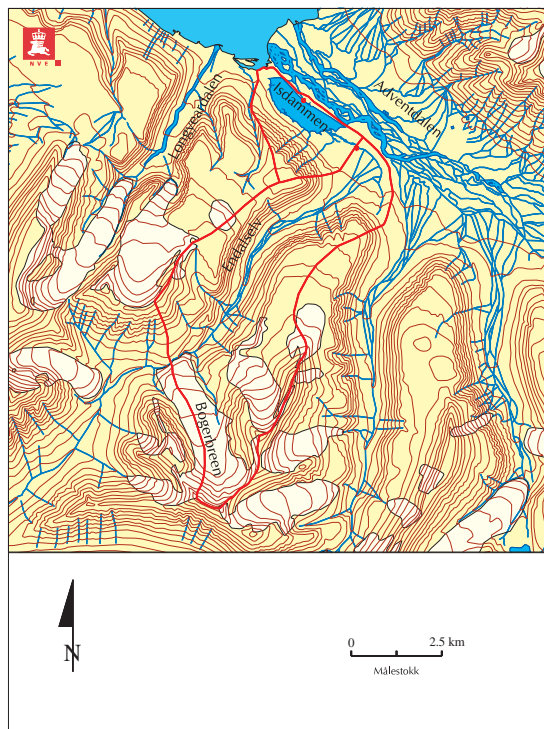


**Fig. 15 Bayelva station in summer (MS)**

The main problems with the runoff measurements are connected to ice and snow blocking the weir at the beginning of the snowmelt season (Fig. 14), leading to errors in calculation of river discharge. This is corrected for as far as possible, but the resulting accuracy is not known precisely.

### 3.3 Isdammen 400.2

Isdammen, a small man-made lake close to the river outlet, is the water supply for Longyearbyen. It is situated directly east of the town in Nordenskiöld Land. The natural catchment area is 34.4 km<sup>2</sup> of which 15 % is covered by glaciers (Fig. 16).



**Fig. 16 The Isdammen, Steintippdalen and Endalselva catchments. Location of Isdammen and Endalselva stations marked with red dot (Bogen and Bønsnes, 2003)**

Precipitation measurements are performed close to the catchment. The station was established in early summer 1992 to study the water balance of the water supply reservoir to Longyearbyen. The outlet was constructed with a controllable beam fence (Fig. 17).

The water discharge out of Isdammen was then calculated on the basis of the water level and the state of the beam fence. To calculate the total discharge it is necessary to know the water consumption also. A periodic transfer of unknown amounts of water from a small neighbour basin complicated the calculations.

The main purpose of the sediment measurements was to monitor the sediment budget to the artificial Isdammen and thus the reservoir sedimentation and compare this with measurements of bottom topography. Due to low erosion rates, reservoir sedimentation is not a problem in mainland Norway. However, the erosional conditions in Svalbard are comparable to semi arid areas, where reservoir sedimentation is a problem (Husebye, 1994).

In order to establish the water balance for Isdammen the inflow (400.7 Endalselva) as well as the outflow (400.2 Isdammen) had to be monitored. During summertime a small brook from Steintippdalen/Gruvedalen (400.6 Steintippdalen) was either diverted into Isdammen, or directly into the water supply system.



**Fig. 17 Isdammen outlet (LEP)**

The main operational problems in Isdammen were caused by uncertain rating curves and ungauged leakage in the outlet. The station was later re-established in Endalselva, upstream of a road culvert close to the inlet of Isdammen. At this site bottom ice build-up in the river profile seems to be the main problem, and there was possibly also leakage outside the main culvert. There is also some uncertainty in the drainage area for these catchments, as the Bogerbreen glacier had some drainage to another catchment (Killingtveit et al., 2003).

### **3.4 Tvillingvatn 400.3, 400.8, 400.10, 400.11, 400.12**

The lake Tvillingvatn - “Twin lake” is located on the coastal plain about 30 m a.s.l South of Ny-Ålesund beneath the mountain Zeppelinfjellet (Fig. 18). The catchment area is 0.36 km<sup>2</sup>, but there are difficulties estimating the exact area and how much of the water from the slope of Zeppelinfjellet, drains into the lake. Field studies in September 2001 concluded that some of the water from the upper part of the mountain may also flow into Tvillingvatnet. If so, the catchment size could be close to 0.4 km<sup>2</sup> (Haldorsen et al., 2002). Tvillingvatn consists of an eastern and western basin where the maximum depths are 6.3 m and 2.2 m, respectively (Fig. 19). The lake surface was 34.750 m<sup>2</sup> and the volume about 47,870 m<sup>3</sup> until the summer 2005. At this time Kings Bay AS, who runs the community, built a new and higher dam (Fig. 21). The threshold depth between the two basins is 1 m below the normal lake level. The Western basin slopes gently towards the



deepest level while the eastern basin is characterised by a steep slope to the bottom on the south side from NVE's experience, the ice in Tvillingvatn can reach a thickness of 1.5 m to 2 m (R. P. Asvall, pers. com). This means that the channel connecting the two basins freezes during winter, so there is no communication between them. There are also indications of the western basin freezing to the bottom during winter (Husebye, 1997). The lake was dammed at the end of the 1940s, and consisted of two almost separated basins before the level rose 0.5 m.



Figur 18 Tvillingvatn (MS)

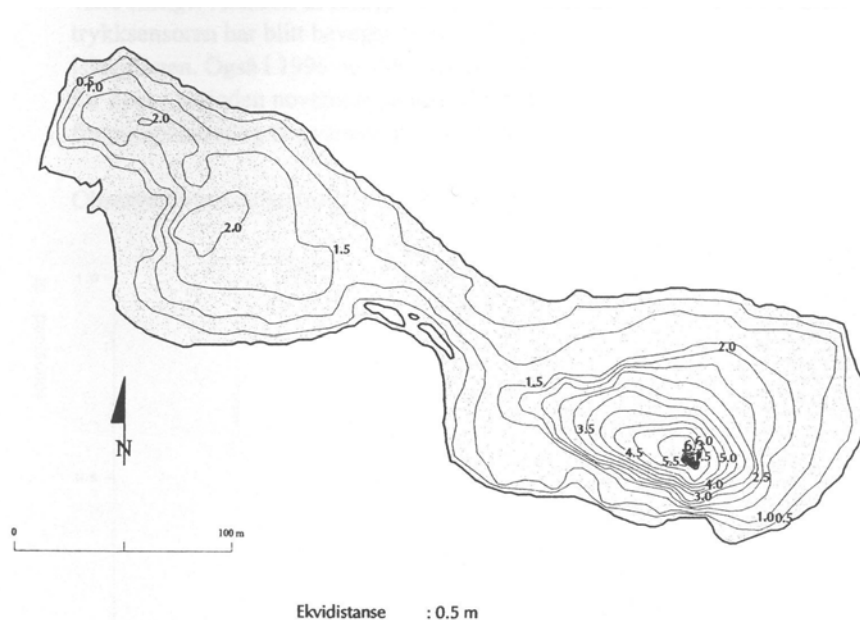


Fig. 19 Depth of Tvillingvatn, contourline interval 0.5 m (Pettersson, 2000)



**Fig. 20 Tvillingvatn, the old weir outlet (LEP)**

The lake has been a source of water supply to the coal mining settlement of Ny-Ålesund since 1925, and was probably the first source of drinking water used. However, water draining from the Ester mine (sjakt I) has also been used for short periods. Horses transported the water to households during the first years, but in 1925 a pump house was built and a waterpipe to the power station in Ny-Ålesund was constructed (Hanoa, 1993). A new water pipe that conducted water from Tvillingvatn to the community was constructed in 1966, as the old pipe was damaged.

Artesian ground water was found during drilling conducted for coal prospecting, at the bank between the twin lakes in 1928 at 18 m depth (Orvin, 1934). Orvin (1934) also states that despite the fact that the eastern lake was constantly pumped out, a little brook issued from the lake for a long time during autumn. Based on this, Orvin (1934, 1944) clearly connects the outflow and the discharge of groundwater from the artesian well. The coastal plain is truncated by several faults. There are several indications, both from water temperature and chemical analyses, of inflow of groundwater into Tvillingvatn during the winter of subsequent years (Haldorsen and Lauritzen, 1993; Haldorsen et al, 2002). However, it's difficult to estimate the amount of this inflow. Based on electrical conductivity measurements Liestøl (1976) and Repp (1979) concluded that groundwater flowed into Tvillingvatn during the winter. Tvillingvatn receives groundwater, probably as a result of water penetrating into the ground underneath the temperate part of glaciers.

Due to an unstable profile a crump weir was constructed in autumn 1991 (Sandsbråten, 1995) at the outlet of the dam (Fig. 20). However, levelling of the weir in the spring 1992 showed that it had been displaced due to frost processes in the ground. Levelling of the weir later became part of the procedure in spring and autumn. The dam is constructed as a rock-fill dam with a wooden core. Observations showed there was a leakage through the dam during summer, but not in winter due to freezing of the mass in the dam. Repeated measurements during summer and autumn indicated little change in leakage rate. The leakage was found to be 10.8 l/s (Sandsbråten, 1995). It is difficult to achieve good values for the total leakage, but an estimate is 5 l/s in June when the snow melt starts, 12 l/s in July and August, 5 l/s in September and 2 l/s in October. This gives a value of annual average leakage of approximately 3 l/s or well 20 % of the runoff through the crump weir in the old (Pettersson, 2000).

During the summer 2005 Kings Bay As built a new higher dam with a diaphragm in the core to avoid further leakage (Fig. 21). The new dam made it possible to increase the

water level in the lake with 1 m, and thus enhancing the water available for e.g. the marine Laboratory in Ny-Ålesund.

The NVE measurements consists of water level and discharge (400.3) bottom temperature in the eastern basin (400.8), water temperature at the outlet of Tvillingvatn (400.10), bottom temperature and ice thickness in the western basin (400.11). The brook Tvillingvannsbekken runs from Tvillingvatnet into Bayelva. Water discharge measurements (400.12) in this stream were conducted out from 15.08.1996 to 31.12.1999.



Fig. 21 Construction work with the new dam at Tvillingvatn (MS)

### 3.5 Londonelva 400.4

The river Londonelva is situated on the island of Blomstrandøya (due to retreat of the glacier Blomstandbreen, the previous peninsula became an island in 1991) on the North side of Kongsfjorden, about 7 km from Ny-Ålesund. Londonelva is one of the few catchments which are free of glaciers (Fig. 22). It is also a typical Svalbard stream, in difficulty in finding a stable profile. The monitoring station is located at a site that ensures water passes in only one channel (Fig. 23).

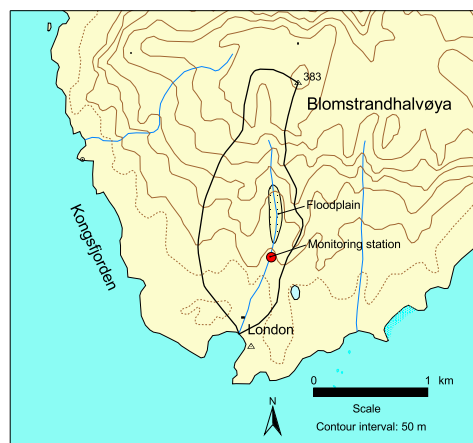


Fig. 22 Catchment of Londonelva. Location of the station is marked with a red dot (Bogen and Bønsnes, 2003)

The measurements in Londonelva started in 1992 with emphasis on studying erosion and sediment transport from a catchment without glaciers. The main sediment sources are weathered solid rocks and fluvial erosion in alluvial deposits and moraines. The sediment

regime is completely dominated by the snowmelt period. 75-90 % of the annual transport appears during the opening of the river channels in spring. Except for this, the sediment load seems to be negligible (Husebye, 1994). The closest meteorological observations are in Ny-Ålesund, about 7 km across the fjord.

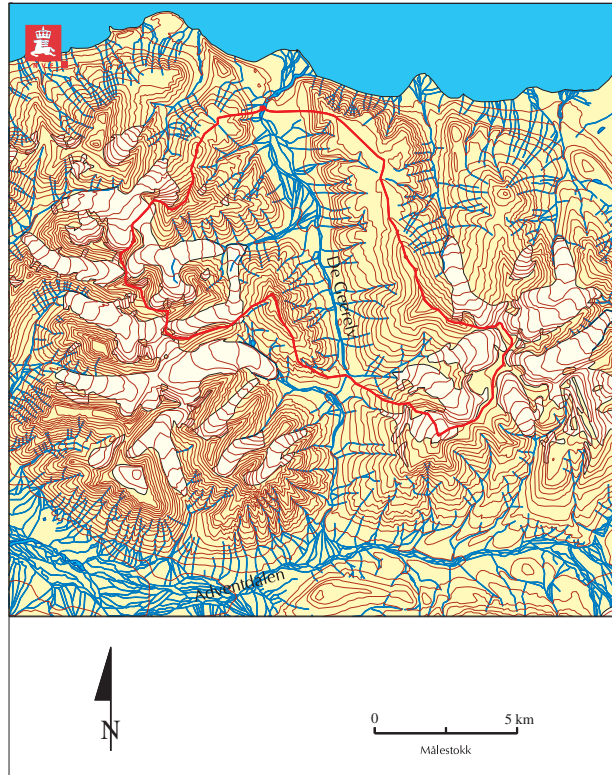


**Fig. 23 Londoneelva station (LEP)**



### 3.6 De Geerdalen 400.5

De Geerdalen station is located in Nordenskiöld Land about 20 km north-east of Longyearbyen. The catchment area is 79.1 km<sup>2</sup> of which 10 % is glacier covered (Fig. 24). The monitoring station (Fig. 25) is placed in a narrow gorge in part of a waterfall with a stable rock profile, close to the river outlet (Fig. 26). The station was established autumn 1990.



**Fig. 24 De Geerdalen. Location of station by the waterfall Hyperittfossen is marked with a red dot**

The sediment monitoring in De Geerdalen represents sediment transport in a large and complex catchment including several valley glaciers.

There are no regular precipitation measurements in the catchment and the closest meteorological station is located at Svalbard Airport, about 20 km south-west of the valley. A number of precipitation stations were operated for a few years in the early 1990s as part of the first water balance studies initiated by the Norwegian Hydrological committee (Killingtveit et al., 1994). A network of snow measurement stations was also operated in the 1990s in order to estimate the winter precipitation (Tveit and Killingtveit, 1994). These measurements were used to estimate precipitation-elevation gradients in the catchments (Killingtveit et al., 1994). The main operational problems at the runoff station are related to ice and snow blocking the gorge



Fig. 25 De Geerdalen station (MS)



Fig. 26. Hyperittfossen waterfall (LEP)

### 3.7 Steintippdalen 400.6

The station Steintippdalen is situated in Gruvedalen, also called Steintippdalen, between Isdammen and Longyearbyen (Fig. 27). The catchment is 3.8 km<sup>2</sup> and there are no glaciers in the area. The station is established in early summer 1993 as part of the water balance studies of Isdammen. Water from Steintippdalen is transferred to Isdammen, or directly to the water intake. The station was operated from 1993 to 1999.



Fig. 27 Steintippdalen station (LEP)

### 3.8 Endalselva 400.7

Endalen is the main inflow to Isdammen (Fig. 28) and shares much of the same catchment with an area of 28.8 km<sup>2</sup> (where the station is situated upstream of Isdammen). The main purpose was to monitor the sediment budget and thus reservoir sedimentation in Isdammen.

Water level (Fig. 28) was measured from 1994 to 2000 and sediment transport between 1995 and 1998 (Fig. 29). Water temperature measurements started in 1994 and still in operation.



Fig. 28 Endalselva water level monitoring (MS)



Fig. 29 Endalselva ISCO instrument hut (MS)

### 3.9 Diesetelva 400.9

The river Diesetelva (Fig. 30) is situated on Mitrahalvøya in Albert I Land, the peninsula west of Krossfjorden. Studies of arctic char in this river system have been performed for several years. NVE carried out measurements on water temperature in Diesetelva from 26.07.1991 to 13.09.1993



Fig. 30 Diesetelva on Mitrahalvøya (MS)

## 3.10 Parameter tables for runoff stations

Tables from the database list the different parameters at the different stations. They are listed with the names and numbers used in the database.

### Key to the tables

- \* When purchasing data from NVE the **code** and **version** is part of the station parameter number, e.g.: 400.1.0.1000.0. represents Bayelva (400.1), the following 0 means the data are given in point values, water level (1000) and version 0.
- \* Version 0 is data from the various sensors that are considered to be the most representative for the different years
- \* Valid to present: refers to the publication date of this report
- \* NP: Norwegian Polar Institute
- \* SSC: Suspended Sediment Concentration

#### BAYELVA

#### 400.1

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Air temperature	17	1		2004	present
Water level	1000	0	mixed	1989	present
Water level	1000	1	float	1989	present
Water level	1000	2	capacitive	1996	present
Water level	1000	3	float	2000	present
Water level	1000	4	pressure	2004	present
Discharge	1001	0		1989	present
Water temperature	1003	1		1991	present
Conductivity	1006	1		2004	present
Inorganic SSC	1200	1	ISCO	1989	present
Organic SSC	1208	1	ISCO	1989	present
<b>Map</b>	NP A7				
<b>Basin area (km<sup>2</sup>)</b>	30.9				
<b>Basin elevation (m.a.s.l.)</b>	Min. 3		Mean 265		Max. 742
<b>Glacier area (%)</b>	55				
<b>Coordinates (WGS84)</b>	33 X 0432207 E 8764350 N				

#### ISDAMMEN

#### 400.2

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water level	1000	1	pressure	1992	1999
Discharge	1001	1		1992	1996
Inorganic SSC	1200	1	ISCO	1996	1998
Organic SSC	1208	1	ISCO	1996	1998
Grain size distribution	1212	1		1996	1998
<b>Map</b>	NP C9				
<b>Basin area (km<sup>2</sup>)</b>	34.4				
<b>Basin elevation (m.a.s.l.)</b>	Min. 3		Mean 427		Max. 1015
<b>Coordinates (WGS84)</b>	33 X 0517135 E 8682095 N				

**TVILLINGVATNET 400.3**

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water level	1000	1	float	1994	present
Discharge	1001	1		1996	present
Water supply - transfer	1015	1		1996	present
Water supply - transfer	1015	2		2000	present
<b>Map</b>	NP A7				
<b>Basin area (km<sup>2</sup>)</b>	0.36				
<b>Basin elevation (m.a.s.l.)</b>	Min. 27		Mean 40		Max. 370
<b>Glacier area (%)</b>	0				
<b>Coordinates (WGS84)</b>	33 X 0433050 E 8762570 N				

**LONDONELVA 400.4**

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water level	1000	1	capacitive	1992	present
Water level	1000	2	pressure	2004	present
Discharge	1001	1		1992	present
Water temperature	1003	1		1992	present
Inorganic SSC	1200	1	ISCO	1995	2004
Organic SSC	1208	1	ISCO	1995	2004
<b>Map</b>	NP A7				
<b>Basin area (km<sup>2</sup>)</b>	0.7				
<b>Basin elevation (m.a.s.l.)</b>	Min. 15		Mean 149		Max. 369
<b>Glacier area (%)</b>	0				
<b>Coordinates (WGS84)</b>	33 X 0437119 E 8767762 N				

**DE GEERDALEN 400.5**

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water level	1000	0	mixed	1990	present
Water level	1000	1	float	1990	2005
Water level	1000	2	capacitive	1995	present
Water level	1000	3	pressure	2004	present
Discharge	1001	0		1990	present
Water temperature	1003	1		1991	present
Inorganic SSC	1200	1	ISCO	1996	1998
Organic SSC	1208	1	ISCO	1996	1998
* NVE is planning to restart monitoring of sediment concentrations in 2006					
<b>Map</b>	NP C9				
<b>Basin area (km<sup>2</sup>)</b>	79.1				
<b>Basin elevation (m.a.s.l.)</b>	Min. 40		Mean 410		Max. 987
<b>Glacier area (%)</b>	10				
<b>Coordinates (WGS84)</b>	33 X 0528980 E 8695924 N				



## STEINTIPPDALEN 400.6

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water level	1000	1	pressure	1993	1999
Discharge	1001	1		1993	1999
Map	NP C9				
Basin area (km²)	3.8				
Basin elevation (m.a.s.l.)	Min. 44		Mean 432		Max. 620
Coordinates (WGS84)	33 X 0515735 E 8682395 N				

## ENDALSELVA 400.7

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water level	1000	1	float	1994	2000
Water discharge	1001	1		1994	2000
Water temperature	1003	1		1994	Present
Inorganic SSC	1200	1	ISCO	1995	1998
Organic SSC	1208	1	ISCO	1995	1998
Grain size distribution	1212	1		1995	1998
Map	NP C9				
Basin area (km²)					
Basin elevation (m.a.s.l.)	Min. 4		Max. 1015		
Glacier area (%)	20				
Coordinates (WGS84)	33 X 0518635 E 8680795 N				

## TVILLINGVATNET BUNN (BOTTOM) 400.8

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water temperature	1003	1		1994	present
Map	NP A7				
Coordinates (WGS84)	33 X 0432986 E 8762405 N				

## DIESETELVA 400.9

PARAMETER	CODE	version	TYPE	VALID FROM	VALID TO
Water temperature	1003	1		1991	1993
Map	NP A6				
Coordinates (WGS84)	33 X 0420096 E 8794015 N				

## TVILLINGVATNET UTLØP (OUTLET) 400.10

PARAMETER	CODE	version	TYPE	VALID FROM	VALID TO
Water temperature	1003	1		1994	1998
Map	NP A7				
Co-rdinates (WGS84)	33 X 0432736 E 8762555 N				

### TVILLINGVATN DEPTH 400.11

1 vertical measured

### TVILLINGVATNBKKN 400.12

PARAMETER	CODE	VERSION	TYPE	VALID FROM	VALID TO
Water level	1000	1	capacitive	1996	1999
Map	NP A7				
Basin area (km²)	0.36				
Basin elevation (m.a.s.l.)	Min. 26		Mean 40		Max. 370
Coordinates (WGS84)	33 X 043275 E 8762790 N				

## 3.11 Other runoff measurements in Svalbard

In addition to the NVE stations many other gauging stations for water level and discharge have been operated in Svalbard. Most of them have been operated for only a few years or there have been observations through only parts of the runoff season.

In addition to the first Norwegian observation carried out by Repp (1988), Vatne et al. (1992) measured water discharge in front of the glaciers Erikbreen and Hannabreen in Liefdefjorden in the Northwest of Spitsbergen in 1990 -1992 and Sandsbråten (1995) carried out water balance measurements in Tvillingvatn in 1991-1992. Students at The University Centre in Svalbard (UNIS) have produced several Masters theses on hydrology in Svalbard.

Observations have also been carried out by other countries. Some river flow measurements from the Mimer river basin in Dickson Land have been reported by Russian scientists (Gokhman and Khodakov, 1986). Polish investigations of Werenskioldbreen are reported in Pulina et al. (1984) and Jania and Pulina (1994) have summarised the results for several catchments in the Hornsund area and Forlandsundet. German groups have examined three different field areas in Liefdefjorden. British scientists have also conducted studies (Hodson Hodgkins). Many of the French investigations have been collected in Mercier (2001) "Le Ruissellement au Spitsberg" or "Runoff in Spitsbergen". Sand (1989, 1990) compiled a synopsis on Polar hydrology.

## 4 Method and instrumentation

### 4.1 Method

Several permanent gauging stations were established in Svalbard in the late 1980s, all on the island of Spitsbergen. A major problem in flow monitoring in Svalbard is the lack of defined water courses and stable riverbed profiles. Sufficient depth in river pools to achieve good resolution in the water level is also a challenge. Numerous braided streams and sandurs (Fig. 31) are a common feature. In addition, there are problems with ice and frost and the general remoteness of the area. The monitoring stations remains frozen solid for most of the year.



Fig. 31 Braided river and sandur (SH)

The runoff and melting season lasts only from late May to the middle of September. Recordings from the start of the season would be under the influence of ice jamming and formation of bottom ice will characterize the end of the period. This necessitates the use of ice reduction curves together with the standard rating curve. To secure the best possible data, it was decided to invest in a purpose designed weir with a known rating curve at the major station at Bayelva. Over the following years further gauging stations were established, some of them for shorter periods.

During the tenth International Northern Research Basins Symposium and Workshop a workshop on the review of methods and experience with hydrometric measurements in Northern basins (Pettersson et al. 1994) was carried out.

#### 4.1.1 Water discharge monitoring

The water discharge is defined as the amount of water that flows through a given cross section per unit of time (e.g.  $\text{m}^3/\text{s}$ ). Locations where the river profile is stable and the water levels are not influenced by water further downstream have a certain relationship between water level and water discharge. This relationship is used in the monitoring of water discharges as registration of the water level is sufficient when the ratio is established. This relationship could be described graphically as a parabola shaped curve – the water discharge curve. This curve is usually established by in situ water discharge measurements (Fig. 32). The propeller type current meter was until recently one of the most common methods for measuring discharge. By observing the rotation speed (RPM) the water velocity could be determined. By using the calibration velocity formula for the propeller, a number of velocity measurements will together with the cross section area



form the basis for calculation of the water discharge. Acoustic Doppler Current Profilers (ADCPs) based on the Doppler technique are more recently often used.

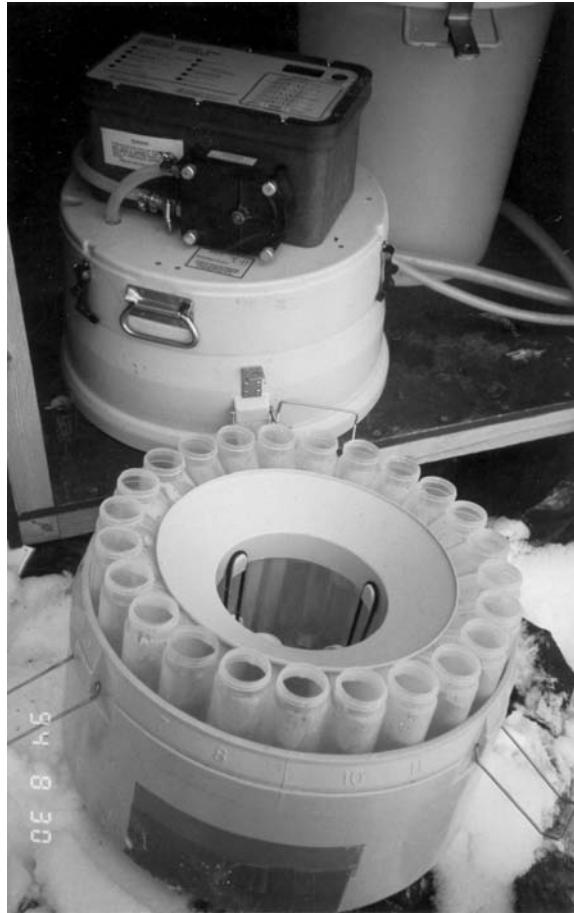


Fig. 32 Water discharge measurements with propeller (LEP)

#### 4.1.2 Suspended sediment monitoring

The stations are equipped according to NVE standards developed in Norway, with an ISCO automatic portable sediment sampler 2700/3700, supported by a Yamaha petrol pump. The standard procedures and methodology are described by Bogen (1992). Standard sampling frequency varies between 1 - 4 samples a day, depending on the rivers response to the discharge changes and the location, with respect to the operation of stations in remote areas. The sampling volume is approximately 750 ml. When the observer renews the sampling bottles, a larger sample to analyse particle distribution and mineralogy is taken.

All samples are filtered in a laboratory, which can also be taken into the field, equipped with an electric under-pressure pump, a manifold with three or more measuring tubes and filters. In this way the filtration is continuous and only 48 sampling bottles are required at each station. The diurnal samples are filter through Whatman GF/C filters with retention size  $1.2\ \mu\text{m}$  while the large samples are filtrated through Millipore membrane filters with pore size  $0.45\ \mu\text{m}$  (Husebye, 1994).



**Fig. 33 ISCO automatic sediment sampler (SH)**

During the last couple of years, the bed load is monitored at Bayelva by an acoustic sensor. The physical principle of the passive acoustic sensor is based on the kinematic impact of particles that strike a steel plate attached to the sensor. The sensor consists of an acoustic sensing device and a digital signal processor. Vibration created by particles sliding or rolling over the plate are picked up by the sensor and analysed based on frequency spectra and amplitude (Bogen and Møen, 2003).

## 4.2 Technical aspects of runoff instrumentation in polar areas

It is usually difficult to find stable profiles in arctic rivers. Erosion is intense and material transport is often heavy causing shifting river beds. Generally there are advantages in establishing stations in lakes as the outlet is usually stable. In arctic rivers the runoff and water stage may often be so low that the water level sensor won't operate. This could be avoided by establishing the station in a lake or pond, where there is usually sufficient depth to maintain registration.

The Svalbard stations are normally visited twice a year, in spring and autumn. The visits must be timed carefully as they should preferably be when runoff begins and ends. However, there will be some ice of the beginning of the season and there may be complications concerning calibration of the logger. When possible it is desirable to get manual observations of the water level during summer to assist the calibration.

The main runoff stations have usually been equipped with at least two independent loggers, which lowers the risk of gaps in the recordings. Until recently, a traditional float sensor has been the main sensor. However, there are climatic drawbacks, which cause freezing with this type of sensor. A capacitive water level sensor, a rod shaped sensor without moving parts, has been used as a support. Thus, the capacitive sensor is operated all year round, while the float sensor is activated every spring and is disconnected in the autumn. The advantage of the capacitive sensor is that it withstands freezing, and records even when water is running on top of bottom ice at the riverbed. Thus, it gives an idea of the beginning and end of the runoff season. However, the capacitive sensor has shown to be less accurate than the float sensor. Recently, a pressure sensor that withstands freezing has been installed in addition. As there are no moving parts the chance of malfunction is smaller and the sensor is also easier to replace. The recording time base is normally one hour during winter and either 15 min or 30 min during summer, depending on the size and response time of the river.

All data collected by NVE are stored in NVE's database, HYDRA II. The database is designed for storage, quality control, retrieval and analysis of hydrological and meteorological data. The system is, in a limited extent, also used for water quality data.

## 5 Data from the hydrological stations

### 5.1 Runoff and discharge

The earliest start of runoff during the period of measurement is in late May in De Geerdalen and early June in Bayelva. The latest end of runoff is in beginning or middle of October. However short periods of runoff can occur during mild weather all winter. In Londonelva runoff usually starts 5- 10 days before it starts in Bayelva, due to its steep catchment and to its southerly exposure.

In the Longyearbyen area there are observations of runoff up to one month earlier than in the Ny-Ålesund area. In Endalselva there was already runoff on 7<sup>th</sup> June, 1993, which was ten days before runoff started in Bayelva that year. The highest flood discharges in the Longyearbyen area occur during snowmelt in late June. Rain floods occur more rarely, and are not as high compared with snowmelt floods (Pettersson, 1994).

Monthly means		
	Bayelva	DeGeerdalen
	mm	mm
May	0	1
June	200	164
July	438	231
August	318	106
September	112	33
October	5	4
November	0	0
Year	1073	539

Table X. Average monthly runoff in 1991-2001 in Bayelva and De Geerdalen.

Examples of runoff pattern in different years and multi-year maximum, mean and minimum discharge are shown in section 5.1.1 for Bayelva (Fig. 34 and Fig. 35) and section 5.1.2 for De Geerdalen (Fig. 36 and Fig. 37).

#### 5.1.1 Bayelva

In Bayelva, there are observations of runoff in parts of the catchment some days before the runoff starts at the station itself. In the steeper areas the meltwater will start running fast after snowmelt begins, and the water is then stored in the flat areas in the lower part of the catchment for several days. The snowmelt floods in the end of June in Bayelva are of the same magnitude as those in De Geerdalen, but rain floods, combined with glacier melting often occur here. The Ny-Ålesund area also gets periods with rather high runoff influenced by rain in August and September.

Annual runoff in Bayelva is much higher than in De Geerdalen. Part of the explanation is the higher glacier coverage in Bayelva, but the main reason is the higher precipitation (Pettersson, 1994).

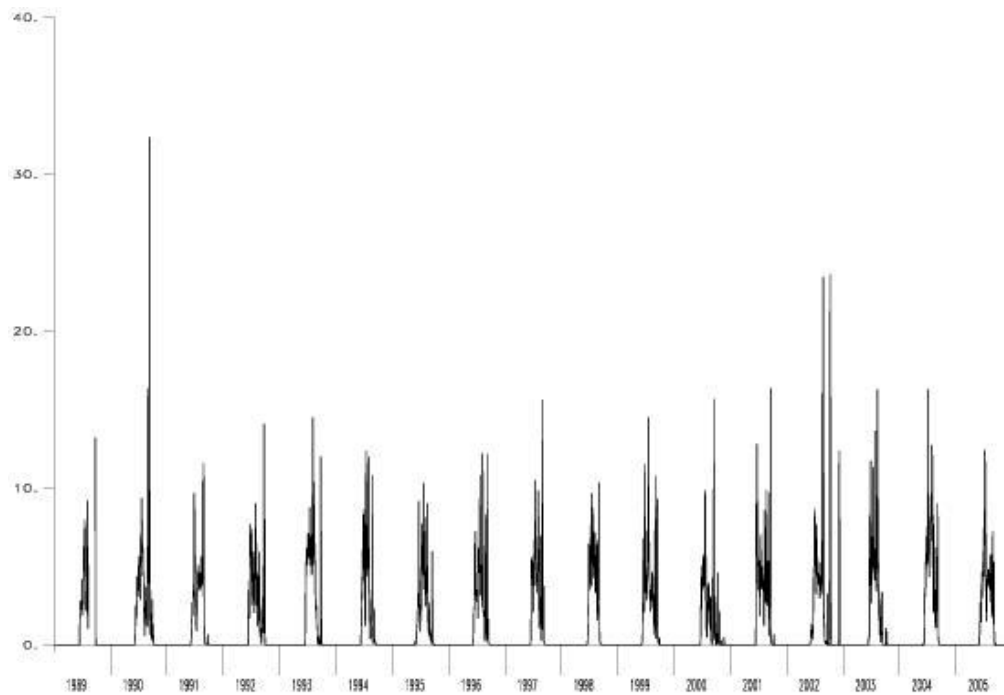


Fig. 34 Runoff pattern in Bayelva in different years. Vertical scale  $\text{m}^3/\text{s}$

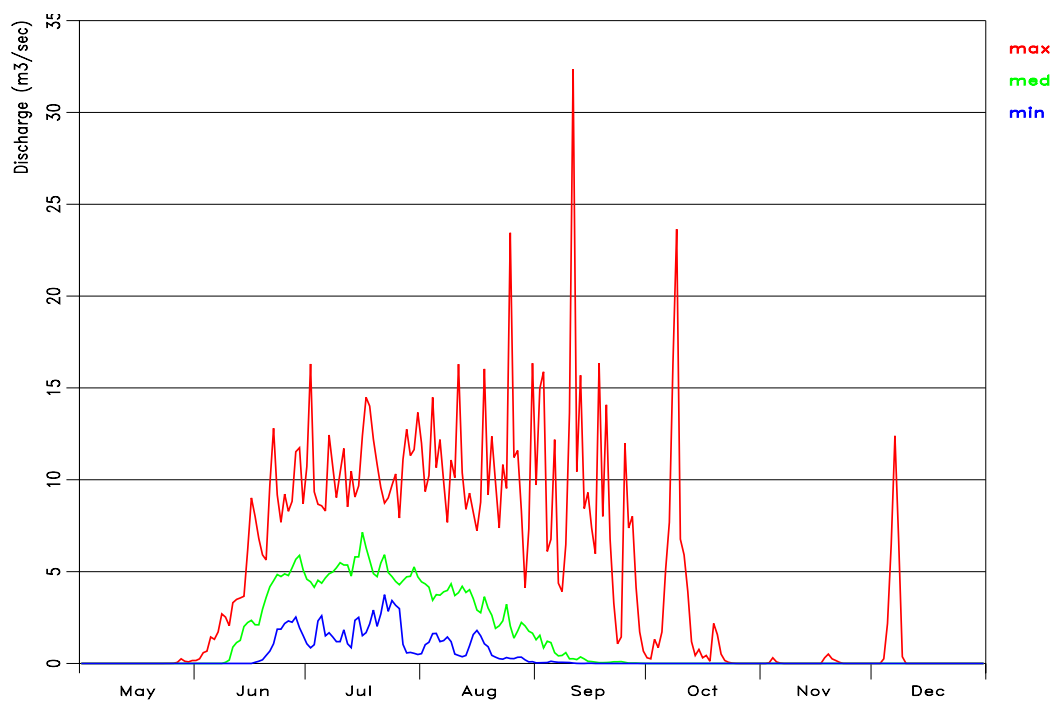


Fig. 35 Multi-year maximum, mean and minimum discharge for Bayelva. Vertical scale  $\text{m}^3/\text{s}$

### 5.1.2 De Geerdalen

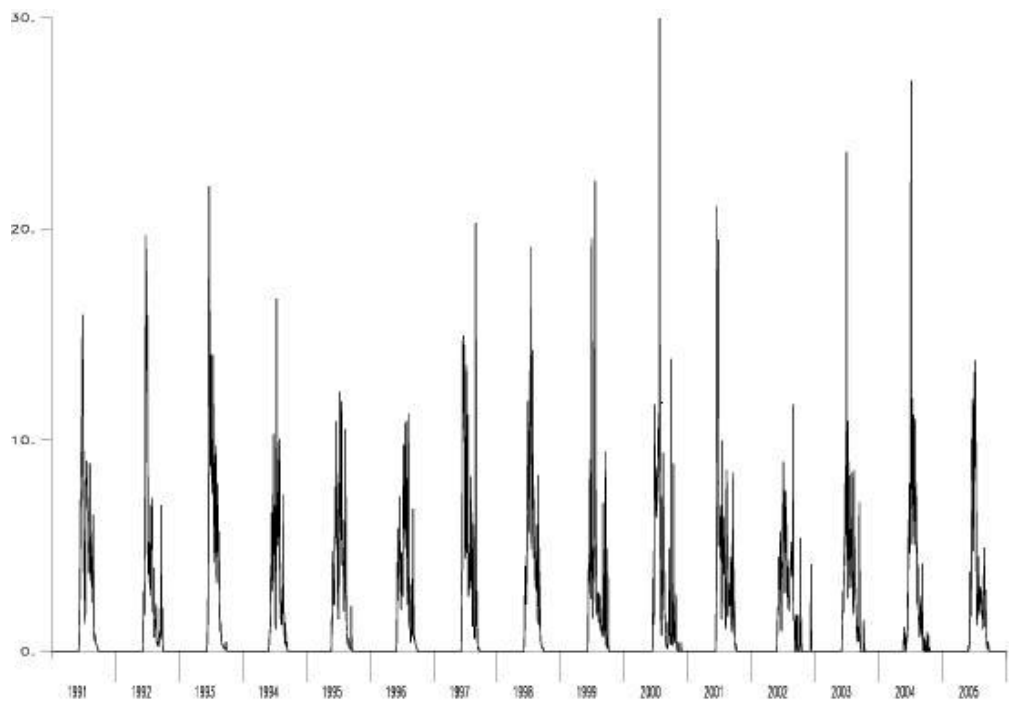


Fig. 36 Runoff pattern in De Geerdalen in different years. Vertical scale  $\text{m}^3/\text{s}$

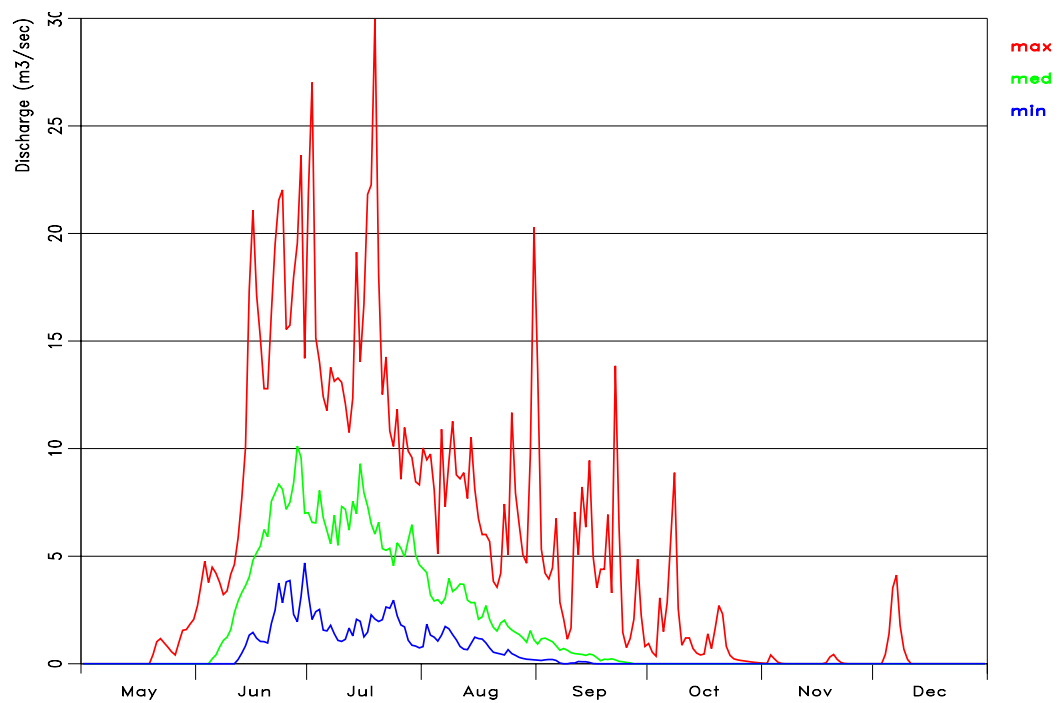


Fig. 37 Multi-year maximum, mean and minimum discharge for De Geerdalen. Vertical scale  $\text{m}^3/\text{s}$

### **5.1.3 HBV model**

An HBV-model is constructed for both Bayelva and De Geerdalen. The aim is to make use of simulated data as a control of observed data, as a basis for completion of the data when there are gaps in the dataset and as a support to evaluate correct discharge at the start of the runoff season when the registrations are under influence of ice. The HBV models could also be used to extend the dataset in periods where there are temperature and precipitation records.

## **5.2 Sediment load**

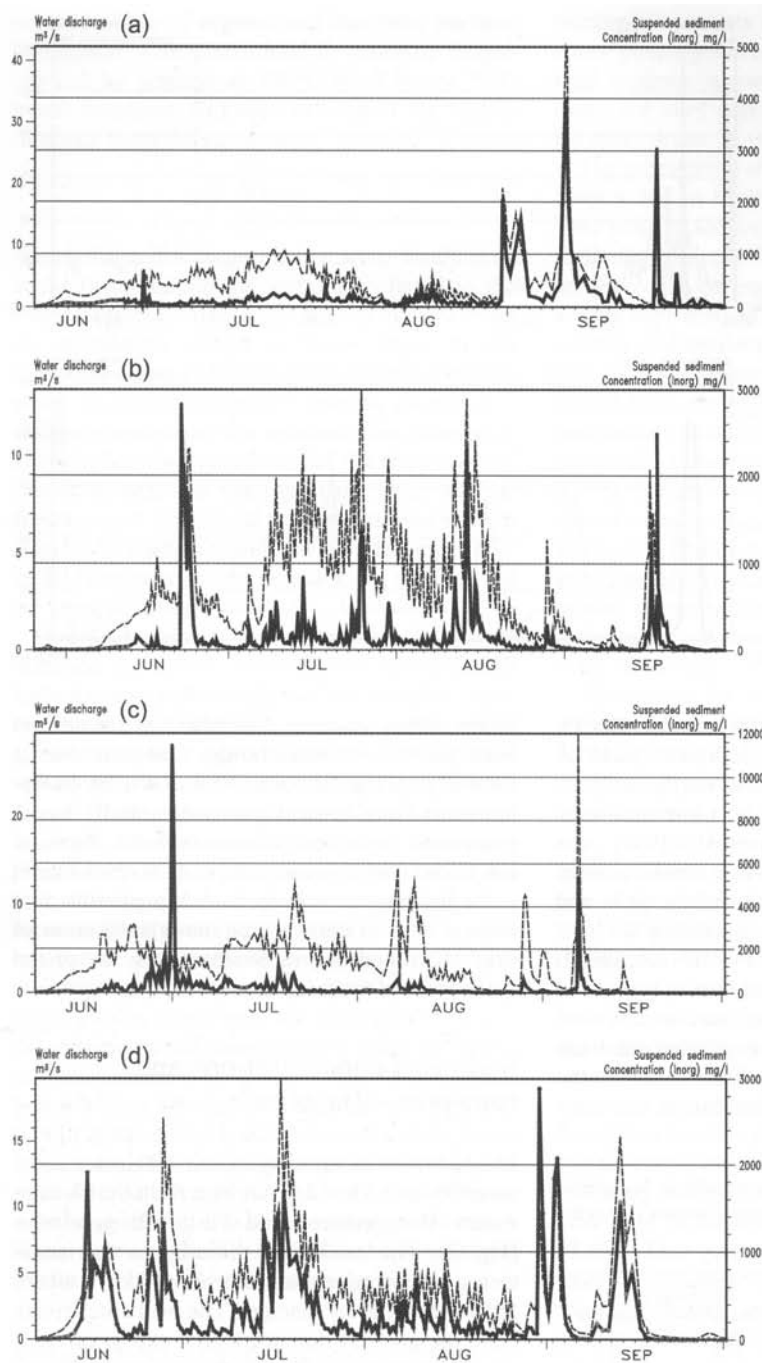
### **5.2.1 Bayelva**

In Bayelva the river material is supplied from erosion by the glaciers Austre Brøggerbreen and Vestre Brøggerbreen, and from the proglacial moraine. During the period of measurement the sediment transport varied from 23.111 tonnes in 1990 to 5076 tonnes in 1991 and 8.510 tonnes in 1992.

The sediment concentrations fluctuate strongly during the season, and the pattern resembles what is observed in glacier rivers in Norway. Concentrations are high at the beginning of the melting season and decrease throughout the summer. The concentration of particles does not vary simply with the water discharge, although the largest concentrations are found during flood conditions. A large amount of the material transport is carried out during the first melt in June. In July and August transport is moderate. In Bayelva, September floods seem to be important to the transport of sediment. When compared with rivers in Norway, Bayelva has characteristics most common with clay rivers. This means that the glacier erosion of the rocks beneath Brøggerbreane supplies a lot of fine grained material (Bogen, 1993).

The sediment regime in Bayelva is characterised by peaks during the snow melt period and heavy rain storm events later in summer and autumn (Husebye, 1994).

In 1993 the three sandurs of Bayelva were surveyed using a total station/ tachymetry. Different parameters were coded to develop a process-geomorphological map of the area. By using GIS, it is possible to present thematic as well as topographic maps and thus, by use of terrain models, to map and calculate accumulation and degradation over time. Changes in drainage pattern can be verified and seen concerning changes in runoff and sediment transport over time. The field data are stored in the Norwegian Polar Institute map base (Husebye, 1994).

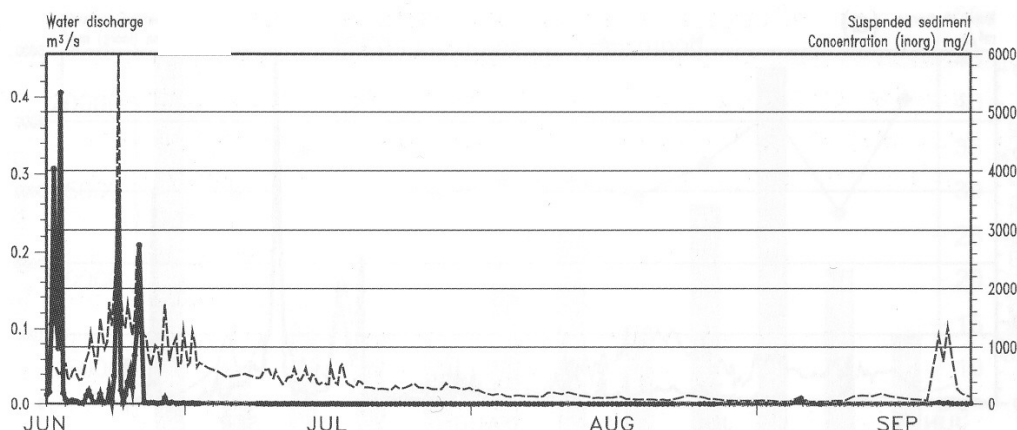


**Fig. 38** Suspended sediment concentration in the river Bayelva in (a) 1990, (b) 1995, (c) 1996 and (d) 1999. The dashed lines represent water discharge. The thick solid lines represent sediment concentration (Bogen and Bønsnes, 2003)

## 5.2.2 Londonelva

The material transport in Londonelva varies greatly from the transport in Bayelva. Almost all of the suspension transport occurs during the melt event/flood in June. Later, the water discharge is insignificant and thus the transport of material is correspondingly low. The material in Londonelva contains a large amount of sand and is relatively coarse, 45 % consisting of sand fractions (Bogen, 1993).





**Fig. 39** Suspended sediment concentration in the river Londonelva in 1992. The dashed lines represent water discharge. The thick solid lines represent sediment concentration (Bogen and Bønsnes, 2003)

### 5.2.3 Endalen and Isdammen

The sediment transport varies from year to year, but show an increase in volume over the period of measurement. Bogen and Bønsnes (1999) reports the following sediment quantities: in 1994 and 1995 the non-organic suspension transport was just 4000 tonnes: in 1996 6600 tonnes passed through the station. The maximum was reached in 1997 with 16,360 tonnes. More than 60 % of this was registered during a flood at the end of August and beginning of September. During 1998, 9.800 tonnes were transported through Endalselva. During the observation period about 5-6 % of the total load was organic material.

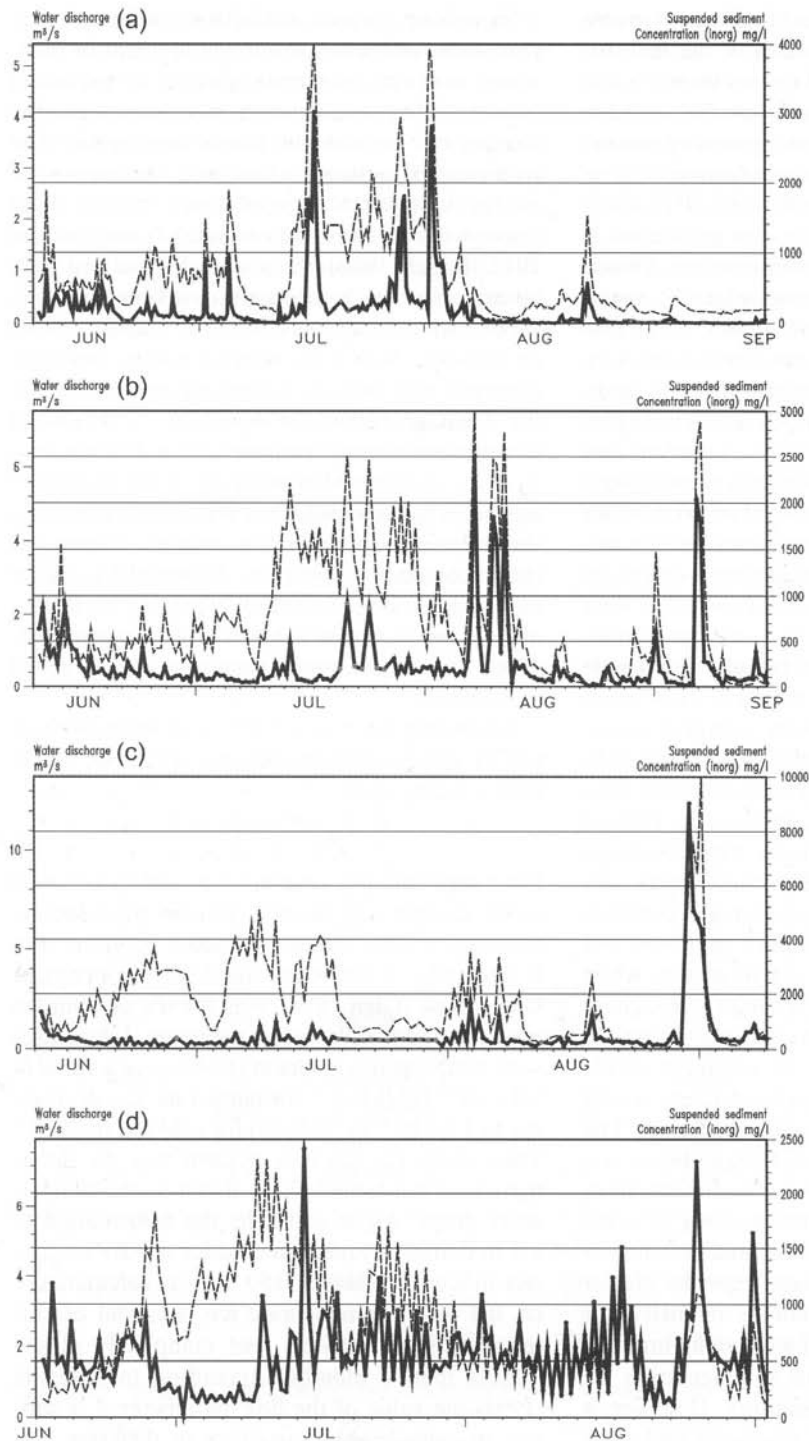
The seasonal variation in the supply of material results in the transport often increasing towards the end of the runoff season. There is often a high load during pulses of short duration. Each year there are flood situations where the concentration exceeds 2000 mg/l. During one flood event in August 1997 a maximum concentration of 900 mg/l was measured. The transport during one 24-hour period in this flood event was approximately 4400 tonnes.

A corresponding trend was also found in the annual sediment load at the outlet of Isdammen during the period 1995 -1998. In 1995 and 1996 the non-organic suspension transport in Isdammen was 2100 tonnes and 3900 tonnes respectively. In 1997, the total measured was 9200 tonnes. This is related to the high load connected with the flood event in August-September. The status for Isdammen in 1998 was 7400 tonnes. 5 % to 10 % of the total load during these years was non-organic.

The grain size distribution of the suspended sediment in Endalen shows large variations, both during the runoff season and from year to year. The content of sand varies from 2 % to a maximum of 60 % sand. The content of clay varies between 3 % and 31 %, but the median diameter is always within the silt fraction.

Some of the coarsest material is deposited in Isdammen, thus the grain size distribution at the outlet is finer towards clay and fine silts. However, some of the distribution curves still show surprisingly large amounts of sand, grain size up to 30 %. Some samples showed a particle content of more than 60 % of the suspended material in the clay

fractions. Size distribution analyses for individual samples can show as little as 5 % clay in the suspended material. However, the clay content is more than 20 % in most of the samples that are collected at the outlet of Isdammen (Bogen and Bønsnes, 1999).



**Fig. 40** Suspended sediment concentration in the river Endalselva in (a) 1994, (b) 1996, (c) 1997 and (d) 1998. The dashed lines represent water discharge, and thick solid lines represent sediment concentration (Bogen and Bønsnes, 2003)

## 6 Studies

### 6.1 Water balance

The water balance or water budget equation is usually given by:

$$P_A - Q_S - Q_G - E_A \pm \Delta M = \varepsilon$$

where  $P_A$  is the precipitation input (mm),  $Q_S$  is surface (river) runoff from the catchment,  $Q_G$  is groundwater runoff from the catchment,  $E_A$  is evaporation from the catchment,  $\Delta M$  is changes in water storage within the catchment and  $\varepsilon$  is an error term. The magnitude of the error indicates the accuracy of the different terms of the water balance.

Finding a representative value for the precipitation is difficult. Further information about the difference between measured and true precipitation in Svalbard can be found in Hanssen-Bauer et al. (1996). Runoff is usually the most reliable measured parameter in the water balance equation. As the runoff is an integrated response from the whole catchment, the problem of representative stations does not exist here. Most errors in the runoff monitoring in arctic rivers are related to problems in establishment, calibration and the stability of the river profile and the rating curve.

The first known water balance study in Svalbard was carried out in the Kongsfjorden area in 1968 (Geoffroy, 1968). Killingtveit et al. (1994, 2003) review and summarises all known previous water balance studies in Svalbard. An updated water balance computation was also carried out for the three water catchments with the best data: Bayelva, De Geerdalen and Isdammen/Endalen for 12 hydrological years, 1990 – 2001. The computations were based on the best available data and correction methods. Special emphasis was put on correction of precipitation data, both for catch errors and gradients in precipitation. Areal precipitation in the three catchments is more than two times the measured precipitation at the closest meteorological station: 548 mm/year in De Geerdalen, 486 mm/year in Isdammen/Endalen and 890 mm/year in Bayelva. Compare this with the average measured precipitation of only 199 mm/year at Svalbard Airport, close to Isdammen/Endalen and De Geerdalen, and 426 mm/year in Ny-Ålesund, close to Bayelva. Evaporation is not well understood in Svalbard; the best estimates indicate an average annual evaporation of about 80 mm/year from glacier-free areas, and no net evaporation from glaciers. Glacier mass balance has in general been negative in Svalbard over the last 40 years, leading to a significant contribution to the water balance, on the order of 450 mm/year on average. Annual runoff ranges from 545 mm in Isdammen/Endalen, 539 mm/year in De Geerdalen and up to 1050 mm/year in Bayelva. Runoff computed from water balance compares well with observed runoff, and average error in water balance is less than  $\pm 30$  mm/year in all three catchments.

## 6.2 Erosion and sediment transport

The processes of erosion and sediment transport in high Arctic rivers in Svalbard differ in many ways from those of middle latitudes. The high Arctic environment of Svalbard is very sensitive to disturbances from human activity. Poor vegetation and the presence of permafrost in the ground affect runoff conditions and slope erosion processes (Fig. 42 and Fig. 42). Thus, for management purposes it is important to investigate the rate of erosion and sediment yields in Svalbard rivers. The thermal regime of the glaciers affects the processes of subglacial erosion since cold ice is frozen to the bed. Subglacial meltwater flow may also be limited in cold areas, with little sediment carried out from the glaciers (Bogen and Bønsnes, 2003).



Fig. 42 River in canyon by Sticky Keep (MS)



Fig. 42 Fluvial erosion in Coloradofjella mountains (MS)

## 6.3 Physical and chemical conditions in Tvillingvatn

The drinking water from Tvillingvatn in Ny-Ålesund developed poor quality in April 1996. Kings Bay, which runs the Ny-Ålesund community, thus planned a new inlet for drinking water in Tvillingvatn to ensure a reliable water supply in the future. The physical and chemical qualities of the water were investigated to give supplementary information on where to place a new inlet. The field investigations included depth measurements, water sampling and investigation of the bedline sediments (Husebye, 1997). Chemical denudation rates in the Bayelva catchment are also described in Krawczyk et al. (2003).

## 6.4 Water supply in Ny-Ålesund

Observations of water level, water discharge and water consumption have been carried out in Tvillingvatn since 1997. Normally the water level is lowest at the end of May or beginning of June, and rise to its highest level during June due to snow melting. It then culminates in end of June or beginning of July. The majority of the water discharge is during June – July, and during August, September and October the discharge is small. The water consumption is an average of 700-800 m<sup>3</sup>/month but varies quite substantially. The water consumption per inhabitant in Ny-Ålesund is lately found to be around 300 l per 24 hours. By analysing the water balance it seems that the ground water inflow to Tvillingvatn is quite high. This inflow is probably from areas that are assumed to be outside the catchment of Tvillingvatn. However, there are uncertainties attached to the calculation of the water balance. The water supply in Tvillingvatn is considerably larger

than required for the inhabitants of Ny-Ålesund as of 1997, but there can be problems with sufficient water supply at the end of winter, before the snow melts. The water reservoir is reduced through winter due to ice freeze-up. If the number of inhabitants in springtime is expected to increase in the future, it may be necessary to take action to ensure the water supply is sufficient years with large draining throughout the winter and simultaneous large ice growth (Pettersson, 2000). Recent water balance studies (Haldorsen et al., 2002) indicate that there is no longer any groundwater flow of the magnitude that was found by Orvin (1944) in the period 1920-30. The present groundwater flow is probably due to shallow groundwater in the active layer along the talus of the mountain Zeppelinfjellet.

## **6.5 The Bayelva compound crump weir**

### **6.5.1 Design and construction**

As the literature gave no indication of corresponding work done in arctic conditions previously, the design of the weir in Ny-Ålesund had to be based on general rules of arctic construction and the standard hydraulics of weir construction. The main problems to be encountered with regard to the construction and performance of the weir were the stability and durability of the weir, influence of ice, permafrost protection and the large sediment transport of the river (up to 3.80 mg/l). Further, the very short construction season had to be taken into account.

### **6.5.2 Weir design**

A two dimensional triangular profile compound weir structure 15 m wide, consisting of a middle third section of crest height 0.35 m and the two outer thirds of the crest height 0.50 m was chosen. The total weir length is 10 m and the total side wall height is 1.5 m. This gives a maximum capacity of approximately 32 m<sup>3</sup>/s. As crest tapping is impossible under arctic conditions due to repeated sub-zero conditions/temperature in the runoff season, this feature was omitted and the weir was designed to operate in the modular range only. Thus, the result was a weir simple to construct, without curved surfaces, robust, relatively insensitive to minor damage and effective even when the flow is silt-laden. The shape of the crown allows a fairly free passage of floating ice and the crown crest is kept ice free under flow conditions. The latter two phenomena have been tested when applied under extreme winter conditions in Norway. The side walls are designed to withstand a 1.5 m water pressure in addition to the force of a 1 m thick ice cover. The side walls and concrete floor are reinforced on both sides and at the top and bottom also, to maintain reverse forces, with closely placed distribution steel to avoid surface cracking. The latter is of special importance for avoiding water entrainment in concrete and subsequent spalling due to frost action. The weir was equipped with a stilling well and a recording system of an optical encoder transferring the water level to an electronic data logger. The instrument hut is placed on top of the stilling well and the stilling well is pre-thawed by solar panels placed on the hut roof, thus ensuring level recordings from the first flood during spring.



**Fig. 43 Construction of the Bayelva crump weir (KR)**

### **6.5.3 Construction**

After removing the coarse sand and gravel from the river bed, the weir was established on a bed consisting mainly of silt, with the two side walls tied into the outcropping rock faces at the rock sill. To ensure frozen conditions, a 0.3 m layer of expanded polystyrene was applied as insulation between the concrete and the foundation and backfill. The surface of the weir, the dividing wall and the abutments flanking the weir were given a smooth finish and the weir crest were capped with non-corrodible steel plates. During construction, special attention was paid to ensuring that there were no voids between the foundation, the insulation and the concrete, as poor contact will cause heat transfer, seepage, piping and possible leakage and failure of the weir. However, bad weather in September during the construction forced work to a halt, and thus later caused several problems, damage and costly repair. For permanent stability it is of greatest importance that the foundations are maintained frozen during the life of the structure (Skretteberg, 1991).

After repairing the construction, the weir has been in operation without any problems, even though the damages involved a tilting of the weir. Annual levelling shows only minor fluctuations in the construction.

## **6.6 Evaluation of the technical aspects of the watercourse in Elvesletta, Longyearbyen**

An investigation of the technical aspects of the watercourse in Elvesletta, Longyearbyen (Fig. 44) has been carried out on commission from the previous Svalbard Samfunnsdrift AS (Svalbard Community Management) (Hoseth and Daae, 1996), now called Bydrift Longyearbyen AS. The aim was to investigate whether the area was suitable for prospective development. Three alternatives for flood safety measures were presented. The alternative using gabion mattresses was found most suitable for this area. A preliminary calculation of design flood has also been carried out (Sværd, 1996).



Fig. 44 Artificial watercourse built to avoid a braided course in Elvesletta, Longyeardalen (SH)

## 6.7 Environmental impacts of road construction between Longyearbyen and Sveagruva

In connection with Store Norske Spitsbergen Kulkompani's (SNSK) plans to start coal mining in the Central Field between Sveagruva and Reindalen, a road and a high voltage powerline have been proposed between Longyearbyen and Sveagruva. The transmission line would follow the same route as the road. Two alternative routes have been put forward. Common to both alternatives is a route through Bolterdalen – Tverrdalen to Reindalen with an alternative Todalen – Gangdalen along the line of an existing snowmobile route. The main alternatives apply to the section between Reindalen and Sveagruva. Alternative 1: Route around Blåhuken: the route crosses lower part of Reindalen. Alternative 2: Route over Reindalspasset: the route goes through upper Reindalen, over Reindalspasset, through Lundstrømdalen and along the lower part of Kjellstrømdalen to Sveagruva.

NVE was contracted by the Ministry of Trade and Industry and the Ministry of the Environment in 1992 to assess the hydrological consequences and the effects on the landscape of the planned road between Longyearbyen and Sveagruva. The hydrological studies consider possible effects on runoff, erosion and sediment transport, while the landscape studies are related to an appraisal of the quality of the landscape, possible effects on outdoor recreation and cultural heritage. The analysis is based on inspection of the course of the road and the available literature, together with the experience NVE has obtained from its research stations and monitoring programmes associated with hydrological gauging in Svalbard.

A road between Longyearbyen and Sveagruva will affect both the hydrological conditions and the landscape. Problems with the road routing are connected primarily to erosion, extraction of building material, drainage and landscape quality. The Svalbard landscape is



easily eroded and the drainage unstable, with continuously changing channels. In order to stabilise conditions, substantial measures need to be taken, which further reduces landscape quality. The problems can be minimised under certain conditions and if these are followed, the alternative via lower Reindalen and Blåhuken is recommended. River channels are more stable and possible damage will be less extensive and have fewer consequences than further up the watercourse, for example at Reindalspasset. The effects from damage high up in the watercourse would rapidly move downstream and thus indirectly affect the present-day channel system. Further assessment of the tunnel alternative between Reindalen and Sveagruva is recommended. The projected road will then be c. 19 km shorter and at the same time the need for extraction of material for road construction will be reduced (Husebye et al., 1993)

## 6.8 Hydrographical mapping in Nordenskiöld Land

Water catchment areas of Nordenskiöld Land were digitised considering hydrogeography and hydrological diversity. Deposits related to the fluvial systems were interpreted from air photos (Fig. 45). To get an overall view of the water catchment area the extent of glaciers was also measured. Rivers in combination with periglacial and glacial processes are an important part of the geodiversity of Svalbard, and the mapping of the river systems contributes to general knowledge that is important for good water system and nature management (Smith-Meyer, 2001).

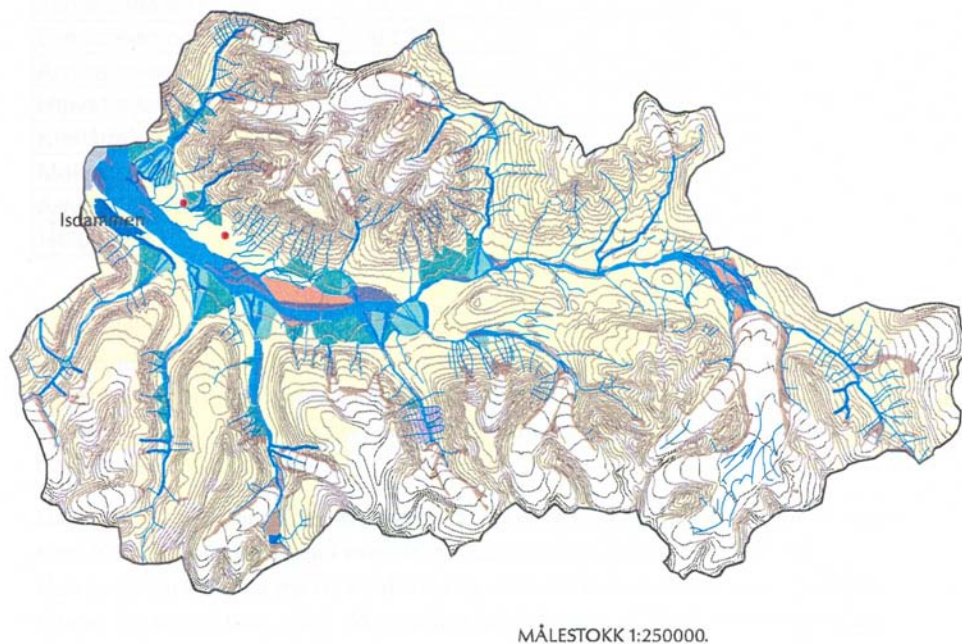


Fig. 45 Example from Adventdalen of a hydrographical map. Scale 1:250 000 (Smith-Meyer, 2001)

## 6.9 Ecosystems

In connection with the EU financed project “Arctic and Alpine Stream Ecosystem Research (AASER)”, ecological investigations were carried out both in Bayelva and Londonelva. One of the main aims of the project was to relate physical variables such as water discharge and temperature to the occurrence of aquatic invertebrates in a range of European glacier rivers, from the Pyrenees in the south to Svalbard in the north (Brittain & Milner, 2001a). The diversity of the benthic fauna of such rivers is determined mainly by two parameters, water temperature and channel stability (Castella et al., 2001). The combination of low temperatures and unstable channels, together with the isolated geographical location of the Svalbard archipelago results in a benthic fauna poor in species dominated by the midge genus, *Diamesa* (Fig. 47) (Lods-Crozet et al., 2001; Milner et al., 2001). Changes in the proportion of water from different sources, glacial meltwater, snowmelt/precipitation and groundwater affect the faunal composition in such river systems. Thus, the benthic community can serve as a good indicator of climate change (Brittain & Milner, 2001b).



Fig. 46 Benthos sampling in Bayelva (JB)



Fig. 47 Close-up of a midge (*Diamesa*)  
Photo: Leopold Füreder (Univ. of Innsbruck)

Snow and ice and hydrological processes associated with snowmelt, have a profound effect on the distribution, transport and uptake of radionuclide pollutants in aquatic ecosystems at northern latitudes. Such systems are also characterised by a close relationship between terrestrial and aquatic habitats, the basis for biological production in both lakes and running waters originating largely from catchment inputs of organic matter. The nature of terrestrial vegetation determines the extent of such inputs and is greatest in forested areas and decreases with altitude and latitude as forest give way to tundra. Pollutants, such as radioactive fallout, associated with such organic matter inputs are thus readily incorporated into many aquatic Arctic food chains (Brittain et al., 1994).

## 7 Future view

The establishment of the NVE-runoff stations is a good beginning for runoff measurements in Svalbard, but the network is sparse. A thorough analysis and better understanding of the hydrological regime of Svalbard demand a supplementary station network. To improve the network in Spitsbergen it would be especially interesting to establish stations in the relatively dry areas in the north between Woodfjorden and Wijdefjorden. A hydrometric station in a large catchment influenced by large glaciers would be very informative (Pettersson, 1994).

A soil water and temperature monitoring station is currently being considered close to Ny-Ålesund to enhance knowledge on the processes in the active layer. These processes are of importance for the water flow, erosion and biology. There is also need of such data to develop hydrological model and the changes of the active layer is anticipated to work as a climate indicator.

# References

- Bogen, J. 1992. Erosjon og sedimenttransport i Bayelva og Londonelv (in Norwegian), p. 45 -54 in K. Sand (ed.) Polar Hydrologi, rapport fra forskermøte i Trondheim 29-30. mars 1993. Norsk hydroteknisk laboratorium, November 1993, SINTEF rapport nr. STF60A93081.
- Bogen, J. 1993. Erosjon og sedimenttransport i Bayelva og Londonelva. (Erosion and sediment transport in Bayelva and Londonelva.) In K. sand (ed.): Polar hydrologi. Rapport fra forskermøte i Trondheim 29-30 mars 1993. (Report from research meeting in Trondheim 29-30 March 1993) *SINTEF Rep. STF60 A93081*, 45-54. Trondheim: Norwegian Institute of Technology.
- Bogen, J. and Bønsnes, T. 1999 Suspensjonstransporten ved målestasjonene I Endalselva og utløpet av Isdammen: sammensetning, volum og sesongmessig variasjon. (The suspended load at the monitoring stations in Endalselva and the outlet of Isdammen. Composition, volume and seasonal variation.) *NVE dok. 11*. Oslo: Norwegian Water Resources and Energy Directorate. 33 pp.
- Bogen, J. and Bønsnes, T. 2003. Erosion and sediment transport in High Arctic Rivers, Svalbard. *Polar Research* 22 (2), 175-189.
- Bogen, J. and Møen, K. 2003. Bedload measurements with a new passive acoustic sensor. In J. Bogen, T. Fergus and D. Walling: Erosion and Sediment transport in Rivers: Technological and Methodological Advances. (Proceedings of the Oslo Workshop, June 2002) *IAHS publ.* 283.
- Brittain, J.E., Håkanson, L., Bergström, U. and Bjørnstad, H.E. 1994. The significance of hydrological and catchment processes for the transport and biological uptake of radionuclides in Northern Aquatic Ecosystems. In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology* , 201-216.
- Brittain, J.E. and Milner, A.M. 2001a. Ecology of glacier-fed rivers: current status and concepts. *Freshwater Biology* 46: 1571-1578.
- Brittain, J.E. and Milner, A.M. (eds) 2001b. Glacier-fed rivers - unique lotic ecosystems. *Freshwater Biology* 46: 1571-1847.
- Castella, E., Adalsteinsson, H., Brittain, J.E., Gislason, G.M., Lehmann, A., Lencioni, V., Lods-Crozet, B., Maiolini, B., Milner, A.M., Olafsson, J.S., Saltveit, S.J. and Snook, D.L. 2001. Macroinvertebrate richness and composition along a latitudinal gradient of European glacier-fed streams. *Freshwater Biology* 46: 1811-1831.
- Førland, E.J., Hanssen-Bauer, I. and Nordli, P.Ø. 1997. Climate statistics & longterm series of temperature and precipitation at Svalbard and Jan Mayen. Report no. 21/97 *KLIMA*. Det norske meteorologiske institutt.

- Geoffray, H. 1968. Etude du bilan hydrologique et de l'érosion sur un bassin partiellement englacé, Spitsberh, Baie du Roi, 79° Lat. Nord. (A study of water balance and erosion in a partly glaciated basin, Spitsbergen Kings Bay 79° N). Thesis. University of Rennes.
- Gokhman, V.V. and Khodakov, V.G. 1986. Hydrological investigations in the Mimer river basin, Svalbard in 1983. *Polar Geography and geology*, 10(4), 309-316.
- Hagen, J.O., Liestøl, O., Roland, E. and Jørgensen, T. 1993. Glacier atlas of Svalbard and Jan Mayen. *Nor. Polarinst. Medd.* 129.
- Hagen, J.O., Kohler, J. Melvold, K and Winther J.-G. 2003. Glaciers in Svalbard: mass balance, runoff and freshwater flux. *Polar Research* 22 (2), 145-159.
- Haldorsen, S. and Lauritzen, S.-E. 1993. Grunnvann i Ny-Ålesund (In Norwegian, English summary). Norsk Hydrologisk Komité Rapport nr. 24. Oslo.
- Haldorsen, S., Heim., Lefauconnier, B., Pettersson, L.-E., Røros, M and Sandsbråten, K. 2002. The water balance of an arctic lake and its dependence on climate change: Tvillingvatnet in Ny-Ålesund, Svalbard. *Norw. Journal of Geography* Vol. 56, 146-151. Oslo. ISSN 0029-1951.
- Hanoa, R. 1993. Kings Bay Kull Compani A/S 1917-1992. Chr. Schibsteds Forlag A/S. Oslo. 245 pp.
- Hansen-Bauer, I., Kristensen Solås, M., Steffensen, E.L. 1990. The climate of Spitsbergen. DNMI klima, Rapport nr 39/90. 40 pp.
- Hanssen-Bauer, I. Førland, E.J. and Nordli, P.Ø. 1996. Measured and true precipitation at Svalbard. Report no. 31/96 KLIMA. Det norske meteorologiske institutt.
- Hisdal, V. 1985. Geography of Svalbard, Polarhåndbok nr. 2. Norsk Polarinstitut
- Hoseth, K.A. (red.) and Daae, T.C. 1996. Longyearbyen – Elvesletta. Vassdragstekniske Vurderinger. NVE-rapport 8/96.
- Husebye, S. 1994. Studies of erosion and sediment transport at Svalbard. In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology*, 232 - 250.
- Husebye, S. 1997. Fysiske og kjemiske forhold undersøkt i forbindelse med vannforsyning og etablering av vanninntak; Tvillingvann, Ny-Ålesund, Spitsbergen NVE-rapport 03/1997

- Husebye, S.(red.), Bogen, J., Helgestad, A.K. and Pettersson, L.-E. 1993. Miljøkonsekvenser av veiutbygging mellom Longyearbyen og Svea: Avrenning, erosjon og landskap. (Environmental Impacts of Road Construction between Longyearbyen and Svea: Runoff, Erosion and Landscape) (Abstract and conclusions in English). NVE Publikasjon nr. 19/1993. 40 pp.
- Jania, J. and Pulina, M. 1994. Polish hydrological studies in Spitsbergen, Svalbard: a review of some results. In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology*, 47-76
- Killingtveit, Å., Pettersson, L.-E. and Sand, K. 1994. Water balance studies at Spitsbergen, Svalbard. In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology*, 77-94.
- Killingtveit, Å., Pettersson, L.-E. and Sand, K. 2003. Water balance investigations in Svalbard. *Polar research* 22 (2), 161-174.
- Krawczyk, W.E., Lefauconnier B. and Pettersson, L.-E. 2003. Chemical denudation rates in the Bayelva Catchment, Svalbard in the Fall of 2000. *Physics and Chemistry of the Earth* 28, 1257-1271.
- Lauritzen, S.-E. 1993. Grunnvann på Svalbard: Hilmarfjellet, Sørkappland. Polar hydrologi, Rapport fra forskermøte i Trondheim 29-30 mars 1993. (Groundwater in Svalbard: Hilmarfjellet, Sørkappland, Polar hydrology Report from a research meeting in Trondheim 29-30 March, 1993)
- Liestøl, O. 1973. Glaciological work in 1971. *Nor. Polarinst. Årb.* 1971, 67-76.
- Liestøl, O. 1976. Pingos, springs and permafrost in Spitsbergen, *Norsk Polarinstt. Årb.* 1975, 7-29.
- Liestøl, O. 1980. Permafrost conditions in Spitsbergen. *Frost i jord*, 21.
- Lods-Crozet, B., Lencioni, V., Olafsson, J., Snook, D., Velle, G., Brittain, J.E., Castella, E. & Rossaro, B. 2001. Chironomid (Diptera: Chironomidae) communities in six European glacier-fed streams. *Freshwater Biology* 46: 1791-1809.
- Mercier, D. 2001. *Le Ruissellement au Spitsber (Runoff in Spitsbergen)*. Clermont-Ferrand, France. Blaise Pascal University Press.
- Milner, A.M., Brittain, J.E., Castella, E. and Petts, G.E. 2001. Trends of macroinvertebrate community structure in glacier-fed rivers in relation to environmental conditions: a synthesis. *Freshwater Biology* 46: 1833-1847.
- Nordseth, K., Hagen, J.O., Sand, K., Winther, J.G. and Wold, B. 1992. National R & D-Programme: Polar Hydrology – Svalbard. NAVF-report, 20 pp.

- Orvin, A. 1934. Geology of the Kings Bay region. Spitsbergen. *Skrifter om Svalbard og ishavet* 57. 190 pp.
- Orvin, A. 1944. Litt om kilder på Svalbard. *N. Geogr. Tidsskrif.*, Vol X (1), 16-38.
- Pettersson, L.-E. 1994. The hydrological regime of Spitsbergen, Svalbard. In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology*, 95 – 108.
- Pettersson, L.-E. 2000. Vannforsyning i Ny-Ålesund. NVE-oppdagsrapport 6/2000.
- Pettersson, L.-E., Gotthardsson, M., Janowicz, R. and Kirkedal Svendsen, S.C. 1994. Methods and experiences with hydrometric measurements in Northern basins. NRB Task Force report #1, In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology*, 665
- Pulina, M., Rereyma, J., Kida, J. and Krawczyk, W. 1984. Characteristics of the polarhydrological year 1979/80 in the basin of the Werenskiöld Glacier, SW Spitsbergen, Polish Polar Research, 5 (3-4), 165-182.
- Repp, K. 1979. Breerosjon, glasio-hydrologi og materialtransport i et høyarktisk miljø. Brøggerbreebe, Vestspitsbergen. (MSc Thesis), Department of Geography, University of Oslo.
- Repp, K. 1988. The hydrology of Bayelva, Spitsbergen. *Nordic Hydrology Vol. 19*, 259-268.
- Sand, K. 1989. Polar hydrology: - Kunnskapsinvestering. NHL-rapport STF60 A89011.
- Sand, K. 1990. Modeling snowmelt runoff process in temperate and arctic environments. PhD thesis. University of Trondheim, Norwegian Institute of Technology, 176 pp.
- Sandsbråten, K. 1995. Vannbalanse i et lite arktisk nedbørsfelt, Tvillingvatn, Svalbard. Rapportserie: Hydrologi. Universitetet i Oslo. 90 pp.
- Skretteberg, R. 1991. Discharge Measurements Structures under Arctic Conditions. Design and Construction Considerations. Arctic Hydrology. Present and Future Tasks NHK-report 23/91.
- Skretteberg, R. 1992. The establishment of Gauging Stations under Arctic Conditions – The Svalbard Experience, in Prowse, T.D., Ommanney, C.S. L. and Ulmer. K. (eds.). *Proceedings 9<sup>th</sup> International Northern Research Basin, Canada 1992. NHRI Symposium no.10* (2), 509-517.
- Smith-Meyer, S. 2001. Hydrogeografisk kartlegging av Nordenskiöld's land. NVE-rapport 11/2001.
- Sværd, R. 1996. Longyearbyen – Elvesletta. Preliminær Flomberegning. NVE-rapport 7/96, 26pp.



- Tveit, J. and Killingtveit, Å. 1994. Snow surveys for study of water budget on Svalbard 1991-1994. In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology*, 489-509.
- Vatne, G., Etzelmüller, B. Ødegård, R.S. and Sollid, J.L. 1992. Glaciofluvial sediment transfer of a subpolar glacier, Erikbreen, Svalbard. *Stuttgarter Geogr. Stud.* 117, 253-266.

# Appendix

- 1 Svalbard related publications by NVE personnel
- 2 External publications including NVE's Svalbard data
- 3 Reference marks at NVEs hydrological stations

# 1 Svalbard related publications by NVE personnel

**These are publications not mentioned in the reference list of the report, and includes either publications where NVE is referred as appurtenant institution or previous publications by people currently (1.1.2006) employed at NVE. Publications by time of employment are marked with bold font. Previous publications at external institutions are marked in bold italic.**

- Bogen, J. 1991. Erosion and sediment transport in Svalbard. In Y. Gjessing, J.O. Hagen, K.A. Hassel, K. Sand and B. Wold (eds.): *Arctic hydrology, present and future tasks. Norwegian National Committee for Hydrology rep. 23/91*, 147-158.
- Bogen, J. 1996. Erosion and sediment yield in Norwegian rivers in: D.E. Walling and B.W. Webb (eds.) *Erosion and sediment yield: Global and regional perspectives, IAHS publ. no 236*, 73-84.
- Bogen J. 1996. Erosion rates and sediment yield of glaciers. *Ann. Glaciol.* 22, 48-52,
- Bogen, J. 1997. Sedimenttransport i høyfjell og arktis. (Sediment transport in mountain and Arctic rivers.) In Haugum (ed.): *Hydrologisk forskning I Norge. Norsk Hydrologiråd Rapp. 1/97*, 30-38. Norwegian National Council for Hydrological Research.
- Brittain, J.E. (ed.) 1997. Arctic and Alpine Stream Ecosystem Research (AASER). Scientific report to the EU Commission (1996-97). Contract no. ENV-CT95-0164. 51 pp.
- Brittain, J.E. (ed.) 1998. Arctic and Alpine Stream Ecosystem Research (AASER). Scientific report to the EU Commission (1997-98). Contract no. ENV-CT95-0164. 85 pp.
- Brittain, J.E. (red.) 1999. Arctic and Alpine Stream Ecosystem Research (AASER). *Final Scientific report to the EU Commission*. Contract no. ENV-CT95-0164. 109 pp.
- Brittain, J.E., Adalsteinsson, H. Castella, E. Gislason, G. M. Lencioni, V. , Lods-Crozet B., Maiolini, B. Milner, A. M. Petts, G. E. and Saltveit, S. J. 2000. Towards a conceptual understanding of arctic and alpine streams. *Verhandlungen der internationale Vereinigung für theoretische und angewandte Limnologie* 27: 740-743.
- Brittain, J.E., Castella, E., Knispel, S., Lencioni, V., Lods-Crozet, B., Maiolini, B., Milner, A.M., Saltveit, S.J. and Snook, D.L. 2003. Ephemeropteran and plecopteran communities in glacial rivers. In Gaino, E. (Ed.) *Research Update on Ephemeroptera and Plecoptera*. University of Perugia, Italy, pp. 271-277.
- Eiken, T. Hagen, J.O. and Melvold, K., 1997. Kinematic GPS survey of geometry changes on Svalbard glaciers. *Annals of Glaciology*. 24, 157-163.
- Engeset, R.V., Kohler, J., Melvold, K. and Lundén, B., 2002. Change detection and monitoring of glacier mass balance and facies using ERS SAR winter images over Svalbard. *International Journal of Remote Sensing*, 23(10), 2023-2050.

- Engeset, R.V. and Ødegård, R.S., 1999. Comparison of annual changes in winter ERS-1 SAR images and glacier mass balance of Slakbreen, Svalbard. *International Journal of Remote Sensing*, 20(2), 259-271.
- Engeset, R.V. and Weydahl, D.J., 1998. Analysis of glaciers and geomorphology at Svalbard using multitemporal ERS-1 SAR images. *IEEE Transactions on Geoscience and Remote Sensing*, 36(6), 1879-1887.
- Engeset, R. and Weydahl, D.J., 1997. Analysis of glaciers and geomorphology at Svalbard using multitemporal ERS-1 SAR images and in situ data. *Report Series in Physical Geography, University of Oslo*, 6.
- Engeset, R. 1996. Simultaneous observation of glacier near-surface properties using satellite and ground radar instruments. *Proc. 4th Circumpolar Symposium on Remote Sensing of Polar Environments*, 29 April - 1 May 1996, Copenhagen, Denmark.
- Erikstad, L. og Smith-Meyer, S. 1992. Naturfaglig landskapsanalyse. Konsekvenser av planlagt vei mellom Longyearbyen og Sveagruva, Svalbard. NINA oppdragsmelding nr. 158, 1992.
- Faugli, P.E. and Aabel, J. 1991. Water Resources Management and Research in Svalbard. Arctic Hydrology. present and Future Tasks NHK-report 23/91.
- Gurnell, A.M., Hodson, A.J., Bogen, J., Clark, M.J., Hagen, J.O. and Tranter, M. 1994. Water and sediment discharge from glacier basins: an Arctic and Alpine comparison. *IAHS publ.no.* 224, 325-344.
- Hagen, J.O., Eiken, T., Kohler, J and Melvold, K. 2005. Geometry changes on Svalbard glaciers - mass balance or dynamic response? *Annals of Glaciology* 42. In press.
- Hagen, J.O. and Lefauconnier, B. 1995. Reconstructed Runoff from the High Arctic Basin Bayelva based on Mass-Balance Measurements. *Nordic Hydrology*, 26, 285-296.
- Hagen, J.O., Melvold, K., et al., 2003. On the net mass balance of the glaciers and ice caps in Svalbard, Norwegian Arctic. *Arctic, Antarctic, and Alpine Research* Vol. 35 No.2, 264-270.
- Hagen, J.O., Melvold, K., Eiken, T., Isaksson, E., Lefauconnier, B., 1999. Mass balance methods on Kongsvegen, Svalbard. *Geografiska Annaler*, Vol. 81 No.4, 593-601.
- Kääb, A. Lefauconnier, B and Melvold, K. 2005. Flow field of Kronebreen, Svalbard, using repeated Landsat7 and ASTER data. *Annals of Glaciology* 42. In press.
- Kummeneje, E. and Øvereng, I.. 1989. Forbygging mot Longyearelva, Spitsbergen, Svalbard, Norges vassdrags- og energiverk, plan nr. 8195, 6 pp.
- Lefauconnier, B., Hagen, J.O., Ørbæk, J.B., Melvold, K., and Isaksson, E., 1999. Glacier balance trends in the Kongsfjorden area, western Spitsbergen, Svalbard, in relation to the climate. *Polar Research*, Vol. 18, No.2, 307-313.

- Liestøl, O., Repp, K. and Wold, B. 1980 Supra glacial lakes in Spitsbergen N. Geogr. Tidsskr., Vol. 34, pp. 89-92.
- Maiolini, B., Lencioni, V. and Brittain, J.E. 2004. Invertebrate drift in a high arctic stream under natural and experimental light conditions: preliminary results. *Verhandlungen der internationale Vereinigung für theoretische und angewandte Limnologie In press.*
- Melvold K. 1992. Studie av brebevegelse på Kongsvegen og Kronebreen, Svalbard. Rapportserie i Naturgeografi, Universitetet i Oslo. Rapport nr. 1. Oslo.
- Melvold, K. 1999. Impact of recent climate on glacier mass balance; studies on Kongsvegen, Svalbard and Jutulstraumen Antarctica. (Ph.D. thesis). Rapport serie i naturgeografi, Universitetet i Oslo, No. 13. Oslo. p. 100.
- Melvold, K. and Hagen, J.O., 1998. Evolution of a surge-type glacier in its quiescent phase: Kongsvegen, Spitsbergen, 1964-95. *Journal of Glaciology*, Vol. 44 No.147, 394-404.
- Melvold, K., Schuler, T., Lappegard, G., 2004. Groundwater intrusions in a mine beneath Høganesbreen, Svalbard: assessing the possibility of evacuating water subglacially. *Annals of Glaciology* Vol 37, 269-274.
- Melvold, K., med flere (2002). Potensiell drenering av vann fra Svea Nord Gruva under Høganesbreen. Oppdragsrapport levert Store Norsk Spitsbergen Kullkompani.
- Oerlemans, J., Bassford, R.P., Chapman, W., Dowdeswell, J.A., Glazovsky, A.F., Hagen, J.O., Melvold, K., de Ruyter de Wildt, M., and van de Wal R.S.W. 2005. Estimating the contribution from Arctic glaciers to sea-level change in the next hundred years. *Annals of Glaciology* 42. In press.
- Pettersson, L.-E. 1991. Hydrometric investigations an Svalbard 1989-90. Arctic Hydrology. Present and Future Tasks. NHK-report 23/91.
- Pettersson, L-E. 1993. Avløpsstasjoner på Svalbard. Polar Hydrologi. Rapport fra forskermøte. SINTEF NHL.
- Pettersson, L.-E. 1994. Hydrological Investigations in Svalbard. Nordic Hydrological Conference. NHP-report 34/94.
- Pettersson, L.-E. 1994. Runoff during Snowmelt in an Arctic River. Nordic Hydrological Conference. NHP-report 34/94.
- Pettersson, L.-E. 1994. The hydrological Regime of Spitsbergen, Svalbard. In K. Sand and Å. Killingtveit (eds.) *Proceedings of the 10<sup>th</sup> International Northern Research Basins Symposium and Workshop, Norway. SINTEF Rep. 22 A96415. Trondheim. Norwegian Institute of Technology*, 95- 107.

- Pinglot J.L., Hagen J.O., Melvold K., Eiken T. and Vincent, C. 2001. A mean net accumulation pattern derived from radioactive layers and radar soundings on Austfonna, Nordaustlandet, Svalbard. *Journal of Glaciology* Vol. 47 No.159. 555-566.
- Pettersson, L.-E. 2000. Runoff in Svalbard. The Changing Physical Environment. Proceedings from the Sixth Ny-Ålesund International Scientific Seminar. Norsk Polarinstitutt Internrapport. Pages 149-152.
- Repp, K. 1979. Breerosjon, glasio-hydrologi og materialtransport i et høyarktisk miljø. Brøggerbreene, Vest-Spitsbergen. Hovedoppgave (Master's thesis) unpublished, Department of Geography, University in Oslo.
- Sand, K., Hagen, J.O., Repp, K. and Berntsen, E. 1991. Climate related research in Svalbard. Present and Future tasks. National Committee for Hydrology Report 23/91.
- Schuler, T.V., Melvold, K., Hagen, J.O. and Hock, R. 2005. Assessing the future evolution of meltwater intrusions into a mine below Gruvefonna, Svalbard. *Annals of Glaciology* 42. In press.
- Skretteberg, R. 1991. Discharge Measurements Structures under Arctic Conditions. Design and Construction Considerations. In Y. Gjessing et al (eds.): *Arctic Hydrology, present and future tasks. Norwegian National Committee for Hydrology rep. 23/91*, 167 – 174/147-158. NHK-report 23/91.
- Smith-Meyer, S. and Erikstad, L. 1994. Scale problems related to the use of the criterion "naturalness" in the context of landscape protection and road construction an apparently pristine arctic environment. In o'Holloran, Green, Harley, Stanley and Knill: *Geological and Landscape conservation*. Geological Society of London, 1994.
- Sand, K., Winther, J.-G., Marèchal, D., Bruland, O., Melvold, K. (2003). Regional variations of snow accumulation on Spitsbergen, Svalbard, 1997-99. *Nordic Hydrology* Vol. 34 No.1-2, 17-32.
- Sund, M. and Eiken, T. 2004. Dynamics and surge history of a polythermal glacier: Hessbreen, Svalbard. *J. Glaciol.* 50(171), 547-555.
- Østhagen, H. 1971. *Cladonia deformis* and *C. gonecha* in Norway and Svalbard. *Norw. J. Bot.* 18, 87-92.

## 2 External publications including NVE's Svalbard data

### List of publications written by external authors

- Bruland, O. 1999. Energy and Water Balance of Active Layer 1991-1994  
Understanding Land Arctic Physical Processes 1996-1998. Sintef Report STF22 A98417, SINTEF, Trondheim.
- Bruland, O. and Hagen, J.O. 2002. Mass Balance of Austre Brøggerbreen modelled with the HBV-model. *Polar Research*, accepted for publishing June 2002.
- Bruland, O. and Killingtveit, Å. 2002. An Energy Balance Based HBV- Model with Application to an Arctic Watershed on Svalbard, Spitsbergen. *Nordic Hydrology*, Vol. 33 (2).
- Bruland, O., Maréchal, D., Sand, K. and Killingtveit, Å. (2001a) Energy and water balance studies of a snow cover during snowmelt period at a high arctic site. *Theoretical and Applied Climatology*, Vol. 70 (1-4), pp. 55-63.
- Førland, E.J., I. Hanssen-Bauer, P.Ø. Nordli. 1997. Orthographic precipitation at the glacier Austre Brøggerbreen, Svalbard. Report no. 02/97 KLIMA. Det norske meteorologiske institutt.
- Førland, E.J., Hanssen-Bauer, I.. 2003. Past and future climate variations in the Norwegian Arctic: overview and novel analysis. *Polar Research* 22 (2), 113-124.
- Hagen, J.O., Kohler, J., K. Melvold and Winther, J.-G. Glaciers in Svalbard: mass balance, runoff and freshwater flux. *Polar Research* 22 (2), 145- 159.
- Hodson, A.J., Kohler, J., Birkhaus, M. and Hagen J.O. 2005. Multi-year water and surface energy budget of a high-latitude polythermal glacier: evidence for overwinter water storage in a dynamic subglacial reservoir. *Annals of Glaciology*, 42-46.
- Hodson, A.J., Mumford, P.N., Kohler, J. and Wynn, P.M. 2005. The High Arctic glacial ecosystem: new insights from nutrient budgets, *Biogeochemistry*. 72 (2), 233-256.
- Hodson, A.J., Tranter, M., Gurnell, A.M., Clark, M.J. and Hagen, J.O. 2002. The hydrochemistry of Bayelva, a High Arctic proglacial stream in Svalbard, *Journal of Hydrology*, 257, 91-114.
- Hodson, A.J., Tranter, M. and Vatne, G. 2000. Contemporary rates of chemical denudation and atmospheric CO<sub>2</sub> sequestration in glacierised basins: an Arctic perspective, *Earth Surface Processes and Landforms*, 25, 1447-1471.
- Hodson, A.J., Gurnell, A.M., Tranter, M., Bogen, J. Hagen, J.O. and Clark, M. 1998. Suspended sediment transfer processes and yields in a High-Arctic, glaciated basin, Svalbard, *Hydrological Processes*, 12, 73-86.
- Hodson, A.J., Gurnell, A.M., Washington, R., Clark, M.J. and Tranter, M. 1998. Meteorological and runoff time series characteristics from a High-Arctic, glaciated basin, Svalbard, *Hydrological Processes*. 12, 509-526.
- Hodson, A.J. and Tranter, M. 1999. CO<sub>2</sub> drawdown by contemporary glacial meltwater fluxes in high arctic Svalbard, *IAHS Publications No.* 256, 259-265.



- Hodson, A.J., Tranter, M., Dowdeswell, J.A., Gurnell, A.M. and Hagen, J.O. 1997. Glacier thermal regime and suspended sediment yield: a comparison of two high-Arctic glaciers. *Annals of Glaciology*, 24, 32 - 37.
- Humlum, O., Instanes, A. and Sollid, J.L.. 2003. Permafrost in Svalbard: an overview of research history, climatic background and engineering challenges. *Polar Research* 22 (2), 191-215.
- Killingtveit, Å, Pettersson, L.E. and Sand, K. 2003. Water balance investigations in Svalbard. *Polar Research* 22 (2), 161-174.
- Sand, K. and Bruland, O. 1999. Water balance of three high Arctic river basins in Svalbard. In: J. Elíasson (Editor), Proceedings of Northern Research Basins Twelfth International Workshop and Symposium. Engineering Research Institute University of Iceland, Iceland, pp. 270-283.
- Sælthun, N.R., Aittoniemi, P., Bergström, S., Einarsson, K., Jóhannesson, T., Lindström, G., Ohlsson, P.-E., Thomsen, T., Vehviläinen, B. and Aamodt, K.O. 1998. Climate change and impacts on runoff and hydropower in the Nordic countries. TemaNord 1998:552, Nordic Council of Ministers, Copenhagen.
- Tveit, J. and Killingtveit, Å. 1994. Snow surveys for studies of Water Budget on Svalbard, Proceedings of Tenth International Northern Research Basins Symposium and Workshop. Norwegian University of Science and Technology, Svalbard, Norway, pp. 489-509.
- Winther J.-G., Bruland, O., Sand, K., Gerland, S., Marechal, D., Ivanov, B., Glowacki, P. and König, M. 2003. Snow research in Svalbard – an overview. *Polar Research* 22 (2), 125-144.

### 3 Reference marks at NVEs hydrological stations

#### Reference marks Bayelva station



Reference mark FM1



Close up reference mark FM1



Reference mark FM2



Close up reference mark FM2

## Reference marks De Geerdalen station



Old mark in rock and new reference bolt

## Reference marks Londonelva station



Reference bolt close to the old radio mast



This series is published by Norwegian Water Resources and Energy Directorate (NVE)

## **Published in the Report series 2008**

No. 1 Gusong Ruan: Utilization of the new features in PEST (22 p.)

No. 2 Monica Sund: Polar hydrology. Norwegian Water Resources and Energy Directorate's work in Svalbard (63 p.)