NILU: OR 72/2008

NILU : OR 72/2008
REFERENCE : O-108067
DATE : DECEMBER 2008
ISBN : 978-82-425-2051-7 (printed)
978-82-425-2052-4 (electronic)

Deposition of major inorganic compounds in Norway 2002-2006

Wenche Aas, Anne Hjellbrekke, Lars R. Hole and Kjetil Tørseth

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

The working group has the following representatives:

Tor Johannessen - SFT
Else Løbersli - DN
Steinar Sandøy - DN

Questions regarding the programme may be given to:

Directorate for Nature Management
N-7485 Trondheim
Norway
Tel.: +47 73 58 05 00
Telefax: +47 73 91 54 33

or:

Norwegian Pollution Control Authority
P.O. Box 8100 Dep.
N-0032 OSLO
Norway
Tel.: +47 22 57 34 00
Telefax: +47 22 67 67 06

Contents

Page

Summary

The total depositions of sulphur and nitrogen compounds in Norway have been estimated with a grid resolution of 50·50 km², based on available measurements of air and precipitation chemistry. The five year deposition estimates covered the periods 1978-1982 (Hole and Tørseth, 2002), 1983-87 (Pedersen et al., 1990), 1988-1992 (Tørseth and Pedersen, 1994), 1992-1996 (Tørseth and Semb, 1997), 1997-2001 (Hole and Tørseth, 2002). This report covers the period from 2002 to 2006. In addition, the depositions of sea-salts and non sea-salt potassium and calcium have been estimated. Results are presented as tabulated values to the individual grid cells, and visualised on geographical maps.

The average total deposition (2002-2006) of the non sea-salt compounds was highest in the south and western part of Norway with maximum sulphur deposition of 0.67 g S/m² in grid cell no. 2 and 3 (Vest-Agder). The lowest depositions were observed along the Swedish border from Finnmark in the north down to Oppland in central Norway with values approximately one order of magnitude lower than in the maximum areas. Similarly, deposition values for individual meteorological sites varied from 0.88 g S/m² to 0.04 g S/m². The largest grid cell depositions of oxidised and reduced nitrogen were 0.87 and 0.75 g N/m², respectively, whereas the lowest depositions were 0.06 and 0.07 g N/m², respectively.

Estimated total annual depositions for the period 2002-2006 were approximately 74 000 tonnes sulphur and 154 000 tonnes nitrogen. Compared with similar estimates for the period 1997-2001, there has been a significant reduction (15%) in the sulphur deposition while the nitrogen deposition has slightly increased (2%) for both reduced and oxidised form. The increase was mainly on the west coast of Norway.

Sammendrag

De totale avsetninger av svovel og nitrogenforbindelser til Norge har vært estimert basert på målinger av luft- og nedbørskjemi. Det første estimatet omfattet perioden 1978-1982 (Hole and Tørseth, 2002). Videre er det avsetningsestimater for periodene 1983-87 (Pedersen et al., 1990), 1988-1992 (Tørseth and Pedersen, 1994), 1992-1996 (Tørseth and Semb, 1997) og 1997-2001 (Hole and Tørseth, 2002). I denne rapporten presenteres estimater for periodene 2002-2006 og disse er sammenlignet med de tidligere perioder. I tillegg er det beregnet avsetninger av sjøsalter og ikke-marint kalium og kalsium. Resultatene er vist som tabulerte verdier til et landsdekkende rutenett på 50·50 km^2, og visualisert på geografiske kart.

Total avsetning av ikke-marine komponenter var størst i de sørvestre deler av landet med maksimal svoveldeposisjon med 0,67 g/m^2 i 2002-2006 i rutene 3 og 4 (Vest-Agder). Laveste avsetninger ble registrert langs svenskegrensen fra Finnmark og til Oppland fylke samt fjelltraktene i Sør Norge. Ruteverdiene for avsetning av oksidert nitrogen for 2002-2006 er fra 0,06 g/m^2 til 0,87 g/m^2. For redusert nitrogen er tallene for denne perioden og 0,07 g/m^2 til 0,75 g/m^2.

Totale avsetninger for Norge i 2002-2006 er estimert til 74 000 tonn svovel og 154 000 tonn nitrogen. Det har vært en signifikant nedgang i den totale sovelavsetningen (15%) mens avsetning av nitrogen (både redusert og oksidert form) har økt noe (2%) siden forrige periode, 1997-2001. Økningen av nitrogenavsetningen var hovedsakelig på vestlandet.

Deposition of major inorganic compounds in Norway 2002-2006

1. Introduction

In order to evaluate the exceedance of critical loads to the ecosystems, quantified atmospheric input to the system is essential. The atmospheric input of pollutants can be determined from atmospheric dispersion models, by using emission data, meteorological data and parameters describing transformation and removal processes (Barrett et al., 1995). Under the Co-operative programme for the monitoring and evaluation of long-range transmissions of air pollutants in Europe (EMEP), concentration and deposition fields of inorganic compounds are calculated at the Meteorological Synthesising Centre - West using a multi-layer Eulerian model with a grid size of 50·50 km^2 (EMEP, 2008).

Atmospheric inputs may also be inferred from measurements of air and precipitation chemistry. Particularly in a country like Norway, where topographical features cause large variations in depositions, use of measured concentrations and precipitation amounts makes it possible to determine the inputs by precipitation more directly and with more detailed spatial resolution than is available from models. Dry deposition may also be inferred from measured airborne concentrations. In this case it is essential to take into account seasonal variations and differences in ground cover. The heterogeneity of the surface characteristics are also reflected in the critical loads for specific receptor areas and ecosystems, which makes it desirable to determine atmospheric inputs with the same spatial resolution.

In this work, estimates of the total depositions of all major inorganic compounds of interest in the evaluation of critical loads for acidity and for nutrient nitrogen, are presented, i.e. sulphur, nitrogen, non sea-salt base cations (K^+ and Ca^{2+}) and sea-salts (Na^+, Mg^{2+}, Cl^-, K^+, Ca^{2+}, SO_4^{2-}). The estimates are based on data available through the national air- and precipitation monitoring program (SFT 2003, 2004, 2005, 2006 and 2007), combined with information about precipitation amounts from the national meteorological network (met.no, 2002-2006). Estimates for the previous periods 1978-1982 (Hole and Tørseth, 2002), 1983-87 (Pedersen et al., 1990), 1988-1992 (Tørseth and Pedersen, 1994), 1992-1996 (Tørseth and Semb, 1997), 1997-2001 (Hole and Tørseth, 2002) are compared for trend analysis.

2. Deposition processes

Sulphur and nitrogen compounds can be deposited either by precipitation (wet deposition) or by dry deposition. Wet deposition is far more important than dry deposition in Norway. In precipitation, the major species are sulphate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), chloride (Cl^-), sodium (Na^+), magnesium

(Mg^{2+}), potassium (K^+) and calcium (Ca^{2+}). The major sulphur and nitrogen compounds in air are sulphur dioxide (SO_2) and particulate sulphate (SO_4^{2-}), nitrogen monoxide (NO), nitrogen dioxide (NO_2), nitric 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.

When using measured concentrations in ambient air to infer dry deposition of sulphur and nitrogen, seasonal deposition velocities (Voldner and Sirois, 1986), that summarise the transfer resistances calculated from more detailed dry deposition models (e.g. Hicks et al., 1987), may be used. 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 and climatic conditions within Norway, a simplistic approach was chosen. The various dry deposition processes and deposition of fog droplets are described in the literature e.g. Lövblad et al. (1993). Only parts of this discussion will 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, which show a considerable geographical variation.

Under dry conditions, the deposition of sulphur dioxide (SO_2) is mainly regulated by stomatal resistance. However, absorption of sulphur dioxide on wetted foliage seems to be an important 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. Snow crystals, on the other hand, do not absorb sulphur dioxide. Therefore, the dry deposition of sulphur dioxide to snow surfaces depends on oxidation of absorbed sulphur dioxide in the liquid-films at the surface nucleated by impurities in the snow (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 below -2ºC (Johansson, 1987).

From catchment mass balances and canopy experiments in southern Sweden, Hultberg and Grennfelt (1992) found that coniferous forest stands in southern Sweden collected 2-3 times more sulphur than adjoining clear-cut areas. It was also shown that the deposition by throughfall was much larger at the forest edges than inside a larger plot of homogenous forest. The interpretation of these results is somewhat ambiguous, since the excess sulphate in throughfall may be caused both by deposition of sulphur dioxide and by deposition of sulphate aerosol particles. In the former case, the results point to deposition of sulphur dioxide in situations with wet foliage, when aerodynamic resistance is controlling the deposition. The observations were made in areas with typically wet and windy climate. In other areas it has been found that spruce stands will collect, on average, 30-70% more sulphur dioxide than stands of pine or deciduous trees. This is readily explainable on the basis of higher leaf area index for spruce (Ivens et al., 1990). For sulphur dioxide, therefore, deposition velocity of 0.4 cm/s and 0.8 cm/s has been chosen for non-forested and forested areas, respectively. 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 under typical Norwegian winter conditions, if there is no frost or snow. 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 to be mainly regulated by stomatal control. A generally low deposition velocity of 0.2 to 0.4 cm/s serves to keep the dry deposition of this component relatively insignificant (Johansson, 1987). In winter, stomatal uptake is insignificant, and deposition velocities correspondingly low (0.02 cm/s).

Only the sum of nitric acid and nitrate (in aerosol particles), is available from the monitoring programme. Measurements at Birkenes and Lista have shown that the concentration of nitric acid is only 10-30% of the sum of nitric acid and particulate nitrate (Sorteberg et al., 1998; Foltescu et al., 1996). Nitric acid is very reactive and only the aerodynamic transfer resistance is limiting the dry deposition velocity (Emberson et al., 2000; Simpson et al., 2001). Cascade impactor measurements indicate that the nitrate is mainly present in the form of particles larger than 2 µm (e.g. Hillamo et al., 1992). A relatively large deposition velocity has therefore been chosen for this component.

The reduced nitrogen species will mainly consist of submicron ammonium sulphates and gaseous ammonia. Several measurements have indicated that the concentration of gaseous ammonia is low (e.g. Tørseth and Semb, 1996). The only exception is in areas influenced by local emissions from farms in connection with animal husbandry and manure. Gaseous ammonia will have a relatively high deposition velocity. The deposition velocities chosen for sulphate and ammonium in aerosols also include deposition by deliquescenting 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 be comparable to annual precipitation (Lovett, 1990; Dollard et al., 1983), but is usually less than 10%. Occult deposition may have a strong effect in the ecosystems because of the relatively 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 $50 \cdot 50\ km^2$. The subject of exposure to pollutants in the mountainous areas of Norway has been discussed further by Lükewille and Semb (1997).

Sea-salts generally occur in the coarse particulate mode (>2 µm). In coastal areas sea spray may generate particles larger than 10 µm. These will however be deposited very fast and normally less than 1-5 km from the coast and will therefore not contribute to the deposition to larger areas. In addition, episodes with high concentration of sea-salts in air will normally be accompanied with large inputs as wet deposition, making the dry deposition of minor importance to the total deposition. Relatively high deposition velocities were chosen for all sea-salt compounds, corresponding well with the excess throughfall of sodium estimated from the Norwegian monitoring programme for forest damage (Solberg et al., 1997).

The larger fraction of calcium and potassium is not derived from sea-salts. For calcium, the main source is assumed to be long-range transport of mineral matter (Semb et al., 1995). There are still large uncertainties with respect to emission, transport and deposition of these compounds. In addition, there may also be local sources by e.g. agricultural activities, soil dust, pollen and bird droppings. For potassium, domestic wood combustion may be of importance locally during winter.

Table 1 summarises the deposition velocities which have been used to infer dry deposition from measured concentrations of the various compounds in this work.

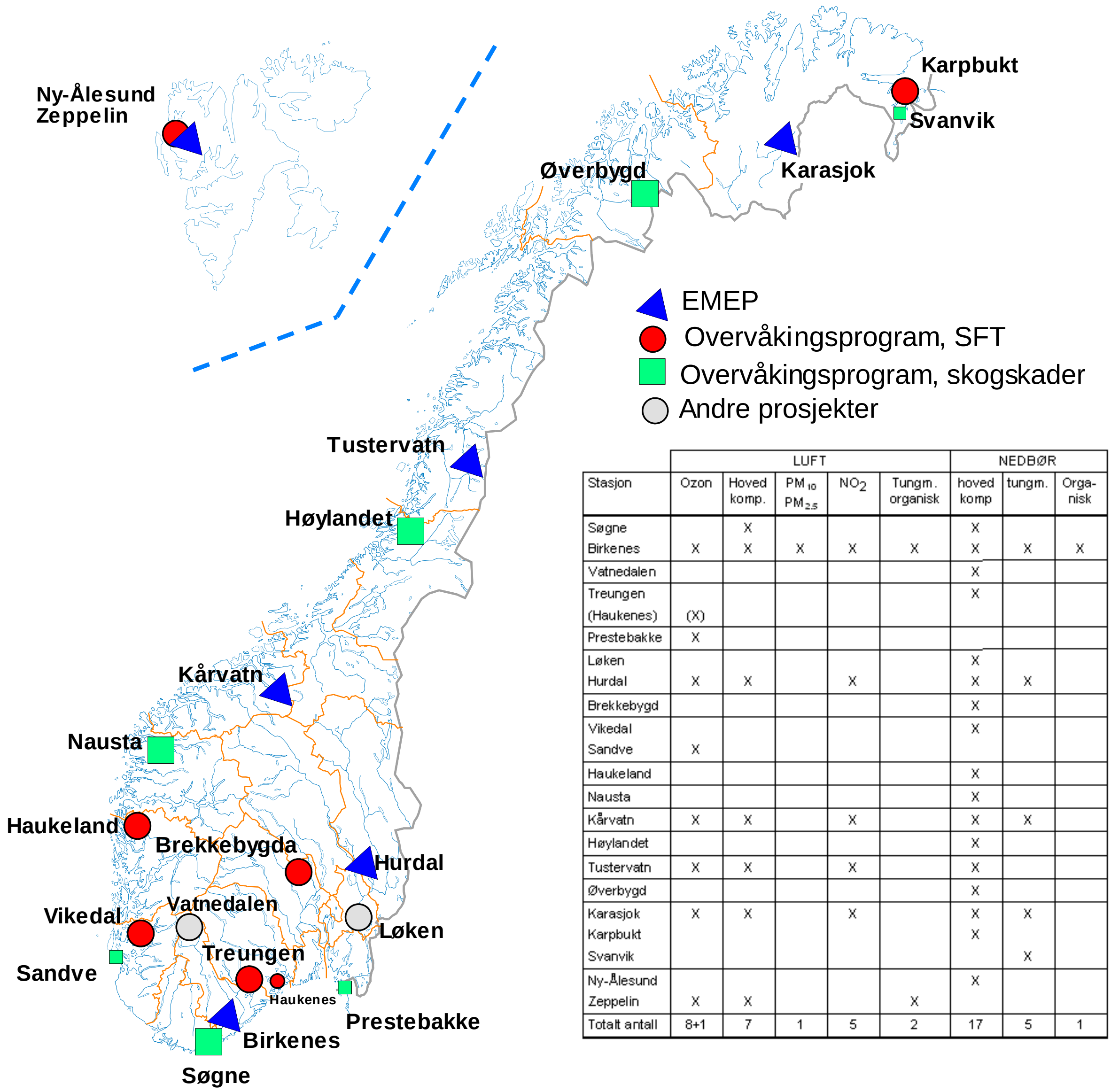
Table 1: Deposition velocities (cm/s) for different inorganic compounds applied to the different landscape types and seasons (nss: non sea salt; ss: sea salt).

	Land use classification			
Compound	Forest		Other	
	summer	winter	summer	Winter
SO_2	0.8	0.1	0.4	0.02
SO_4^{--}, Sum (NH_3+NH_4^+)	0.4	0.4	0.2	0.1
NO_2	0.4	0.02	0.2	0.02
Sum (HNO_3+NO_3)	2.0	2.0	1.0	0.25
nss K^+	1	1	0.25	0.1
nss Ca^{2+}	2	2	1	0.25
Na^+, Mg^{2+}, Cl^-, ss K^+, ss Ca^{2+}, ss S	2	2	1	0.25

3. Data used for mapping

NILU started routine sampling of precipitation and air in background areas on daily basis in 1971, with sites located in the southernmost parts of Norway. In later years the measuring network has expanded to cover all regions in Norway. In this investigation we have used between 16 and 23 stations for the period 2002-2006 (Figure 1) serving different monitoring programmes. Valle, Voss, Skreådalen, Fagernes, Svanvik, Lardal, Osen were sites in operation in 2002 but not in 2006.

In addition, concentrations in precipitation and air at the Swedish and Finnish EMEP-stations and have been used in the statistical analysis. We have also used data from one Russian (RU01). These data has been taken from the EMEP web site (www.emep.int). Additional precipitation data as well as SO_2, NO_2 from the Swedish sites connected to the national PMK network (28 sites) has also been included (Håkan Blomgren, IVL, pers com).



	LUFT					NEDBØR		
Stasjon	Ozon	Hoved komp.	PM_{10} $PM_{2.5}$	NO_2	Tungm. organisk	hoved komp	tungm.	Orga-nisk
Søgne		X				X		
Birkenes	X	X	X	X	X	X	X	X
Vatnedalen						X		
Treungen						X		
(Haukenes)	(X)							
Prestebakke	X							
Løken						X		
Hurdal	X	X		X		X	X	
Brekkebygd						X		
Vikedal						X		
Sandve	X							
Haukeland						X		
Nausta						X		
Kårvatn	X	X		X		X	X	
Høylandet						X		
Tustervatn	X	X		X		X		
Øverbygd						X		
Karasjok	X	X		X		X	X	
Karpbukt						X		
Svanvik							X	
Ny-Ålesund						X		
Zeppelin	X	X			X			
Totalt antall	8+1	7	1	5	2	17	5	1

Figure 1: Norwegian background stations and measurement programme 2006.

All sites are located in rural areas and are believed to generally 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 (2003-2007).

Precipitation samples are collected in bulk-samplers on a daily or weekly basis. Precipitation amounts are measured by local observers and the samples are sent to NILU for analysis of all main compounds. 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^{2-}, HNO_3+NO_3^- and NH_3+ NH_4^+, while absorbing solutions or NaI-impregnated filters are analysed for NO_2. All results are checked against expected values and results from neighbouring sites. Obviously contaminated samples are rejected.

The precipitation amount data used for the calculations of the wet deposition is taken from the national meteorological observation network (met.no) in addition to the about 20 NILU sites. Data from in total 678 sites for the five-year period 2002-2006 have been applied (met.no, 2002-2006). However much less sites were in operation in 2006 (462 sites) compared to 2002 (678 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; Journel and Huijbregts, 1981), but has also been used in connection with environmental studies, e.g. on long range transported air pollutants in Europe (Simpson and Olsen, 1990; Schaug et al., 1993).

Linear kriging provides the best linear unbiased estimator for a variable. Non-linear kriging (Armstrong and Matheron, 1986) may 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 ordinary linear kriging. A grid size of 50·50 km^2 has been applied (EMEP sub-grid). The applied grid is shown in figure 1.1 in Appendix.

5. Data analysis

Seasonal mean airborne concentrations during winter (Jan.-Apr., Nov.- Dec.) and summer (May-October) were calculated for SO_2, non sea-salt (nss) SO_4^{--}, NO_2, sum NO_3^-+HNO_3, sum NH_4^++NH_3, Na^+, non sea-salt K^+ and non sea-salt Ca^{2+}. For all compounds but nss K^+, a significant seasonal variation was evident whereas the inter-annual variation was generally small. As a result of this the five year seasonal average concentration values measured at 15 Norwegian sites were interpolated to a 50·50 km^2 grid using the kriging technique to obtain values for the individual grid cells. Concentration fields for Cl^- and Mg^{2+} were estimated based on the ratio between these compounds and Na in seawater.

The dry deposition was estimated from the concentration fields and assessed dry deposition velocities for the two seasons, respectively. The dry deposition estimate was given for each meteorological site and for two land type categories; productive forests and other land use (e.g. unproductive land, rocks, agricultural land). When estimating the grid cell average dry deposition, deposition was weighted on the distribution of land use types in the individual grid cells. The applied statistics on percentage productive forest in each cell is shown in Figure 1.2 in Appendix.

The annual averages of non sea-salt sulphate, nitrate, ammonium, non sea-salt potassium and non sea-salt calcium in precipitation have been used to calculate a concentration field for each year using the kriging interpolation.

For the sea-salt derived ions, the number and the location of the sites are not sufficient to generate concentrations fields. However, concentrations may be described as a function of distance from the coast weighted by the wind speed and direction in the prevailing precipitation forming air masses. Based on annual median values of sodium concentration in precipitation at the background sites for the period 2002-2006, a general function was fitted (Figure 2). From this function, concentration values were given to each individual meteorological site as a function of distance from the coast and by climatic regions. Further, concentrations for the other sea-salt derived ions were estimated by their expected ratio to sodium based on the content in sea-water.

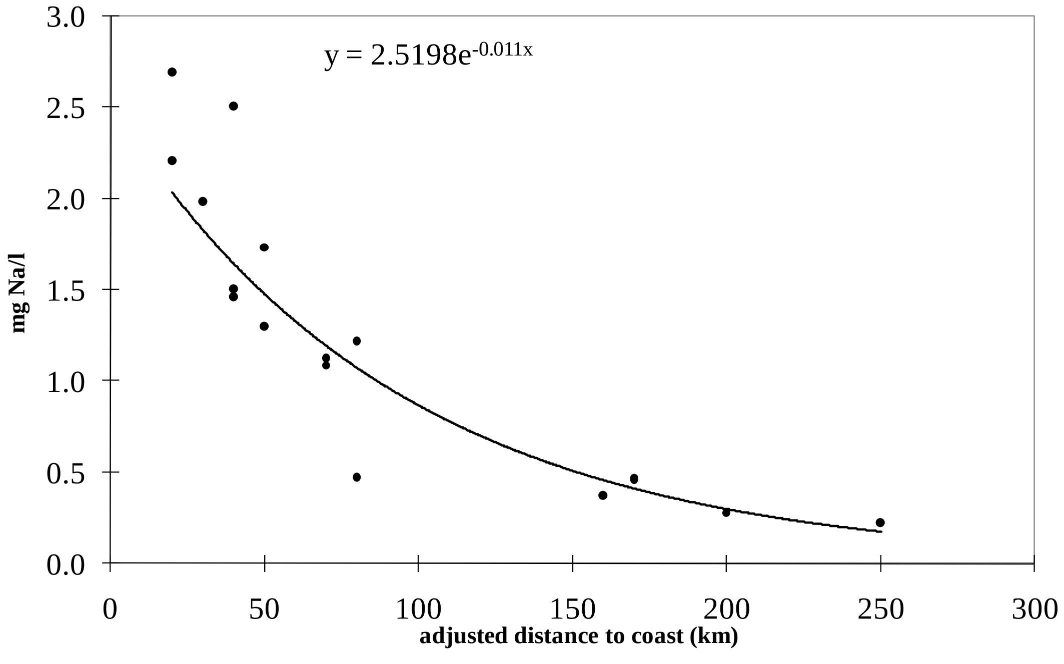


Figure 2: Sodium content in precipitation as a function of regionally adjusted distance to the coast.

To provide annual wet deposition values for each meteorological site, the precipitation amount at the site was multiplied with the interpolated concentration in the respective grid cell. The average wet deposition to each grid cell was estimated as the average deposition to the meteorological sites within the grid cell. For grid cells with no meteorological sites, the value of a representative neighbouring cell was chosen. The average precipitation amounts in the individual grid cells are given in Table 1.1 and 1.3 in Appendix.

The total deposition of the various inorganic compounds during 2002-2006 was calculated as the sum of the dry and wet deposition both for each meteorological site and for each grid cell. The results for the individual sites (deposition values to forested areas) are visualised on maps in Figures 5-17 whereas land use area weighted results for individual grid cells are given in Tables 1.1 in Appendix. The maps are produced using standard interpolation routines.

This report gives only a summary of the results. Deposition estimates for individual years and for the different landscape types are stored in our database, and are available upon request.

6. Results and discussion, 2002-2006

Annual average precipitation amounts measured at the met.no sites varied between 151 and 3808 mm, with the highest amount on the west coast and lowest amounts along the Swedish border in northern Norway and in Oppland county, southern Norway (Table 2). Aggregated to grid cell averages, the amount varied from 386 in Troms county (cell no. 150) to 2839 mm in Sogn og Fjordane (cell no. 25).

Table 2: Minimum, median and maximum deposition for individual sites and 50·50 grid cells in the period 2002-2006.

Compound	Deposition to individual sites (n=701)			Grid cell averaged deposition (n=191)		
Units (mg/m^2 yr)	**min.**	**med.**	**Max.**	**min.**	**med.**	**Max.**
Precip. (mm)	151	1012	3808	386	930	2839
nss S	38	205	876	71	180	673
N (oxi)	41	205	1110	59	148	869
N (red)	53	241	984	71	202	752
N (oxi+red)	94	446	2077	132	358	1611
nss K	17	86	255	34	83	205
nss Ca	22	109	338	41	99	256
Na	80	1223	7332	85	1252	6142
Mg	10	147	883	10	151	740
Cl	142	2184	13092	151	2236	10968
ss S	7	102	614	7	105	514
ss K	3	44	264	3	45	221
ss Ca	3	46	278	3	47	233

The total deposition of the non sea-salt compounds were highest in the south-western part of Norway as a combination of relatively high concentrations and large precipitation amounts, whereas the lowest depositions were observed along the Swedish border from Finnmark in the north down to Oppland in central Norway as well as the mountain area in southern Norway. Maximum average annual depositions of non sea-salt sulphur was 0.67 g S/m^2 in grid cell no. 3 and 4 (Vest-Agder). This is approximately one order of magnitude higher than the sulphur depositions in grid cells 127 in Nordland. Similarly, deposition values for individual meteorological sites varied from at most 0.88 g S/m^2 down to 0.04 g S/m^2.

The nitrogen deposition pattern is similar to the deposition of sulphur. This is partly due to the strong influence of the precipitation frequency and amounts on the deposition of both species. The largest grid cell depositions of oxidised- and reduced nitrogen were 0.87 and 0.75 g N/m^2, whereas the lowest depositions were 0.06 and 0.07 g N/m^2, respectively. Total nitrogen deposition for the individual sites varies from 0.10 to 2.1 g N/m^2 as a annual mean.

Adding up the values in Table 1.1 gives a total annual mean deposition in Norway of approximately 74 000 tonnes sulphur and 154 000 tonnes nitrogen. Comparing with the previous periods, there is a significant decrease in sulphur deposition (15%), while a small increase in the nitrogen deposition (2%), both in the reduced and oxidized form. There is a distinct increase in deposition of base cations, Table 3. The same methodology was used in four of the periods (1978-1982, 1992-1996, 1997-2001 and 2002-2006). For 1988-1992, the methodology was slightly different, but we assume that this has no relevance for the comparability of results. However, the number of measurement sites increased significantly from 1978-82 to 1988-92. It then has decreased again from the nineties up to 2006. For this reason, the deposition estimates for the five periods may not be directly comparable.

Table 3: Total deposition of inorganic compounds in Norway (tonnes/year).

Year	nss S	N (oxi)	N (red)	tot N	nss K	nss Ca
1978-1982	197368	83882	93342	177224	27702	43061
1983-1987	171710	93456	93602	187058		
1988-1992	149688	82462	76782	159245		
1992-1996	117289	80251	71602	151852	19989	33412
1997-2001	87206	73564	77572	151136	23769	25890
2002-2006	73852	75612	79244	154856	28092	34266

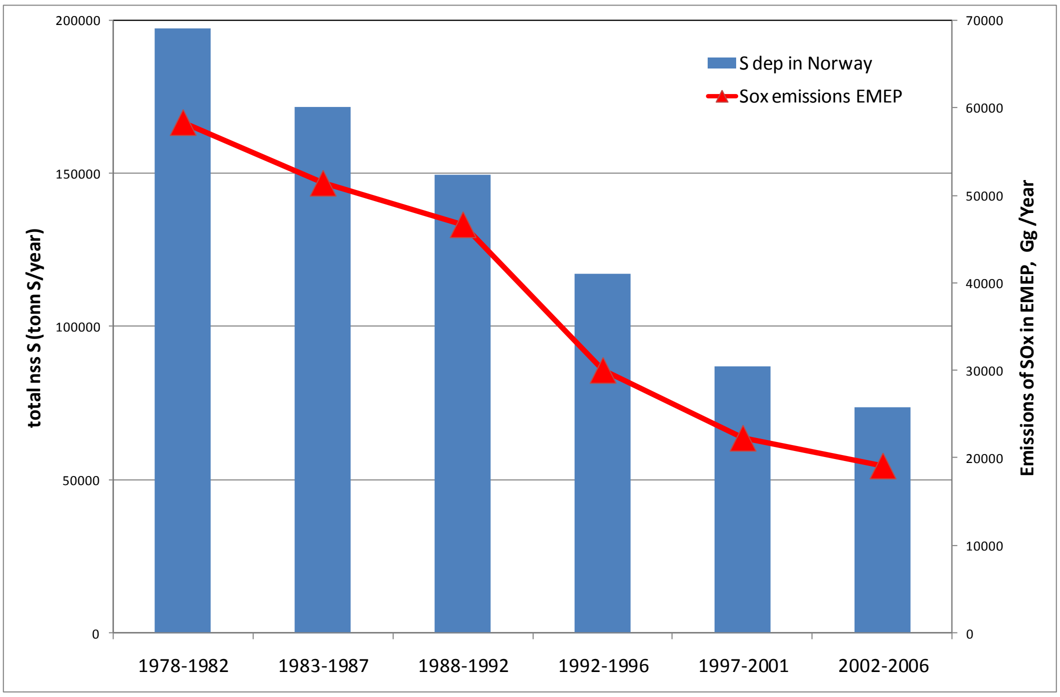


Figure 3: Deposition of non sea salt sulphur in Norway (tonnes/year) compared with total S (GgS/year) emissions in Europe.

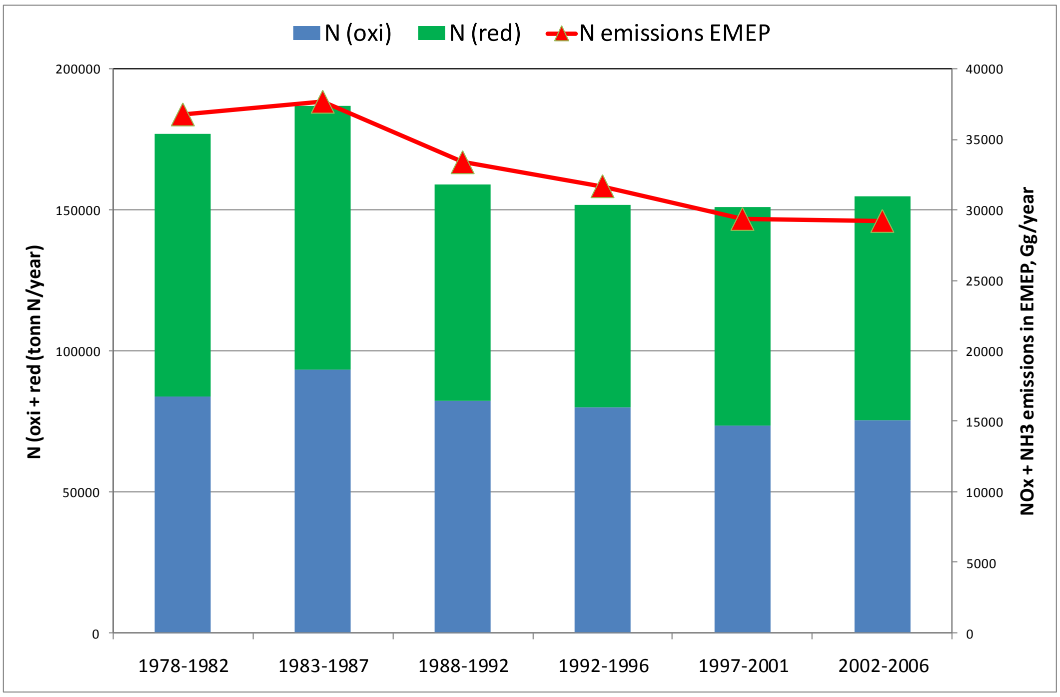


Figure 4: Deposition of nitrogen in Norway (tonnes/year) compared with total N (GgN/year) emissions in Europe.

The trend in sulphur deposition is very well correlated with the total emission trends in Europe, Figure 3. The nitrogen deposition follows the general trend in EMEP as well (Figure 4), but there is a slight increase in the latter period in

Norway which is not seen in the sum of all the EMEP emissions. The increase in total nitrogen is due to somewhat higher concentrations observed at some of the sites in the west coast combined with an increased precipitation amount in the same area. It is a slight decrease in the most southern part of Norway (Figure 15), which is most influence of long range transport from the continent. The increase on the west coast can be due to the meteorological variability (Hole et al., 2008) and increased emissions in the North Sea, as well as potential changes in the local conditions. One should however notice that the increase is not a general trend. The concentration levels in Norway in 2007 are lower at most sites for most of the components compared to the previous years (SFT, 2008).

Total depositions of sea-salt ions, non sea-salt potassium and non sea-salt calcium were estimated in three of the previous five year periods (Tørseth and Semb, 1997; Hole and Tørseth, 2002). There are relatively large uncertainties in these estimates due to possible influence of local sources, uncertain deposition velocities and the effect of sea salt correction. There is a significant reduction in the calcium concentrations in precipitation (SFT, 2007) and the deposition (Table 3) since the late seventies, but no major change since the 1992-1996 period. The deposition was lower in the period in-between (1997-2001), but this may partly be an effect of the sea salt correction. The sodium concentration was higher in that period. For potassium the level seems to have increased, but the uncertainty is rather high. Deposition of base cations calculated by the method used here should be compared to more conventional method using i.e. throughfall measurements (Lövblad et al., 1992; Hellsten et al., 2007).

The deposition amounts of sea-salts will be dependent on the frequency of westerly winds, and in particular the frequency of winter storms. It is assumed that there are no other significant sources of sodium, magnesium or chloride than from sea-spray. Deposition of sea-salts is particularly large in the coastal zone (0-20 km from the coast) and decreasing exponentially with distance. This deposition pattern is not taken into account in the presented maps, and deposition estimates will be significantly underestimated to these areas.

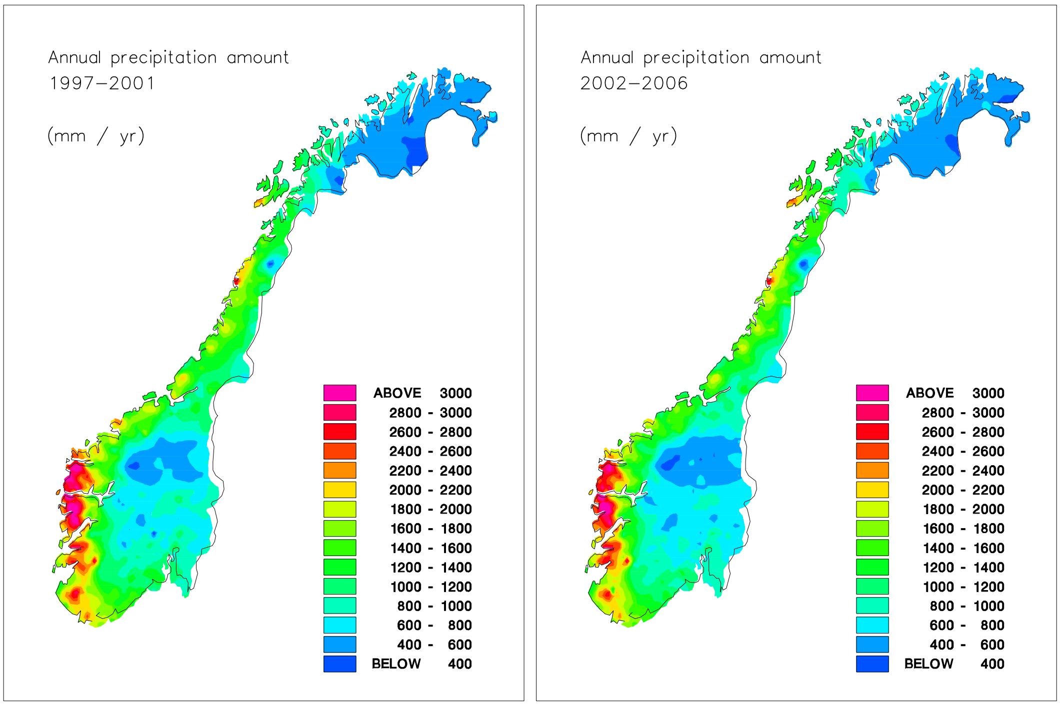


Figure 5: Average precipitation amount 1997-2001 and 2002-2006.

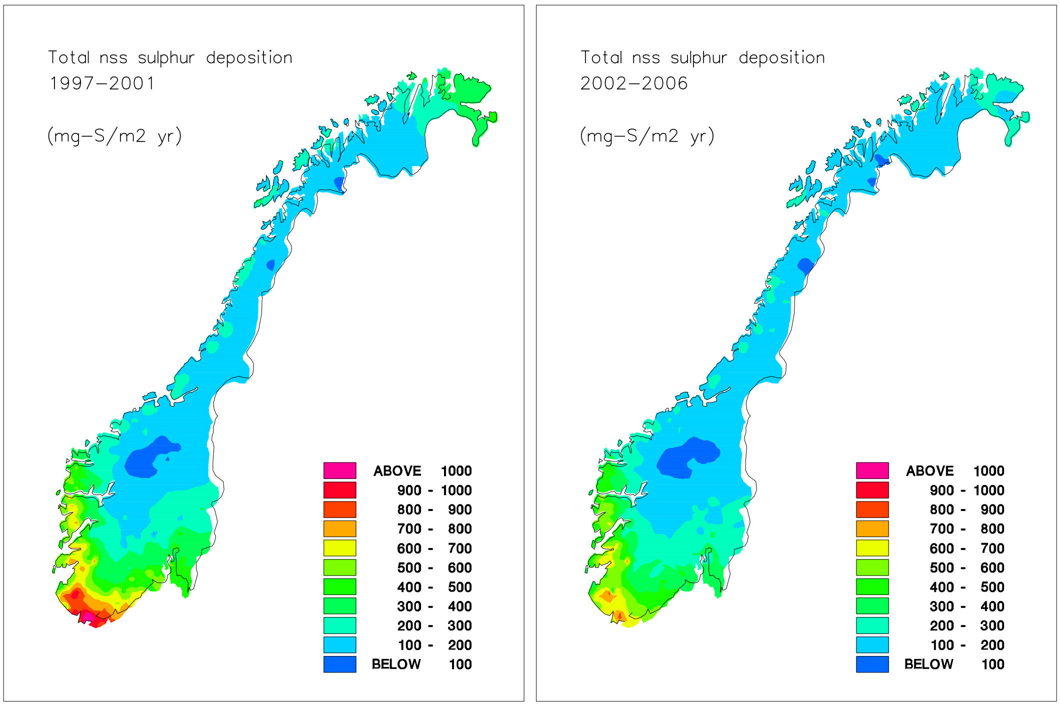


Figure 6: Total nss sulphur deposition 1997-2001 and 2002-2006.

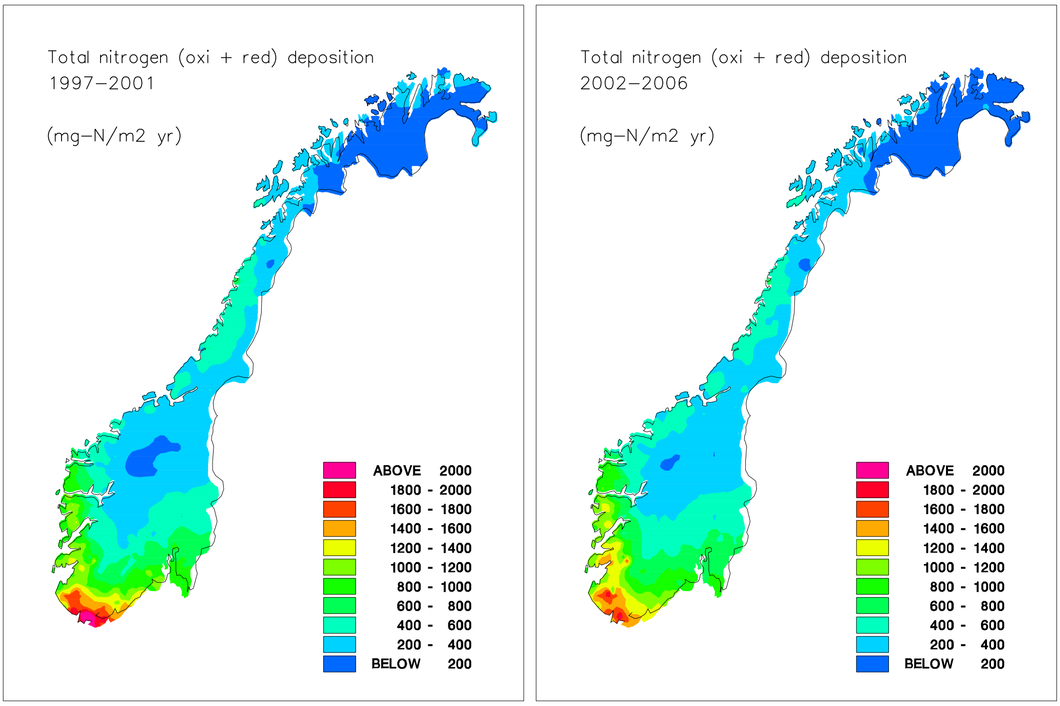


Figure 7: Total deposition of nitrogen (oxi+red) (mg N/m^2 year 1997-2001 and 2002-2006.

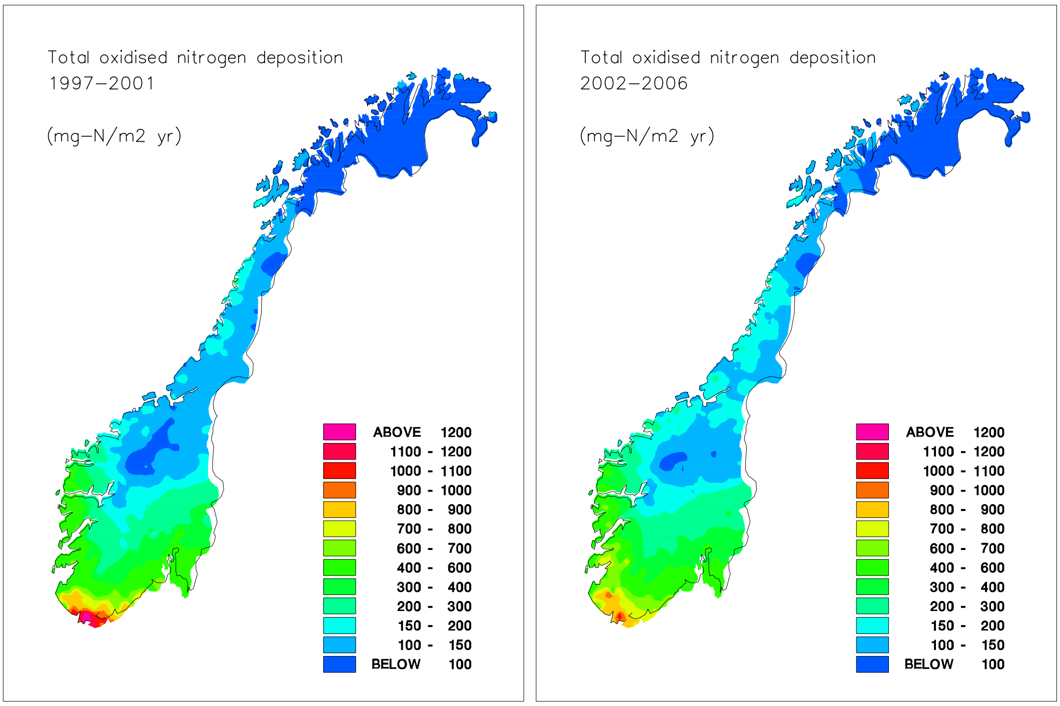


Figure 8: Total deposition oxidised nitrogen (mg N/m^2 year) 1997-2001 and 2002-2006.

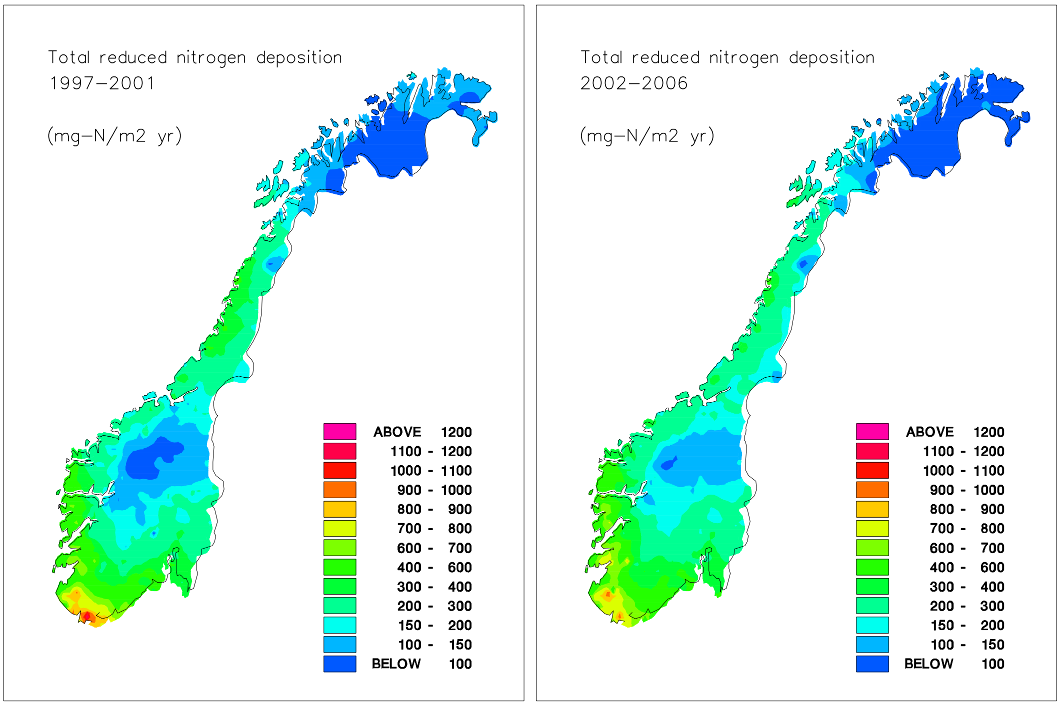


Figure 9: Total deposition reduced nitrogen (mg N/m^2 year 1997-2001 and 2002-2006.

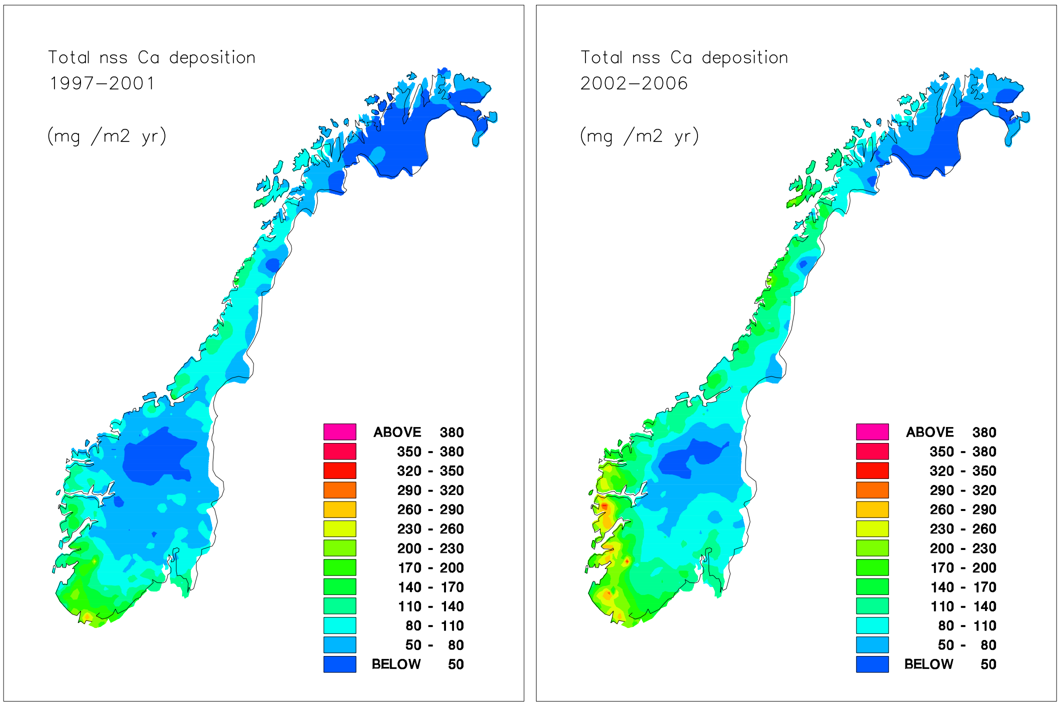


Figure 10: Total deposition of non sea salt calcium (mg Ca/m^2 year) 1997-2001 and 2002-2006.

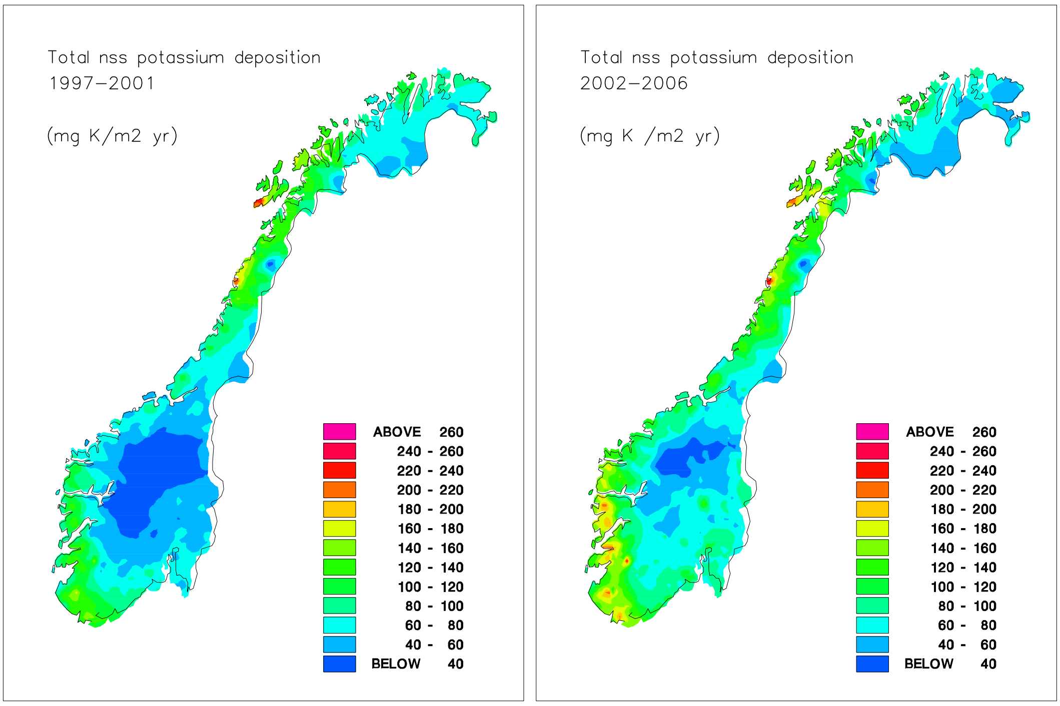


Figure 11: Total deposition non sea salt potassium (mg K/m^2 year) 1997-2001 and 2002-2006.

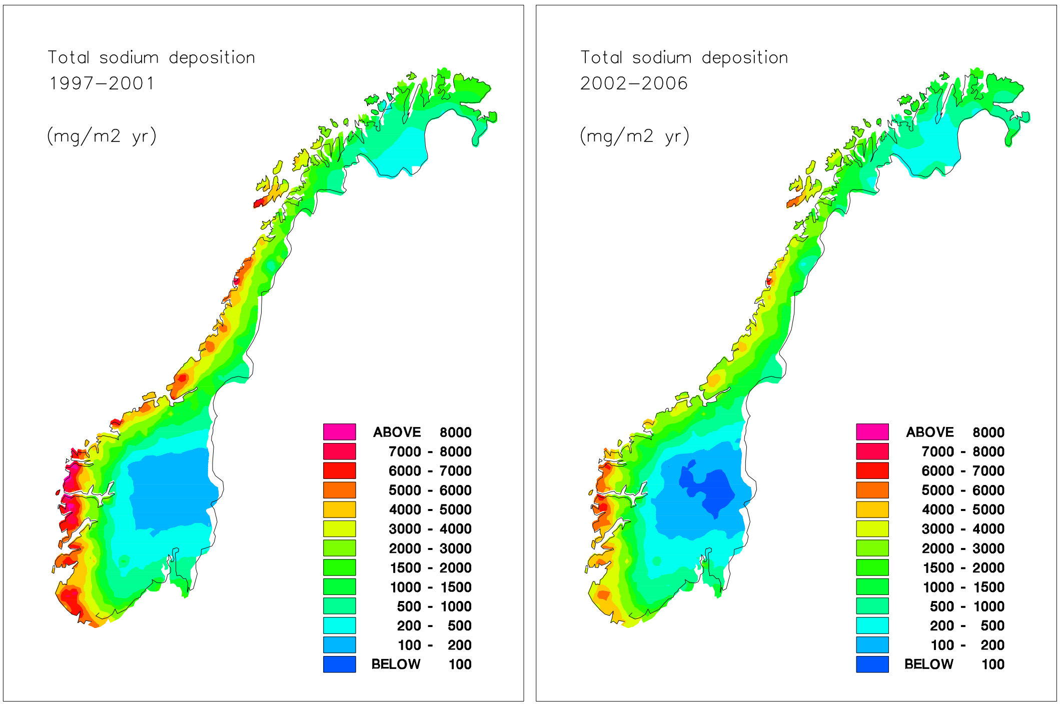


Figure 12: Total deposition of sodium (mg Na/m^2 year) 1997-2001 and 2002-2006.

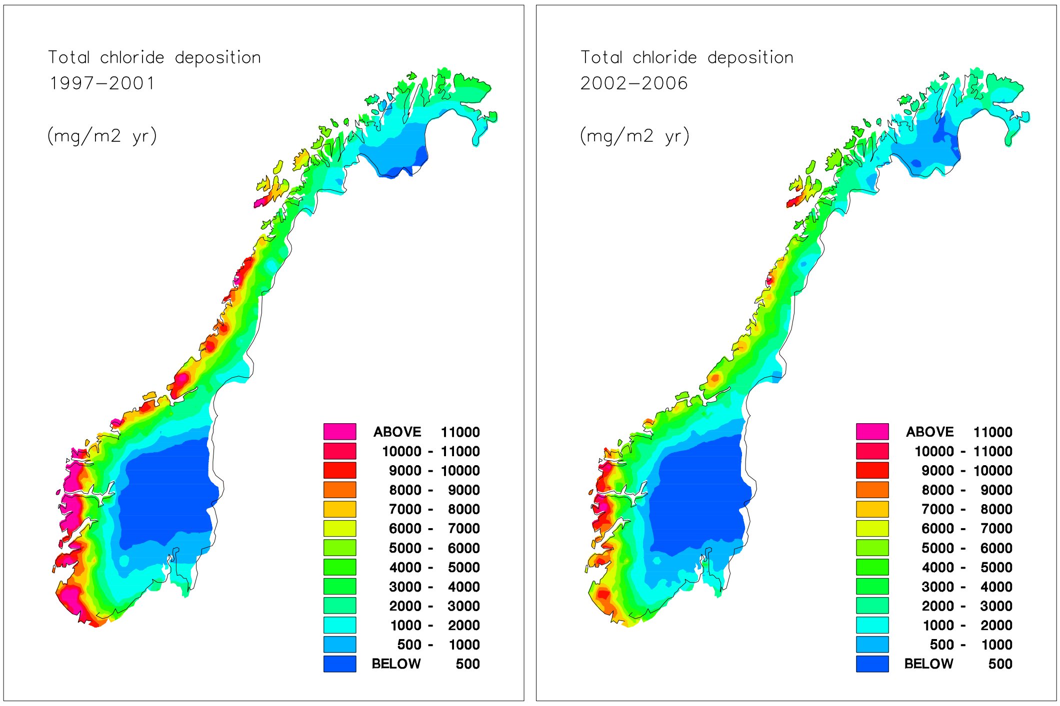


Figure 13: Total deposition of chloride (mg Cl/m^2 year) 1997-2001 and 2002-2006.

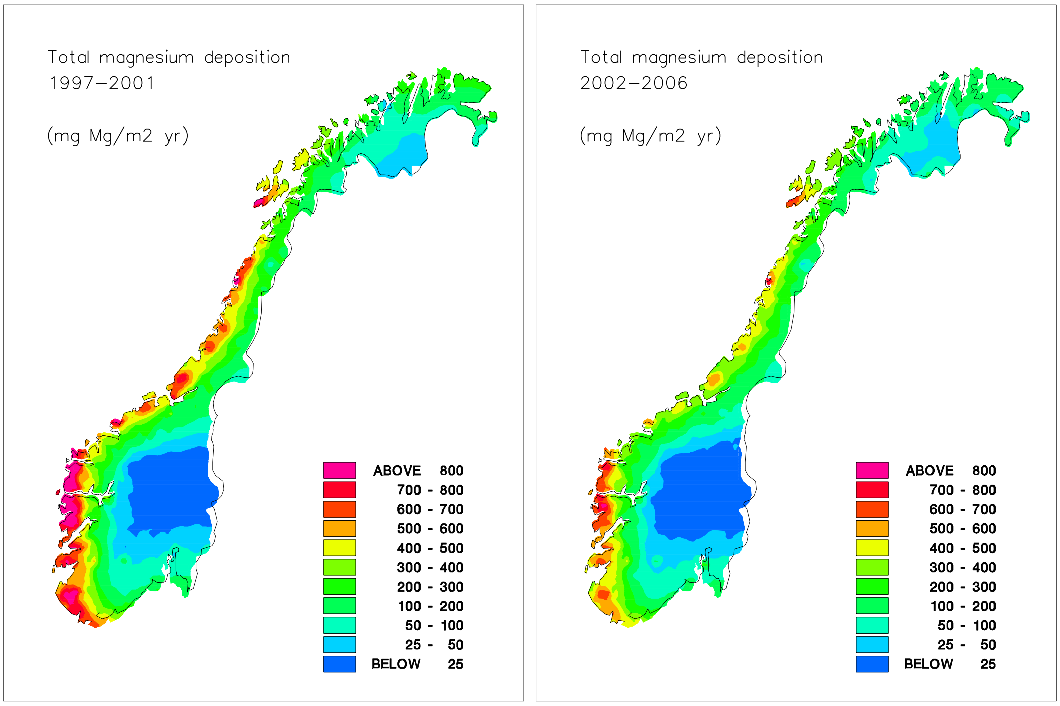


Figure 14: Total deposition of magnesium (mg Mg/m^2 year) 1997-2001 and 2002-2006.

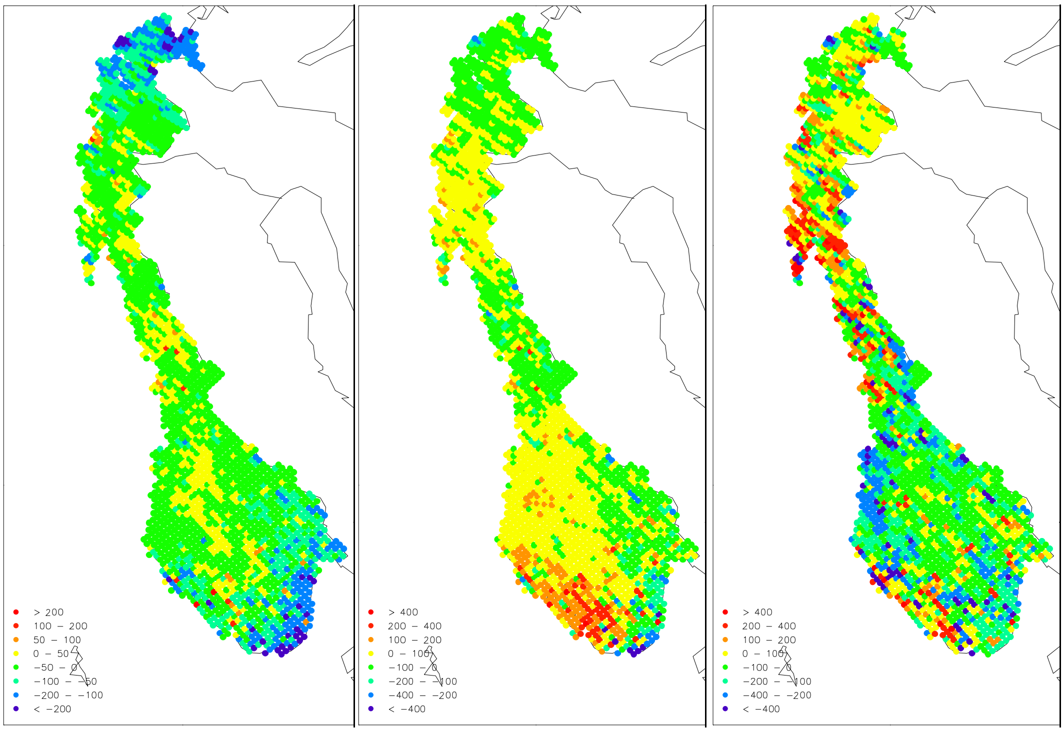


Figure 15: Difference in nss sulphur deposition (left), total nitrogen deposition (middle) and precipitation amount (right) between the periods 1997-2001 and 2002-2006 (units mg S/m² year, mg N/m² year and mm/year, respectively).

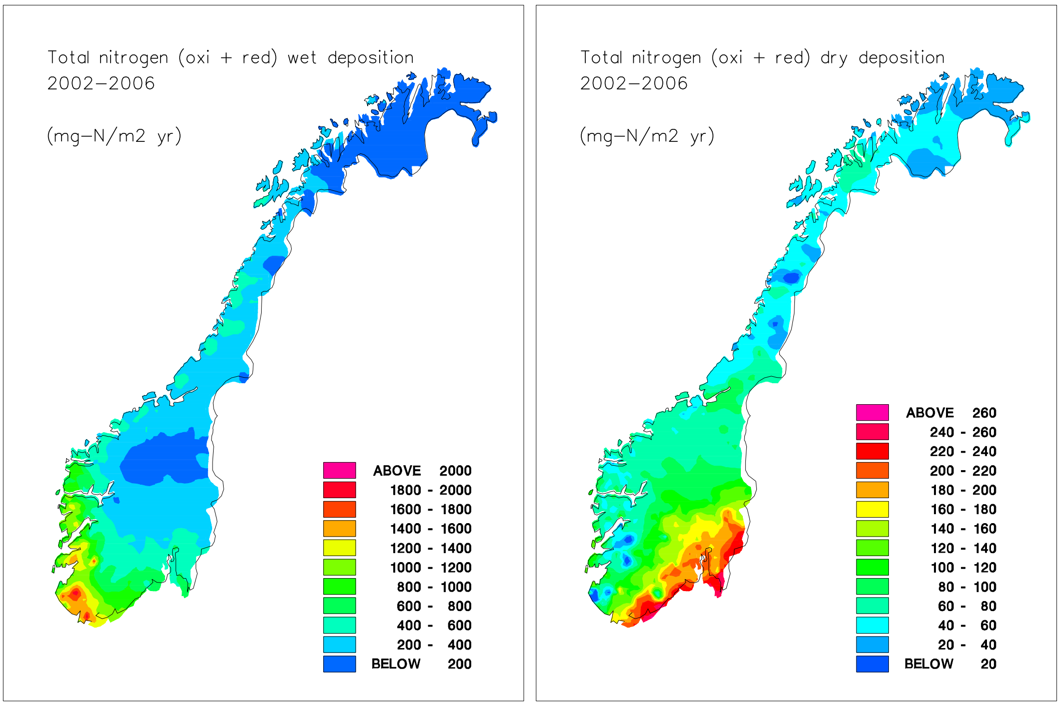


Figure 16: Total wet- and dry deposition of total nitrogen (oxi + red) in 2002-2006 (mg N/m² year).

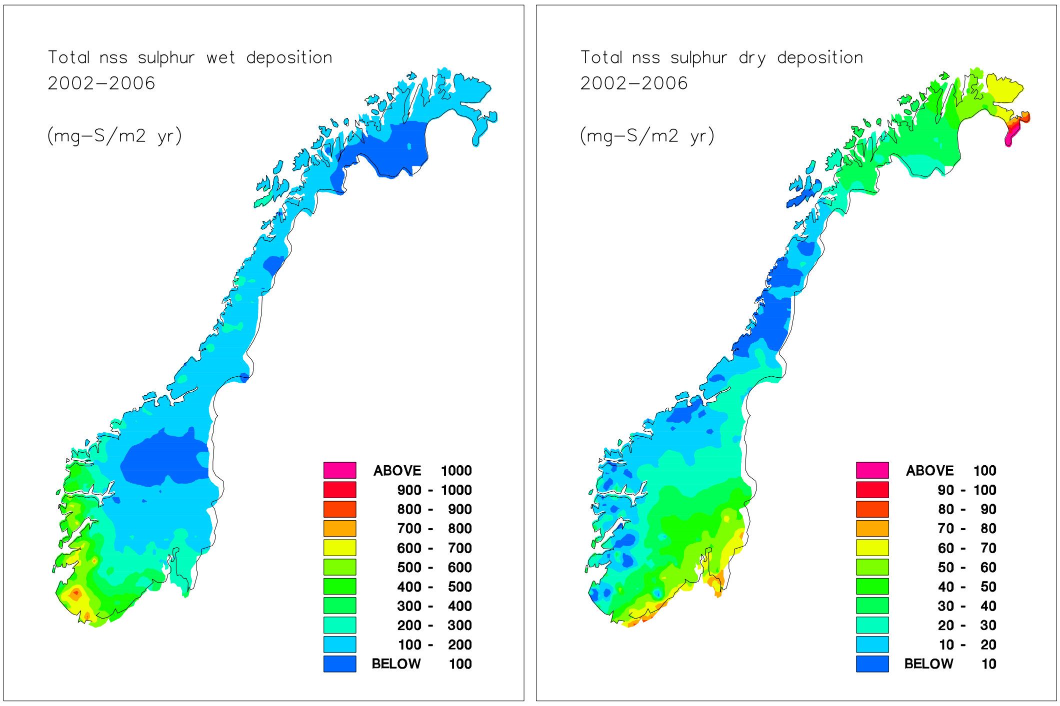


Figure 17: Total wet- and dry deposition of sulphur in 2002-2006 (mg S/m^2 year).

7. References

Armstrong, M. and Matheron, G. (1986) Disjunctive kriging revisited: Part I and part II. *Math. Geol.*, *18*, 711-742.

Barrett, K., Seland, Ø., Foss, A., Mylona, S., Sandnes, H., Styve, H. and Terrason, L. (1995) European Transboundary Acidifying Air Pollution. Ten years calculated fields and budgets to end of the first Sulphur Protocol. Oslo, The Norwegian Meteorological Institute (EMEP/MSC-W Report 1/95).

Met.no (2002-2006) Monthly climatological reviews, January 2002 - December 2006. Oslo, Det norske meteorologiske institutt.

Dollard, G.J., Unsworth, M.H. and Harvey, M.J. (1983) Pollutant transfer in upland regions by occult deposition. *Nature, 302*, 241-243.

Emberson, L.D., Simpson, D., Tuovinen, J.-P., Ashmore, M.R. and Cambridge, H.M. (2000). Towards a model of ozone deposition and stomatal uptake over Europe. Oslo, Norwegian Meteorological Institute (EMEP MSC-W Note 6/2000).

EMEP (2008) Transboundary acidification, eutrophication and ground level ozone in Europe in 2006. Oslo, Norwegian Meteorological Institute (EMEP Status Report 1/08).

Foltescu, V.L., Selin Lindgren, E., Isakson, J., Öblad, M., Tiede, R., Sommar, J., Pacyna, J.M. and Tørseth, K. (1996) Airborne concentrations and deposition fluxes of major and trace species at marine stations in Southern Norway. *Atmos. Environ., 30*, 3857-3872.

Hellsten, S., van Loon, M., Tarrason, L., Vestreng, V., Tørseth, K., Kindbom, K. and Aas, W. (2007) Base cations deposition in Europe. Stockholm, Swedish Environmental Research Institute (IVL Report B1722).

Hicks, B.B., Baldocchi, D.D., Meyers, T.P., Hosker Jr., R.P. and Matt, D.R. (1987) A preliminary multiple resistance routine for deriving dry deposition velocities from measured quantities. *Water, Air, Soil Poll., 36*, 311-329.

Hillamo, R.E., Pacyna, J.M., Semb, A. and Hanssen, J.E. (1992) Size distributions of inorganic ions in atmospheric aerosol in Norway. In: *Development of Analytical Techniques for Atmospheric Pollutants*. Ed. by I. Allegrini., Brussels, Commission of European Communities (Air Pollution Research Report, 41) pp. 51-65.

Hole, L.R. and Tørseth, K. (2002) Deposition of major inorganic compounds in Norway 1978-1982 and 1997-2001: status and trends. Kjeller, Norwegian Institute for Air Research (NILU OR 61/2002).

Hole, L.R. de Wit. H. and Aas, W. (2008) Influence of summer and winter climate variability on nitrogen wet deposition in Norway. *Hydrol. Earth Syst. Sci., 12*, 405-414.

Hultberg, H. and Grennfelt, P. (1992) Sulphur and seasalt deposition as reflected by throughfall and runoff chemistry in forested catchments. *Environ. Poll., 75*, 215-222.

Ivens, W.P.M.F. (1990) Atmospheric deposition onto forests. Ph.D. Thesis, University of Utrecht, Utrecht, The Netherlands.

Journel, A.G., and Huijbregts, C.J. (1981) Mining Geostatistics. London, Academic Press.

Lovett, G.M. and Kuisman, J.D. (1990) Atmospheric pollutant deposition to high elevation ecosystems. *Atmos. Environ., 24*, 2767-2786.

Lükewille, A. and Semb, A. (1997) Deposition and deposition processes in Norwegian mountain areas. Kjeller (NILU OR 66/97).

Lövblad, G., Erisman, J. W. and Fowler, D. (eds.) (1993) Models and methods for the quantification of atmospheric input to ecosystems. Report from a workshop held in Gothenborg, Sweden, 3-6 November 1993, Copenhagen, Nordic Council of Ministers (Nordiske Seminar- og Arbejdsrapporter 1993:573).

Lövblad, G., Andersen, B, Joffre, S., Pedersen, U., Hovmand, M. and Reissell, A. (1992) Mapping deposition of sulphur, nitrogen and base cations in the Nordic countries. Göteborg (IVL Report B 1055).

Matheron, G. (1963) Principles of geostatistics. *Econ. Geol., 58*, 1246-1266.

Pedersen, U., Walker, S.E. and Kibsgaard, A. (1990) Deposition mapping of sulphur and nitrogen compounds in Norway. Lillestrøm (NILU OR 28/90). In Norwegian.

Schaug, J., Iversen, T. and Pedersen, U. (1993) Comparison of measurements and model results for airborne sulphur and nitrogen compounds with kriging. *Atmos. Environ., 6*, 831-844.

Semb, A., Hanssen, J.E., Francois, F., Maenhaut, W. and Pacyna, J.M. (1995) Long range transport and deposition of mineral matter as a source for base cations. *Water, Air Soil Poll., 85*, 1933-1940.

SFT (2003) Monitoring of long range transported air pollutants and acid precipitation. Annual report 2002. Oslo (The Norwegian State Pollution Control Authority Report no. 877/2003). In Norwegian.

SFT (2004) Monitoring of long range transported air pollutants and acid precipitation. Annual report 2003. Oslo (The Norwegian State Pollution Control Authority Report no. 903/2004). In Norwegian.

SFT (2005) Monitoring of long range transported air pollutants and acid precipitation. Annual report 2004. Oslo (The Norwegian State Pollution Control Authority Report no. 929/2005). In Norwegian.

SFT (2006) Monitoring of long range transported air pollutants and acid precipitation. Annual report 2005. Oslo (The Norwegian State Pollution Control Authority Report no. 955/2006). In Norwegian.

SFT (2007) Monitoring of long range transported air pollutants and acid precipitation. Annual report 2006. Oslo (The Norwegian State Pollution Control Authority Report no. 985/2007). In Norwegian.

SFT (2008) Monitoring of long range transported air pollutants and acid precipitation. Annual report 2007. Oslo (The Norwegian State Pollution Control Authority Report no. 1033/2008). In Norwegian.

Simpson, D., Tuovinen, J.P., Emberson, L.D. and Ashmore, M.R., (2001) Characteristics of an ozone deposition module. *Water Air Soil Pollut. Focus, 1,* 253–262.

Simpson, J.C. and Olsen, A.R. (1990) Wet deposition temporal and spatial patterns of North America, 1987. Research Triangle Park, NC: U.S. Environmental Protection Agency, Atmospheric Research and Exposure Assessment Laboratory (EPA report no. EPA-600/4-90-019).

Solberg, S., Horntvedt, R., Berg, I.A., Aamlid, D. and Tørseth, K. (1997) Intensive monitoring plot, Results 1996. Ås (Aktuelt fra Skogforsk 6/97). In Norwegian.

Sorteberg, A., Hov, Ø., Solberg, S., Tørseth, K., Areskoug, H., Ferm, M., Granby, K., Lättilä, H., Persson, K. and Simpson, D. (1998) Gaseous and particulate oxidized and reduced nitrogen species in the atmospheric boundary layer in Scandinavia in spring. *J. Atmos. Chem. 30*, 241-271.

Tørseth, K. and Pedersen, U. (1994) Deposition of sulphur and nitrogen compounds in Norway 1988-1992. Kjeller (NILU OR 16/94).

Tørseth, K. and Semb, A. (1995) Sulphur and nitrogen deposition in Norway, status and trends. *Water, Air Soil Poll., 85*, 623-628.

Tørseth, K. and Semb, A. (1997) Deposition of major inorganic compounds in Norway 1992-1996. Kjeller (NILU OR 67/97).

Valdez, M.P., Bales, R.C., Stanley, D.A., and Dawson, G.A. (1987) Gaseous deposition to snow 1. Experimental study of SO_2 and NO_2 deposition. *J. Geophys. Res., 92*, 9889-9787.

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 1.1-1.2 and Tables 1.1

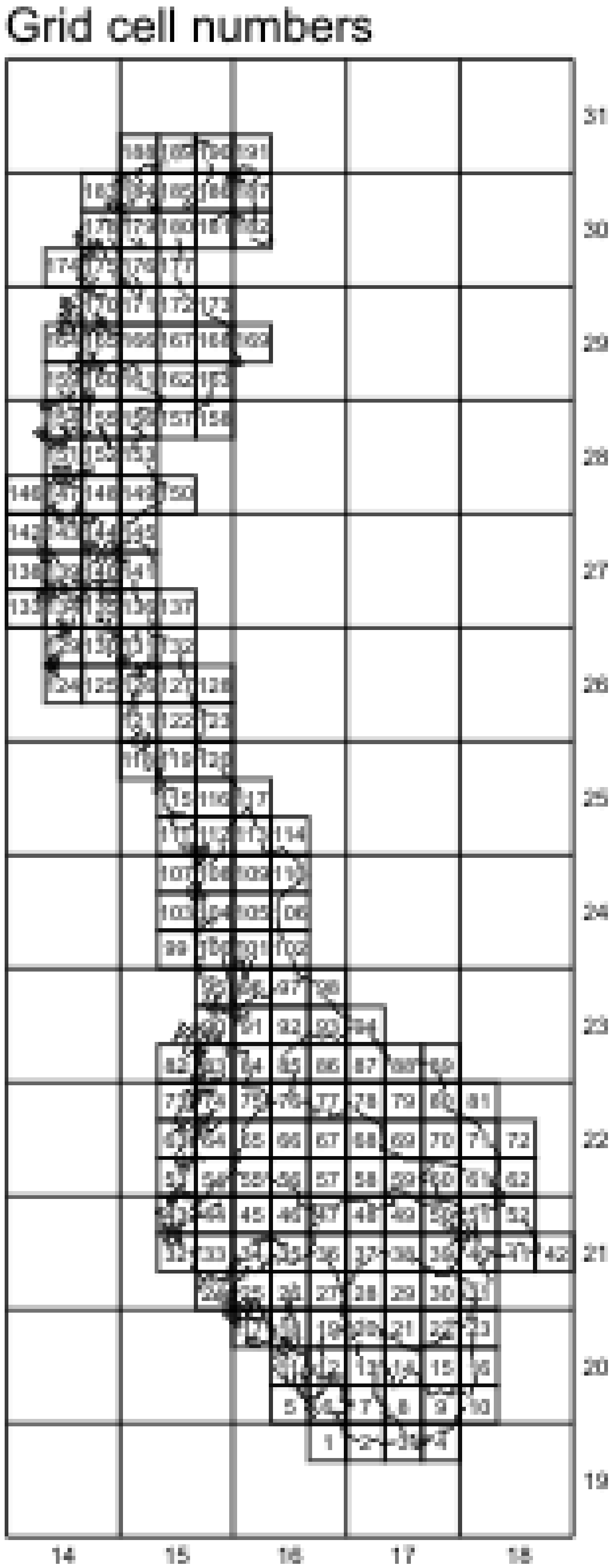


Figure 1.1: The 50·50 km² grid and grid cell numbers (EMEP sub-grid) used for interpolating concentration fields.

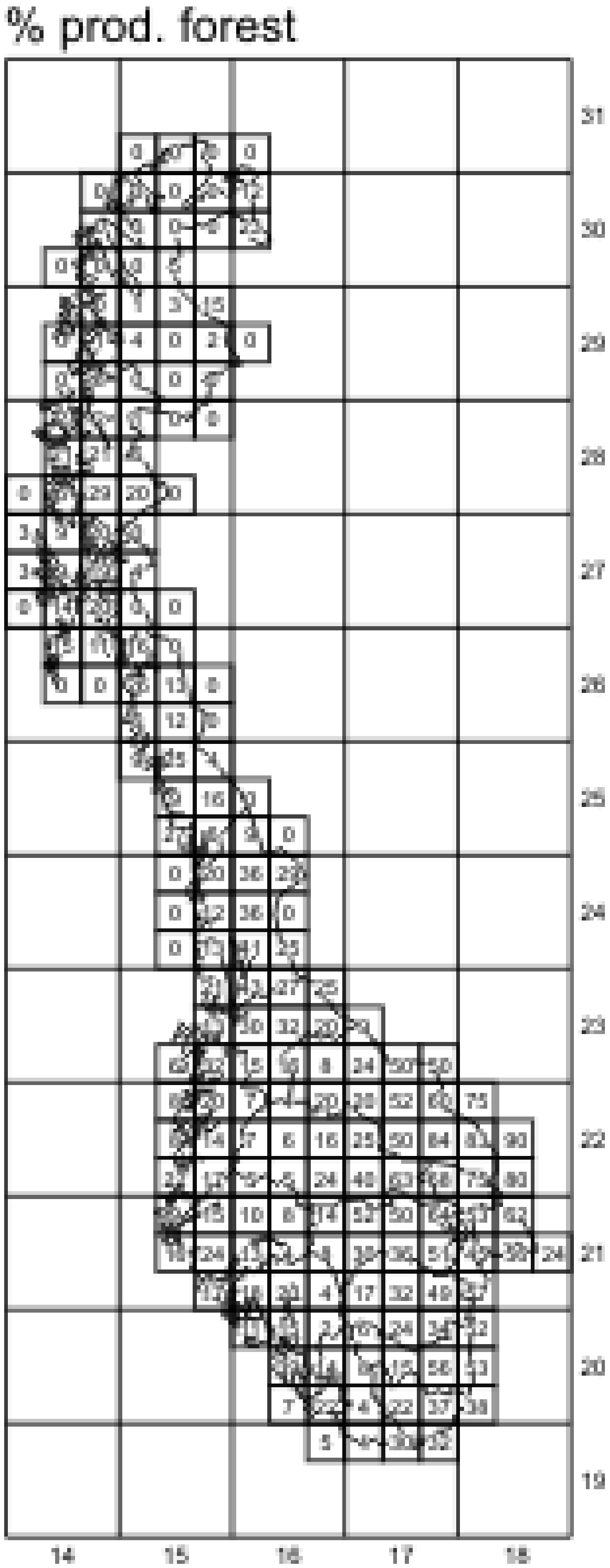


Figure 1.2: Percent productive forest used in estimating dry deposition.

Table 1.1: Values of each 50·50 km² grid cell, 2002-2006 (see Figure 1.1).

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
1	100	1538	448	545	512	1057	113	141	163	148	3910	471	6983	327	45	55	51	106	11	16	1
2	1270	1701	570	698	652	1351	139	149	198	157	4139	499	7390	346	724	887	829	1715	177	252	6
3	1060	1881	667	847	752	1599	151	165	226	174	4596	554	8206	385	707	897	797	1695	160	239	5
4	950	1778	673	869	742	1611	158	143	220	150	3966	478	7082	332	639	826	705	1530	150	209	4
5	430	1245	322	380	366	747	87	114	126	120	3168	382	5658	265	138	164	158	321	37	54	1
6	450	1458	419	502	487	989	104	127	161	134	3543	427	6326	297	189	226	219	445	47	73	6
7	2480	2124	633	740	716	1457	160	157	228	165	4364	526	7794	365	1569	1836	1776	3612	396	566	9
8	2500	1952	652	795	729	1524	155	115	222	121	3207	386	5726	268	1630	1987	1823	3810	388	554	8
9	2480	1690	636	812	695	1507	147	117	204	123	3248	391	5800	272	1577	2014	1723	3737	364	506	6
10	280	1351	560	738	600	1337	126	112	173	118	3110	375	5553	260	157	207	168	374	35	48	3
11	1310	1817	456	521	518	1039	124	149	189	157	4155	501	7420	348	598	682	679	1361	162	248	6
12	2450	2414	616	688	699	1387	165	166	240	175	4607	555	8227	386	1510	1687	1712	3399	404	587	8
13	2500	1884	524	612	588	1200	139	107	198	112	2968	358	5300	248	1311	1529	1470	2999	348	494	2
14	2450	1266	411	504	460	963	97	48	143	50	1330	160	2374	111	1007	1234	1126	2360	238	351	3
15	2500	1374	501	668	550	1218	99	52	157	55	1441	174	2574	121	1253	1670	1375	3045	247	393	7
16	750	1238	499	678	536	1214	102	75	150	79	2090	252	3733	175	375	508	402	910	76	113	6
17	1830	2336	466	493	526	1019	151	194	218	205	5400	651	9642	452	853	902	963	1865	276	399	4
18	1950	2512	546	573	607	1180	172	159	251	168	4427	533	7905	371	1065	1118	1183	2301	336	489	7
19	2500	2148	514	551	568	1119	153	117	216	123	3240	390	5787	271	1285	1377	1420	2798	382	541	6
20	2500	1578	419	481	463	943	120	67	176	70	1854	223	3310	155	1048	1202	1157	2359	300	439	5
21	2500	1001	320	393	351	744	78	19	118	20	523	63	934	44	801	983	877	1861	194	296	6
22	2500	1096	396	504	429	933	86	21	130	22	591	71	1055	49	989	1260	1073	2333	214	325	8
23	1350	1136	456	605	487	1092	100	51	143	53	1405	169	2508	118	616	817	657	1474	134	193	4
24	1150	2449	416	420	476	897	138	189	207	199	5246	632	9368	439	478	483	548	1031	159	238	7
25	2500	2839	517	528	568	1096	167	171	256	180	4763	574	8506	399	1292	1319	1421	2740	418	639	11

Table 1.1, cont.

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
26	2250	1832	392	407	429	836	117	90	176	94	2492	300	4450	209	883	916	965	1880	263	397	9
27	2450	1267	305	320	327	647	93	41	135	43	1132	136	2022	95	746	784	802	1586	228	331	4
28	2400	827	235	280	257	537	68	10	97	11	290	35	518	24	563	671	617	1289	162	233	5
29	2500	902	286	358	313	671	74	15	111	16	427	51	763	36	716	894	783	1677	186	276	7
30	2500	991	349	457	377	833	86	18	125	19	510	61	911	43	872	1142	941	2083	215	312	8
31	1930	971	378	519	402	921	89	45	127	47	1254	151	2239	105	729	1002	775	1778	171	245	7
32	940	2692	398	377	486	863	156	221	214	233	6142	740	10968	514	374	354	457	811	147	201	1
33	2450	2676	428	414	494	908	147	169	223	178	4687	565	8370	392	1048	1015	1210	2226	360	547	8
34	2360	1595	279	290	318	607	95	80	144	84	2215	267	3955	185	658	684	749	1433	223	339	8
35	2450	1143	230	240	256	496	76	38	110	40	1049	126	1873	88	564	587	627	1214	186	269	5
36	2500	805	191	207	209	416	61	8	86	8	211	25	377	18	477	517	522	1040	152	215	3
37	2500	734	202	247	224	471	68	7	90	8	203	24	362	17	506	617	560	1177	170	225	5
38	2500	775	235	304	257	561	70	9	99	9	242	29	433	20	588	759	643	1401	174	247	3
39	2500	860	289	381	308	689	78	16	111	17	437	53	780	37	723	952	771	1722	195	278	7
40	1730	969	358	455	368	822	85	23	123	24	631	76	1128	53	620	787	636	1423	148	213	8
41	1250	866	352	493	371	864	84	38	117	40	1059	128	1890	89	441	616	464	1080	105	147	8
42	125	877	349	470	371	841	86	37	112	39	1020	123	1821	85	44	59	46	105	11	14	1
43	1375	2120	292	270	365	635	130	159	171	167	4412	532	7878	369	401	372	502	874	179	236	5
44	2500	2133	319	305	381	686	119	112	172	118	3124	376	5579	261	797	762	952	1714	297	430	10
45	2500	1585	258	262	297	558	96	56	138	59	1552	187	2772	130	645	654	742	1396	241	346	6
46	2400	657	135	150	155	305	47	21	66	22	585	70	1044	49	323	360	371	731	113	159	5
47	2500	720	162	185	179	364	60	6	79	6	168	20	299	14	405	463	447	910	150	197	4
48	2500	602	174	229	193	423	55	5	78	6	148	18	263	12	434	574	483	1057	138	196	6
49	2500	805	235	307	253	560	79	7	105	8	205	25	367	17	588	767	633	1399	198	263	5
50	2500	866	286	378	301	679	85	12	114	13	346	42	618	29	714	945	752	1697	211	285	16

Table 1.1, cont.

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
51	2500	864	308	413	324	737	81	25	110	27	706	85	1261	59	769	1032	811	1844	203	275	8
52	1210	841	325	459	342	801	82	25	111	26	685	82	1223	57	393	555	414	970	100	135	4
53	900	1565	201	191	266	457	106	117	144	123	3242	391	5789	271	181	172	239	411	95	130	4
54	2400	1612	229	220	282	502	102	79	139	84	2209	266	3944	185	549	528	677	1205	245	333	5
55	2500	1030	160	157	186	343	68	30	99	31	823	99	1470	69	399	394	465	859	170	247	3
56	2500	713	138	137	151	288	57	10	69	10	274	33	489	23	346	342	379	721	141	172	3
57	2500	677	144	172	166	338	62	5	74	6	150	18	268	13	361	431	415	846	154	185	4
58	2500	700	178	221	195	416	66	4	81	5	119	14	212	10	446	553	489	1041	165	204	8
59	2400	654	198	259	209	468	63	5	84	5	139	17	248	12	475	621	502	1123	150	201	6
60	2500	845	265	350	274	623	90	9	111	10	259	31	462	22	661	874	685	1559	226	277	9
61	2400	773	274	381	279	660	77	14	105	15	396	48	708	33	658	914	671	1584	184	252	4
62	250	773	295	435	308	743	80	9	106	10	253	30	451	21	74	109	77	186	20	27	1
63	900	1252	169	165	228	393	82	94	103	99	2611	315	4662	219	152	149	205	354	73	93	4
64	2100	1287	180	179	236	416	84	59	108	62	1627	196	2906	136	378	377	496	873	177	226	6
65	2300	500	87	100	116	216	35	11	50	12	317	38	565	26	200	231	266	497	81	114	4
66	2500	407	81	99	104	203	34	4	43	4	111	13	198	9	203	248	260	508	84	107	8
67	2500	589	124	145	144	289	54	3	62	4	96	12	172	8	309	362	359	722	136	154	7
68	2550	761	168	202	187	389	83	3	83	4	95	11	170	8	427	516	476	992	213	212	5
69	2500	673	182	236	195	431	68	3	79	4	95	11	169	8	456	590	487	1077	170	198	6
70	2500	687	221	308	230	538	74	5	90	5	126	15	225	11	553	770	575	1345	184	224	4
71	2300	713	248	350	255	605	73	10	96	11	288	35	513	24	571	805	587	1392	168	220	2
72	200	727	276	408	278	686	79	8	101	8	221	27	395	19	55	82	56	137	16	20	1
73	620	1723	207	193	284	477	107	147	141	155	4090	493	7304	342	128	120	176	296	66	87	3
74	2300	1415	184	184	249	433	87	72	117	76	2007	242	3584	168	424	423	572	995	201	270	8
75	2500	1096	153	155	202	358	70	40	95	42	1121	135	2002	94	383	389	505	894	175	236	3

Table 1.1, cont.

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
76	2500	574	103	113	124	236	43	4	55	4	107	13	191	9	258	282	310	591	107	137	3
77	2500	489	105	125	126	252	44	4	52	4	107	13	191	9	262	313	316	629	109	130	4
78	2500	507	115	138	128	266	55	3	55	3	85	10	151	7	287	345	320	666	139	138	1
79	2500	718	187	227	191	419	68	3	79	4	93	11	167	8	469	569	478	1047	170	196	5
80	2000	734	217	273	216	489	72	5	85	5	129	15	230	11	434	546	431	977	144	170	4
81	200	735	241	328	242	570	80	6	94	6	156	19	279	13	48	66	48	114	16	19	1
82	770	1272	155	150	222	372	80	114	102	120	3173	382	5666	266	119	115	171	286	62	78	1
83	1900	1535	194	196	267	463	98	109	129	115	3042	366	5432	255	368	372	508	880	186	246	4
84	2500	860	125	135	171	306	56	31	75	33	864	104	1543	72	314	338	427	765	141	188	5
85	2500	479	90	105	117	223	39	10	48	11	279	34	498	23	226	263	294	557	98	119	3
86	2500	505	102	112	120	232	43	5	51	5	141	17	251	12	255	281	299	580	107	128	5
87	2450	512	113	134	130	263	68	4	57	4	108	13	194	9	277	328	318	646	167	139	3
88	1400	782	195	227	202	429	98	4	87	5	124	15	221	10	273	317	283	601	138	121	2
89	400	756	212	254	208	462	93	5	88	5	128	15	228	11	85	102	83	185	37	35	1
90	1500	1218	141	143	212	355	89	94	105	99	2617	315	4674	219	212	214	318	532	134	158	7
91	2300	983	141	147	187	334	66	47	91	50	1318	159	2354	110	325	338	429	767	152	209	11
92	2500	787	136	145	163	308	60	22	77	23	606	73	1081	51	341	363	407	770	149	193	3
93	2450	551	114	121	129	249	46	7	56	8	204	25	365	17	279	296	315	610	113	138	6
94	800	664	146	152	150	302	89	4	70	4	112	14	200	9	117	122	120	242	72	56	3
95	1400	1565	188	174	263	437	107	127	133	134	3543	427	6327	297	263	244	368	612	150	187	2
96	2100	1082	158	165	211	376	77	51	102	54	1413	170	2523	118	332	346	443	789	161	214	5
97	2230	936	158	161	190	351	69	25	89	26	689	83	1230	58	352	359	423	782	153	198	5
98	600	865	164	164	177	341	74	13	86	14	370	45	661	31	98	98	106	204	44	52	1
99	100	836	99	92	154	246	57	76	73	80	2102	253	3754	176	10	9	15	25	6	7	2
100	2150	1503	179	164	259	423	100	127	128	134	3528	425	6300	295	386	354	557	910	214	275	5

Table 1.1, cont.

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
101	2450	1004	147	148	199	346	63	56	93	59	1567	189	2798	131	360	362	486	849	155	229	7
102	800	1029	162	155	192	348	67	35	96	37	968	117	1728	81	130	124	154	278	53	77	2
103	400	1092	116	105	194	299	79	97	94	103	2708	326	4836	227	47	42	77	119	32	37	2
104	2500	1323	161	149	238	387	86	102	111	108	2839	342	5069	238	402	373	595	968	216	279	3
105	2500	983	145	144	197	341	65	47	93	49	1293	156	2309	108	363	361	492	854	162	232	3
106	300	1013	158	147	185	332	65	26	92	27	717	86	1280	60	47	44	56	100	20	28	1
107	400	1378	147	134	236	371	105	123	115	129	3410	411	6089	285	59	54	95	148	42	46	1
108	2500	1606	193	178	285	463	110	112	138	118	3119	376	5569	261	483	444	713	1158	274	344	3
109	2500	1067	157	154	212	365	73	59	98	62	1630	196	2911	136	392	384	529	913	183	246	1
110	2100	737	129	126	155	281	54	22	73	24	622	75	1110	52	270	265	325	590	112	153	2
111	1100	1387	156	148	252	400	113	122	124	128	3385	408	6044	283	171	163	278	441	124	136	1
112	2500	1543	185	167	270	437	116	111	135	117	3082	371	5503	258	463	418	674	1092	290	337	3
113	2200	936	142	129	183	312	74	40	90	43	1124	135	2008	94	313	285	402	687	163	197	2
114	100	793	132	120	153	273	60	21	77	22	574	69	1025	48	13	12	15	27	6	8	1
115	2350	1432	153	139	252	391	115	114	123	120	3170	382	5660	265	359	326	592	918	271	289	7
116	2450	1514	186	168	268	437	120	84	132	89	2341	282	4180	196	457	412	658	1069	294	325	3
117	700	800	121	110	156	266	63	35	75	37	984	119	1757	82	84	77	109	186	44	53	1
118	1100	1525	145	124	254	378	125	129	132	136	3597	433	6424	301	160	136	279	416	138	146	4
119	2390	1690	196	173	292	465	134	111	146	117	3087	372	5512	258	467	414	699	1112	320	349	4
120	1200	1244	162	142	222	364	95	60	110	63	1661	200	2966	139	194	171	267	437	114	131	5
121	2000	1672	167	137	258	395	134	120	139	126	3326	401	5939	278	333	274	516	790	267	278	4
122	2500	1373	162	132	240	372	111	69	125	72	1909	230	3409	160	405	329	600	929	278	312	5
123	400	1314	177	149	224	373	104	63	115	67	1758	212	3140	147	71	60	90	149	42	46	1
124	300	1580	155	111	236	347	117	141	137	148	3917	472	6994	328	47	33	71	104	35	41	2
125	100	1404	156	115	217	332	120	125	125	132	3475	419	6205	291	16	11	22	33	12	12	1

Table 1.1, cont.

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
126	2300	1427	162	126	233	359	124	97	132	103	2709	326	4837	227	373	290	537	827	285	305	5
127	2400	443	71	65	94	159	42	20	48	21	563	68	1006	47	171	155	226	382	100	115	3
128	200	443	74	65	91	155	41	22	46	24	625	75	1117	52	15	13	18	31	8	9	1
129	400	1382	162	115	213	328	117	121	122	127	3355	404	5991	281	65	46	85	131	47	49	2
130	900	1121	134	101	177	278	100	98	106	103	2731	329	4877	229	120	91	159	250	90	95	2
131	2500	1381	164	122	219	341	126	70	130	73	1936	233	3457	162	410	305	548	853	316	325	3
132	1300	895	121	92	150	242	80	36	86	37	989	119	1766	83	157	119	195	314	104	112	3
133	100	853	108	78	140	218	86	76	81	80	2109	254	3767	177	11	8	14	22	9	8	2
134	700	2032	224	150	290	440	177	176	178	186	4902	591	8753	410	157	105	203	308	124	124	5
135	1500	1228	152	112	193	304	110	96	114	101	2674	322	4775	224	227	168	289	457	165	170	5
136	1400	1526	198	140	226	366	125	81	139	86	2260	272	4035	189	277	196	316	512	175	195	1
137	100	1173	169	128	184	311	123	46	120	48	1279	154	2284	107	17	13	18	31	12	12	1
138	400	1473	175	115	211	325	140	131	129	138	3643	439	6505	305	70	46	84	130	56	52	2
139	1000	1236	158	112	187	299	121	108	113	114	3000	361	5357	251	158	112	187	299	121	113	2
140	1400	1306	170	120	195	314	155	92	130	97	2567	309	4583	215	238	168	273	440	216	182	5
141	1400	1220	167	116	183	299	129	56	121	59	1556	188	2779	130	234	162	256	418	180	169	2
142	400	1234	171	109	170	280	152	110	122	116	3060	369	5465	256	68	44	68	112	61	49	1
143	900	1306	186	124	183	307	155	114	129	120	3165	381	5652	265	167	112	165	276	140	116	2
144	1600	971	143	99	158	257	105	58	96	61	1620	195	2893	136	229	158	252	411	169	154	3
145	1100	1018	155	105	157	262	91	40	103	42	1115	134	1990	93	171	116	173	288	100	114	1
146	100	1243	181	111	173	285	149	113	123	119	3141	378	5608	263	18	11	17	28	15	12	1
147	1600	1140	171	109	163	272	135	102	113	107	2830	341	5053	237	273	174	261	434	215	181	3
148	2450	951	168	114	153	267	100	54	92	57	1506	181	2689	126	411	279	376	655	246	227	3
149	2450	742	135	91	123	214	77	30	76	32	835	101	1491	70	332	223	301	524	187	186	2
150	200	386	86	59	73	132	37	16	45	17	450	54	803	38	17	12	15	26	7	9	1

Table 1.1, cont.

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
151	1400	930	172	107	147	254	105	76	92	80	2105	254	3758	176	240	150	206	356	147	129	3
152	2400	737	147	94	125	220	82	39	72	41	1087	131	1941	91	352	227	300	527	197	173	4
153	1800	703	140	89	114	203	72	28	69	30	788	95	1407	66	253	160	205	366	130	124	1
154	1550	914	178	95	124	219	105	81	88	85	2242	270	4004	188	276	148	192	340	163	137	2
155	2300	719	137	84	114	199	88	36	74	37	989	119	1766	83	316	194	263	457	203	171	5
156	2100	428	104	64	78	142	48	15	45	15	403	49	720	34	219	135	164	299	102	95	1
157	1300	429	107	67	79	146	48	14	47	15	403	49	719	34	139	88	103	190	62	61	1
158	300	437	111	71	80	151	46	40	48	42	1110	134	1981	93	33	21	24	45	14	15	1
159	900	542	130	69	82	151	68	49	60	52	1373	165	2452	115	117	62	74	136	61	54	1
160	2500	507	128	70	85	155	65	20	57	21	566	68	1011	47	319	174	213	387	162	143	2
161	2500	489	125	71	79	150	60	13	52	14	368	44	657	31	313	177	198	375	150	131	1
162	2500	429	116	68	72	141	52	8	45	9	225	27	402	19	291	170	181	351	131	113	1
163	1500	445	123	73	75	148	53	32	47	34	891	107	1591	75	185	110	112	222	79	70	1
164	300	1647	336	160	217	378	205	135	170	143	3763	453	6720	315	101	48	65	113	61	51	1
165	1800	807	195	100	120	220	99	35	84	37	985	119	1760	82	351	180	215	395	179	152	1
166	2500	488	135	73	86	159	68	16	55	17	446	54	796	37	337	182	215	397	170	137	3
167	2500	431	124	70	77	146	59	11	45	12	311	37	555	26	309	174	191	366	147	112	3
168	2400	426	132	73	75	149	57	7	45	7	191	23	341	16	317	175	181	356	138	109	1
169	300	425	141	75	74	149	53	31	47	32	852	103	1521	71	42	22	22	45	16	14	1
170	2000	772	204	98	117	215	101	44	84	46	1222	147	2182	102	408	196	235	431	201	169	2
171	2400	452	139	71	77	148	61	8	48	8	218	26	389	18	334	170	186	356	146	114	1
172	2300	396	126	67	74	141	55	10	41	11	288	35	514	24	290	155	170	325	126	94	4
173	400	402	152	77	77	154	58	37	48	39	1036	125	1850	87	61	31	31	62	23	19	1
174	300	741	210	96	111	207	90	59	81	62	1627	196	2906	136	63	29	33	62	27	24	1
175	2200	611	184	83	97	180	75	37	65	39	1038	125	1854	87	405	183	214	397	166	142	2

Table 1.1, cont.

Grid cell no.	Total area (km2)	Average precipitation amount (mm)	Total nss S dep. (mg S/m2 yr)	Total N (oxi) (mg N/m2 yr)	Total N (red) (mg N/m2 yr)	Total N (red+oxi) (mg N/m2 yr)	Total nss K (mg/m2 yr)	Total ss K (mg /m2 yr)	Total nss Ca (mg/m2 yr)	Total ss Ca (mg/m2 yr)	Total Na (mg/m2 yr)	Total Mg (mg/m2 yr)	Total Cl (mg/m2 yr)	Total ss S (mg S/m2 yr)	Total nss S deposition (ton S in grid)	Total N (oxi) deposition (ton N in grid)	Total N (red) deposition (ton N in grid)	Total N deposition (ton N in grid)	Total nss K deposition (ton K in grid)	Total nss Ca deposition (ton Ca in grid)	Number of meteorol. sites in grid
176	2340	609	191	88	99	186	77	23	64	24	644	78	1149	54	446	205	231	436	181	149	1
177	1300	390	149	69	71	140	52	36	43	38	998	120	1782	84	194	90	92	182	67	56	1
178	900	734	232	100	114	215	89	64	81	68	1787	215	3192	150	209	90	103	193	80	73	1
179	2300	512	180	77	85	162	62	40	54	42	1115	134	1990	93	415	178	196	373	142	125	3
180	2000	507	194	81	87	168	66	26	58	27	713	86	1273	60	388	161	175	336	132	115	3
181	1300	467	196	78	81	159	59	20	54	21	555	67	990	46	255	101	105	206	77	70	1
182	1300	487	248	92	90	182	67	45	68	47	1252	151	2236	105	322	120	117	236	87	88	1
183	300	674	218	85	107	192	96	61	80	64	1698	205	3033	142	65	25	32	58	29	24	1
184	1600	734	256	103	116	218	83	58	77	61	1611	194	2877	135	410	164	185	349	132	124	1
185	2500	560	218	86	93	179	62	46	57	48	1278	154	2282	107	545	215	232	448	154	143	1
186	2300	419	189	71	75	146	48	21	44	23	597	72	1066	50	434	164	173	337	111	101	3
187	1400	485	232	81	94	175	65	32	58	34	897	108	1602	75	325	113	131	245	91	81	3
188	400	557	220	85	94	179	67	50	63	53	1400	169	2499	117	88	34	37	72	27	25	1
189	1400	557	226	86	93	179	61	50	58	53	1400	169	2500	117	317	120	130	250	86	81	1
190	700	496	218	80	87	167	56	44	52	47	1235	149	2206	103	152	56	61	117	39	36	2
191	300	541	237	87	91	178	58	51	53	53	1404	169	2508	118	71	26	27	53	17	16	1
Sum															73852	75612	79244	154856	28092	34266	

Naturens Tålegrenser – Oversikt over utgitte rapporter

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, NO_x 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.

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), Oppdrags-melding 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. Metall-belastninger i lirype. Norsk institutt for naturforskning (NINA), Oppdrags-melding 71.

19 Lien, L., Raddum, G.G. & Fjellheim, A., 1991. Tålegrenser for overflate-vannevertebrater 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-rapport 91.265.

21 Bølviken, B., Nilsen, R., Romundstad, J. & Wolden, O., 1992. Surhet, forsuringsfølsomhet og lettløselige basekationer 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. & Fjellheim, A., 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 litteratur-studie. 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. Makro-vegetasjon. 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.

31 Pedersen, H.C., Myklebust, I., Nygård, T. & Sæther, M., 1992. Akkumulering og effekter av kadmium i lirype. Norsk institutt for naturforskning (NINA), Oppdragsmelding 152.

32 Amundsen, C.E., 1992. Sammenligning av relativ forsuringsfølsomhet med tålegrenser beregnet med modeller, i jord. Norges geologiske undersøkelse. NGU-rapport 92.294.

33 Frogner, T., Wright, R.F., Cosby, B.J., Esser, J.M., Håøya, A.-O. & Rudi, G., 1992. Map of critical loads for coniferous forest soils in Norway. Norsk institutt for vannforskning (NIVA), O-91147.

34 Henriksen, A., Lien, L., Traaen, T.S. & Taubøll, S., 1992. Tålegrenser for overflatevann - Kartlegging av tålegrenser og overskridelser av tålegrenser for tilførsler av sterke syrer. Norsk institutt for vannforskning (NIVA), O-89210.

35 Lien, L. Henriksen, A. & Traaen, T.S., 1993. Tålegrenser for sterke syrer på overflatevann - Svalbard. Norsk institutt for vannforskning (NIVA), O-90102.

36 Henriksen, A., Hesthagen, T., Berger, H.M., Kvenild, L., Taubøll, S., 1993. Tålegrenser for overflatevann - Sammenheng mellom kjemisk kriterier og fiskestatus. Norsk institutt for vannforskning (NIVA), O-92122.

37 Odasz, A.M., Øiesvold, S., & Vange, V., 1993. Nitrate nutrition in *Racomitrium lanuginosum* (Hedw.)Brd., a bioindicator of nitrogen deposition in Norway. Direktoratet for naturforvaltning. Utredning for DN 1993-2.

38 Espelien, I.S., 1993. Genetiske effekter av tungmetaller på pattedyr. En kunnskapsoversikt. Norsk institutt for naturforskning (NINA), Utredning 051.

39 Økland, J. & Økland, K.A., 1993. Database for bioindikatorer i ferskvann - et forprosjekt . Laboratorium for ferskvannsøkologi og innlandsfiske (LFI), Zoologisk Museum, Oslo, Rapport 144, 1993.

40 Aamlid, D. & Skogheim, I., 1993. Nikkel, kopper og andre metaller i multer og blåbær fra Sør-Varanger, 1992. Rapport Gkogforsk 14/93. 14/93.

41 Kålås, J.A., Ringsby, T.H. & Lierhagen, S., 1993. Metals and radiocesium in wild animals from the Sør-Varanger area, north Norway. Norsk institutt for naturforskning (NINA), Oppdragsmelding 212.

42 Fløisand, I. & Løbersli, E. (red.), 1993. Tilførsler og virkninger av luft-transporterte forurensninger (TVLF) og Naturens tålegrenser. Sammendrag av foredrag og postere fra møte i Stjørdal, 15.-17.februar 1993. Norsk institutt for luftforskning (NILU), OR 17/93.

43 Henriksen, A. & Hesthagen, T., 1993. Critical load exceedance and damage to fish populations. Norsk institutt for vannforskning (NIVA), O-89210.

44 Lien, L., Henriksen, A. & Traaen, T.S., 1993. Critical loads of acidity to surface waters, Svalbard. Norsk institutt for vannforskning (NIVA), O-90102.

45 Løbersli, E., Johannessen, T. & Olsen, K.V (red.), 1993. Naturens tålegrenser. Referat fra seminar i 1991 og 1992. Direktoratet for naturforvaltning, DN-notat 1993-6.

46 Bakken, S., 1993. Nitrogenforurensning og variasjon i nitrogen, protein og klorofyllinnhold hos barskogsmosen blanksigd (*Dicranum majus*). Direktoratet for naturforvaltning (DN). Utredning for DN 1994-1.

47 Krøkje, Å., 1993. Genotoksisk belastning i jord . Effektstudier, med mål å komme fram til akseptable grenser for genotoksisk belastning fra langtransportert luftforurensning. Direktoratet for naturforvaltning (DN). Utredning for DN 1994-2.

48 Fremstad, E., 1993. Heigråmose (*Racomitrium lanuginosum*) som indikator på nitrogenbelastning. Norsk institutt for naturforskning (NINA) Oppdrags-melding 239.

49 Nygaard, P.H. & Ødegaard, T.H., 1993. Effekter av nitrogengjødsling på vegetasjon og jord i skog. Rapport Skogforsk 26/93.

50 Fløisand, I. og Johannessen, T. (red.), 1994. Langtransporterte luftforurensninger. Tilførsler, virkninger og tålegrenser. Sammendrag av foredrag og postere fra møte i Grimstad, 7.-9.3.94. Norsk institutt for luftforskning NILU OR: 17/94.

51 Kleivane, L. Skåre, J.U. & Wiig, Ø., 1994. Klorerte organiske miljøgifter i isbjørn. Forekomst, nivå og mulige effekter. Norsk Polarinstitutt, Meddelelse nr. 132.

52 Lydersen, E., Fjeld, E. & Andersen, T., 1994. Fiskestatus og vannkjemi i norske innsjøer. Norsk institutt for vannforskning (NIVA), O-93172

53 Schartau, A.K.L. (red.), 1994. Effekter av lavdose kadmium-belastning på littorale ferskvanns-populasjoner og -samfunn. Norsk institutt for naturforskning (NINA) Forskningsrapport 055.

54 Mortensen, L., 1994. Variation in ozone sensitivity of *Betula pubescens* Erh. from different sites in South Norway. Direktoratet for naturforvaltning (DN). Utredning for DN, Nr. 1994-6.

55 Mortensen, L., 1994. Ozone sensitivity of *Phleum alpinum* L. from different locations in South Norway. Direktoratet for naturforvaltning (DN). Utredning for DN, Nr. 1994-7.

56 Frogner, T., Wright, R.F., Cosby, J.B. and Esser, J.M., 1994. Maps of critical loads and exceedance for sulfur and nitrogen to forest soils in Norway. Norsk institutt for vannforskning (NIVA) O-91147.

57 Flatberg, K.I. & Frisvoll, A.A., 1994. Moseskader i Agder 1989-92 (1994). Norsk institutt for naturforskning (NINA), Oppdragsmelding 298.

58 Hesthagen, T. & Henriksen, A., 1994. En analyse av sammenhengen mellom overskridelser av tålegrenser for overflatevann og skader på fiskebestander. Norsk institutt for naturforskning (NINA), Oppdragsmelding 288.

59 Skåre, J.U., Wiig, Ø. & Bernhoft, A., 1994. Klorerte organiske miljøgifter; nivåer og effekter på isbjørn. Norsk Polarinstitutt Rapport nr. 86 - 1994.

60 Tørseth, K. & Pedersen, U., 1994. Deposition of sulphur and nitrogen components in Norway. 1988-1992. Norsk institutt for luftforskning (NILU): OR 16/94.

61 Nygaard, P.H., 1994. Virkning av ozon på blåbær (*Vaccinium myrtillus*), etasjehusmose (*Hylocomium splendens*), furumose *(Pleurozium schreberi*) og krussigd (*Dicranum polysetum*). Rapport Skogforsk 9/94.

62 Henriksen, A. & Lien, L., 1994. Tålegrenser for overflatevann: Metode og usikkerheter. Norsk institutt for vannforskning (NIVA), O-94122.

63 Hilmo, O. & Larssen, H.C., 1994. Morfologi hos epifyttisk lav i områder med ulik luftkvalitet. ALLFORSK Rapport 2.

64 Wright, R.F., 1994. Bruk av dynamiske modeller for vurdering av vann- og jordforsuring som følge av redusert tilførsel av sur nedbør. Norsk institutt for vannforskning (NIVA), O-94112.

65 Hesthagen, T., Henriksen, A. & Kvenild, L., 1994. Overskridelser av tålegrenser for overflatevann og skader på fiskebestander i norske innsjøer med spesiell vekt på Troms og Finnmark. Norsk institutt for naturforskning (NINA), Oppdragsmelding 298.

66 Sagmo Solli, I.M, Flatberg, K.I.F., Söderström, L., Bakken S. & Pedersen, B., 1996. Blanksigd og luftforurensningsstudier. NTNU. Vitenskapsmuseet. Rapport botanisk serie 1996-1.

67 Stuanes, A. & Abrahamsen, G., 1996. Tålegrenser for nitrogen i skog - en vurdering av kunnskapsgrunnlaget. Aktuelt fra Skogforsk 7-96.

68 Ogner, G. 1995. Tålegrenser for skog i Norge med hensyn til ozon. Aktuelt fra Skogforsk 3-95.

69 Thomsen, M., Nellemann, C. Frogner, T., Henriksen A., Tomter, S. & Mulder, J., 1995. Tilvekst og vitalitet for granskog sett i relasjon til tålegrenser og forurensning. Rapport fra Skogforsk 22-95.

70 Tomter, S. M. & Esser, J., 1995. Kartlegging av tålegrenser for nitrogen basert på en empirisk metode. Norsk institutt for jord- og skogkartlegging (NIJOS). Rapport nr 10/95.

71 Pedersen, H.Chr. (red.), 1995. Kadmium og bly i lirype: akkumulering og cellulære effekter. Stiftelsen for naturforskning og kulturminneforskning (NINA-NIKU) Oppdragsmelding 387

72 Bakken, S. & Flatberg, K.I.F., 1995. Effekter av økt nitrogendeposisjon på ombrotrof myrvegetasjon. En litteraturstudie. ALLFORSK Rapport 3.

73 Sogn, T.A., Stuanes, A.O. & Abrahamsen, G., 1995. Akkumulering av nitrogen - en kritisk parameter for beregning av tålegrenser for nitrogen i skog. Rapport fra Skogforsk 21/95.

74 Nygaard, P.H. & Eldhuset, T., 1996. Forholdet mellom basekationer og aluminium i jordløsning som kriterium for tålegrenser i skogsjord. Norsk institutt for skogforskning (NISK). Rapport fra Skogforsk 1/96.

75 Mortensen, L., 1993. Effects of ozone on growth of several subalpine plant species. Norw. J. Agric. Sci. 7: 129-138.

76 Mortensen. L., 1994. Further studies on the effects of ozone concentration on growth of subalpine plant species. Norw. J. Agric. Sciences 8:91-97.

77 Fløisand, I. & Løbersli, E. (red.), 1996. Lufttransporterte forurensninger - tilførsler, virkninger og tålegrenser. Norsk institutt for luftforskning (NILU) OR 2/96.

78 Thomsen, M.G., Esser; J., Venn, K. & Aamlid, D., 1996. Sammenheng mellom trærs vitalitet og næringsstatus i nåler og humus på skogovervåkingsflater i Sørøst-Norge (in prep).

79 Tørseth, K., Mortensen, L. & Hjellbrekke, A.-G., 1996. Kartlegging av bakkenær ozon etter tålegrenser basert på akkumulert dose over 40 ppb. Norsk institutt for luftforskning (NILU) OR 12/96.

80 Esser, J.M. & Tomter, S.M., 1996. Reviderte kart for tålegrenser for nitrogen basert på empiriske verdier for ulike vegetasjonstyper. Norsk institutt for jord- og skogkartlegging (NIJOS).

81 Henriksen, A., Hindar; A., Styve, H., Fjeld, E. & Lien, L., 1996. Forsuring av overflatevann, beregningsmetodikk, trender og mottiltak. Norsk institutt for vannforskning (NIVA). Rapport LNR 3528-96.

82 Henriksen, A., Hesthagen, T. & Fjeld, E., 1996. Overskridelser av tålegrenser for overflatevann og skader på fiskebestander. Norsk institutt for vannforskning (NIVA). Rapport LNR 3565-96.

83 Wright, R.F., Raastad, I.A., & Kaste, Ø., 1996. Atmospheric deposition of nitrogen, runoff of organic nitrogen, and critical loads for soils and waters. Norsk institutt for vannforskning (NIVA) Report SNO 3592-97.

84 Mortensen, L.M., 1995. The influence of ozone pollution on growth of young plants of Betula pubescens Ehrh. And Phleum alpinum L. Dose-response relations. Norw. J. Agr. Sci. 9:249-262

85 Mortensen, L.M., 1996. Ozone senistivity of Betula pubescens at different growth stages after budburst in spring. Norw. J. Agr. Sci. 10:187-196.

86 Tørseth, K., Rosendahl, K.E., Hansen, A.C., Høie, H. & Mortensen, L.M., 1997. Avlingstap som følge av bakkenært ozon. Vurderinger for perioden 1989-1993. SFT-rapport.

87 Rognerud, S, Hognve, D. & Fjeld, E., 1997. Naturlige bakgrunns-konsentrasjoner av metaller. Kan atmosfæriske avsetninger påvirke metall-konsentrasjoner slik at det ikke reflekterer berggrunnens geokjemi? Norsk institutt for vannforskning (NIVA) Rapport LNR 3670-97.

88 Skjelkvåle, B.L., Wright, R.F. & Tjomsland, T., 1997. Vannkjemi, forsuringsstatus og tålegrenser i nasjonalparker; Femundsmarka og Rondane. Norsk institutt for vannforskning (NIVA) Rapport LNR 3646-97.

89 Nordbakken; J.-F., 1997. Småskalaendringer i ombrotrof myrvegetasjon i SØ-Norge 1990/91-96. Botanisk Hage og Museum, Univ. Oslo Rapp. 1.

90 Sogn, T.A., Kjønnås, J., Stuanes, A.O., & Abrahamsen, G., 1997. Akkumulering av nitrogen - variasjoner avhengig av bestandsutvikling, nitrogentilførsel og simulert snødekke. Norges Landbrukshøgskole, Institutt for jord- og vannfag, Rapport nr. 10/97.

91 Nygaard, P.H., Ødegård, T. & Flatberg, K.I.F. Vegetasjonsendringer over 60 år i fattig skog- og myrvegetasjon i Karlshaugen skogreservat. Skogforsk (in prep.).

92 Knutzen, J., Gabrielsen, G.W., Henriksen, O.E., Hylland, K., Källqvist, T., Nygård, T., Pacyna, J.M. Skjegstad, N. & Steinnes, E., 1997. Assessment of the applicability for pollution authorities of the concept “critical load” of long-range transported micropollutants in relation to aquatic an terrestrial ecosystems. Norsk institutt for vannforskning (NIVA) Report SNO 3751-97.

93 Tørseth, K. & Semb, A., 1997. Deposition of major inorganic components in Norway 1992-1996. Norsk institutt for luftforskning (NILU), OR 67/97.

94 Henriksen, A., 1998. Application of the first order activity balance (FAB) model to Norwegian surface waters. Norsk institutt for vannforskning (NIVA) Report SNO 3809-98

95 Sogn, T.A. & Wright, R.F., 1998. The model MERLIN applied to Nordmoen, Norway. Norsk institutt for vannforskning (NIVA) Report SNO 3844-98

96 Skjelkvåle, B.L. & Henriksen, A., 1998. Vannkjemi, forsuringsstatus og tålegrenser i nasjonalparker; Hardangervidda. Norsk institutt for vannforskning (NIVA). Report SNO 3895-98

97 Henriksen, A., 1998. Binding grid cells – Norway. An evaluation. Norsk institutt for vannforskning (NIVA) Report SNO 3942-98

98 Lükewille, A. & Semb, A., 1998. Deposition in Norwegian Mountain areas. Norsk institutt for luftforskning (NILU) OR 66/97

99 Strand, L.T., Stuanes, A.O. & Abrahamsen, G., 1998. Akkumulering av karbon og nitrogen i unge jordsmonn. Institutt for jord og vannfag, rapport nr 9/98.

100 Wright, R.F. & Henriksen, A., 1999. Gap closure; use of MAGIC model to predict time required to achieve steady-state following implementation of the Oslo protocol. Norsk institutt for vannforskning (NIVA) Report SNO 4012-99.

101 Henriksen, A., 1999. Tålegrenser i fjellområder. Hva vet vi og hva bør vi vite? Rapport fra seminar 16.-17. Februar 1999. Rondablikk Høyfjellshotell. Norsk institutt for vannforskning (NIVA) Rapport LNR 4017-99.

102 Wright, R.F., 1999. Risk of N leaching from forests to surface waters in Norway. Norsk institutt for vannforskning (NIVA) Report SNO 4038-99.

103 Wright, R.F., Mulder, J. & Esser, J.M., 1999. Soils in mountain uplands regions of southwestern Norway: nitrogen leaching and critical loads. Norsk institutt for vannforskning (NIVA) Report SNO 4130-99.

104 Lindstrøm, E.A., Kjellberg, G. & Wright, R.F., 1999. Tålegrensen for nitrogen som næringsstoff i norske fjellvann: økt "grønske"? Norsk institutt for vannforskning (NIVA) Rapport LNR 4187-2000.

105 Thomsen, M.G. & Nellemann, Chr., 2000. Mortalitet og tilvekst i relasjon til forurensningsbelastningen i Sør Norge 1920-2000 (under trykking).

106 Henriksen, A & Buan, A.K., 2000. Tålegrenser og overskridelse av tålegrenser for overflatevann, skogsjord og vegetasjon i Norge. Norsk institutt for vannforskning (NIVA). Rapport LNR 4179-2000.

107 Aarrestad, P.A. & Vandvik, V., 2000. Vegetasjonsendringer i vestnorsk kystlynghei - effekter av skjøtselsformene brann og sauebeite ved rehabilitering av gammel lynghei på Lurekalven i Hordaland. - NINA fagrapport 044.

108 Oredalen, J.T. & Aas, W., 2000. Vurdering av atmosfærisk fosforavsetning i sørøst-Norge. Norsk institutt for vannforskning Rapport LNR 4310-2000.

109 Bruteig, I., Thomsen, M.G. & Altin, D., 2001. Vekstrespons hos tre aerofyttiske algar på tilførsel av nitrogen. NINA oppdragsmelding 680. (*Rapporten er feilnummerert og har fått nummer 108).*

110 Sogn; T.A., Mulder, J., Haugen, L.E., Berge, G., Rustad, K.B. & Stuanes, A., 2001. N-omsetning i hei-/fjellområder: En første tilnærming til dynamiks modellering av N-omsetningen. Institutt for jord- og vannfag, Norges landbrukshøgskole. Rapport nr 11/2001.

111 Kroglund, F., Wright, R.F. & Burchart, C., 2001. Acidification and Atlantic salmon: critical limits for Norwegian rivers. Norwegian Institute for Water Research Report No. O-20191.

112 Lindstrøm, E.A., 2001. Økt plantevekst i uberørt fjellvann: et samspill mellom langtransporterte forurensninger og klima. Norsk institutt for vannforskning. Rapport LNR 4459-2001.

113 Larssen, T., Clarke, N., Tørseth, K. & Skjelkvåle, B.L., 2002. Prognosis for future recovery from acidification of water, soils and forests: Dynamic modelling of Norwegian data from ICP Forests, ICP IM and ICP Waters. Norsk institutt for vannforskning. Report no. O-21172.

114 Hindar, A. Tørseth, K., Henriksen, A. & Orsolini, Y., 2002. Betydningen av den nordatlantiske svingning (NAO) for sjøsaltepisoder og forsuring i vassdrag på Vestlandet og i Trøndelag. Norsk institutt for vannforskning. Rapport LNR 4592-2002.

115 Hole, L. R. & Tørseth, K., 2003. Deposition of major inorganic compounds in Norway 1978-1982 and 1997-2001: status and trends. Norsk institutt for luftforskning OR 61/2002. ISBN 82-425-1410-0.

116 Larssen, T. & Høgåsen, T. 2003. Tålegrenser og overskridelse av tålegrenser i Norge. Norsk institutt for vannforskning. Rapport LNR 4722-2003.

117 Hesthagen,T., Kristensen, T., Rosseland, B.O. & Saksgård, R. 2004. Relativ tetthet og rekruttering hos aure i innsjøer med forskjellig vannkvalitet En analyse basert på prøvefiske med garn og vannets syrenøytraliseriende kapasitet (ANC). NINA Oppdragsmelding 806.

118 Lindstrøm, E.-A., Brettum, P., Johansen, S.W. & Mjelde, M. 2004. Vannvegetsjon i norske vassdrag. Kritiske grenseverdier for forsuring. Effekter av kalking. Norsk institutt for vannforskning. Rapport LNR 4821-2004.

119 Larssen, T., Skjelkvåle, B.L. og Høgåsen, T. 2004. Critical loads for lead (Pb) and cadmium (Cd) in surface waters in Norway – evaluation of methodology and preliminary maps. NIVA-rapport 4808-2004. 18s.

120 Hindar, A. og Larssen, T. 2005. Modifisering av ANC- og tålegrenseberegningene ved å inkludere sterke organiske syrer. NIVA-rapport 5030-2005. 39s.

121 Larssen, T., Høgåsen, T. og Wright, R.F. 2005. Target loads for acidification of Noregian surface waters. NIVA Report SNO 5099-2005. 33s.

122 Schartau, A.K., Halvorsen, G. og Walseng, B. 2007. Northern Lakes Recovery Study (NLRS) – microcrustaceans. Refernce conditions, acidification and biological recovery. NINA Report 235. 66s.

123 Hesthagen, T. og Østborg, G. 2008. Endringer i areal med forsuringsskadede fiskebestander i norske innsjøer fra rundt 1990 til 2006. NINA rapport 169. 100s.

124 Larsen, T., Cosby, B.J., Høgåsen, T., Lund, E. og Wright, R.F. 2008. Dynamic modelling of acidification of Norwegian surface waters. NIVA-rapport 5705-2008. 45s.

125 Aas, W., Hjellbrekke, A.-G., Hole, L.R. og Tørseth, K. 2008. Deposition of major inorganic compounds in Norway 2002-2006. Norwegian Institute for Air Research (NILU), OR 72/2008.

126 Larssen, T., Lund, E. og Høgåsen, T. 2008. Overskridelser av tålegrenser for forsuring og nitrogen for Norge. Oppdatering med perioden 2002-2006. NIVA-rapport 5697-2008. 24s.

Henvendelser vedrørende rapportene rettes til utførende institusjon.

Norwegian Institute for Air Research (NILU)
P.O. Box 100, N-2027 Kjeller, Norway

REPORT SERIES	REPORT NO.	ISBN / ISSN
SCIENTIFIC REPORT	OR 72/2008	ISBN 978-82-425-2051-7 (printed) 978-82-425-2052-4 (electronic) ISSN 0807-7207

DATE	SIGN.	NO. OF PAGES	PRICE
		53	NOK 150.-

TITLE

Deposition of major inorganic compounds in Norway 2002-2006

PROJECT LEADER

Wenche Aas

NILU PROJECT NO.

O-108067

AUTHOR(S)

Wenche Aas, Anne Hjellbrekke, Lars R. Hole and Kjetil Tørseth

CLASSIFICATION *

A

CONTRACT REF.

Naturens tålegrense
Rapport nr. 125

REPORT PREPARED FOR
Statens forurensningstilsyn (SFT)
The Norwegian State Pollution Control Authority
P.O. Box 8100 Dep
0032 OSLO

ABSTRACT

The total deposition of sulphur and nitrogen compounds in Norway during the period 2002-2006 has been estimated on the basis of available measurement data for concentrations and precipitation. Deposition of non-marine base cations is also estimated. Results are compared with previous estimates for 1997-2001.

NORWEGIAN TITLE

Avsetning av svovel og nitrogenforbindelser i Norge, 2002-2006

KEYWORDS

Sulphur	Nitrogen	Precipitation

ABSTRACT (in Norwegian)

Avsetning av svovel og nitrogenforbindelser i Norge i perioden 2002-2006 er beregnet på basis av målinger av luft- og nedbørkjemi samt nedbørmengder. Avsetning av ikke-marine basekationer er også beregnet. Resultatene er sammenlignet med tidligere estimater for 2002-2006.

** Classification*	*A*	*Unclassified (can be ordered from NILU)*
	B	*Restricted distribution*
	C	*Classified (not to be distributed)*