NATURENS TÅLEGRENSER

Miljøverndepartementet

FAGRAPPORT NR.56

Maps of critical loads and exceedance for sulfur and nitrogen to forest soils in Norway

Norsk institutt for vannforskning NIVA
Norsk institutt for naturforskning NINA
Norsk institutt for jord og skogkartlegging NIJOS

Naturens Tålegrenser

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

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

Arbeidsgruppen har for tiden følgende sammensetning:

Kjell Huseby - NP
Tor Johannessen - SFT
Else Løbersli - DN
Steinar Sandøy - DN

Styringsgruppen i Miljøverndepartementet består av representanter fra avdelingen for naturvern og kulturminner, avdelingen for vannmiljø, industri- og avfallssaker og avdelingen for internasjonalt samarbeid, luftmiljø og polarsaker.

Henvendelse vedrørende programmet kan rettes til:

Direktoratet for naturforvaltning
Tungasletta 2
7005 Trondheim
Tel: 73 58 05 00

eller
Statens forurensningstilsyn
Postboks 8100 Dep
0032 Oslo 1
Tel: 22 57 34 00

NIVA - REPORT

Norwegian Institute for Water Research NIVA

Report No.:	Sub-No.:
O-91147	
Serial No.:	Limited distrib.:
3090	

Main Office
P.O. Box 173, Kjelsås
N-0411 Oslo
Norway
Phone (47) 22 18 51 00
Telefax (47) 22 18 52 00

Regional Office, Sørlandet
Televeien 1
N-4890 Grimstad
Norway
Phone (47) 37 04 30 33
Telefax (47) 37 04 45 13

Regional Office, Østlandet
Rute 866
N-2312 Ottestad
Norway
Phone (47) 62 57 64 00
Telefax (47) 62 57 66 53

Regional Office, Vestlandet
Thormøhlensgt 55
N-5008 Bergen
Norway
Phone (47) 55 32 56 40
Telefax (47) 55 32 88 33

Akvaplan-NIVA A/S
Søndre Tollbugate 3
N-9000 Tromsø
Norway
Phone (47) 77 68 52 80
Telefax (47) 77 68 05 09

Report Title:	Date:	Printed:
MAPS OF CRITICAL LOADS AND EXCEEDANCE FOR SULFUR AND NITROGEN TO FOREST SOILS IN NORWAY	May 1994	NIVA 1994
	Topic group: Acid precipitation	
Author(s): *Tore Frogner*, Richard F. Wright, *B. Jack Cosby*, *Jacqueline M. Esser*	Geographical area: Norway	
	Pages: 27	Edition:

Client(s):	Client ref.:
Norwegian Directorate for Nature Management	

Abstract:

We use the dynamic MAGIC model to calculate critical loads of sulfur and nitrogen for forest soils in Norway. Inputs include the soil survey data of NIJOS and NISK, the atmospheric deposition data of NILU, the forest productivity data of NIJOS, and the surface water chemistry data of NIVA. Two scenarios for future sulfur deposition are used with two scenarios of nitrogen retention in catchments. The magnitude and patterns of calculated nitrogen critical loads and exceedance differ substantially depending on the scenario chosen for sulfur deposition and nitrogen retention. In the worst case critical loads for N are low and exceeded in southernmost Norway. In the best case critical loads for N are high and not exceeded. More information on the processes controlling N retention in forested ecosystems is of utmost importance for the specification of nitrogen critical loads.

4 keywords, Norwegian

1. sur nedbør
2. tålegrenser
3. jord
4. kart

4 keywords, English

1. acid precipitation
2. critical loads
3. soil
4. map

Project manager

Richard F. Wright

For the Administration

Bjørn Olav Rosseland

ISBN 82-577-2536-6

Norwegian Forest Research Institute, NISK

Norwegian Institute for Water Research, NIVA

Norwegian Institute for Land Inventory, NIJOS

O-91147

MAPS OF CRITICAL LOADS AND EXCEEDANCE FOR SULFUR AND NITROGEN TO FOREST SOILS IN NORWAY

Tore Frogner [1], Richard F. Wright [2], B. Jack Cosby [3], Jacqueline M. Esser [3]

[1] NISK, Norwegian Forest Research Institute, Høgskoleveien 12, N-1432 Ås, Norway

[2] NIVA, Norwegian Institute for Water Research, Box 173 Kjelsås, N-0411 Oslo, Norway

[3] Department of Environmental Sciences, University of Virginia, Charlottesville, VA 22903, USA

[4] NIJOS, Norwegian Institute for Land Inventory, Box 115, N-1430 Ås, NORWAY

Prepared under contract for the Norwegian State Pollution Control Authority

CONTENTS

NORSK SAMMENDRAG

Kartlegging av tålegrenser for vann, vegetasjon og skogsjord er et felles europeisk prosjekt lagt under UN/ECE-konvensjonen. Begrepet tålegrenser må sees i sammenheng med at en ønsker å kvantifisere økosystemets toleranse ovenfor en belastning av forsurende komponenter som ikke medfører langvarige skadelige effekter på økosystemets struktur og funksjon. Formålet er at tålegrenser skal legges til grunn for fremtidige reduksjoner i utslipp av S og N. Kartlegging av tålegrenser for S er avsluttet og danner et viktig underlagsmateriale for den felles-europeiske reduksjonsavtale for S. Beregningen av tålegrenser for skogsjord er gjort på ca. 600 ruter og tålegrenser for S i skogsjord er tidligere beskrevet i Fagrapport nr. 33. Denne rapporten fokuserer på grunnlag og metodikk for å beregne tålegrenser for N.

Norske skogøkosystemer har generelt hatt et svært lukket nitrogenkretsløp med relativ liten tilførsel og liten lekkasje ut av systemet. Likevel er det i de senere år vist at nitratkonsentrasjonen i vann og vassdrag har økt. En kan ikke si noe sikkert om hva som har gitt denne økningen. Forklaringer som har vært trukket inn er økt nitrogennedfall og økt lekkasje av nitrogen fra hei og skogområder. Et sentralt spørsmål er når skog, vegetasjon og jord ikke lengre er i stand til å ta hånd om nitrogenet. Inn-ut data fra feltforskningsområder i barskog i Europa viser at områder med tilførsel av N mer enn 25 kg/ha/år har en utvasking av N som utgjør 50-100 % av tilførselen, mens områder hvor tilførselen av N er mindre enn 10 kg/ha/år vil utvasking av N være minimal. Disse empiriske data er brukt i MAGIC for å lage beste og verste prognoser for tålegrensen for N. Kritiske belastningsverdier som er brukt i MAGIC er:

1) 100 % utvasking av NO3 når tilførselen er større enn 10 kg N/ha/år og 100 % tilbakeholdelse når tilførselen er mellom 0 og 10 kg/N/ha/år (dårligste N-prognosen).

2) 50 % utvasking av NO3 når tilførselen er større enn 25 kg N/ha/år og 100 % tilbakeholdelse når tilførselen er mellom 0 og 25 kg/N/ha/år (beste N-prognosen).

Disse beregningene av tålegrensen for N er kombinert med en 20 % og en 60 % reduksjon i utslipp av S.

Resultater av modellberegningene viser at økt nitrogennedfall kan gi store effekter i skogøkosystemene og vil overskygge positive effekter av reduksjoner i utslipp av S. En prognose basert på dagens deposisjon av N og lav tilbakeholdelse av N i skogsjord viser at 9 % av rutene i den sørligste del av Sør-Norge er overskredet; uansett om utslippene av S reduseres med 60 %. Ved stor tilbakeholdelse av N er kun 1 % av rutene overskredet. Modellresultatene viser at tålegrensen for N vil sterkt avhenge av tilførsel og grad av tilbakeholdelse av nitrogen i jord. Det trengs mer forskning for å klargjøre hvilke konsekvenser den økte tilførselen får på økosystemnivå.

1. INTRODUCTION

The critical load of a pollutant is 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 present knowledge" (Nilsson and Grennfelt 1988).

For forest soils the pollutants of concern are sulfur and nitrogen deposited from the atmosphere and which contribute acidity to the soil. The forests are the sensitive elements affected by the accumulation of these acids in soils. Harmful effects include nutrient depletion, water stress, decreased tolerance of climate extremes, increased susceptibility to pests and diseases, and even death. The critical load for forest soils is the deposition level at which the soil acidity becomes great enough to cause significant harmful effects.

The acidifying effects of sulfur and nitrogen deposited from the atmosphere depend on the mobility and retention of the sulfate and nitrate anions once in the ecosystem. Soils in glaciated regions such as Scandinavia typically have low-to-moderate sulfate adsorption capacities and thus sulfate inputs and outputs are generally in steady state (i.e., inputs equal outputs). Changes in sulfate deposition rather quickly appear as changes in the sulfate concentration of waters draining from the soils. If these sulfate concentrations decline, acid stresses on the soils are reduced.

Nitrogen, on the other hand, is generally retained within the coniferous forest ecosystems of Scandinavia, largely because nitrogen is the growth-limiting nutrient in these forests. Nitrogen deposition (either ammonium or nitrate) that is assimilated by the biota has no net acidifying effect on soils. Chronic elevated deposition of nitrogen, however, can produce quantities of inorganic nitrogen in the soils in excess of that needed by the biota for growth. The un-assimilated nitrogen remains in the soil water and can be leached from the soils by drainage waters. Generally this leached nitrogen appears as nitrate in runoff (excess ammonium is quickly converted to nitrate in forest soils). The term "nitrogen saturation" has been given to this loss of nitrate in runoff. As with the sulfate, nitrate is a mobile strong anion and acts to acidify the soils. Nitrogen saturation, therefore, reduces the critical loads of both nitrogen and sulfur for forest systems.

Prediction of nitrogen saturation is difficult at best. The processes responsible are difficult to quantify. The best information currently available on the magnitude and timing of nitrogen saturation (or retention) comes from empirical observations. Input-output data from coniferous forest ecosystems in Europe can be used to set empirical "best case" and "worst case" limits for nitrogen retention. Such data have been compiled by Abrahamsen (1980), Grennfelt and Hultberg (1986), Hauhs et al. (1989), and most recently by Dise and Wright (in press) (Figure 1).

These data suggest that:

a) nitrate leaching from soils is minimal in catchments with nitrogen deposition levels less than 10 kgN/ha/yr (70 meq/m2/yr);

b) nitrate leaching varies from 0% to 100% of nitrogen deposition in catchments with nitrogen deposition in the range 10-25 kgN/ha/yr (70-175 meq/m2/yr);

c) nitrate leaching is 50-100% of nitrogen deposition in all catchments with nitrogen deposition more than 25 kgN/ha/yr (175 meq/m2/yr).

The amount of sulfur deposition that can be tolerated by a forest soil without harmful effects on the trees is dependent on the amount of nitrogen deposition, and, conversely, the amount of nitrogen deposition that can be tolerated depends on the sulfur deposition. Either the sulfur or nitrogen deposition must be specified first before the critical load and exceedance (either positive or negative) of the other can be calculated. This is the approach used by Henriksen et al. (1993) to calculate exceedances for sulfur and nitrogen for lakes in Finland, Norway and Sweden.

The effects of deposition of sulfur and nitrogen on soil acidity can be simulated, and the critical load calculated, using models of soil acid-base chemistry. These models are of two basic types: static models based on soil type and mineralogy; and dynamic models which additionally take into account the time-dependent processes involved in soil acidification and recovery (Sverdrup et al. 1990; Frogner et al. 1992). Both types rely on an input-output mass balance approach. Both are, therefore, consistent with the concept of critical load which implies that each receptor (forest soils, in this case) has an intrinsic capacity to neutralize acid inputs. Static models determine critical loads such that all sources of acidity are balanced by all sources of alkalinity. Dynamic models also include processes such as cation exchange, anion adsorption and the role of forest growth and management that result in time-dependency of soil response to acidic inputs.

A procedure for calculation of critical loads of sulfur for coniferous forest soils in Norway using the dynamic MAGIC model was developed by Frogner et al. (1992). Input data for this procedure included the soil survey data of NIJOS and NISK, the atmospheric deposition data of NILU, the forest productivity data of NIJOS, and the surface water chemistry data base of NIVA (Frogner et al. 1992). The damage criterion chosen was the Ca/Al molar ratio in soil solution, with a critical value of 1.

We use the same procedure here to generate critical loads maps for nitrogen deposition to forest soils in Norway. Two scenarios for future sulfur deposition are used with two scenarios of nitrogen retention in catchments in order to bracket the likely future behavior. The nitrogen critical loads are calculated for all four combinations of these scenarios.

2. METHODS, DATA SOURCES AND SCENARIOS

2.1 Selection of damage criterion

The calculation of a critical load is dependent upon a damage criterion for the harmful effect on trees. Several different chemical criteria have been proposed (Hettelingh et al. 1991). Here we use the Ca/Al molar ratio limit of 1.0 in soil water. The Ca/Al ratio provides a measure of soil acidification because over the long-term a depletion of the ion exchange pool will decrease calcium concentrations and result in a mobilization of aluminum in the soil water. High concentrations of aluminum are toxic to roots and available field and laboratory data indicate that Ca/Al = 1.0 may be used as an indicator for separating declining from healthy stands (Ulrich 1983; Schulze 1989; Sverdrup et al. 1992). The effects of low Ca/Al ratios on forest growth are as yet poorly documented, and thus the calculated critical load for forest soils should be interpreted with care.

2.2 NIJOS soil data base

The Norwegian Institute for Land Inventory (NIJOS) soils data are from areas in productive spruce, pine and birch forests (Esser and Nyborg 1992; Esser 1994). A soil pit was objectively located within the representative vegetation type five or twelve meters from the plot center in a 9 x 9 km grid. The soil pit was dug to at least a 50-cm depth where possible. Soil stratification and soil moisture class were determined in the field. Procedures are further described by Frogner et al. (1992).

2.3 NIJOS forest productivity data base

The NIJOS coniferous forest monitoring programme includes over 900 plots in a 9 x 9 km permanent national grid. The plots are located in Norway spruce (Picea abies L.), Scots pine (Pinus sylvestris L.), or birch (Betula pubescens L.) forests. Plot setup is described in Kvamme (1992). Sampling and registration of the plots occurred from June through August, 1988-1992. Procedures for estimating annual yield and uptake of cations and nitrogen are given by Frogner et al. (1992).

2.4 NIVA water data base

The Norwegian Institute for Water Research (NIVA) has assembled a database for lakewater chemistry for each square in the 12 x 12 km grid. The data come mainly from the 1000 lake survey conducted in 1986 and supplemented by similar data from other sources as described by Henriksen et al. (1990). The database includes values for concentrations of major ions and specific discharge.

2.5 NILU atmospheric deposition data base

The Norwegian Institute for Air Research (NILU) has estimated present-day deposition (wet plus dry) of sulfur and nitrogen compounds to each square in the 12 x 12 km grid.

The estimates are based largely on deposition measurements taken in 1985-1988 at monitoring stations throughout Norway. Estimated dry-deposition takes into account the type of vegetation cover. Details are given by Henriksen et al. (1990) and Lövblad et al. (1992).

2.6 The MAGIC model

MAGIC (Model of Acidification of Groundwater In Catchments) is an intermediate-complexity process-oriented model for constructing acidification history and predicting future acidification over time periods of decades to centuries (Cosby et al. 1985a, 1985b).

MAGIC makes use of lumped parameters on a catchment scale and focuses on chemical changes in the soil caused by atmospheric deposition, forest growth, and leaching to runoff. The processes in MAGIC include atmospheric deposition, sulfate adsorption, cation exchange, CO2 dissolution, precipitation and dissolution of Al, chemical weathering, uptake and release of cations by vegetation and export in runoff.

MAGIC has been extensively used in a variety of applications at sites in both North America and Europe. Application of MAGIC to the whole-catchment experimental manipulations of the RAIN project shows that this intermediate-complexity lumped model predicts the response of water and soil acidification to large and rapid changes in acidic deposition (Wright et al. 1990). These results reinforce other evaluations of MAGIC such as comparisons with paleolimnological reconstructions of lake acidification (Jenkins et al. 1990) and changes in regional lake chemistry in southern Norway (Wright et al. 1991). In addition, several of the assumptions in MAGIC have been tested experimentally (Grieve 1989). MAGIC is one of several dynamic models included in the Mapping Critical Loads Project (Sverdrup et al. 1990, Warfvinge et al. 1992). Together these applications indicate that MAGIC provides a robust tool for predicting future soil and water acidification following changes in acid deposition.

We use the surface water chemistry database from NIVA and the forest soil survey data base from NIJOS to derive a data set of paired lake and soil chemistry values for each square in the 12 x 12 km grid. (Actually, the critical load grid is 0.5 degrees latitude by 1.0 degrees longitude with 16 subdivisions within each. Thus the grid widths decrease at higher latitudes.) About 720 of these grid squares have productive forest of spruce, pine or birch.

The soils data from the 9 x 9 km grid were aggregated to the 12 x 12 km critical loads grid net. The original soils data were analyzed by horizon. These were aggregated to obtain single values for soils less than 60 cm in depth, and values for 0-50 cm and >50 cm for soils with total depth greater than 60 cm. The aggregation procedure weighted horizons by thickness and bulk density and also corrected for stone and pebble content. The MAGIC calibrations used a one-box version for those sites with soil depth less than 60 cm, and a two-box version for those sites with soils greater than 60 cm in depth (the upper box in these cases corresponds to the 0-50 cm soil layer and the lower box to the

>50 cm soil layer).

Uptake of base cations for each grid square was estimated from values of stem+bark harvest and typical concentrations of nitrogen, calcium, magnesium and potassium in stem and bark. The concentrations in stem and bark were taken from different literature sources and typical concentrations in stem and bark are: calcium = 0.15%, magnesium = 0.09%, potassium = 0.06% and nitrogen = 1.12*(K+Ca+Mg).

Present-day deposition of major ions was estimated from the water chemistry and specific discharge under the assumptions that all sulfur and chloride comes from atmospheric deposition and that the lakes are in steady state with atmospheric inputs. Further, it was assumed that deposition of Na, Mg and K is of seasalt origin and the atmospheric inputs of these ions were set using the previously calculated chloride deposition. Deposition of Ca, NO3 and NH4 were estimated from ratios of these ions to sulfate in precipitation in southern Norway.

The MAGIC calibration procedure assumes steady-state conditions 140 years in the past (year 1846); at that time deposition of pollutants is assumed to be negligible and chemical composition of soils and surface waters was not changing. During the ensuing 140-year period to 1986, the deposition of sulfur was assumed to increase parallel to the estimated historical emissions of sulfur in Europe.

An automated calibration routine was used (Jenkins and Cosby 1989) to obtain estimates of weathering rates and original base saturation in the soil such that, when subjected to the 140-year sulfur deposition, the simulated water and soil chemistry for the year 1986 agreed with the measured values.

The critical load at each grid square was calculated using the MAGIC model under the condition that total nitrogen deposition (nitrate plus ammonium) is suddenly changed to a new level and then held constant for 50 years. MAGIC is run repeatedly with different levels of nitrogen deposition until the criterion of Ca/Al molar ratio = 1.0 in the soil solution of the upper box (050 cm, taken as the rooting zone) is met. This deposition is the critical load (nitrogen) for soil.

2.7 Scenarios

Two scenarios were chosen for future nitrogen retention in forest ecosystems based on the empirical input-output data analysed by Dise and Wright (in press) (Figure 1). For the "worst" case we assumed no nitrate leaching would occur (100% retention) for nitrogen deposition in the range of 0-10 kgN/ha/yr (NO3+NH4) and 100% leaching of atmospheric inputs would occur for nitrogen deposition greater than 10 kgN/ha/yr. For the "best" case we assumed no nitrate leaching would occur (100% retention) for nitrogen deposition in the range 0-25 kgN/ha/yr and 50% leaching of atmospheric inputs would occur for nitrogen deposition greater than 25 kgN/ha/yr. All nitrogen leached is assumed to be in the form of nitrate.

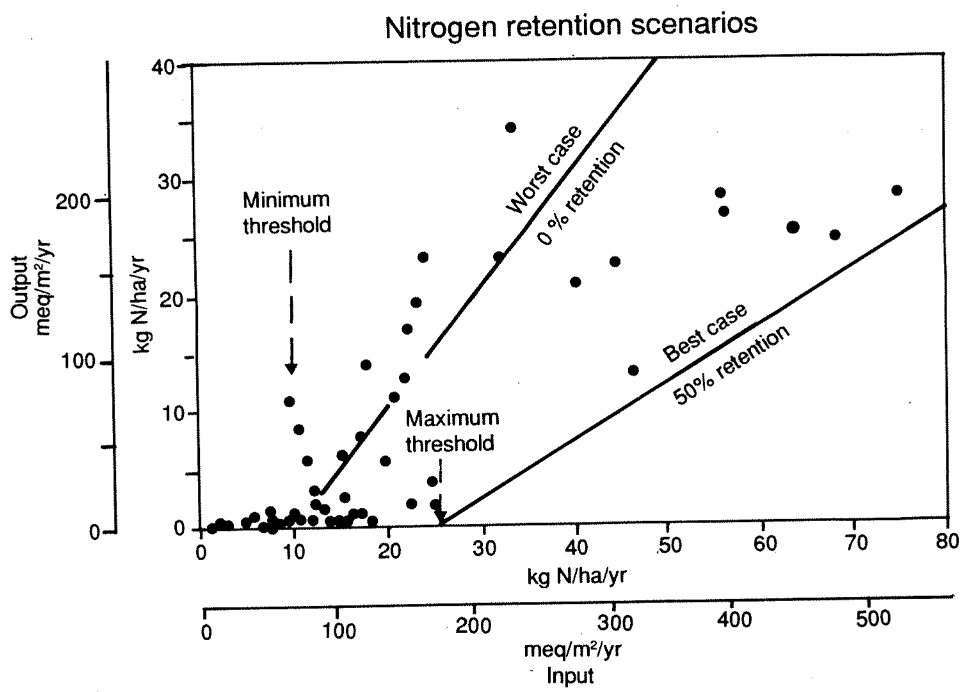

Figure 1. Empirical relationship between nitrogen input (wet+dry) and output at coniferous forest ecosystems in Europe. Data are from the ENSF data base compiled by Hauhs and Rost-Siebert (1991) and analyzed by Dise and Wright (in press). The data are delimited by "worst case" and "best case" lines of nitrogen retention; these were used as scenarios in determining nitrogen critical loads.

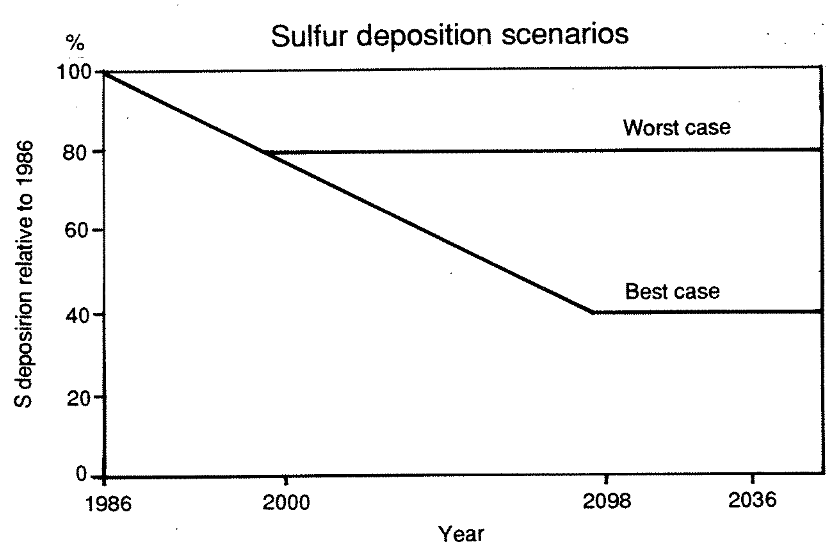

Figure 2. Future scenarios for sulfur deposition used to calculate critical loads for nitrogen. The "worst case" corresponds to current reduction plans in Europe. The "best case" corresponds to energy efficiency scenario for sulfur emissions in Europe (Lövblad et al. 1992).

Two scenarios were chosen for future sulfur deposition. These scenarios span the range of probable deposition reductions in Scandinavia over the next 30 years (Lövblad et al. 1991). The "worst" case was assumed to be a 20% reduction in deposition from the year 1986 to the year 2000 with constant levels out to the year 2036 (50 years into the future) (Figure 2). This scenario corresponds to the current reduction plans for S emissions in Europe, but with no additional reductions. The "best" case was assumed to be a 60% reduction from the year 1986 to 2028 with constant deposition out to the year 2036 (Figure 2). This scenario corresponds to S emissions reductions obtained by introducing energy efficiency measures in Europe (Lövblad et al. 1991).

3. RESULTS

The critical load was calculated using MAGIC for 598 of the 720 grids squares with productive forest. Of the remainder: 11 lacked complete water data, 3 lacked complete deposition data, and 11 lacked uptake data. A total of 607 of the 695 grids squares were successfully calibrated by MAGIC, and critical loads were calculated for 598 grid squares.

Critical loads for sulfur were calculated assuming no future change in nitrogen deposition and no future change in nitrogen retention characteristics of the catchments.

The map of critical loads (sulfur) for forest soils in Norway reveals soils with generally low critical loads in southern and southeastern Norway with higher critical loads in central and northern Norway (Figure 3). This general picture reflects the distribution of granitic bedrock (and hence moraine generally derived from granitic bedrock) in Norway. Soils derived from these materials typically have very low rates of chemical weathering. Critical loads will be low in such areas. This map of sulfur critical loads for Norway (Figure 3) shows patterns similar to those on the preliminary map presented by Frogner et al. (1992).

Present-day sulfur deposition exceeds the sulfur critical loads in southernmost Norway and in a few squares in eastern Norway (Figure 4). Southernmost Norway is generally highly sensitive and receives relatively high loadings (for Norway) of acidic pollutants.

Critical loads for nitrogen were calculated using two future scenarios for sulfur deposition and two future scenarios for nitrogen retention. Critical loads for nitrogen were calculated and mapped for all four possible combinations of these two sets of scenarios. The magnitudes and patterns of calculated nitrogen critical loads and exceedances differ substantially depending on the scenario chosen for sulfur deposition and nitrogen retention.

The map of critical loads for the combined scenarios of worst case S deposition and worst case N retention reveals very low N critical loads for many grid squares in southernmost Norway (Figure 5). Present-day nitrogen deposition in southernmost Norway is high enough that these critical loads are already exceeded for many of these squares (Figure 6).

Critical Loads - forest soil

Method : MAGIC

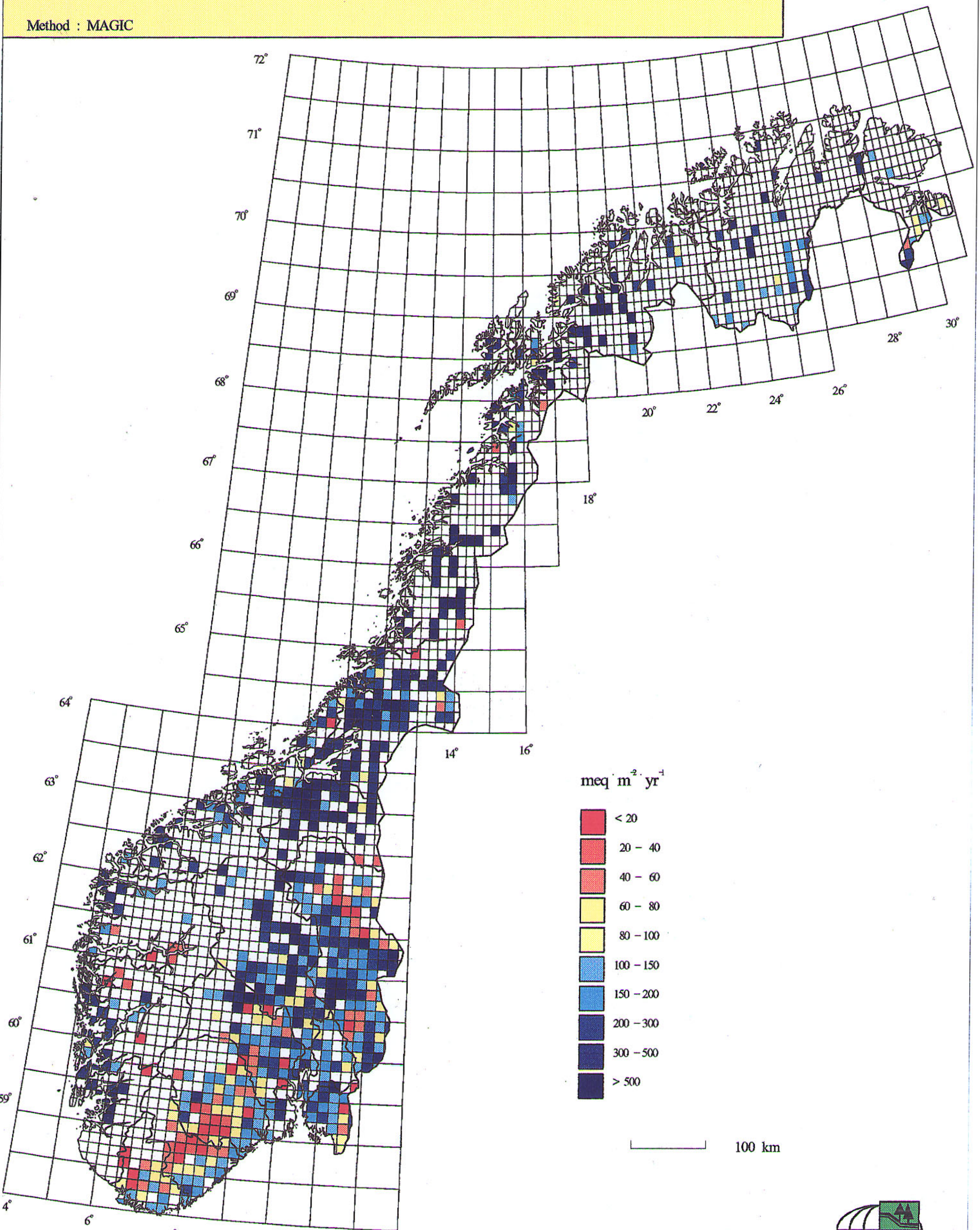

Figure 3. Map of critical loads of sulfur to forest soils in Norway as calculated by MAGIC.

NATURENS TÅLEGRENSER

NIJOS

Exceedance of the Critical Loads – forest soil

Method : MAGIC

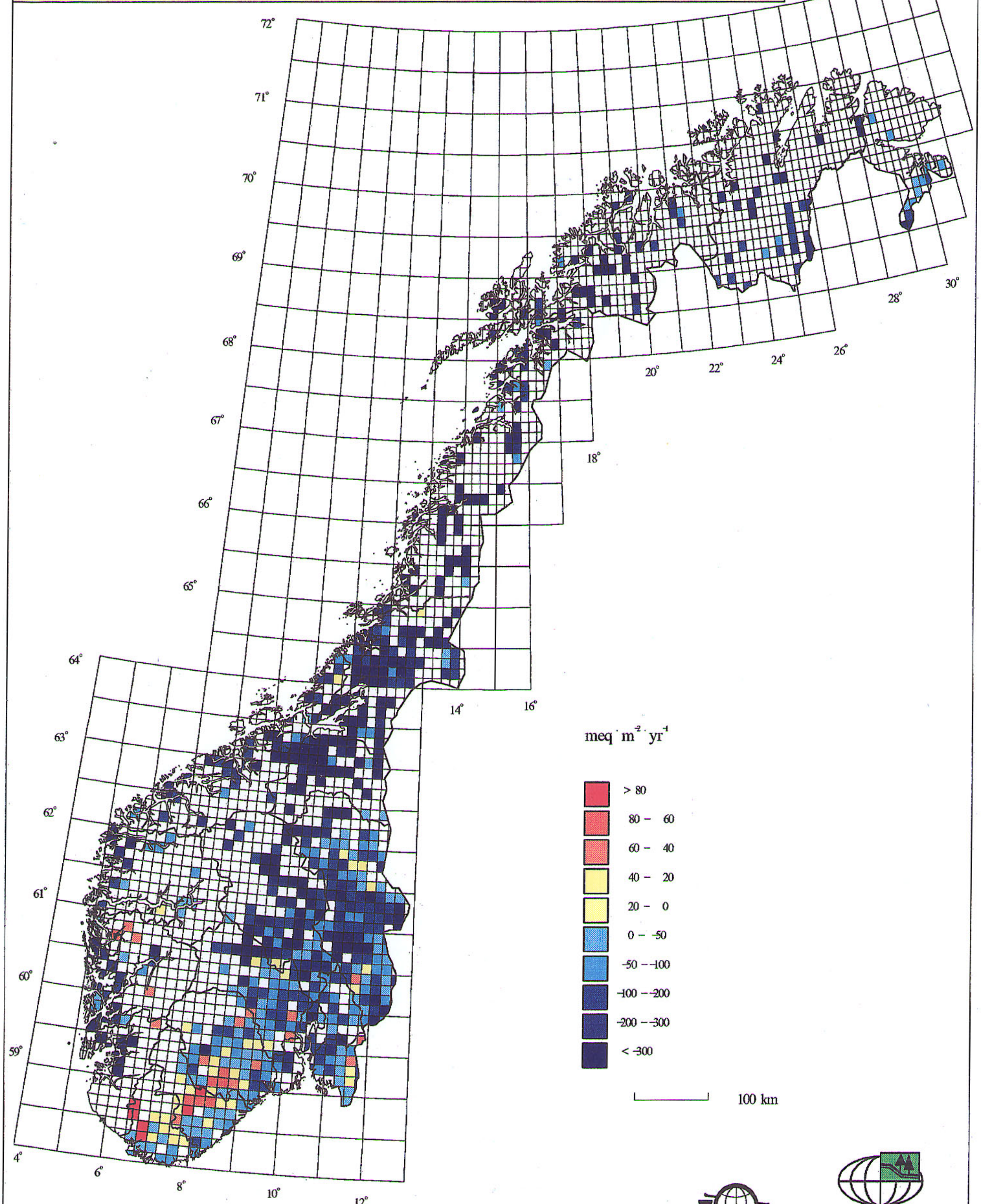

Figure 4. Map of exceedance of critical loads of sulfur to forest soils assuming no change in present-day nitrogen deposition or retention.

NATURENS TÅLEGRENSER

NIJOS

Critical Loads – forest soil, N deposition

(worst case S deposition, worst case N retention)

Method : MAGIC

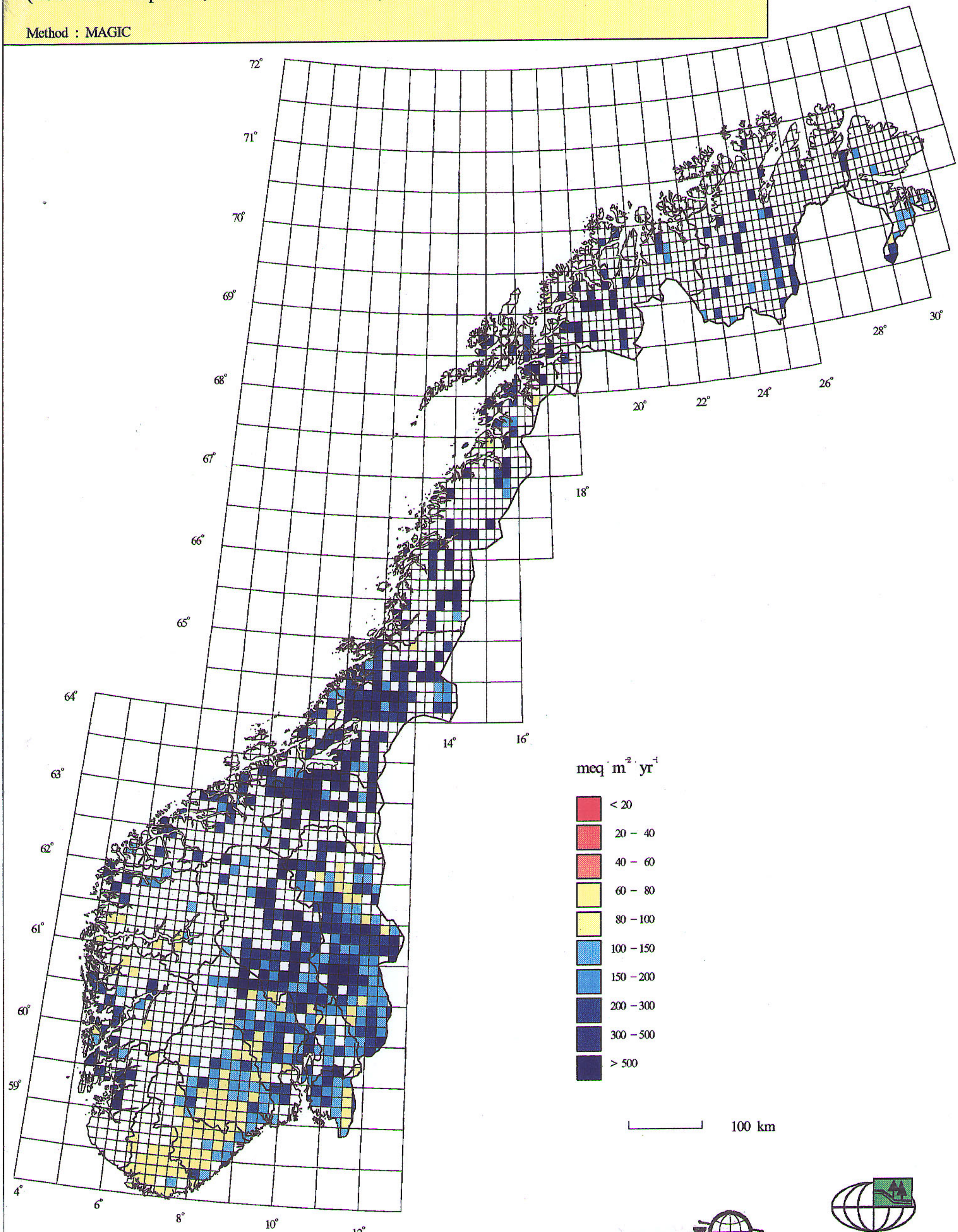

Figure 5. Map of critical loads of nitrogen to forest soils in Norway as calculated by MAGIC assuming the worst case for future sulfur deposition and the worst case for future nitrogen retention.

NATURENS TÅLEGRENSER

NIJOS

Exceedance of Critical Loads – forest soil, N deposition

(worst case S deposition, worst case N retention)

Method : MAGIC

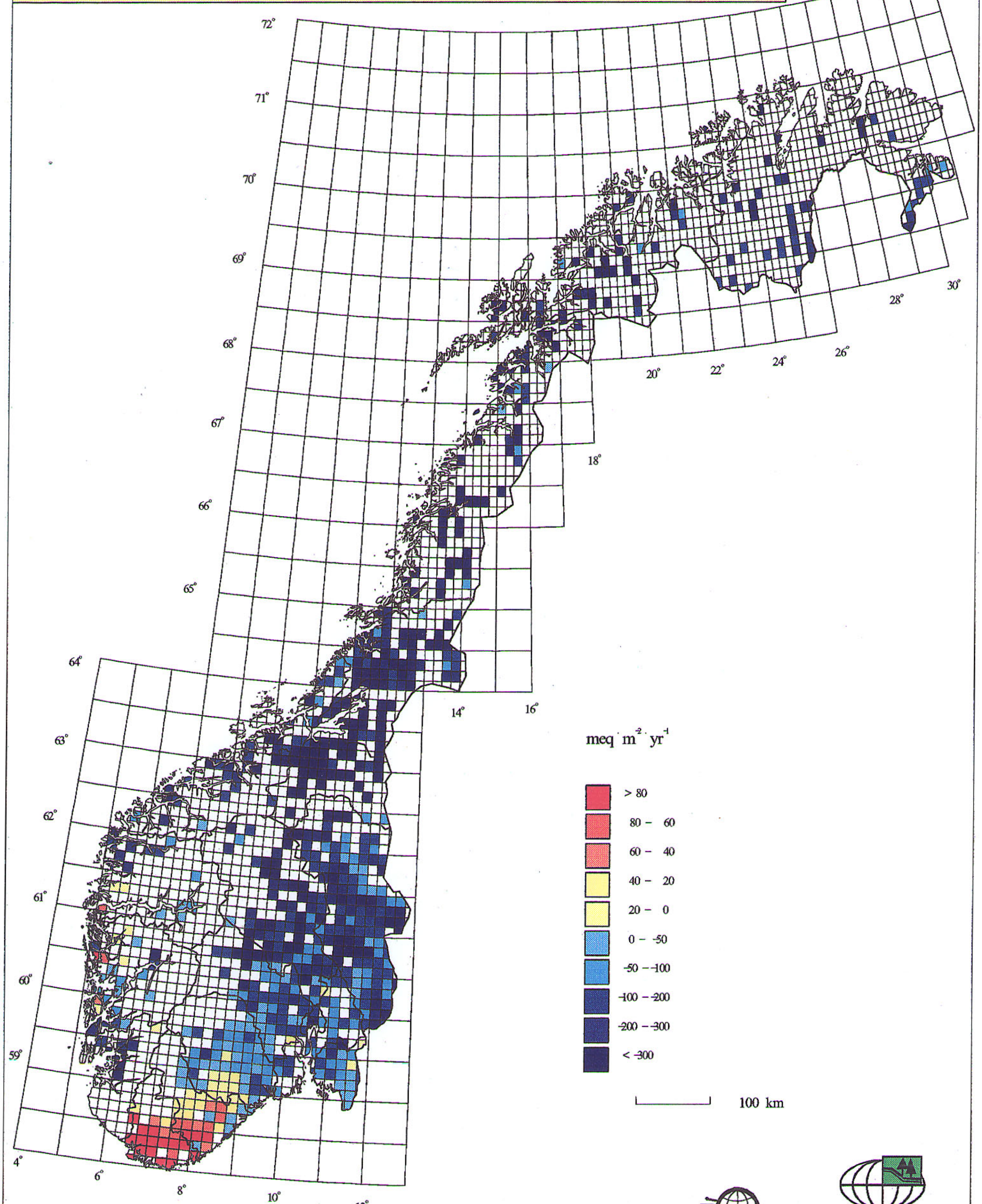

Figure 6. Map of exceedance of critical loads of nitrogen to forest soils assuming the worst case for future sulfur deposition and the worst case for future nitrogen retention.

NATURENS TALEGRENSER

NIJOS

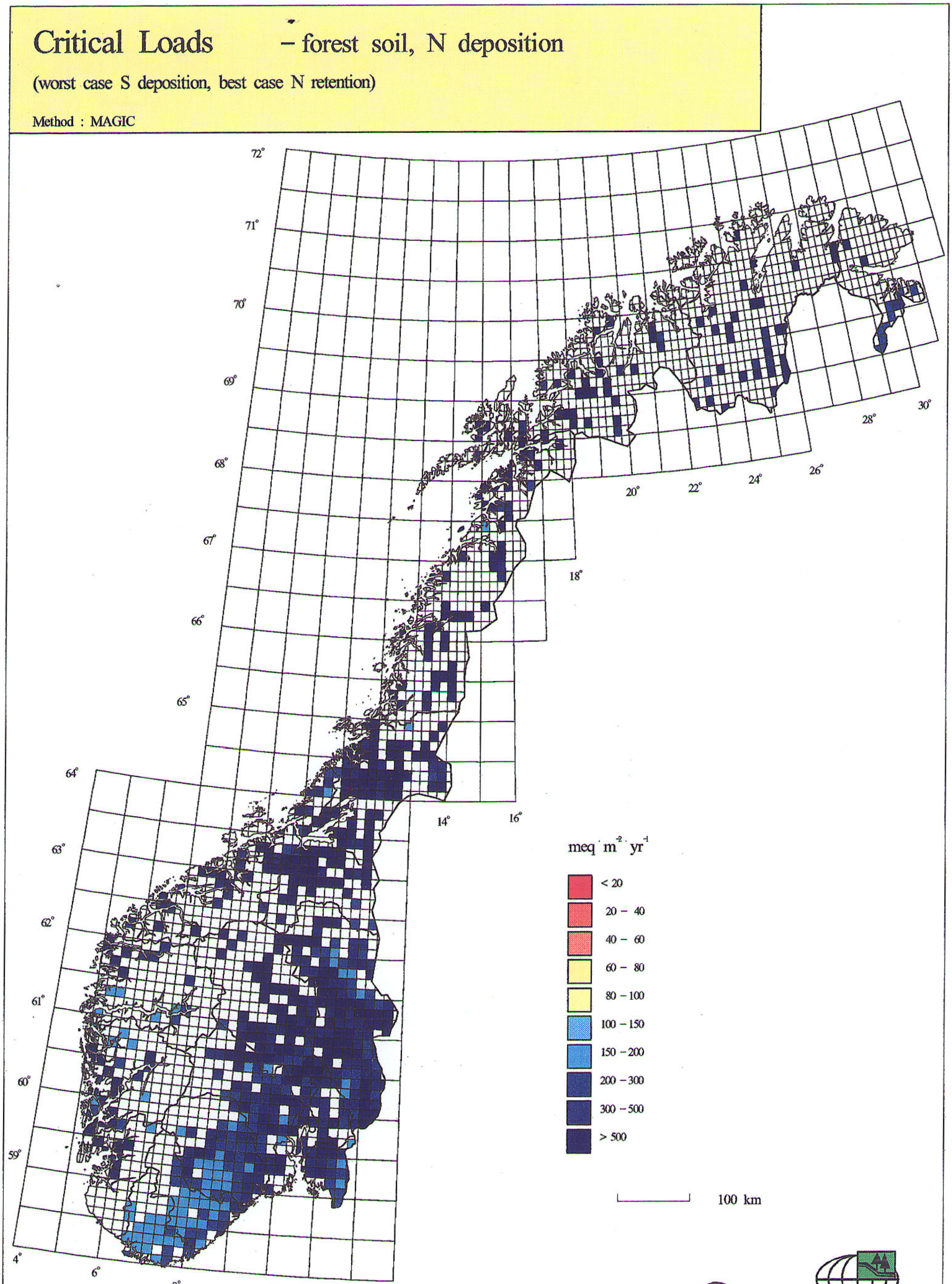

Figure 7. Map of critical loads of nitrogen to forest soils in Norway as calculated by MAGIC assuming the worst case for future sulfur deposition and the best case for future nitrogen retention.

NATURENS TÅLEGRENSER

NIJOS

Exceedance of Critical Loads – forest soil, N deposition

(worst case S deposition, best case N retention)

Method : MAGIC

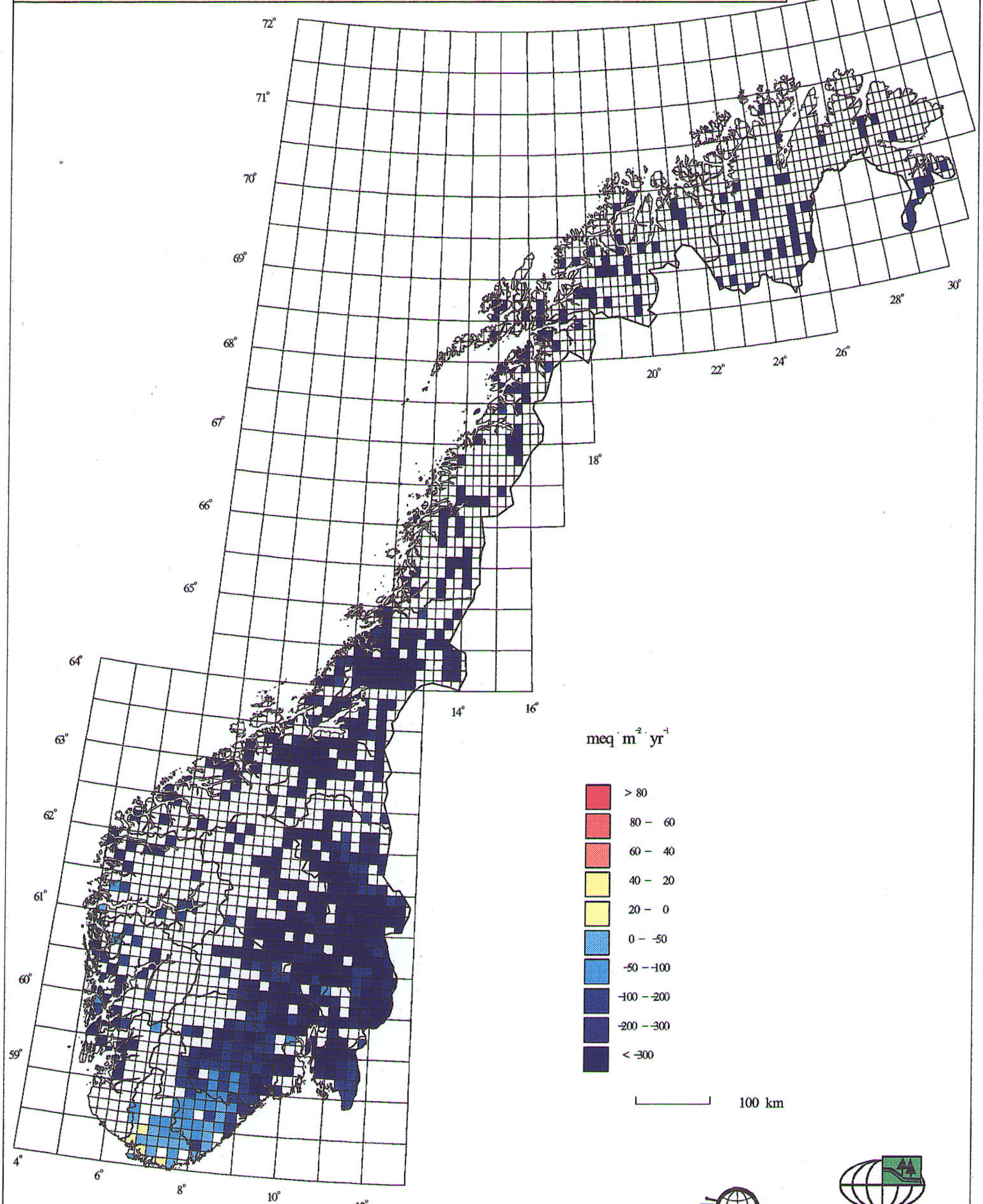

Figure 8. Map of exceedance of critical loads of nitrogen to forest soils assuming the worst case for future sulfur deposition and the best case for future nitrogen retention.

NATURENS TÅLEGRENSER

NIJOS

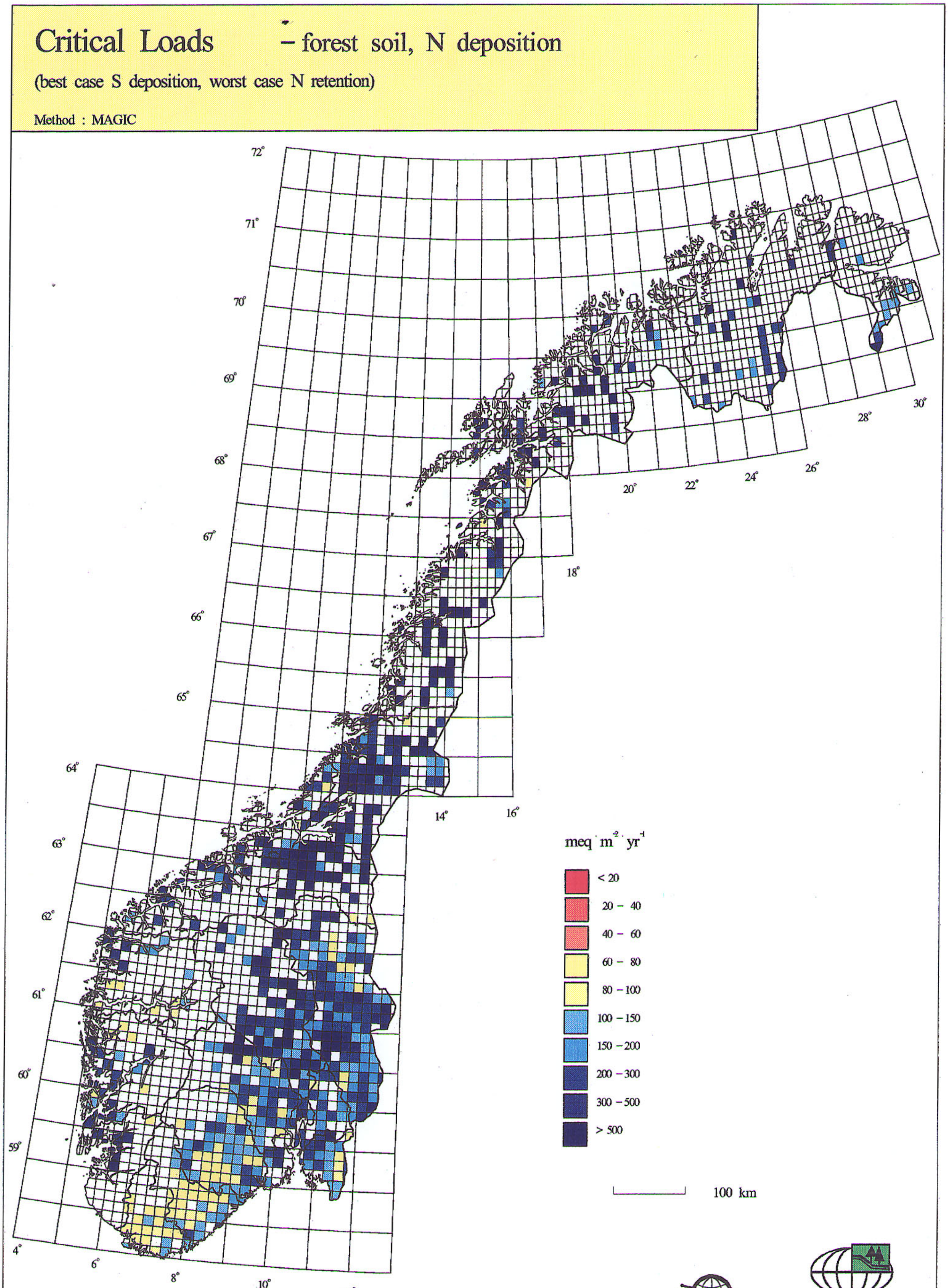

Figure 9. Map of critical loads of nitrogen to forest soils in Norway as calculated by MAGIC assuming the best case for future sulfur deposition and the worst case for future nitrogen retention.

Exceedance of Critical Loads – forest soil, N deposition

(best case S deposition, worst case N retention)

Method : MAGIC

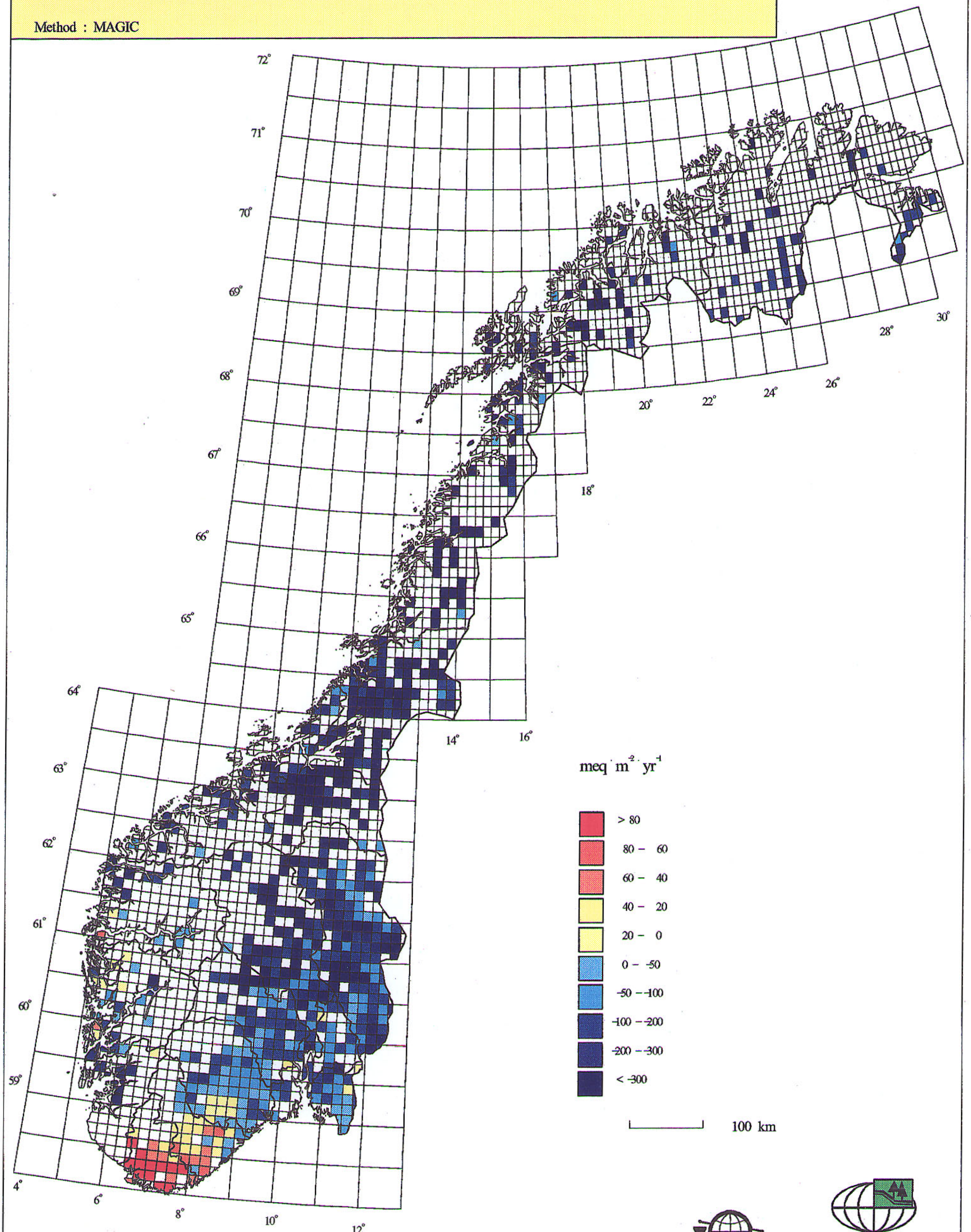

Figure 10. Map of exceedance of critical loads of nitrogen to forest soils assuming the best case for future sulfur deposition and the worst case for future nitrogen retention.

NATURENS TÅLEGRENSER

NIJOS

Critical Loads – forest soil, N deposition

(best case S deposition, best case N retention)

Method : MAGIC

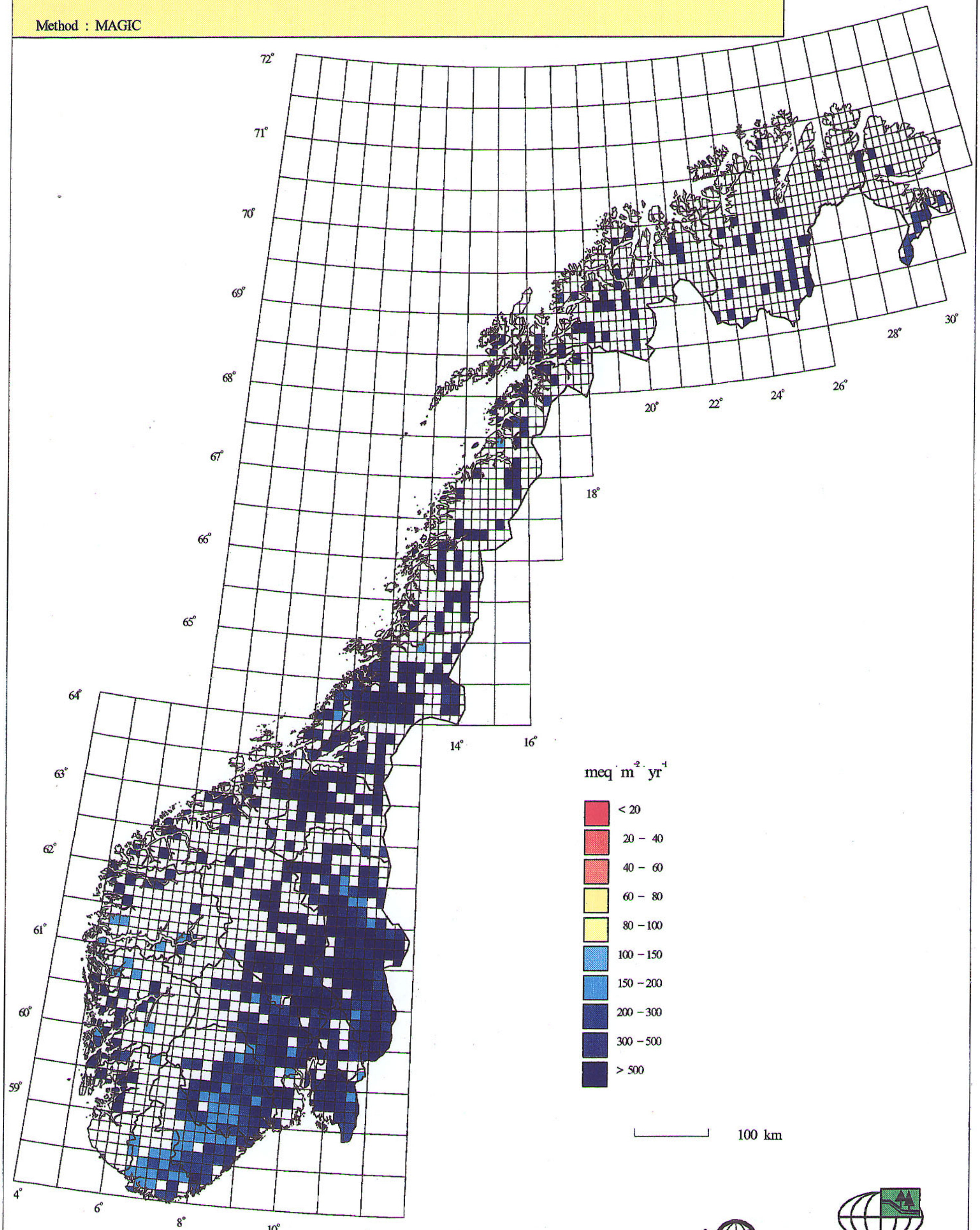

Figure 11. Map of critical loads of nitrogen to forest soils in Norway as calculated by MAGIC assuming the best case for future sulfur deposition and the best case for future nitrogen retention.

NATURENS TÅLEGRENSER

NIJOS

Exceedance of Critical Loads – forest soil, N deposition

(best case S deposition, best case N retention)

Method : MAGIC

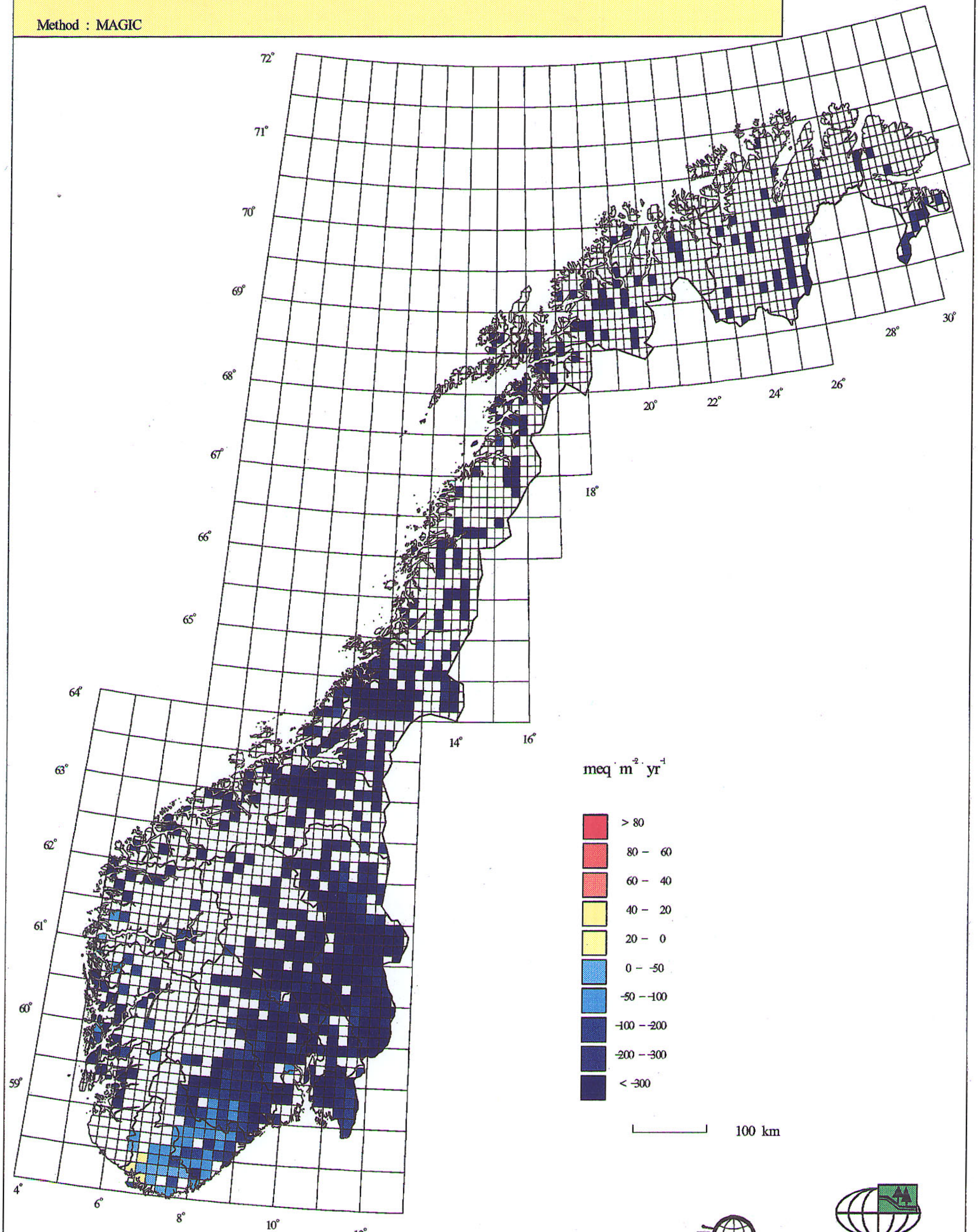

Figure 12. Map of exceedance of critical loads of nitrogen to forest soils assuming the best case for future sulfur deposition and the best case for future nitrogen retention.

NATURENS TÅLEGRENSER

NIJOS

The modest 20% reduction in sulfur deposition combined with the 100% leaching of nitrogen inputs assumed under this scenario results in high concentrations of sulfate and nitrate in the forest soils, with a large accompanying acid stress. The amount of additional nitrogen that can be tolerated from atmospheric deposition is therefore rather low.

The map of critical loads for the combined scenarios of worst case S deposition and best case N retention presents a very different picture. Critical loads in southern Norway are higher (Figure 7) and present-day nitrogen deposition levels exceed these critical loads in only a very few squares in the extreme south of Norway (Figure 8).

The much higher nitrogen retention assumed for this combined scenario more than doubles the amount of nitrogen deposition that is assimilated (thus producing no acid stress on the soils) before nitrate becomes mobile in the soil. Therefore, higher loads of nitrogen deposition can be tolerated before adverse soil effects appear (even with the modest reductions for sulfate deposition).

The map of critical loads for the combined scenarios of best case S deposition and worst case N retention is more similar to the first scenario described above than the second. Critical loads for nitrogen are again low (Figure 9) and are again exceeded by current nitrogen deposition in many squares in southernmost Norway (Figure 10).

The map of critical loads for the combined scenarios of best case S deposition and best case N retention results in the highest critical loads of any of the four combinations of future scenarios evaluated. The critical loads for nitrogen are high even in southernmost Norway (Figure 11), and in none of the grid squares does present-day nitrogen deposition exceed the calculated nitrogen critical load (Figure 12).

Present-day (year 1986) sulfur deposition exceeds the critical load for coniferous forest soils in 67 of the 598 grid squares for which MAGIC calibration has been completed, under the conditions of present-day N deposition and N retention (Figure 13). Nitrogen deposition in the year 2036 exceeds the critical load for coniferous forest soils in 68 of 598 grid squares under the scenario of worst case S deposition combined with worst case N retention, but in only 3 of 598 of the grids under the scenario of best case S deposition and best case N retention (Figure 14).

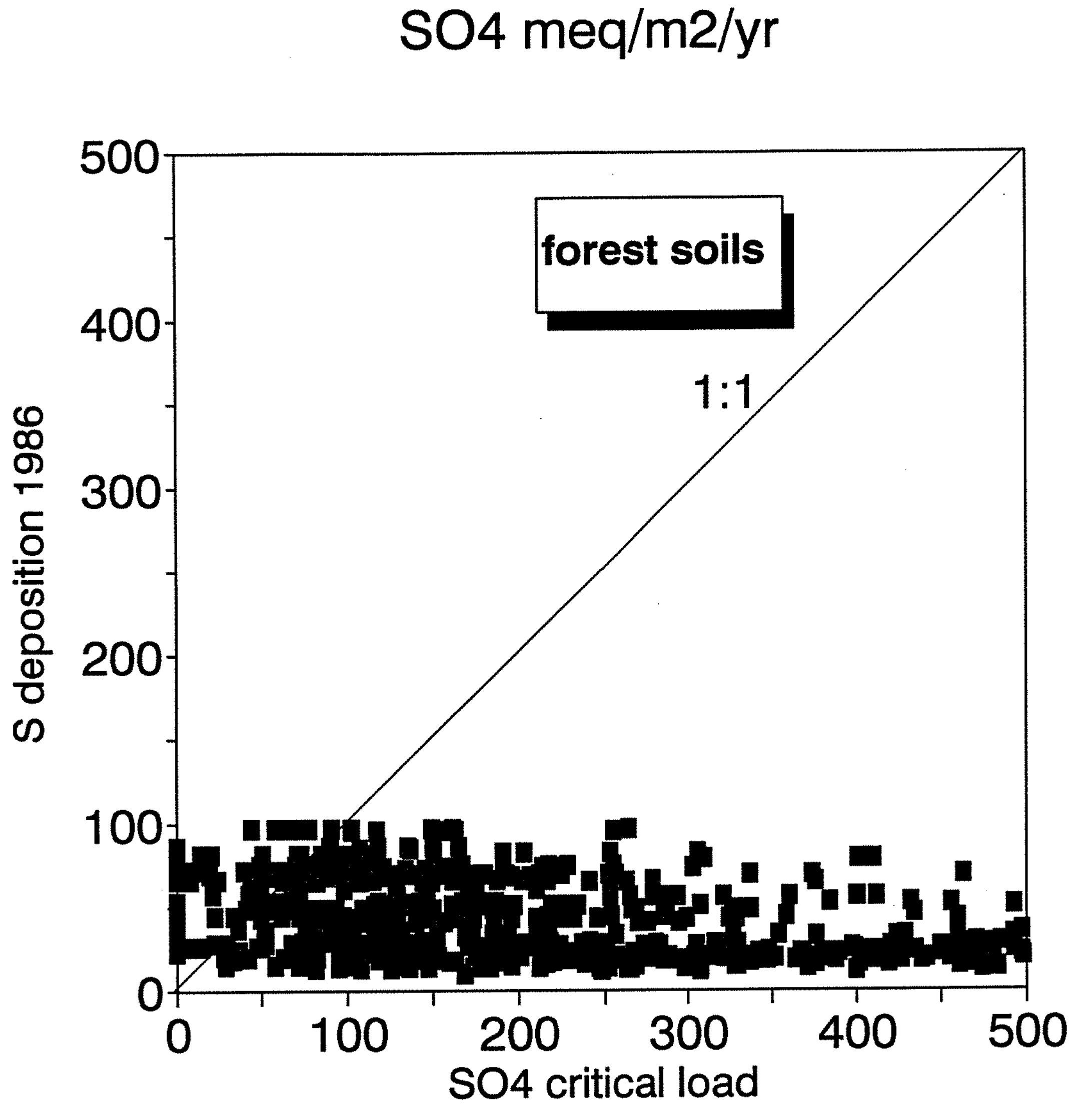

Figure13. Present-day sulfur deposition and critical load for sulfur at 598 grid squares in Norway assuming present-day N deposition and retention. Squares falling above the 1:1 line have S deposition exceeding the critical load.

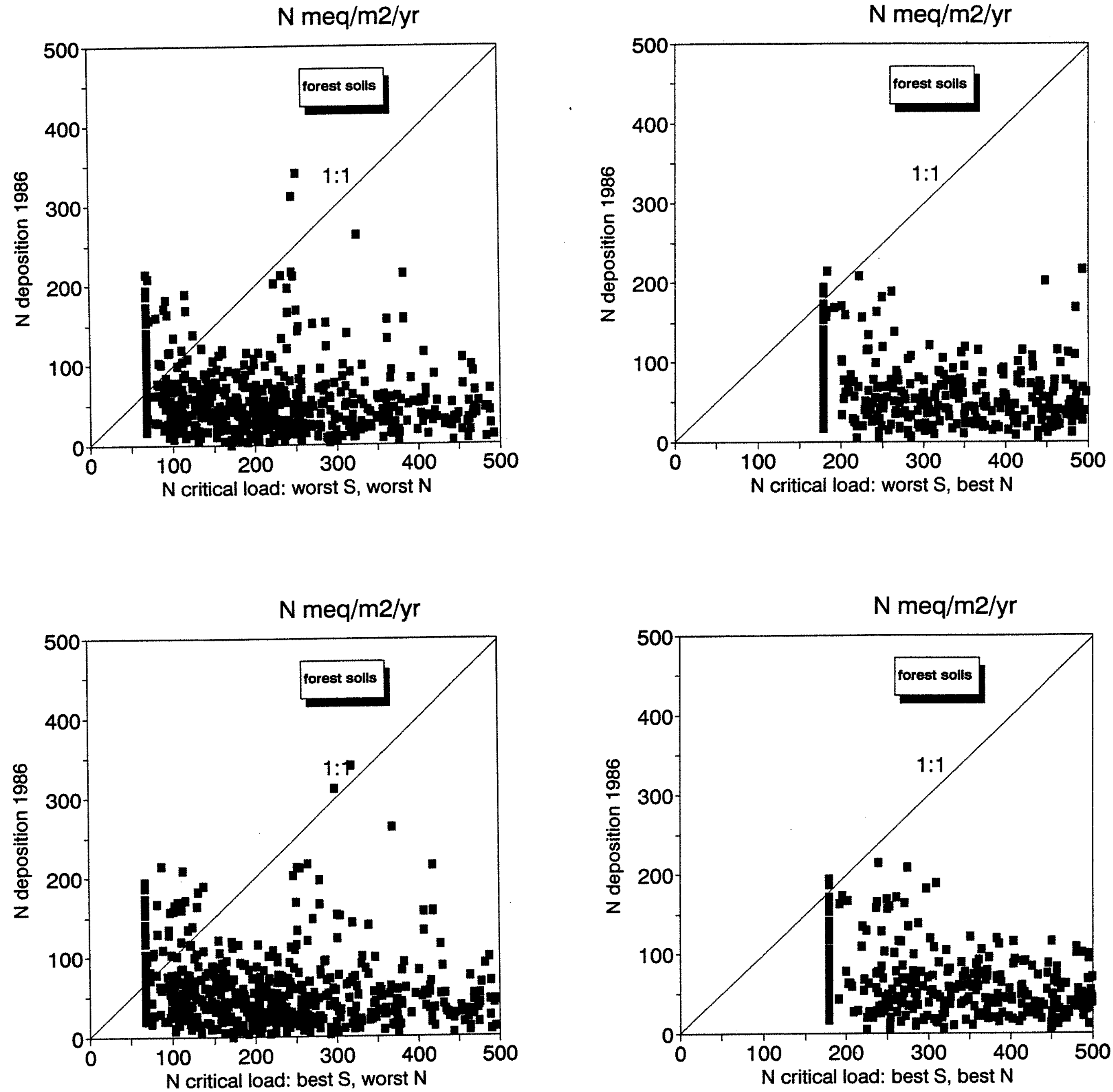

Figure14. Present-day nitrogen deposition and critical load for nitrogen at 598 grid squares in Norway under 2 sulfur deposition scenarios and 2 nitrogen retention scenarios. Squares falling above the 1:1 line have N deposition exceeding the critical load. Upper left panel: worst case sulfur deposition, worst case nitrogen retention.Upper right panel: worst case sulfur deposition, best case nitrogen retention. Lower left panel: best case sulfur deposition, worst case nitrogen retention. Lower right panel: best case sulfur deposition, best case nitrogen retention.

4. DISCUSSION

Nitrogen critical loads were evaluated for forest soils in Norway using the dynamic model MAGIC, and the criterion that the Ca/Al ratio in the uppermost 50 cm soil solution should not be less than 1.0 at a point fifty years in the future. Assumptions were made regarding best and worse case future scenarios of sulfur deposition and nitrogen retention. These evaluations show that the assumptions regarding decreases in nitrogen retention in soils (future nitrogen saturation) are of great importance in determining the nitrogen critical load to these soils and can have a large effect upon the magnitude of the calculated critical loads. Surprisingly, alternate assumptions about future sulfur deposition scenarios (20 and 60% reductions) appear to have smaller effects on the calculated nitrogen critical loads.

The term "retention" as used here is the net result of several sources and sinks of nitrogen within the ecosystem. The terminology used by Henriksen et al. (1993) to calculate exceedances for nitrogen and sulfur in surface waters in the Nordic countries considers the following sources and sinks of nitrogen in terrestrial catchments:

$$N_{le} = N_{dep} - N_{den} - N_{upt} - N_{imm} - N_{exp}$$

where N_{le} is nitrogen leached in runoff from the catchment; N_{dep} is total nitrogen deposition; N_{den} is nitrogen lost by denitrification; N_{upt} is the net uptake of nitrogen by the biomass in the catchment; N_{imm} is the nitrogen immobilized in the soils; and N_{exp} is the export of organic nitrogen out of the catchment in drainage waters. Nitrogen fixation is not considered to be an important source of inorganic nitrogen for forest soils.

The catchment input-output data used by Dise and Wright (in press) to establish the patterns of leaching do not allow discrimination among these components of nitrogen leaching. It can generally be assumed that N_{exp} and N_{den} are low (relative to the other terms) for the forested systems in Norway. The nitrogen retention estimated for catchments with depositions levels above 10 kgN/ha/yr can thus be understood to result primarily from uptake by plants (N_{upt}) and net immobilization by the soils (N_{imm}).

With the worst case scenario for nitrogen retention, current deposition of nitrogen exceeded the calculated critical loads for nitrogen (and to a high degree) in many areas in southernmost Norway, regardless of which sulfur scenario was assumed. With the worst case scenario for nitrogen retention, it appears that critical loads of nitrogen are already exceeded in about 9% of the map-grid squares containing forests (Table 1).

Table 1. Percent grid squares in which critical load for coniferous forest soils is exceeded in the year 2036 under various scenarios for S and N deposition and N retention.

critical load	scenario S deposition	N deposition	N retention	% squares exceeded
sulfur	present-day	present-day	present-day	11
nitrogen	20% reduction	present-day	worst case	9
nitrogen	20% reduction	present-day	best case	1
nitrogen	60% reduction	present-day	worst case	9
nitrogen	60% reduction	present-day	best case	1

With the best case scenario for nitrogen retention, current deposition of nitrogen exceeded the calculated critical loads for nitrogen at only a few areas in the extreme south of Norway, again regardless of which sulfur scenario was assumed. With the best case scenario for nitrogen retention, it appears that critical loads of nitrogen are already exceeded in fewer than 1% of the grid squares containing forests (Table 1).
In approximately 9% of the forested grid squares examined sulfur deposition exceeded sulfur critical loads (Table 1). If the worst case nitrogen retention assumption is justifiable, then we must conclude that current nitrogen deposition (9% exceedances) has a potential for damage to these systems roughly equivalent to that of the current sulfur deposition.

These results strongly suggest that more information regarding the magnitude of nitrogen retention and the processes controlling cycling in forested ecosystems is of utmost importance for the specification of nitrogen critical loads.

5. REFERENCES

Abrahamsen, G. 1980. Acid precipitation, plant nutrients and forest growth. p. 58-63, In: Ecological Impact of Acid Precipitation. Drabløs, D., and A. Tollan (eds.) SNSF-project, 1432-Ås, Norway, 383pp.

Cosby, B. J., Hornberger, G.M., Galloway, J.N. and Wright, R.F. 1985a. Modelling the effects of acid deposition: assessment of a lumped-parameter model of soil water and streamwater chemistry. Water Resour. Res. 21: 51-63.

Cosby, B. J., Wright, R. F., Hornberger, G. M. and Galloway, J. N. 1985b. Modelling the effects of acid deposition: estimation of long-term water quality responses in a small forested catchment. Water Resour. Res. 21: 1591-1601.

Dise, N.B., and Wright, R.F. In press. Nitrogen deposition and leaching from coniferous forests in Europe. Forest Ecol. Manage.

Esser, J.M., and Nyborg, Å. 1992. Coniferous forest soils - A Nationwide Representative Registration Project. NIJOS Rapport 3/92, 50 pp. ISBN: 82-7464-034-9.

Esser, J.M. 1994. Birch forest soils - A Nationwide Representative Registration Project. NIJOS Rapport 4/94, 36 pp. ISBN: 82-7464-045-4.

Frogner, T., R.F. Wright, B.J. Cosby, J.M. Esser, A.-O. Håøya, and Rudi, G. 1992. Map of critical loads for coniferous forest soils in Norway. Report 33, Naturens Tålegrenser, Ministry of Environment, Oslo, Norway, 30pp.

Grennfelt, P. and Hultberg, H. 1986. Effects of nitrogen deposition on the acidification of terrestrial and aquatic ecosystems. Water Air Soil Pollut. 30: 945-963.

Grieve, I,C. 1989. A laboratory test of the soil chemical submodels of two models of catchment acidification. Hydrological Processes 3: 339-346.

Hauhs, M., Rost-Siebert, K., Raben, G., Paces, T. and Vigerust, B. 1989. Summary of European Data. In: Malanchuk, J.L., and Nilsson, J. (eds), The Role of Nitrogen in the Acidification of Soils and Surface Waters, NORD 1989:92, Nordic Council of Ministers, Copenhagen.

Henriksen, A., Forsius, M., Kämäri, J., Posch, M. and Wilander, A. 1993. Exceedance of critical loads for lakes in Finland, Norway, and Sweden: Reduction requirements for nitrogen and sulfur deposition. Acid Rain Research Report 32/1993, Norwegian Institute for Water Research, Oslo, Norway, 44pp.

Henriksen, A., Lien, L. and Traaen, T.S. 1990. Tålegrenser for overflatevann - Kjemiske kriterier for tilførsler av sterke syrer. Fagrapport Nr. 2, Naturens Tålegrenser, Direktoratet for Naturforvaltning, Trondheim.

Hettelingh, J.P. (ed.) 1991 Mapping critical loads for Europe. CCT Technical Report No. 1, Coordination Center for Effects, RIVM, Bilthoven, The Netherlands.

Jenkins, A. and Cosby, B. J. 1989. Modelling surface water acidification using one and two soil layers and simple flow routing. In: J. Kamari, D. F. Brakke, A. Jenkins, S. A. Norton and R. F. Wright (Editors), Regional Acidification Models, Springer-Verlag, New York.

Jenkins, A., Whitehead, P. G., Cosby, B. J. and Birks, H. J. B. 1990. Modelling long term acidification: a comparison with diatom reconstructions and the implications for reversibility. Phil. Trans. R. Soc. Lond. B 327: 435-440.

Kvamme, H. 1992. Program "Overvåking av skogens sunnhetstilstand". NIJOS Rapport 1/92, Ås, Norway. pp. 8-26.

Lövblad, G., Amann, M., Andersen, B., Hovmand, M., Joffre, S. and Pedersen, U. 1992. Deposition of sulfur and nitrogen in the Nordic countries: present and future. Ambio 21: 339-347.

Nilsson, J, and Grennfelt, P. 1988. Critical loads for Sulphur and Nitrogen. Miljørapport 1988: 15, Nordic Council of Ministers, Copenhagen, 418pp.

Schulze, E.-D. 1989. Air pollution and forest decline in a spruce (Picea abies) forest. Science 244: 776-783.

Sverdrup, H., de Vries, W. and Henriksen, A. 1990. Mapping Critical Loads. Nordic Council of Ministers, Copenhagen.

Sverdrup, H., Warfvinge, P. and Rosén, K. 1992. A model for the impact of soil solution Ca:Al ratio on tree base cation uptake. Water Air Soil Pollut. 61: 197-221

Ulrich, B. 1983. An ecosystem oriented hypothesis on the effect of air pollution on forest ecosystems. In Ecological effects of acid deposition. pp 221-231. National Swedish Environmental Protection Board, Report PM 1636.

Warfvinge, P., Holmberg, M., Posch, M., and Wright, R.F. 1992. The use of dynamic models to set target loads. Ambio 21: 369-376.

Wright, R. F., Cosby, B. J., Flaten, M. B. and Reuss, J. O. 1990. Evaluation of an acidification model with data from manipulated catchments in Norway. Nature 343: 53-55.

Wright, R. F., Cosby, B. J. and Hornberger, G. M. 1991. A regional model of lake acidification in southernmost Norway. Ambio 20: 222-225.

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, 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.

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 (in prep)

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 Muesum, Oslo, Rapport 144, 1993.

40 Aamlid, D. & Skogheim, I. 1993. Nikkel, kopper og andre metaller i multer og blåbær fra Sør-Varanger, 1992. Norsk institutt for skogforskning (NISK), Skogforsk, rapport 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 lufttransporterte 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 Flatberg, K.I. & Frisvoll, A.A. 1993. Moseskader i Agder 1989-92. Norsk institutt for naturforskning (NINA), Oppdragsmelding (in prep).

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*) (in prep)

47 Krøkje, Å. 1993. Genotoksisk belastning i jord. Effektstudier, med mål å komme fram til akseptable grenser for genotoksisk belastning fra langtransportert luftforurensning (in prep)

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

49 Nygaard, P.H. & Ødegaard, T.H. 1993. Effekter av nitrogengjødsling på vegetasjon og jord i skog. Norsk institutt for skogforskning (NISK), 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 (in prep)

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

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.

Henvendelser vedrørende rapportene rettes til utførende institusjon

NIVA

Norsk institutt for vannforskning
Postboks 173 Kjelsås, 0411 Oslo
Telefon: 22 18 51 00 Fax: 22 18 52 00

ISBN 82-577-2536-6