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Deposition of sulphur and nitrogen components in Norway 1988-1992

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NATURENS TÅLEGRENSER

Preface

Nature Tolerance Levels

The programme on Tolerance Levels in Nature was started by the Norwegian Ministry of Environment in 1989. The programme aims to obtain background material for international agreements on reductions of emissions. Within the Convention on Long Range Transboundary Air Pollution the members have decided that new agreements on emission reduction will be based on the principle of critical load.

A steering group with members from the Ministry of Environment has the overall responsibility of the programme. The following departments in the Ministry are represented in the steering group:

- Department for Nature Conservation and Cultural Heritage
- Department for International Cooperation, Air Management and Polar Affairs
- Department for Water, Waste Management and Industry

The administration of the programme has been given to a working group with representatives from the Directorate for Nature Management (DN), Norwegian Pollution Control Authority (SFT) and Norwegian Polar Institute (NP).

The working group has the following representatives:

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The total deposition of sulphur and nitrogen components in Norway during the period 1988-1992 has been estimated on the basis of available measurement data, as indicated below.

Precipitation chemistry: Annual weighted mean concentrations of non-seasalt sulphate, nitrate and ammonium for the period 1988-1992 at 39 Norwegian, 37 Swedish and 1 Finnish rural monitoring stations.

Precipitation amounts: Annual values from 786 stations operated by the Norwegian Meteorological Institute (DNMI).

Air chemistry: Mean concentrations of sulphur dioxide, sulphate, nitrogen dioxide, sum of nitrate+nitric acid and sum of ammonium+ammonia for 1988-1992 at 15 Norwegian sites.

Wet deposition: Annual weighted mean concentrations of SO_4^{2-}, NO_3^- and NH_4^+ in precipitation were interpolated using the kriging technique and mean values calculated for each 50x50 km^2 EMEP subgrid. Average yearly precipitation amounts in the grid squares were multiplied with the grid concentration values to obtain the wet deposition.

Dry deposition: Mean concentrations of SO_2, SO_4^{2-}, NO_2, NH_4^++NH_3 and NO_3^- +HNO_3 in air were also interpolated using the kriging technique to obtain values for individual grids. The dry deposition of these components has been estimated considering land use data, duration of snow cover and available dry deposition velocities.

Total deposition: By adding the wet deposition and dry deposition the total deposition of sulphur, oxidised nitrogen and reduced nitrogen have been estimated for the period 1988-1992.

Deposition of sulphur and nitrogen components in Norway 1988-1992

1. Introduction

Long range transport of acidifying components is recognised to be the most severe environmental problem in Norway. Abatement strategies so far have been to reduce sulphur emissions, however, not sufficient to reduce depositions down to or below the critical loads in Scandinavia. The new protocol which was signed in 1994 is based on the critical load concept. Critical loads are defined as: "A quantitative estimate of an exposure to one or more pollutants below which significant, harmful effects on specified sensitive elements of the environment do not occur according to our present knowledge" (Nilsson and Grennfelt, 1988).

In order to evaluate critical load exceedances for ecosystems, it is necessary to know the atmospheric inputs with sufficient geographic resolution. This input can be determined from atmospheric disperson models, using emission data, meteorological data, and parameterisation of transformation and deposition processes, or from measurements.

Model calculations of concentration and deposition fields are carried out by the Norwegian Meteorological Institute, as part of the Co-operative Programme for Monitoring and Evaluation of Long-Range Transmission of Air Pollutants in Europe (EMEP) (Iversen et al., 1990).

These calculations employ a one-layer Lagrangian trajectory model with a grid size of 150 x 150 km^2 , which allow very detailed source apportioning of the calculated deposition amounts. Implementation of a multilayer Eulerian model with 50 x 50 km^2 grid resolution is in progress.

Measurements of air quality, precipitation chemistry and precipitation amounts at individual sites may also be used to infer deposition amounts if the number of sites is large enough to reflect the spatial variability. In a country like Norway, with large variability in precipitation amounts, a large number of precipitation gauges are needed. The number of sites needed for determining the geographical variation in the concentrations of sulphur and nitrogen compounds in air and precipitation is fortunately smaller. A total of 15 and 37 sites with measurements of air and precipitation chemistry respectively, is available for determining concentration fields, together with 786 sites which measure precipitation amounts. This provides a good basis for determining the geographical variability of dry and wet deposition.

2. Deposition processes

Sulphur and nitrogen components can be deposited either by precipitation (wet deposition) or by dry deposition. In precipitation, the major species are sulphate (SO_4^{--}), nitrate (NO_3^-) and ammonium (NH_4^+). The major sulphur and nitrogen components in air are sulphur dioxide (SO_2) and particulate sulphate (SO_4^{--}),

nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitrous acid (HNO_3), particulate nitrate (NO_3^-), ammonia (NH_3) and particulate ammonium (NH_4^+).

Wet deposition is generally obtained from measured precipitation amounts and the concentration of chemical species in the precipitation samples. This procedure does not include deposition by fog or dew, since the usual precipitation sampler usually collects no precipitation sample from such events. However, since the deposition of pollutants by fog droplets is related to ambient concentrations and fog frequency, this phenomenon is treated together with dry deposition.

When using measured concentrations in ambient air to infer dry deposition of sulphur and nitrogen, seasonal deposition velocities (Voldner and Sirois, 1986) may be used which summarize the transfer resistances calculated from more detailed dry deposition models (eg. Hicks et al., 1987). Such extrapolation from detailed modelling also requires knowledge of climatic conditions and ground cover characteristics. In view of the large uncertainties involved, particularly in connection with variation in ground cover, plant growth and climatic conditions within Norway, a more simplistic approach was chosen.

At a recent workshop in Gothenburg (Lövblad, Erisman and Fowler, 1993) the various dry deposition processes and deposition of fog droplets were discussed. This discussion will therefore not be repeated here. Instead a short description will be given for each component on how the dry deposition has been estimated from the measured concentration of each airborne component. The procedures are chosen to be as simple and straightforward as possible, taking into account differences in ground cover, climatic conditions and exposure to pollutants.

Sulphur dioxide is the most important gaseous compound in relation to dry deposition. Under dry conditions, the deposition is mainly regulated by stomatal resistance. However, one of the outcomes of the Gothenburg workshop was to focus on absorption of sulphur dioxide on wetted foliage as an explanation for "dry deposition" under wintertime conditions. Because sulphur dioxide concentrations in ambient air are relatively high in winter, and because of enhanced frequency and duration of wetness, this may explain a relatively large part of the sulphur deposition as inferred from canopy throughfall measurements, particularly in coastal areas.

From budget studies and canopy throughfall experiments Hultberg and Grennfelt (1992) found that coniferous forest stands in southern Sweden collected 2-3 times more sulphur than adjoining clear-cut areas. Spruce trees will collect 30-70% more sulphur dioxide than pine or deciduous trees, due to higher leaf area index (Ivens et al., 1990). Trees situated at the edge of a forest or on a hill will be more exposed than trees inside a forest.

Snow crystals, on the other hand, do not absorb sulphur dioxide. Therefore, the dry deposition of sulphur dioxide to snow surfaces depends of absorbed sulphur dioxide in the small volumes of concentrated salt solution which exist in equilibrium with the snow crystals down to approximately -16°C. (Valdez et al., 1987). The result is a very small deposition of sulphur dioxide to snow surfaces as

well as to snow-covered vegetation at temperatures below 0°C. Even nitric acid does not deposit onto snow surfaces at below -2°C (Johansson and Granat, 1987).

For sulphur dioxide therefore, a general dry deposition velocity of 0.3 cm s^{-1} was chosen for non-forested areas, and 0.8 cm s^{-1} for forested areas (productive forest land). It is implicated that, while stomatal uptake rate is reduced during the non-growing season, this is largely compensated because of a higher occurrence of wet surfaces. The deposition rate for SO_2 has been strongly reduced for all types of surface cover in the presence of a lasting snow cover.

The deposition velocity for NO_2 is not influenced by the presence of wet surfaces and has been shown mainly to be regulated by stomatal control. A generally low deposition velocity of 0.2 to 0.4 cm s^{-1} serves to keep the dry deposition of this component relatively insignificant (Johansson, 1987). Only the sum of nitric acid and nitrate (in aerosol particles), is available from the measurements. Sampling by the denuder technique indicates that in the rural areas of Sweden, the particle phase is dominating (Ferm, 1988). This has been confirmed in Southern Norway within an EMEP measurement campaign (Bartonova, pers. com.). Cascade impactor measurements indicate that the nitrate is mainly present in the form of particles larger than 2 μm (Hillamo et al., 1992). A relatively large deposition velocity has therefore been chosen for this component.

While nitrate is mainly associated with larger particles (>2 μm), the reduced nitrogen species will mainly consist of submicron ammonium sulphate and gaseous ammonia. Denuder measurements have indicated that the concentration of gaseous ammonia is low, and occurs only when there is an excess of NH_3 + NH_4^+ over the concentration of aerosol sulphate. The only exception is in areas influenced by local emissions from farms in connection with animal husbandry and manure. The Norwegian sites Skreådalen and to some extent Søgne and Svanvik are periodically influenced by local emissions of ammonia. Gaseous ammonia will have a relatively high deposition velocity, but is probably of very local origin.

The dry deposition rate for submicron particles is a controversial issue. While some experiments indicate significant deposition rates, particularly to coniferous forest (e.g. Dollard and Vitols, 1980), other studies and theoretical considerations imply that the deposition rate is low. The deposition velocities chosen for sulphate and ammonium in aerosols also include deposition by deliquescing sulphate droplets under conditions with high humidity and advection fogs. Particle growth in periods with high relative humidity (e.g. > 95%) may give significant deposition of sulphate particles, and to coniferous stands in particular. The latter processes are important at sites which are frequently exposed to advection fogs and low clouds. In mountainous regions cloud water deposition may exceed annual precipitation (Lovett, 1990; Dollard et al., 1983). Occult deposition may have a strong effect in the ecosystems because of the high concentrations of pollutants found in cloud and fog water, but is less important for estimating the total deposition in calculations of critical loads using a resolution of 50x50 km^2.

It has been suggested to use throughfall monitoring (e.g. Ivens, 1990) as an alternative method for deposition monitoring. For sulphur, the throughfall is a

good measure of the total deposition, as observed in the runoff from gauged catchments at the Lake Gårdsjön experimental area (Hultberg and Grennfelt, 1992). Measurement of canopy throughfall has been carried out at Birkenes (Bjor et al., 1974). The Norwegian Institute for Forest Research (NISK) has maintained a network of stations for measurement of canopy throughfall since 1988 (Horntvedt et al., 1993). These measurements indicate a low excess deposition, typically in the order of 10-30%, which may be due to either sulphate or sulphur dioxide.

Table 1 summarizes the "deposition velocities" which have been used to infer dry deposition from measured concentrations of airborne sulphur and nitrogen compounds in this work:

Table 1: Deposition velocities (cm s^{-1}) for different components of sulphur and nitrogen.

Component	Land use classification			
	Arable land	Forest	Other	Snow
SO_2	0.3	0.8	0.3	0.02
SO_4^{--}	0.2	0.4	0.2	0.1
NO_2	0.2	0.4	0.2	0.02
Sum (HNO_3+NO_3)	1.0	2.0	1.0	0.5
Sum (NH_3+NH_4^+)	0.2	0.4	0.2	0.1

3. Data used for mapping

NILU started routine sampling of precipitation and air in background areas on daily basis in 1971, with most sites located in the southernmost parts of Norway. In later years the measuring network has expanded to cover all regions in Norway. In 1992 the network consists of some 40 stations serving different monitoring programmes:

- "Monitoring programme for long range transported polluted air and precipitation" financed by the State Pollution Control Authority (SFT). In 1992 this programme includes 12 stations, of which 7 are EMEP-stations (European Monitoring and Evaluation Programme).

- Since 1985 the "Monitoring programme for forest damage" has been financed by the State Pollution Control Authority (SFT) and the Ministry of Agriculture, which in 1992 included a total of 13 sites.

- In the "Monitoring programme for Terrestrial Ecosystems" financed by the Directorate for Nature Management, NILU has since 1990 had measurements at 5 sites.

The remaining sites are part of other projects, of which some are financed by NILU.

All sites are located in rural areas and are believed to give good estimates of long range transported pollutants. In regions with local sources such as emissions from

industry, traffic or agriculture, pollutant levels may be significantly higher. In this work no corrections for local sources have been performed.

Information about the sites and the results for the years used in this report has been published in SFT 1989, SFT 1991, SFT 1991b, SFT 1992 and SFT 1993.

Precipitation samples are collected in bulk-samplers on a daily or weekly basis. Precipitation amount is measured by local observers and the samples are sent to NILU for analysis of all main components. Analysis results are tested for ion balance and the measured conductivity is compared with calculated conductivity. Filter-pack samples are analysed for SO_2, SO_4, HNO_3+NO_3 and NH_3+NH_4, while absorbing solutions are analysed for NO_2. At one site gas/particle distributions for HNO_3/NO_3 and NH_3/NH_4 have been determined by the use of annular denuder/filter-pack sampling in 1992-93. All results are checked against expected values and results from neighbouring sites. Obviously contaminated samples are rejected.

The total background network represents more than 3000 precipitation samples and about 8000 air samples per year. Figure 1 shows the location of the background stations and the measuring programme.

In addition concentrations in precipitation from the Swedish national network and one Finnish station, and air concentrations at the Swedish EMEP-stations have been used in the statistical analysis. The Swedish data on wet deposition consist mainly of monthly bulk precipitation chemistry from 37 sites run by the Swedish Environmental Research Institute (IVL). Figure 1.1 in Appendix shows the location of all background sites used in the analysis.

The precipitation amount data used for the calculations of the wet deposition are taken from the national meteorological observation network (DNMI). Data from 786 sites for the five-year period 1988-1992 have been applied. Figure 1.2 in Appendix shows the location of the meteorological sites.

4. Interpolation

The interpolation of the concentrations in precipitation and air from fixed sites to a regular grid is done by kriging, which is a statistical method that can be used to estimate unknown data from neighbouring measurements. The method was originally developed for geostatistical purposes (Matheron, 1963, 1971; Journel and Huijbregts, 1981), but has also been used for the past 12 years in connection with environmental studies, e.g. long range transported air pollutants in Europe (Simpson and Olsen, 1990, Schaug et al. 1991 and 1993).

Linear kriging provides the best linear unbiased estimator for a variable (Journel and Huijbregts, 1978). Non-linear kriging (Journel and Huijbregts, 1978: Armstrong and Matheron, 1986) would give more accurate estimates, but is far more complicated and requires much more statistical information. There are three levels of linear kriging: simple kriging where the expectations of the variable are known; ordinary kriging with unknown but stationary expectations; and universal

kriging where there is a drift in the data. In universal kriging the expectations are neither stationary nor known, but their functional form has been identified.

The kriging weights are computed from a variogram, which measures the degree of correlation among sample values in the area as a function of distance and direction of samples.

All interpolations in this work were performed using universal linear kriging. A grid size of 50x50 km^2 has been applied (EMEP subgrid). The applied grid is shown in figure 1.4 in Appendix.

5. Data analysis

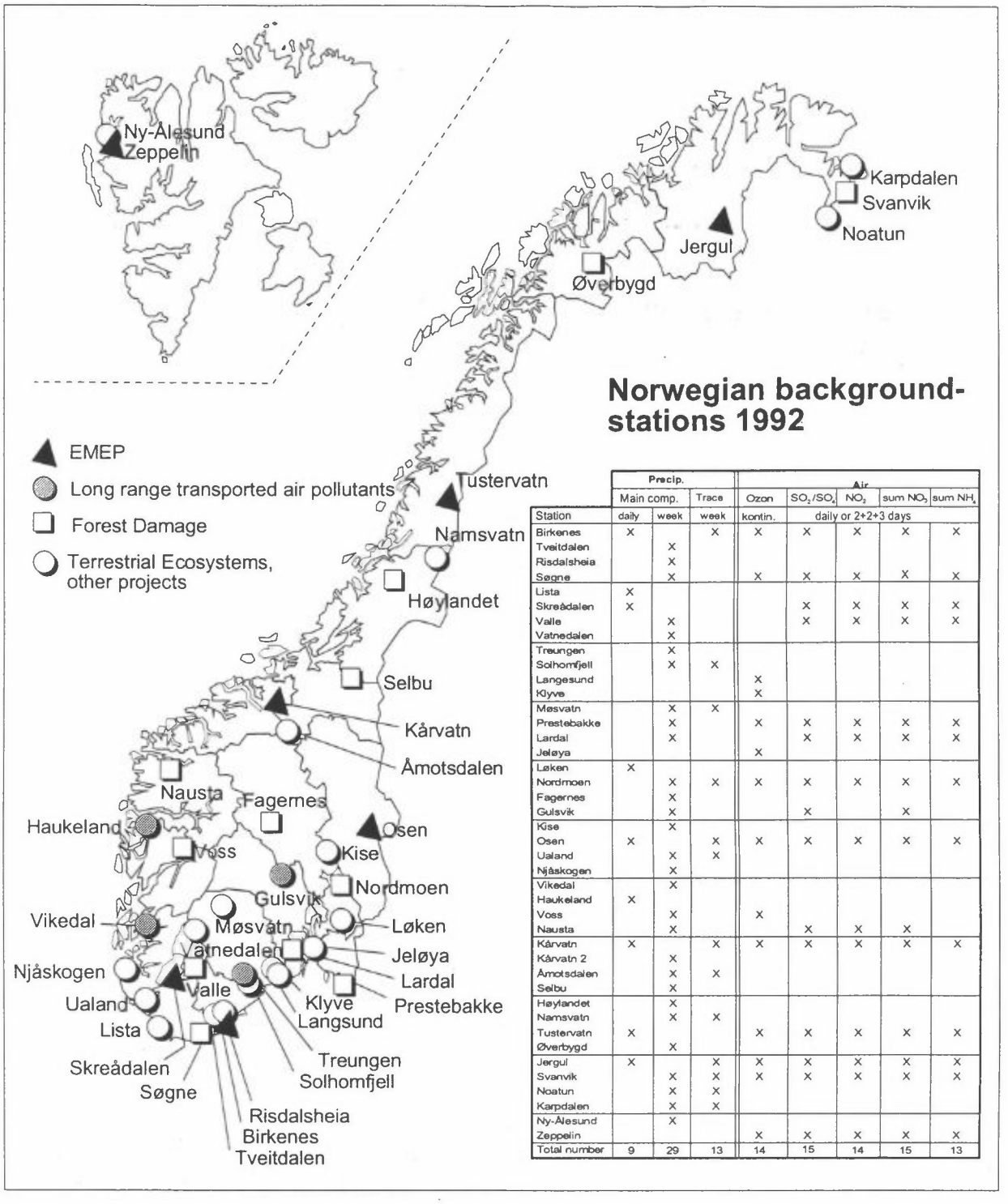
Mean airborne concentrations of SO_2, SO_4^{--}, NO_2, sum NO_3^-+HNO_3 and sum NH_4^++NH_3, measured at 15 Norwegian sites, were interpolated using the kriging technique to obtain concentration values for individual grids. The dry deposition of these components has been estimated, considering land use data, duration of snow cover and estimated dry deposition velocities. The applied statistics on land use and duration of snow cower are shown in figure 1.5 and 1.6 in appendix, respectively.

The yearly averages of sulphate, nitrate and ammonium in precipitation measured at a total of 39 Norwegian background stations have been used to calculate a concentration field for each year using the kriging interpolation. In addition, results from 37 Swedish and 1 Finish background stations have been used in the kriging to give a better approximation along the border area. This gives a total of 77 stations, although for some stations some data are missing.

To provide deposition values for each 50x50 km^2 grid, a precipitation value has been calculated as the average precipitation amount for the meteorological stations in the grid square. In some of these grid squares the number of meteorological stations is small, making the results unreliable. Therefore in the grid cells with less than three meteorological stations, the precipitation values are calculated as the average of the values in the up to eight adjacent grid squares. To further reduce this uncertainty only the average for the five-year period 1988-1992 is reported. The average precipitation amount in the individual grid cells are given in table 1.1 in Appendix.

The total deposition of sulphur, oxidised nitrogen and reduced nitrogen for the period 1988-1992 in each grid cell was calculated as the sum of the dry and wet deposition. The results for the individual grids are given in Table 1.1 in Appendix.

The total depositions are in addition given on maps in figures 2, 3 and 4, using wet deposition for each DNMI site calculated on a yearly basis, added the dry deposition for the respective grid cell. The maps are produced using Uniras interpolation routines.



	Precip.			Air				
	Main comp.		Trace	Ozon	SO_2/SO_4	NO_3	sum NO_3	sum NH_4
Station	daily	week	week	kontin.	daily or 2+2+3 days			
Birkenes	X		X	X	X	X	X	X
Tveitdalen		X						
Risdalsheia		X						
Søgne		X		X	X	X	X	X
Lista	X							
Skreådalen	X				X	X	X	X
Valle		X			X	X	X	X
Vatnedalen		X						
Treungen		X						
Solhomfjell		X	X					
Langesund				X				
Klyve				X				
Møsvatn		X	X					
Prestebakke		X		X	X	X	X	X
Lardal		X			X	X	X	X
Jeløya				X				
Løken	X							
Nordmoen		X	X	X	X	X	X	X
Fagernes		X						
Gulsvik		X			X		X	
Kise		X						
Osen	X		X	X	X	X	X	X
Ualand		X	X					
Njåskogen		X						
Vikedal		X						
Haukeland	X							
Voss		X		X				
Nausta		X			X	X	X	
Kårvatn	X		X	X	X	X	X	X
Kårvatn 2		X						
Åmotsdalen		X	X					
Selbu		X						
Høylandet		X						
Namsvatn		X	X					
Tustervatn	X			X	X	X	X	X
Øverbygd		X						
Jergul	X		X	X	X	X	X	X
Svanvik		X	X	X	X	X	X	X
Noatun		X	X					
Karpdalen		X	X					
Ny-Ålesund		X						
Zeppelin				X	X	X	X	X
Total number	9	29	13	14	15	14	15	13

Figure 1: Norwegian background stations and measuring programme.

6. Discussion

The highest concentrations of sulphur and nitrogen components occurs along the southern coast from Vest-Agder to Østfold, whereas the concentrations are low north of Møre og Romsdal (62°N). High concentrations of sulphur dioxide are also observed near the Russian border, due to large emissions from nickel smelters. The high total deposition is highest in the south-western part of Norway is due to a combination of relatively high concentrations and large precipitation amounts.

The relatively lowest depositions of sulphur and nitrogen were observed along the Swedish border from Finnmark in the north down to Oppland in central Norway. In these areas the annual precipitation amounts may be as low as 200-500 mm compared to more than 3000 mm along the western coast of Norway.

Maximum depositions of excess (non-marine) sulphur exceed 1.7 g S m^{-2} in gridcell no. 4, whereas the corresponding values in the neighbouring gridcells are in the range 1.29-1.53 g S m^{-2}. These values are approximately one order of magnitude higher than the sulphur depositions in gridcells 65-66, 149-150 and 156-157.

The pattern of nitrogen deposition is rather similar to the deposition of sulphur. This is partly due to the importance of the precipitation frequency and amounts on the deposition of both species. The largest depositions of oxidised and reduced nitrogen were 1.31 and 1.12 g N m^{-2}, respectively. In some regions local sources of NH_3 and NO_x may give a significant contribution to the nitrogen deposition.

The sources of ammonia and nitrogen oxides are different from the sources of sulphur dioxide emissions, and the geographical distributions of these emissions are also somewhat different, with larger emissions of nitrogen dioxide and ammonia in relation to sulphur dioxide in Western Europe, compared to Eastern Europe. This is barely reflected in the composition of precipitation samples in Southern Norway with ratio of sulphur deposition to the deposition of oxidised- and reduced nitrogen typically around 1.5. The ratio of sulphur to nitrogen is increasing in central Norway and further north, reaching values up to 5-6 in Finnmark.

The ratio of oxidised nitrogen to reduced nitrogen is in the range of 1-1.3 in Southern Norway. In gridcells 100-140 and 180-191 the ratio is in the range 0.6-0.9. The lower ratio in these gridcells is probably due to a relatively higher frequency of easterly winds, containing lower concentrations of oxidised species of nitrogen.

Adding up the values in Table 1.1 gives a total yearly deposition in Norway of approximately 150 000 tonnes sulphur and 160 000 tonnes nitrogen. Compared with similar estimates for the period 1983-87 (Pedersen et al., 1990) there has been a reduction in sulphur deposition of 13% and a 15% reduction in nitrogen deposition.

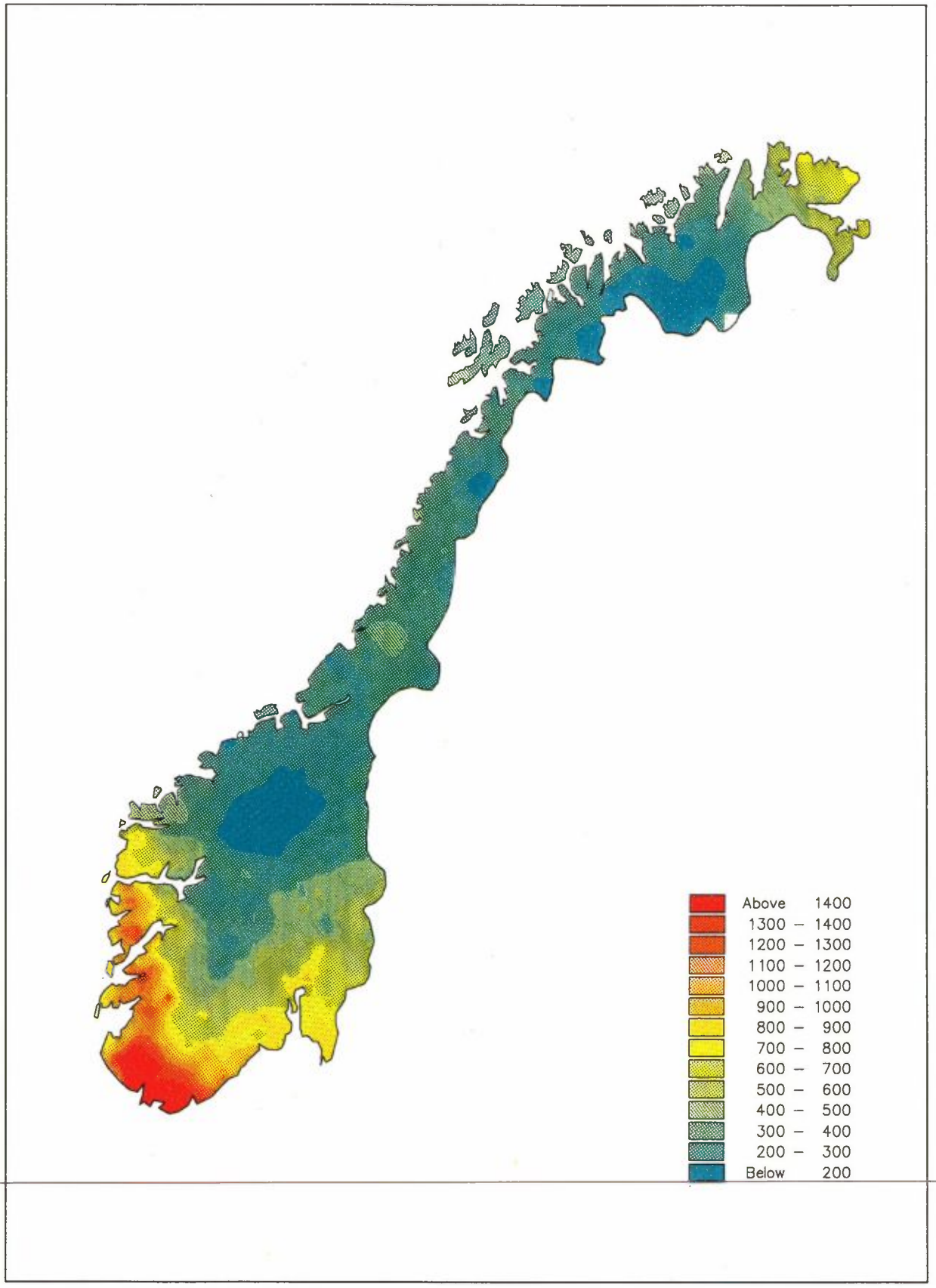


Figure 2: Total sulphur deposition 1988-1992 (mg S m^{-2} $year^{-1}$).

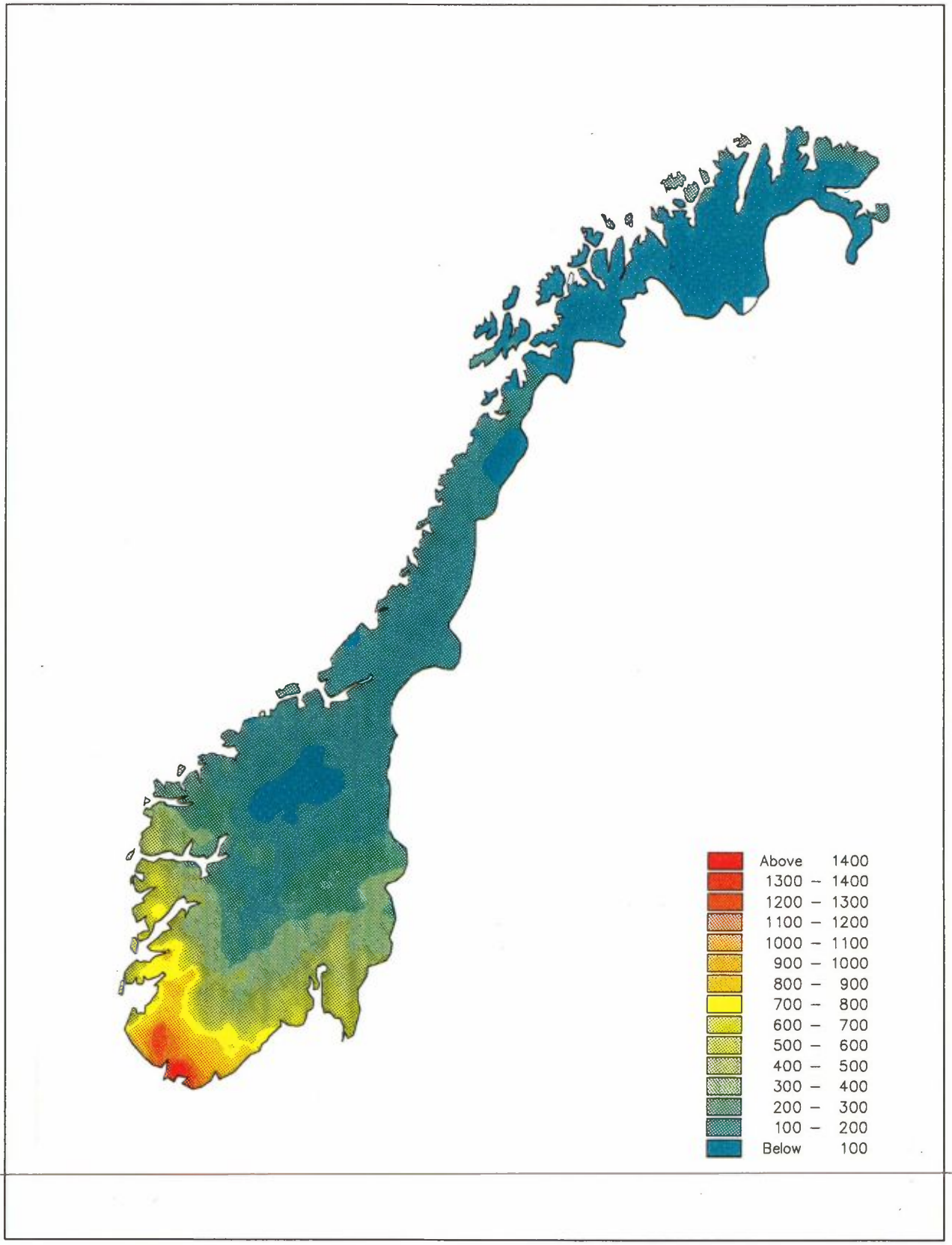


Figure 3: Total deposition of oxidised nitrogen 1988-1992 (mg N m^{-2} $year^{-1}$).

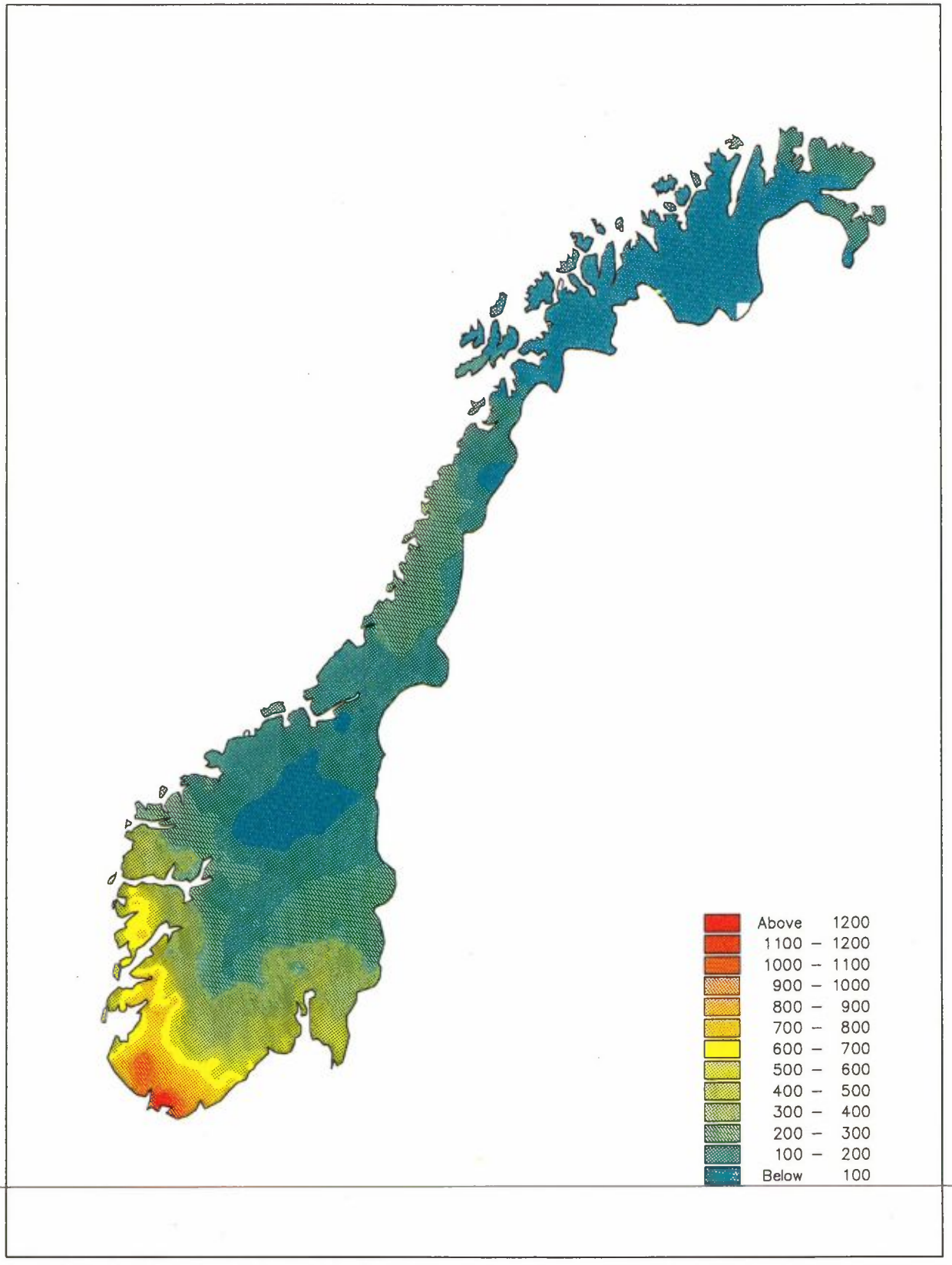


Figure 4: Total deposition of reduced nitrogen, 1988-1992 (mg N m^{-2} $year^{-1}$).

The reductions are largest in the south-eastern part of Norway, while in the south-east depositions are somewhat larger due to large precipitation amounts in the period 1988-92. In central and northern Norway there has been minor reductions. Although there are some slight differences in the way depositions have been estimated for these periods, this is assumed to be of minor importance for the final results.

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Voldner, R.C. and Sirois, A. (1986) Monthly mean spatial variations of dry deposition velocities of oxides of sulphur and nitrogen. *Water, Air, Soil Poll., 30*, 179-186.

Appendix A

Figures 1.1-1.6 and Table 1.1

Figure 1.1: Norwegian, Swedish and Finnish background stations used for interpolating concentration fields.

Figure 1.2: Location of the meteorological stations used in calculating wet deposition.

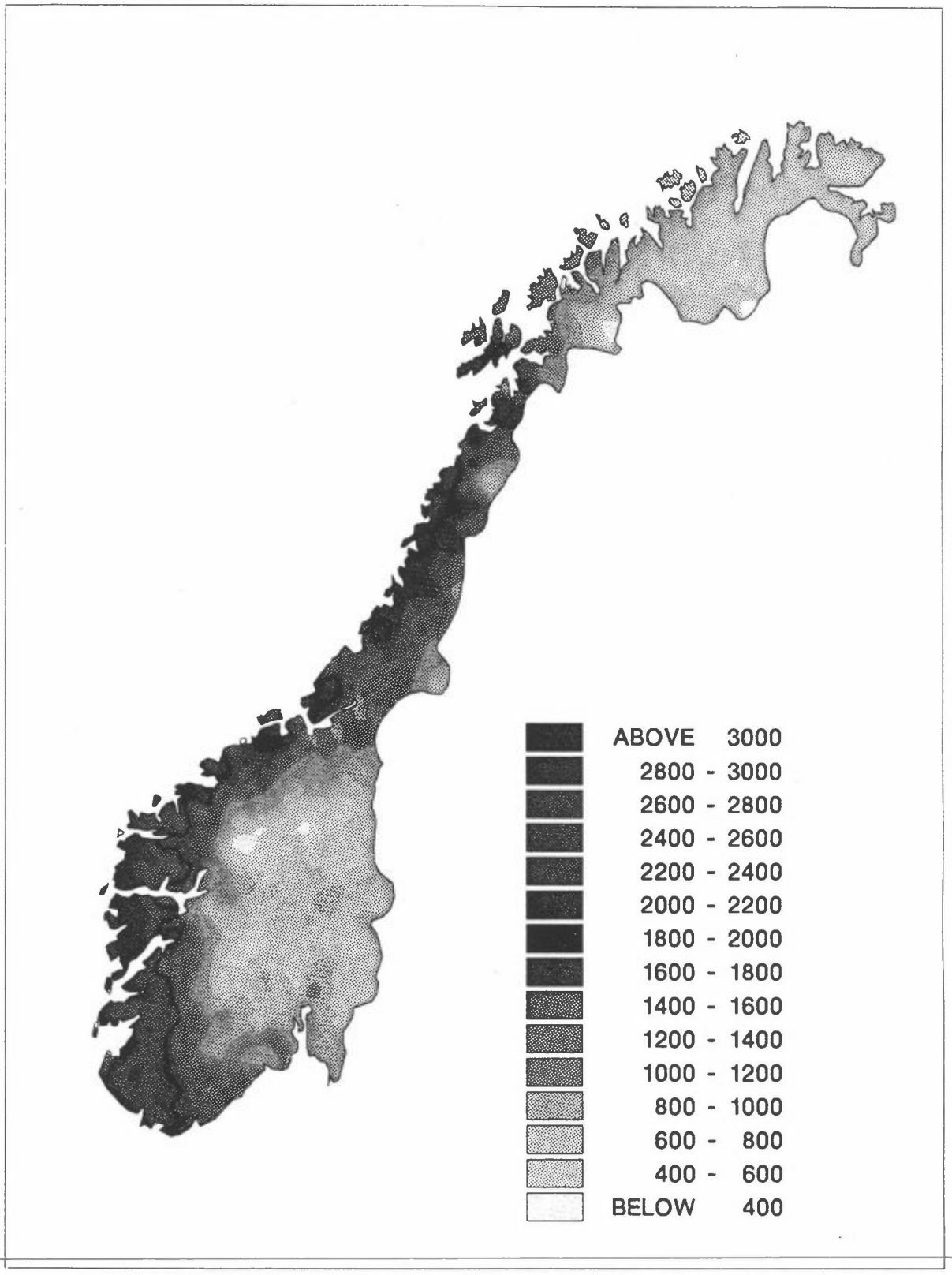

Figure 1.3: Precipitation amount calculated as the five-year average 1988-1992, for the meteorological sites.

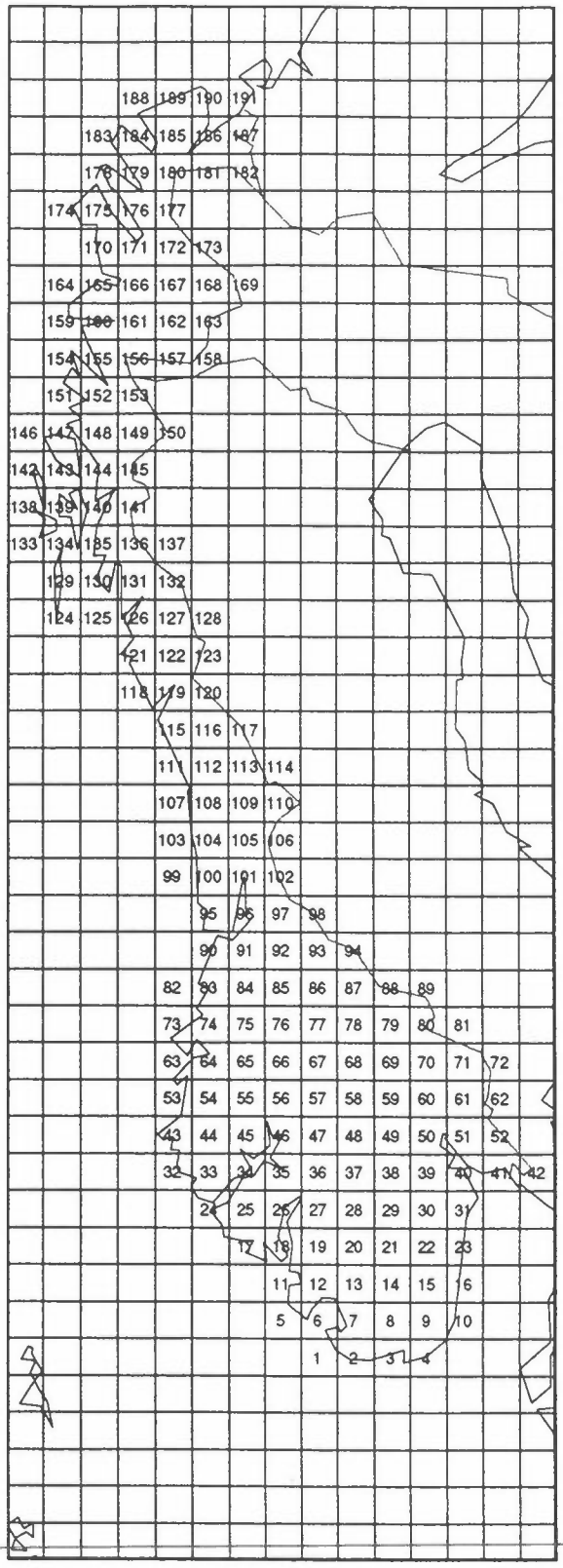

Figure 1.4: The 50x50 km² grid (EMEP subgrid) used for interpolating concentration fields. Grid reference numbers are also given.

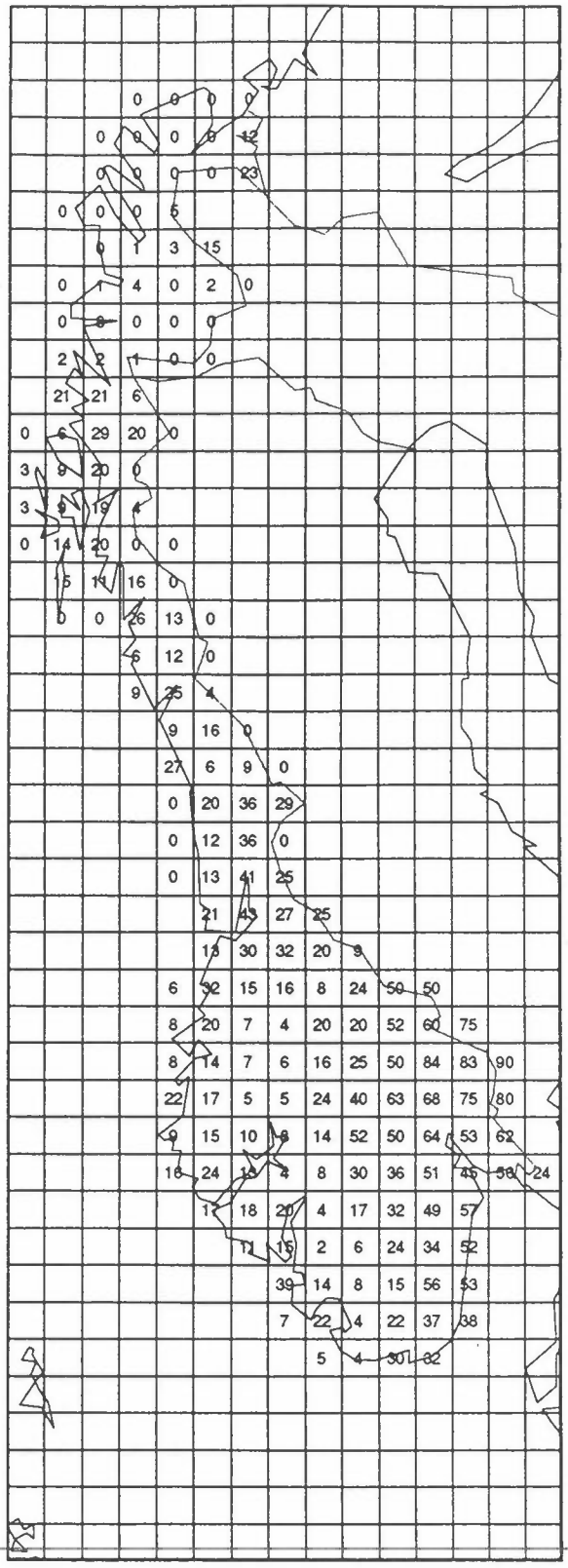

Figure 1.5: Percentage productive forest in individual grids, used in estimating dry deposition.

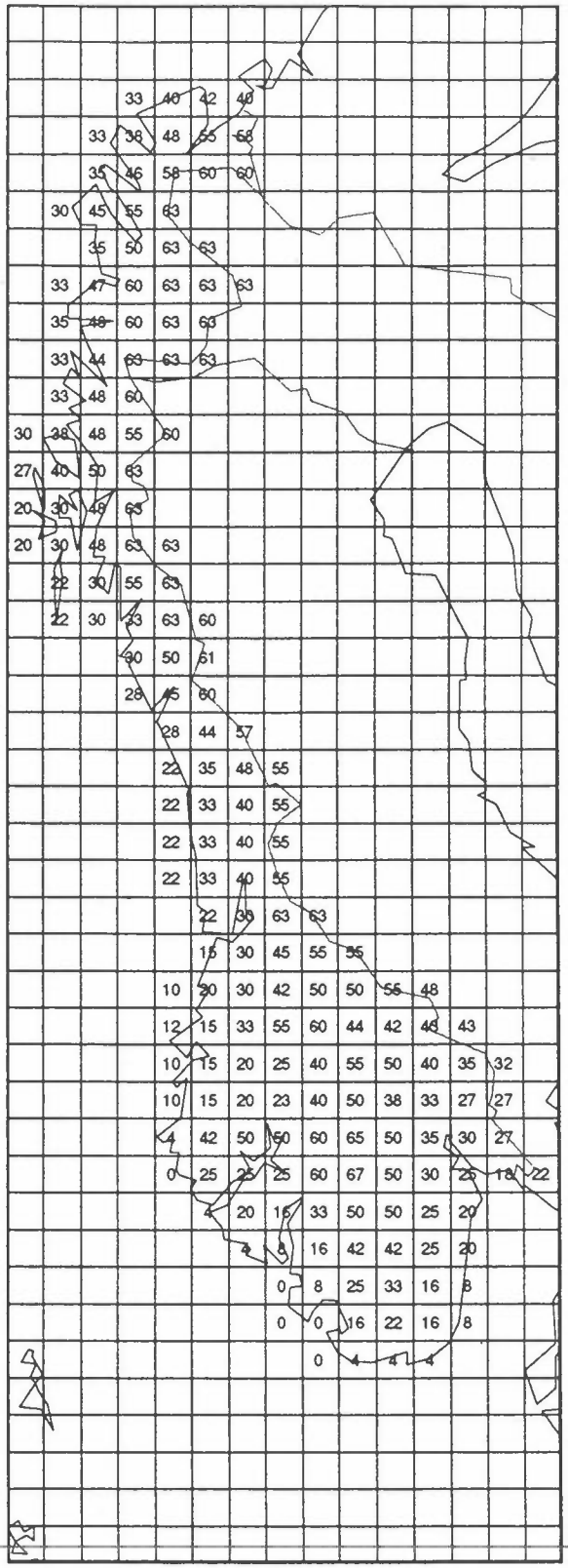

Figure 1.6: Duration of snow cover, in percent of the year.

Table 1.1: Values of each 50x50 km² square (see figure 1.4).

Grid no.	Grid area (km²)	Precipitation (mm)	Total sulphur	Oxidised nitrogen	Reduced nitrogen	Total sulphur	Total nitrogen
			(grammes/m²)			(tonnes in grid)	
1	100	1 862	1.05	0.76	0.67	105	143
2	1 270	1 894	1.18	0.92	0.78	1 499	2 159
3	1 060	2 007	1.50	1.18	0.98	1 590	2 290
4	950	1 947	1.72	1.31	1.12	1 634	2 309
5	430	1 556	0.73	0.48	0.46	314	404
6	450	1 533	0.81	0.56	0.53	365	491
7	2 480	2 465	1.28	0.97	0.83	3 174	4 464
8	2 500	2 298	1.45	1.12	0.94	3 625	5 150
9	2 480	1 845	1.53	1.12	0.97	3 794	5 183
10	280	1 283	1.29	0.93	0.81	361	487
11	1 310	2 259	0.98	0.59	0.58	1 284	1 533
12	2 450	2 522	1.13	0.74	0.68	2 769	3 479
13	2 500	2 508	1.13	0.87	0.72	2 825	3 975
14	2 450	1 374	0.80	0.62	0.50	1 960	2 744
15	2 500	1 376	1.09	0.81	0.67	2 725	3 700
16	750	1 165	1.13	0.83	0.67	848	1 125
17	1 830	2 773	0.93	0.52	0.52	1 702	1 903
18	1 950	3 036	1.15	0.67	0.64	2 243	2 555
19	2 500	2 250	0.92	0.60	0.54	2 300	2 850
20	2 500	1 741	0.75	0.56	0.46	1 875	2 550
21	2 500	1 015	0.59	0.44	0.36	1 475	2 000
22	2 500	1 125	0.85	0.61	0.50	2 125	2 775
23	1 350	1 033	0.94	0.67	0.54	1 269	1 634
24	1 150	3 197	0.85	0.43	0.48	978	1 047
25	2 500	3 380	1.02	0.56	0.59	2 550	2 875
26	2 250	2 324	0.82	0.48	0.46	1 845	2 115
27	2 450	1 336	0.55	0.35	0.33	1 348	1 666
28	2 400	792	0.39	0.27	0.24	936	1 224
29	2 500	904	0.55	0.38	0.33	1 375	1 775
30	2 500	971	0.73	0.52	0.42	1 825	2 350
31	1 930	937	0.84	0.59	0.47	1 621	2 046
32	940	2 853	0.56	0.27	0.30	526	536
33	2 450	3 286	0.78	0.43	0.42	1 911	2 083
34	2 360	1 921	0.54	0.31	0.34	1 274	1 534
35	2 450	1 512	0.50	0.32	0.34	1 225	1 617
36	2 500	844	0.36	0.23	0.22	900	1 125
37	2 500	637	0.34	0.22	0.21	850	1 075
38	2 500	840	0.55	0.36	0.33	1 375	1 725
39	2 500	850	0.66	0.45	0.38	1 650	2 075
40	1 730	904	0.78	0.54	0.43	1 349	1 678
41	1 250	863	0.86	0.58	0.44	1 075	1 275
42	125	843	0.88	0.57	0.46	110	129
43	1 375	2 698	0.47	0.23	0.25	646	660
44	2 500	2 587	0.54	0.28	0.30	1 350	1 450
45	2 500	1 919	0.49	0.30	0.31	1 225	1 525
46	2 400	842	0.28	0.18	0.19	672	888
47	2 500	667	0.29	0.18	0.18	725	900
48	2 500	572	0.33	0.20	0.20	825	1 000
49	2 500	774	0.54	0.33	0.32	1 350	1 625
50	2 500	882	0.70	0.44	0.39	1 750	2 075
51	2 500	862	0.74	0.49	0.41	1 850	2 250
52	1 210	823	0.80	0.51	0.41	968	1 113
53	900	2 163	0.33	0.17	0.20	297	333
54	2 400	2 006	0.40	0.22	0.22	960	1 056
55	2 500	1 307	0.33	0.20	0.21	825	1 025

Table 1.1 (contd.)

Grid no.	Grid area (km^2)	Precipitation (mm)	Total sulphur	Oxidised nitrogen	Reduced nitrogen	Total sulphur	Total nitrogen
			($grammes/m^2$)			(tonnes in grid)	
56	2 500	855	0.29	0.18	0.18	725	900
57	2 500	725	0.32	0.20	0.19	800	975
58	2 500	656	0.38	0.22	0.21	950	1 075
59	2 400	658	0.48	0.29	0.26	1 152	1 320
60	2 500	828	0.66	0.40	0.35	1 650	1 875
61	2 400	718	0.66	0.40	0.34	1 584	1 776
62	250	771	0.76	0.46	0.37	190	208
63	900	1 751	0.25	0.13	0.15	225	252
64	2 100	1 560	0.29	0.17	0.16	609	693
65	2 300	514	0.14	0.09	0.09	322	414
66	2 500	407	0.15	0.10	0.08	375	450
67	2 500	532	0.23	0.14	0.13	575	675
68	2 550	770	0.40	0.23	0.21	1 020	1 122
69	2 500	687	0.44	0.26	0.23	1 100	1 225
70	2 500	664	0.52	0.31	0.26	1 300	1 425
71	2 300	679	0.60	0.35	0.29	1 380	1 472
72	200	722	0.71	0.40	0.34	142	148
73	620	2 020	0.22	0.13	0.13	136	161
74	2 300	1 645	0.25	0.15	0.15	575	690
75	2 500	1 106	0.22	0.14	0.13	550	675
76	2 500	552	0.16	0.10	0.08	400	450
77	2 500	487	0.20	0.12	0.10	500	550
78	2 500	643	0.33	0.19	0.16	825	875
79	2 500	747	0.45	0.26	0.21	1125	1 175
80	2 000	780	0.54	0.32	0.25	1 080	1 140
81	200	711	0.56	0.32	0.26	112	116
82	770	1 310	0.17	0.08	0.08	131	123
83	1 900	1 835	0.25	0.15	0.14	475	551
84	2 500	935	0.19	0.11	0.10	475	525
85	2 500	509	0.16	0.09	0.08	400	425
86	2 500	568	0.23	0.12	0.10	575	550
87	2 450	545	0.29	0.15	0.12	711	662
88	1 400	808	0.49	0.25	0.21	686	644
89	400	778	0.54	0.29	0.24	216	212
90	1 500	1 506	0.24	0.12	0.11	360	345
91	2 300	1 086	0.25	0.13	0.11	575	552
92	2 500	866	0.27	0.13	0.12	675	625
93	2 450	650	0.28	0.13	0.11	686	588
94	800	695	0.38	0.17	0.14	304	248
95	1 400	1 945	0.32	0.13	0.15	448	392
96	2 100	1 187	0.28	0.12	0.10	588	462
97	2 230	1 006	0.28	0.13	0.11	624	535
98	600	953	0.38	0.16	0.14	228	180
99	100	973	0.16	0.05	0.08	16	13
100	2 150	1 717	0.30	0.12	0.14	645	559
101	2 450	1 092	0.27	0.12	0.11	662	564
102	800	1 111	0.32	0.15	0.13	256	224
103	400	1 354	0.22	0.08	0.13	88	84
104	2 500	1 454	0.30	0.12	0.16	750	700
105	2 500	1 078	0.30	0.12	0.14	750	650
106	300	1 116	0.32	0.14	0.15	96	87
107	400	1 338	0.23	0.09	0.15	92	96
108	2 500	2 194	0.45	0.19	0.29	1 125	1 200
109	2 500	1 532	0.43	0.17	0.23	1 075	1 000
110	2 100	765	0.28	0.11	0.12	588	483

Table 1.1 contd.

Grid no.	Grid area (km^2)	Precipitation (mm)	Total sulphur	Oxidised nitrogen	Reduced nitrogen	Total sulphur	Total nitrogen
			($grammes/m^2$)			(tonnes in grid)	
111	1 100	1 634	0.31	0.12	0.21	341	363
112	2 500	1 640	0.36	0.16	0.24	900	1 000
113	2 200	1 200	0.34	0.14	0.20	748	748
114	100	1 102	0.39	0.16	0.21	39	37
115	2 350	1 844	0.32	0.14	0.24	752	893
116	2 450	1 515	0.35	0.15	0.22	858	907
117	700	913	0.27	0.12	0.15	189	189
118	1 100	2 469	0.35	0.15	0.24	385	429
119	2 390	1 830	0.35	0.15	0.23	837	908
120	1 200	1 415	0.34	0.14	0.20	408	408
121	2 000	2 205	0.36	0.14	0.22	720	720
122	2 500	1 639	0.34	0.14	0.20	850	850
123	400	1 366	0.37	0.14	0.20	148	136
124	300	2 748	0.32	0.10	0.19	96	87
125	100	935	0.16	0.06	0.09	16	15
126	2 300	1 550	0.30	0.10	0.15	690	575
127	2 400	578	0.15	0.05	0.07	360	288
128	200	1 129	0.33	0.12	0.16	66	56
129	400	1 570	0.25	0.08	0.11	100	76
130	900	1 405	0.25	0.09	0.11	225	180
131	2 500	1 629	0.31	0.10	0.13	775	575
132	1 300	934	0.23	0.08	0.10	299	234
133	100	1 663	0.25	0.07	0.12	25	19
134	700	1 949	0.35	0.10	0.12	245	154
135	1 500	1 404	0.27	0.09	0.09	405	270
136	1 400	1 718	0.34	0.12	0.13	476	350
137	100	1 358	0.33	0.12	0.13	33	25
138	400	1 552	0.31	0.08	0.10	124	72
139	1 000	1 581	0.31	0.09	0.08	310	170
140	1 400	1 326	0.27	0.09	0.07	378	224
141	1 400	1 149	0.25	0.08	0.08	350	224
142	400	1 262	0.27	0.07	0.07	108	56
143	900	944	0.21	0.06	0.05	189	99
144	1 600	1 088	0.25	0.08	0.06	400	224
145	1 100	934	0.22	0.07	0.05	242	132
146	100	1 126	0.26	0.07	0.06	26	13
147	1 600	1 175	0.26	0.09	0.06	416	240
148	2 450	857	0.23	0.07	0.05	564	294
149	2 450	553	0.18	0.05	0.04	441	221
150	200	553	0.19	0.06	0.04	38	20
151	1 400	1 124	0.31	0.09	0.07	434	224
152	2 400	979	0.27	0.09	0.07	648	384
153	1 800	703	0.22	0.07	0.05	396	216
154	1 550	1 071	0.31	0.10	0.07	481	264
155	2 300	666	0.21	0.07	0.06	483	299
156	2 100	462	0.16	0.05	0.04	336	189
157	1 300	461	0.18	0.06	0.04	234	130
158	300	435	0.20	0.06	0.05	60	33
159	900	864	0.29	0.09	0.07	261	144
160	2 500	530	0.21	0.07	0.05	525	300
161	2 500	515	0.19	0.06	0.04	475	250
162	2 500	449	0.18	0.06	0.04	450	250
163	1 500	421	0.20	0.06	0.05	300	165
164	300	911	0.34	0.10	0.08	102	54

Table 1.1 contd.

Grid no.	Grid area (km^2)	Precipitation (mm)	Total sulphur	Oxidised nitrogen	Reduced nitrogen	Total sulphur	Total nitrogen
			($grammes/m^2$)			(tonnes in grid)	
165	1 800	706	0.28	0.09	0.07	504	288
166	2 500	484	0.20	0.06	0.06	500	300
167	2 500	404	0.18	0.06	0.04	450	250
168	2 400	433	0.23	0.07	0.05	552	288
169	300	433	0.27	0.07	0.07	81	42
170	2 000	747	0.36	0.10	0.09	720	380
171	2 400	387	0.23	0.07	0.05	552	288
172	2 300	454	0.24	0.07	0.06	552	299
173	400	439	0.29	0.07	0.07	116	56
174	300	818	0.44	0.11	0.10	132	63
175	2 200	669	0.39	0.10	0.09	858	418
176	2 340	607	0.37	0.09	0.09	866	421
177	1 300	397	0.29	0.06	0.06	377	156
178	900	868	0.56	0.13	0.13	504	234
179	2 300	545	0.43	0.09	0.09	989	414
180	2000	483	0.41	0.08	0.09	820	340
181	1 300	480	0.43	0.08	0.09	559	221
182	1 300	471	0.52	0.09	0.09	676	234
183	300	568	0.51	0.10	0.10	153	60
184	1 600	614	0.56	0.10	0.11	896	336
185	2 500	482	0.51	0.09	0.10	1 275	475
186	2 300	470	0.53	0.08	0.10	1 219	414
187	1 400	566	0.65	0.10	0.12	910	308
188	400	737	0.71	0.13	0.16	284	116
189	1 400	617	0.67	0.11	0.14	938	350
190	700	610	0.72	0.11	0.14	504	175
191	300	549	0.73	0.11	0.13	219	72
Sum						149 688	159 245

Appendix B

Nature Tolerance Levels (Naturens tålegrenser) Reports

Naturens Tålegrenser (Tolerance Levels in Nature) - Reports

1 Nygaard, P. H., 1989. Forurensningers effekt på naturlig vegetasjon en litteraturstudie. Norsk institutt for skogforskning (NISK), Ås.

Uten nr. Jaworovski, Z., 1989. Pollution of the Norwegian Arctic: A review. Norsk polarinstitutt (NP), rapportserie nr. 55. Oslo

2 Henriksen, A., Lien, L. & Traaen, T.S. 1990. Tålegrenser for overflatevann. Kjemiske kriterier for tilførsler av sterke syrer. Norsk institutt for vannforskning (NIVA), O-89210.

3 Lien, L., Henriksen, A., Raddum ,G. & Fjellheim, A. 1989. Tålegrenser for overflatevann. Fisk og evertebrater. Foreløpige vurderinger og videre planer. Norsk institutt for vannforskning (NIVA), O-89185.

4 Bølviken, B. & medarbeidere, 1990. Jordforsuringsstatus og forsuringsfølsomhet i naturlig jord i Norge. Norges geologiske undersøkelse (NGU), NGU-rapport 90.156. 2 bind (Bind I: Tekst, Bind II:Vedlegg og bilag).

5 Pedersen, H. C. & Nybø, S. 1990. Effekter av langtransporterte forurensninger på terrestriske dyr i Norge. En statusrapport med vekt på SO_2, NOx og tungmetaller. Norsk institutt for naturforskning (NINA), Utredning 005.

6 Frisvoll, A. A., 1990. Moseskader i skog i Sør-Norge. Norsk institutt for naturforskning (NINA), Oppdragsmelding 018.

7 Muniz, I. P. & Aagaard, K. 1990. Effekter av langtransportert forurensning på ferskvannsdyr i Norge - virkninger av en del sporelementer og aluminium. Norsk institutt for naturforskning (NINA), Utredning 013.

8 Hesthagen, T., Berger, H. M. & Kvenild, L. 1992. Fiskestatus i relasjon til forsuring av innsjøer. Norsk institutt for naturforskning (NINA), Forskningsrapport 032.

9 Pedersen, U., Walker, S.E. & Kibsgaard, A. 1990. Kart over atmosfærisk avsetning av svovel- og nitrogenforbindelser i Norge. Norsk institutt for luftforskning (NILU), OR 28/90.

10 Pedersen, U. 1990. Ozonkonsentrasjoner i Norge. Norsk institutt for luftforskning (NILU), OR 28/90.

11 Wright, R. F., Stuanes, A. Reuss, J.O. & Flaten, M.B. 1990. Critical loads for soils in Norway. Preliminary assessment based on data from 9 calibrated catchments. Norsk institutt for vannforskning (NIVA), O-89153.

11b Reuss, J. O., 1990. Critical loads for soils in Norway. Analysis of soils data from eight Norwegian catchments. Norsk institutt for vannforskning (NIVA), O-89153.

12 Amundsen, C. E., 1990. Bufferprosent som parameter for kartlegging av forsuringsfølsomhet i naturlig jord. Universitetet i Trondheim, AVH (stensil).

13 Flatberg, K I., Foss, B., Løken,A. & Saastad, S.M. 1990. Moseskader i barskog. Direktoratet for naturforvaltning (DN), notat (under trykking)

14 Frisvoll, A A., & Flatberg, K.I., 1990. Moseskader i Sør-Varanger. Norsk institutt for naturforskning (NINA) , Oppdragsmelding 55.

15 Flatberg, K.I., Bakken, S., Frisvoll, A.A., & Odasz, A.M. 1990. Moser og luftforurensninger. Norsk institutt for naturforskning (NINA) , Oppdragsmelding 69.

16 Mortensen, L.M. 1991. Ozonforurensning og effekter på vegetasjonen i Norge. Norsk landbruksforsk. 5:235-264.

17 Wright, R.F., Stuanes, A.O. & Frogner, T. 1991. Critical Loads for Soils in Norway Nordmoen. Norsk

institutt for vannforskning (NIVA), O-89153.

18 Pedersen, H.C., Nygård, T., Myklebust, I. og Sæther, M. 1991. Metallbelastninger i lirype. Norsk institutt for naturforskning (NINA), Oppdragsmelding 71.

19 Lien, L., Raddum, G.G. & Fjellheim, A. 1991. Tålegrenser for overflatevann evertebrater og fisk. Norsk institutt for vannforskning (NIVA), Rapport 0-89185,2.

20 Amundsen, C.E. 1992. Sammenlingning av parametre for å bestemme forsuringsfølsomhet i jord. NGU-rappport 91.265.

21 Bølviken, B., R. Nilsen, J. Romundstad & O. Wolden. 1992. Surhet, forsuringsfølsomhet og lettløselige baeskationer i naturlig jord fra Nord-Trøndelag og sammenligning med tilsvarende data fra Sør Norge. NGU-rapport 91.250.

22 Sivertsen, T. & medarbeidere. 1992. Opptak av tungmetaller i dyr i Sør-Varanger. Direktoratet for naturforvaltning, DN-notat 1991-15.

23 Lien, L., Raddum, G.G. & A. Fjellheim. 1992. Critical loads of acidity to freshwater. Fish and invertebrates. Norwegian Institute for Water Research (NIVA), Rapport O-89185,3

24 Fremstad, E. 1992. Virkninger av nitrogen på heivegetasjon. En litteraturstudie. Norsk institutt for naturforskning (NINA), Oppdragsmelding 124.

25 Fremstad, E. 1992. Heivegetasjon i Norge, utbredelseskart. Norsk institutt for naturforskning (NINA), Oppdragsmelding 188.

26 Flatberg, K.I. & Frisvoll, A. 1992. Undersøkelser av skader hos to sigdmoser i Agder. Norsk institutt for naturforskning (NINA), Oppdragsmelding 134

27 Lindstrøm, E.A.1992. Tålegrenser for overflatevann. Fastsittende alger. Norsk institutt for vannforskning (NIVA), O-90137/E-90440, rapport-2

28 Brettum, P. 1992. Tålegrenser for overflatevann. Planteplankton. Norsk institutt for vannforskning (NIVA), O-90137/E-90440, rapport-3

29 Brandrud, T.E., Mjelde, M. 1992. Tålegrenser for overflatevann. Makrovegetasjon. Norsk institutt for vannforskning (NIVA), O-90137/E-90440, rapport-1

30 Mortensen, L.M. & Nilsen, J. 1992. Effects of ozone and temperature on growth of several wild plant species. Norwegian Journal of Agricultural Sciences 6:195-204.

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ABSTRACT
The total deposition of sulphur and nitrogen components in Norway during the period 1988-1992 has been estimated on the basis of available measurement data.

NORWEGIAN TITLE

Avsetning av svovel og nitrogenforbindelser i Norge, 1988-1992

DESCRIPTORS		
Sulphur	Nitrogen	Deposition

ABSTRACT (in Norwegian)
Avsetning av svovel og nitrogenforbindelser i Norge i perioden 1988-1992 er beregnet på basis av målinger av luft- og nedbørkjemi.

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