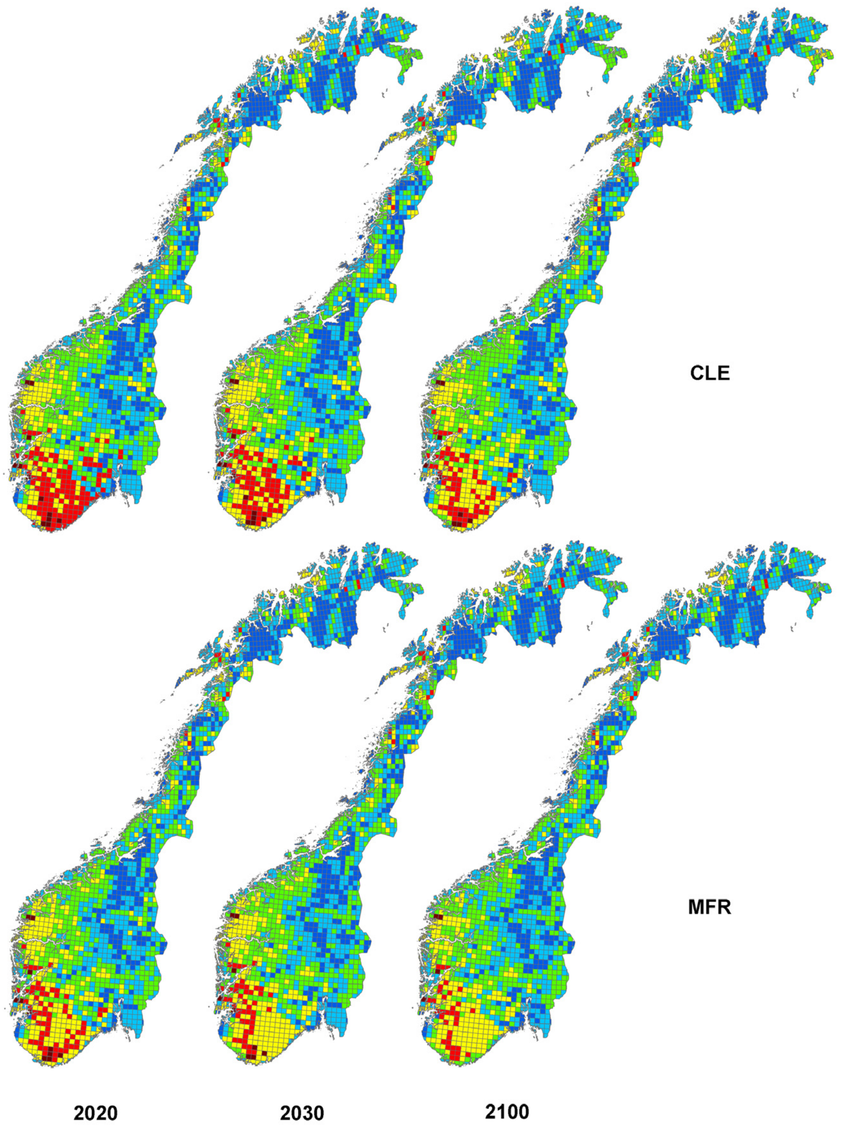
RAPPORT L.NR. 5705-2008

NATURENS
TÅLEGRENSER
Miljøverndepartementet
Fagrapport nr. 124

Dynamic modelling of acidification of Norwegian surface waters



Norwegian Institute for Water Research
– an institute in the Environmental Research Alliance of Norway

REPORT

Main Office
Gaustadalléen 21
NO-0349 Oslo, Norway
Phone (47) 22 18 51 00
Telefax (47) 22 18 52 00
Internet: www.niva.no

Regional Office, Sørlandet
Televeien 3
NO-4879 Grimstad, Norway
Phone (47) 22 18 51 00
Telefax (47) 37 04 45 13

Regional Office, Østlandet
Sandvikaveien 41
NO-2312 Ottestad, Norway
Phone (47) 22 18 51 00
Telefax (47) 62 57 66 53

Regional Office, Vestlandet
P.O.Box 2026
NO-5817 Bergen, Norway
Phone (47) 22 18 51 00
Telefax (47) 55 23 24 95

Regional Office Central
P.O.Box 1266
NO-7462 Trondheim
Phone (47) 22 18 51 00
Telefax (47) 73 54 63 87

Title Dynamic modelling of acidification of Norwegian surface waters	Serial No. 5705-2008	Date 2008.12.03
	Report No. Sub-No. O-26474	Pages Price 45
Author(s) Thorjørn Larssen, B. Jack Cosby, Tore Høgåsen, Espen Lund and Richard F. Wright	Topic group Acid rain	Distribution Open
	Geographical area Norway	Printed CopyCat AS

Client(s) Norwegian Pollution Control Authority (SFT)	Client ref. 5008052

Abstract

In 2006 and November 2007, the Coordination Centre for Effects (CCE) under the UNECE LRTAP Convention issued calls for data on results from dynamic models to soils and surface waters given specified future scenarios of sulphur (S) and nitrogen (N) deposition. Submitted data from Norway is summarized here. 1007 lakes sampled in 1995 were modelled using the MAGIC model. The results were then matched to 2304 grid squares in the critical load grid for Norway. The past, present and future deposition (CLE=current legislation, i.e. Gothenburg protocol, and MFR=maximum feasible reduction) were specified by the CCE for each EMEP grid square. The results showed that the increasing trend in acid neutralizing capacity (ANC) in surface waters observed since 1990 will continue slightly through 2020. Many lakes in southernmost Norway will continue to be acidified (critical load exceeded) unless deposition of S and N is reduced substantially below requirements of the Gothenburg protocol. Under the MFR scenario, ANC can increase in most lakes throughout the country. Many lakes in Finnmark in northernmost Norway will experience reacidification due to projected increases in S and N deposition.

4 keywords, Norwegian	4 keywords, English
1. Sur nedbør	1. Acid deposition
2. MAGIC modell	2. MAGIC model
3. Innsjø	3. Lake
4. Norge	4. Norway

BritLise Skjelkvåle

Jarl Nygard

Thorjørn Larssen
Project manager

Brit Lisa Skjelkvåle
Research manager

Jarle Nygard
Strategy Director

ISBN 978-82-577-5440-2

Naturens tålegrenser

Fagrapport nr. 124

Dynamic modelling of acidification of Norwegian surface waters

Thorjørn Larssen, B. Jack Cosby, Tore Høgåsen, Espen Lund
and Richard F. Wright

Preface

The Norwegian Institute for Water Research (NIVA) is the Norwegian National Focal Centre in the UNECE International Cooperative Programme on Modelling and Mapping of Critical Loads & Levels and Air Pollution Effects, Risks and Trends (ICP M&M) and participates with data and methodology regarding critical loads and dynamic modelling.

In November 2006 and again in November 2007 the Coordination Center for Effects (CCE) of the ICP M&M issued a call for data for dynamic modelling of acidification of soils and surface waters given several specified scenarios of future sulphur and nitrogen deposition. In response to this call, NIVA calculated future water chemistry for surface waters in Norway using the dynamic model MAGIC. The data were submitted to the CCE in March 2007 (preliminary results for two counties) and March 2008 (full results for the entire country).

The work was conducted in cooperation with the Swedish Environmental Institute IVL (Filip Moldan and Veronika Kronnäs) who kindly provided analogue matching with the IVL "MAGIC library" between the 990 modelled Norwegian lakes and the 2304 critical load grid squares in Norway. NIVA engaged B. Jack Cosby, University of Virginia, USA, to modify the MAGIC model, provide auxiliary programmes and assist in the model applications. At NIVA the work was led by Thorjørn Larssen. Espen Lund prepared the databases used as inputs and the database of outputs submitted to CCE and together with Tore Høgåsen prepared the maps and charts in this report. Richard Wright prepared this report. We thank Max Posch at CCE and Filip Moldan at IVL for help and fruitful discussions during the calculations and work with the report.

The work was conducted under contract from the Norwegian Pollution Control Authority (SFT). Contact at SFT was Tor Johannessen.

Oslo, November 2008

Thorjørn Larssen

Contents

Summary

The concept of *critical loads* has been well established as a scientific basis in developing emission reduction plans of sulphur and nitrogen emissions in Europe. As the deposition of sulphur and nitrogen in Europe has decreased, the area exceeeding critical load has decreased. It has been increasingly evident that a modelling approach that takes into account time lags would be useful as supplement to the static, steady-state critical loads approach. As a response to this, dynamic models have been developed that are compatible with and supplementary to the steady-state methods used to calculate critical loads.

Critical loads and dynamic modelling work within the framework of the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) is organised under the Working Group on Effects (WGE), through the International Cooperative Programme on Modelling and Mapping of Critical Loads & Levels and Air Pollution Effects, Risks and Trends (ICP M&M). The calls for data and syntheses of results are carried out by the Coordination Centre for Effects (CCE). In November 2006 and again in November 2007, the CCE issued calls for data on results from application of dynamic models to soils and surface waters given specified future scenarios of sulphur (S) and nitrogen (N) deposition. Norway submitted data in response to these calls: in March 2007 results were sent for two counties only (Østfold and Hedmark), while in March 2008 results were submitted for the entire country. The Norwegian data are summarized and presented in this report.

The data are based on lake chemistry data for 990 of the 1007 statistically selected lakes sampled in 1995 under the national monitoring programme. These were then matched to 2304 grid squares in the critical load grid (approximately 12x12 km) for Norway. The calculations were done using the MAGIC model. Submitted to the CCE were data for four "historic" years (1980, 1990, 2000, 2010) and five future years (2020, 2030, 2040, 2050, 2100) given one specified historic S and N deposition and a total of 14 future deposition scenarios. The future S and N deposition was assumed to be implemented during the 10-year period 2010–2020. The past, present and future deposition under these scenarios were specified by the CCE for each EMEP grid square in Norway. Results are presented here as development in the acid neutralizing capacity (ANC) for four evaluation years (2020, 2030, 2050, 2100) given two main scenarios for future S and N deposition scenarios (CLE=current legislation, i.e. Gothenburg protocol, and MFR=maximum feasible reduction).

The results show that the increased ANC in Norwegian surface waters observed since 1990 can be expected to continue to increase slightly through 2020 if the planned emission reductions of the Gothenburg protocol and other legislation are implemented. With no further reductions after 2020 (CLE scenario) the ANC will show a very small increase, due to slow build up of base cations in the soils. Many lakes in northeastern Norway (Finmark county), however, will experience reacidification during the 21st century due to projected increases in S and N deposition. The results indicate that many surface waters in southernmost Norway will continue to be acidified (critical load exceeded) long into the 21st century unless deposition of S and N is reduced substantially beyond requirements of the Gothenburg protocol (CLE scenario). Under the MFR scenario, ANC will continue to increase in most lakes throughout the country. The results from the MFR scenario show that there remains potential for additional increases in ANC if deposition is reduced beyond the Gothenburg protocol.

For southern Norway, deposition reductions below the critical load are needed if the goal is to restore conditions suitable for sustainable fish populations within a few decades.

1. Introduction

The link between the emission of sulphur and nitrogen compounds to the atmosphere and the acidification of soils and surface waters is now well established and understood. These links form the basis for calculation of *critical loads* (CL) for surface waters and soils. Critical loads contributed to the scientific basis for the 1994 Oslo Protocol and the 1999 Gothenburg Protocol to the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (LRTAP) (internet web site www.unece.org/env/lrtap).

Ongoing work within the Convention now includes review and revision of these protocols. It has become increasingly clear that the static model approach used in estimating critical loads may be insufficient to determine the reduction in level of acid deposition necessary to allow recovery of acidified ecosystems within acceptable time. Deposition may have to be reduced to a *target load* below the critical load.

In November 2006 and again in November 2007, the Coordination Centre for Effects (CCE) of the International Cooperative Programme for Modelling and Mapping (ICP M&M) issued a call for data for results from application of dynamic models to soils and surface waters given several specified future scenarios of sulphur (S) and nitrogen (N) deposition. Requested was information on future acidification of surface waters for the entire country, ideally a set of values for each of the 2304 grid squares in the critical load grid that covers entire Norway. The critical load database includes several basic water chemistry parameters necessary to calculate cricitial loads, but it does not include sufficient data (for example soil characteristics) to enable application of dynamic models. This was resolved by applying the dynamic model to the largest representative lake dataset available, the 1995 national lake survey, and then extrapolating the results to the 2304 CL grid squares by means of analogue matching.

In response to the 2007 call, the National Focal Centre at the Norwegian Institute for Water Research (NIVA) calibrated the dynamic model MAGIC to 990 of the 1007 statistically selected lakes in the 1995 national lake survey (Skjelkvåle et al. 1996, Henriksen et al. 1998), applied the 14 S and N deposition scenarios specified by the CCE, and calculated acid neutralising capacity (ANC) and several other chemical species of the lakes in five years in the future (2020, 2030, 2040, 2050, 2100). The results were matched to the water chemistry of the 2304 squares in the critical load grid for Norway. The work was conducted under contract from the Norwegian Pollution Control Authority (SFT). The data were submitted in March 2007 (Hedmark and Østfold counties only) and March 2008 (entire country) to the CCE. Sweden and the UK also submitted data for surface waters. All three countries used the same dynamic model (MAGIC) and largely the same procedures to calculate future acidification. Here we describe the data used, the calculation procedures and the results obtained for Norway. The 2007 results for both waters and soils for all of Europe have been reported by the CCE (Slootweg et al. 2007).

The calls for data issued in November 2006 and 2007 by the CCE contained a number of specifications designed to obtain consistent and harmonised dynamic modelling results for all countries in Europe. The scenarios specified by the CCE are based on three key assumptions: (i) the protocol year, (ii) the implementation year, and (iii) the evaluation year (Figure 1.). These were defined as follows:

The ***protocol year*** for dynamic modelling is the year up to which the deposition path is assumed to be known and cannot be changed. This can be the present year or a year in the (near) future, for which emission reductions are already agreed.

For the 2007 call the protocol year was 2010, and the deposition of S, NOx (oxidised nitrogen species) and NHy (reduced nitrogen species) from 1880 to 2010 was specified by the CCE for each EMEP grid square in Europe. The values from the CCE for deposition for 2010 were assumed to be those obtained following full implementation of the Gothenburg Protocol, the EU NEC Directive and other (national) legislation. This is termed the *current legislation scenario* (CLE).

The ***implementation year*** for dynamic modelling is the year in which all reduction measures to reach the final deposition are assumed to be implemented. Sometimes the prefix 'DM' for 'dynamic modelling' is added to avoid confusion with the term 'implementation year' as used by integrated assessment modellers. For the 2007 call the DM-implementation year was specified by the CCE to 2020, and deposition was assumed to change linearly between the protocol year (2010) and the implementation year (2020) (Figure 1.).

The ***evaluation year*** for dynamic modelling is the year for which the results (e.g., the lake water ANC) are to be examined. For the 2007 call there were four "historic" years (1980, 1990, 2000, 2010) and five future years (2020, 2030, 2040, 2050, 2100) specified.

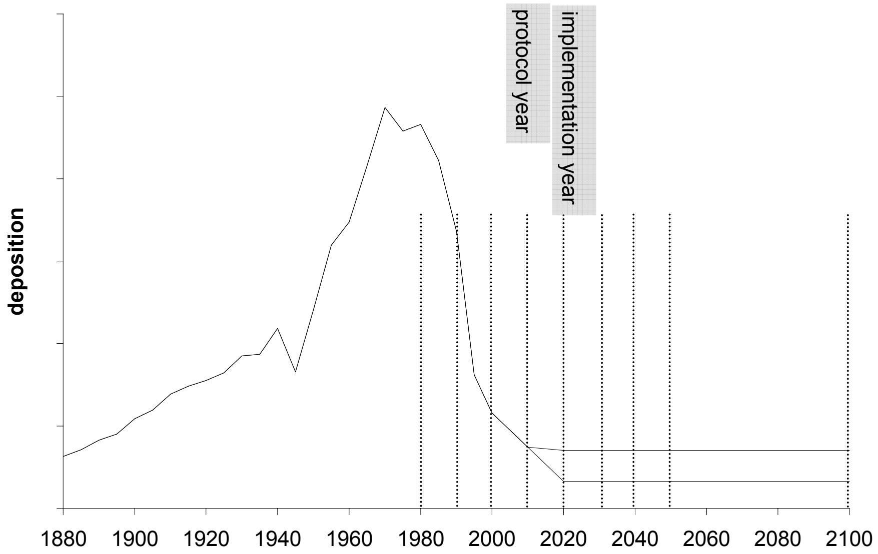


Figure 1. *Illustration of a deposition path (for example, S, for two future scenarios) and the terminology used in dynamic model calculations (adapted from the CCE 2004 call document). (i) the year up to which the deposition is fixed (protocol year); (ii) the year in which the emission reductions leading to a target load are implemented (DM implementation year); and (iii) the years in which the chemical criterion is to be evaluated (DM evaluation years; denoted by vertical lines).*

2. Methods

2.1 The MAGIC Model

The dynamic model MAGIC was used to calculate future acidification status (as measured by acid neutralising capacity ANC) for Norwegian surface waters. MAGIC (**M**odel of **A**cidification of **G**roundwater **I**n **C**atchments) is a lumped-parameter model of intermediate complexity, developed to predict the long-term effects of acidic deposition on soils and surface water chemistry (Cosby et al. 1985, Cosby et al. 1985, Cosby et al. 2001). The model simulates soil solution chemistry and surface water chemistry to predict the annual average concentrations of the major ions in lakes and streams. MAGIC represents the catchment with aggregated, uniform soil compartments (one or two) and a surface water compartment that can be either a lake or a stream. MAGIC consists of (1) a section in which the concentrations of major ions are assumed to be governed by simultaneous reactions involving sulphate adsorption, cation exchange, dissolution-precipitation-speciation of aluminium and dissolution-speciation of inorganic and organic carbon, and (2) a mass balance section in which the flux of major ions to and from the soil is assumed to be controlled by atmospheric inputs, chemical weathering inputs, net uptake in biomass and losses to runoff. At the heart of MAGIC is the size of the pool of exchangeable base cations in the soil. As the fluxes to and from this pool change over time owing to changes in atmospheric deposition, the chemical equilibria between soil and soil solution shift to give changes in surface water chemistry. The degree and rate of change in surface water acidity thus depend both of flux factors and the inherent characteristics of the affected soils.

The soil layers can be arranged vertically or horizontally to represent important vertical or horizontal flowpaths through the soils. If a lake is simulated, seasonal stratification of the lake can be implemented. Time steps are monthly or yearly. Time series inputs to the model include annual or monthly estimates of (1) deposition of ions from the atmosphere (wet plus dry deposition); (2) discharge volumes and flow routing within the catchment; (3) biological production, removal and transformation of ions; (4) internal sources and sinks of ions from weathering or precipitation reactions; and (5) climate data. Constant parameters in the model include physical and chemical characteristics of the soils and surface waters, and thermodynamic constants. The model is calibrated using observed values of surface water and soil chemistry for a specific period.

MAGIC has been modified and extended several times from the original version of 1984. In particular, organic acids have been added to the model (version 5; (Cosby et al. 1995)) and most recently nitrogen processes have been added (version 7; (Cosby et al. 2001)).

The MAGIC model has been extensively applied and tested over the past 20 years at many sites and in many regions around the world (Cosby et al. 2001). Overall, the model has proven to be robust, reliable and useful in a variety of scientific and environmental management activities (Cosby et al. 1995, Ferrier et al. 1995, Jenkins et al. 1998, Wright et al. 1998). Recently MAGIC was used to assess the recovery of European surface waters given the CLE (Gothenburg protocol and other agreed legislation) deposition scenario (Wright et al. 2005).

2.2 List of required data

The data required to run MAGIC must be spatially and temporally averaged (or ‘lumped’) to represent the whole catchment area (divided into one or several soils and waters compartments) and the time step of the model (annual or monthly). If physical and chemical data are available at only one point in the catchment or from one point in time, it must be assumed that this is representative of the whole catchment at that time step. Any uncertainty in these data and in the representativeness is incorporated into the model and the prediction must be interpreted accordingly. The minimum data requirement is given below:

Hydrological parameters:
- Annual runoff (m/yr)
- Annual precipitation (m/yr)

Soil parameters:
- Soil depth (m)
- Porosity (%)
- Bulk density (kg/m^3)
- CEC (meq/kg)
- SO_4 maximum adsorption capacity (meq/kg)
- SO_4 half-saturation coefficient (meq/m^3)
- Dissociation constant for aluminium hydroxide solid phase, K_{Al} ($\log_{10}$)
- Temperature (annual average)(°C)
- pCO_2 (%)
- Organic acids (mmol C/m^3)
- Dissociation constants for organic acids (pK)
- Nitrification (% of input)

Surface water parameters:
- Retention time (yr)
- Relative area (%)
- Temperature (annual average) (°C)
- Dissociation constant for aluminium hydroxide solid phase, K_{Al} ($\log_{10}$)
- pCO_2 (%)
- Organic acids (mmol C/m^3)
- Dissociation constants for organic acids (pK)
- Nitrification (% of input)

Surface water/soil chemistry in calibration year (i.e. 2001):
- Concentration of major ions (Ca, Mg, Na, K, NH_4, SO_4, Cl, NO_3) (meq/m^3)
- Soil exchangeable base cations (Ca, Mg, Na, K) (meq/kg)

Deposition parameters in calibration year (i.e. 2001):
- Concentration of major ions (Ca, Mg, Na, K, NH_4, SO_4, Cl, NO_3)
- Time sequence of change in:
  - deposition concentration
  - dry deposition factors for each ion (= total deposition/wet deposition)

2.3 Sequence of tasks

There are in all five major tasks that must be carrried out to generate the results requested by the CCE calls for data. These are schematically depicted in Figure 2.

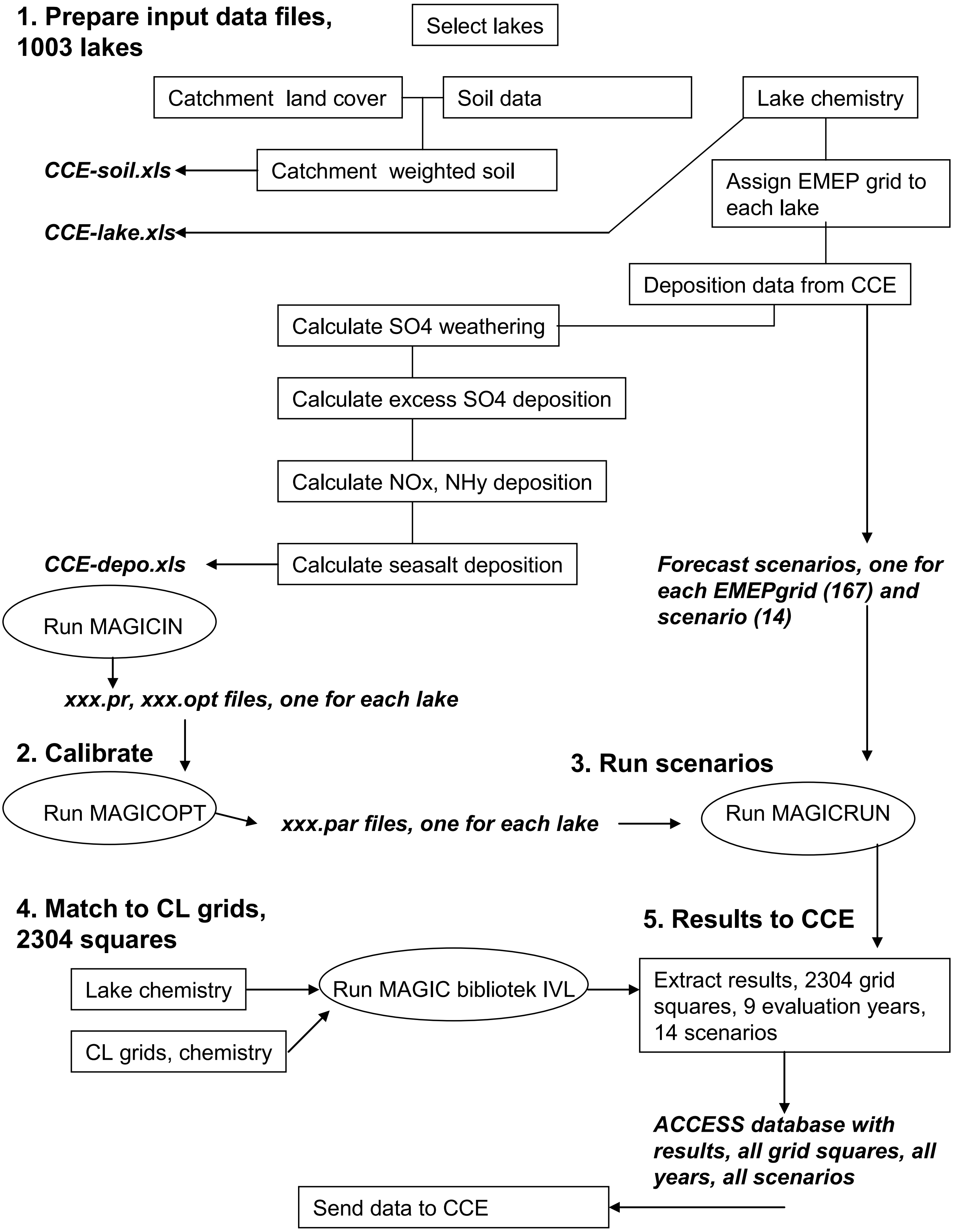


Figure 2. *Schematic flow diagram showing sequece of tasks to be carried out to generate the data requested in the CCE 2006 and 2007 calls for data. (Dates of calls November 2006 and 2007, deadlines for submission March 2007 and 2008).*

2.3.1 Preparation of input data files

The Norwegian lakes were taken from the 1995 national survey of 1500 lakes (Skjelkvåle et al. 1996). Of these, 1007 were statistically selected. The lakes were sampled in autumn 1995 and samples analysed for major ions. In addition lake and catchment characteristics were obtained from topographic maps and other national databases. Of these 1007 lakes, 1003 had all the necessary input data for chemistry and lake/catchment characteristics. The lake chemistry and characteristics data were put into EXCEL spreadsheet CCE-lake.xls, with one line for each lake.

Soil data calculations

Forest soil data came from the NIJOS (Norwegian Institute for Soil and Forest Inventory, now part of The Norwegian Forest and Landscape Institute) national forest inventory on a 9x9 km grid basis. These were aggregated up (arithmetic averages weighted by soil mass) to the 12x12 km critical load grid. Of the 1003 lakes, 345 were located in a grid cell were forest data were available (and hence forest present); 658 lakes in grid cells had no forest data available (i.e. no forest present).

Mountain/upland/heath soils: In the absense of a national soil inventory of soils in non-forested land we were relegated to assigning from data available from various research projects. Data sources used were:

- Vest-Adger and Rogaland: About 30 sites in heathlands sampled in 1998 by NIJOS using the same protocol as for the national surveys of forest soils. Grid based site selection. In addition, one site (Stavsvatn) in Telemark. Reference: (Wright et al. 1999)
- Yndesdal, Hordaland/Sogn og Fjordane. Catchment weighted average of data from about 8 soil samples collected in 2003. Reference: (Bjerknes et al. 2004)
- Dalelva, Finnmark. Soil data from national monitoring sampled in 1990 with original data in the SFT 1991 annual report. Aggregated data used here are from the MAGIC calibration to Dalelva. Reference: (Wright and Traaen 1992)
- Storgama, Vikedal, Gaular, Naustal, Sogndal, Risdalsheia. Soil data from national monitoring sampled in 1980s and with original data reported in SFTs annual reports. RAIN data (Sogndal, Risdalsheia) from NIVA. Aggregated data used here are from the MAGIC calibrations of the late 1980s. Reference: (Wright et al. 1990)
- Vosso, Hordaland. Catchment weighted averages from about 6 soil samples collected in 2000. Reference: (Kroglund et al. 2002)
- Hardangervidda. (Prikkaureprosjekt). Averages from 6 soil samples colleced in 2000. Reference: (Fjellheim et al. 2002)
- Rondane. Data from Dahl 1982 (Dahl 1982), averaged for MAGIC calibration. Reference: (Skjelkvåle et al. 1997)

Assignment of data for % heathland/mountain was done based on county (fylke) in which each lake was located.

- Finnmark: used Dalelva
- Hordaland, Rogaland, Agder: used "nearest neighbor"
- Østfold, Hedmark: used Rondane
- Telemark, Vestfold, Akershus: used "nearest neighbor".
- Buskerud: used Hardangervidda for northern sites, Stavsvatn for southern sites (nearest neighbor)
- Oppland: used Rondane
- Møre og Romsdal: used Naustdal
- Trøndelag, Nordland: used Daleva

Peat soil data were taken as the Langtjern average peat soil for all locations. A depth of 50 cm was used.

The three types of soil for each site were area-weighted for each parameter. The soils data for mountain and heathland areas are given in 5.Appendix B.

Base cation uptake (actually annual net accumulation in biomass) was assumed to be zero for non-forested areas. For forests, the rates were assumed to be Ca 21 meq/m^2/yr, Mg 4 meq/m^2/yr, and K 4.5 meq/m^2/yr.

The soil chemistry and characteristics and uptake data were put into EXCEL spreadsheet CCE-soil.xls, with one line for each lake.

Deposition in the calibration year 1995 was estimated for each lake catchment from the measured lake chemistry and the deposition estimates for EMEP squares provided by CCE. The file for grid-average land cover was used. First SO_4 deposition was calculated. The sources for SO_4 in lakewater were assumed to be comprised of (1) weathering of soil minerals, (2) deposition of seasalts, (3) natural background (pre-industrial) deposition of non-marine SO_4, and (4) anthropogenic SO_4. Seasalt SO_4 was assumed to equal 0.103 Cl (ratio of these ions in seawater). The natural background was provided in the CCE data. SO_4 from weathering was assumed zero in all cases where excess SO_4 deposition calculated from the water chemistry and discharge was below 100 meq/m^2/yr (in 1995). In cases where calculated excess SO_4 deposition was above 100 meq/m^2/yr, the weathering component was assumed to account for the remainder of the excess SO_4.

Deposition of NOx and NHy was then calcualted from the anthropogenic SO_4 (above) and the ionic ratios in the deposition data (NO_x/SO_4, NH_y/SO_4) provided by the CCE. Deposition of Cl was assumed equal to the output flux at each lake (based again on concentration in lakewater and discharge). The deposition of Na, Mg, Ca, K, and marine SO_4 were then calculated from the deposition of Cl and the ionic ratios of these ions in seawater. The deposition chemistry data were put into the EXCEL spreadsheet CCE-depo.xls, with one line for each lake.

Deposition sequences for the “historical” period 1880–2010 were specified by the CCE for each EMEP50 grid square for the three components S, NO_x, and NH_y. In some cases these 2007 values were significantly different from those provided for the 2006 call. No explanation for the changes was given by the CCE. As a result the preliminary calibrations for the counties of Østfold and Hedmark made in 2007 could not be used in 2008. The 2008 work thus comprised re-calibration of MAGIC to Østfold and Hedmark as well as to the rest of the country.

The historical deposition values were normalised to the deposition values calculated for the year 1995.

2.3.2 Model Calibration

Of the 1003 lakes with sufficient data, 13 were excluded because of one or more of the following reasons: high base saturation >80 % (lake 3206), sum base cations or sum strong acid anions > 2500 µeq/l (lakes 3032, 3332, 3636, 3772), high NO_3 concentration in the lake indicated large local source (lakes 55, 3007, 3404, 3728, 3773, 3796), incorrect lake or catchment area (lakes 3111, 3911).
The remaining 990 lakes were carried on for calibration with MAGICOPT.

Prior to calibration a number of MAGIC parameters were specified for the lakes. These assumptions are given in the table in 5.Appendix D. The value of lake DOC was adjusted in MAGICOPT (after the acid anions and base cations had been optimized) so that simulated lake pH matched observed lake pH. The value of lake K_{Al} was set to 8.0 (a priori) for all lakes. We assumed straight throughput of SO_4 with no delay due to SO_4 adsorption (Emx = 0). We used lake output fluxes of excess SO_4 to set the total deposition of excess SO_4. This was done by the MAGICOPT program in a dynamic simulation so that the effects of lag times in lakes and soils would be "corrected" when the calculations were performed. The soil K_{Al} was estimated from observed surface water Ca and Mg concentrations, observed soil %exchangeable Ca and Mg, soil pH under the assumption that the selectivity coefficient for Ca-Al and Mg-Al is 0, and that H exponent is 3.0. The average of the two calculated values for K_{Al} soil was used.

MAGIC was calibrated to each lake using an automatic optimiser that iteratively adjusts the values of a series of parameters such that the simulated lake chemistry for the calibration year 1995 matches the observed to within a specified margin of error. The programme MAGICIN takes the three input worksheets (lake, soil, depo) and makes one starting parameter file (xxx.pr) and one optimiser control file for each lake (xxx.opt). These are then read into the optimiser programme MAGICOPT which then finds a set of values for key soil parameters (initial base saturation, weathering rates) such that the simulated lake chemistry matches the observed for each ion to within ± 2 μeq/l and the simulated base saturation matches the observed for each base cation to within ± 0.2%. In the automatic calibration routine of MAGIC the following switches were set: BC optimizer (weathering calibration): on, SO_4 adsorption optimizer: off, soil pH optimizer: on, N dynamics optimizer: off.

All the 990 lakes were successfully calibrated by the MAGICOPT automatic optimiser. On the final run only 16 out of 990 missed calibrating. Of the 16 that missed the windows: 3 were a matter of changing the weights (original windows worked the second try - just bad luck they missed the first time); 10 were Mg from sea salt, had to open the windows to +/- 5 ueq/L; 2 needed the Ca windows opened to +/- 5 ueq/L; and one needed the exchangeable BC windows opened to +/- 0.5% (this was a high BS site). The MAGICOPT programme automatically generates one calibrated parameter file for each lake, xxx.par. These calibrated files were then run with MAGICRUN and the data for the four "historical" evaluation years produced.

2.3.3 Running scenarios

The CCE 2007 call requested results for a total of 14 scenarios of future S and N deposition. (In the 2006 call, fully 28 scenarios were specified). These were defined relative to the two main scenarios CLE and MFR (Figure 3). Accordingly one file for each EMEPgrid and each scenario was prepared to run along with the calibrated parameter file for each lake. A list file assigned an EMEP grid to each lake: These were fed into the programme MAGICRUN, which then produced the simulated lake chemistry data for the five future years for each of the lakes and each of the scenarios.

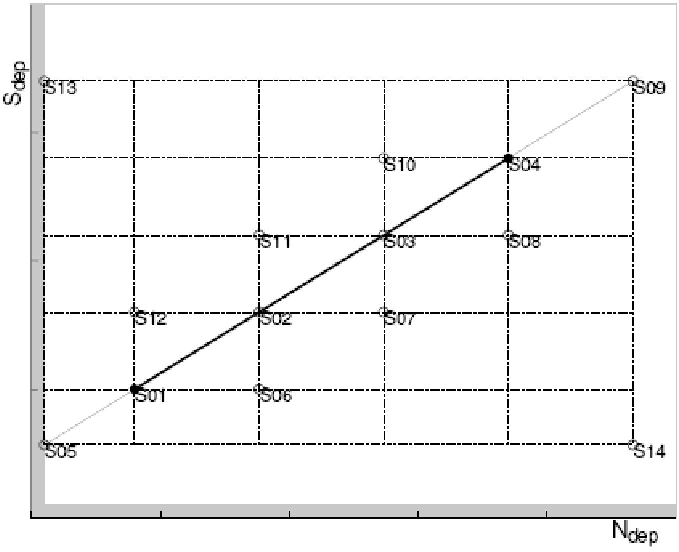


Figure 3. Schematic view of the scenarios provided by the CCE in the 2007 call for dynamic modelling data. Scenarios S01–S14, i.e. deposition pairs (Ndep, Sdep), derived from given MFR (=S01) and CLE (=S04) scenarios.

2.3.4 Extrapolate to critical loads grids

Norway has earlier reported data for critical loads (CL) for each of 2304 squares in a grid net covering the entire country (Henriksen and Buan 2000). The net was defined as 0.125° latitude and 0.25° longitude. Each square is approximately 12x12 km. For each of the grid squares representative water chemistry data were collected or extrapolated from existing data sources and used to calculate CL for surface waters. The data reflect water chemistry of 1995. The results for dynamic modelling of the 990 lakes thus needed to be extrapolated to the 2304 squares in the CL grid net.

This extrapolation was done by means of an analogue matching procedure in the "MAGIC library" held at the Swedish Environment Insitute IVL (IVL 2007) (see also country report for Sweden). This procedure takes the water chemistry data each of the 2304 grid squares and finds the closest match in the 990 lakes calibrated by MAGIC. The match was judged as the lake with the minimum Euclidian distance of the following parameters: geographical distance (latitude, longitude), annual runoff (m/yr), and concentrations of Ca, Cl, Mg, and SO_4 (µeq/l). Each of the 2304 grid cells was thus assigned a MAGIC modelled lake. The Norwegian grid cells were only matched to Norwegian lakes (unlike in the 2007 submission, where they might also have been matched to Swedish lakes).

2.3.5 Extract requested data into ACCESS database for reporting to CCE

The final step was then to extract the requested information for each CL grid square, each parameter, each of the 14 scenarios and each of the evaluation years. This was done in an ACCESS database as suggested by the CCE and the data were sent in the requested format in March 2008. The following water chemistry parameters were reported: pH, BC (sum of concentrations of Ca+Mg+K), ANC, and nitrogen (sum of concentrations of NO_3+NH_4). The soil base saturation (BS) was not reported. This parameter is indeed simulated by MAGIC and thus available for the 990 lakes for all years, but the MAGIC library matching routine has not been set up to account for soil BS.

3. Results

3.1 Development of ANC in Norwegian surface waters 2000 - 2100

The simulated ANC values for the 990 lakes in Norway indicate that a large number of lakes in southern and especially southernmost Norway have negative or very low ANC and thus unsuitable water quality for healthy populations of brown trout. The data also suggest that there are improvements over the period 2000 - 2010 (Figure 4).

This picture is largely the same when the results are extrapolated to the CL grids (Figure 5).

For the future, the simulations indicate that there will be small continued improvements given the CLE scenario (i.e. no change in S and N deposition after 2010) and, of course, greater improvements under the MFR scenario (Figure 6). This same picture is shown by the data extrapolated to the CL grid (Figure 7).

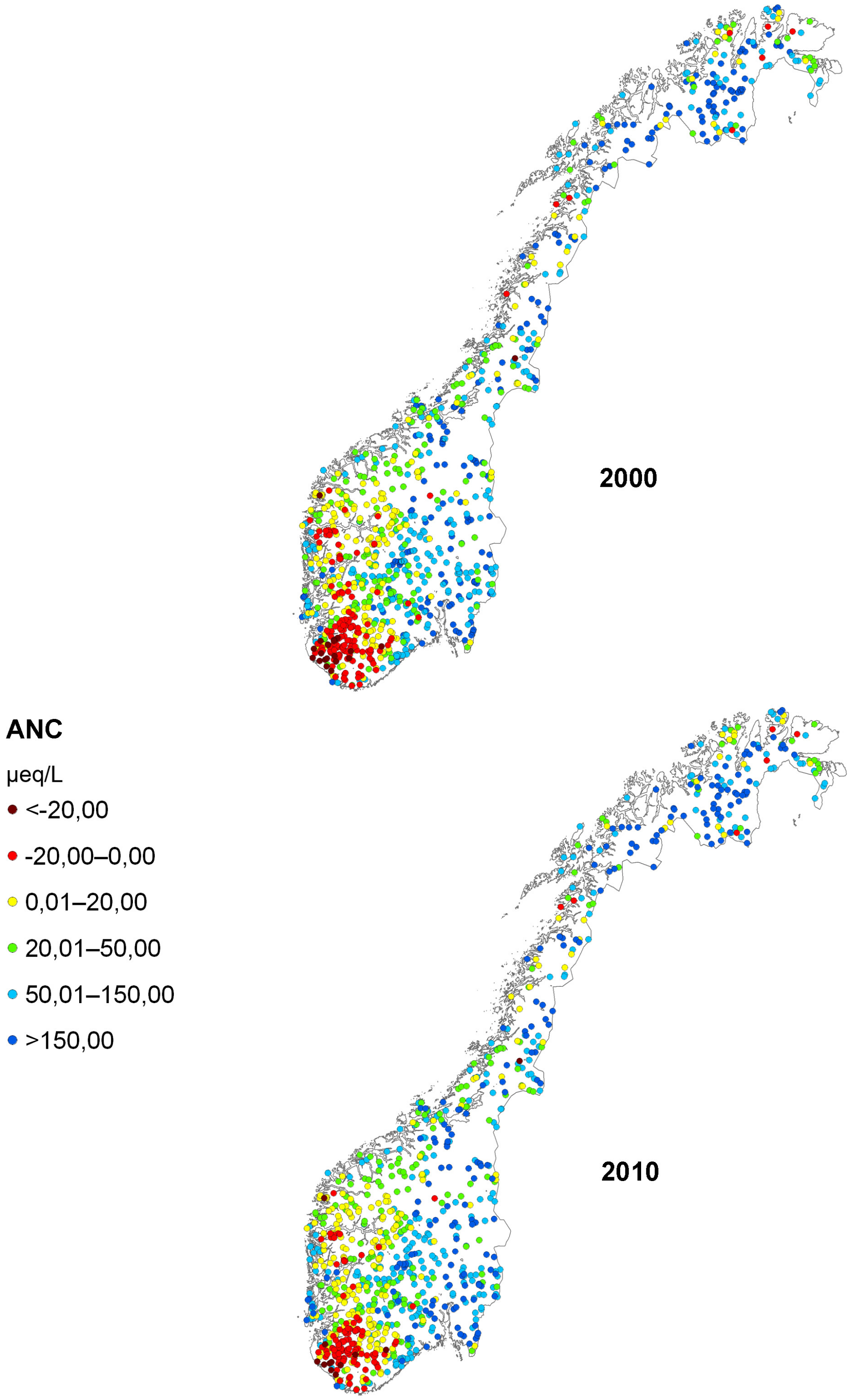


Figure 4. *ANC values for 990 lakes in Norway for the years 2000 and 2010 simulated by the dynamic model MAGIC based on water chemistry data from the 1995 national lake survey and S and N depositon sequences provided by the CCE for EMEP50 grids. In general lakes with ANC < 0 (red and orange points) have high risk of extinct fish (brown trout) populations, lakes with ANC 0–20 µeq/l (yellow points) have risk of damaged populations, and lakes with ANC > 20 µeq/l (light and dark blue points) have good populations.*

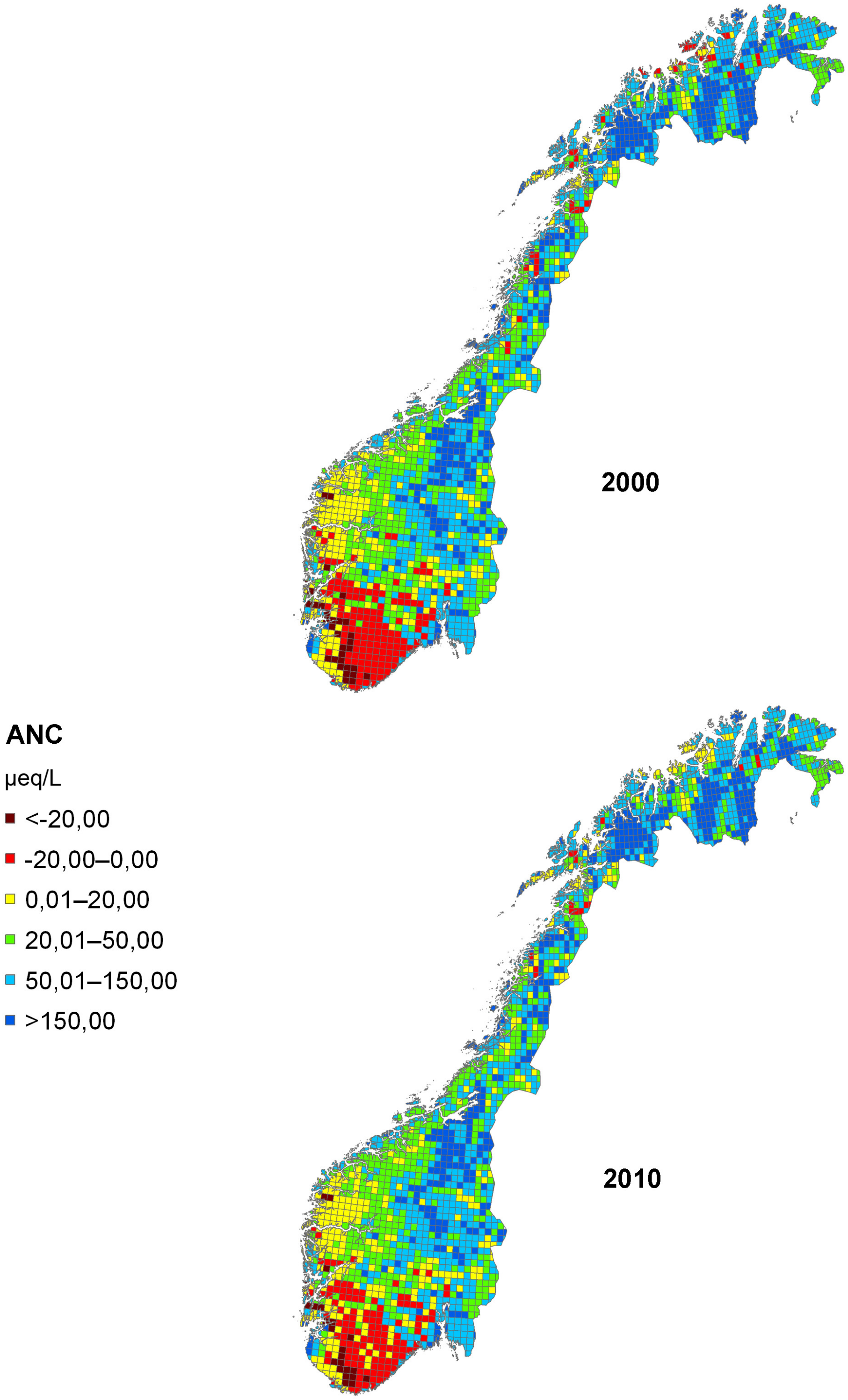


Figure 5. *ANC values for surface waters in the CL grid in Norway for the years 2000 and 2010 simulated by MAGIC and extrapolated with the MAGIC library.*

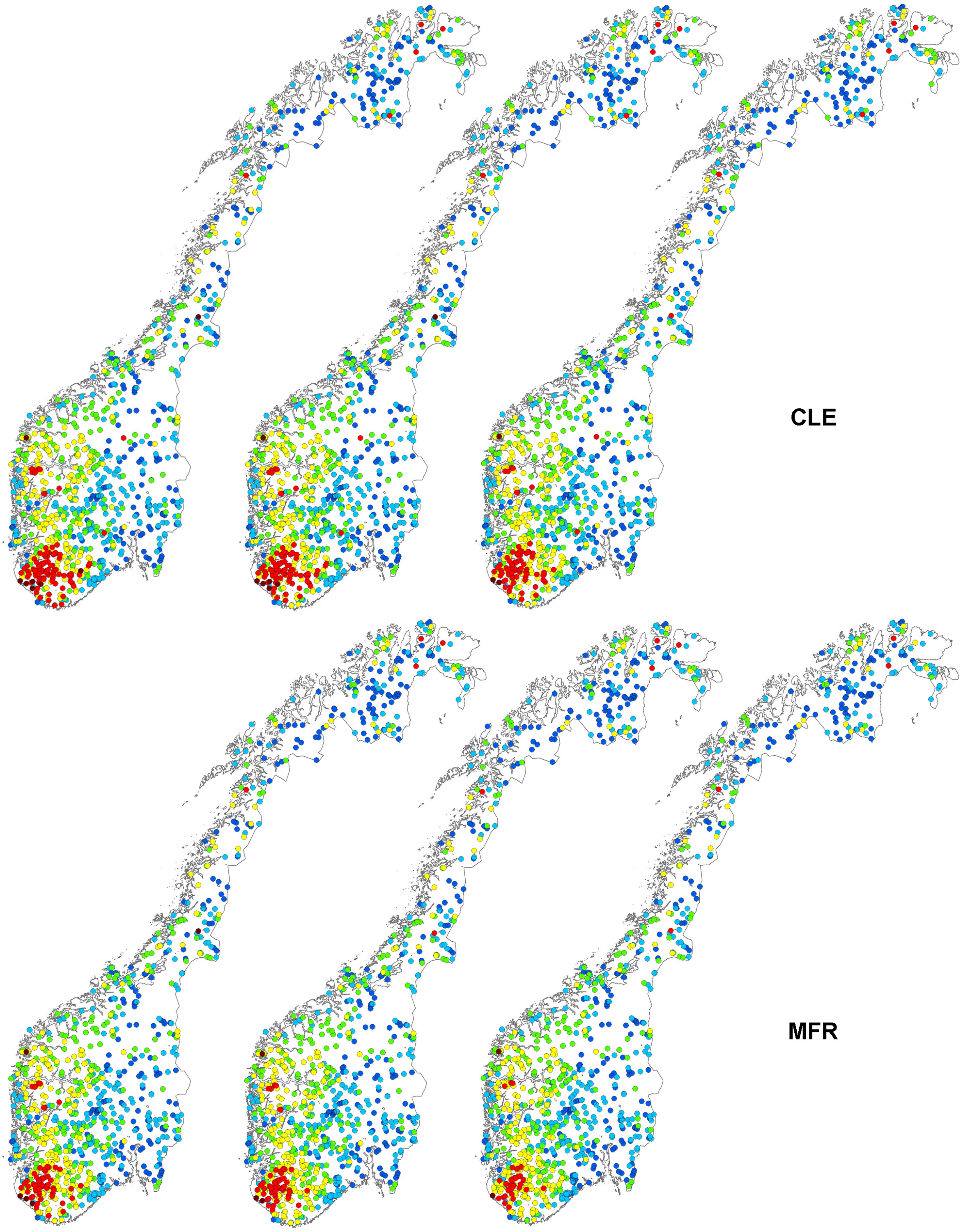


Figure 6. *ANC values for 990 lakes in Norway for the years 2020, 2030 and 2100 simulated by MAGIC given two future scenarios of S+N deposition. Top panels CLE=current legislation; bottom panels MFR=maximum feasible reduction. See Figure 4 for explanation of colors.*

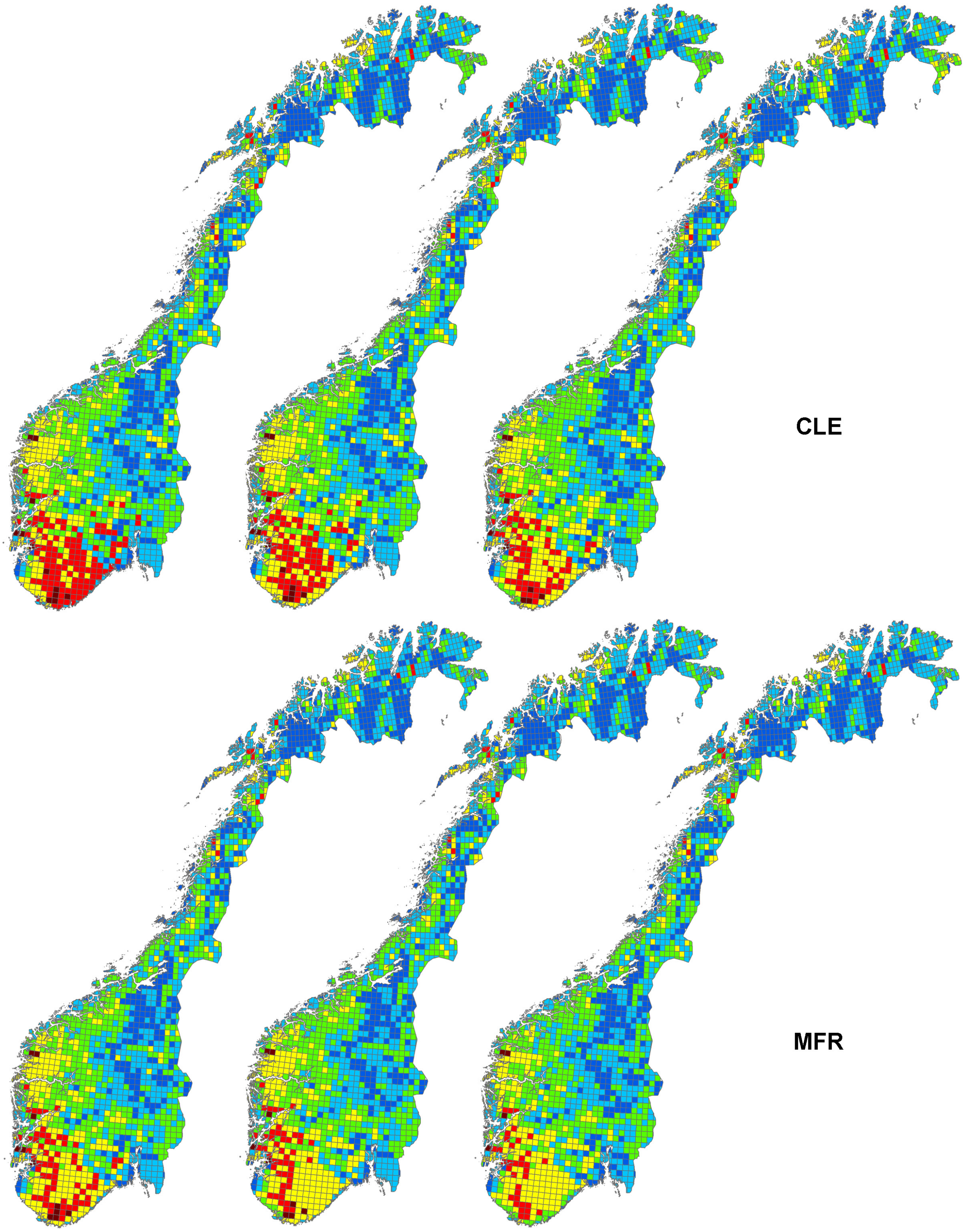


Figure 7. *ANC values for for surface waters in the CL grid in Norway for the years 2020, 2030 and 2100 simulated by MAGIC given two future scenarios of S+N deposition. Top panels CLE=current legislation; bottom panels MFR=maximum feasible reduction. See Figure 5 for explanation of colours.*

3.2 Simulated trends compared to observed data

Several of the 1007 statistically selected lakes in the 1995 national lake survey, by chance, also have observed historical data for development of water chemistry during the past 20–30 years. One of these is Lake Lille Hovvatn, a severely acidified lake, barren of trout, located in southernmost Norway. Lille Hovvatn has been the site of long-term research on acidification and liming, and NIVA holds water quality data from the site beginning in the 1980s (Hindar and Wright 2005).

The MAGIC simulated trends in water chemistry at Lille Hovvatn agree reasonably well with measurements (Figure 8). Year-to-year variations, of course, are not captured by the MAGIC simulations as the model was driven by the smooth deposition trends supplied by the CCE and did not take into account wet and dry years, for example. The observed trend in ANC shows a somewhat greater increase as compared to the simulated. This is apparently mostly due to the strong-acid anion Cl which has been present at lower concentrations since the calibration year 1995. High concntrations of Cl lead to lower ANC (as simulated), whereas lower Cl concntrations lead to higher ANC (as observed).

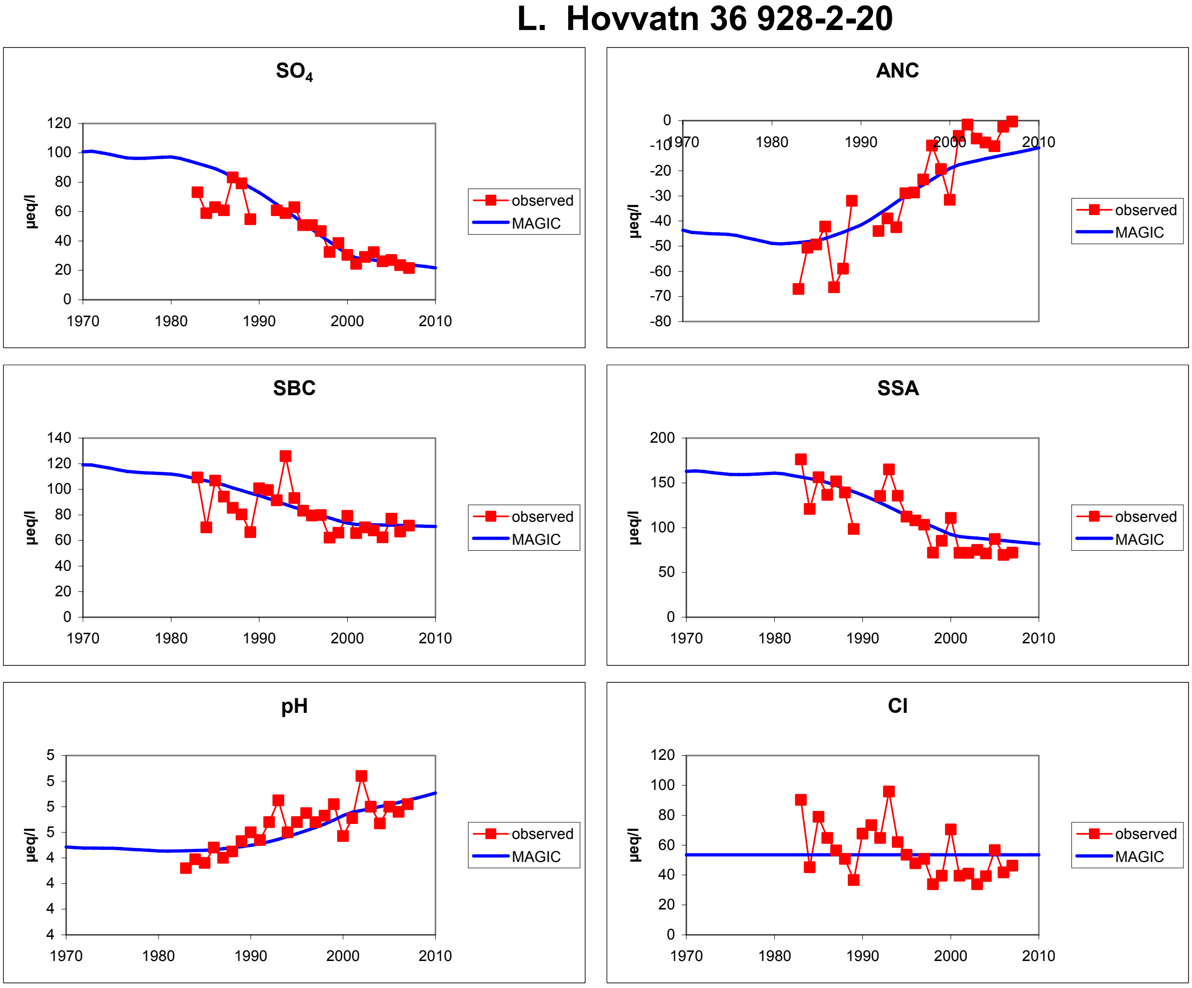


Figure 8. *Observed and simulated water chemistry at Lille Hovvtan, southernmost Norway. MAGIC simulations were made with the protocol used for the 990 lakes in Norway described here and driven by the S+N deposition history supplied by the CCE. Observed data from (Hindar and Wright 2005). SSA=sum strong acid anions; SBC=sum base cations.*

Hindar and Wright (2005) made a detailed site-specific calibration of MAGIC to Lille Hovvatn in which all the observed year-to-year variations in atmospheric deposition (water, seasalts and pollutants) were included. Their results show a very close match between simulated and observed ANC (Figure 9).

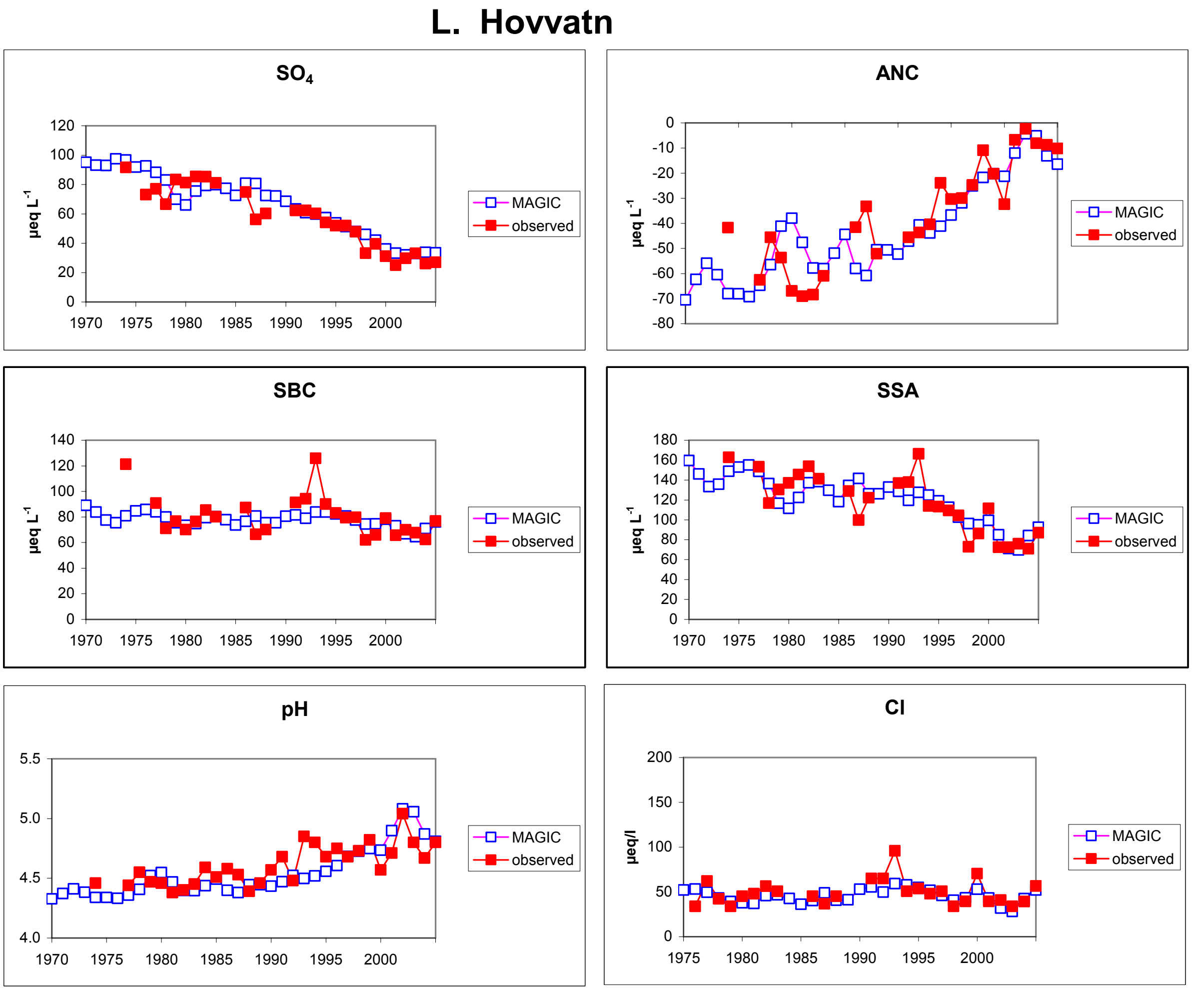


__Figure 9.__ Observed and simulated water chemistry at Lille Hovvtan, southernmost Norway. Here the MAGIC simulations included year-to-year measured variations in atmospheric deposition (Hindar and Wright 2005).

3.3 Deposition of sulphur and nitrogen in Finnmark

The CCE supplied deposition data for sulphur (S) and nitrogen (N) for each of the EMEP50 grid squares. As EMEP itself does not provide deposition data for years before 1980, the CCE estimated these data based on historical emission estimates and other similar methods, along the lines used by Mylona (1996). The historical estimates were scaled for each EMEP square such that there was a smooth transition in 1980 from the estimated historical data to the modelled EMEP data. This approach is simliar to that of Schöpp et al. (2003).

The CCE also provided deposition data for each EMEP grid square for the modelled period 1980 to 2010, as well as deposition for the future scenarios. For Finnmark in northernmost Norway the stipulated S deposition from about year 2000 onwards indicated an *increase*. This increase is apparently due to the fact that the emission data for Russia for years prior to 2000 were broken down to several regions within Russia, but after 2000 were given only for the entire European part of the country. Thus the EMEP modelled deposition for grid squares near the Russian border show an appraent increase from year 2000, while the measured data from the NILU station in the area show no such increase. Part of the increase after year 2000 may also be due to projected increased ship traffic to Murmansk.

For example, S deposition in EMEP square i46 j90 (located at the extreme northeastern corner of Norway, east Finnmark) shows significant increase with respect to the projections for the future given CLE scenario (Figure 10). The measured depostion (wet plus dry) at the nearest NILU station Jergul/Karasjok indicates close agreement with the CCE estimates for the grid square for the period 1987–the late 1990s. The estimated deposition for 2020 under the CLE scenario is projected to increase by nearly 100 % relative to the 1995 values.

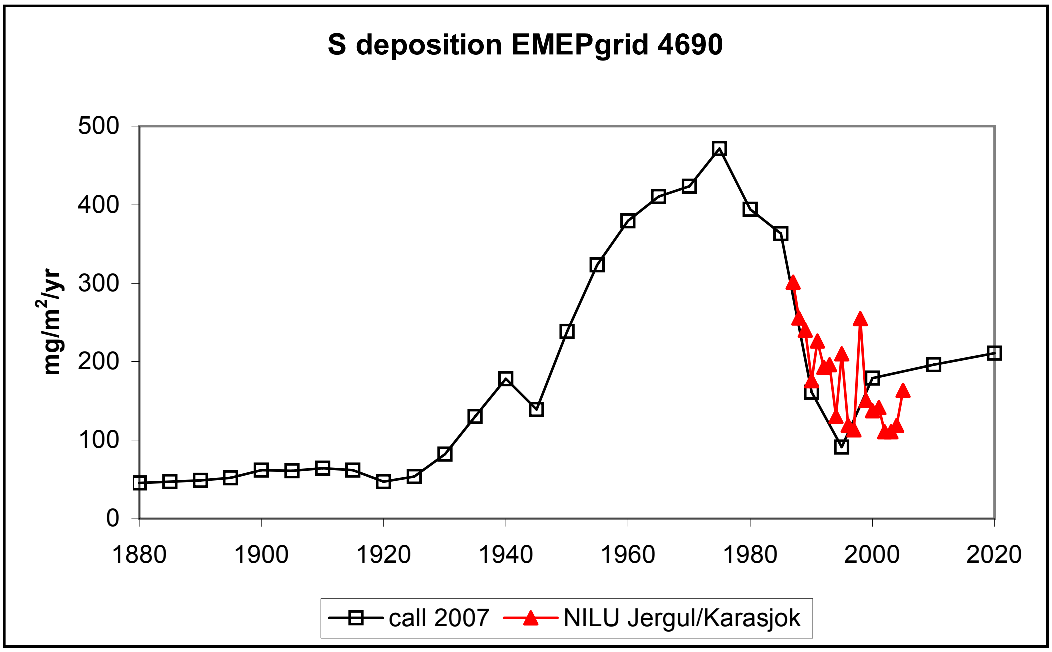


Figure 10. *Historical deposition of S in northeasternmost Norway (Finnmark) as specified by the CCE in the 2006 and 2007 calls (for EMEPgrid i46 j90) and as measured by NILU at Jergul (1987–96) and Karasjok (1997–2007). NILU data from (Aas et al. 2008).*

The MAGIC modelled result of an increase in S deposition under the CLE scenario is that many of the surface waters in the region are forecast to reacidify, with lower ANC in 2020 and subsequent years relative to 1995 (Figure 11). Future acididication trends in surface waters in northernmost Norway thus should be followed closely.

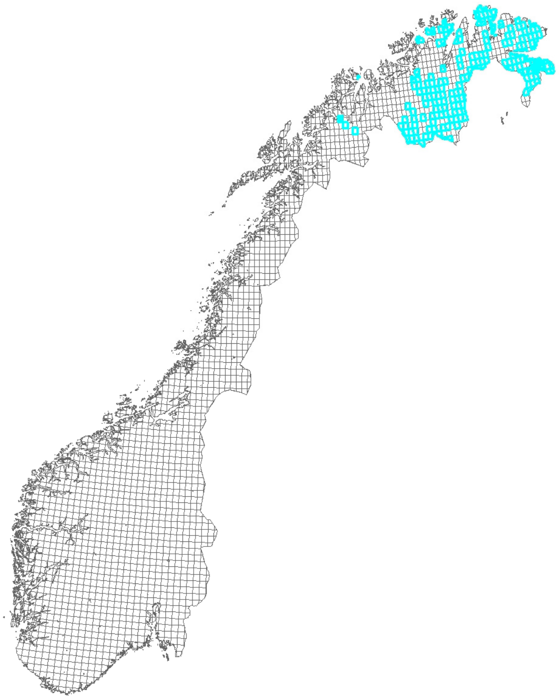


Figure 11. *Map of Norway showing the CL grid squares in which surface water ANC is forecast to decline during the 21st century under the CLE scenario.*

4. Concluding remarks

The dynamic modelling results for acidification of freshwaters in Norway provide new information that can be used to supplement maps of critical loads for ecosystems in Norway as part of the scientific basis for the ongoing revision of the Gothenburg protocol. The dynamic model results can be used in conjunction with Integrated Assessment Modelling.

Any such modelling entails a degree of uncertainty, which can arise from many sources. There is uncertainty in (1) the measured data used (water chemistry, soil chemistry, catchment characteristics), (2) estimated data such as historical S+N deposition, (3) the methods used to aggregate up to lake catchments or grid squares, (3) assumptions behind the model, and not least (4) confounding factors which might operate in the future, such as climate change. Nevertheless, it can be stated with some degree of confidence that site-specific applications of MAGIC closely simulate long-term measurements of water chemistry, such as the case shown here for Lake Lille Hovvatn. Perhaps the greatest source of uncertainty in the dynamic modelling results here are associated to future confounding factors such as climate change.

There have been great achievements in reducing European emissions of S (and to a lesser extent N), such that acidified Norwegian freshwaters have shown major recovery during the past 20 years. But as this dynamic modelling work shows, even with full implementation of the CLE scenario, freshwaters in large areas of southernmost Norway will continue to suffer from acidification during the 21st century. Water quality will not be sufficient to allow viable populations of fish and other organisms. The implications are two-fold: further reductions in S+N emissions are required, and in the meantime freshwaters or their terrestrial catchments will have to be limed to create water quality conditions suitable for fish.

The apparent threat of re-acidification of freshwaters in northeastern Norway poses several questions. First, the modelling results here highlight the implications of uncertainty in the estimated historical and future S+N deposition data used in the simulations. Second, if the freshwaters in this region are indeed threatened, then perhaps a strategy of regional emission reductions is called for.

The MAGIC model supplemented with the automatic optimiser programme and now with the additional programmes for preparing input and output files for large batches of sites has given us a powerful tool for running regional scale assessments and simulations of future acidification. This set of programmes will likely find other useful applications in the future, and can be useful tools in evaluation of the combined effects of climate change and acid deposition.

5. References

Aas, W., S. Solberg, T. Berg, S. Manø, and K. E. Yttri. 2008. Monitoring of Long-Range Transported Air and Precipitation -- Atmospheric deposition, 2007. Report 1033/2008. State Pollution Control Authority, Oslo, Norway.

Bjerknes, V., R. F. Wright, T. Larssen, and J. Håvardstun. 2004. Kalkingsplan for Yndesdal-Frøysetvassdraget basert på tålegrenseberegninger og prognoser for reduksjoner av surt nedfall. 4882-2004, Norsk institutt for vannforskning (NIVA), Oslo.

Cosby, B. J., R. C. Ferrier, A. Jenkins, and R. F. Wright. 2001. Modelling the effects of acid deposition: refinements, adjustments and inclusion of nitrogen dynamics in the MAGIC model. Hydrology and Earth System Sciences **5**:499-518.

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

Cosby, B. J., R. F. Wright, and E. Gjessing. 1995. An acidification model (MAGIC) with organic acids evaluated using whole-catchment manipulations in Norway. Journal of Hydrology **170**:101-122.

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

Dahl, E. 1982. Acidification of soils in the Rondane Mountains, south Norway, due to acid precipitation. 1988:1, Økoforsk, Ås, Norway.

Ferrier, R. C., R. F. Wright, B. J. Cosby, and A. Jenkins. 1995. Application of the MAGIC model to the Norway spruce stand at Solling, Germany. Ecological Modelling **83**:77-84.

Fjellheim, A., Å. Tysse, V. Bjerknes, and R. F. Wright. 2002. Finprikkauren på Hardangervidda. DN-utredning 2002-1, Direktoratet for naturforvaltning, Trondheim.

Henriksen, A., and A. K. Buan. 2000. Critical Loads and exceedances of Critical Loads for Surface Water, Soils and Vegetation in Norway (In Norwegian). NIVA Report 4179-2000, Norwegian Institute for Water Research, Oslo.

Henriksen, A., B. L. Skjelkvåle, J. Mannio, A. Wilander, R. Harriman, C. Curtis, J. P. Jensen, E. Fjeld, and T. Moiseenko. 1998. Northern European Lake Survey - 1995. Finland, Norway, Sweden, Denmark, Russian Kola, Russian Karelia, Scotland and Wales. Ambio **27**:80-91.

Hindar, A., and R. F. Wright. 2005. Long-term records and modelling of acidification, recovery, and liming at Lake Hovvatn, Norway. Can. J. Fish. Aquat. Sci. **62**:2620-2631.

IVL. 2007. Description of the MAGIC library (In Swedish) http://www.ivl.se/affar/grundl_miljos/proj/magic/bibliotek.asp. *in*.

Jenkins, A., R. F. Wright, and B. J. Cosby. 1998. Modelling long-term hydrochemical response at ENCORE catchments in the UK and Norway. 35/1994, Norwegian Institute for Water Research, Oslo.

Kroglund, F., R. F. Wright, and C. Burchart. 2002. Acidification and Atlantic salmon: critical limits for Norwegian rivers. 111, Norwegian Institute for Water Research, Oslo.

Mylona, S. 1996. Sulphur dioxide emissions in Europe 1880-1991 and their effect on sulphur concentrations and depositions. Tellus **48B**:662-689.

Schöpp, W., M. Posch, S. Mylona, and M. Johansson. 2003. Long-term development of acid deposition (1880-2030) in sensitive freshwater regions in Europe. Hydrology and Earth System Sciences **7**:436-446.

Skjelkvåle, B. L., A. Henriksen, B. Faafeng, E. Fjeld, T. S. Traaen, L. Lien, E. Lydersen, and A. K. Buan. 1996. Regional innsjøundersøkelse 1995. En vannkjemisk undersøkelse av 1500 norske innsjøer. 677/96, Statens forurensningstilsyn, Oslo, Norway.

Skjelkvåle, B. L., R. F. Wright, and T. Tjomsland. 1997. Vannkjemi, forsuringsstatus og tålegrenser i nasjonalparker; Femundsmarka og Rondane. 88, NIVA, Oslo.

Slootweg, J., M. Posch, and J.-P. Hettelingh. 2007. Critical Loads of Nitrogen and Dynamic Modelling. CCE Progress Report 2007. MNP Report 500090001/2007, Coordination Centre for Effects, Bilthoven, Netherlands.

UBA. 2004. Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends. 52/04, Umwelt Bundes Amt, Berlin.

Wright, R. F., C. Beier, and B. J. Cosby. 1998. Effects of nitrogen deposition and climate change on nitrogen runoff at Norwegian boreal forest catchments: The MERLIN model applied to Risdalsheia (RAIN and CLIMEX projects). Hydrology and Earth System Sciences **2**:399-414.

Wright, R. F., T. Larssen, L. Camarero, B. J. Cosby, R. C. Ferrier, R. C. Helliwell, M. Forsius, A. Jenkins, J. Kopácek, V. Majer, F. Moldan, M. Posch, M. Rogora, and W. Schöpp. 2005. Recovery of acidified European surface waters. Environmental Science & Technology **39**:64A-72A.

Wright, R. F., J. Mulder, and J. M. Esser. 1999. Soils in mountain and upland regions of southwestern Norway: nitrogen leaching and critical loads. 103, Norwegian Institute for Water Research, Oslo.

Wright, R. F., A. O. Stuanes, J. O. Reuss, and M. B. Flaten. 1990. Critical Loads for Soils in Norway. Preliminary Assessment based on Data from 9 Calibrated Catchments. 11, Norwegian Institute for Water Research, Oslo.

Wright, R. F., and T. S. Traaen. 1992. Dalelva, Finnmark, northernmost Norway: prediction of future acidification using the MAGIC model. 2728, Norwegian Institute for Water Research, Oslo.

Appendix A. Glossary

ANC Acid neutralising capacity, defined as the equivalent sum of base cations (Ca, Mg, Na, K) less the equivalent sum of strong acid anions (SO4, NO3, Cl). Units: µeq/l

CCE Coordination Centre for Effects, part of the ICP M&M

CLE current legislation, i.e. Gothenburg protocol, EU directives and other national legislation

LRTAP Convention on Long-range Transboundary Air Pollution, an organ of the UNECE

EMEP Co-operative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe, a body under the LRTAP Convention

ICP M&M International Cooperative Programme on Modelling and Mapping of Critical Loads & Levels and Air Pollution Effects, Risks and Trends, part of the WGE

IVL Swedish Environmental Institute IVL

MFR deposition scenario of maximum feasible reduction

NIVA Norwegian Institute for Water Research

SFT Norwegian Pollution Control Authority

UNECE United Nations Economic Commission for Europe

WGE Working Group on Effects, a body under the LRTAP Convention

Appendix B. Soils data for mountain and heathland areas used in MAGIC calibrations 2007-2008

Site name/ BLR	Lat deg	min	Long deg	min	UTM R	UTM NS	UTM OV	ExCa %	ExMg %	ExNa %	ExK %	Depth m	BD kg/m3	CEC meq/kg	Source
Storgama	59	1	8	32				3.3	2.2	0.7	0.7	0.32	503	121	Wright et al. 1990 Tålegrense 11
Vikedal					32	66032	3291	3.8	2.6	2.0	2.2	0.75	1036	23	Wright et al. 1990 Tålegrense 11
Gaular					32	68033	3483	7.5	1.7	1.7	2.0	0.75	955	38	Wright et al. 1990 Tålegrense 11
Nausdal					32	68312	3314	7.9	3.6	4.4	2.4	0.75	800	62	Wright et al. 1990 Tålegrense 11
Sogndal	61	11	7	5				17.5	3.9	2.0	3.0	0.30	618	37	Wright et al. 1990 Tålegrense 11
Risdalsheia	58	25	8	24				5.5	2.7	1.4	1.9	0.11	400	82	Wright et al. 1990 Tålegrense 11
N Hardangervidda					32	67087	4283	14.5	1.7	1.6	2.0	0.30	643	120	Fjellheim et al. 2002 DN-Utredning 2002-1
Vosso	60	37	6	25				4.7	3.9	1.4	3.0	0.23	743	77	Kroglund et al. 2002 Tålegrense 111, NIVA 450
Dalelva	69	41	30	23				11.7	3.6	3.3	2.5	0.46	1179	27	Wright and Traaen 1992 NIVA 2728
Yndesdal	60	55	5	20				18.2	24.5	2.1	4.7	0.15	526	104	Bjerknes et al. 2004 NIVA 4882
Rondane	61	53	9	48				3.3	0.7	0.3	1.0	0.23	944	112	Dahl 1988 Økoforsk 1988:1, Skjelkvåle et al. 1997 Tålegrense 88, NIVA 3646
58006005								5.2	3.1	4.1	4.3	0.38	689	44	Wright et al. 1999. Tålegrense 103, NIVA 4130
58006006								7.2	4.1	3.5	2.2	0.56	499	58	Wright et al. 1999. Tålegrense 103, NIVA 4130
58006016								13.2	8.7	4.7	3.1	0.33	553	112	Wright et al. 1999. Tålegrense 103, NIVA 4130
58007013								6.5	4.0	3.8	2.2	0.50	686	60	Wright et al. 1999. Tålegrense 103, NIVA 4130
58007015								7.2	6.0	7.1	3.6	0.38	477	61	Wright et al. 1999. Tålegrense 103, NIVA 4130
58505008								49.2	19.5	5.8	1.3	0.63	520	91	Wright et al. 1999. Tålegrense 103, NIVA 4130
58505012								7.7	5.1	3.7	2.9	0.50	465	64	Wright et al. 1999. Tålegrense 103, NIVA 4130
58505016								33.9	13.3	5.3	2.0	0.75	374	201	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506001								7.9	7.1	2.6	3.0	0.49	758	56	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506003								3.0	7.0	1.3	1.7	0.22	1045	59	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506004								19.8	8.3	2.1	1.0	1.10	298	403	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506005								10.5	7.1	2.9	1.8	0.63	862	54	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506007								5.2	5.3	2.4	3.1	0.25	967	47	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506009								17.1	11.4	3.2	4.0	0.40	617	102	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506010								41.5	21.7	1.9	7.5	0.23	311	361	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506011								8.7	8.7	4.5	3.6	0.50	192	189	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506013								9.0	6.9	3.0	3.3	0.50	577	70	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506014								11.6	6.6	2.8	3.3	0.28	907	69	Wright et al. 1999. Tålegrense 103, NIVA 4130
58506016								14.3	12.0	2.9	3.4	0.28	659	59	Wright et al. 1999. Tålegrense 103, NIVA 4130
58507005								11.1	9.4	5.4	2.7	0.35	298	276	Wright et al. 1999. Tålegrense 103, NIVA 4130
58507006								13.9	7.3	2.6	5.0	0.14	552	72	Wright et al. 1999. Tålegrense 103, NIVA 4130
58507007								16.6	7.2	2.1	4.3	0.16	599	72	Wright et al. 1999. Tålegrense 103, NIVA 4130
58507009								6.3	2.7	2.9	3.0	0.51	876	26	Wright et al. 1999. Tålegrense 103, NIVA 4130
58507010								8.0	6.1	2.7	5.6	0.19	215	177	Wright et al. 1999. Tålegrense 103, NIVA 4130
58507014								9.6	5.8	2.2	4.5	0.12	558	39	Wright et al. 1999. Tålegrense 103, NIVA 4130
59006016								14.5	12.5	2.3	4.2	0.22	378	232	Wright et al. 1999. Tålegrense 103, NIVA 4130
59508009								14.9	4.1	3.9	2.8	0.22	668	65	Wright et al. 1999. Tålegrense 103, NIVA 4130

Appendix C. Norway national report to CCE 2007

National Focal Centre

Thorjørn Larssen
Norwegian Institute for Water Research (NIVA)
Gaustadallén 21
0349 Oslo
Norway
tel: +47 22185100
fax: +47 22185200
email: thorjorn.larssen@niva.no

Collaborating institutions

IVL Swedish Environmental Institute
P.O.Box 5302
SE-40014 Gothenburg
Sweden

Norwegian Institute for Nature Research (NINA)
Tungasletta 2
7485 Trondheim
Norway

Norwegian Institute for Air Research (NILU)
P.O. Box 100
2007 Kjeller
Norway

Procedures

Dynamic modelling

Due to resource limitation a limited part of the country (counties Østfold and Hedmark) was selected for calculations of scenarios for this call for data. The MAGIC model was used (Cosby et al. 1985, Cosby et al. 2001). Calibrated lakes were those from the statistically selected lakes (1007 nationwide) in the 1995 National lake survey (Skjelkvåle et al. 1996). The survey had 62 lakes in the two counties. Two of the lakes were disregarded due to very high phosphorus concentrations (and ANC) from local pollution. The model was calibrated to observed water chemistry for each of the lakes and to estimated soil base saturation in 1995. In the automatic calibration routine of MAGIC the following switches were set: BC optimizer: on, SO4 adsorption optimizer: off, soil pH optimizer: off, N dynamics optimizer: off.

Atmospheric deposition history was provided by CCE for EMEP grid cells. These were grouped into 6 groups (the squares in each group had similar history). Each lake was placed into one of the six groups by location. The 27 scenarios were calculated for each of the 6 groups (162 scenarios in total).

After calibration, all 27 scenarios were run for all 60 lakes. In order to get a reasonable coverage within each EMEP grid cell, the calibrated lakes were then used to assign scenarios to all grid cells

(1/4*1/8 degree) in the Norwegian critical loads database in the two counties (217 cells) using a matching routine called “MAGIC library” (IVL 2007) (see also country report for Sweden). The “MAGIC library” is operated and developed by IVL, and includes data for several hundred lakes calibrated with MAGIC in both Sweden and Norway. The 60 lakes here, was added to the database, then the 217 grid cells lakes were matched according to a Eucledian distance routine based on water chemistry and location. Each of the 217 grid cell lakes was thus assigned a MAGIC modelled lake in the library. Sweden used the same approach to calculate the MAGIC predicted water chemistry for the 27 scenarios. Norwegian grid cell lakes may be matched to a Swedish lake (and vice versa). The data reported is then MAGIC calculated water chemistry for each of the 27 scenarios.

Empirical critical loads for nutrient nitrogen

The empirical critical loads for nutrient nitrogen were updated using the harmonised land use map by SEI provided by the CCE and the lower limits of the critical load values given in the Mapping Manual (UBA 2004).

Map code category	**EUNIS code**	**Critical limit (mg m^{-2} yr^{-1})**
0	0	0
301	C1	500
302	C2	500
401	D1	500
501	E1	1000
502	E2	1000
503	E3	1000
504	E4	500
601	F1	500
602	F2	500
603	F3	500
604	F4	1000
701	G1	1000
703	G3	1000
704	G4	1000
804	H4	500
805	H5	500
901	I1	2000
1000	J	

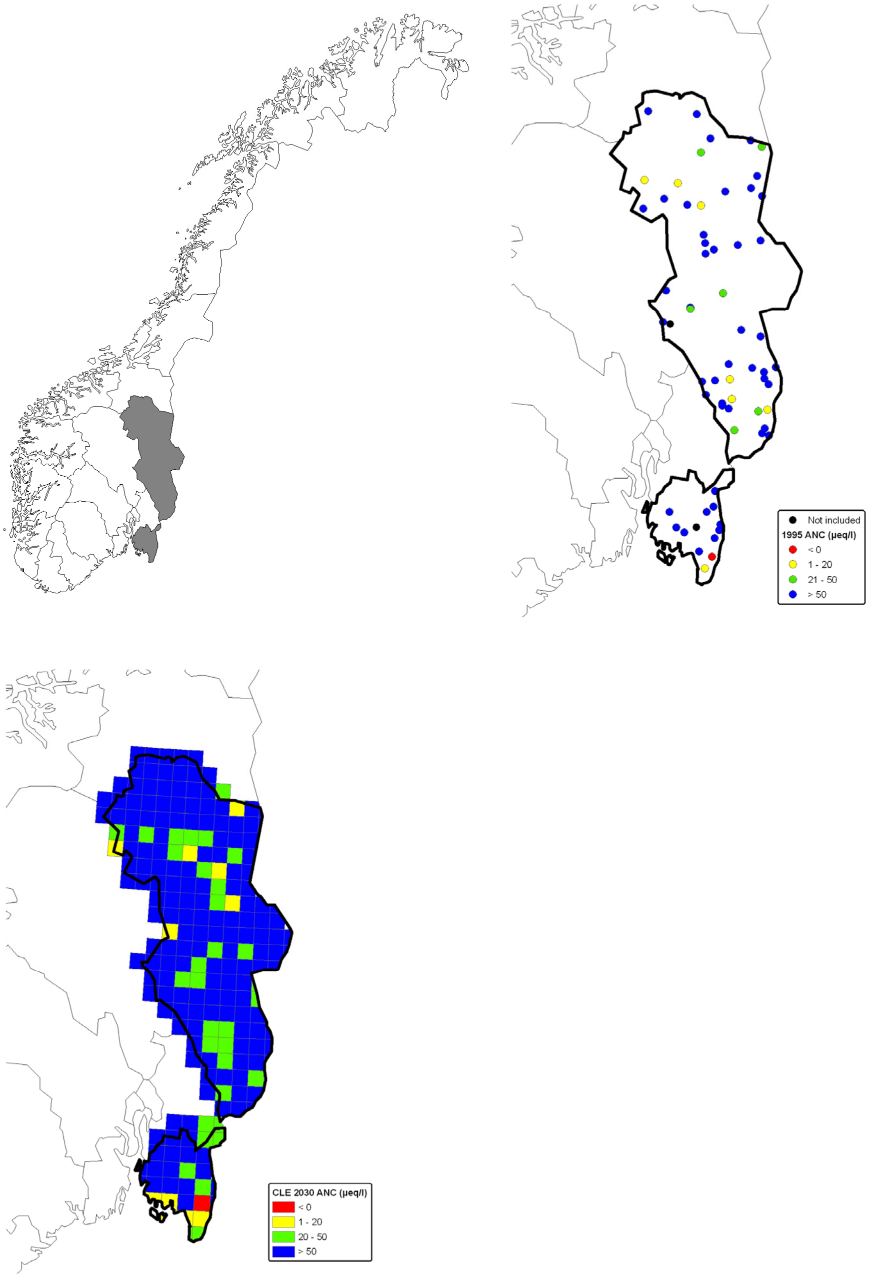


Figure NO. Left map: Observed ANC in 1995 for each calibrated lake.Right map: Modelled ANC in 2030 according to the CLE scenario for each "grid cell lake". Open circle on the left map show: disregarded lake due to very high phosphorus concentrations (and ANC) from local pollution: Stomperudtjern (128-1-4) and Kinnlitjernet (412-1-20).

Data Sources

Ranges of model inputs and parameters and comments on their sources and justifications are listed in the table.

Var	Unit	Min	Max	Assumptions, data sources and justifications
EcoArea	km^2	3.2	204.6	We consider 100% of the land area to contain watersheds for lakes and rivers. We have not calculated the area of the EMEP grid cells, which should be given here (minus the part of the cell covering ocean).
CLmaxS	eq ha^{-1} a^{-1}	50.9	20800	Calculated with FAB model (according to Mapping Manual, except BC^*_0 taken from MAGIC calibrations (1860))
CLminN	eq ha^{-1} a^{-1}	32.0	504	
CLmaxN	eq ha^{-1} a^{-1}	103	25354	
CLnutN	mgN m^{-2} a^{-1}	500	2000	Empirical values taken as minimum of range suggested in mapping manual
crittype		6	6	ANC is used as criterion for all lakes
critvalue	µeq L^{-1}	1.2	50	Variable ANC_{limit}
SoilYear		1985	2000	
ExCa	%	2.2	42.4	Lake catchment split into 4 categories: i) Forest area, taken from nearest relevant soil sampling locations (National Forest Inventory) for the percent forest in the lake catchment. ii) Peat area, taken from Langtjern soil pits no. 2 and 3 (1991 and 2000 average). iii) Non-forested upland, all from one project (Rondane National Park (Skjelkvåle et al. 1997)); arithmetic average from six sampling points. iv) Open water, including lake itself.
ExMg	%	0.8	22.2	
ExNa	%	0.3	4.9	
ExK	%	0.6	6.1	
thick	m	0.20	1.4	
BulkDens	g cm^{-3}	0.32	1.28	
CEC	meq kg^{-1}	18.0	430	
Porosity	%	50	50	Assumption. Constant value used for all sites.
DOCsoil	µmol L^{-1}	100	100	Assumption. Constant value used for all sites.
UptCa	meq m^{-2} a^{-1}	0.00	34.5	Based National Forest Inventory. Same as in critical loads database: value for the 12x12 km^2 grid cell in which the lake was located.
UptMg	meq m^{-2} a^{-1}	0.00	8.5	
UptK	meq m^{-2} a^{-1}	0.00	10.0	
UptNa	meq m^{-2} a^{-1}	0.00	1.7	
UptSO4	meq m^{-2} a^{-1}	0.00	0.00	
HlfSat	µeq L^{-1}	100	100	Assumption. Constant value used for all sites.
Emx	meq kg^{-1}	0.10	0.10	Assumption. Constant value used for all sites.
Nitrif	%	100	100	Assumption based on the fact that ammonium concentrations are very low.
Denitrf	%	0.00	0.00	
DepYear		1985	2000	
Cldep	eq ha^{-1} a^{-1}	17.5	1755	Deposition flux of chloride, sat equal to catchment output flux
Cadep	eq ha^{-1} a^{-1}	0.7	175	Calculated from [Cl$^-$] using standard sea salt ratios and assuming no non-sea salt deposition. When Na deposition was calculated to be higher than base cation flux out, the base cation deposition was reduced such that net flux is 0 (2 cases of the 60).
Mgdep	eq ha^{-1} a^{-1}	3.4	350	
Nadep	eq ha^{-1} a^{-1}	15	1506	
Kdep	eq ha^{-1} a^{-1}	0.3	74.3	
NH4dep	eq ha^{-1} a^{-1}	22.0	596	Calculated from observed ratios in deposition to SO_4. NO_3 deposition was increased to make net flux always negative or 0 (1 case of the 60). SO4 deposition was calculated from runoff flux assuming geological contribution (calculated as 0.17*([Ca]+[Mg]-0.234*[Cl])*Qs) and background deposition from CCE scenarios. If excess deposition was less than 5 meq/m2/yr, the weathering was reduced to give excess deposition that was the same as others in the EMEP grid (10 cases).
NO3dep	eq ha^{-1} a^{-1}	48.0	593	
LakeYear		1985	2000	Lake chemistry taken from the statistically selected lakes (1007 nationwide) in the

Var	Unit	Min	Max	Assumptions, data sources and justifications
Calake	μmol L^{-1}	8.2	835	1995 National lake survey.
Mglake	μmol L^{-1}	2.0	206	
Nalake	μmol L^{-1}	13.9	463	
Klake	μmol L^{-1}	1.1	35.3	
NH4lake	μmol L^{-1}	0	7.1	
SO4lake	μmol L^{-1}	11.1	259	
Cllake	μmol L^{-1}	5.6	363	
NO3lake	μmol L^{-1}	0.1	363	
DOC	μmol L^{-1}	1.7	765	Calculated from pH and charge balance
pKAl		7.5	11.4	Calculated from pH and Al-tot
RelArea	%	0.01	30.0	Data for each catchment
RelForArea	%	3.0	100	Data for each catchment
RetTime	yr	0.20	5.30	Assumption. 3 classes, by lake size.
Qs	m	0.3	1.2	Runoff taken from digital 30-year normal runoff database.
expAllake		3.00	3.00	Assumption. Constant value used for all sites.
pCO2	%	0.05	0.06	Assumption. Constant value used for all sites. (0.06 used for the matched Swedish sites)
Cased	m a^{-1}	0.00	0.00	Assumption. Constant value used for all sites.
Mgsed	m a^{-1}	0.00	0.00	
Nased	m a^{-1}	0.00	0.00	
Ksed	m a^{-1}	0.00	0.00	
SO4sed	m a^{-1}	0.00	0.00	
Clsed	m a^{-1}	0.00	0.00	
NH4sed	m a^{-1}	0.00	0.00	
NO3sed	m a^{-1}	0.00	0.00	
UptNH4lake	%	0.00	0.00	Assumption. Constant value used for all sites.
UptNO3lake	%	0.00	0.00	Assumption. Constant value used for all sites.
DMstatus		-1	1	1 for all data from Østfold and Hedmark counties, -1 for all others in this submission (although target loads have been submitted previously, but included in the scenario assessment)

References

Aas, W., S. Solberg, T. Berg, S. Manø, and K. E. Yttri. 2008. Monitoring of Long-Range Transported Air and Precipitation -- Atmospheric deposition, 2007. Report 1033/2008. State Pollution Control Authority, Oslo, Norway.

Bjerknes, V., R. F. Wright, T. Larssen, and J. Håvardstun. 2004. Kalkingsplan for Yndesdal-Frøysetvassdraget basert på tålegrenseberegninger og prognoser for reduksjoner av surt nedfall. 4882-2004, Norsk institutt for vannforskning (NIVA), Oslo.

Cosby, B. J., R. C. Ferrier, A. Jenkins, and R. F. Wright. 2001. Modelling the effects of acid deposition: refinements, adjustments and inclusion of nitrogen dynamics in the MAGIC model. Hydrology and Earth System Sciences **5**:499-518.

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

Cosby, B. J., R. F. Wright, and E. Gjessing. 1995. An acidification model (MAGIC) with organic acids evaluated using whole-catchment manipulations in Norway. Journal of Hydrology **170**:101-122.

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

Dahl, E. 1982. Acidification of soils in the Rondane Mountains, south Norway, due to acid precipitation. 1988:1, Økoforsk, Ås, Norway.

Ferrier, R. C., R. F. Wright, B. J. Cosby, and A. Jenkins. 1995. Application of the MAGIC model to the Norway spruce stand at Solling, Germany. Ecological Modelling **83**:77-84.

Fjellheim, A., Å. Tysse, V. Bjerknes, and R. F. Wright. 2002. Finprikkauren på Hardangervidda. DN-utredning 2002-1, Direktoratet for naturforvaltning, Trondheim.

Henriksen, A., and A. K. Buan. 2000. Critical Loads and exceedances of Critical Loads for Surface Water, Soils and Vegetation in Norway (In Norwegian). NIVA Report 4179-2000, Norwegian Institute for Water Research, Oslo.

Henriksen, A., B. L. Skjelkvåle, J. Mannio, A. Wilander, R. Harriman, C. Curtis, J. P. Jensen, E. Fjeld, and T. Moiseenko. 1998. Northern European Lake Survey - 1995. Finland, Norway, Sweden, Denmark, Russian Kola, Russian Karelia, Scotland and Wales. Ambio **27**:80-91.

Hindar, A., and R. F. Wright. 2005. Long-term records and modelling of acidification, recovery, and liming at Lake Hovvatn, Norway. Can. J. Fish. Aquat. Sci. **62**:2620-2631.

IVL. 2007. Description of the MAGIC library (In Swedish) http://www.ivl.se/affar/grundl_miljos/proj/magic/bibliotek.asp. *in*.

Jenkins, A., R. F. Wright, and B. J. Cosby. 1998. Modelling long-term hydrochemical response at ENCORE catchments in the UK and Norway. 35/1994, Norwegian Institute for Water Research, Oslo.

Kroglund, F., R. F. Wright, and C. Burchart. 2002. Acidification and Atlantic salmon: critical limits for Norwegian rivers. 111, Norwegian Institute for Water Research, Oslo.

Mylona, S. 1996. Sulphur dioxide emissions in Europe 1880-1991 and their effect on sulphur concentrations and depositions. Tellus **48B**:662-689.

Schöpp, W., M. Posch, S. Mylona, and M. Johansson. 2003. Long-term development of acid deposition (1880-2030) in sensitive freshwater regions in Europe. Hydrology and Earth System Sciences **7**:436-446.

Skjelkvåle, B. L., A. Henriksen, B. Faafeng, E. Fjeld, T. S. Traaen, L. Lien, E. Lydersen, and A. K. Buan. 1996. Regional innsjøundersøkelse 1995. En vannkjemisk undersøkelse av 1500 norske innsjøer. 677/96, Statens forurensningstilsyn, Oslo, Norway.

Skjelkvåle, B. L., R. F. Wright, and T. Tjomsland. 1997. Vannkjemi, forsuringsstatus og tålegrenser i nasjonalparker; Femundsmarka og Rondane. 88, NIVA, Oslo.

Slootweg, J., M. Posch, and J.-P. Hettelingh. 2007. Critical Loads of Nitrogen and Dynamic Modelling. CCE Progress Report 2007. MNP Report 500090001/2007, Coordination Centre for Effects, Bilthoven, Netherlands.

UBA. 2004. Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads and Levels and Air Pollution Effects, Risks and Trends. 52/04, Umwelt Bundes Amt, Berlin.

Wright, R. F., C. Beier, and B. J. Cosby. 1998. Effects of nitrogen deposition and climate change on nitrogen runoff at Norwegian boreal forest catchments: The MERLIN model applied to Risdalsheia (RAIN and CLIMEX projects). Hydrology and Earth System Sciences **2**:399-414.

Wright, R. F., T. Larssen, L. Camarero, B. J. Cosby, R. C. Ferrier, R. C. Helliwell, M. Forsius, A. Jenkins, J. Kopácek, V. Majer, F. Moldan, M. Posch, M. Rogora, and W. Schöpp. 2005. Recovery of acidified European surface waters. Environmental Science & Technology **39**:64A-72A.

Wright, R. F., J. Mulder, and J. M. Esser. 1999. Soils in mountain and upland regions of southwestern Norway: nitrogen leaching and critical loads. 103, Norwegian Institute for Water Research, Oslo.

Wright, R. F., A. O. Stuanes, J. O. Reuss, and M. B. Flaten. 1990. Critical Loads for Soils in Norway. Preliminary Assessment based on Data from 9 Calibrated Catchments. 11, Norwegian Institute for Water Research, Oslo.

Wright, R. F., and T. S. Traaen. 1992. Dalelva, Finnmark, northernmost Norway: prediction of future acidification using the MAGIC model. 2728, Norwegian Institute for Water Research, Oslo.

Appendix D. Norway national report to CCE 2008

National Focal Centre

Thorjørn Larssen
Norwegian Institute for Water Research (NIVA)
Gaustadallén 21
0349 Oslo
Norway
tel: +47 22185100
fax: +47 22185200
email: thorjorn.larssen@niva.no

Collaborating institutions

IVL Swedish Environmental Institute
P.O.Box 5302
SE-40014 Gothenburg
Sweden

Norwegian Institute for Nature Research (NINA)
Tungasletta 2
7485 Trondheim
Norway

Norwegian Institute for Air Research (NILU)
P.O. Box 100
2007 Kjeller
Norway

Bernard J. Cosby
Department of Environmental Sciences
University of Virginia
Charlottesville, VA 22932-4123
USA

Dynamic modelling

Modelling of aquatic ecosystems (lakes) have been carried out for the entire country using the MAGIC model (Cosby et al. 1985, Cosby et al. 2001). The model was calibrated to observational data from 990 of the 1007 statistically selected lakes in the 1995 National lake survey (Skjelkvåle et al. 1996). (17 lakes of the total 1007 lakes in the survey were disregarded due to very high phosphorus concentrations (and ANC) from local pollution, extremely high sea salt concentrations or inconsistencies in the catchment characteristics data available.) The model was calibrated to observed water chemistry for each of the lakes and to soil base saturation from nearest available (or most relevant) sample. In the automatic calibration routine of MAGIC the following switches were set: BC optimizer (weathering calibration): on, SO4 adsorption optimizer: off, soil pH optimizer: on, N dynamics optimizer: off (this means that nitrogen uptake in the catchment was assumed proportional (with a constant proportion) to the input at all times).

Atmospheric deposition history was provided by CCE for EMEP grid cells and a sequence for each grid cell assigned to the lakes with each cell. After calibration, all 14 scenarios were run for all 990 lakes. In order to get a reasonable coverage within each EMEP grid cell, the calibrated lakes were then used to assign scenarios to all grid cells (1/4*1/8 degree) in the Norwegian critical loads database (2304 cells) using a matching routine called "MAGIC library" (IVL 2007) (see also country report for Sweden). The 2304 grid cells were matched to the 990 lakes to which the model was calibrated according to a Eucledian distance routine based on water chemistry and location. Each of the 2304 grid cells was thus assigned a MAGIC modelled lake. The Norwegian grid cells were only matched to Norwegian lakes (unlike in the 2007 submission, where they might also have been matched to Swedish lakes. Input data ranges and data sources are described in the table.

Ranges of model inputs and parameters (for the 990 calibrated lakes) and comments on their sources and justifications are listed in the table.

Var	Unit	Min	Max	Assumptions, data sources and justifications
EcoArea	km^2	2.7	204.6	We consider 100% of the land area to contain watersheds for lakes and rivers. The reported values are based on grid cells (see text) reported for each grid cell. This has not been split on different EMEP grid cells in cases were our small grid cells are split between two EMEP grid cells.
CLmaxS	eq ha^{-1} a^{-1}	56.7	20404	Calculated with FAB model (according to Mapping Manual, except BC^*_0 taken from MAGIC calibrations (1860))
CLminN	eq ha^{-1} a^{-1}	32.0	504	
CLmaxN	eq ha^{-1} a^{-1}	122	24873	
CLnutN	mgN m^{-2} a^{-1}	500	2000	Empirical values taken as minimum of range suggested in mapping manual
crittype		5	5	ANC is used as criterion for all lakes
critvalue	µeq L^{-1}	1.3	50	Variable ANC_{limit}
SoilYear		1985	2000	
ExCa	%	3.0	69.4	Lake catchment split into 4 categories: i) Forest area, taken from nearest relevant soil sampling locations (National Forest Inventory) for the percent forest in the lake catchment. ii) Peat area, taken from Langtjern soil pits no. 2 and 3 (1991 and 2000 average). iii) Non-forested upland, assigned county-wise, according to available data. iv) Open water, including lake itself. See details in text below.
ExMg	%	0.7	26.8	
ExNa	%	0.3	13.7	
ExK	%	0.7	11.0	
thick	m	0.11	1.3	
BulkDens	g cm^{-3}	0.19	1.18	
CEC	meq kg^{-1}	8.4	533	
Porosity	%	50	50	Assumption. Constant value used for all sites.
UptCa	meq m^{-2} a^{-1}	0.00	37.3	Based on National Forest Inventory. Same as in critical loads database: value for the 12x12 km^2 grid cell in which the lake was located.
UptMg	meq m^{-2} a^{-1}	0.00	7.0	
UptK	meq m^{-2} a^{-1}	0.00	8.1	
UptNa	meq m^{-2} a^{-1}	0.00	0.00	
UptSO4	meq m^{-2} a^{-1}	0.00	0.00	
HlfSat	µeq L^{-1}	0.00	0.00	Assumption. Constant value used for all sites.
Emx	meq kg^{-1}	0.00	0.00	Assumption. Constant value used for all sites.
Nitrif	%	100	100	Assumption based on the fact that ammonium concentrations are very low.
Denitrf	%	0.00	0.00	
DepYear		1995	1995	
Cldep	eq ha^{-1} a^{-1}	17.5	11502	Deposition flux of chloride, sat equal to catchment output flux
Cadep	eq ha^{-1} a^{-1}	0.7	432	Calculated from [Cl$^-$] using standard sea salt ratios and assuming no non-sea salt deposition.
Mgdep	eq ha^{-1} a^{-1}	3.4	2208	
Nadep	eq ha^{-1} a^{-1}	15	8257	

Var	Unit	Min	Max	Assumptions, data sources and justifications
Kdep	eq ha^{-1} a^{-1}	0.3	216	
NH4dep	eq ha^{-1} a^{-1}	4.8	530	Calculated from observed ratios in deposition to SO_4. NO_3 deposition was increased to make net flux always negative or 0 (1 case of the 60). SO4 deposition was calculated from runoff flux and background deposition from CCE scenarios adjusted for SO_4 weathering in cases were excess SO_4 output flux were >100 meq/m^2/yr (56 of the 990 lakes).
NO3dep	eq ha^{-1} a^{-1}	9.1	897	
LakeYear		1995	1995	1995 National lake survey.
Calake	µmol L^{-1}	2.0	1801	
Mglake	µmol L^{-1}	0.7	821	
Nalake	µmol L^{-1}	3.5	905	
Klake	µmol L^{-1}	0.5	81.8	
NH4lake	µmol L^{-1}	0.0	11.6	
SO4lake	µmol L^{-1}	4.2	583	
Cllake	µmol L^{-1}	5.6	832	
NO3lake	µmol L^{-1}	0.07	97.1	
DOC	µmol L^{-1}	8.3	1208	
RelArea	%	0.24	78.1	Data for each catchment
RelForArea	%	0.0	95.7	Data for each catchment
RetTime	yr	0.5	20	Assumption. 3 classes, by lake size.
Qs	m	0.16	5.2	Runoff taken from digital 30-year normal (1961-1990) runoff database.
expAllake		3.00	3.00	Assumption. Constant value used for all sites.
pCO2	%	0.06	0.06	Assumption. Constant value used for all sites.
Cased	m a^{-1}	0.00	0.00	Assumption. Constant value used for all sites.
Mgsed	m a^{-1}	0.00	0.00	
Nased	m a^{-1}	0.00	0.00	
Ksed	m a^{-1}	0.00	0.00	
SO4sed	m a^{-1}	0.00	0.00	
Clsed	m a^{-1}	0.00	0.00	
NH4sed	m a^{-1}	0.00	0.00	
NO3sed	m a^{-1}	0.00	0.00	
UptNH4lake	%	0.00	0.00	Assumption. Constant value used for all sites.
UptNO3lake	%	0.00	0.00	Assumption. Constant value used for all sites.

Soil data calculations and assignments

Forest soil data available from the national forest inventory on a grid cell basis. Of the 990 lakes, 342 were located in a grid cell were forest data were available (and hence forest present). Additional 221 lakes had forest in their catchments; for these lakes soils data were taken from nearest neighbor with data. 427 of the lakes had no forest in the catchments.

Mountain/upland/heath soils: Assigned from data available from different research projects.
Data sources used:

- Vest-Adger and Rogaland: About 30 sites in heathlands sampled in 1998 by NIJOS using the same protocol as for the national surveys of forest soils. Grid based site selection. In addition one site (Stavsvatn) in Telemark. Reference: (Wright et al. 1999)
- Yndesdal, Hordaland/Sogn og fjordane. Catchment weighted average of data from about 8 soil samples collected in 2003. Reference: (Bjerknes et al. 2004)

- Dalelva, Finnmark. Soil data from national monitoring sampled in 1990 with original data in the SFT 1991 annual report. Aggregated data used here are from the MAGIC calibration to Dalelva. Reference: (Wright and Traaen 1992)
- Storgama, Vikedal, Gaular, Naustal, Sogndal, Risdalsheia. Soil data from national monitoring sampled in 1980s and with original data reported in SFTs annual reports. RAIN data from NIVA, in ARRR. Aggregated data used here are from the MAGIC calibrations. Reference: (Wright et al. 1990)
- Vosso, Hordaland. Catchment weighted averages from about 6 soil samples collected in 2000. Reference: (Kroglund et al. 2002)
- Hardangervidda. (Prikkaureprosjekt). Averages from 6 soil samples collected in 2000. Reference: (Fjellheim et al. 2002)
- Rondane. Data from Dahl 1982 (Dahl 1982), averaged for MAGIC calibration. Reference: (Skjelkvåle et al. 1997)

Assignment of data for the heathland/mountain area was done based on county (fylke) in which each lake was located.

- Finnmark: Dalelva
- Hordaland, Rogaland, Agder: "nearest neighbor"
- Østfold, Hedemark: Rondane
- Telemark, Vestfold, Akerhus: "nearest neighbor".
- Buskerud: Hardangervidda for northern sites, Stavsvatn for southern sites (nearest neighbor)
- Oppland: Rondane
- Møre og Romsdal: Naustdal
- Trøndelag, Nordland: Daleva

Peat soil data were taken as the Langtjern average peat soil for all locations. A depth of 50 cm was used.

The three types of soil for each site were area-weighted for each parameter.

Critical loads for surface waters

Calculations were carried out with the FAB model in accordance with the Mapping Manual.

Empirical critical loads for nutrient nitrogen

The empirical critical loads for nutrient nitrogen were updated using the harmonised land use map by SEI provided by the CCE and the lower limits of the critical load values given in the Mapping Manual (UBA 2004).

Map code category	EUNIS code	Critical limit (mg m^{-2} yr^{-1})
0	0	0
301	C1	500
302	C2	500
401	D1	500
501	E1	1000
502	E2	1000
503	E3	1000
504	E4	500
601	F1	500
602	F2	500

603	F3	500
604	F4	1000
701	G1	1000
703	G3	1000
704	G4	1000
804	H4	500
805	H5	500
901	I1	2000
1000	J	

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 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.

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) og Statens forurensningstilsyn (SFT).

Arbeidsgruppen har for tiden følgende sammensetning:

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

Henvendelse vedrørende programmet kan rettes til:

Direktoratet for naturforvaltning
7485 Trondheim
Tel: 73 58 05 00

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

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.

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-rapport 91.265.

21 Bølviken, B., R. Nilsen, J. Romundstad & O. Wolden. 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. & 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. 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 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 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) Oppdragsmelding 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., A. Henriksen & 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 empriske 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 bakgrunnskonsentrasjoner av metaller. Kan amosfæriske 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.S. Skjegstad, N. & Steinnes, E. 1997. Assessment of the applicability for pollution authorities ofthe concept “critical load” of long-range transported micrpollutants 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 acicvity 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. & A. Henriksen, 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. & A. Semb. 1998. Deposition in Norwegian Mountain areas. Norsk institutt for luftforskning (NILU) OR 66/97

99 Strand, L.T., Stuanes, A.O. & G. Abrahamsen. 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 Føyfjellshotell. 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: Dynaic modelling of Norwegina 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 compunds 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 Larssen, 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. 45 s.

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. 24 s.

Henvendelser vedrørende rapportene rettes til utførende institusjon

NIVA: Norges ledende kompetansesenter på vannmiljø

NIVA gir offentlig vannforvaltning, næringsliv og allmennheten grunnlag for god vannforvaltning gjennom oppdragsbasert forsknings-, utrednings- og utviklingsarbeid. NIVA kjennetegnes ved stor faglig bredde og godt kontaktnett til fagmiljøer i inn- og utland. Faglig tyngde, tverrfaglig arbeidsform og en helhetlig tilnærmingsmåte er vårt grunnlag for å være en god rådgiver for forvaltning og samfunnsliv.

NIVA
Norsk institutt for vannforskning

Gaustadalléen 21 • 0349 Oslo
Telefon: 02348 • Faks: 22 18 52 00
www.niva.no • post@niva.no