NATURENS TÅLEGRENSER

Miljøverndepartementet

FAGRAPPORT NR. 44

Critical Loads of Acidity to Surface Waters

SVALBARD

Norwegian Institute for Water Research NIVA

Naturens Tålegrenser

Programmet Naturens Tålegrenser ble satt igang i 1989 i regi av Miljøverndepartementet. Programmet skal blant annet gi innspill til arbeidet med Nordisk Handlingsplan mot Luftforurensninger og til pågående aktiviteter under Konvensjonen for Langtransporterte Grensoverskridende Luftforurensninger (Genevekonvensjonen). I arbeidet under Genevekonvensjonen er det vedtatt at kritiske belastningsgrenser skal legges til grunn ved utarbeidelse av nye avtaler om utslippsbegrensning av svovel, nitrogen og hydrokarboner.

En styringsgruppe i Miljøverndepartementet har det overordnete ansvar for programmet, mens ansvaret for den faglige oppfølgingen er overlatt en arbeidsgruppe bestående av representanter fra Direktoratet for naturforvaltning (DN), Norsk polarinstitutt (NP) og Statens forurensningstilsyn (SFT).

Arbeidsgruppen har for tiden følgende sammensetning:

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Abstract:

Water samples from 162 sites from Svalbard and Bjørnøya were analysed. A precipitation map for Svalbard was prepared. Coloured maps of critical loads and exceedance of critical loads were made for inputs of strong acids. 12 % of the ice-free area of mainly northern Svalbard has very low critical loads (< 25 keq/km^2/yr), while 67 % of Svalbard is well protected against acid precipitation (critical load > 100 keq/km^2/yr). Using ANC_{limit} = 20 µeq/l, a minor exceedance of critical load was recorded in 5 % of the ice-free area of Svalbard, and only in the northern parts.

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For the Administration

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CRITICAL LOADS OF ACIDITY TO SURFACE WATERS

SVALBARD

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PREFACE

The national programme "Naturens Tålegrenser" (Environmental Tolerance Levels) was initiated by the Norwegian Ministry of Environment. The programme will give inputs to the Nordic Action Plan against Air Pollution and to the ongoing activities under the Convention on Long-Range Transboundary Air Pollution (The Geneva Convention). For the work under the Geneva Convention critical loads will be used for establishing new agreements on reduced emissions of sulphur, nitrogen and hydrocarbons.

A steering group with members from the Ministry of Environment has the overall responsibility for the Norwegian programme, while the scientific responsibility is given to a working group with representatives from the Directorate of Nature Management (DN), The Norwegian Polar Research Institute (NP) and the State Pollution Control Authority (SFT).

The working group has requested the Norwegian Institute for Water Research (NIVA) to relate chemical criteria of surface waters to critical loads of acidity for Svalbard.

Sampling was carried out in co-operation with Norwegian Polar Research Institute and with the local authority: "Sysselmannen på Svalbard". Sampling was also done by Heidi Hansen.

A map of precipitation was drawn by Olav Liestøl.

The Norwegian Institute for Land Inventory has prepared the maps of critical load and exceedance of critical load.

This report is a modified English translation of the programme report: "Tålegrenser for sterke syrer på overflatevann - Svalbard".

CONTENTS page

SUMMARY

The international accepted definition of critical loads is:

"a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements do not occur according to present knowledge."

A method for calculation of critical loads and exceedance of critical loads: "The Water Chemistry Method" (worked out at The Norwegian Institute of Water Research), is based on the Acid Neutralizing Capacity of the water. ANC is defined as the difference between the sum of base cations (Ca + Mg + Na + K) and the sum of strong acid anions ($Cl + SO_4 + NO_3$).

Critical loads (CL) and exceedance of critical loads (CL_{ex}) for input of strong acids to surface waters at Svalbard are calculated according to the equations (modified after Henriksen et al. 1992):

$$CL = ([BC]^*_t - ([SO_4]^*_t - [SO_4]^*_d) - [ANC_{limit}])\ Q - BC^*_d$$

$$CL_{ex} = SO_4{}^*_d + NO_{3\,le} - BC^*_d - CL$$

$[BC]^*_t$ is the concentration of non - marine base cations in a surface water sample (µeq/l).
$[SO_4]^*_t$ is the concentration of non - marine sulphate in a surface water sample (µeq/l).
$[SO_4]^*_d$ is the concentration of non - marine deposition of sulphate in the catchment (µeq/l).
$SO_4{}^*_d$ is the annual non - marine deposition of sulphate in the catchment (keq/km^2/yr).
ANC_{limit} is the critical biological value (limit) for acid neutralizing capacity of the water.
(20 µeq/l is an acceptable ANC_{limit} for fish and invertebrates.)
Q is the specific annual water discharge (l/sec/km^2)
BC^*_d is the annual non - marine deposition of base cations (keq/km^2/yr).
$NO_{3\,le}$ is the annual leaching of nitrate from the catchment into the surface water (keq/km^2/yr).
(= nitrate concentrations measured in the surface water sample x Q)

The calculations were based on 162 water samples from Svalbard and Bjørnøya. The samples were analysed for pH, alkalinity, conductivity, turbidity, Ca, Mg, Na, K, SO_4, Cl, Tot-N, NH_4, NO_3, Tot-P, TOC, and fractions of aluminium.

A map showing annual precipitation on Svalbard has been prepared.

Coloured maps for critical loads and exceedance of critical loads have been prepared for Svalbard and Bjørnøya.

12 % of the ice-free area of Svalbard (about 3 400 km^2) has low critical loads, less than 25 keq/km^2/yr or 0.4 g S/m^2/yr. These areas were found mainly in the northern part, but also scattered around all over the islands. Two-thirds of Svalbard is well protected against acid precipitation with a critical load of more than 100 keq/km^2/yr or 1.6 g S/m^2/yr.

5 % of ice free area of Svalbard (about 1 500 km^2) shows exceedance of critical loads. The exceedances are small, less than 25 keq/km^2/yr using an ANC_{limit} of 20 µeq/l. These areas are all located to the northern part of the islands.

1 INTRODUCTION

In the 1970's it was documented that the Norwegian Arctic region received long-range air transported pollutants (Gjessing 1977). In 1981 a permanent station was located at Ny-Ålesund, Svalbard, for monitoring of the long-range air pollutions. Based on precipitation samples for the period 1982 - 1984 from many localities including Ny-Ålesund, Bjørnøya, Hopen and Jan Mayan, isoline maps for sulphate and nitrate were drawn for the Norwegian Arctic region (Fig. 1).

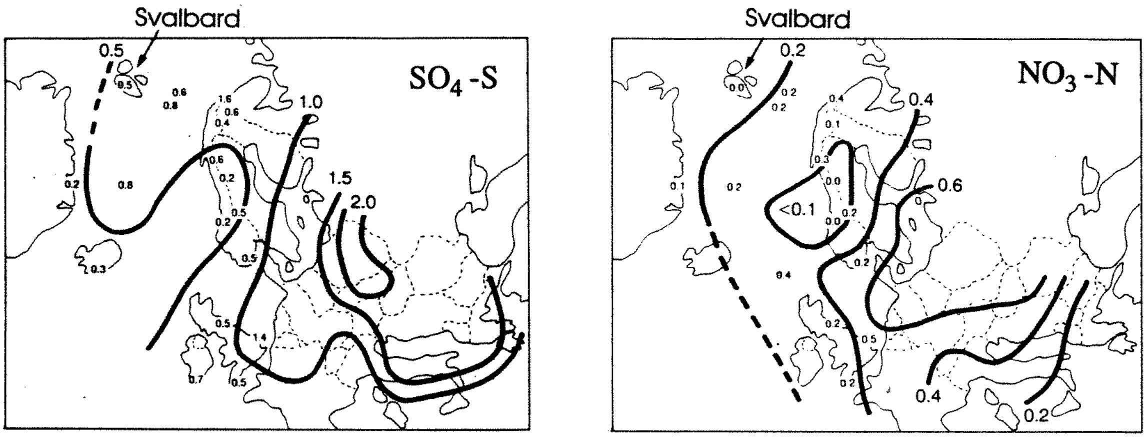


Fig. 1. Mean concentration of non-marine sulphate and nitrate in precipitation at measuring stations in northern Europe, August 1982 - July 1984 (Joranger and Semb 1989).

Fig. 1 shows that Svalbard receives small amounts of sulphate, and information from the permanent station at Ny-Ålesund (State Pollution Control Authority 1992) conferms depositions of small but significant amounts of sulphate and also nitrate.

Acidification of surface waters is caused by inputs of strong acids, mainly sulphate and nitrate. The sulphate ion is normally a mobile anion. After dry or wet deposition in the catchment, all or most of the sulphate moves with the water through the catchment ending in the surface water as an acidifying component. Nitrate and ammonium fertilize the vegetation. In warm and temperate zones, most of the nitrogen compounds are taken up by the trees and the plants. If more nitrogen is deposited than required by the vegetation, the excess, mainly nitrate, will drain into the surface water. There it has the same acidifying effect as sulphate. Therefore, the sum of sulphate and nitrate must be taken into account in the cause of acidification.

In Arctic regions the growth period for the vegetation is very short (0 - 2 months). The ground at Svalbard has permafrost, and most of the deposited nitrogen compounds are expected to be found in the surface waters.

Critical loads of acidity to surface waters have been most thoroughly studied and described for deposition and transport of sulphur through the catchment. Critical loads for sulphur were exceeded many decades ago in exposed regions of Norway and in many other countries in Europe and North America. The effects of acidification are manifested in the form of acidified fish-less lakes and rivers where also significant components of the invertebrate fauna become extinct. Concerning sulphur the cause/effect relationship is well known, and the dose/response relations are expressed in simple models. Most of the deposited sulphur is found in the surface water. The documentation is considerably sparser in the case of nitrogen.

Critical loads for inputs of acidic compounds (sulphate and nitrate) must be established in relation to living organisms. In Scandinavia, critical loads to surface waters have been estimated in relation to effects on fish or invertebrates. It is customary to establish criteria for damage to fish in relation to several chemical components. pH, calcium, labile aluminium and humic content are most often used. However, it is difficult to calculate critical loads according to such combinations. A more practical method for calculations is based on the use of acid neutralization capacity (ANC), which also includes the components mentioned above.

Effects of acid precipitation on surface waters have not been previously examined on Svalbard, and no study has focused on the neutralizing capacity of the lakes and rivers against acid rain on these islands. Information from former studies was rather limited. Chemical analyses from 20 - 30 localities were available for estimation of critical loads and exceedance of critical loads, but the chemical analyses seemed to be of variable quality. The most extensive studies of water chemistry took place on the west coast of Svalbard, near the permanent settlements at Sveagruva, Longyearbyen and Ny-Ålesund (Bøyum and Kjensmo 1970, Bøyum and Kjensmo 1978, Lund 1983, Faafeng et al. 1990), but some data are also available from the Northern- (Jørgensen and Eie 1993) and Southern Spitsbergen (Raskusa-Suszczewski 1963). Some of these localities were re-sampled during this study for comparison of data.

2 MATERIAL AND METHODS

2.1 Selection of sampling localities

Geological maps of Svalbard in 1 : 500 000 (Flood et al. 1971, Winsnes and Worsley 1981, Hjelle and Lauritzen 1982, Lauritzen and Ohta 1984) and topographical maps in 1 : 100 000, all produced by Norwegian Polar Research Institute, were used for selection of sampling localities. An even geographical distribution was sought together with representation of the main geological provinces. Localities with former chemical analysis were also selected. Lakes with surface area of more than 0.2 km^2 were preferred. If not available within reasonable distance, smaller lakes or bigger rivers were sampled. The 162 localities sampled in 1990, 1991 and 1992 are shown in Fig. 2.

A grid system was prepared for Svalbard. Each main grid consisted of 1 ° in longitude x 0.5 ° in latitude, and one grid was 1/16 of a main grid. The area of the grids varied from 91 km^2 to 63 km^2 from south to north at Svalbard. On the main land of Norway the grid area varied between 196 km^2 and 126 km^2, and estimation of critical load for one grid was represented mainly by one sampling locality (Henriksen et al. 1990). Compared to the main land of Norway, the grid area at Svalbard was approximately of half the size, and one sampling locality usually represented two or more grids at Svalbard. The geology of a sampling locality (Flood et al. 1971, Winsnes and Worsley 1981, Hjelle and Lauritzen 1982, Lauritzen and Ohta 1984) determined the grouping of the grids. The total ice-free area of Svalbard is ca 28 000 km^2. 162 sampling localities gives a mean grid area of 175 km^2, the same as on the main land of Norway. Critical load and exceedance of critical load were calculated separately for each of the small grids at Svalbard.

2.2 Analysis of water samples

All samples of water from Svalbard were analysed for pH, conductivity, turbidity, calcium, magnesium, sodium, potassium, sulphate, chloride, alkalinity, total nitrogen, ammonium, nitrate, total phosphorus, total organic carbon, reactive and non-labile aluminium.

Several of the water samples showed very high turbidity caused by high concentrations of silt from the glaciers. Considerable contamination arose resulting in large differences between anions and cations. The problems were solved by filtering and re-analysis of sensitive parameters.

Water samples for analysis of heavy metals were also taken. Ten sites were examined for copper, cadmium, zinc, lead, iron and manganese. Mainly low values were registered.

2.3 Calculations of critical loads and exceedance of critical loads.

Critical loads of acidity to surface waters (CL) have been calculated e.g. for the main land of Norway and northern Europe according to the formula:

$$CL = ([BC]^*_0 - [ANC_{limit}])\, Q - BC^*_d \qquad \text{(Henriksen et al. 1992)}$$

$[BC]^*_0$ is the concentration of non-marine base cations from the pre-acidification period. ANC is the acid neutralizing capacity of the water, and ANC_{limit} is an empirical value of a critical level for an indicator organism. Q is the run-off, and BC^*_d the annual deposition of non-marine base cations.

Critical loads for Svalbard will be calculated according to a somewhat modified formula compared to the one given above.

SVALBARD

Sampling localities at Svalbard and Bjørnøya. (Permission to use the map are given by Norwegian Polar Research Institute).

$[BC]^*_0$ Pre-acidification concentration of base cations.

The sensitivity of acidification for a lake is determined by the weathering rate in the catchment. Deposition of acidic sulphate and nitrate for many years may change the weathering rate and the concentration of base cations in the runoff from the catchment $[BC]^*_t$. The pre-acidification concentration of base cations can be calculated according to the equation:

$$[BC]^*_0 = [BC]^*_t - \sin [BC^*_t/400] \cdot ([SO_4]^*_t - 15 - 0.16[BC]^*_t) \quad \text{(Henriksen et al. 1990)}$$

Svalbard has received and still receives small amounts of acidifying components compared to other parts of Europe. Calculations of $[BC]^*_0$ for Svalbard showed insignificant differences from $[BC]^*_t$. The measured and estimated values for today's concentrations of base cations $[BC]^*_t$ were therefore used instead of $[BC]^*_0$ for calculations of critical loads and exceedance.

ANC_{limit} Critical level of acid neutratization capacity.

Based on empirical data of water quality for fish and invertebrates living in freshwater localities on the main land of Norway, a critical level of ANC_{limit} of 20 µeq/l was recommended (Lien et al. 1992). This value have also been used elsewhere (Henriksen et al. 1992). $[ANC_{limit}]$ of 20 µeq/l is a mean annual value, and includes acid episodes throughout the year in regions receiving moderate to heavy loads of sulphur and nitrogen. In regions of low acid loads and mean ANC concentrations between 20 and 0 µ eq/l, we still find some healthy populations of fish and invertebrates. Svalbard receives low acid loads and the critical level of ANC are probably below 20 µeq/l. However, in order to compare the maps of critical loads and exceedanse of critical loads with the rest of Europe, a critical level of $[ANC_{limit}] = 20$ µeq/l will also be used for Svalbard.

Q Run-off.

There are no run-off maps available for Svalbard. Precipitation data could possibly be used, but the few meteorological stations and uncertain measurements of precipitation is insufficient for mapping of precipitation (Steffensen 1982). However, maps of accumulation of snow on glaciers are available (Liestøl and Roland 1981, presented in Steffensen 1992). Most of the precipitation on Svalbard comes as snow, which is easy to measure, and it is evenly distributed on the glaciers. The accumulation of snow was therefore used as the basis for drawing a precipitation map of Svalbard. The map was drawn by Olav Liestøl (former glaciologist, Norwegian Polar Research Institute) for the purpose of this critical load work (Fig. 3). The precipitation varies considerably with altitude, and the smoothing of the isolines on the map is therefore quite rough. The eastern part of Svalbard had fewer observations, and the uncertainty is somewhat higher there. The run-off of each grid was calculated according to the precipitation minus 15 % evaporation (sublimation), which is the same evaporation as recorded in Finnmark, northern Norway (Central Bureau of Statistics 1978).

BC^*_d and $SO_4{}^*_d$ Deposition of non-marine base cations and sulphate.

Air transported pollutions is continuously measured at Ny-Ålesund since 1981. This is the only long term measuring station on Svalbard, and the deposition values for Ny-Ålesund were used for the whole Svalbard region. The figures are given in the annual reports from the Norwegian State Pollution Control Authority (1989, 1991a, 1991b and 1992). Calculations of critical loads were based on mean deposition values for 1988, 1989, 1990 and 1991, and the figures are listed in Table 1.

Fig. 3. Annual precipitation (mm) of Svalbard (Drawn by Olav Liestøl).

Table 1. Concentrations of non-marine deposition at Ny-Ålesund, Svalbard, for 1988, 1989, 1990 and 1991, and mean values for all years (in μeq/l).

Year	H_+	SO_4-S	NO_3-N	NH_4-N	Ca	Mg	K	Na	BC^*_d
1988	7	17	5	15	20	10	4	2	36
1989	3	24	4	4	22	8	2	0	32
1990	12	21	5	4	14	3	2	0	19
1991	11	21	8	7	25	13	4	5	47
Mean	8	21	6	8	20	9	3	2	34

The data presented in Table 1 were originally not given as sea salt corrected values in the annual reports from the State Pollution Control Authority (1989, 1991a, 1991b and 1992), and the ionic balance showed a small percentage excess of cations. By adjusting to non-marine deposition the relative excess of cations was strongly increased, and for the mean values for all years, the cations were doubled compared to anions. An excess of H^+-ions in the precipitation was observed each year (mean pH between 4.6 and 5.2). A total excess of base cations was therefore not likely. The measurements of pH were probably the most correct together with the measurements of sulphate and nitrate. Reductions of base cations in accordance to the concentrations of anions were therefore done before the calculations of critical loads.

In the period 1982 to 1984 comparisons of air transported pollutions were carried out for four Arctic Norwegian localities, Ny-Ålesund, Hopen, Bjørnøya and Jan Mayen (Joranger and Semb 1989). Also in this study an excess of cations was recorded for Ny-Ålesund, while for the other localities the ionic composition was balanced. The reason for the ionic non-balance at Ny-Ålesund has not been explained.

Former studies of critical loads on the main land of Norway the calculations of exceedance were based on sulphate concentrations of the run-off waters. Higher concentrations of sulphate of geological origin in the catchment caused problems for the calculations. In many areas of Svalbard geological sulphate was present. However, the recent calculations of exceedance of critical loads used the deposition of sulphate and thereby avoided the geological part. Also calculations of critical loads are more complicated when geological sulphate are present. Weathering of sulphate from the catchment reduces the capacity of the surface waters to neutralize the input of air transported sulphate and nitrate, and the weathering sulphate should be subtracted. This can simply be done by subtracting the non-marine deposition of sulphate from the non-marine observations of sulphate from the surface waters ($SO_4{*}_t$ - $SO_4{*}_d$).

<u>$NO_{3\,le}$ Leaching of nitrate from the cathment</u>
In contrast to sulphur which passes through the catchment, nitrogen will to varying degree be retained by the vegetation in the catchment. Due to scattered vegetation and short growing season at Svalbard, only a minor part of the nitrogen deposition, both NO_3 and NH_4, was expected to be retained. After oxidation of NH_4 most of the nitrogen deposition might appear in the surface waters as nitrate. The acidifying contribution of nitrogen was measured as nitrate in the surface waters at Svalbard.

The presented equation for calculation of critical loads (CL):

$$CL = ([BC]^*_0 - [ANC_{limit}])\,Q - BC^*_d \qquad \text{(Henriksen et al. 1992),}$$

was adjusted for Svalbard as outlined above:

$$CL = ([BC]^*_t - ([SO_4]^*_t - [SO_4]^*_d) - [ANC_{limit}])\,Q - BC^*_d$$

Exceedance of critical loads including deposition of sulphate and leaching of nitrate was calculated according to the same formula as for the main land of Norway:

$$CL_{ex} = SO_4{}^*_d + NO_{3\,le} - BC^*_d - CL \qquad \text{(Henriksen et al. 1992)}$$

3 RESULTS AND DISCUSSIONS

3.1 Mapping of critical loads

The map of critical loads at Svalbard is shown in Fig. 4. The critical loads are given at ten intervals, each with a separate colour code. The red colours symbolise the lowest critical loads, orange to yellow intermediate figures, and gradually darker blue colours symbolise increasing values for critical loads. Grids covered by glacier and snow are shown in white colour. Parts of some grids are marked grey. These parts are nunataks and smaller areas (islands) where no permanent surface waters were recorded. The total grey area was 2 336 km^2 or 8.3 % of the ice-free ground.

The lowest critical loads were found on the northern parts of the islands. In addition, low values of critical loads were also observed scattered all over Svalbard including Bjørnøya. However, in addition to the glacier and snow covered areas, the main impression of Fig. 4. is the darker blue grids indicating high critical loads for most of the ice-free archipelago.

The critical loads reflect the main feature of the geological conditions of the bedrock at Svalbard (Winsnes 1988). The lowest critical loads were mainly found on the "hard" gneiss and granitic bedrocks. These rock types are mainly located on the northern parts, but also in the middle and western areas where low critical loads were found. Lower critical loads were also observed in southern and eastern regions of Svalbard where the geology would indicate high critical loads. This could be explained by smaller areas of harder bedrocks. It could also be caused by a sampling period with high contributions of melting water that had little contact with the ground. The ground is usually permanent frozen at Svalbard, and only the upper decimetres melt during the short summer season.

The frequency of critical load intervals on ice-free land areas at Svalbard, presented in table 2, shows that 12 % or about 3 400 km^2 has critical loads less than 25 $keq/km^2/yr$. That is the same low critical loads that was reported for e.g. the highly acidified regions of southern Norway (Henriksen et al. 1990). However, 67 % of the ice-free ground at Svalbard is well protected against acid rain with a critical load of more than 100 $keq/km^2/yr$.

Table 2. Distribution of critical load intervals at Svalbard, calculated according to ANC_{limit} = 20 µeq/l (Bjørnøya not included). The distribution is given as km^2 of ice-free ground, and % of total and ice-free area.

Critical loads $keq/km^2/yr$	Area km^2	Percentage of (total area)	- ice-free area
0 - 25	3.414	(6)	12
25 - 50	1.668	(3)	6
50 - 75	834	(1)	3
75 - 100	1.133	(2)	4
> 100	18.727	(30)	67

3.2 Mapping of exceedance of critical loads

The map of exceedance of critical loads at Svalbard is shown in Fig. 5. The exceedance of critical loads are given in ten intervals, each with a separate colour code. The grids of exceedances for sulphate and nitrate are shown in yellow colours. The non-exceeded areas are marked with various blue colours. Increasing resistance to acidification are marked with lighter to darker blue. For comparison, the same colours were used as for the main land of Norway (Henriksen et al. 1992). The red and orange colour are also marked on the scale of the map, even though so high exceedance has not been observed at Svalbard. Glacier and snow covered grids are shown in white. Parts of some grids are marked grey. These parts are nunataks and smaller areas (islands) where no permanent surface waters were recorded or sampled.

Critical loads and exceedance of critical loads were calculated according to an ANC_{limit} = 20 µeq/l. This is an empirical value of critical limit for fish and invertebrates living in areas receiving acid precipitation (Lien et al. 1992). In areas of low acid input and ANC concentration of surface waters between 20 and 0 µeq/l, healthy populations of fish and invertebrates can be found, e.g. on the main land of Norway. Several freshwater localities at Svalbard also showed ANC values lower than 20 µeq/l, and Svalbard receives low acid inputs. However, the effects of acidification on invertebrates and fish in these Arctic region is not yet documented. Mapping of critical loads and exceedance of critical loads at Svalbard were based on ANC_{limit} = 20 µeq/l because this was the most obvious biological indicator value, and also because the maps become comparable for the whole country.

The frequency of exceedance of critical load intervals on ice-free land areas at Svalbard are presented in table 3.

Table 3. Distribution of exceedance of critical load intervals at Svalbard, calculated according to ANC_{limit} = 20 µeq/l (Bjørnøya not included). The distribution is given as km² of ice-free ground, and % of total and ice-free area.

Exceedance of critical loads keq/km²/yr	Area km2	Percentage of (total area)	- ice-free area.
25 - 0	1.444	(2)	5
0 - -25	2.281	(4)	8
-25 - -50	1.466	(2)	5
< -50	20.586	(33)	73

The critical loads of acid inputs with ANC_{limit} = 20 µeq/l were exceeded for five percent of the ice-free area of Svalbard or almost 1 500 km². The stipulation of ANC_{limit} = 20 µeq/l was essential for both the extent of the exceedance and also for the areas that were exceeded. Eight percent of the ice-free land area, or almost 2 300 km², had values of exceedance between 0 and -25. (Negative values of exceedance mean the critical loads are not exceeded.) This implies that these areas could receive additional amounts of acid input before the critical loads were exceeded. Table 3 also shows that almost 75 percent of ice-free land at Svalbard has high buffering capacity (at least 50 keq/km²/yr, or 0.8 g S/m²/yr), before the critical load of acidity is exceeded.

SVALBARD

Inputs of strong acids

COLOUR MAPS FOR CRITICAL LOADS AND EXCEEDANCE OF CRITICAL LOADS

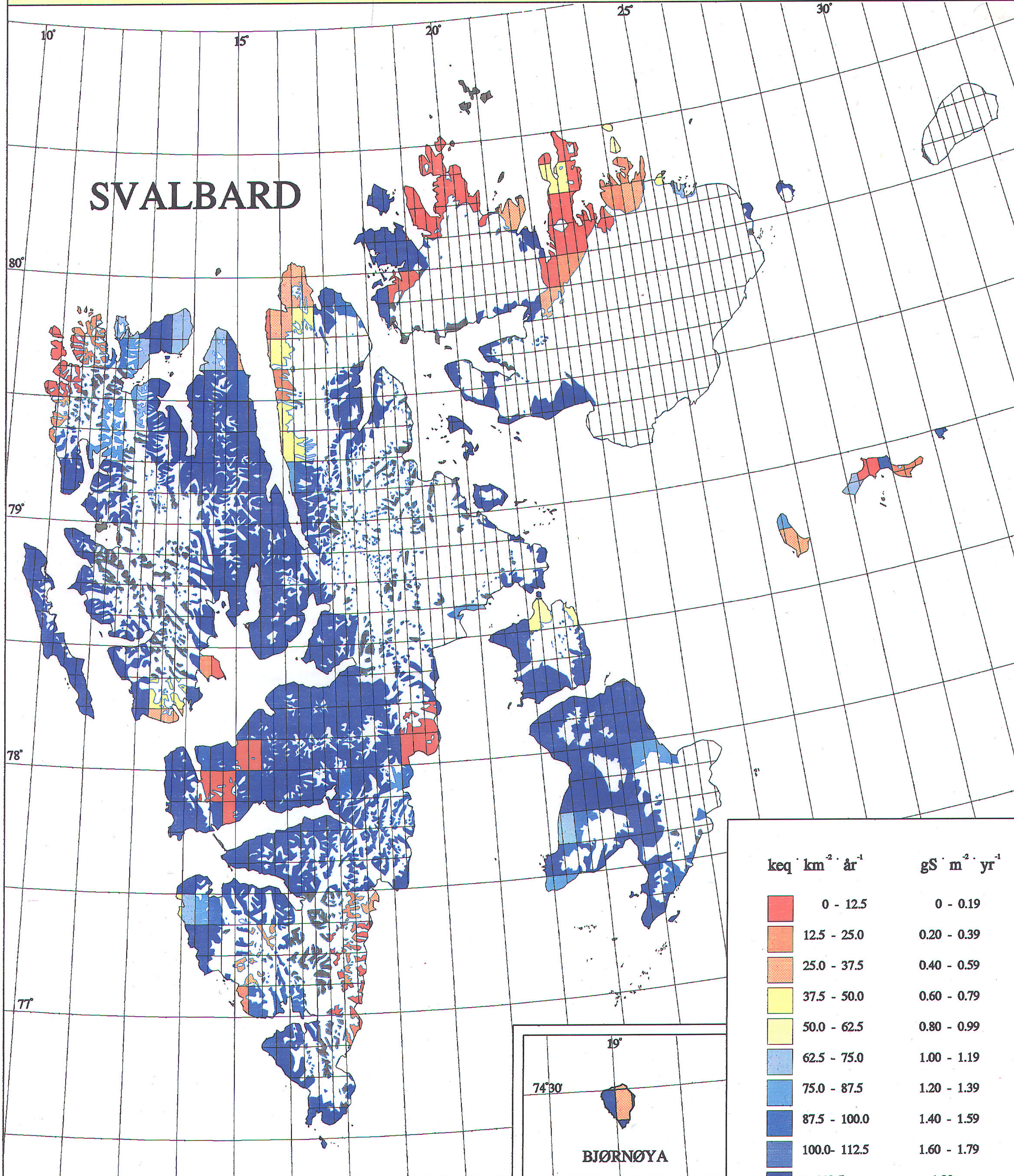
The coloured maps are shown on the next two pages, and the figure captions are given below.

Fig 4. Critical loads of acidity to surface waters at Svalbard. Critical loads are calculated according to ANC_{limit} = 20 µeq/l. Red - orange - yellow - blue illustrate increasing levels of critical loads. White areas represent snow and glaciers, and grey parts show nunataks and small islands not sampled.

Fig 5. Exceedance of critical loads for sulphate and nitrate at Svalbard. Exceeded areas are marked yellow, and non-exceeded are blue. White and grey parts as Fig 4.

Critical Loads - surface waters

ANC_{LIMIT} = 20 ueq · l^{-1}



NIJOS

NATURENS TÅLEGRENSER

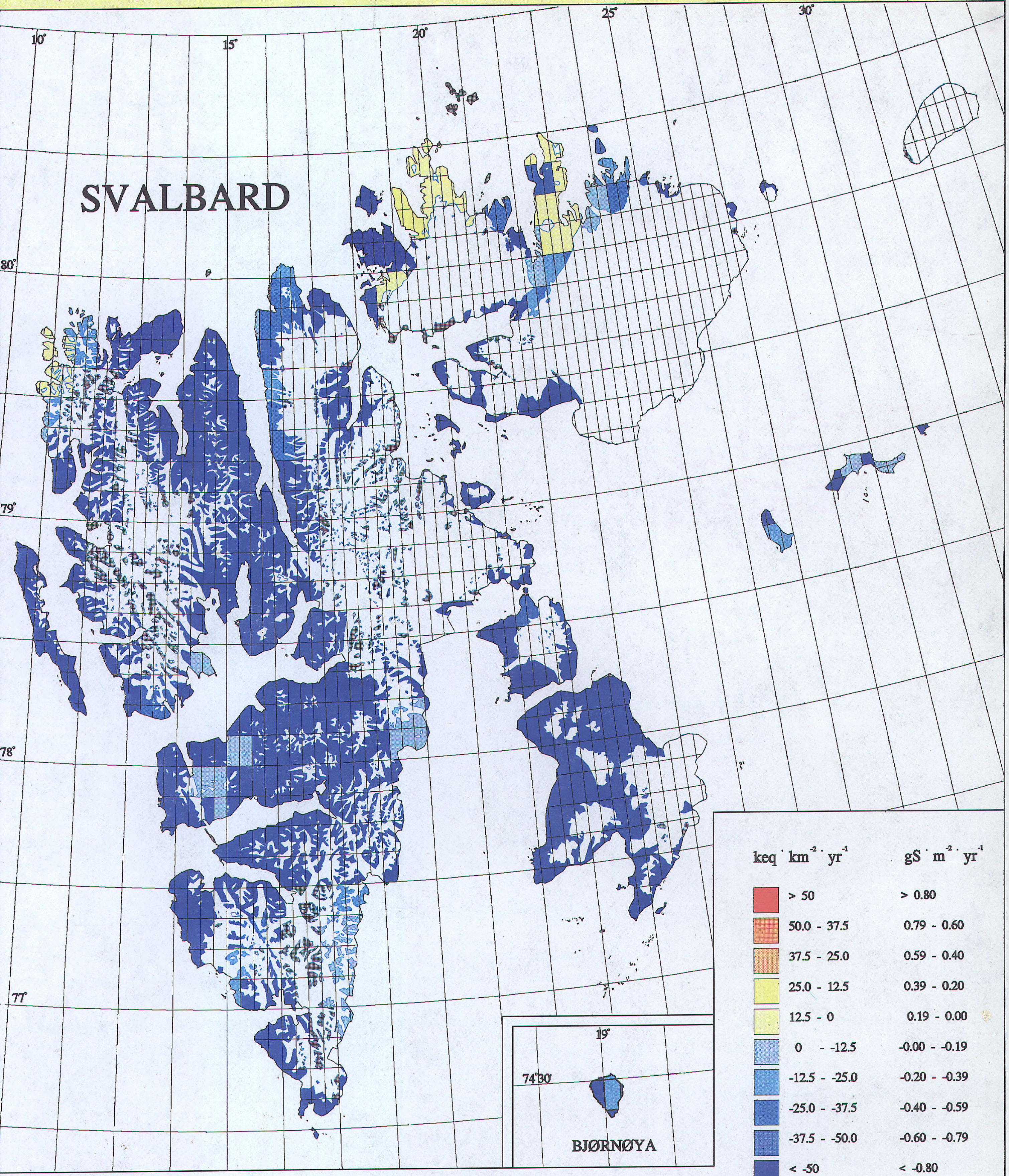
NIVA

100 km

Exceedance of Critical Loads - surface waters

Amounts of sulphur plus nitrogen

ANC_{LIMIT} = 20 ueq · l^{-1}



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100 km

3.3 Comparison with former data from Svalbard

Previous analyses of water from 20 -30 localities at Svalbard were adequate for calculations of critical loads and exceedance of critical loads. Approximately half of these were small ponds and not relevant for estimation of critical loads. According to our criteria, six former localities were re-sampled for comparison with this study. Calculations of critical loads and exceedance of critical loads for both the earlier and the present analyses for this six lakes are given in table 4.

Table 4. Critical loads and exceedance of critical loads calculated according to earlier water analysis from Svalbard. Corresponding figures from this study are given in parenthesis.

Locality, Lake (Literature)	Critical loads	Exceedance of critical loads
Linnévatn (Bøyum and Kjensmo 1978)	257 (209)	–253 (–205)
Linnévatn (Faafeng et al. 1990)	258 (209)	–253 (–205)
Diesetvatn (Lund 1983)	96 (120)	–91 (–115)
Diesetvatn (Faafeng et al. 1990)	135 (120)	–130 (–115)
Mosselvatn (Jørgensen and Eie 1993)	48 (35)	–43 (–30)
Flåtan (Jørgensen and Eie 1993)	30 (28)	–26 (–24)
Femmilsjøen (Jørgensen and Eie 1993)	33 (34)	–30 (–30)
Gunvorvatn (Jørgensen and Eie 1993)	6 (10)	–3 (–6)

The differences of critical loads and exceedance of critical loads are small between this study and the earlier analyses, particularly localities of low critical loads (Lakes Gunvorvatn, Flåtan, Femmilsjøen and Mosselvatn). There are no tendency of increasing or decreasing of critical loads or exceedance of critical loads compared with this data.

4. CONCLUSIONS

Svalbard receives small amounts of long-range air transported components of acidifying sulphur and nitrogen.

Low critical loads of acidity were demonstrated for 12 % of ice-free land at Svalbard. 67 % showed high critical loads.

Small exceedance of critical loads of acidity were calculated for 5 % of the ice-free areas of Svalbard using ANC_{limit} = 20 µeq/l. These areas were located on northern parts of the archipelago.

The calculations of critical loads and exceedance of critical loads do have some uncertainties. Both the models for calculations and the relationship between the water chemistry and the indicator organisms are a matter of discussion. However, the uncertainties are similar to those for the main land of Norway and elsewhere.

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