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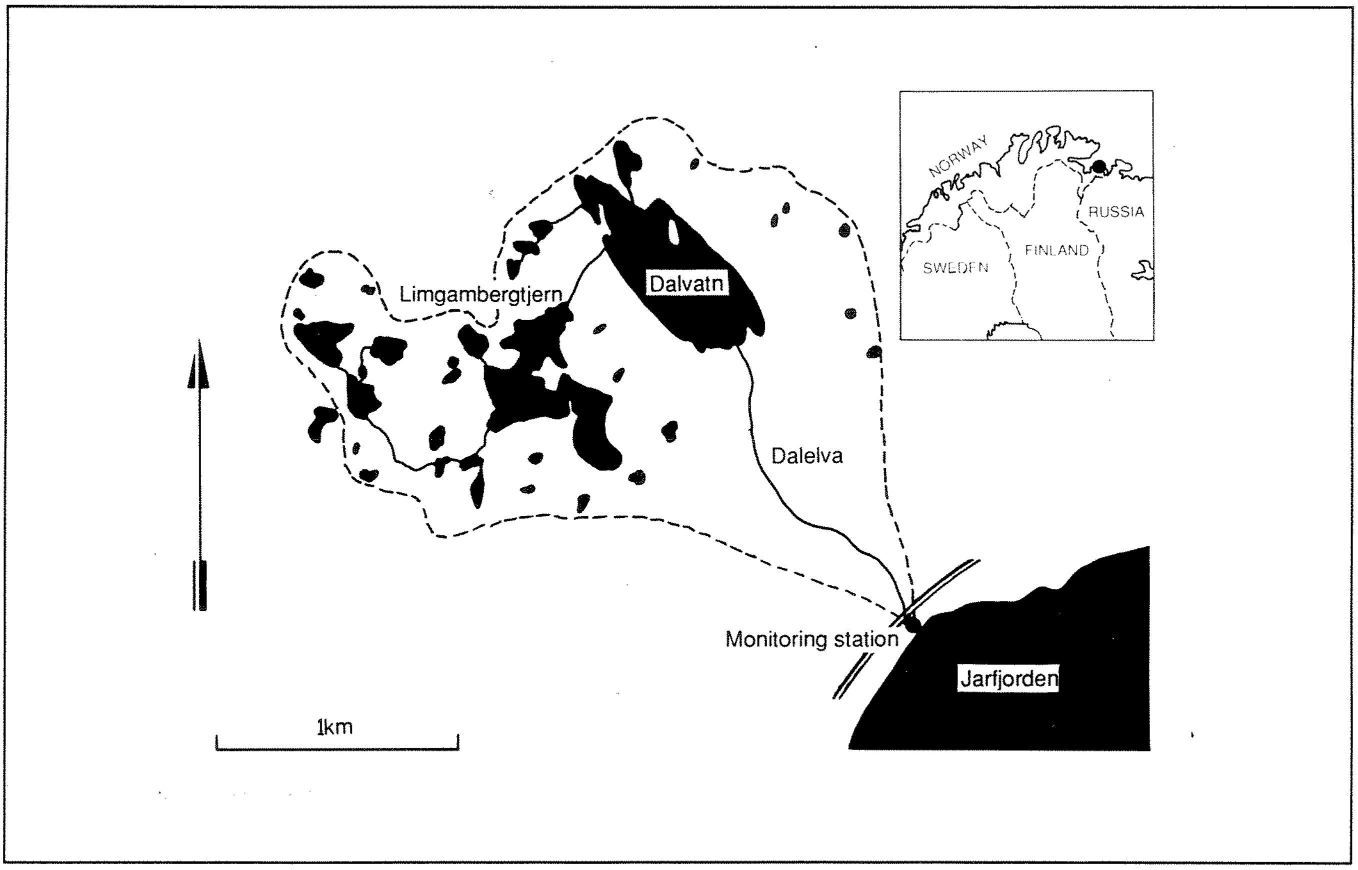

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NIVA - RAPPORT

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Dalelva er sterkt påvirket av sur nedbør grunnet utslipp av svoveldioksid fra nærliggende smelteverk i Nikel og Zapolyarnyy i Russland. MAGIC modellen er brukt til å forutsi forsurningsutviklingen i Dalelva ved 3 ulike scenarier. Ved fortsatt belastning på dagens nivå vil elva trolig bli kronisk sur i løpet av 50 år. Ved 95% reduksjon i svoveldeposisjonen vil vannkvaliteten i elva nærme seg før-industriell vannkvalitetet i løpet av 10-20 år.

4 emneord, norske:
1. Forsuring
2. Prediksjonsmodeller
3. Feltforskningsområde
4. Norsk-russiske grenseområde

4 emneord, engelske:
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Oslo, Mars 1992

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ARBEIDSGRUPPEN FOR VANN OG MILJØPROBLEMER
UNDER DEN NORSK-SOVJETISKE BLANDEDE KOMMISJON

Norsk institutt for vannforskning NIVA

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Norsk sammendrag

Innsjøer og elver i forsuringsfølsomme områder i Øst-Finnmark, spesielt Sør-Varanger, er påvirket av sur nedbør fra SO_2-utslipp fra smelteverkene i Nikel og Zapolyarnyy. Som en del av Statlig program for Forurensningsovervåking er det siden 1989 målt mengder og kvalitet av nedbør og avrenning i feltforskningsområdet Dalelva, et 3.2 km^2 nedbørfelt ved Jarfjorden i Sør-Varanger. Nedbørfeltet mottar en svoveldeposisjon på ca 63 meq/m^2/år SO_4 og elva har lav syrenøytraliserende evne. Flere små innsjøer i den øvre delen av nedbørfeltet er kronisk sure og gir ikke levelige forhold for fisk.

Vi har brukt MAGIC, en prosessorientert modell for forsuring av jord og vann, til å rekonstruere forsuringshistorien til Dalelva og til å forutsi fremtidig forsuring ved 3 ulike scenarier for fremtidig sulfatdeposisjon i området. Hvis dagens svoveldeposisjon fortsetter vil Dalelva bli kronisk sur i løpet av 50 år, med medfølgende skader på fisk og annet akvatisk liv. En gjennomføring av den planlagte utslippsreduksjonen på 95% vil imidlertid raskt kunne gjenopprette en vannkvalitet som vil være tilnærmet upåvirket av antropogen forsuring. Tålegrenser for svoveldeposisjon i Dalelva er 64 meq/m^2/år (vann, $ANC_{limit} = 0$ µekv/l), og 42 $mekv/m^2$/år (vann, $ANC_{limit} = 20$ µekv/l), og 104 $mekv/m^2$/år (jord, Ca/Al =1 mol/mol).

Abstract

Lakes and streams in acid-sensitive areas of northernmost Norway are affected by deposition of acid sulfur compounds derived from emissions of SO_2 from smelting activities in nearby Nikel, Russia. As part of the Norwegian environmental monitoring programme, precipitation and runoff quantity and chemical composition have been measured since 1989 at Dalelva, a 3.2 km^2 calibrated catchment. The site currently receives about 63 $meq/m^2/yr$ SO_4 and the stream is characterized by low acid neutralizing capacity. Several small lakes in the upper parts of the catchment are chronically acidic with damage to fish populations.

We use MAGIC, a process-oriented model for soil and water acidification, to reconstruct the acidification history at Dalelva, and to predict the future acidification under 3 scenarios of future sulfate deposition at the site. With no reduction in SO_4 deposition ("business as usual"), streamwater at Dalelva will become chronically acidic within 50 years, with expected damage to fish and other organisms. On the other hand, the proposed 95% emission control measures at the smelters will result in rapid recovery to pristine conditions. The critical load for sulfur at Dalelva calculated by means of MAGIC is 64 $meq/m^2/yr$ (water ANC=0), 42 $meq/m^2/yr$ (water ANC=20 μeq/l), and 104 $meq/m^2/yr$ (soil Ca/Al=1 mol/mol).

Preface

Dalelva Brook is heavily polluted by sulfur deposition derived from emissions of SO_2 *from smelters in nearby Nikel and Zapolyarnyy, Russia. This report presents predictions of future acidification in Dalelva Brook under 3 scenarios of future sulfate deposition at the site.*

The work is a part of The Norwegian Monitoring Programme for Long-Range Transported Air Pollutants, administered and financed by the Norwegian State Pollution Control Authority. The work is coordinated with the activities of the Working Group for Water and Environmental Problems and the Working Group for Air Pollution, both under the Norwegian-Russian Environmental Commission.

1. Introduction

The Varanger peninsula in northernmost Norway receives substantial deposition of acidic sulfur compounds along with heavy metals such as copper and nickel due to ore smelting activities in nearby Nikel, Russia (Figure 1). Emissions began in 1933 when the smelter was first brought into production in what was then Finland. Except for a few years in the early 1940's ore smelting and emissions of SO_2 generally increased until a peak of about 400 000 metric tons SO_2 in 1979 with subsequent decrease to 1990 levels of about 235 000 metric tons (Figure 2).

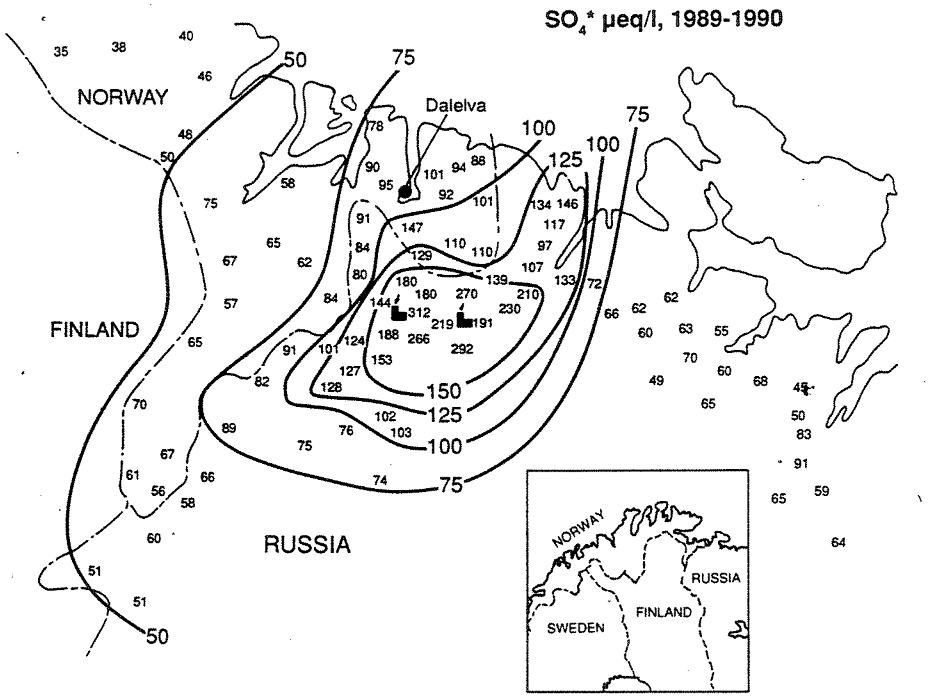

Figure 1. **Distribution of non-marine sulfate concentrations in lakes in the border areas of Norway, Russia and Finland (Traaen et al. 1991). Also shown are locations of smelters in Russia and the calibrated catchment Dalelva.**

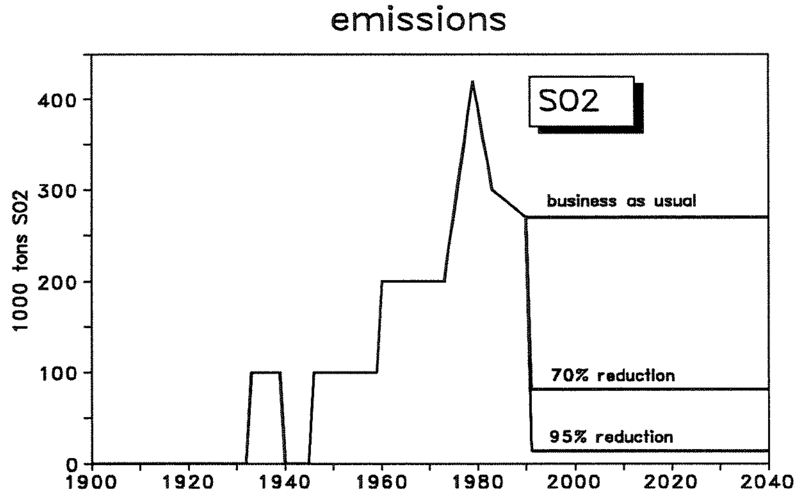

Figure 2. **Estimated historical emissions of SO_2 from smelters at Nikkel, Russia, and future emissions under 3 scenarios.**

Waters in the Varanger Peninsula have elevated concentrations of sulfate and a number of acid-sensitive lakes have been acidified as a result of the SO_2 pollution (Traaen et al. 1991). Concern over the environmental consequences of air pollution in the area led the Norwegian State Pollution Control Authority (SFT) to set up a calibrated catchment at Dalelva. Investigations began in July 1988 and include daily measurements of bulk precipitation (Norwegian Institute for Air Research NILU), continuous measurements of discharge (Norwegian Institute for Water Research NIVA), weekly sampling of the stream for chemical analysis (NIVA), and a survey of soil chemistry (Norwegian Forest Research Institute NISK). The data are reported in annual reports of the Norwegian State Pollution Control Authority (SFT 1989, 1990, 1991).

For several years environmental authorities in Norway, USSR (now Russia) and Finland have conducted negotiations aimed at reducing the emissions of air pollutants from the smelters in Russia. One possible conclusion of these negotiations is that extensive emission control equipment will be installed in the near future such that emissions are reduced by 95% relative to 1990 levels.

The past and future effects of SO_2 emissions on soil and water chemistry at Dalelva can be evaluated by means of acidification models. Here we calibrate MAGIC (Model for Acidification of Groundwater In Catchments) (Cosby et al. 1985a, 1985b) to the Dalelva calibrated catchment, and then use the calibrate model to predict the soil and water response to 3 possible future scenarios of SO_2 emissions.

2. Site description

The site at Dalelva is located near Jarfjord (Figures 1 and 3) at 69°41'N latitude and 30°23'E longitude. The weir and recording station is located at 10 m above sealevel with maximum elevation in the catchment 241 m. The catchment is 3.2 km^2 and lies on bedrock of mica- schist and micaceous gneiss covered by glacial sediments of similar lithology. Soils are podzolic, thin and patchy in the upper parts of the catchment. Vegetation is comprised of birch forest up to about 150 m elevation with lichen tundra and moorlands above. Several lakes lie in the catchment, including Limgambergtjern (0.14 km^2 with catchment of 1.2 km^2) and Dalvatn (0.24 km^2 with 2.2 km^2 catchment). Total lake area comprises about 15% of the catchment area at the weir. Mean annual specific runoff at Dalelva is estimated at 17 $l/s/km^2$ (equivalent to 540 mm/yr).

3. Data sources

Precipitation chemistry at Dalelva has been measured on weekly bulk samples by NILU beginning in mid-1988, but much of the data are suspect due to inconsistencies in the volume of precipitation collected as compared with nearby station run by the Norwegian Meteorological Institute. Estimated mean concentrations of major ions in precipitation at Dalelva given in SFT (1990) were used here (Table 1). Volume of precipitation was assumed to be 700 mm/yr, as obtained from the assumptions that runoff volume is 540 mm/yr, that the concentrations of Cl in runoff and precipitation are correct as reported in SFT (1990), and that all Cl in runoff originates from precipitation (ie. Cl flux in = Cl flux out).

Runoff chemistry at Dalelva is measured in weekly samples collected at the weir. Discharge is measured continuously by pressure transducer and data logger. Fluxes of major ions are calculated on a daily basis from concentrations times discharge with linear interpolation of concentrations for days between chemical samples. Flux calculations for 1989 and 1990 are given in SFT (1991a, 1991b). Here the reported annual discharge is only 189 mm, substantially lower than the long-term average specific runoff of 17 $l/s/km^2$ (540 mm/yr) given by the regional maps produced by the Norwegian Electricity and Water Resources Board

(NVE). Also meteorological stations in the vicinity of Jarfjord report precipitation volume in 1989 and 1990 in the range 500-600 mm/yr. Thus we assume that the mean concentrations reported by SFT (1991a, 1991b) are correct, but that the discharge is much too low. We assume that discharge is 540 mm and obtain fluxes by multiplying the annual concentrations by annual discharge (Table 1). We use only the 1989 data because of the lack of full precipitation data for 1990.

Soils in the lower part of Dalelva catchment were sampled by the Norwegian Forest Research Institute (NISK) in 1988 and analyzed for major components. The soils data have been collated by Reuss (1990) to give one set of chemical parameters characteristic for the entire catchment.

Historical trends in sulfur and acid deposition at Dalelva are derived from estimates in past emissions of SO_2 from the smelters at Nikel, 32 km to the southeast (Figure 3). Traaen et al. (1991) present estimates for the period 1973-1989. Emissions prior to 1973 are more uncertain. The plant started production in 1933 and was not operating for several years during World War II. We assume a modest annual emission of SO_2 during the 1930's and again from 1945-1960. A jump to 1973 levels in 1969 is assumed to be the result of plant expansion. The large increase in the 1970's is due to the smelting of sulfur-rich ores imported from Norilsk, Siberia.

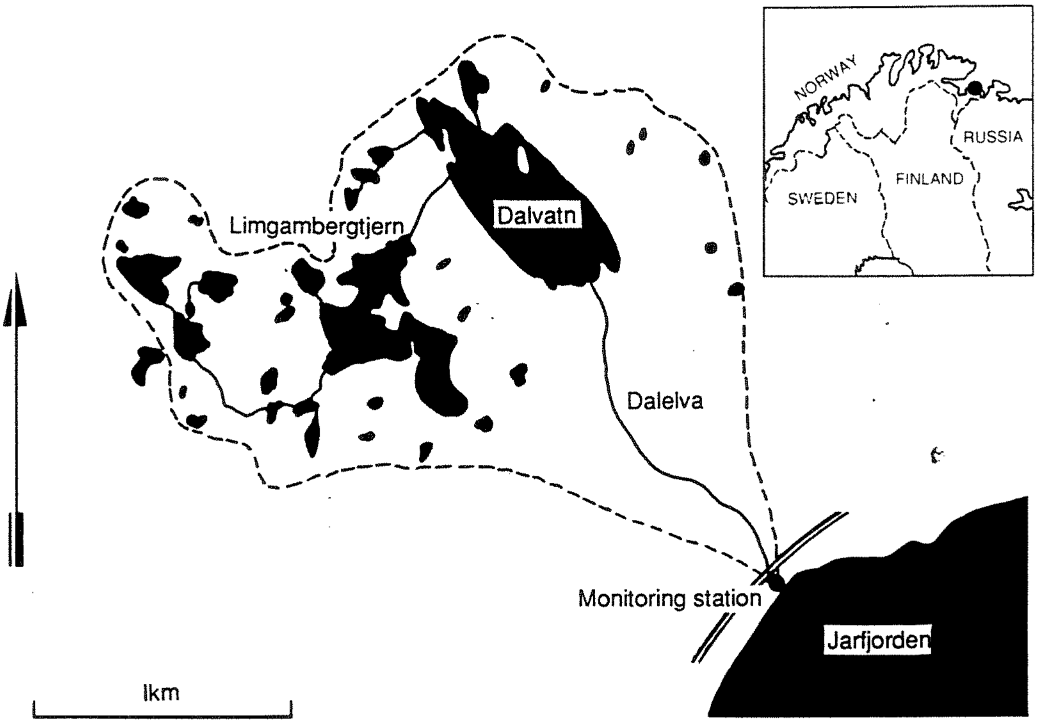

Figure 3. The calibrated catchment at Dalelva.

Table 1. Dalelva. Upper panel: input-output data used to calibrate the MAGIC model. Data from SFT (1991b) p. 315. Units: flux meq/m^2/yr, concentrations µeq/l, H_2O mm/yr. Total inputs are calculated from reported wet deposition values by first scaling by a factor such that Cl in = Cl out, and then adding dry deposition of SO_4 (and an equivalent amount of H^+) such that SO_4 in = SO_4 out. Lower panel: soils data used to calibrate the MAGIC model (from Reuss 1990).

Yr.	wet	Input flux Cl-corr	1989 meq/m2/yr dry	total	Output flux meas.	1989 meq/m2/y corr.	conc. ueq/l
H2O	348	769	0	769	188	540	540
H+	14	31	13	44	0	1	2
Na	30	66	0	66	27	78	144
K	0	0	0	0	1	3	5
Ca	5	11	0	11	14	40	74
Mg	8	18	0	18	14	40	74
Al					1	3	5
NH4	11	24	0	24	0	0	1
SO4	24	53	13	66	23	66	122
Cl	39	86	0	86	30	86	160
NO3	5	11	0	11	0	1	1
HCO3					4	11	21
SBC	54	120	0	120	56	161	298
SAA	68	150	13	163	53	153	283
ANC	-14	-30	-13	-44	3	8	15

Dalelva soil summary
Depths: A. Stuanes Means: J. Reuss Table 3 (density)
Table 4 (rest)

Horizon means	Depth cm	Density g/l	CEC mmol/kg	Ca %	Mg %	Na %	K %	BS %
O	4	312	391,3	39,4	20,1	1,2	7,1	67,8
E	2	1067	22,4	11,8	8,7	2,5	4,7	27,7
B	15	1063	37,5	12,8	4,2	1,8	2,0	20,8
C	25	1396	9,5	10,2	2,4	4,1	2,4	19,1
Total mean	46	1179	27	11,7	3,6	3,3	2,5	21,1

4. MAGIC model

MAGIC is an intermediate-complexity process-oriented model for constructing acidification history and predicting future acidification over time periods of decades to centuries (Cosby et al. 1985a, 1985b). MAGIC makes use of lumped parameters on a catchment scale and focusses on chemical changes in the soil caused by atmospheric deposition, vegetation, and leaching to runoff. The processes in MAGIC include atmospheric deposition, sulfate adsorption, cation exchange, CO_2 dissolution, precipitation and dissolution of aluminum, chemical weathering, uptake and release of cations by vegetation, and export in runoff.

MAGIC has been extensively used in a variety of applications at sites in both North America and Europe. Application of MAGIC to the whole-catchment experimental manipulations of the RAIN project shows that this intermediate-complexity lumped model predicts the response of water and soil acidification to large and rapid changes in acid deposition (Wright et al. 1990a). These results reinforce other evaluations of MAGIC such as comparison with paleolimnological reconstructions of lake acidification (Jenkins et al. 1990, Neal et al. 1988) and changes in regional lake chemistry in southern Norway (Wright et al. 1991). In addition several of the assumptions in MAGIC have been tested experimentally (Grieve 1989). MAGIC is one of several dynamic models included in the UN-ECE Handbook on Mapping Critical Loads (Sverdrup et al. 1989). MAGIC has been used to estimate critical loads for soils and waters at 9 calibrated catchments in Norway (Wright et al. 1990b). Together these applications indicate that MAGIC provides a robust tool for predicting future soil and water acidification following changes in acid deposition.

In the application to Dalelva we use an optimization procedure to calibrate MAGIC (Jenkins and Cosby 1989). We use soils data, precipitation data, streamwater data and estimated acid deposition history at each site together with the optimization routine to produce a calibrated model for each site. The optimization routine determines the set of initial saturation and weathering rates for each of the 4 base cations for the assumed pre-acidification condition in 1900. This set of initial values when run forward 140 years in time to the present (1990) produces the best fit to the present-day measured streamwater and soil chemistry. The calibrated model is then used to predict future soil and water acidification 0-50 years into the future given various deposition scenarios.

For future scenarios we have chosen "business as usual" in which deposition continues unabated at 1990 levels, "70% reduction" in which deposition is assumed to be reduced by 70% as a result of stopping import and smelting of high-sulfur ores from Siberia, and "95% reduction" in which deposition is assumed to decrease by 95% relative to 1990 levels as a result of SO_2 emission controls. We run these scenarios 50 years into the future to predict the soil and water chemistry characteristics in the year 2040.

5. Results

MAGIC indicates that sulfate concentrations in runoff at Dalelva have risen from about 25 µeq/l prior to operation of the smelters to a peak of about 150 µeq/l in the early 1980's and a modest decline to present-day levels of 120 µeq/l (Figure 4a). For the future sulfate levels are not expected to decline if deposition of sulfate does not change (the "business as usual scenario"), whereas under the 70% and 95% reduction scenarios, concentrations will decrease to about 50 and 20 µeq/l, respectively, within 10 years (Figure 4a).

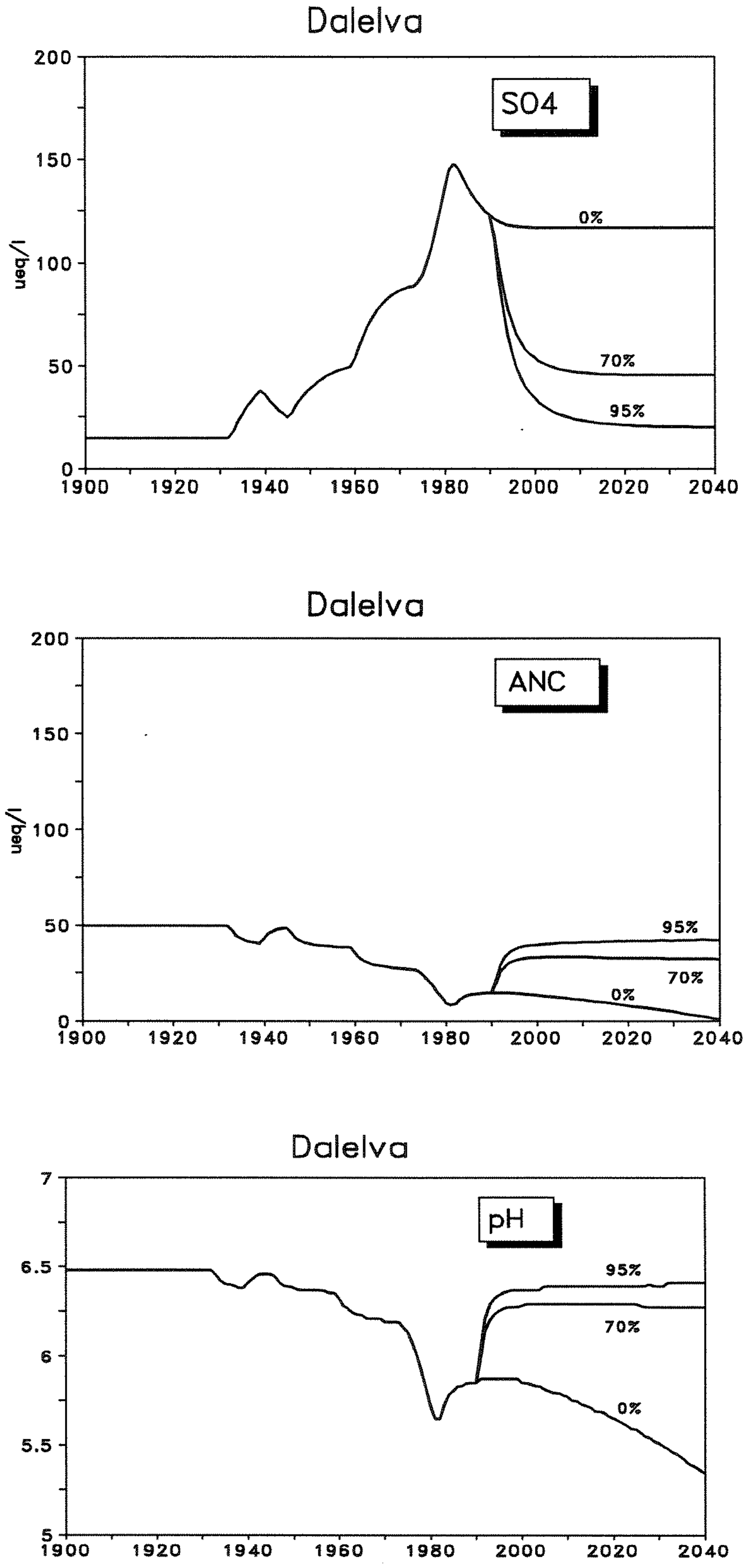

Figure 4. SO_4, ANC,and pH in streamwater at Dalelva as simulated by MAGIC for the past 90 years and predicted for 50 years into the future given 3 scenarios of deposition.

Acid neutralizing capacity (ANC, defined as difference in sum of base cations minus sum of strong acid anions) has apparently declined from about 45 µeq/l prior to onset of acid deposition to about 15 µeq/l in 1990 in response to the loading of acid sulfur from the atmosphere. ANC will continue to decline under the "business as usual" scenario to about 0 µeq/l in the year 2040. The 70% reduction scenario will result in rapid increase of ANC to about 30 µeq/l, and to about 40 µeq/l in the 95% reduction scenario (Figure 4b).

Similarly pH levels at Dalelva have declined over the past 60 years from pH 6.5 prior to acid deposition to about 5.7 in 1990. Again the modest decline in acid deposition during the past 10 years has resulted in a slight improvement in pH. For the future the "business and usual" scenario bodes ill for the stream with pH levels expected to decrease to about 5.4. With the 70% and 95% reduction scenarios, however, rapid and nearly complete recovery can be expected (Figure 4c).

MAGIC results also suggest substantial soil acidification during the past 60 years of acid deposition at Dalelva. Base saturation has apparently decreased from about 30% to present- day levels of 20%. Further decline is expected in the future under the "business as usual" scenario, whereas stabilization at present-day levels is the result of 70% and 95% reduction in deposition (Figure 5).

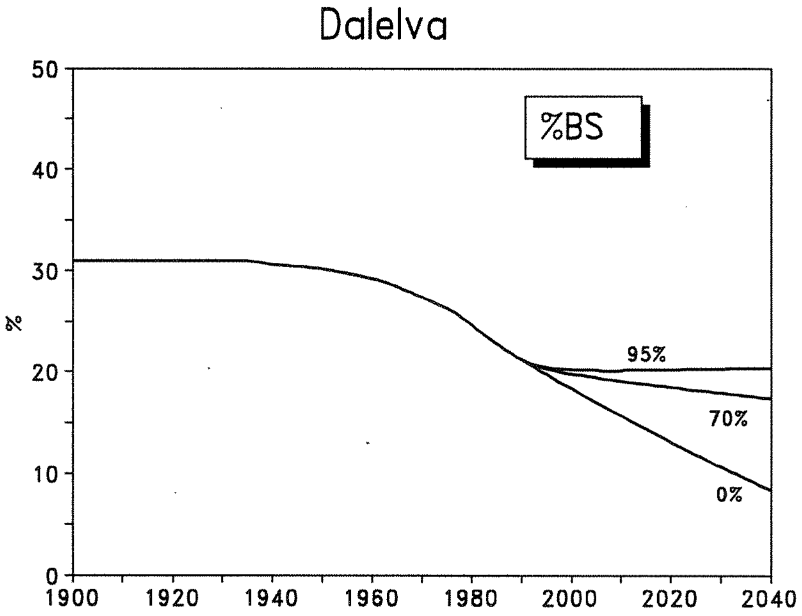

Figure 5. **Base saturation (%) in the soils at Dalelva as simulated by MAGIC for the past 90 years and predicted for 50 years into the future given 3 scenarios of deposition.**

Critical load for both soil and water for Dalelva can be calculated using this MAGIC calibration. For water ANC is the key parameter with the criteria of ANC = 0 or 20 µeq/l commonly used limits. For soil the molar ration of Ca/Al in soil solution is the key parameter with Ca/Al = 1 mol/mol the commonly used limit. Critical loads calculated from Dalelva by MAGIC indicate that for water the critical load is already met or exceeded, whereas by the soil criterion the system can tolerate additional loading (Table 2).
As for the soil critenion, it must be mentioned that peak SO_2-concentration in the air, rather than soil parameters might be the critical parameter for forest in this area.

Table 2. Critical load for sulfur at Dalelva calculated by means of the MAGIC model using criteria for water and soils such that the system is protected for 50 years into the future. Present-day loading is 63 meq/m^2/yr.

Criterion	Criterion value	Critical load
stream ANC	0 µeq/l	64 meq/m2/yr
stream ANC	20 µeq/l	42 meq/m2/yr
soil Ca/Al	1 mol/mol	104 meq/m2/yr

6. Discussion

The MAGIC application to Dalelva data indicates that the stream draining this catchment is acid sensitive and threatened by continued acid deposition. Under the "business as usual" scenario for the future, the annual mean chemistry of runoff can be expected to acidify further and reach critical levels for fish and other aquatic organisms. By the year 2040 mean ANC is predicted to reach nearly 0 µeq/l, the criterion for critical load for surface waters. Lakes in the headwater regions of the Dalelva catchment are already chronically acidic with ANC < 0, pH < 5, and damage to fish populations.

Major reductions in SO_2 emissions at the Nikel smelters and hence sulfate deposition at Dalelva will stop the ongoing water and soil acidification, and recovery in water quality is expected to be rapid. Under these scenarios no adverse effects to freshwater biota are expected.

The critical load for sulfur for Dalelva calculated by the MAGIC model is consistent with the values obtained for this grid square in the Norwegian map. Dalelva is one of the more sensitive sites within the grid square.

This application of MAGIC uses annual mean values for hydrology, precipitation chemistry and discharge. The seasonal patterns of discharge and water chemistry at Dalelva, however, show major variations over time with maximum discharge and maximum acidification during spring snowmelt. Measurements in 1989 and 1990 show that already with current acidification status at Dalelva, key water chemical parameters such as ANC, pH and labile Al reach near- toxic levels for brown trout during spring snowmelt (SFT 1991a, 1991b). A more rigorous application of MAGIC which takes into account the seasonal patterns is thus recommended. Such an application would require additional monthly data for precipitation, runoff and water chemistry.

The soils data from Dalelva are perhaps the weakest part of this application. The soil samples were collected only from the lower part of the catchment in the forest, and thus are probably not typical for the catchment as a whole, much of which lies above the treeline in tundra or moorland. Before a new application of MAGIC to Dalelva is carried out, the soils data should be substantially expanded to include a soils map and samples characteristic of the whole catchment.

7. References

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

Cosby, B.J., R.F. Wright, G.M. Hornberger, and J.N. Galloway. 1985b. Modelling the effects of acid deposition: estimation of long-term water quality responses in a small forested catchment. Water Resour. Res. 21: 1591-1603.

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

Jenkins, A., and B.J. Cosby. 1989. Modelling surface water acidification using one and two soil layers and simple flow routing. In J. Kamari, D.F. Brakke, A. Jenkins, S.A. Norton and R.F. Wright (eds): Regional Acidification Models. Berlin: Springer- Verlag, pp. 253-266.

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

Neal, C., P. Whitehead, and A. Jenkins. 1988. Reversal of acidification. Nature 334: 109-110.

Reuss, J.O. 1990. Critical loads for soils in Norway. Analyses of soils data from eight Norwegian catchments. Fagrapport 11b. Naturens tålegrenser, Norwegian Institute for Water Research, 78pp.

SFT 1989. Monitoring of long-range transported polluted air and precipitation. Annual report for 1988. Rapport 375/89, Norwegian State Pollution Control, Authority (SFT), Oslo, 274pp. (in Norwegian).

SFT 1991a. Monitoring of long-range transported polluted air and precipitation. Annual report for 1989. Rapport 437/91, Norwegian State Pollution Control, Authority (SFT), Oslo, 306pp. (in Norwegian).

SFT 1991b. Monitoring of long-range transported polluted air and precipitation. Annual report for 1990. Rapport 466/91, Norwegian State Pollution Control, Authority (SFT), Oslo, 320pp. (in Norwegian).

Sverdrup, H., I.W. deVries, and A. Henriksen. 1989. Mapping Critical Loads of Acid Deposition for Soils, Groundwater, Lakes and Streams. Workshop on Mapping Critical Loads, Bad Harzburg, FRG, United Nations Economic Commission for Europe and Nordic Council of Ministers.

Traaen, T.S., T. Moiseenko, V. Dauvalter, S. Rognerud, A. Henriksen & L. Kudravseva. 1991. Acidification of surface waters, nickel and copper in water and lake sediments in the Russian-Norwegian border areas. Working group for water and environmental problems under the Norwegian-Sovjet environmental protection commission. Oslo and Apatity, November,1991.

Wright, R.F., B.J. Cosby, G.M. Hornberger, and J.N. Galloway. 1986. Comparison of paleolimnological with MAGIC model reconstructions of water acidification. Water Air Soil Pollut. 30: 367-380.

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

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

Wright, R.F., A.O. Stuanes, J.O. Reuss, and M.B. Flaten. 1990b. Critical loads for soils in Norway. Preliminary assessment based on data from 9 calibrated catchments. Fagrapport 11. Naturens tålegrenser, Norwegian Institute for Water Research, 56pp.

8. Appendix

Table A1. Catchment and soil parameters used in application of MAGIC to the calibrated catchment at Dalelva, northernmost Norway. Data from SFT (1991a, 1991b).

Parameter	Units	Dalelva
catchment area	km2	3,2
precipitation	mm/yr	770
runoff	mm/yr	540
soil depth	m	0,46
porosity	%	50
bulk density	kg/m3	1179
CEC	meq/kg	27
SO4 ads. half-sat.	meq/m3	100
SO4 ads. max-capacity	meq/kg	1
solubility Al(OH)3	log	8,1
select. coeff. Al-Ca	log	3,5
select. coeff. Al-Mg	log	5,0
select. coeff. Al-Na	log	-0,2
select. coeff. Al-K	log	-4,0
total organics, solution	mmol/m3	60
organic pK1	-log	4,4
organic pK2	-log	8,0
CO2, soil air	atm	0,004
soil temperature	oC	1,0
CO2, streamwater	atm	0,0007
stream temperature	oC	2,0

Table A2. Results of MAGIC applications to the calibrated catchment at Dalelva.

Parameter	Units	Dalelva
Ca saturation, soil 1983/4	%	11,7
Mg saturation, soil 1983/4	%	3,6
Na saturation, soil 1983/4	%	3,3
K saturation, soil 1983/4	%	2,5
total base saturation 1983/	%	21,1
Ca saturation, soil 1844	%	15,8
Mg saturation, soil 1844	%	7,2
Na saturation, soil 1844	%	5,4
K saturation, soil 1844	%	2,7
total base saturation 1844	%	31,1
Ca weathering	meq/m2/yr	9,3
Mg weathering	meq/m2/yr	10,7
Na weathering	meq/m2/yr	7,8
K weathering	meq/m2/yr	0,9
total weathering	meq/m2/yr	28,7
Ca* deposition	meq/m2/yr	8,1
Mg* deposition	meq/m2/yr	3,3
Na* deposition	meq/m2/yr	0,0
K* deposition	meq/m2/yr	0,0
total BC* deposition	meq/m2/yr	11,4
BC* weathering + dep	meq/m2/yr	40,1
SO4* deposition	meq/m2/yr	55,0

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