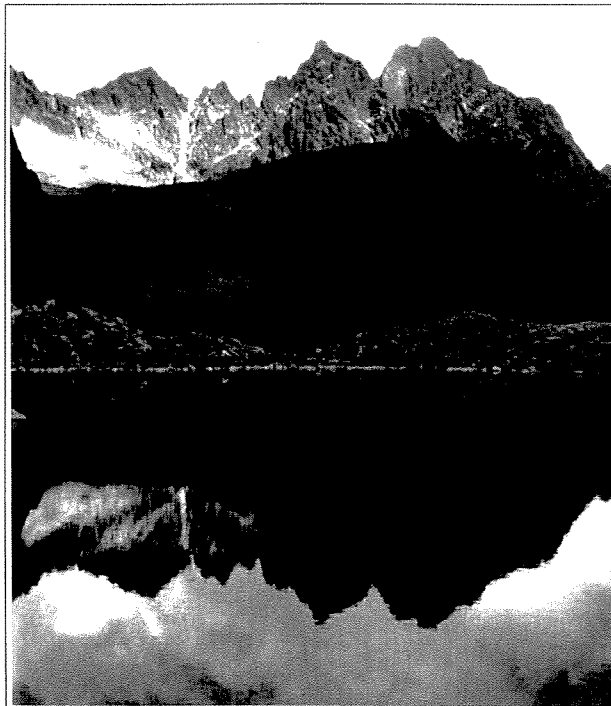


Acid Rain Research

REPORT 43/1996

Mapping
critical levels/loads for
the Slovak Republic

Final Report



NIVA 

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Norwegian Institute for Water Research



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Author(s): Dušan Závodský Gabriela Babiaková Marta Mitošinková Katarína Pukaněšková Peter Roněák Dušan Bodiš Stanislav Rapant Jozef Mind'áš Jaroslav Škvarenina	SHMÚ SHMÚ SHMÚ SHMÚ SHMÚ GÚDŠ GÚDŠ LVÚ LU	Boris Cambel Štefan Rehák Bente M. Wathne Arne Henriksen Harald Sverdrup Kjetil Tørseth Arne Semb Dan Aamlid Jan Mulder	VÚZH VÚZH NIVA NIVA Lund University NILU NILU NISK NISK	-Geographical area: Slovakia	Pages: 93	Edition:

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As a part of the Agreement on Environmental Co-operation between Norway and Slovakia a project "Mapping Critical Levels / Loads for Slovakia" was established. The final project results are presented. Critical loads for forest, surface and ground waters and their exceedances were calculated, using the steady-state mass balance model PROFILE for soils and the steady-state water chemistry (SSWC) method for waters. A grid distance of 10 km was applied. Because of decrease in sulphur deposition, the exceedances (5 percentiles) of critical load of acidity and critical sulphur deposition for forest soils were higher in 1990 (54 % resp. 40 % of grid cells) compared to 1995 (42 % resp. 23 % of cells). Practically no acidity exceedances for neither surface nor ground waters was found in 1995. Critical level of ozone for forest was exceeded over the whole Slovakia. The exceedance in the Tatra mountains was above 25,000 ppb.h.

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Project manager

Bente M. Wathne

For the Administration

Gunnar Aasgaard

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Mapping critical levels/loads for the Slovak Republic

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Authors:

Bente M. Wathne	-	NIVA	Dušan Závodský	-	SHMÚ
Arne Henriksen	-	NIVA	Gabriela Babiaková	-	SHMÚ
Harald Sverdrup	-	Lund University	Marta Mitošinková	-	SHMÚ
Kjetil Tørseth	-	NILU	Katarína Pukančíková	-	SHMÚ
Arne Semb	-	NILU	Peter Rončák	-	SHMÚ
Dan Aamlid	-	NISK	Dušan Bodiš	-	GÚDŠ
Jan Mulder	-	NISK	Stanislav Rapant	-	GÚDŠ
			Jozef Mindáš	-	LVÚ
			Jaroslav Škvarenina	-	LU
			Boris Cambel	-	VÚZH
			Štefan Rehák	-	VÚZH
			Jozef Čurlík	-	VÚPÚ

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MAPPING CRITICAL LEVELS/LOADS FOR THE SLOVAK REPUBLIC

Dušan Závodský¹
Gabriela Babiaková¹
Marta Mitošinková¹
Katarína Pukančíková¹
Peter Rončák¹
Dušan Bodiš²
Stanislav Rapant²
Jozef Mindáš³
Jaroslav Škvarenina⁴
Boris Cambel⁵
Štefan Rehák⁵
Jozef Čurlík⁶
Bente M. Wathne⁷
Arne Henriksen⁷
Harald Sverdrup⁸
Kjetil Tørseth⁹
Arne Semb⁹
Dan Aamlid¹⁰
Jan Mulder¹⁰

- ¹ SHMÚ - Slovak Hydrometeorological Institute, Jeséniova 17, 833 15 Bratislava, Slovakia
² GÚDŠ - Dionýz Štúr Institute of Geology, Mlynská dolina 1, 817 04 Bratislava, Slovakia
³ LVÚ - Forest Research Institute, T.G. Masaryka 22, 960 92 Zvolen, Slovakia
⁴ LU - Forest University, Zvolen, Slovakia
⁵ VÚZH - Research Institute for Irrigation, Ľubovnianska 3, 851 07 Bratislava, Slovakia
⁶ VÚPU - Soil Fertility Research Institute, Gagarinova 10, 827 13 Bratislava, Slovakia
⁷ NIVA - Norwegian Institute for Water Research, Brekkevn. 19, P.O.B. 173 Kjelsas, N-0411 Oslo, Norway
⁸ Lund University, Dept. of Chemical Engineering II, P.O.B. 124, S-22100 Lund, Sweden
⁹ NILU - Norwegian Institute for Air Research, Instituttvn. 18, P.O.B. 100, N-2007 Kjeller, Norway
¹⁰ NISK - Norwegian Institute for Forest Research, Hf̄gskolevn. 12, N-1432 As, Norway

TABLE OF CONTENTS

	Page
PREFACE	7
SUMMARY	11
1. INTRODUCTION	12
2. DEFINITION	13
3. CALCULATION METHOD	14
3.1 Receptors mapped: Forest soils	14
3.2 Receptors mapped: Surface and ground water	15
3.3 Exceedances of critical levels of ozone	16
4. GRID SIZE	16
5. BASIC GEOGRAPHICAL DATA	17
6. THE WEST CARPHATIANS: OUTLINE OF THE GEOLOGICAL STRUCTURE ...	17
7. DATA SOURCES	22
8. RESULTS	25
REFERENCES	29
ANNEX 1 Geographical map of Slovakia; Grid cells (10x10 km) numbering	
ANNEX 2 Precipitation and runoff in the territory of Slovakia	
ANNEX 3 Critical loads of acidity for forest soils - input data for calculations	
ANNEX 4 Critical loads of acidity for surface and ground waters - input data for calculations	
ANNEX 5 Critical loads/levels maps	
ANNEX 6 Warfinge, P. - Sverdrup, H.: Calculation of CL/CD with PROFILE model	

PREFACE

As a part of the Agreement on Environmental Co-operation between Norway and Slovakia, a project "Mapping Critical Levels/Loads for the Slovak Republic" was established in 1994, with participants from the Norwegian Institute for Water Research and the Slovak Hydrometeorological Institute, with contributions from the Lund University, Sweden, the Norwegian Institute for Air Research, the Norwegian Forest Research Institute, the Dionýz Štúr Institute of Geology in Bratislava, the Forest Research Institute in Zvolen, the Forest University in Zvolen and the Research Institute for Irrigation in Bratislava. Mrs. Bente M. Wathne from NIVA was nominated as the project manager. The Slovak team has been co-ordinated by Dušan Závodský from SHMI Bratislava.

Critical loads mapping is an activity resulting from the ECE UNO Convention on long-range transboundary transport of air pollutants. Slovakia was established as an independent country in 1993, and there were no previous experiences in this field. The Norwegian partners were asked to:

- provide assistance to start the Slovak mapping project
- provide calculation methods
- provide consultation and personal training for Slovak scientists
- harmonize the Norwegian and Slovak approaches

The project was planned for a period of two years.

Progress of project in 1994

The first direct contact between the partners was made during a Norwegian visit to Bratislava in June 1994. During this visit a detailed work plan for the project was prepared. This visit was followed by a Norwegian/Slovak Workshop in Oslo (October 5-7, 1994). The Workshop started with background scientific lectures presented by Norwegian experts. Appropriate software of the model PROFILE and the SSWC method, including personal training were provided to the Slovak partners. The practical calculations of critical loads and exceedances for forest soils, surface and ground waters on the basis of the Slovak input data were also included. The Workshop was very instructive. The Slovakian participants highly appreciated the efforts of the prominent Scandinavian experts.

The results from the first part on the co-operation and critical loads/exceedances mapping of the pilot area (approximately 20% of the Slovak territory) were presented as a NIVA report finalized in January 1995 (Acid Rain Research Report 37/1995, 74 pp.). In this report are also given a summary of the Oslo Workshop programme and summaries of the most central presentations for the practical work during the Workshop.

Norwegian lecturers and resource persons were the following:

Bente M. Wathne	Norwegian Institute for Water Research
Arne Henriksen	Norwegian Institute for Water Research
Bjørn O. Rosseland	Norwegian Institute for Water Research
Tor Johannessen	State Pollution Control Authority
Anton Eliassen	The Norwegian Meteorological Institute
Kjetil Tørseth	Norwegian Institute for Air Research
Arne Semb	Norwegian Institute for Air Research
Harald Sverdrup	University of Lund
Dan Aamlid	The Norwegian Forest Research Institute
Mette G. Thomsen	The Norwegian Forest Research Institute

Slovak experts and resource persons to the workshop were:

Dušan Závodský	- co-ordinator	Slovak Hydrometeorological Institute, Bratislava
Gabriela Babiaková	- run off data	Slovak Hydrometeorological Institute, Bratislava
Marta Mitošinková	- deposition data	Slovak Hydrometeorological Institute, Bratislava
Katarína Pukančíková	- data processing	Slovak Hydrometeorological Institute, Bratislava
Peter Rončák	- water quality data	Slovak Hydrometeorological Institute, Bratislava
Dušan Bodiš	- geological data	Dionýz Štúr Institute of Geology, Bratislava
Stanislav Rapant	- geological data	Dionýz Štúr Institute of Geology, Bratislava
Jozef Mind'áš	- biomas uptake	Forest Research Institute, Zvolen
Jaroslav Škvarenina	- forest pedology data	Forest University, Zvolen
Boris Cambel	- pedology data	Research Institute for Irrigation, Bratislava

Progress of project in 1995

The project continued in 1995 with further work and calculations at the national level in the Slovak institutions. However, the financial support for the project from the Slovak Ministry of Environment sources started, in reduced form, in the second half of 1995. It caused some delay in the progress of the project. During the last week of September a group of four Slovak scientists visited Norway for discussion of the project results.

The Slovak visitors were:

Gabiela Babiaková	Slovak Hydrometeorological Institute, Bratislava
Peter Rončák	Slovak Hydrometeorological Institute, Bratislava
Jozef Mind'áš	Forest Research Institute, Zvolen
Jaroslav Škvarenina	Forest University, Zvolen

The next phase of the co-operation started with a Scandinavian visit to Slovakia. Special consultations as well as two seminars in Bratislava and Zvolen were arranged.

The Scandinavian visitors were:

Bente M. Wathne	Norwegian Institute for Water Research
Arne Henriksen	Norwegian Institute for Water Research
Arne Semb	Norwegian Institute for Air Research
Harald Sverdrup	University of Lund
Jan Mulder	The Norwegian Forest Research Institute

Programme of the Seminars

B.M. Wathne:	Norway-Slovak status of the project. Critical loads in the Polish Tatra mountains.
A. Semb:	Mapping exposure and deposition in relation to critical loads in Norway.
A. Henriksen:	Mapping critical loads to surface waters in Norway.
J. Mulder:	Relationships between critical loads and forest growth parameters.
H. Sverdrup:	Mapping critical loads for forest in Scandinavia.
J. Čurlík:	Soil resistivity to acidification in Slovakia.
D. Závodský, G. Babiaková, D. Bodiš, B. Cambel, J. Mindáš, M. Mitošinková, K. Pukančíková, Š. Rehák, P. Rončák, J. Škvarenina:	Mapping critical loads of forest soils in Slovakia. Mapping critical loads of surface/underground waters in Slovakia.

The Seminar in Bratislava was more informative for governmental officers and specialists from miscellaneous branches. At the Seminar in Zvolen (Forestry faculty) specialists from related branches participated. To the Slovak team Jozef Čurlík, pedologist from Soil Fertility Research Institute in Bratislava, was invited.

During the Norwegian visit the possibility of new Norwegian/Slovak co-operative project "Impact of acid deposition on forest and aquatic ecosystems in Tatra Mountains Region" (Slovak proposal) was discussed. A high resolution dynamic model for this most sensitive part of Slovakia was recommended.

To the end of 1995 the whole input data set for critical loads/exceedances calculation and mapping of the Slovak Republic was completed (meteorological, deposition, vegetation uptake, geological, pedological and water quality data). Evaluation of runoff and weathering rate data was finished in February 1996. The final draft report was completed in April 1996.

Acknowledgements

The Slovak participants wish to gratefully acknowledge the support of the Norwegian Ministry of Environment and express their warm thanks to all Norwegian partners for their kind help. It is necessary to thank extra to the project manager Mrs. Bente M. Wathne and to Mr. Arne Henriksen and Mr. Harald Sverdrup who provided the Slovakian team with the SWs PROFILE and the SSWC method.

SUMMARY

There is a considerable interest in determining the effects of acidic deposition on various environments, e.g. surface water and forest soils. One of the important issues is to evaluate and set limits on the deposition of acidic compounds according to the effects on the ecosystem. The limits, or critical loads of acidity to an environment, is defined as "the highest deposition of acidifying compounds that will not cause changes leading to long-term harmful effects on ecosystem structure and function".

As a part of the Agreement on Environmental Co-operation between Norway and Slovakia a project "Mapping Critical Levels/Loads for Slovakia" was established. Critical loads for forest soils, surface and ground waters and their exceedances were calculated, using the steady-state mass balance model PROFILE for forest soils and the steady-state water chemistry (SSWC) method for surface and ground waters. Because the present regional level of sulphur dioxide and nitrogen oxides is below the critical levels, only exceedances of ozone critical level were evaluated. GIS ARC/INFO was applied (530 grid cells, approximately 10x10 km, interpolation of EMEP cells).

Slovakia is a mountainous country (the West Carpathians) with very complex geological structure. Forest ecosystems exist practically in all cells. Spruce, beech and oak are prevailing forest species.

Because sulphate deposition has decreased, the exceedances (5 percentiles) of critical loads of acidity and critical sulphur deposition for forest soils were higher in 1990 (54% resp. 40% of grid cells) than in 1995 (42% resp. 23% of cells). Critical loads of acidity for ground waters were found to be generally higher than those for surface waters with a correlation coefficient of 0.70. Practically no acidity exceedance for neither surface nor ground waters was found in 1995. The SSWC-method could not be applied to the Danube lowlands with runoff/precipitation share below 6% (Danube infiltration, large direct anthropogenic effects). The forest soil is clearly the most sensitive ecosystem. The critical loads reflect to a large extend the geological structure and soil composition in Slovakia.

Critical level of ozone for forest (AOT 40-10,000 ppb.h) was exceeded over the whole territory of Slovakia in 1995. The exceedances below 5,000 ppb.h were registered in Danube and East Slovakian lowlands, whereas in Tatra mountains they exceeded 25,000 ppb.h.

1. INTRODUCTION

There has been considerable scientific and political interest in determining the effects of acid deposition on various environments. Beyond the linkage of atmospheric deposition of strong acids to the effects on forests, lakes, crops, human health and materials, one of the important issues has been in evaluating and setting limits on the deposition of acidic compounds. These limits, or the critical loads of acids in the environment, are defined as "the highest deposition of acidifying compounds which will not cause changes leading to long-term harmful effects on ecosystem structure and function" (Nilsson and Grennfelt, 1988).

Criteria for "unacceptable change" are set relative to effects on terrestrial and aquatic organisms. Both sulphur and nitrogen contribute to the total input of acidifying compounds to an ecosystem. The ratio of sulphur to nitrogen can, therefore, vary without changing the critical load for acidifying compounds. The purpose of determining critical loads is to set goals for future deposition rates of acidifying compounds such that the environment is protected. Critical loads are determined separately for different receptors. Forest soils, ground and surface waters are considered as the most sensitive.

Under the auspices of the Convention on Long - Range Transboundary Air Pollution (the "Geneva Convention"), a "Task Force for Mapping the Critical Loads and the Areas where the Critical Loads are Exceeded" has been formed. A manual for calculating critical loads and their exceedances both for forest soils and for surface waters has been worked out (Sverdrup et al. 1990). Norway has mapped the critical loads of acidity and the exceedance for sulphur to surface water, and a project under the Nordic Council of Ministers has mapped critical loads and their exceedance for surface waters for the three Nordic countries Finland, Norway and Sweden (Henriksen et al. 1990).

The Slovak Republic was established at the beginning of 1993 after the disintegration of the Czechoslovak Federal Republic. Projects dealing with critical loads mapping was stagnant. For this reason as a part of the Agreement on Environmental Co-operation between Norway and Slovakia a project "Mapping Critical Levels/Loads for Slovakia" was launched in 1994, with participants from the Norwegian Institute for Water Research (NIVA), the Lund University in Sweden, the Slovak Hydrometeorological Institute, the Dionýz Štúr Institute of Geology in Bratislava, the Forest Research Institute in Zvolen, the Forest University in Zvolen and Research Institute for Irrigation in Bratislava. The Norwegian partners were asked:

- to provide assistance to start the Slovak mapping project
- to provide calculation method
- to provide consultation and personal training for Slovak scientists
- to harmonise the Norwegian and Slovak approaches.

The project was planned for two years. In this final report of the project the results of mapping critical loads for forest soils, surface and ground waters for the territory of Slovakia are presented. A map showing exceedances of critical level (AOT 40) for ozone in Slovakia has also been worked out.

2. DEFINITIONS

Critical loads for "unacceptable change" are set in relation to effects on terrestrial and aquatic organisms. Some useful definitions are given in the box.

DEFINITIONS	
<i>Critical load:</i>	The highest load that will not lead to long-term harmful effects on biological systems, such as forest decline or decline and disappearance of fish populations.
<i>Receptor:</i>	An ecosystem which may potentially be affected by atmospheric inputs of sulphur and nitrogen (soil, ground water, surface water).
<i>Biological indicator:</i>	Selected organism(s) or populations which are sensitive to chemical changes as a result of atmospheric inputs of sulphur and nitrogen (forest, fish, invertebrates).
<i>Critical chemical value:</i>	The value of a critical chemical component or combinations of components above or below no rise to a harmful response in a biological indicator is given (pH, ANC, Al/Ca ratio).

The critical load definition provides a framework for making numerical estimates of the loads at which adverse effects occurs. Such estimates may be based upon a number of different methods and the selection of method depends to a large extent upon the receptor chosen and the availability of relevant data for the calculations. The effects on sensitive biological indicators are used to identify harm to forest and freshwater systems. Organisms are often efficient "integrators" of the chemical conditions in their environment and may thus provide a convenient means of measuring effects. All the methods for calculating the critical loads for acidity of freshwater use chemical data, often making assumptions regarding the water chemistry to acidification. The critical chemical value is based on present knowledge of the ecological tolerance of sensitive biological species to water chemistry.

3. CALCULATION METHOD

3.1 RECEPTORS MAPPED: Forest soils

Critical loads of potential acidity, CL(A), for forest soils were calculated using the steady-state mass balance model (SSMB), implemented as the PC version of the PROFILE model (Sverdrup et al. 1990, 1994; Sverdrup and Warfwinge, 1992, 1995).

The input data needed for calculation:

- precipitation
- runoff
- sulphur deposition
- NO₃⁻ deposition
- NH₄⁺ deposition
- base cation deposition
- base cation uptake
- nitrogen uptake
- nitrogen immobilization
- temperature
- primary mineral composition
- thickness of organic layer
- thickness of E/A or second layer

Weathering rates were calculated using bedrock geology data (14 bedrock minerals were taken into account) and physical soil characteristic (Warfwinge and Sverdrup, 1992). CL(A) and exceedance of critical loads of acidity Ex(A) are direct outputs from PROFILE model (details can be found in ANNEX 6). The critical load values in this report are calculated as 5 percentile values from ecosystem cover on a 10x10 km grid.

Critical load of sulphur, CL(S), has been defined from the critical load of potential acidity by allocating a part of the allowable acidity deposition to the sulphur deposition:

$$CL(S) = S_f \cdot CL(A) \quad \text{where } S_f \text{ is sulphur fraction, defined as:}$$

$$S_f = \begin{cases} \frac{S_{\text{dep}}}{S_{\text{dep}} + N_{\text{dep}} - N_u - N_i} & \text{if } N_{\text{dep}} > N_u + N_i \\ 1 & \text{otherwise} \end{cases}$$

where S_{dep} = present sulphur deposition
 N_{dep} = present nitrogen deposition
 N_u = net uptake of nitrogen in the tree biomass
 N_i = net immobilization of nitrogen in the root zone.

Base cation deposition and uptake, BC_{dep} resp. BC_u, have been included in the calculation of the sulphur exceedance to allow a direct comparison with modelled deposition patterns. To distinguish this new value from CL(S) the term critical deposition of sulphur, CD(S), has been defined as:

$$CD(S) = S_f \cdot (CL(A) + BC_{\text{dep}} - BC_u)$$

The exceedance of critical deposition of sulphur is given by:

$$\text{Ex(S)} = S_{\text{dep}} - \text{CD(S)}$$

To compare the critical loads data with the Czech Republic the critical load map of actual acidity for Slovakia was calculated. The Czech approach was used (Posch et al., 1995).

$$\text{CL}_a(\text{A}) = \text{ANC}_w + 0.09 \cdot Q + 0.2 \cdot Q$$

where $\text{CL}_a(\text{A})$ = critical load of actual acidity
 ANC_w = alkalinity produced by weathering
 Q = runoff of water under root zone (ground water runoff according to the Czech approach was used, i.e. 75 percentile - 270th day from yearly runoff distribution curve).

3.2 RECEPTORS MAPPED: Surface and ground water

The basic steady-state surface water chemistry method (SSWC) is based on the assumption that the sulphate found in surface water originates largely from sea salt spray and polluted deposition, and the method gives ways of correcting for sea salt and a minor contribution from geological sources to obtain the atmospheric contribution of sulphate in the water (Henriksen et al., 1988, 1990). This sulphate concentration, together with base cation fluxes, are then used to calculate the integrated weathering rate for the lake catchment. The chemical data from the Slovak territory indicate that the geology in many areas supplies significant amounts of sulphate to the water. This sulphate is assumed to be balanced largely by base cations BC (Ca+Mg). Thus, to calculate the critical load, the method must be modified. The atmospheric contributed sulphate concentration in the surface and ground water is estimated by multiplying the sulphur concentration in deposition by the ratio of precipitation to runoff. The difference between this value and the sulphate concentration is then geologically supplied sulphate. Since this component is balanced by Ca+Mg, this amount must be deducted from the concentration of base cations to obtain those due to weathering and ion exchange processes. To estimate the ion exchanged base cations a modified F - factor has been used because of the very high weathering rate in the surface and ground water. Ignoring nitrate concentration the following calculation method results:

$$\text{SO}_{4\text{dep}} = S_{\text{dep}} \cdot P/Q/10 \quad \text{where} \quad \begin{array}{l} S_{\text{dep}} = \text{present sulphur deposition in } \text{keq} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1} \\ P = \text{yearly precipitation in m} \\ Q = \text{yearly runoff in m} \end{array}$$

$$\text{BC}_{\text{geol}} = \text{SO}_{4\text{r}} - \text{SO}_{4\text{dep}} \quad \text{where} \quad \begin{array}{l} \text{BC}_{\text{geol}} = \text{base cations of geological origin} \\ \text{SO}_{4\text{r}} = \text{sulphate concentration in runoff water} \end{array}$$

$$\text{BC}_{\text{wt}} = \text{BC}_t - \text{BC}_{\text{geol}} \quad \text{where} \quad \begin{array}{l} \text{BC}_{\text{wt}} = \text{present weathering rate} \\ \text{BC}_t = \text{present Ca+Mg concentration in runoff water} \end{array}$$

The F-factor is defined as the change in base cation concentration due to a change in the concentration of sulphate

$$F = BC_{wt} / S$$

where S = base cation concentration at which F=1. A value of 4 meq.l⁻¹ for S has been used in this report.

Then : $BC_w = BC_{wt} - F \cdot SO_{4dep}$

The critical loads of acidity (CL) and critical loads exceedance (CL-Ex) are then given:

$$CL = BC_w \cdot Q \cdot 10 \quad [\text{keq} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}]$$

$$CL - Ex = S_{dep} - CL \quad [\text{keq} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}]$$

The input data needed for the calculations:

- precipitation
- runoff
- sulphur deposition
- sulphate concentration in surface - and/or ground waters
- basic cation concentration in surface-and/or ground waters

3.3 Exeedances of critical levels of ozone

The spatial distribution of ozone critical level exceedances for forest areas were calculated (for grid cells with 10x10 km). Data from 17 surface ozone monitoring stations were used. The data from typical urban ozone monitoring stations were not taken into account. A special elevation-dependence function of accumulated exposure over threshold 40 ppb (AOT 40) during 6-month (from April to September, 24 hours a day) was evaluated. Based on this function and average elevation of cells the AOT 40 values were estimated. AOT 40 = 10,000 ppb.h is recommended as critical level for forest. The map of AOT 40 values is presented (ANNEX 5). To determine the exceedance in each cell the critical level (10,000 ppb.h) has to be subtracted.

4. GRID SIZE

Grid size for the construction of critical load maps for Slovakia corresponds to the EMEP grid. The EMEP grid cell 50x50 km was subdivided into 25 cells, it means that a grid distance of approximately 10 km was chosen. Grids are numbered using a Slovak system of numbering (see ANNEX 1). Calculations were made for about 530 grid cells. About 40% of the Slovak territory is covered by forest. Spruce, beech and oak are prevailing forest species in Slovakia. Forest ecosystems exist practically in all cells. For several cells totally without forest the data from surrounding squares were interpolated. The geographical information system ARC/INFO was applied.

5. BASIC GEOGRAPHICAL DATA

The Slovak Republic lies at the heart of Europe. It occupies the territory between the river Danube and the Tatra Mountains. The area of the country is 49,036 km², including agricultural land (50%), arable land (30%), forest land (41%), water area (2%), built-up areas (3%). Slovakia is a mountainous country. All Slovak mountains belong to the Carpathian system. The Danube and East-Slovakian lowlands are the northern parts of Pannonian plains. About 60% of the Slovak surface is above 300 m, 15% above 800 m and 1% above 1,500 m a.s.l. The lowest point in Slovakia is 94 m a.s.l. and the highest (the Gerlach peak in the High Tatras) is 2,654 m a.s.l. The territory belongs to the Danube river drainage basin, only a small part in the north drains into the Baltic Sea. The enclosed map (ANNEX 1) illustrates the basic geographical features of Slovakia.

6. THE WEST CARPATHIANS: OUTLINE OF THE GEOLOGICAL STRUCTURE

The West Carpathians as part the northern Alpine branch extend mostly on Slovak territory SE from the line Znojmo-Karvina, in Eastern Moravia. The West Carpathian area is characterized by large, elongated ridges and, in Slovakia, by depressions among the ridges. Extensive lowlands passing into the Pannonian Basin occupy the southern part. The geographical border to the West Carpathians is formed by the Danube river on the SW and the Uh river in the E. Their external border against the Bohemian Massif and the Podolian Platform runs along the erosive margin of mappes in the Flysch Belt. The southern border against the Pannonian Basin is not distinct.

Nappe structure composed of Paleozoic (perhaps even Precambrian) to Cenozoic rock complexes is the principal feature of the West Carpathians. Areal distribution of partial units and the time of their main folding inspired subdivision of the West Carpathians already since the last century. Several zones have been distinguished each with its particular history and specific structural pattern. The Inner Carpathians (named also the Central Carpathians) are on the south whereas the Outer or Flysch Carpathians occur on the north. Along the border of these both principal zones, there is a narrow belt of klippen (the Pieniny Klippen Belt) regarded as part of the Outer Carpathians.

The Inner Carpathians

Characteristic feature of the Inner Carpathians are plentiful pre-Upper Carboniferous crystalline schists and granitoids, Late Paleozoic sediments and volcanites, a mostly carbonatic Mesozoic complex, pre-Senonian (Mediterranean) age of the first nappe system, Alpine metamorphic and magmatic products and the numerous post-nappe sedimentary and volcanic formations.

The definition of the West Carpathian structure by Matějka - Andrusov (1931) modified later by D. Andrusov was close to the present conception.

Nappes of two main categories create the pre-Senonian structure. Nappes of first category consist of a pre-Upper Carboniferous basement overlain in turn by Late Paleozoic and Mesozoic sequences. This group of nappes represents the Tatric, Veporic and the "Gemic" units. The second category of nappes is represented by rootless nappes composed of Mesozoic, somewhere even of Late Paleozoic, sequences which have completely been detached from their original basement. The group comprises of the Fatric, Hronic units and the Mesozoic of the "Gemic".

The **Tatric** occurs in the outer part of the Inner Carpathians being exposed in "Core Mountain" ranges. This is a term for mountain ridges (Little Carpathians, Považský Inovec, Strážovské vrchy, Malá Fatra, Veľká Fatra, High and Low Tatra, and the Branisko Mts.) individualized due to Cenozoic structural elevations which exposed the crystalline basement in their cores. Such elevations occur mostly in the northern part of the Inner Carpathians.

The structure of the Tatric unit consists of crystalline schists (migmatite, gneiss, mica-schist, phyllite and amphibolite) which, in their pre-metamorphic state represented monotonous geosynclinal, pelitic to psammitic, sediments locally associating with basic volcanites. The last authors presumed Proterozoic age of sediments and their metamorphism ascribed, with the exception of Little Carpathians, to Assyntian orogenic events. However, quite in the Little Carpathians, where the crystalline sequences have various metamorphic degrees, not only the Harmónia Group (green-schist grade) but also the Pezinok-Pernek crystalline complex (amphibolite grade) is produced from sediments of Paleozoic age. Crystalline schists in the Tatric Unit are intruded by granitoids for which a Variscan age of intrusion is generally accepted judging from the Little Carpathians and the available radiometric dating.

There are two principal types of granitoids: the Ďumbier and Prašivá types, granitoids of the Ďumbier type correspond, by mineral composition (oligoclase, less orthoclase, biotite and quartz) and chemistry, to granodiorite and quartz diorite. Granitoids of the Prašivá type correspond to biotite granite and contain pink K-felspar (ortoclase) phenocrysts. In some ranges, the crystalline complexes are overlain by Permian terrestrial sediments. Mesozoic developments of the Tatric involve Lower Triassic to Cenomanian, reaching, in the High Tatra Mts., into the Lower Turonian. Local hiatuses characterize mainly the Upper Triassic and Lower Cretaceous portions, Mesozoic beds are mostly carbonatic, only the Lower and Upper Triassic parts are detrital. The entire sequence rests in stratigraphic position upon the crystalline creating its cover.

Also the **Veporic** unit comprises of crystalline complexes and their normal, Late Paleozoic to Mesozoic cover. The unit is confined by the Čertovica line in the north and by the Lubeník-Margecany line on the south. The crystalline is similar to that of the Tatric but it is more affected by Alpine metamorphism. At least part of the crystalline originated from Early Paleozoic sequences. Its normal cover is of Late Paleozoic to Mesozoic age being best preserved along the Lubeník-Margecany line, beneath the Muráň plateau and in northern subzones of the unit.

Carboniferous to Permian sequences are composed of conglomerate and sandstone-shale with rhyolite and rhyolite tuff. Mesozoic strata are better preserved in northern subzones where a Lower Triassic to Neocomian sequence resembles lithologies in the Fatric unit. But rudimen-

tarily preserved Mesozoic beds occur in southern subzones (only Triassic) where the entire cover sequence is metamorphosed.

The Veporic is thrust over the Tatric and their tectonic contact runs along the Čertovica line. The internal structure of the Veporic was recently characterized and, accordingly, granitoid and migmatite complexes rest upon crystalline schists mostly in subhorizontal, nappe position.

The **Gemic** unit occupies southern parts of the Inner Carpathians. The term was originally used for unit thought to be composed of slightly metamorphosed Early to Late Paleozoic complexes southernly from the Lubeník-Margecany line together with Mesozoic of the Slovak Karst Area, the Galmus Zone and of tectonic outliers named "Higher Subtratic Nappes". Recent investigations proved however that the Mesozoic in the Slovak Karst Area rests in tectonic position over its proper basement which is the Meliata Group.

Hence the relations between Paleozoic and Mesozoic developments of the Gemic domain remain hitherto problematic. In the category of basement nappes, the term Gemic could only mean Paleozoic sequences and the Meliata Group (which is partly of Mesozoic age) and then the Mesozoic developments in the Slovak Karst Area and the Galmus Zone should represent rootless nappes.

Early Paleozoic developments of the Gemic are represented by two sedimentary-volcanogenic sequences metamorphosed in green-schist grade. The lower, mostly flyschoid, sequence with acidic volcanites is of Cambrian to Silurian age. The second, mostly pelitic, sequence with basic volcanites is assumed to be of Devonian age. The discordance between both sequences was regarded as indicative of a Late Caledonian folding but this opinion is not generally accepted.

Paleozoic formations of the Gemic were folded and slightly metamorphosed already prior to the Middle Carboniferous time. In contrast to the Veporic and Tatric units, the folding in the Gemic unit was not widely associated with granitoid plutonism. Middle to Upper Carboniferous sediments rest already unconformably over the folded basement. Carboniferous strata are mostly in shallow water facies with local basic volcanites, Permian sediments occur mostly in the Verrucano facies with acidic volcanites.

The Meliata Group is composed of a sequence of schists and limestones. The Gemic unit is thrust over the Veporic one and their contact runs along the Lubeník-Margecany line.

The **Fatric** unit is represented by a group of rootless nappes resting over the Tatric. Nappes comprise Lower Triassic to Cenomanian sequences where Jurassic beds are frequently in shallow water facies in the Vysoká nappe whereas mostly deep-sea facies characterizes the Krížna nappe. Also Permian and crystalline elements do occur in the Krížna nappe (Staré Hory area). It is assumed that the sedimentation area of the unit was between the Tatric and Veporic units.

The **Hronic** unit represents a higher group of rootless nappes resting, especially in the area of Tatric, over the Fatric unit whereas the Veporic creates its underlier elsewhere. Nappes of the Hronic unit comprise sequences ranging in age from Carboniferous to Neocomian. Continental Permian sediments associate with basic volcanites. The Triassic of the Choč nappe is of

variegated marine facies or, in the Šturec nappe, a dolomitic one. It is assumed that the original sedimentation area was between the Gemeric and Veporic units.

Nappes composed of mostly Triassic lithologies and ranged formerly to the Gemeric are assumed to originate in the same sedimentation area as the Hronic unit.

The Middle Cretaceous tectogenesis of the Inner Carpathians resulted in total reduction of the crystalline basement which underfloored the sedimentation area of rootless nappes.

After the formation of the nappe system, this was partly ingressed by the Senonian sea. However, poorly preserved Senonian sediments prevent the reconstruction of basins. During the Paleogene time, the Inner Carpathians gradually became again a sedimentation area. Thick flysch sequences of the Central Carpathian Paleogene deposited in the northern part whereas the Buda Paleogene covered the southern part of the area. The Central Carpathian Paleogene and its basement were folded into megafolds during the Savian phase. This folding in the Inner Carpathians was followed by the development of late-tectonic and post-tectonic molasse basins associating with strong volcanic activity. Mostly marine and brackish sediments deposited also in the area of recent mountaneous relief of the Inner Carpathians in this Early Miocene time. During the Late Miocene and Pliocene, molasse basins developed over new structural strikes coincident with the recent orography. Basins are mostly filled by brackish and continental sediments.

The Neogene tectonic regime resulted in disintegration of the Inner Carpathians into block units. Tectonic movements of these blocks supported the ascent of magmatic masses along their contacts. Magmatites are represented by effusive series of rhyolite-andesite-basalt and by intrusive bodies of granite to granodiorite composition.

The Outer Carpathians

The **Pieniny Klippen Belt** represents the most intriguing tectonic zone of the Carpathians. The belt emerges from the basement of the Vienna Basin at Podbranč and continues in arc-like shape till into the East Carpathians. The belt is an extremely narrow structural element which broadens only to 20 km in central Váh river valley. The unit is characterized by the absence of pre-Mesozoic rocks, by small proportion of Triassic beds, by a variable Jurassic to Cretaceous development, by the tectonic style of "klippen" and by its position along the contact between the Inner and Outer Carpathians.

There is a widely accepted view that the complicated system of Jurassic and Lower Cretaceous klippen covered by marly and flysch sediments of Cretaceous to Paleogene age resulted from polyphase alpinotype deformation. According to this idea, the Pieniny Klippen Belt arised from a dissected geosynclinal area related to the southern Inner Carpathians. Before the Senonian, the history of this Pieniny Geosyncline was similar to that of the Inner Carpathian one. During the Albian time the former pelagic sedimentation was disturbed by the rise of Ultra-Pieniny Cordillera which became the source of flysch sediments during the Middle and Upper Cretaceous time. After the Senonian and during the Laramian phase of folding, the geosyncline has been transformed into a system of northvergent folds and nappes. This Pieniny Nappe System was further deformed by the end of Paleogene and during the Miocene. In its superficial parts,

the southward vergences in the Pieniny Klippen Belt are mostly due to Styrian processes. Paleogeographic data reveal that the Pieniny Geosyncline was fairly wide: up to 30-100 km. Nevertheless, a complete subduction of basement to Mesozoic sequences in the Pieniny Klippen Belt must be presumed.

The **Carpathian Flysch Belt** extends in arc-like form along the outer side of the West Carpathians. The basic feature of the belt is that pre-Mesozoic formations lack on the surface, the special terrigenous facies of its Cretaceous to Paleogene sediments, Cenozoic age of the nappe generation and infrequent post-nappe formations. The geosyncline of the Flysch Belt developed over the margin of the North European Platform creating part of the Vindelic continent in Triassic time. Onsetting with Jurassic time, NW-SE trending structural strikes strongly affected this sedimentation area, the distribution of facial zones and the thicknesses of sediments. Similar strikes affected also the Neogene development of the Bohemian Massif. From Paleogene time, also the Laramide nappe structure of the Pieniny Klippen Belt was incorporated into the history of the Flysch Geosyncline.

Reduction of the basement of Mesozoic sequences in the Flysch Geosyncline must inevitably be presumed if we want to explain the nappe structure of the Flysch Belt. This reduction is estimated to attain at least 100 km but it might be larger. The driving force of main tectonic phenomena in the Outer Carpathian area was the gradual approach of the foreland and hinterland associating with subduction of a large portion of the basement in the Magura Flysch and in the Pieniny Klippen Belt.

The folding in the Flysch Geosyncline commenced during Eocene and more intense movements proceeded in Magura sedimentation area (internal belt of the geosyncline). The main tectonic processes took place during the Savian phase. The pronounced reduction of the area resulted in detachment of Mesozoic and Paleogene sediments from their original basement and in their outward displacement creating a nappe system. During the Styrian phase of folding, at further approach of the hinterland to the foreland, the Savian nappe system has been transformed into a bilateral fold-nappe system the northern part of which (Subsilesian and Silesian nappes together with part of the Magura nappe) has been displaced toward the foreland whereas the inner parts were thrust to the hinterland. In accordance with this phenomenon, the axis of the Carpathian gravimetric minimum is assumed to represent the deep Badenian contact between the North European Platform and the Inner Carpathian block unit.

Units of the Flysch Belt are only represented by the Magura nappe group and the Dukla unit in Eastern Slovakia.

Foredeep

On former Czecho-Slovak territory, the foredeep occurs only in Moravia. Its Neogene sediments confine the Bohemian Massif from SE. The filling of the foredeep is tectonically limited from the side of the Bohemian Massif but it partly creates also the platform cover. On the south and southwest, it extends into the Alpine Molasse Zone in Austria. In reality, this is a system of foredeeps developing during Lower to Middle Miocene time in the front of folded Carpathians over which the Carpathian nappes are thrust (mainly during Karpatian and Badenian times).

The zone of the foredeep is ranged either to the Bohemian Massif or to the Carpathians. The Moravian part of the foredeep developed over a downfaulted block unit of the North European Platform between the Neogene "Horst-Like platform block" of the Bohemian Massif on one side and the Carpathians on the other. Since Mesozoic and Cenozoic sediments over this downfaulted block unit reveal peculiarities proper to the tectonic history of the platform cover, it is regarded this block unit to represent part of the North European Platform calling it the Block of the Moravian Foredeep.

7. DATA SOURCES

The following data sources have been used for the mapping purpose:

- Geological map of Slovakia
- Geochemical Atlas of Slovakia
- Data base of Dionýz Štúr Institute of Geology, Bratislava
- Soil map of Slovakia (Hraško et al., 1993)
- Map of soil resistivity to acidification in Slovakia (Čurlík, 1992)
- Slovak forestry inventory (Forest Research Institute, Zvolen)
- Data base of Slovak Hydrometeorological Institute (precipitation, temperature, runoff, atmospheric deposition and water quality data)

For the assessment of different input parameters to the mass balance equations the following approaches were used:

Base cation release by weathering

Due to lack of the soil mineralogy data the base cation weathering rates have been calculated on the basis of bedrock geology (14 bedrock minerals were taken into account) and soil geophysical characteristic, using PROFILE model (Warfvinge and Sverdrup, 1992). Considering the complex orography, and geology as well, of the Slovak territory the calculated data were slightly modified taking into account the map of soil resistivity to acidification in Slovakia (Čurlík, 1992).

Precipitation - Long-term (50-years averages) isohyetal lines map of Slovakia was taken (ANNEX 2).

Runoff - Long-term (50-years) average specific runoff lines map of Slovakia was used (ANNEX 2).

Temperature - Long-term (50-years) average temperature isolines map was applied (ANNEX 3).

Deposition data

To estimate the wet deposition of sulphate, nitrate, ammonium and base cations (concentration x grid cell precipitation amount) the data from Slovak regional air pollution monitoring stations, including 4 EMEP stations were used. Dry and occult deposition, including leaching effect of base cations from assimilation apparatus have been estimated from wet deposition using enrichment factor:

sulphate	factor = 2
nitrate and ammonium	factor = 1.5
base cation	factor = 1.3 (above 1300 m a.s.l. factor = 1.0)

The factor values respect the empirical results from some Slovak forest research stands and correspond to the results from Austria, Czech Republic, Germany and Scandinavian countries. (Škvarenina, 1993, 1994; Pačes, 1985; Moldan, 1987; Downing et al., 1993).

Nitrogen and base cation uptake in biomass

For calculation of biomass uptake the following sources of input data were used:

- forest tree species composition map
- data of wood volume according to the individual forest regions (forest inventory data)
- nitrogen and base cation content data of individual parts of tree species (Bublinec, 1992)

Biomass uptake data (nitrogen and base cations) were calculated according to the formula:

$$BC_u = \frac{\text{Wood volume} \times \text{BC content in wood} + \text{Bark volume} \times \text{BC content in bark}}{\text{Stand age}}$$

Mean value of wood volume has been estimated as weighted mean from individual tree species volume data and areas of individual tree species. Wood volume for individual tree species has been evaluated for each forest region and data from the largest forest region in the grid cell were used for calculation. Bark volume was obtained as 10% (coefficient 0.1) from wood volume.

Nitrogen immobilization in soils

Nitrogen immobilization has been estimated upon the basis of C/N ratio of soil types according to the German approach (Downing et al., 1993). Forest soil types have been divided into three categories:

Soil types	N _i [keq.ha ⁻¹ .yr ⁻¹]
1. Podzols, Dystric Cambisols and Stagnogleyic Cambisols	0.5
2. Rankers	1.0
3. Others	1.5

N_i values for each grid cell have been estimated as weighted mean of N_i values (see the above table) and areas of individual forest soil type category.

Thickness of organic layer, xH, thickness of E/A or second layer, xE, and granulity of soils particles, Z (% of particles < 0,01 mm)

According to percentage of soil sub-types in each cell. The data from following table have been used:

	Soil units - nomenclature according to the "Elements of the Legend for the Soil Map of Europe at Scale 1:1 000 000 (FAO Rome 1970) and "Key to Soil Units for the Soil Map of the World (FAO 1970)	xH m	xE m	Z %
H ₁	Eutric Cambisols to Dystric Cambisols, associated with Rankers and with Stagno-gleyic Cambisols	0.30	0.30	30
H ₂	Eutric Cambisols ass. with Rankers and with Stagno-gleyic Cambisols	0.30	0.30	30
H ₃	Eutric Cambisols, ass. with Calcaric Regosols	0.30	0.30	30
H ₄	Mollic Andosols, Andi=mollic Cambisols and Eutric Cambisols, ass. With Rankers	0.30	0.30	30
H ₅	Stagno-gleyic Cambisols and Gkeyic Phaezems, ass. with Mollic Gleysols local Eutric Histosols	0.30	0.30	30
H ₆	Stagno-gleyic Cambisols, ass. with Planosols, local Gleysols	0.30	0.30	30
H ₇	Dystric Cambisols, ass. with Rankers	0.30	0.30	30
H ₈	Dystric Cambisols, ass. with leached Rendzinas	0.30	0.30	30
H ₉	Humic Andosols, Ando-humic Cambisols and Dystric Cambisols, local Rankers	0.30	0.30	30
H ₁₀	Dystric Cambisols, ass. with Spodo-dystric Cambisols and with Rankers	0.30	0.30	30
H ₁₁	Stagno-gleyic Cambisols, local Dystric Planosols and Dystric Gleysols	0.30	0.30	30
D ₁	Eutric Regosols, ass. with eutric Cambic Arenosols	0.20	0	10
D ₂	Calcaric Regosols	0.20	0	10
D ₃	Dystric Regosols and dystric Cambic Arenosols, ass. with Lepto/ortic Podzols	0.20	0	10
C ₁	Calcaro/haplic Chernozems	0.50	0	35
C ₂	Haplic Chernozems	0.50	0	35
C ₃	Calcaro-haplic Chernozems and Calcaro-arenic Chernozems, ass. with Calcaric Regosols	0.50	0	35
C ₄	Luvi-haplic Chernozems and Luvi-gleyic Chernozems	0.50	0	35
C ₅	Calcaro-haplic Chernozems, sporadically Fluvi-calcaric Phaeozems	0.50	0	35
C ₆	Calcaro-haplic Chernozems, local Fluvi-calcaric Phaeozems to Calcaro-mollic Gleysols	0.50	0	35
C ₇	Calcaro-haplic Phaeozems, ass. with Fluvi-calcaric Phaeozems	0.50	0	35
I ₁	Albic Luvisols to Albo-gleyic Luvisols, ass. with Plano-gleyic Luvisols	0.20	0.20	30
I ₂	Albic Luvisols to Albo-gleyic Luvisols, ass. with Rendzinas	0.20	0.20	30
I ₃	Albic Luvisols, ass. with Eutric Cambisols, local Pararendzinas	0.20	0.20	30
I ₄	Albo-gleyic Luvisols, ass. with Plano-gleyic Luvisols, local Cambisols	0.20	0.20	30
R ₁	Rendzinas and Calcic Cambisols ass. with Calcaric Lithosols	0.20	0	15
R ₂	(Ortic and Lithic) Rendzinas and Chromic Rendzinas	0.20	0	15
R ₃	Leached Rendzinas and Calcic Cambisols, ass. with Calcaric Lithosols and Rock-debris Rendzinas	0.20	0	15
R ₄	Leached Humic and Tangel Rendzinas, ass. with Calcaric Lithosols	0.20	0	15
R ₅	Pararendzinas and Regosols, ass. with eroded Orthic Luvisols	0.20	0	15
R ₆	Pararendzinas, Regosols and Calcic Cambisols	0.20	0	15
P ₁	Ferro-Orthic Podzols, ass. with Lithosols and with Rankers	0.20	0.20	30
P ₂	Spodo dystric Cambisols, ass. with Rankers and with Lithosols	0.20	0.20	30
P ₃	Ferro-humic Podzols ass. with Histo-humic Podzols and with Rankers	0.20	0.20	30
N ₁	Eutric Fluvisols, ass. with Fluvi-eutric Gleysols	0.20	0	30
N ₂	Eutric Fluvisols, ass. with Fluvi-eutric Gleysols, sporadically Eutric Regosols	0.20	0	30
N ₃	Calcaric Fluvisols ass. with Fluvi-calcaric Gleysols	0.20	0	30
N ₄	Fluvi-eutric Gleysols and Verti-eutric Gleysols, ass. with other Gleys.	0.20	0	30
N ₅	Fluvi-eutric Gleysols, ass. with other Gleysols	0.20	0	30
N ₆	Verti-eutric Gleysols, ass. with other Gleysols, sporadically saline to sodic Fluvisols and Solonchaks to Solonetz	0.20	0	30
L ₁	Fluvi-gleyic Phaeozems, ass. with Fluvi-mollic Gleysols	0.50	0	30
L ₂	Arenic Fluvi-gleyic Phaeozems, ass. with arenic Fluvi-mollic Gleysols and with other Gleysols	0.50	0	30
L ₃	Fluvi-calcaric Phaeozems, ass. with calcaric Fluvi-haplic and Fluvi-vertic Phaeozems and with calcaric Fluvi-mollic Gleysols, local Eutric and Lepto-eutric Histosols	0.50	0	30
L ₄	Fluvi-mollic Gleysols, ass. with Fluvi-gleyic Phaeozems and with Eutric Gleysols	0.50	0	30
L ₅	Fluvi-calcaric Phaeozems and Fluvi-mollic Gleysols	0.50	0	30

9 ₁	Eutric to Dystric Planosols and Plano-gleyic Luvisols	0.20	0.30	50
9 ₂	Eutric Planosols and Plano-gleyic Luvisols ass. with overlapped Mollic Gleysols	0.20	0.30	50
9 ₃	Dystric Planosols and Stagno-gleyic Planosols, ass. with Histo-humic Planosols	0.20	0.30	50
r	Dystric Lithosols and Rankers	0.10	0	15
M ₁	Orthic Luvisols	0.20	0.20	30
M ₂	Orthic Luvisols and eroded Orthic Luvisols, ass. with Calcaric Regosols and Pararendzinas	0.20	0.20	30
M ₃	Ortho-chromic Luvisols and Albo-chromic Luvisols	0.20	0.20	30
M ₄	Ortho-albic Luvisols and Albic Luvisols	0.20	0.20	30
M ₅	Stagno-gleyic Luvisols, Plano-gleyic Luvisols and Planosols	0.20	0.20	30
T ₁	Eutric Histosols	0.60	0	35
T ₂	Dystric Histosols	0.60	0	35

Sulphate and base cation concentrations in surface and ground waters

The hydrochemical data base of Slovak Hydrometeorological Institute and Dionýz Štúr Institute of Geology in Bratislava have been used.

The input data for mapping of forest soils are summarized in ANNEX 3 and for surface and ground waters in ANNEX 4.

8. RESULTS

The results of critical loads and their exceedances calculation from Slovakia can be found in ANNEX 5, which contains the following maps:

Receptor - forest soils

- Critical loads of potential acidity (5 percentile)
- Critical loads of actual acidity (5 percentile) - using the Czech approach
- Exceedance of critical loads of potential acidity (5 percentile) - 1990 and 1995
- Critical loads of sulphur (5 percentile) - 1990 and 1995
- Critical deposition of sulphur (5 percentile) - 1990 and 1995
- Exceedance of critical sulphur deposition (5 percentile) - 1990 and 1995

Receptor - surface water

- Critical loads of acidity
- Exceedance of critical loads of acidity - 1995

Receptor - ground water

- Critical loads of acidity
- Exceedance of critical loads of acidity - 1995

Receptor - forest

- Ozone level (AOT 40) - 1995

Critical loads values are expressed in $\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$. The colour and scale were chosen to allow expression of the differences within the study area. The scale has been shifted to higher values compared to international presentation of critical loads.

The distributions of critical loads of potential acidity CL(A) (PROFILE model) and of actual acidity $\text{CL}_a(\text{A})$ (Czech Republic approach - the data were included only for information) are presented in the following table:

Range [$\text{keq}\cdot\text{ha}^{-1}\cdot\text{yr}^{-1}$]	CL(A) [% of grid cells]	$\text{CL}_a(\text{A})$ [% of grid cells]
< 0.5	4	-
0.5 - 1	7	2
1 - 2	25	17
2 - 4	39	49
> 4	25	32

The most sensitive parts of Slovakia according this model calculations are:

- Lowlands in the West Slovakia between the river Morava and the Little Carpathians
- The southern half of the Middle Slovakia
- The whole East Slovakia.

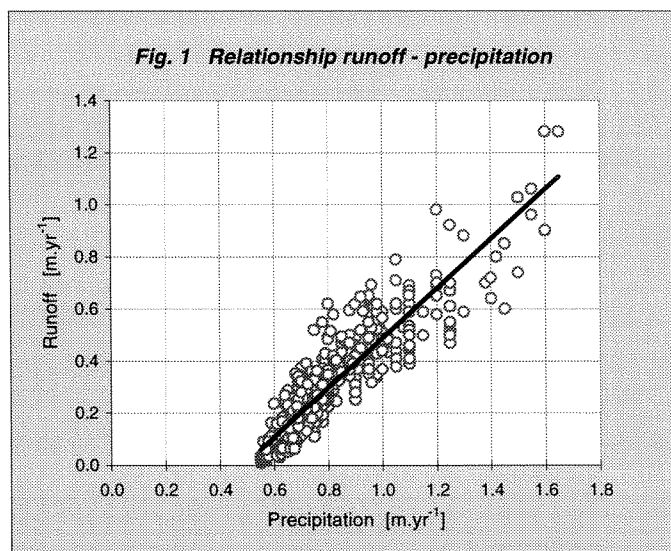
The basic features of the critical loads maps for forest soils correspond well with the map of soil resistivity to acidification (Čurlík, 1992) and with bedrock geology as well.

Except for sulphate the chemical composition of precipitation water exhibited no significant trends for all species at the Slovak regional monitoring stations in the last ten years (average values were taken in calculations). Sulphate is now continuously decreasing. In the period 1990-1995 the decrease was about 25%. Therefore, exceedances of critical loads of acidity and critical sulphur deposition for forest soils were more frequent in 1990 (54% resp. 40% of the grid cells) as in 1995 (42% resp. 23% of the grid cells).

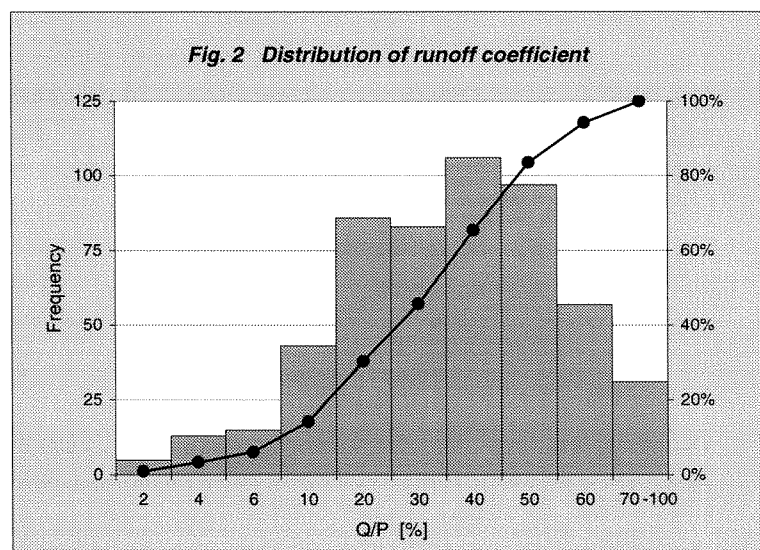
The calculated exceedance values for surface and ground water display high negative values in the greatest part of Slovakia, i.e. they indicate that there are reserves for further contributions of acid deposition. This situation is related to the time of water sampling in the studied territory, i.e. it does not record changes in the chemical composition in time and does not allow to make a prognose. The calculated critical loads reflect in practice the conditions in which chemical composition of water formed, especially geological setting of the territory and hydrodynamic conditions of circulation. The locally higher sensitivity has been caused by outflow from mine works and dispersion of groundwater from the underlier into surface streams.

It also became evident that in the region of High Tatra surface water is most sensitive receptor, and can practically not accept higher load. This is largely due to cristalline rocks character of the area, absence of soil layers in the top parts, as well as high surface runoff. In the case of low critical loads values in the southern part of Slovakia, especially the Danube lowland, calculation by the SSWC method is practically impossible. The basic idea of the model philosophy considers the mass balance between input (precipitation amount) and output (runoff height) for each grid cell in the whole network. The relationship runoff - precipitation illustrates the share

of runoff on precipitation (Fig. 1). In case of minimum values it is practically insignificant. The runoff coefficient distribution on whole territory of Slovakia is documented on Fig. 2. In dependence on morphology, height above sea level and other factors as well, there is increasing share of the runoff/precipitation and exceeds 60% of value in the high mountain regions.



On the contrary, in area of Danube lowlands, particularly in the ripariant zone of the Danube this share approaches to 2%, which is result of fact, that main ground water source supply is presented by the Danube surface water infiltration. Under these conditions, an application of SSWC to calculate the critical loads is not applicable, due to the fact that data on present deposition of sulphur, correction of basic cations for their geological origin as well as the subsequent procedure of calculation due to the mentioned fact is inadequate one. This situation is still more complicated because the concentrations of sulphates in runoffwater are misrepresented by the sulphate grants from the terrestrial contamination sources, the fact which is demonstrated by relatively high correlation



SO₄ - NO₃ (r = 0.65)
 (Ca + Mg) - SO₄ (r = 0.84)
 (Ca + Mg) - HCO₃ (r = 0.95)

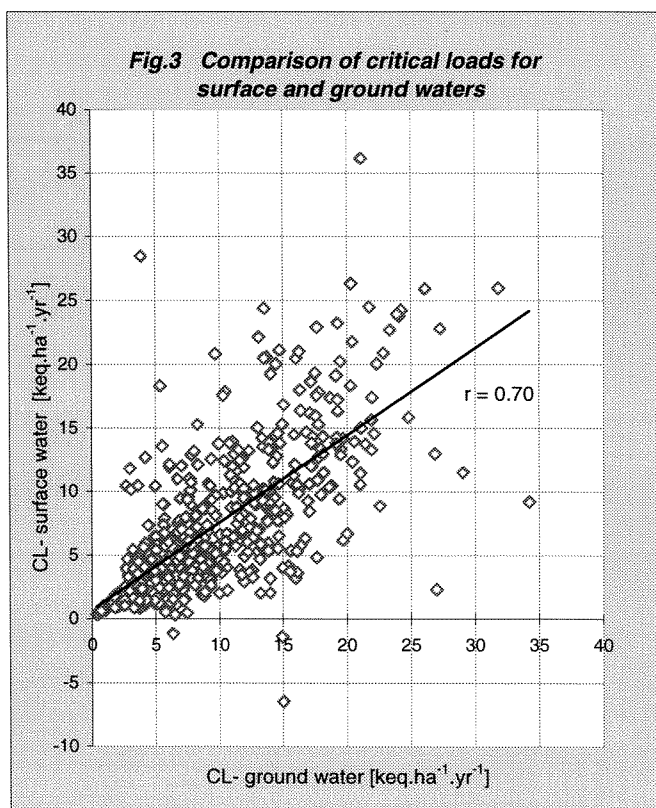
Similarly, an interpretation by the used model is impossible in region with runoff/precipitation share to 6%, i.e. region corresponding with the territory called the inland delta.

The critical loads of acidity values of surface water were generally lower than those for ground water with a correlation coefficient of 0.70 (Fig. 3). The calculated values show that ground water is less sensitive than the surface water and have a reserve for additional acid deposition.

Critical loads of acidity for waters in the whole territory of Slovakia is generally significantly higher than those for forest soils. The forest soil is clearly the most sensitive ecosystem in the area considered.

The average rural and suburban concentrations of sulphur dioxide and nitrogen oxides did not exceed the recommended critical levels at the whole territory of Slovakia in the period 1991-1995. Therefore exceedance maps for this pollutants were not elaborated.

Critical level of ozone for forest AOT 40 = 10,000 ppb.h (accumulated sum over a threshold of 40 ppb from April-September for the whole days - 24 hours) have been accepted. The AOT 40 map (ANNEX 5) documents exceedances of the ozone critical level over the whole territory of Slovakia in 1995. The exceedances below 5,000 ppb.h were registered in Danube and East-Slovakian lowlands, whereas in Tatra mountains they were above 25,000 ppb.h.



REFERENCES

- Bublinec, E.**, 1992, The content of biogenic elements in forest tree species. *Lesnícky časopis (Forestry Journal)* 38, 4, p. 365-375.
- Critical Loads of Acidity for High Precipitation Areas**, UBA-Reports 93-083, Vienna 1993, 16 pp.
- Čurlík, J.**, 1992, Map of soil resistivity to acidification in Slovakia. VÚPÚ Bratislava.
- Downing, R. J., Hettelingh, J. P. and de Smet P. A. M.**, 1993, Calculation and mapping of critical loads in Europe. Status Report 1993. RIVM Bilthoven, 163 pp.
- Henriksen, A., Lien, L., Traaen, T. S., Sevaldrud, I. S. and Brakke, D. F.**, 1988, Lake acidification in Norway - Present and predicted chemical status. *Ambio* 17, p. 259-266.
- Henriksen, A., Kämäri, J., Posch, M., Lövblad, G., Forsius, M. and Wilander, A.**, 1990, Critical loads to surface waters in Fennoscandia. Nordic Council of Ministers, Copenhagen 1990, 44 pp.
- Hettelingh, J. P., Downing, R. J. and de Smet, P. A. M.**, 1991, Mapping critical loads for Europe. CCE Technical Report No.1. Coordination Center for Effects, National Institute of Public Health and Environmental Protection, Bilthoven, 163 pp.
- Hraško, J. et al.**, Soil map of Slovakia, Bratislava 1993.
- Moldan, B. and Dvořáková, M.**, 1987, Atmospheric deposition into small drainage basin studied by geological survey. In: B. Moldan and T. Pačes (eds.), *GEOMON-International Workshop on Geochemistry and Monitoring in Representative Basins*, Geological Survey, Prague 1987, p.127-129.
- Nilsson, J. and Grennfelt, P.**, 1988, Critical loads for sulphur and nitrogen. *Miljörappport 1988*, No.15. Nordic Council of Ministers, Copenhagen.
- Pačes, T.**, 1985, Sources of acidification in Central Europe estimated from elemental budgets in small basins. *Nature* 315, 6014, p. 31-36.
- Posch, M. et al.**, 1993, Guidelines for the computation and mapping of critical loads and exceedances of sulphur and nitrogen in Europe. TF on Mapping UN ECE.
- Posch, M., de Smet, P. A. M., Hettelingh, J. P. and Downing, R. J.**, 1995, Calculation and mapping of critical thresholds in Europe. Status Report 1995. RIVM Bilthoven, 197 pp.
- Sverdrup, H., de Vries, W., and Henriksen, A.**, 1990, Mapping critical loads. Nordic Council of Ministers, Oslo, 125 pp.
- Sverdrup, H. and Warfvinge, P.**, 1992, Past and future changes in soil acidity and implications for forest growth under different deposition scenarios. *Ecological Bulletin*, in press. Task Force on Mapping. 7th Meeting, 1-2 June 1992, Berlin.
- Sverdrup, H. and de Vries, W.**, 1994, Calculation critical loads for acidity with the simple mass balance method. *Water, Air and Soil pollution* 72, p. 143-162.
- Sverdrup, H. and Warfvinge, P.**, 1995, Critical loads of acidity for Swedish forest ecosystems. *Ecological Bulletin* 44, 1995, p. 75-89.

- Sverdrup, H., Warfvinge, P. and Nihlgard, B.*, 1994, Assessment of soil acidification effects on forest growth in Sweden. *Water, Air and Soil Pollution*, 77, p. 1-30.
- Škvarenina, J.*, 1993, Horizontal precipitation in fir - beech ecosystem as a source of deposition of some chemical elements (in slovak). PhD thesis, FU Zvolen, 170 pp.
- Škvarenina, J.*, 1994, Determination of atmospheric inputs in Abieto - Fagetum ecosystem by balance method (in slovak). In: *Zborník prác z Bioklimatologických pracovných dní, 3- 5.11.1993*, Nitra, SBkS pri SAV Bratislava, p. 99-104.
- Warfvinge, P. and Sverdrup, H.*, 1992, Calculation critical loads of acid deposition with PROFILE - A steady state soil chemistry model. *Water, Air and Soil Pollution* 63, p. 119-143.
- Wathne, B. M., Mill, W. A., Kot, M., Rzychon, D., Henriksen, A. and Torseth, K.*, 1993, Critical loads of acidity to lakes in the Polish Tatra. NIVA Report 33/1993, 37 pp.
- Závodský, D., Babiaková, G., Mitošinková, M., Pukančíková, K., Rončák, P., Bodiš, D., Rapant, S., Mind'áš, J., Škvarenina, J., Cambel, B., Rehák, Š., Wathne, B. M., Henriksen, A., Sverdrup, H., Torseth, K., Semb, A. and Aamlid, D.*, 1995, Mapping critical levels/loads for the Slovak Republic. NIVA Acid Rain Research Report 37/1995, Oslo, 74 pp.

ANNEX 1

-
- **Geographical map of Slovakia**
 - **Grid cells (10x10 km) numbering**
-

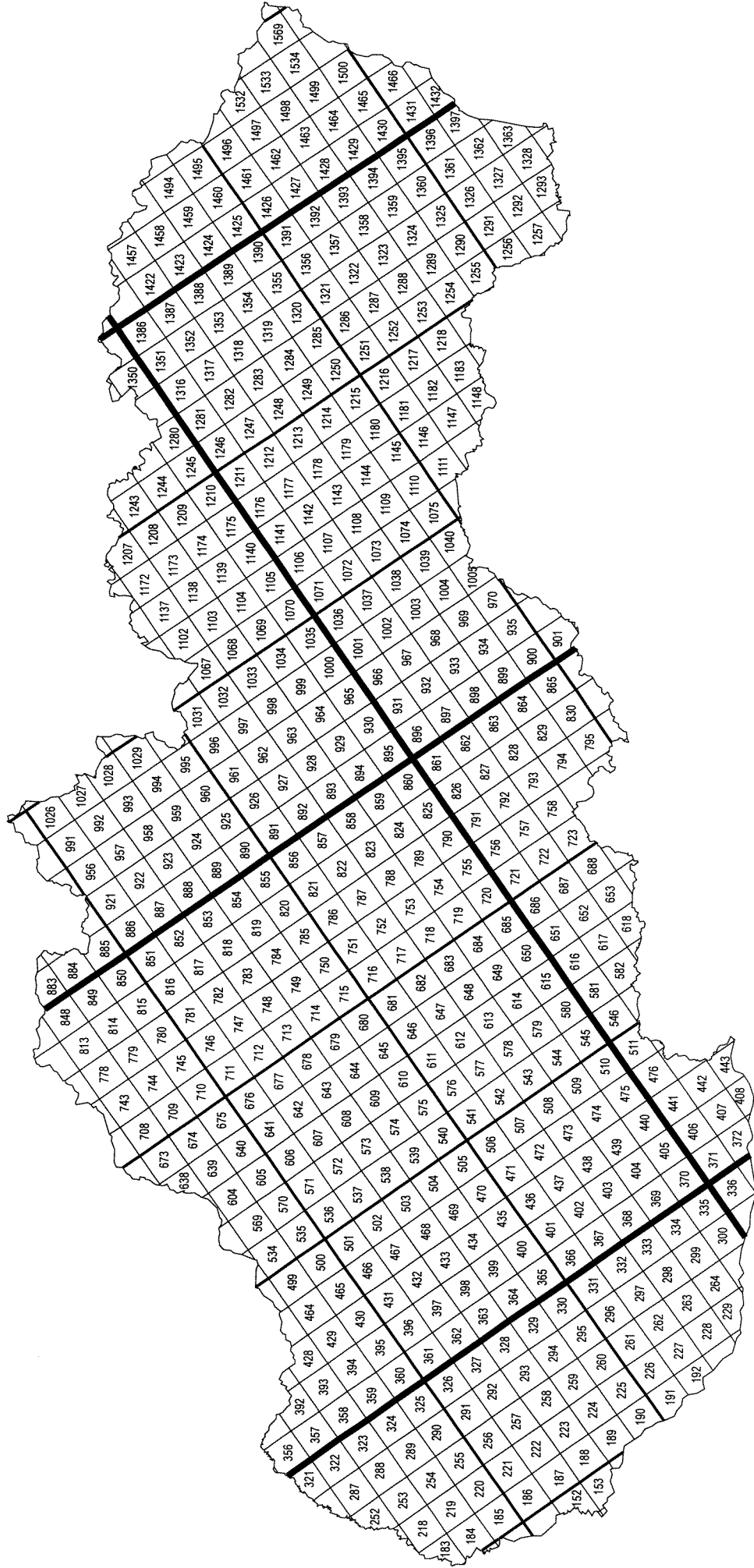


SLOVENSKÁ REPUBLIKA

Drieňová 3
821 02 Bratislava
Tel./fax: 23 00 78, 23 04 44

Slovak Republic - grid cells numbering (10x10 km)

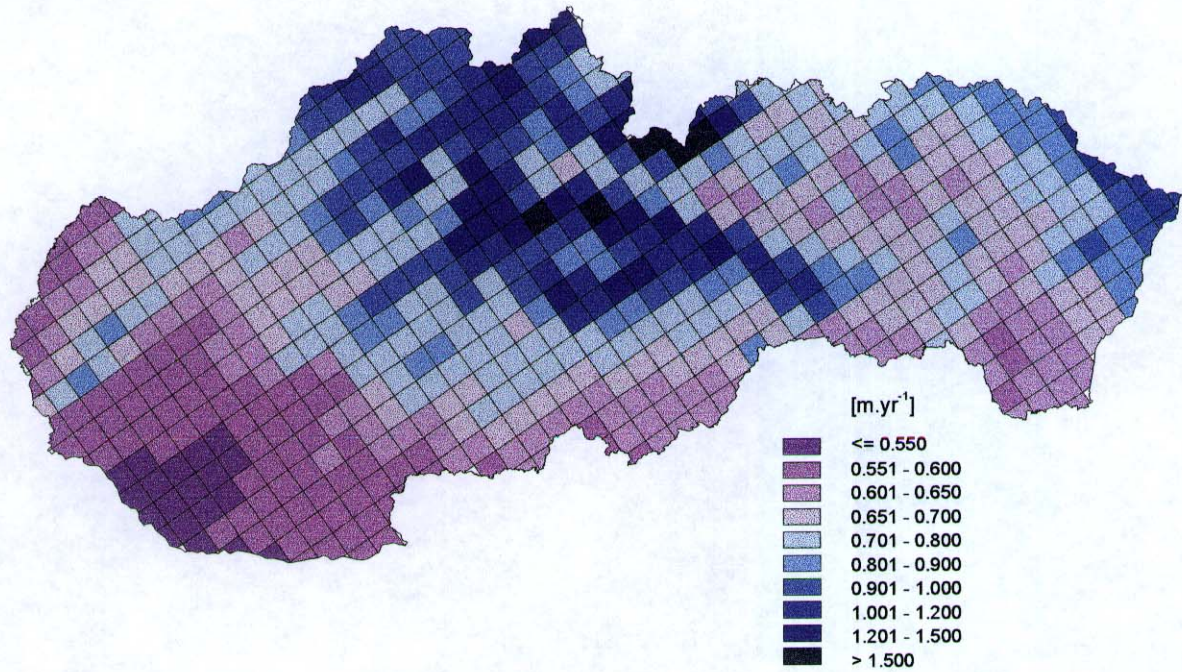
Course lines EMEP grid (150x150 km)



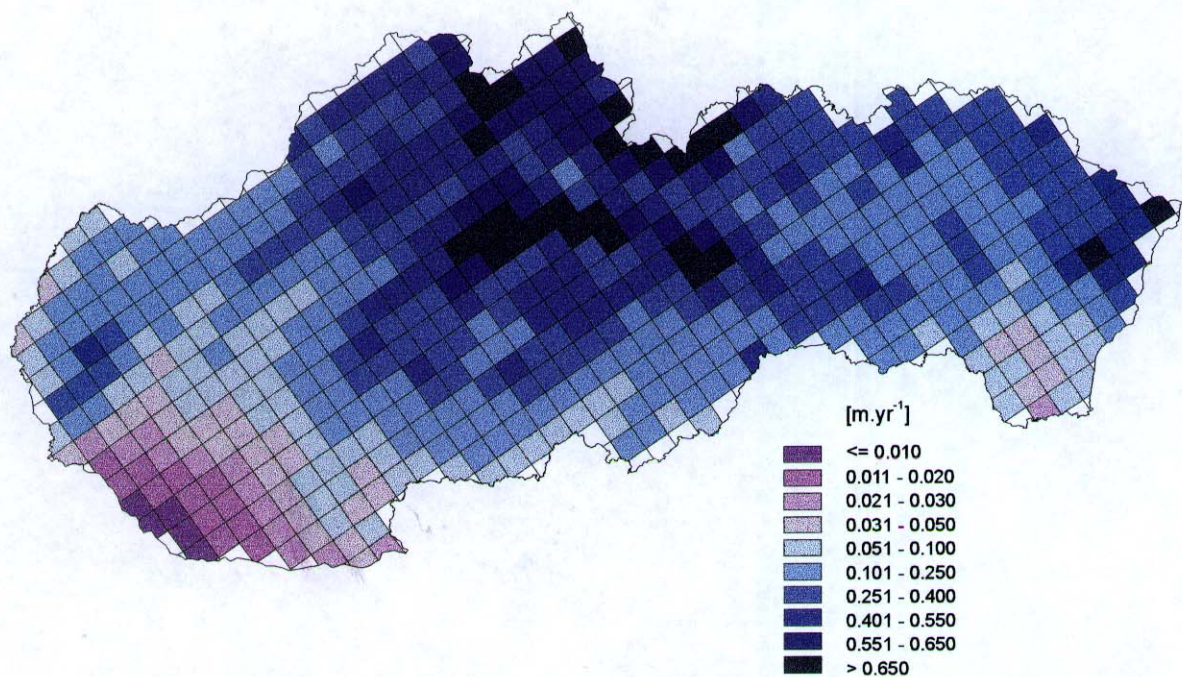
ANNEX 2

**Precipitation and runoff
at the territory of Slovakia**

Precipitation (50-years averages) in Slovakia



Runoff (50-years averages) at the territory of Slovakia



ANNEX 3

Critical loads of acidity for forest soils - input data for calculation

No.	-	number of grid cell	
P	-	precipitation	[m.yr ⁻¹]
Q	-	runoff	[m.yr ⁻¹]
S₉₀	-	sulphur deposition 1990	[keq.ha ⁻¹ .yr ⁻¹]
S₉₅	-	sulphur deposition 1995	[keq.ha ⁻¹ .yr ⁻¹]
NO₃	-	nitrate deposition	[keq.ha ⁻¹ .yr ⁻¹]
NH₄	-	ammonium deposition	[keq.ha ⁻¹ .yr ⁻¹]
BC_d	-	base cation deposition	[keq.ha ⁻¹ .yr ⁻¹]
BC_u	-	base cation uptake	[keq.ha ⁻¹ .yr ⁻¹]
N_u	-	nitrogen uptake	[keq.ha ⁻¹ .yr ⁻¹]
N_i	-	nitrogen immobilization	[keq.ha ⁻¹ .yr ⁻¹]
w	-	weathering rate	[keq.ha ⁻¹ .yr ⁻¹]
T	-	temperature	[°C]
xH	-	thickness of soil organic layer	[m]
xE	-	thickness of E/A or second layer	[m]

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
152	0.59	0.058	1.40	1.03	0.32	0.63	0.54	1.11	0.28	0.50	7.02	9.6	0.26	0.01
153	0.56	0.034	1.33	0.98	0.30	0.60	0.51	1.13	0.29	0.50	7.02	9.7	0.29	0.01
183	0.56	0.046	1.33	0.98	0.30	0.60	0.51	0.60	0.25	0.50	3.42	9.7	0.34	0.01
184	0.58	0.055	1.38	1.02	0.31	0.62	0.53	0.49	0.24	0.50	3.42	9.5	0.35	0.01
185	0.62	0.100	1.48	1.09	0.33	0.66	0.57	0.76	0.35	0.50	3.64	9.4	0.30	0.07
186	0.76	0.287	1.81	1.33	0.41	0.81	0.69	0.70	0.37	0.50	1.81	8.2	0.28	0.23
187	0.60	0.127	1.43	1.05	0.32	0.64	0.55	1.03	0.28	0.50	6.79	9.5	0.27	0.02
188	0.57	0.029	1.36	1.00	0.31	0.61	0.52	0.85	0.24	0.50	7.02	9.6	0.38	0.01
189	0.56	0.016	1.33	0.98	0.30	0.60	0.51	1.10	0.28	0.50	7.02	9.7	0.44	0.01
190	0.55	0.013	1.30	0.96	0.29	0.59	0.51	1.12	0.29	0.50	7.02	9.8	0.44	0.01
191	0.55	0.009	1.30	0.96	0.29	0.59	0.51	1.16	0.30	0.50	7.02	9.9	0.38	0.01
192	0.55	0.009	1.30	0.96	0.29	0.59	0.51	1.21	0.32	0.50	7.02	10.2	0.32	0.01
218	0.59	0.072	1.40	1.03	0.32	0.63	0.54	0.40	0.25	0.50	3.42	9.3	0.32	0.01
219	0.64	0.124	1.52	1.12	0.34	0.69	0.59	0.21	0.24	0.50	3.42	9.4	0.30	0.01
220	0.68	0.192	1.62	1.19	0.36	0.73	0.63	0.74	0.49	0.50	3.71	8.1	0.30	0.20
221	0.82	0.290	1.95	1.44	0.44	0.88	0.75	0.71	0.37	0.50	2.05	8.0	0.30	0.24
222	0.59	0.163	1.40	1.03	0.32	0.63	0.54	1.07	0.29	0.50	7.02	9.2	0.36	0.06
223	0.58	0.032	1.37	1.01	0.31	0.62	0.53	1.20	0.32	0.50	7.02	9.5	0.38	0.01
224	0.57	0.024	1.34	0.99	0.30	0.61	0.52	1.06	0.31	0.50	7.02	9.6	0.47	0.01
225	0.55	0.016	1.30	0.96	0.29	0.59	0.51	1.07	0.27	0.50	7.02	9.7	0.50	0.01
226	0.55	0.013	1.30	0.96	0.29	0.59	0.51	1.17	0.32	0.50	7.02	9.8	0.50	0.01
227	0.55	0.009	1.30	0.96	0.29	0.59	0.51	1.18	0.32	0.50	7.02	9.9	0.49	0.01
228	0.55	0.009	1.30	0.96	0.29	0.59	0.51	1.03	0.28	0.50	7.02	10.3	0.50	0.01
229	0.55	0.009	1.30	0.96	0.29	0.59	0.51	1.14	0.30	0.50	7.02	10.4	0.44	0.01
252	0.57	0.047	1.36	1.00	0.31	0.61	0.52	0.73	0.27	0.50	3.42	9.6	0.25	0.01
253	0.62	0.116	1.48	1.09	0.33	0.66	0.57	0.23	0.22	0.50	3.42	9.5	0.29	0.01
254	0.68	0.192	1.60	1.18	0.36	0.72	0.62	0.26	0.24	0.50	3.53	9.1	0.25	0.01
255	0.80	0.404	1.62	1.19	0.43	0.86	0.73	0.65	0.35	0.50	4.61	7.5	0.29	0.21
256	0.75	0.267	1.78	1.31	0.40	0.80	0.69	0.47	0.18	0.50	2.29	8.5	0.27	0.23
257	0.59	0.088	1.40	1.03	0.32	0.63	0.54	0.97	0.22	0.50	7.02	9.4	0.31	0.13
258	0.58	0.038	1.38	1.02	0.31	0.62	0.53	1.15	0.32	0.50	7.02	9.5	0.44	0.01
259	0.57	0.027	1.36	1.00	0.31	0.61	0.52	1.21	0.32	0.50	7.02	9.5	0.34	0.01
260	0.56	0.022	1.32	0.97	0.30	0.59	0.51	1.21	0.32	0.50	7.02	9.6	0.31	0.01
261	0.55	0.016	1.30	0.96	0.29	0.59	0.51	1.20	0.32	0.50	7.02	9.7	0.35	0.01
262	0.55	0.013	1.30	0.96	0.29	0.59	0.51	1.14	0.30	0.50	7.02	9.7	0.35	0.01
263	0.55	0.013	1.30	0.96	0.29	0.59	0.51	1.14	0.30	0.50	7.02	9.8	0.49	0.01
287	0.60	0.058	1.43	1.05	0.32	0.64	0.55	0.26	0.23	0.50	3.42	9.4	0.35	0.01
288	0.63	0.107	1.49	1.10	0.34	0.67	0.58	0.31	0.22	0.50	3.42	9.1	0.28	0.01
289	0.68	0.146	1.62	1.19	0.36	0.73	0.63	0.31	0.24	0.50	3.65	8.5	0.30	0.08
290	0.82	0.356	1.95	1.44	0.44	0.88	0.75	0.80	0.53	0.50	5.73	7.6	0.25	0.19
291	0.66	0.230	1.57	1.16	0.35	0.71	0.61	0.76	0.22	0.50	3.66	9.2	0.28	0.16
292	0.59	0.085	1.40	1.03	0.32	0.63	0.54	0.75	0.27	0.50	6.63	9.4	0.50	0.01
293	0.58	0.044	1.38	1.02	0.31	0.62	0.53	1.19	0.32	0.50	7.02	9.5	0.48	0.01
294	0.57	0.038	1.36	1.00	0.31	0.61	0.52	1.16	0.32	0.50	7.02	9.5	0.49	0.01
295	0.56	0.038	1.33	0.98	0.30	0.60	0.51	1.17	0.32	0.50	7.02	9.6	0.37	0.01
296	0.55	0.023	1.30	0.96	0.29	0.59	0.51	1.17	0.32	0.50	7.02	9.7	0.31	0.01
297	0.55	0.016	1.30	0.96	0.29	0.59	0.51	1.19	0.31	0.50	7.02	9.7	0.35	0.01
298	0.55	0.016	1.30	0.96	0.29	0.59	0.51	1.14	0.30	0.50	7.02	9.8	0.32	0.01
299	0.57	0.016	1.36	1.00	0.31	0.61	0.52	1.14	0.30	0.50	7.02	9.9	0.36	0.01
300	0.56	0.016	1.33	0.98	0.30	0.60	0.51	1.14	0.30	0.50	7.02	9.8	0.44	0.01

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
321	0.57	0.072	1.36	1.00	0.31	0.61	0.52	0.42	0.23	0.50	3.42	9.2	0.31	0.01
322	0.62	0.124	1.48	1.09	0.33	0.66	0.57	0.71	0.22	0.50	3.42	9.1	0.30	0.04
323	0.66	0.117	1.57	1.16	0.35	0.71	0.61	0.28	0.22	0.50	3.47	9.2	0.26	0.01
324	0.68	0.142	1.62	1.19	0.36	0.73	0.63	0.34	0.25	0.50	3.49	8.4	0.30	0.02
325	0.80	0.224	1.90	1.40	0.43	0.86	0.73	0.77	0.42	0.50	3.93	8.0	0.23	0.12
326	0.65	0.083	1.55	1.14	0.35	0.70	0.59	0.69	0.22	0.50	3.69	9.2	0.31	0.13
327	0.59	0.047	1.40	1.03	0.32	0.63	0.54	1.10	0.29	0.50	7.02	9.3	0.50	0.01
328	0.58	0.054	1.38	1.02	0.31	0.62	0.53	1.05	0.30	0.50	5.49	9.5	0.46	0.01
329	0.57	0.055	1.36	1.00	0.31	0.61	0.52	1.06	0.27	0.50	7.02	9.5	0.40	0.01
330	0.56	0.041	1.33	0.98	0.30	0.60	0.51	1.04	0.27	0.50	7.02	9.6	0.38	0.01
331	0.55	0.035	1.30	0.96	0.29	0.59	0.51	1.04	0.27	0.50	7.02	9.6	0.35	0.01
332	0.55	0.028	1.30	0.96	0.29	0.59	0.51	1.19	0.31	0.50	7.02	9.7	0.38	0.01
333	0.56	0.025	1.33	0.98	0.30	0.60	0.51	1.13	0.30	0.50	7.02	9.7	0.43	0.01
334	0.57	0.025	1.36	1.00	0.31	0.61	0.52	1.07	0.28	0.50	7.02	9.8	0.47	0.01
335	0.57	0.023	1.36	1.00	0.31	0.61	0.52	1.19	0.31	0.50	7.02	9.8	0.47	0.01
336	0.56	0.023	1.33	0.98	0.30	0.60	0.51	1.19	0.31	0.50	7.02	9.9	0.44	0.01
356	0.56	0.091	1.33	0.98	0.30	0.60	0.51	1.13	0.33	0.50	3.42	9.1	0.44	0.01
357	0.65	0.169	1.55	1.14	0.35	0.70	0.59	0.86	0.20	0.50	3.35	8.6	0.28	0.14
358	0.68	0.081	1.62	1.19	0.36	0.73	0.63	0.56	0.25	0.50	3.27	8.7	0.23	0.09
359	0.69	0.129	1.64	1.21	0.37	0.74	0.63	0.60	0.32	0.50	3.82	8.5	0.20	0.11
360	0.78	0.165	1.86	1.37	0.42	0.84	0.71	0.73	0.40	0.50	4.37	8.5	0.20	0.16
361	0.65	0.101	1.55	1.14	0.35	0.70	0.59	0.58	0.21	0.50	4.37	9.1	0.32	0.08
362	0.59	0.057	1.40	1.03	0.32	0.63	0.54	0.93	0.27	0.50	7.02	9.2	0.49	0.01
363	0.59	0.090	1.40	1.03	0.32	0.63	0.54	0.87	0.23	0.50	4.32	9.2	0.46	0.01
364	0.58	0.098	1.38	1.02	0.31	0.62	0.53	0.91	0.24	0.50	7.02	9.4	0.50	0.01
365	0.57	0.047	1.36	1.00	0.31	0.61	0.52	0.92	0.28	0.50	7.02	9.5	0.50	0.01
366	0.56	0.044	1.33	0.98	0.30	0.60	0.51	1.19	0.31	0.50	7.02	9.6	0.50	0.01
367	0.56	0.036	1.33	0.98	0.30	0.60	0.51	1.19	0.31	0.50	7.02	9.6	0.50	0.01
368	0.57	0.041	1.36	1.00	0.31	0.61	0.52	1.17	0.32	0.50	7.02	9.7	0.49	0.01
369	0.58	0.044	1.38	1.02	0.31	0.62	0.53	1.19	0.31	0.50	3.42	9.8	0.44	0.01
370	0.59	0.041	1.40	1.03	0.32	0.63	0.54	1.17	0.31	0.50	7.02	9.8	0.47	0.02
371	0.57	0.038	1.36	1.00	0.31	0.61	0.52	0.78	0.17	0.50	7.02	9.9	0.46	0.03
372	0.56	0.030	1.33	0.98	0.30	0.60	0.51	0.89	0.27	0.50	4.52	10.1	0.46	0.01
392	0.72	0.217	1.71	1.26	0.39	0.77	0.66	0.75	0.30	0.50	1.89	7.8	0.25	0.20
393	0.73	0.194	1.74	1.28	0.39	0.78	0.67	0.81	0.38	0.50	3.43	8.6	0.26	0.24
394	0.72	0.198	1.71	1.26	0.39	0.77	0.66	0.46	0.34	0.50	4.79	8.0	0.24	0.13
395	0.70	0.145	1.67	1.23	0.37	0.75	0.64	0.72	0.39	0.50	5.70	8.0	0.20	0.12
397	0.59	0.089	1.40	1.03	0.32	0.63	0.54	0.75	0.19	0.50	3.75	9.1	0.37	0.01
398	0.61	0.114	1.45	1.07	0.33	0.65	0.56	0.81	0.18	0.50	3.75	8.9	0.25	0.17
399	0.62	0.071	1.48	1.09	0.33	0.66	0.57	1.01	0.25	0.50	3.69	9.1	0.32	0.12
400	0.59	0.066	1.40	1.03	0.32	0.63	0.54	0.95	0.23	0.50	3.79	9.2	0.32	0.12
401	0.57	0.053	1.36	1.00	0.31	0.61	0.52	0.88	0.20	0.50	4.32	9.4	0.46	0.03
402	0.57	0.047	1.36	1.00	0.31	0.61	0.52	1.13	0.32	0.50	5.22	9.3	0.55	0.01
403	0.58	0.050	1.38	1.02	0.31	0.62	0.53	1.09	0.31	0.50	7.02	9.4	0.49	0.01
404	0.60	0.061	1.43	1.05	0.32	0.64	0.55	1.16	0.30	0.50	3.42	9.3	0.48	0.02
405	0.59	0.058	1.40	1.03	0.32	0.63	0.54	1.08	0.34	0.50	7.02	9.6	0.40	0.06
406	0.57	0.053	1.36	1.00	0.31	0.61	0.52	0.83	0.32	0.50	4.28	9.8	0.41	0.06
407	0.56	0.038	1.33	0.98	0.30	0.60	0.51	0.92	0.22	0.50	3.92	9.9	0.47	0.01
408	0.56	0.032	2.69	1.98	0.30	0.60	0.51	1.05	0.27	0.50	3.92	10.4	0.46	0.01
428	0.77	0.233	1.83	1.35	0.41	0.82	0.71	0.69	0.50	0.50	2.42	7.4	0.27	0.25

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
429	0.76	0.172	1.81	1.33	0.41	0.81	0.69	0.51	0.34	0.50	5.32	7.7	0.22	0.13
430	0.67	0.145	1.59	1.17	0.36	0.72	0.61	0.55	0.27	0.50	3.74	8.6	0.31	0.07
431	0.63	0.075	1.49	1.10	0.34	0.67	0.58	0.70	0.18	0.50	7.03	9.1	0.29	0.04
432	0.65	0.157	1.55	1.14	0.35	0.70	0.59	0.75	0.23	0.53	5.40	8.8	0.20	0.16
433	0.62	0.079	1.48	1.09	0.33	0.66	0.57	0.93	0.24	0.50	3.64	9.1	0.23	0.18
434	0.65	0.058	1.55	1.14	0.35	0.70	0.59	0.88	0.22	0.50	3.69	9.5	0.25	0.12
435	0.65	0.089	1.55	1.14	0.35	0.70	0.59	0.67	0.21	0.50	4.77	8.9	0.24	0.11
436	0.58	0.085	1.38	1.02	0.31	0.62	0.53	1.02	0.25	0.50	4.32	9.2	0.29	0.12
437	0.58	0.095	1.38	1.02	0.31	0.62	0.53	1.04	0.25	0.50	5.22	9.1	0.32	0.12
438	0.59	0.097	1.40	1.03	0.32	0.63	0.54	1.11	0.28	0.50	4.32	9.3	0.35	0.10
439	0.62	0.090	1.48	1.09	0.33	0.66	0.57	1.14	0.29	0.50	4.31	9.1	0.22	0.19
440	0.59	0.060	1.40	1.03	0.32	0.63	0.54	1.12	0.28	0.50	3.34	9.5	0.38	0.08
441	0.57	0.044	1.36	1.00	0.31	0.61	0.52	0.99	0.27	0.50	3.41	9.9	0.49	0.01
442	0.57	0.054	1.36	1.00	0.31	0.61	0.52	0.96	0.24	0.50	3.24	10.1	0.36	0.06
443	0.57	0.029	1.36	1.00	0.31	0.61	0.52	0.87	0.20	0.50	1.74	10.1	0.28	0.10
464	0.75	0.198	1.78	1.31	0.40	0.80	0.69	0.51	0.29	0.50	4.74	8.1	0.22	0.15
465	0.69	0.101	1.64	1.21	0.37	0.74	0.63	0.60	0.19	0.50	5.01	9.0	0.31	0.03
466	0.68	0.138	1.62	1.19	0.36	0.73	0.63	0.60	0.25	0.50	7.03	9.0	0.24	0.12
467	0.70	0.217	1.67	1.23	0.37	0.75	0.64	0.70	0.25	0.55	5.21	7.9	0.23	0.20
468	0.66	0.096	1.57	1.16	0.35	0.71	0.61	0.62	0.10	0.50	3.42	9.1	0.20	0.20
469	0.68	0.081	1.62	1.19	0.36	0.73	0.63	0.65	0.13	0.59	3.69	9.1	0.22	0.14
470	0.75	0.160	1.78	1.31	0.40	0.80	0.69	0.66	0.14	0.52	2.52	8.5	0.27	0.22
471	0.59	0.101	1.40	1.03	0.32	0.63	0.54	1.21	0.32	0.50	4.32	9.2	0.20	0.18
472	0.59	0.110	1.40	1.03	0.32	0.63	0.54	1.09	0.27	0.50	5.22	9.3	0.22	0.15
473	0.62	0.106	1.48	1.09	0.33	0.66	0.57	1.17	0.30	0.50	4.32	9.4	0.20	0.20
474	0.59	0.073	1.40	1.03	0.32	0.63	0.54	1.24	0.32	0.50	4.31	9.3	0.30	0.09
475	0.58	0.038	1.38	1.02	0.31	0.62	0.53	1.24	0.32	0.50	3.47	9.5	0.47	0.01
476	0.58	0.050	1.38	1.02	0.31	0.62	0.53	1.15	0.29	0.50	3.24	9.8	0.30	0.04
499	0.75	0.161	1.78	1.31	0.40	0.80	0.69	0.68	0.43	0.50	2.20	8.0	0.22	0.10
500	0.65	0.123	1.55	1.14	0.35	0.70	0.59	0.63	0.16	0.53	4.96	8.8	0.26	0.19
501	0.80	0.291	1.90	1.40	0.43	0.86	0.73	0.69	0.38	0.57	2.72	7.1	0.29	0.28
502	0.68	0.224	1.62	1.19	0.36	0.73	0.63	0.69	0.27	0.50	2.99	7.9	0.23	0.21
503	0.66	0.087	1.57	1.16	0.35	0.71	0.61	0.94	0.22	0.50	3.42	9.0	0.21	0.21
504	0.75	0.124	1.78	1.31	0.40	0.80	0.69	0.63	0.23	0.53	1.96	8.0	0.23	0.16
505	0.75	0.243	1.78	1.31	0.40	0.80	0.69	0.76	0.29	0.57	1.55	7.8	0.29	0.28
506	0.65	0.117	1.55	1.14	0.35	0.70	0.59	0.72	0.16	0.50	3.42	9.1	0.20	0.18
507	0.60	0.235	1.43	1.05	0.32	0.64	0.55	0.83	0.20	0.50	4.32	8.5	0.21	0.22
508	0.65	0.120	1.55	1.14	0.35	0.70	0.59	0.86	0.20	0.50	3.03	9.1	0.28	0.06
509	0.63	0.065	1.49	1.10	0.34	0.67	0.58	1.21	0.31	0.50	3.38	9.4	0.28	0.06
510	0.62	0.072	1.48	1.09	0.33	0.66	0.57	1.01	0.27	0.50	3.67	9.4	0.25	0.12
511	0.59	0.079	1.40	1.03	0.32	0.63	0.54	1.03	0.27	0.50	3.24	9.6	0.25	0.12
534	0.76	0.211	1.81	1.33	0.41	0.81	0.69	0.73	0.43	0.50	4.00	7.8	0.25	0.15
535	0.68	0.173	1.62	1.19	0.36	0.73	0.63	0.65	0.28	0.55	3.12	8.2	0.26	0.20
536	0.75	0.311	1.78	1.31	0.40	0.80	0.69	0.70	0.40	0.60	2.10	7.3	0.29	0.28
537	0.68	0.146	1.62	1.19	0.36	0.73	0.63	0.75	0.25	0.50	2.75	8.4	0.29	0.27
538	0.67	0.070	1.59	1.17	0.36	0.72	0.61	0.80	0.27	0.50	3.42	8.6	0.21	0.17
539	0.75	0.110	1.78	1.31	0.40	0.80	0.69	0.63	0.19	0.54	5.69	8.0	0.21	0.09
540	0.80	0.248	1.90	1.40	0.43	0.86	0.73	0.73	0.31	0.62	1.24	7.5	0.27	0.25
541	0.75	0.348	1.78	1.31	0.40	0.80	0.69	0.73	0.33	0.50	2.46	8.0	0.29	0.28
542	0.73	0.366	1.74	1.28	0.39	0.78	0.67	0.63	0.13	0.50	1.50	7.8	0.27	0.25

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
543	0.68	0.220	1.62	1.19	0.36	0.73	0.63	0.69	0.14	0.50	2.07	8.1	0.26	0.25
544	0.66	0.137	1.57	1.16	0.35	0.71	0.61	0.86	0.23	0.50	1.49	9.2	0.21	0.19
545	0.64	0.129	1.52	1.12	0.34	0.69	0.59	1.02	0.27	0.50	4.20	9.3	0.21	0.21
546	0.58	0.091	1.38	1.02	0.31	0.62	0.53	0.95	0.24	0.50	3.12	9.4	0.20	0.12
569	0.76	0.194	1.81	1.33	0.41	0.81	0.69	0.73	0.34	0.50	5.03	7.6	0.28	0.21
570	0.75	0.233	1.78	1.31	0.40	0.80	0.69	0.73	0.45	0.50	7.69	8.0	0.21	0.04
571	0.78	0.257	1.86	1.37	0.42	0.84	0.71	0.51	0.27	0.50	1.40	8.1	0.21	0.15
572	0.69	0.166	1.64	1.21	0.37	0.74	0.63	0.50	0.19	0.50	2.84	8.2	0.21	0.19
573	0.68	0.143	1.62	1.19	0.36	0.73	0.63	0.52	0.15	0.50	3.92	8.3	0.24	0.19
574	0.70	0.114	1.67	1.23	0.37	0.75	0.64	0.62	0.24	0.50	4.67	8.2	0.21	0.10
575	0.90	0.334	2.14	1.58	0.48	0.96	0.83	0.68	0.40	0.53	3.48	7.3	0.26	0.19
576	0.90	0.416	2.14	1.58	0.48	0.96	0.83	0.78	0.47	0.50	2.88	7.3	0.29	0.27
578	0.74	0.190	1.76	1.30	0.40	0.79	0.68	0.74	0.17	0.50	1.14	7.6	0.29	0.28
579	0.71	0.211	1.68	1.24	0.38	0.76	0.65	0.67	0.16	0.50	1.27	8.4	0.23	0.22
580	0.65	0.151	1.55	1.14	0.35	0.70	0.59	0.50	0.10	0.50	1.17	9.1	0.24	0.22
581	0.63	0.134	1.49	1.10	0.34	0.67	0.58	1.01	0.28	0.50	1.52	9.2	0.23	0.20
582	0.62	0.076	1.48	1.09	0.33	0.66	0.57	1.02	0.28	0.50	2.35	8.8	0.25	0.21
604	0.74	0.216	1.76	1.30	0.40	0.79	0.68	0.60	0.39	0.50	4.68	8.0	0.23	0.13
605	0.77	0.290	1.82	1.34	0.41	0.82	0.71	0.54	0.39	0.50	6.69	7.9	0.21	0.04
606	0.85	0.395	2.02	1.49	0.46	0.91	0.78	0.55	0.39	0.50	7.93	6.8	0.21	0.03
607	0.83	0.245	1.97	1.45	0.44	0.89	0.76	0.50	0.29	0.50	5.46	7.0	0.23	0.09
608	0.78	0.193	1.86	1.37	0.42	0.84	0.71	0.64	0.40	0.50	7.26	7.5	0.23	0.08
609	0.70	0.167	1.67	1.23	0.37	0.75	0.64	0.67	0.22	0.50	2.66	8.1	0.21	0.14
610	0.99	0.530	2.35	1.73	0.53	1.06	0.91	0.70	0.53	0.50	1.26	5.2	0.29	0.30
611	0.88	0.370	2.09	1.54	0.47	0.94	0.81	0.80	0.66	0.50	0.88	7.0	0.30	0.30
612	0.79	0.400	1.87	1.38	0.42	0.85	0.73	0.67	0.55	0.50	1.47	8.0	0.29	0.30
613	0.85	0.420	2.02	1.49	0.43	0.91	0.78	0.80	0.64	0.50	0.62	6.6	0.30	0.29
614	0.75	0.260	1.78	1.31	0.40	0.80	0.69	1.09	0.76	0.50	1.08	8.1	0.30	0.30
615	0.68	0.181	1.62	1.19	0.36	0.73	0.63	0.69	0.22	0.50	1.17	8.5	0.25	0.24
616	0.67	0.205	1.59	1.17	0.36	0.72	0.61	0.64	0.20	0.50	1.17	8.2	0.26	0.26
617	0.64	0.110	1.52	1.12	0.34	0.69	0.59	0.86	0.22	0.50	1.94	8.2	0.27	0.24
618	0.60	0.063	1.43	1.05	0.32	0.64	0.55	0.97	0.26	0.50	2.29	9.5	0.20	0.12
638	0.85	0.433	2.02	1.49	0.46	0.91	0.78	0.44	0.37	0.50	1.19	5.8	0.29	0.26
639	0.75	0.280	1.78	1.31	0.40	0.80	0.69	0.41	0.33	0.50	5.34	7.8	0.22	0.26
640	0.79	0.275	1.87	1.38	0.42	0.85	0.73	0.47	0.33	0.50	5.45	7.6	0.21	0.03
641	1.00	0.467	2.38	1.75	0.54	1.07	0.91	0.47	0.34	0.50	3.90	6.3	0.21	0.03
642	0.96	0.340	2.28	1.68	0.51	1.03	0.88	0.62	0.47	0.66	2.16	6.8	0.27	0.20
643	0.80	0.253	1.90	1.40	0.43	0.86	0.73	0.54	0.33	0.51	3.13	7.6	0.28	0.24
644	0.78	0.230	1.86	1.37	0.42	0.84	0.71	0.48	0.35	0.50	1.16	7.7	0.23	0.23
645	0.97	0.500	2.31	1.70	0.52	1.04	0.89	1.10	0.69	0.50	0.90	5.5	0.30	0.30
646	0.78	0.320	1.86	1.37	0.42	0.84	0.71	0.82	0.67	0.50	1.08	7.9	0.27	0.30
647	0.80	0.370	1.90	1.40	0.43	0.86	0.73	0.95	0.64	0.50	1.11	7.5	0.26	0.23
648	0.85	0.400	2.02	1.49	0.46	0.91	0.78	0.72	0.67	0.50	0.95	7.2	0.30	0.30
649	0.75	0.300	1.78	1.31	0.40	0.80	0.69	1.11	0.78	0.50	1.17	7.4	0.30	0.30
650	0.69	0.220	1.64	1.21	0.37	0.74	0.63	1.09	0.79	0.50	1.09	8.0	0.28	0.27
651	0.72	0.212	1.71	1.26	0.39	0.77	0.66	0.73	0.29	0.50	1.17	7.5	0.26	0.26
652	0.66	0.134	1.57	1.16	0.36	0.71	0.61	0.84	0.27	0.50	1.44	7.9	0.26	0.25
653	0.61	0.072	1.45	1.07	0.33	0.65	0.56	0.94	0.24	0.50	3.18	9.4	0.20	0.10
673	0.92	0.375	2.19	1.61	0.49	0.99	0.68	0.41	0.36	0.58	2.67	7.0	0.29	0.27
674	0.73	0.238	1.74	1.28	0.39	0.78	0.67	0.38	0.23	0.50	5.60	8.0	0.22	0.09

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
675	0.88	0.344	2.09	1.54	0.47	0.94	0.81	0.38	0.30	0.50	6.59	7.5	0.21	0.01
676	0.98	0.580	2.33	1.72	0.52	1.05	0.90	0.41	0.29	0.50	7.68	6.0	0.21	0.03
677	0.90	0.490	2.14	1.58	0.48	0.96	0.83	0.53	0.46	0.58	5.27	6.0	0.22	0.06
678	0.79	0.283	1.87	1.38	0.42	0.85	0.73	0.47	0.38	0.52	2.26	8.1	0.24	0.27
679	0.80	0.300	1.90	1.40	0.43	0.86	0.73	0.78	0.56	0.70	2.12	7.5	0.29	0.27
680	0.96	0.450	2.28	1.68	0.51	1.03	0.88	0.73	0.57	0.50	1.97	6.5	0.28	0.24
681	0.80	0.340	1.90	1.40	0.43	0.86	0.73	0.83	0.64	0.50	0.41	7.5	0.30	0.30
682	0.78	0.340	1.86	1.37	0.42	0.84	0.71	1.12	0.66	0.50	0.93	7.9	0.29	0.26
683	0.80	0.280	1.90	1.40	0.43	0.86	0.73	1.11	0.69	0.50	0.82	7.5	0.29	0.29
684	0.72	0.250	1.71	1.26	0.39	0.77	0.66	1.18	0.81	0.50	1.14	7.3	0.27	0.30
685	0.75	0.280	1.78	1.31	0.40	0.80	0.69	1.18	0.81	0.50	1.17	6.6	0.29	0.30
686	0.74	0.230	1.76	1.30	0.40	0.79	0.68	0.81	0.36	0.50	1.06	7.3	0.30	0.30
687	0.66	0.142	1.57	1.16	0.35	0.71	0.61	0.83	0.26	0.50	1.54	7.8	0.27	0.26
688	0.61	0.099	1.45	1.07	0.33	0.65	0.56	0.96	0.26	0.50	2.95	9.2	0.20	0.15
708	0.98	0.445	2.33	1.72	0.52	1.05	0.77	0.27	0.25	0.50	2.08	6.4	0.29	0.27
709	0.80	0.299	1.90	1.40	0.43	0.86	0.73	0.49	0.38	0.50	5.59	8.0	0.22	0.13
710	0.92	0.393	2.19	1.61	0.49	0.99	0.84	0.39	0.34	0.50	6.65	7.3	0.24	0.11
711	0.95	0.520	2.25	1.66	0.51	1.02	0.87	0.38	0.35	0.50	7.58	6.8	0.30	0.30
712	1.08	0.530	2.57	1.89	0.58	1.16	0.99	0.60	0.50	0.50	8.61	5.0	0.23	0.09
713	0.82	0.400	1.95	1.44	0.44	0.88	0.75	0.73	0.55	0.50	6.97	6.3	0.21	0.02
714	0.80	0.410	1.90	1.40	0.43	0.86	0.73	0.46	0.42	0.50	2.03	6.4	0.26	0.22
715	0.98	0.470	2.33	1.72	0.52	1.05	0.90	0.42	0.37	0.50	1.41	5.0	0.27	0.27
716	0.95	0.650	2.25	1.66	0.51	1.02	0.87	0.68	0.53	0.50	1.01	4.8	0.30	0.30
717	0.98	0.430	2.33	1.72	0.52	1.05	0.90	0.82	0.63	0.50	1.22	7.0	0.30	0.29
718	0.73	0.170	1.74	1.28	0.39	0.78	0.67	1.23	0.65	0.50	1.09	8.4	0.23	0.21
719	0.71	0.200	1.68	1.24	0.38	0.76	0.65	1.16	0.69	0.50	1.04	6.5	0.28	0.24
720	0.80	0.420	1.90	1.40	0.43	0.86	0.73	1.04	0.64	0.50	1.13	5.9	0.30	0.29
721	0.74	0.270	1.76	1.30	0.40	0.79	0.68	1.16	0.74	0.50	1.27	7.2	0.30	0.30
722	0.66	0.180	1.57	1.16	0.35	0.71	0.61	0.86	0.24	0.50	1.17	7.6	0.28	0.27
723	0.62	0.100	1.48	1.09	0.33	0.66	0.57	0.90	0.24	0.50	1.20	9.0	0.22	0.21
743	1.10	0.442	2.62	1.93	0.59	1.18	0.82	0.29	0.32	0.61	2.05	6.2	0.30	0.30
744	0.79	0.263	1.87	1.38	0.42	0.85	0.73	0.21	0.20	0.50	4.05	7.5	0.25	0.17
745	1.02	0.435	2.43	1.79	0.55	1.09	0.93	0.35	0.30	0.50	8.06	6.5	0.22	0.05
746	1.00	0.472	2.38	1.75	0.54	1.07	0.91	0.31	0.29	0.53	4.40	6.5	0.24	0.15
747	1.25	0.520	2.97	2.19	0.67	1.34	1.14	0.90	0.60	0.80	4.70	6.0	0.23	0.08
748	0.76	0.360	1.81	1.33	0.41	0.81	0.69	0.59	0.48	0.50	3.38	7.2	0.30	0.08
749	0.90	0.420	2.14	1.58	0.48	0.96	0.83	0.40	0.37	0.50	7.07	6.0	0.23	0.06
750	1.38	0.700	3.28	2.42	0.74	1.48	1.26	0.61	0.45	0.50	5.82	4.8	0.25	0.15
751	1.15	0.590	2.73	2.01	0.62	1.23	1.05	0.75	0.53	0.70	4.77	6.5	0.25	0.17
752	0.80	0.320	1.90	1.40	0.48	0.86	0.73	0.98	0.63	0.50	4.24	7.2	0.25	0.15
753	0.75	0.280	1.78	1.31	0.40	0.80	0.69	0.85	0.46	0.50	1.27	7.5	0.21	0.08
754	0.67	0.160	1.59	1.17	0.36	0.72	0.61	1.20	0.66	0.50	0.97	7.2	0.24	0.12
755	0.74	0.290	1.76	1.30	0.40	0.79	0.68	0.64	0.46	0.50	0.89	6.8	0.30	0.30
756	0.73	0.310	1.74	1.28	0.39	0.78	0.67	1.18	0.76	0.50	1.64	7.1	0.30	0.30
757	0.67	0.200	1.59	1.17	0.36	0.72	0.61	1.18	0.80	0.60	1.44	7.5	0.29	0.29
758	0.62	0.085	1.48	1.09	0.33	0.66	0.57	0.74	0.17	0.52	2.43	9.1	0.21	0.18
778	1.10	0.454	2.62	1.93	0.59	1.18	0.82	0.24	0.26	0.50	2.05	5.8	0.30	0.30
779	0.78	0.304	1.86	1.37	0.42	0.84	0.71	0.27	0.25	0.50	2.45	7.3	0.27	0.20
780	0.85	0.349	2.02	1.49	0.46	0.91	0.78	0.25	0.24	0.50	4.76	7.0	0.24	0.14
781	1.10	0.536	2.62	1.93	0.59	1.18	1.01	0.22	0.23	0.84	4.11	6.3	0.25	0.22

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
782	0.80	0.493	1.90	1.40	0.43	0.86	0.73	0.27	0.23	1.09	1.79	5.9	0.28	0.21
783	0.77	0.360	1.83	1.35	0.41	0.82	0.71	0.40	0.43	0.50	2.83	7.0	0.29	0.09
784	1.30	0.590	3.09	2.28	0.70	1.39	1.19	0.40	0.33	0.50	7.93	4.2	0.22	0.05
785	1.45	0.850	3.45	2.54	0.78	1.55	1.33	0.55	0.38	0.50	9.18	4.0	0.25	0.14
786	1.10	0.690	2.62	1.93	0.59	1.18	1.01	0.75	0.60	0.90	5.49	5.0	0.24	0.16
787	0.98	0.340	2.33	1.72	0.52	1.05	0.90	0.98	0.66	0.70	6.08	7.0	0.24	0.12
788	1.00	0.510	2.38	1.75	0.54	1.07	0.91	0.76	0.54	0.70	1.83	5.5	0.29	0.28
789	0.90	0.410	2.14	1.58	0.48	0.96	0.83	0.86	0.55	0.50	0.95	5.0	0.29	0.26
790	0.73	0.310	1.74	1.28	0.39	0.78	0.67	0.57	0.44	0.50	0.50	7.0	0.29	0.27
791	0.75	0.270	1.78	1.31	0.40	0.80	0.69	1.09	0.67	0.60	0.56	7.4	0.29	0.29
792	0.70	0.150	1.67	1.23	0.37	0.75	0.64	1.20	0.83	0.60	1.64	8.0	0.26	0.23
793	0.63	0.090	1.49	1.10	0.34	0.67	0.58	1.16	0.83	0.50	1.46	8.4	0.20	0.19
794	0.62	0.096	1.48	1.09	0.33	0.66	0.57	0.91	0.27	0.50	2.80	8.2	0.26	0.10
795	0.61	0.158	1.45	1.07	0.33	0.65	0.56	0.87	0.28	0.50	2.84	7.8	0.22	0.16
813	0.99	0.492	2.35	1.73	0.53	1.06	0.76	0.21	0.24	0.74	1.64	6.5	0.30	0.29
814	0.97	0.479	2.31	1.70	0.52	1.04	0.89	0.22	0.25	0.59	1.42	6.6	0.30	0.30
815	0.82	0.399	1.95	1.44	0.44	0.88	0.75	0.28	0.23	0.50	5.47	7.0	0.25	0.17
816	1.02	0.492	2.43	1.79	0.55	1.09	0.93	0.32	0.25	0.67	3.80	7.0	0.24	0.15
817	0.95	0.490	2.25	1.66	0.51	1.02	0.87	0.31	0.19	1.03	2.64	7.3	0.25	0.17
818	1.25	0.546	2.97	2.19	0.67	1.34	1.14	0.42	0.33	0.58	5.69	6.0	0.21	0.03
819	1.40	0.640	3.33	2.45	0.75	1.50	1.28	0.43	0.35	1.43	5.51	4.0	0.21	0.11
820	1.42	0.800	3.38	2.49	0.76	1.52	1.30	0.36	0.32	0.60	6.86	5.0	0.25	0.15
821	1.50	0.740	3.57	2.63	0.80	1.61	1.38	0.40	0.34	0.90	5.44	4.0	0.21	0.21
822	0.98	0.350	2.33	1.72	0.52	1.05	0.90	0.78	0.55	0.70	6.82	6.1	0.25	0.15
823	1.10	0.520	2.62	1.93	0.59	1.18	1.01	0.52	0.46	0.80	0.63	4.5	0.29	0.27
824	1.25	0.550	2.97	2.19	0.67	1.34	1.14	0.39	0.33	1.00	0.46	4.5	0.30	0.30
825	1.05	0.440	2.50	1.84	0.56	1.12	0.96	0.55	0.43	1.20	0.50	5.0	0.30	0.30
826	0.80	0.320	1.90	1.40	0.43	0.86	0.73	0.96	0.60	0.70	0.49	6.5	0.30	0.29
827	0.73	0.150	1.74	1.28	0.39	0.78	0.67	1.20	0.79	0.50	1.15	7.5	0.26	0.24
828	0.66	0.100	1.57	1.16	0.35	0.71	0.61	1.30	0.85	0.50	2.44	8.0	0.21	0.25
829	0.63	0.120	1.49	1.10	0.34	0.67	0.58	1.16	0.74	0.50	2.46	8.1	0.21	0.21
830	0.62	0.113	1.48	1.09	0.33	0.66	0.57	0.85	0.27	0.50	2.99	7.9	0.21	0.11
848	0.95	0.351	2.25	1.66	0.51	1.02	0.70	0.19	0.24	0.58	1.99	7.5	0.29	0.26
849	0.96	0.545	2.28	1.68	0.51	1.03	0.88	0.24	0.26	0.84	2.09	7.0	0.29	0.26
850	1.00	0.483	2.38	1.75	0.54	1.07	0.91	0.32	0.25	0.55	2.98	5.5	0.29	0.27
851	1.05	0.601	2.50	1.84	0.56	1.12	0.96	0.30	0.20	0.52	5.56	6.0	0.25	0.14
852	1.20	0.730	2.85	2.10	0.64	1.29	1.10	0.34	0.22	1.16	4.03	4.5	0.25	0.21
853	0.98	0.525	2.33	1.72	0.52	1.05	0.90	0.32	0.23	0.53	7.39	6.3	0.23	0.08
854	1.05	0.600	2.50	1.84	0.56	1.12	0.96	0.53	0.28	0.83	6.58	4.0	0.23	0.17
855	0.98	0.560	2.33	1.72	0.52	1.05	0.90	0.32	0.30	0.80	5.68	5.0	0.24	0.12
856	1.60	0.900	3.80	2.80	0.86	1.71	1.17	0.28	0.28	1.40	0.95	3.5	0.24	0.24
857	0.96	0.530	2.28	1.68	0.51	1.03	0.88	0.53	0.44	1.00	4.44	5.8	0.26	0.22
858	0.90	0.420	2.14	1.58	0.48	0.96	0.83	0.44	0.44	1.10	2.29	5.6	0.29	0.27
859	1.05	0.410	2.50	1.84	0.56	1.12	0.96	0.30	0.31	1.40	0.46	4.7	0.30	0.30
860	1.15	0.500	2.73	2.01	0.62	1.23	1.05	0.41	0.36	1.50	0.41	4.5	0.30	0.30
861	0.87	0.390	2.06	1.52	0.47	0.93	0.79	0.92	0.59	1.20	0.47	6.0	0.30	0.30
862	0.76	0.230	1.81	1.33	0.41	0.81	0.69	1.24	0.76	0.60	0.74	7.0	0.30	0.30
863	0.67	0.120	1.59	1.17	0.36	0.72	0.61	1.20	0.79	0.50	2.89	8.0	0.24	0.27
864	0.64	0.110	1.52	1.12	0.34	0.69	0.59	0.99	0.56	0.90	2.18	8.1	0.23	0.20
865	0.63	0.100	1.49	1.10	0.34	0.67	0.58	0.63	0.33	1.44	3.68	8.2	0.25	0.12

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
883	0.96	0.612	2.28	1.68	0.51	1.03	0.72	0.21	0.26	0.50	1.38	6.0	0.30	0.29
884	1.00	0.590	2.38	1.75	0.54	1.07	0.73	0.23	0.26	0.59	2.05	5.5	0.30	0.29
885	1.20	0.688	2.85	2.10	0.64	1.29	0.88	0.23	0.24	0.69	2.05	5.5	0.28	0.23
886	1.20	0.653	2.85	2.10	0.64	1.29	0.88	0.26	0.26	0.50	3.51	4.5	0.30	0.30
887	1.10	0.621	2.62	1.93	0.59	1.18	1.01	0.28	0.23	0.50	7.14	5.5	0.24	0.12
888	0.95	0.374	2.25	1.66	0.51	1.02	0.87	0.28	0.22	0.50	5.15	4.5	0.20	0.01
889	0.75	0.327	1.78	1.31	0.40	0.80	0.69	0.18	0.22	0.50	7.07	5.4	0.21	0.03
890	0.78	0.409	1.86	1.37	0.42	0.84	0.71	0.36	0.33	0.51	6.02	5.2	0.24	0.14
891	1.30	0.880	3.09	2.28	0.70	1.39	1.19	0.30	0.29	1.20	2.44	3.0	0.28	0.26
892	1.20	0.980	2.85	2.10	0.64	1.29	0.88	0.31	0.28	1.40	1.26	3.5	0.21	0.19
893	0.88	0.400	2.09	1.54	0.47	0.94	0.81	0.46	0.43	0.80	2.06	5.7	0.27	0.23
894	0.90	0.310	2.14	1.58	0.48	0.96	0.83	0.40	0.40	0.50	1.21	5.5	0.27	0.30
895	1.25	0.470	2.97	2.19	0.67	1.34	1.14	0.42	0.34	1.40	1.27	4.0	0.29	0.28
896	0.90	0.250	2.14	1.58	0.48	0.96	0.83	1.11	0.68	0.90	2.01	6.1	0.29	0.28
897	0.76	0.200	1.81	1.33	0.41	0.81	0.69	1.05	0.62	0.60	1.19	7.2	0.31	0.24
898	0.69	0.160	1.64	1.21	0.37	0.74	0.63	0.68	0.12	0.52	2.86	7.5	0.26	0.20
899	0.66	0.130	1.57	1.16	0.35	0.71	0.61	0.90	0.49	0.50	2.90	8.1	0.24	0.14
900	0.62	0.110	1.48	1.09	0.33	0.66	0.57	0.86	0.42	0.50	3.40	8.4	0.26	0.06
901	0.61	0.080	1.45	1.07	0.33	0.65	0.56	0.67	0.22	0.50	3.09	8.3	0.29	0.09
921	1.25	0.670	2.97	2.19	0.67	1.34	0.92	0.20	0.24	0.50	2.25	4.6	0.30	0.30
922	1.20	0.650	2.85	2.10	0.64	1.29	1.10	0.22	0.26	0.67	2.88	3.9	0.28	0.23
923	0.84	0.427	2.00	1.47	0.45	0.90	0.77	0.20	0.22	0.50	5.33	6.1	0.20	0.01
924	0.85	0.436	2.02	1.49	0.46	0.91	0.78	0.16	0.19	0.50	6.47	4.5	0.24	0.12
925	0.70	0.221	1.67	1.23	0.37	0.75	0.64	0.19	0.17	0.50	1.98	6.2	0.20	0.17
926	1.10	0.390	2.62	1.93	0.59	1.18	1.01	0.54	0.19	0.56	5.02	4.9	0.24	0.15
927	1.55	0.960	3.68	2.71	0.83	1.66	1.42	0.28	0.28	1.20	2.75	2.0	0.19	0.10
928	1.40	0.720	3.33	2.45	0.75	1.50	1.03	0.30	0.28	1.50	0.73	3.9	0.30	0.29
929	0.95	0.400	2.25	1.66	0.51	1.02	0.87	0.31	0.29	1.40	0.51	5.0	0.29	0.27
930	1.25	0.500	2.97	2.19	0.67	1.34	1.14	0.36	0.31	1.30	1.69	4.2	0.23	0.18
931	0.91	0.370	2.16	1.59	0.49	0.97	0.83	0.59	0.39	0.95	2.84	6.0	0.26	0.18
932	0.78	0.250	1.86	1.37	0.42	0.84	0.71	0.68	0.37	0.50	1.18	6.9	0.30	0.30
933	0.73	0.160	1.74	1.28	0.39	0.78	0.67	0.68	0.28	0.54	2.69	7.4	0.28	0.27
934	0.67	0.140	1.59	1.17	0.36	0.72	0.61	0.92	0.44	0.50	3.56	8.1	0.24	0.22
935	0.65	0.110	1.55	1.14	0.35	0.70	0.59	1.00	0.56	0.50	3.35	8.2	0.26	0.09
956	0.97	0.610	2.31	1.70	0.52	1.04	0.71	0.19	0.24	0.58	2.05	5.0	0.29	0.26
957	0.98	0.590	2.33	1.72	0.52	1.05	0.90	0.18	0.23	0.54	2.20	5.1	0.29	0.27
958	1.05	0.620	2.50	1.84	0.56	1.12	0.96	0.28	0.24	0.54	5.00	6.0	0.28	0.24
959	1.10	0.590	2.62	1.93	0.59	1.18	1.01	0.15	0.17	0.68	4.28	4.6	0.28	0.24
960	0.79	0.405	1.87	1.38	0.42	0.85	0.73	0.14	0.18	0.53	3.69	5.2	0.29	0.16
961	0.79	0.430	1.87	1.38	0.42	0.85	0.73	0.16	0.21	0.50	2.17	5.8	0.24	0.20
962	1.00	0.440	2.38	1.75	0.54	1.07	0.91	0.32	0.30	0.50	3.84	5.1	0.22	0.09
963	1.45	0.600	3.45	2.54	0.78	1.55	1.33	0.32	0.31	1.00	2.25	2.9	0.26	0.26
964	1.10	0.460	2.62	1.93	0.59	1.18	0.81	0.32	0.30	1.30	1.71	4.8	0.25	0.24
965	1.10	0.500	2.62	1.93	0.59	1.18	1.01	0.63	0.31	1.20	3.84	4.1	0.26	0.19
966	0.95	0.390	2.25	1.66	0.51	1.02	0.87	0.52	0.28	0.50	4.74	6.5	0.24	0.12
967	0.78	0.290	1.86	1.37	0.42	0.84	0.71	0.63	0.32	0.50	0.91	7.1	0.28	0.27
968	0.74	0.180	1.76	1.30	0.40	0.79	0.68	0.62	0.24	0.50	3.97	7.2	0.25	0.17
969	0.67	0.160	1.59	1.17	0.36	0.72	0.61	0.53	0.26	0.50	4.53	8.0	0.23	0.13
970	0.66	0.125	1.57	1.16	0.35	0.71	0.61	0.88	0.42	0.50	2.72	8.0	0.24	0.22
991	0.98	0.619	2.33	1.72	0.52	1.05	0.57	0.19	0.24	0.69	2.25	5.0	0.30	0.29

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
992	0.82	0.580	1.95	1.44	0.44	0.88	0.75	0.18	0.22	0.59	2.00	5.4	0.33	0.27
993	0.88	0.596	2.09	1.54	0.47	0.94	0.81	0.18	0.22	0.59	5.13	5.8	0.29	0.26
994	1.00	0.566	2.38	1.75	0.54	1.07	0.91	0.15	0.18	1.41	2.99	4.7	0.27	0.23
995	1.50	1.027	3.57	2.63	0.80	1.61	1.38	0.11	0.13	1.34	0.97	1.3	0.19	0.14
996	0.92	0.627	2.19	1.61	0.49	0.99	0.84	0.11	0.13	0.89	1.68	4.5	0.20	0.21
997	0.78	0.360	1.86	1.37	0.42	0.84	0.71	0.15	0.18	0.50	3.77	5.5	0.21	0.23
998	0.85	0.470	2.02	1.49	0.46	0.91	0.78	0.30	0.29	0.60	7.28	4.4	0.25	0.15
999	1.25	0.610	2.97	2.19	0.67	1.34	1.14	0.27	0.14	1.10	3.72	3.0	0.26	0.26
1000	1.20	0.700	2.85	2.10	0.64	1.29	0.88	0.17	0.21	1.24	2.73	4.0	0.21	0.16
1001	1.10	0.669	2.62	1.93	0.59	1.18	1.01	0.25	0.23	0.50	3.33	4.0	0.25	0.20
1002	0.86	0.480	2.05	1.51	0.46	0.92	0.79	0.40	0.26	0.50	1.39	5.8	0.26	0.26
1003	0.76	0.240	1.81	1.33	0.41	0.81	0.69	0.53	0.27	0.51	5.42	7.0	0.27	0.25
1004	0.68	0.170	1.62	1.19	0.36	0.73	0.63	0.42	0.18	0.50	6.80	7.5	0.21	0.03
1005	0.69	0.200	1.64	1.21	0.37	0.74	0.63	0.79	0.39	0.50	6.46	7.6	0.20	0.03
1026	1.10	0.652	2.62	1.93	0.59	1.18	0.81	0.18	0.24	0.86	2.05	5.0	0.29	0.27
1027	0.80	0.620	1.90	1.40	0.43	0.86	0.58	0.17	0.21	0.69	1.65	5.5	0.29	0.26
1028	0.78	0.550	1.86	1.37	0.42	0.84	0.71	0.18	0.22	0.55	2.34	5.5	0.40	0.23
1029	1.05	0.790	2.50	1.84	0.56	1.12	0.96	0.18	0.22	1.40	2.60	4.6	0.28	0.25
1031	1.55	1.060	3.68	2.71	0.83	1.66	1.14	0.09	0.11	1.32	0.90	2.0	0.15	0.11
1032	0.93	0.593	2.21	1.63	0.50	1.00	0.85	0.14	0.16	0.86	1.20	4.3	0.29	0.24
1033	0.74	0.305	1.76	1.30	0.40	0.79	0.68	0.18	0.23	1.08	3.63	4.6	0.23	0.22
1034	0.76	0.330	1.81	1.33	0.41	0.81	0.69	0.18	0.23	0.51	3.92	4.2	0.28	0.23
1035	1.20	0.580	2.85	2.10	0.64	1.29	1.10	0.18	0.22	0.79	4.19	3.8	0.23	0.15
1036	1.25	0.700	2.97	2.19	0.67	1.34	1.14	0.31	0.27	0.90	3.90	4.5	0.26	0.18
1037	0.88	0.370	2.09	1.54	0.47	0.94	0.81	0.49	0.28	0.56	2.58	6.3	0.29	0.27
1038	0.79	0.270	1.87	1.38	0.42	0.85	0.73	0.50	0.28	0.53	2.01	7.0	0.28	0.23
1039	0.68	0.163	1.62	1.19	0.36	0.73	0.63	0.57	0.30	0.50	2.74	7.8	0.22	0.12
1040	0.68	0.250	1.62	1.19	0.36	0.73	0.63	0.55	0.29	0.50	6.87	7.3	0.21	0.06
1067	1.65	1.280	3.92	2.89	0.88	1.77	1.21	0.08	0.10	1.14	0.41	1.9	0.13	0.06
1068	0.75	0.520	1.78	1.31	0.40	0.80	0.69	0.16	0.18	0.92	1.70	4.5	0.21	0.22
1069	0.65	0.290	1.55	1.14	0.35	0.70	0.59	0.19	0.23	0.56	3.15	5.2	0.26	0.18
1070	0.70	0.345	1.67	1.23	0.37	0.75	0.64	0.20	0.22	0.50	4.47	5.2	0.26	0.18
1071	0.95	0.550	2.25	1.66	0.51	1.02	0.87	0.24	0.21	0.74	7.48	4.5	0.22	0.08
1072	1.05	0.470	2.50	1.84	0.56	1.12	0.96	0.27	0.25	1.45	1.47	5.5	0.27	0.27
1073	1.10	0.410	2.62	1.93	0.59	1.18	1.01	0.39	0.28	1.27	1.55	5.0	0.28	0.28
1074	0.95	0.370	2.25	1.66	0.51	1.02	0.87	0.48	0.28	1.11	1.52	6.0	0.24	0.21
1075	0.72	0.260	1.71	1.26	0.39	0.77	0.66	0.59	0.32	0.61	4.28	6.8	0.21	0.05
1102	1.60	1.280	2.80	2.80	0.86	1.71	1.17	0.15	0.11	0.87	2.67	2.0	0.20	0.10
1103	0.90	0.618	2.14	1.58	0.48	0.96	0.83	0.13	0.16	1.05	1.33	4.9	0.18	0.19
1104	0.67	0.255	1.59	1.17	0.36	0.72	0.61	0.17	0.21	0.50	1.98	5.5	0.27	0.24
1105	0.64	0.236	1.52	1.12	0.34	0.69	0.59	0.18	0.21	0.50	1.87	5.7	0.27	0.21
1106	0.69	0.300	1.64	1.21	0.37	0.74	0.63	0.18	0.21	0.58	3.86	6.0	0.29	0.18
1107	0.79	0.250	1.87	1.38	0.42	0.85	0.73	0.20	0.24	0.73	3.26	5.5	0.30	0.29
1108	0.96	0.320	2.28	1.68	0.51	1.03	0.88	0.23	0.28	0.78	1.56	5.8	0.28	0.28
1109	1.05	0.380	2.50	1.84	0.56	1.12	0.96	0.25	0.29	0.67	1.67	5.2	0.28	0.28
1110	1.00	0.370	2.38	1.75	0.54	1.07	0.91	0.49	0.35	0.55	3.86	5.9	0.23	0.09
1111	0.65	0.230	1.55	1.14	0.35	0.70	0.59	0.76	0.36	0.50	5.83	8.0	0.20	0.09
1137	1.25	0.921	2.19	2.19	0.67	1.34	0.92	0.25	0.21	0.77	2.10	4.1	0.27	0.21
1138	0.75	0.233	1.78	1.31	0.40	0.80	0.69	0.20	0.23	0.57	3.10	5.5	0.26	0.20
1139	0.74	0.290	1.76	1.30	0.40	0.79	0.68	0.22	0.25	0.50	1.99	5.2	0.28	0.25

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
1140	0.71	0.270	1.68	1.24	0.38	0.76	0.65	0.30	0.26	0.53	2.08	4.6	0.30	0.29
1141	0.66	0.186	1.57	1.16	0.35	0.71	0.61	0.19	0.21	0.50	1.95	6.2	0.28	0.20
1142	0.68	0.170	1.62	1.19	0.36	0.73	0.63	0.20	0.23	0.50	4.46	6.3	0.27	0.21
1143	0.80	0.290	1.90	1.40	0.43	0.86	0.73	0.30	0.29	0.72	3.89	5.0	0.28	0.23
1144	0.90	0.310	2.14	1.58	0.48	0.96	0.83	0.37	0.35	1.11	1.66	6.1	0.30	0.30
1145	0.90	0.280	2.14	1.58	0.48	0.96	0.83	0.64	0.44	0.73	1.65	6.6	0.30	0.29
1146	0.68	0.190	1.62	1.19	0.36	0.73	0.63	0.83	0.45	0.51	4.23	8.1	0.24	0.18
1147	0.64	0.120	1.52	1.12	0.34	0.69	0.59	0.88	0.51	0.50	2.88	8.3	0.20	0.12
1148	0.65	0.200	1.55	1.14	0.35	0.70	0.59	0.61	0.30	0.50	1.76	8.5	0.20	0.18
1172	0.92	0.646	2.19	1.61	0.49	0.99	0.84	0.19	0.24	1.01	1.98	4.5	0.30	0.30
1173	0.69	0.350	1.64	1.21	0.37	0.74	0.63	0.21	0.25	0.57	2.14	5.6	0.32	0.21
1174	0.72	0.292	1.71	1.26	0.39	0.77	0.66	0.20	0.24	0.64	2.05	5.0	0.30	0.26
1175	0.82	0.405	1.95	1.44	0.44	0.88	0.75	0.21	0.24	1.39	2.07	3.8	0.26	0.18
1176	0.70	0.260	1.67	1.23	0.37	0.75	0.64	0.25	0.28	0.50	2.09	4.8	0.32	0.26
1177	0.65	0.160	1.55	1.14	0.35	0.70	0.59	0.24	0.21	0.50	2.78	6.3	0.30	0.15
1178	0.69	0.142	1.64	1.21	0.37	0.74	0.63	0.27	0.26	0.65	2.61	6.0	0.28	0.23
1179	0.78	0.280	1.86	1.37	0.42	0.84	0.71	0.33	0.31	0.64	1.82	6.1	0.30	0.30
1180	0.90	0.460	2.14	1.58	0.48	0.96	0.83	0.51	0.36	1.10	2.65	5.4	0.29	0.27
1181	0.70	0.280	1.67	1.23	0.37	0.75	0.64	0.82	0.47	0.52	1.63	7.0	0.29	0.27
1182	0.67	0.230	1.59	1.17	0.36	0.72	0.61	0.91	0.54	0.50	2.66	8.2	0.25	0.11
1183	0.65	0.155	1.55	1.14	0.35	0.70	0.59	1.06	0.63	0.50	2.10	8.3	0.31	0.14
1207	0.80	0.486	1.90	1.40	0.43	0.86	0.73	0.22	0.26	0.57	4.95	5.3	0.27	0.21
1208	0.70	0.375	1.67	1.23	0.37	0.75	0.64	0.21	0.26	0.59	2.61	5.5	0.29	0.26
1209	0.79	0.341	1.87	1.38	0.42	0.85	0.73	0.20	0.24	1.10	2.04	4.5	0.27	0.27
1210	0.78	0.374	1.86	1.37	0.42	0.84	0.71	0.33	0.27	0.75	2.06	4.2	0.26	0.26
1211	0.69	0.228	1.62	1.19	0.36	0.73	0.63	0.27	0.26	0.66	2.07	4.8	0.30	0.30
1212	0.76	0.247	1.81	1.33	0.41	0.81	0.69	0.26	0.29	1.02	5.23	5.0	0.25	0.21
1213	0.69	0.190	1.64	1.21	0.37	0.74	0.63	0.42	0.26	0.65	3.18	6.3	0.28	0.28
1214	0.66	0.210	1.57	1.16	0.35	0.71	0.61	0.53	0.31	0.55	2.67	6.2	0.29	0.27
1215	0.72	0.250	1.71	1.26	0.39	0.77	0.66	0.71	0.37	0.50	3.64	5.8	0.26	0.18
1216	0.69	0.350	1.64	1.21	0.37	0.74	0.63	0.70	0.44	0.50	2.57	7.5	0.29	0.26
1217	0.66	0.200	1.57	1.16	0.35	0.71	0.61	0.88	0.47	0.54	2.96	8.3	0.22	0.15
1218	0.68	0.100	1.62	1.19	0.36	0.73	0.63	0.89	0.50	0.50	2.31	8.2	0.23	0.16
1243	0.80	0.366	1.90	1.40	0.43	0.86	0.73	0.23	0.30	0.50	4.25	5.5	0.28	0.24
1244	0.69	0.322	1.64	1.21	0.37	0.74	0.63	0.23	0.29	0.50	3.52	6.0	0.28	0.24
1245	0.68	0.352	1.62	1.19	0.36	0.73	0.63	0.24	0.27	0.57	2.22	5.5	0.28	0.25
1246	0.65	0.204	1.55	1.14	0.35	0.70	0.59	0.29	0.29	0.52	1.99	6.2	0.28	0.24
1247	0.64	0.269	1.52	1.12	0.34	0.69	0.59	0.36	0.31	0.77	2.43	5.8	0.30	0.30
1248	0.63	0.183	1.49	1.10	0.34	0.67	0.58	0.42	0.28	0.50	1.77	6.8	0.27	0.26
1249	0.66	0.200	1.57	1.16	0.35	0.71	0.61	0.55	0.31	0.51	2.75	7.0	0.29	0.26
1250	0.67	0.150	1.59	1.17	0.36	0.72	0.61	0.71	0.38	0.63	3.99	7.5	0.25	0.19
1251	0.66	0.140	1.57	1.16	0.35	0.71	0.61	0.78	0.43	0.54	3.11	7.8	0.21	0.16
1252	0.68	0.150	1.62	1.19	0.36	0.73	0.63	0.82	0.44	0.61	2.44	7.8	0.22	0.25
1253	0.72	0.130	1.71	1.26	0.39	0.77	0.66	0.75	0.40	0.50	2.21	7.5	0.25	0.25
1254	0.66	0.130	1.57	1.16	0.35	0.71	0.61	0.78	0.41	0.50	1.84	7.9	0.26	0.24
1255	0.64	0.053	1.52	1.12	0.34	0.69	0.59	0.82	0.46	0.50	2.71	8.5	0.22	0.21
1256	0.62	0.070	1.48	1.09	0.33	0.66	0.57	0.88	0.51	0.50	2.12	9.2	0.30	0.17
1257	0.58	0.060	1.38	1.02	0.31	0.62	0.53	0.85	0.49	0.50	2.51	9.4	0.27	0.11
1280	0.69	0.341	1.64	1.21	0.37	0.74	0.63	0.49	0.29	0.52	2.21	5.4	0.28	0.24
1281	0.80	0.344	1.90	1.40	0.43	0.86	0.73	0.53	0.34	0.83	2.95	5.0	0.28	0.27

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
1282	0.68	0.209	1.62	1.19	0.36	0.73	0.63	0.50	0.39	0.55	2.57	6.8	0.29	0.26
1283	0.63	0.167	1.49	1.10	0.34	0.67	0.58	0.66	0.37	0.50	1.97	7.2	0.27	0.22
1284	0.65	0.151	1.55	1.14	0.35	0.70	0.59	0.71	0.36	0.50	2.85	7.3	0.25	0.18
1285	0.67	0.230	1.59	1.17	0.36	0.72	0.61	0.85	0.46	0.50	2.95	7.2	0.25	0.27
1286	0.71	0.234	1.68	1.24	0.38	0.76	0.65	0.85	0.46	0.50	1.65	7.0	0.28	0.28
1287	0.75	0.220	1.78	1.31	0.40	0.80	0.69	0.80	0.43	0.50	2.14	7.3	0.23	0.27
1288	0.72	0.225	1.71	1.26	0.39	0.77	0.66	0.84	0.43	0.50	1.62	7.2	0.29	0.30
1289	0.65	0.070	1.55	1.14	0.35	0.70	0.59	0.94	0.55	0.50	3.35	8.2	0.25	0.21
1290	0.58	0.035	1.38	1.02	0.31	0.62	0.53	1.17	0.47	0.50	4.59	8.8	0.30	0.08
1291	0.57	0.060	1.36	1.00	0.31	0.64	0.52	0.65	0.25	0.50	2.33	9.4	0.25	0.11
1292	0.61	0.048	1.45	1.07	0.33	0.65	0.56	0.96	0.47	0.50	2.54	9.5	0.18	0.03
1293	0.62	0.030	1.48	1.09	0.33	0.66	0.57	0.84	0.39	0.50	1.20	9.2	0.29	0.02
1316	0.82	0.416	1.95	1.44	0.44	0.88	0.75	0.67	0.36	0.65	2.25	5.4	0.30	0.30
1317	0.82	0.421	1.95	1.44	0.44	0.88	0.75	0.51	0.36	0.88	2.25	5.2	0.30	0.30
1318	0.66	0.212	1.57	1.16	0.35	0.71	0.61	0.56	0.33	0.50	2.95	7.0	0.27	0.23
1319	0.68	0.207	1.62	1.19	0.36	0.73	0.63	0.66	0.35	0.50	2.96	7.2	0.22	0.18
1320	0.72	0.393	1.71	1.26	0.39	0.77	0.66	0.80	0.52	0.50	1.42	5.5	0.30	0.30
1321	0.82	0.330	1.95	1.44	0.44	0.88	0.75	0.73	0.37	0.50	1.13	6.5	0.30	0.30
1322	0.70	0.270	1.67	1.23	0.37	0.75	0.64	0.79	0.39	0.50	1.52	7.2	0.30	0.30
1323	0.67	0.150	1.59	1.17	0.36	0.72	0.61	0.78	0.39	0.50	2.09	8.2	0.27	0.27
1324	0.62	0.057	1.48	1.09	0.33	0.66	0.57	0.98	0.58	0.50	2.81	8.4	0.28	0.06
1325	0.61	0.047	1.45	1.07	0.33	0.65	0.56	0.93	0.27	0.50	4.49	8.7	0.25	0.01
1326	0.61	0.036	1.45	1.07	0.33	0.65	0.56	1.01	0.28	0.50	1.67	9.3	0.38	0.01
1327	0.63	0.043	1.48	1.09	0.33	0.67	0.58	1.23	0.39	0.50	2.46	9.5	0.22	0.02
1328	0.63	0.061	1.49	1.10	0.34	0.67	0.58	0.66	0.24	0.50	2.49	9.5	0.21	0.03
1350	0.79	0.327	1.87	1.38	0.42	0.85	0.73	0.60	0.31	0.58	1.98	5.6	0.30	0.30
1351	0.72	0.248	1.71	1.26	0.39	0.77	0.60	0.44	0.31	0.54	2.05	6.4	0.30	0.29
1352	0.68	0.240	1.62	1.19	0.36	0.73	0.63	0.53	0.32	0.50	2.14	6.3	0.30	0.30
1353	0.68	0.226	1.62	1.19	0.36	0.73	0.63	0.51	0.29	0.50	1.96	6.9	0.29	0.30
1354	0.65	0.233	1.55	1.14	0.35	0.70	0.59	0.61	0.31	0.50	3.60	7.2	0.25	0.21
1355	0.66	0.129	1.57	1.16	0.35	0.71	0.61	0.61	0.31	0.50	4.08	7.3	0.23	0.18
1356	0.67	0.137	1.59	1.17	0.36	0.72	0.61	0.56	0.27	0.50	3.84	7.4	0.24	0.24
1357	0.66	0.110	1.57	1.16	0.35	0.71	0.61	0.75	0.42	0.50	2.26	8.2	0.24	0.22
1358	0.65	0.100	1.55	1.14	0.35	0.70	0.59	0.44	0.25	0.50	1.84	8.4	0.21	0.15
1359	0.66	0.138	1.57	1.16	0.35	0.71	0.61	0.88	0.51	0.50	1.15	8.5	0.20	0.17
1360	0.64	0.076	1.51	1.11	0.34	0.68	0.58	1.03	0.60	0.50	1.90	8.6	0.26	0.02
1361	0.63	0.065	1.49	1.10	0.34	0.67	0.58	0.82	0.28	0.50	3.37	9.2	0.28	0.01
1362	0.65	0.052	1.55	1.14	0.35	0.70	0.59	1.11	0.49	0.50	3.42	9.5	0.22	0.10
1363	0.63	0.065	1.49	1.10	0.34	0.67	0.58	1.25	0.44	0.50	2.70	9.5	0.23	0.01
1386	0.74	0.363	1.76	1.30	0.40	0.79	0.68	0.51	0.33	0.70	1.84	6.4	0.30	0.30
1387	0.70	0.325	1.67	1.23	0.37	0.75	0.64	0.49	0.27	0.75	2.23	6.4	0.28	0.26
1388	0.69	0.218	1.64	1.21	0.37	0.74	0.63	0.50	0.27	0.80	2.05	7.0	0.28	0.27
1389	0.67	0.208	1.59	1.17	0.36	0.72	0.61	0.64	0.32	0.50	2.25	7.1	0.26	0.26
1390	0.69	0.205	1.64	1.21	0.37	0.74	0.63	0.66	0.34	0.50	2.25	7.2	0.28	0.27
1391	0.69	0.171	1.64	1.21	0.37	0.74	0.63	0.73	0.36	0.50	4.09	7.3	0.27	0.23
1392	0.69	0.148	1.64	1.21	0.37	0.74	0.63	0.62	0.31	0.50	5.02	8.0	0.25	0.15
1393	0.70	0.243	1.67	1.23	0.37	0.75	0.64	0.73	0.39	0.50	5.09	8.2	0.23	0.14
1394	0.71	0.200	1.68	1.24	0.38	0.76	0.65	0.86	0.45	0.50	1.85	8.3	0.21	0.18
1395	0.67	0.105	1.59	1.17	0.36	0.72	0.61	1.08	0.65	0.50	2.72	8.5	0.20	0.04
1396	0.66	0.064	1.57	1.16	0.35	0.71	0.61	0.73	0.24	0.50	3.42	9.0	0.20	0.03

No.	P	Q	S ₉₀	S ₉₅	NO ₃	NH ₄	BC _d	BC _u	N _u	N _i	w	T	xH	xE
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹									°C	m	m
1397	0.68	0.063	1.60	1.18	0.36	0.70	0.62	0.94	0.56	0.50	2.84	9.2	0.20	0.06
1422	0.75	0.334	1.76	1.30	0.40	0.80	0.68	0.58	0.30	0.66	2.18	6.7	0.29	0.30
1423	0.71	0.259	1.68	1.24	0.38	0.76	0.65	0.58	0.28	0.53	2.25	7.2	0.29	0.27
1424	0.69	0.252	1.64	1.21	0.37	0.74	0.63	0.59	0.27	0.50	2.25	6.8	0.27	0.24
1425	0.78	0.252	1.86	1.37	0.42	0.84	0.71	0.75	0.36	0.58	2.25	6.6	0.29	0.28
1426	0.72	0.214	1.71	1.26	0.39	0.77	0.66	0.71	0.35	0.50	2.21	7.2	0.29	0.27
1427	0.70	0.280	1.67	1.23	0.37	0.75	0.64	0.62	0.34	0.50	2.74	7.6	0.28	0.26
1428	0.75	0.327	1.78	1.31	0.40	0.80	0.69	0.72	0.45	0.50	6.95	8.0	0.23	0.14
1429	0.88	0.501	2.09	1.54	0.47	0.94	0.81	0.76	0.37	0.50	1.36	6.8	0.30	0.29
1430	0.69	0.227	1.63	1.20	0.37	0.73	0.63	0.66	0.28	0.50	2.22	8.3	0.19	0.21
1431	0.69	0.190	1.64	1.21	0.37	0.74	0.63	1.08	0.65	0.50	3.12	8.5	0.20	0.17
1432	0.69	0.180	1.64	1.21	0.37	0.74	0.63	0.87	0.46	0.50	1.19	8.5	0.21	0.15
1457	0.84	0.388	2.00	1.47	0.45	0.90	0.77	0.71	0.32	0.93	2.16	6.4	0.30	0.30
1458	0.84	0.350	2.00	1.47	0.45	0.96	0.77	0.67	0.31	0.79	2.25	6.4	0.28	0.29
1459	0.82	0.311	1.95	1.44	0.44	0.88	0.75	0.60	0.27	0.61	2.25	6.8	0.30	0.29
1460	0.80	0.300	1.90	1.40	0.43	0.86	0.73	0.69	0.33	0.50	2.25	6.9	0.30	0.30
1461	0.76	0.270	1.81	1.33	0.41	0.81	0.69	0.74	0.36	0.50	2.24	7.0	0.29	0.27
1462	0.73	0.312	1.72	1.27	0.39	0.78	0.66	0.72	0.36	0.50	2.50	7.2	0.28	0.26
1463	0.76	0.364	1.81	1.33	0.41	0.81	0.69	0.77	0.38	0.50	2.35	7.5	0.27	0.24
1464	0.96	0.693	2.28	1.68	0.51	1.03	0.88	0.81	0.56	0.50	1.40	5.5	0.30	0.30
1465	0.81	0.514	1.93	1.42	0.43	0.87	0.74	0.83	0.37	0.50	1.21	7.0	0.28	0.30
1466	0.84	0.325	2.00	1.47	0.45	0.90	0.77	0.84	0.43	0.50	1.78	7.0	0.26	0.29
1494	0.83	0.404	1.97	1.45	0.44	0.89	0.76	0.72	0.35	0.59	2.05	6.5	0.30	0.30
1495	0.89	0.391	2.12	1.56	0.48	0.95	0.81	0.68	0.32	0.56	2.03	5.6	0.30	0.30
1496	0.85	0.360	2.02	1.49	0.46	0.91	0.78	0.62	0.31	0.81	2.07	6.5	0.30	0.30
1497	0.80	0.350	1.90	1.40	0.43	0.86	0.73	0.62	0.31	0.72	2.15	6.5	0.29	0.27
1498	0.78	0.310	1.86	1.37	0.42	0.84	0.71	0.71	0.34	0.67	1.42	7.0	0.30	0.29
1499	0.85	0.495	2.02	1.49	0.46	0.91	0.78	0.67	0.34	0.91	2.07	6.5	0.30	0.30
1500	0.88	0.470	2.09	1.54	0.47	0.94	0.81	0.67	0.34	0.73	2.15	6.8	0.29	0.30
1532	1.02	0.486	2.43	1.79	0.55	1.09	0.93	0.63	0.32	0.74	1.70	5.5	0.30	0.30
1533	0.92	0.451	2.19	1.61	0.49	0.99	0.84	0.50	0.20	0.51	1.82	6.4	0.30	0.29
1534	0.92	0.520	2.19	1.61	0.49	0.99	0.84	0.67	0.34	0.89	1.80	5.5	0.30	0.30
1569	1.05	0.710	2.50	1.84	0.56	1.12	0.96	0.69	0.36	0.56	1.95	5.5	0.30	0.30

ANNEX 4

Critical loads of acidity for surface and ground waters - input data for calculation

No.	-	number of grid cell	
P	-	precipitation	[m.yr ⁻¹]
Q	-	runoff	[m.yr ⁻¹]
S_{dep}	-	wet deposition of sulphate - 1995	[keq.ha ⁻¹ .yr ⁻¹]
Ca	-	calcium concentration in runoff water - 1995	[meq.l ⁻¹]
Mg	-	magnesium concentration in runoff water - 1995	[meq.l ⁻¹]
SO_{4r}	-	sulphate concentration in runoff water - 1995	[meq.l ⁻¹]

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
152	0.59	0.058	0.515	5.143	2.388	2.342	3.743	1.127	0.607
153	0.56	0.034	0.490	3.937	1.757	1.304	3.743	1.127	0.607
183	0.56	0.046	0.490	7.417	3.298	5.450	4.750	1.219	1.943
184	0.58	0.055	0.510	5.397	2.149	3.152	4.760	1.217	1.941
185	0.62	0.100	0.545	6.464	2.555	3.473	7.435	1.900	2.713
186	0.76	0.287	0.665	3.340	1.468	2.171	4.516	1.258	1.941
187	0.60	0.127	0.525	6.262	2.771	2.844	3.623	1.102	0.750
188	0.57	0.029	0.500	5.240	2.157	1.969	3.623	1.102	0.750
189	0.56	0.016	0.490	4.000	1.653	1.134	3.743	1.127	0.607
190	0.55	0.013	0.480	4.469	2.244	1.532	3.743	1.127	0.607
191	0.55	0.009	0.480	4.667	2.205	1.899	4.667	2.205	1.899
192	0.55	0.009	0.480	3.944	1.603	0.767	3.944	1.603	0.767
218	0.59	0.096	0.515	5.858	3.418	3.012	5.452	1.738	1.937
219	0.64	0.124	0.560	4.460	1.647	2.147	5.452	1.738	1.937
220	0.68	0.192	0.595	5.179	1.264	1.993	5.179	1.264	1.993
221	0.82	0.290	0.720	3.434	1.881	2.113	3.973	1.242	0.863
222	0.59	0.163	0.515	6.663	5.377	4.078	3.973	1.242	0.863
223	0.58	0.032	0.505	4.785	1.955	1.477	3.886	1.308	0.876
224	0.57	0.024	0.495	6.554	3.857	3.352	6.836	2.778	2.421
225	0.55	0.016	0.480	5.576	3.435	2.700	6.836	2.778	2.421
226	0.55	0.013	0.480	4.523	2.644	1.996	5.180	1.787	1.276
227	0.55	0.009	0.480	4.416	3.380	2.589	4.675	2.056	1.879
228	0.55	0.009	0.480	4.599	3.550	2.332	4.675	2.056	1.879
229	0.55	0.009	0.480	5.466	5.072	3.616	4.675	2.056	1.879
252	0.57	0.047	0.500	5.758	3.088	3.768	4.388	1.088	1.742
253	0.62	0.102	0.545	4.520	2.181	2.574	4.862	1.575	1.249
254	0.68	0.192	0.590	5.425	1.578	1.587	4.862	1.575	1.249
255	0.80	0.404	0.595	2.523	0.976	1.138	4.862	1.575	1.249
256	0.75	0.367	0.655	5.259	3.247	3.661	3.662	1.252	0.821
257	0.59	0.088	0.515	5.097	5.554	1.917	3.662	1.252	0.821
258	0.58	0.038	0.510	5.942	3.895	2.825	3.662	1.252	0.821
259	0.57	0.027	0.500	6.391	3.828	3.701	3.624	1.250	0.796
260	0.56	0.022	0.485	6.015	3.415	3.469	3.624	1.250	0.796
261	0.55	0.016	0.480	5.801	3.338	3.097	3.966	1.475	0.901
262	0.55	0.013	0.480	5.488	3.671	3.487	3.992	1.548	1.056
263	0.55	0.013	0.480	6.894	3.965	4.003	4.675	2.056	1.879
264	0.56	0.013	0.490	5.303	4.739	3.922	4.675	2.056	1.879
287	0.60	0.058	0.525	5.626	3.008	3.586	7.614	2.103	3.561
288	0.63	0.107	0.550	5.203	2.242	2.682	7.614	2.103	3.561
289	0.68	0.146	0.595	4.640	1.596	1.602	4.862	1.575	1.249
290	0.82	0.356	0.720	3.633	1.149	1.106	4.509	3.251	1.461
291	0.66	0.230	0.580	6.058	3.990	2.406	4.509	3.251	1.461
292	0.59	0.085	0.515	6.817	6.565	2.659	4.509	3.251	1.461
293	0.58	0.044	0.510	6.633	4.448	1.850	6.025	2.891	1.848
294	0.57	0.038	0.500	6.117	5.014	3.295	6.025	2.891	1.848
295	0.56	0.038	0.490	7.165	5.711	4.289	4.500	1.419	1.178
296	0.55	0.025	0.480	8.073	3.529	4.310	3.966	1.475	0.901
297	0.55	0.016	0.480	7.268	3.603	3.581	3.966	1.475	0.901
298	0.55	0.016	0.480	7.429	3.552	3.540	3.966	1.475	0.901

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
299	0.57	0.016	0.500	5.995	3.537	2.628	3.830	1.225	1.006
300	0.56	0.016	0.490	4.730	4.045	3.763	3.830	1.225	1.006
321	0.57	0.072	0.500	7.831	3.183	5.163	3.882	0.846	1.508
322	0.62	0.124	0.545	7.832	4.601	3.707	3.882	0.846	1.508
323	0.66	0.117	0.580	5.373	1.912	3.007	10.142	2.788	3.714
324	0.68	0.142	0.595	4.109	1.589	1.654	4.862	1.575	1.249
325	0.80	0.224	0.700	5.854	2.513	1.708	4.509	3.251	1.461
326	0.65	0.083	0.570	6.632	4.788	1.878	4.509	3.251	1.461
327	0.59	0.047	0.515	6.380	4.074	1.739	4.509	3.251	1.461
328	0.58	0.054	0.510	6.865	5.805	3.567	3.024	1.283	0.820
329	0.57	0.055	0.500	6.478	4.968	4.968	3.024	1.283	0.820
330	0.56	0.041	0.490	7.397	4.487	4.401	2.733	1.336	0.904
331	0.55	0.035	0.480	7.513	5.237	4.689	2.733	1.336	0.904
332	0.55	0.028	0.480	7.536	3.934	3.923	2.733	1.336	0.904
333	0.56	0.027	0.490	6.481	3.357	2.761	4.692	2.067	1.671
334	0.57	0.025	0.500	6.872	5.254	4.940	4.692	2.067	1.671
335	0.57	0.023	0.500	6.148	6.179	3.259	6.148	6.179	3.259
336	0.56	0.023	0.490	7.015	6.619	4.475	7.015	6.619	4.475
356	0.56	0.091	0.490	7.227	3.211	3.489	3.882	0.846	1.508
357	0.65	0.169	0.570	7.401	3.408	2.603	3.882	0.846	1.508
358	0.68	0.081	0.595	7.575	3.069	2.398	8.694	2.547	13.138
359	0.69	0.129	0.605	5.683	2.392	1.437	5.683	2.392	1.437
360	0.78	0.165	0.685	5.871	2.694	1.282	4.509	3.251	1.461
361	0.65	0.101	0.570	6.959	5.523	1.561	4.509	3.251	1.461
362	0.59	0.057	0.515	6.058	4.812	1.934	2.992	1.209	0.838
363	0.59	0.090	0.515	7.343	5.901	3.914	4.333	2.059	1.760
364	0.58	0.098	0.510	6.019	6.088	2.245	3.024	1.283	0.820
365	0.57	0.047	0.500	4.203	5.209	1.521	3.024	1.283	0.820
366	0.56	0.044	0.490	5.261	5.965	3.104	2.733	1.336	0.904
367	0.56	0.036	0.490	5.192	4.121	2.104	4.692	2.067	1.671
368	0.57	0.041	0.500	6.249	4.362	2.642	4.692	2.067	1.671
369	0.58	0.044	0.510	6.523	5.604	3.690	4.692	2.067	1.671
370	0.59	0.041	0.515	5.662	6.568	2.458	5.662	6.568	2.458
371	0.57	0.038	0.500	6.571	6.851	3.831	6.571	6.851	3.831
372	0.56	0.030	0.490	6.762	6.366	5.694	6.762	6.366	5.694
392	0.72	0.217	0.630	8.055	3.330	4.334	7.347	2.547	13.138
393	0.73	0.194	0.640	7.208	2.510	2.306	6.935	1.897	1.863
394	0.72	0.198	0.630	5.509	2.950	1.540	6.935	1.897	1.863
395	0.70	0.145	0.615	6.214	3.515	1.470	7.607	1.873	1.958
396	0.64	0.091	0.605	5.220	3.881	1.259	2.992	1.209	0.838
397	0.59	0.089	0.515	6.788	4.227	3.077	2.992	1.209	0.838
398	0.61	0.114	0.535	6.501	5.732	1.748	2.992	1.209	0.838
399	0.62	0.071	0.545	6.801	4.805	2.080	2.992	1.209	0.838
400	0.59	0.066	0.515	6.659	7.281	2.322	4.625	1.800	1.552
401	0.57	0.053	0.500	5.541	6.740	1.927	4.408	1.934	1.667
402	0.57	0.047	0.500	5.357	5.892	2.259	4.408	1.934	1.667
403	0.58	0.050	0.510	5.906	6.332	2.956	3.851	2.226	2.126
404	0.60	0.061	0.525	5.275	5.869	1.702	3.851	2.226	2.126
405	0.59	0.058	0.515	5.364	6.425	1.754	2.092	0.976	1.019

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
406	0.57	0.053	0.500	6.802	7.100	2.862	2.092	0.976	1.019
407	0.56	0.038	0.490	6.627	8.305	4.468	2.092	0.976	1.019
408	0.56	0.032	0.990	6.190	7.863	4.299	3.784	1.189	0.813
428	0.77	0.233	0.675	6.244	1.592	1.847	8.679	1.686	1.300
429	0.76	0.172	0.665	6.362	2.563	1.900	7.607	1.889	1.958
430	0.67	0.145	0.585	6.649	3.395	1.582	2.992	1.209	0.838
431	0.63	0.075	0.550	7.940	3.953	3.722	2.992	1.209	0.838
432	0.65	0.157	0.570	6.261	3.806	1.626	2.992	1.209	0.838
433	0.62	0.079	0.545	6.249	5.599	1.517	4.625	1.800	1.552
434	0.65	0.058	0.570	6.668	6.283	2.781	4.625	1.800	1.552
435	0.65	0.089	0.570	6.162	3.189	1.835	4.625	1.800	1.552
436	0.58	0.085	0.510	5.569	6.697	1.653	4.775	2.057	1.686
437	0.58	0.090	0.510	5.714	6.470	1.819	3.543	2.001	1.540
438	0.59	0.097	0.515	5.813	6.123	1.744	3.851	2.226	2.126
439	0.62	0.090	0.545	5.529	5.482	1.103	1.980	0.956	0.909
440	0.59	0.060	0.515	5.447	5.394	1.293	2.092	0.976	1.019
441	0.57	0.044	0.500	5.333	5.838	1.738	2.092	0.976	1.019
442	0.57	0.054	0.500	7.098	7.359	4.646	2.092	0.976	1.019
443	0.57	0.029	0.500	6.576	5.660	3.705	3.784	1.189	0.813
464	0.75	0.198	0.655	6.273	1.792	1.296	2.991	1.465	0.933
465	0.69	0.101	0.605	5.936	2.997	1.612	2.991	1.465	0.933
466	0.68	0.138	0.595	5.910	2.713	1.705	2.992	1.209	0.838
467	0.70	0.217	0.615	4.913	2.113	1.112	4.625	1.800	1.552
468	0.66	0.096	0.580	6.824	5.049	2.112	4.600	1.734	1.566
469	0.68	0.081	0.595	6.041	3.790	1.864	4.600	1.734	1.566
470	0.75	0.160	0.655	5.066	2.406	1.585	2.950	1.400	1.210
471	0.59	0.101	0.515	6.030	4.799	1.736	2.950	1.400	1.210
472	0.59	0.110	0.515	5.939	3.865	1.352	3.543	2.001	1.540
473	0.62	0.106	0.545	6.629	5.127	1.412	1.980	0.956	0.909
474	0.59	0.073	0.515	6.374	5.989	1.961	1.980	0.956	0.909
475	0.58	0.038	0.510	8.131	6.234	3.177	8.131	6.234	3.177
476	0.58	0.050	0.510	6.231	5.315	2.788	2.092	0.976	1.019
499	0.75	0.161	0.655	6.032	1.477	1.252	2.991	1.465	0.933
500	0.65	0.123	0.570	5.293	2.542	1.641	2.991	1.465	0.933
501	0.80	0.291	0.700	2.680	1.403	0.683	4.600	1.734	1.566
502	0.68	0.224	0.595	3.389	1.701	1.008	4.600	1.734	1.566
503	0.66	0.087	0.580	6.791	3.780	2.067	4.600	1.734	1.566
504	0.75	0.124	0.655	3.836	1.650	1.341	4.600	1.734	1.566
505	0.75	0.243	0.655	2.593	1.100	0.911	2.950	1.400	1.210
506	0.65	0.117	0.570	4.818	2.224	1.052	2.950	1.400	1.210
507	0.60	0.235	0.525	5.920	2.860	1.202	1.980	0.956	0.909
508	0.65	0.120	0.570	5.628	2.711	2.210	1.980	0.956	0.909
509	0.63	0.065	0.550	6.672	3.355	2.335	1.980	0.956	0.909
510	0.62	0.072	0.545	7.152	3.768	2.791	2.932	1.419	1.545
511	0.59	0.079	0.515	7.626	5.050	3.336	2.932	1.419	1.545
534	0.76	0.211	0.665	5.591	1.984	1.388	2.783	1.359	0.983
535	0.68	0.173	0.095	5.230	1.995	1.266	2.234	1.359	0.983
536	0.75	0.311	0.655	1.980	1.094	0.602	2.958	2.417	1.230
537	0.68	0.146	0.595	4.025	1.798	1.048	2.958	2.417	1.230

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
538	0.67	0.070	0.585	7.461	3.399	2.125	4.050	2.109	1.006
539	0.75	0.110	0.655	4.901	2.285	1.271	4.558	1.734	1.994
540	0.80	0.248	0.700	2.264	0.854	0.898	2.950	1.400	1.210
541	0.75	0.348	0.655	1.864	0.629	0.619	2.950	1.400	1.210
542	0.73	0.366	0.640	1.838	0.892	0.834	1.967	0.916	0.901
543	0.68	0.220	0.595	4.514	1.823	1.123	4.681	1.872	1.205
544	0.66	0.137	0.580	5.416	2.229	1.105	5.416	2.229	1.105
545	0.64	0.129	0.560	5.591	2.032	1.155	5.591	2.032	1.155
546	0.58	0.091	0.510	7.245	3.338	2.050	7.245	3.338	2.050
569	0.76	0.194	0.665	5.841	2.183	1.344	2.709	1.484	0.900
570	0.75	0.233	0.655	5.690	1.857	1.118	2.709	1.484	0.900
571	0.78	0.257	0.685	5.570	2.476	1.283	2.958	2.417	1.230
572	0.69	0.166	0.605	5.865	2.769	1.520	2.958	2.417	1.230
573	0.68	0.143	0.595	6.248	2.526	1.326	3.333	1.659	1.266
574	0.70	0.114	0.615	5.318	2.796	1.694	3.333	1.659	1.266
575	0.90	0.334	0.790	2.572	1.191	0.666	5.217	1.859	1.645
576	0.90	0.416	0.790	1.947	0.721	0.816	2.950	1.400	1.210
577	0.78	0.363	0.685	1.781	0.688	0.992	1.962	0.916	0.901
578	0.74	0.190	0.650	2.310	0.899	0.776	1.630	0.610	0.830
579	0.71	0.211	0.620	1.515	0.678	0.518	1.870	0.857	0.447
580	0.65	0.151	0.570	3.792	1.689	1.091	3.792	1.689	1.091
581	0.63	0.134	0.550	3.172	1.334	1.058	1.905	1.047	0.939
582	0.62	0.076	0.545	5.422	2.298	1.926	2.349	1.341	1.359
604	0.74	0.216	0.650	5.541	1.648	1.151	3.493	1.544	0.887
605	0.77	0.290	0.670	5.473	1.599	1.060	3.493	1.544	0.887
606	0.85	0.395	0.745	4.324	1.289	0.694	2.958	2.417	1.230
607	0.83	0.245	0.725	3.581	2.013	0.580	2.958	2.417	1.230
608	0.78	0.193	0.685	5.122	2.670	1.213	3.333	1.659	1.266
609	0.70	0.167	0.615	4.181	2.053	1.529	5.217	1.859	1.644
610	0.99	0.530	0.865	0.630	0.229	0.255	5.217	1.859	1.644
611	0.88	0.370	0.770	1.475	0.610	0.451	1.340	0.650	0.910
612	0.79	0.400	0.690	2.470	1.100	1.100	1.880	0.820	1.110
613	0.85	0.420	0.740	1.860	0.700	0.680	1.450	0.600	0.810
614	0.75	0.260	0.650	1.922	0.903	0.492	1.450	0.600	0.810
615	0.68	0.181	0.595	2.983	1.434	0.762	2.983	1.434	0.762
616	0.67	0.205	0.585	2.405	1.062	1.139	2.349	1.341	1.359
617	0.64	0.110	0.560	5.071	2.192	2.006	2.349	1.341	1.359
618	0.60	0.063	0.525	7.951	4.577	3.620	2.349	1.341	1.359
638	0.85	0.433	0.740	4.337	1.113	0.920	2.695	0.971	0.612
639	0.75	0.280	0.650	12.060	3.492	3.045	2.909	0.996	0.579
640	0.79	0.307	0.690	4.928	1.913	0.972	3.493	1.544	0.887
641	1.00	0.467	0.875	3.893	1.523	0.669	3.333	1.659	1.266
642	0.96	0.340	0.840	1.013	0.606	0.537	3.333	1.659	1.266
643	0.80	0.253	0.700	4.718	1.958	1.162	3.324	1.819	2.093
644	0.78	0.230	0.685	3.292	1.634	0.997	3.324	1.819	2.093
645	0.97	0.500	0.850	0.930	0.355	0.308	0.690	0.300	0.560
646	0.78	0.320	0.680	2.520	1.160	0.660	1.500	0.740	0.860
647	0.80	0.370	0.700	3.280	1.470	1.650	2.320	1.010	1.560
648	0.85	0.400	0.745	2.300	0.820	1.570	2.710	1.430	4.190

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
649	0.75	0.300	0.655	1.030	0.590	0.220	2.400	0.860	0.860
650	0.69	0.220	0.605	1.816	0.885	0.459	2.400	0.860	0.860
651	0.72	0.212	0.630	1.735	0.838	0.629	1.735	0.838	0.629
652	0.66	0.134	0.580	4.201	1.826	1.733	4.201	1.826	1.733
653	0.61	0.072	0.535	7.385	4.245	2.819	2.400	0.860	0.860
673	0.92	0.375	0.810	4.746	1.065	0.929	3.044	1.506	0.729
674	0.73	0.238	0.640	5.633	2.004	1.209	3.174	1.103	0.645
675	0.88	0.344	0.770	5.603	1.738	1.098	3.897	1.185	0.695
676	0.98	0.580	0.860	3.889	1.417	0.571	3.190	1.609	0.862
677	0.90	0.490	0.790	2.467	1.144	0.782	3.190	1.609	0.862
678	0.79	0.283	0.690	2.440	0.863	0.903	2.808	1.668	1.156
679	0.80	0.300	0.700	3.890	1.320	1.050	3.180	1.250	1.850
680	0.96	0.450	0.840	1.190	0.600	0.420	1.740	0.830	1.610
681	0.80	0.340	0.700	1.420	0.650	0.450	1.000	0.490	0.800
682	0.78	0.340	0.685	1.510	0.710	0.320	1.380	0.660	0.840
683	0.80	0.280	0.700	1.390	0.670	0.360	0.800	0.340	0.790
684	0.72	0.250	0.630	1.690	0.690	0.450	0.800	0.340	0.790
685	0.75	0.280	0.655	1.268	0.526	0.392	0.800	0.340	0.790
686	0.74	0.230	0.650	1.287	0.579	0.414	1.453	0.647	0.498
687	0.66	0.142	0.580	3.096	1.249	1.049	3.096	1.249	1.049
688	0.61	0.099	0.535	5.968	3.396	2.781	1.967	1.039	1.125
708	0.98	0.445	0.860	3.125	0.766	0.556	3.164	0.905	0.650
709	0.80	0.299	0.700	5.643	1.547	1.160	3.680	2.021	0.536
710	0.92	0.393	0.805	4.662	1.867	0.758	3.680	2.021	0.536
711	0.95	0.520	0.830	3.788	1.999	0.720	3.563	2.057	0.591
712	1.08	0.530	0.945	3.271	1.171	0.603	3.563	2.057	0.591
713	0.82	0.400	0.720	3.370	1.270	0.630	4.070	1.980	0.890
714	0.80	0.410	0.700	1.630	0.850	0.510	2.200	2.000	0.480
715	0.98	0.470	0.860	0.970	0.620	0.370	1.110	0.550	0.930
716	0.95	0.650	0.830	0.860	0.400	0.290	1.110	0.550	0.930
717	0.98	0.430	0.860	2.100	1.010	1.030	0.750	0.350	0.550
718	0.73	0.170	0.640	2.290	1.000	0.690	2.350	0.800	0.880
719	0.71	0.200	0.620	1.170	0.670	0.220	2.350	0.800	0.880
720	0.80	0.420	0.700	0.730	0.340	0.210	1.200	0.700	0.690
721	0.74	0.270	0.650	1.430	0.607	0.298	1.200	0.700	0.690
722	0.66	0.180	0.580	2.013	0.935	0.459	1.967	1.039	1.125
723	0.62	0.100	0.545	3.216	1.530	1.111	1.967	1.039	1.125
743	1.10	0.442	0.965	2.677	0.720	0.510	3.248	0.890	0.763
744	0.79	0.263	0.690	4.934	1.260	0.973	3.248	0.890	0.763
745	1.02	0.435	0.895	4.693	2.108	0.988	3.293	0.987	0.646
746	1.00	0.472	0.875	3.984	1.522	1.412	4.578	0.956	0.557
747	1.25	0.520	1.095	3.107	1.327	1.063	3.780	1.270	0.579
748	0.76	0.360	0.665	4.290	2.330	1.390	4.290	2.330	1.760
749	0.90	0.420	0.790	3.730	2.070	0.530	2.200	2.000	0.480
750	1.38	0.700	1.210	1.890	1.320	0.250	4.400	1.920	1.020
751	1.15	0.590	1.005	2.760	1.660	0.540	3.100	1.500	1.070
752	0.80	0.320	0.700	3.540	1.920	0.610	1.500	0.500	0.790
753	0.75	0.280	0.655	2.920	0.980	0.280	1.500	0.500	0.790
754	0.67	0.160	0.585	2.290	1.080	0.560	1.200	0.700	0.690

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
755	0.74	0.290	0.650	0.950	0.450	0.260	1.200	0.700	0.690
756	0.73	0.310	0.640	1.460	0.700	0.470	1.200	0.700	0.690
757	0.67	0.200	0.585	2.817	1.192	0.711	0.690	0.290	0.520
758	0.62	0.085	0.545	6.737	3.165	3.390	2.117	1.076	1.157
778	1.10	0.454	0.965	2.668	0.803	0.569	1.228	0.295	0.476
779	0.78	0.304	0.685	4.767	0.893	0.911	2.959	0.852	0.711
780	0.85	0.349	0.745	5.051	1.661	1.258	2.937	0.849	0.819
781	1.10	0.536	0.965	2.388	1.154	1.091	4.203	1.046	0.651
782	0.80	0.493	0.700	2.874	1.154	1.215	0.491	0.375	0.533
783	0.77	0.360	0.675	5.196	1.958	1.254	2.660	1.170	0.920
784	1.30	0.590	1.140	2.970	1.540	0.390	2.500	2.100	0.540
785	1.45	0.850	1.270	3.310	1.200	0.760	2.500	1.800	1.300
786	1.10	0.690	0.965	2.300	1.000	0.490	1.200	1.000	0.220
787	0.98	0.340	0.860	3.990	1.770	0.620	3.800	2.500	0.700
788	1.00	0.510	0.875	0.940	0.490	0.220	1.200	0.300	0.800
789	0.90	0.410	0.790	1.290	0.640	0.410	1.200	0.300	0.800
790	0.73	0.310	0.640	0.870	0.410	0.500	1.200	0.700	0.700
791	0.75	0.270	0.655	1.530	0.750	0.550	1.200	0.700	0.700
792	0.70	0.150	0.615	2.500	1.290	0.610	1.200	0.700	0.700
793	0.63	0.090	0.550	6.809	3.651	4.459	1.200	0.700	0.700
794	0.62	0.096	0.545	7.046	4.112	3.088	7.046	4.112	3.088
795	0.61	0.158	0.535	6.829	4.105	2.427	1.200	0.700	0.700
813	0.99	0.492	0.865	3.085	0.837	0.640	2.221	0.411	0.625
814	0.97	0.479	0.850	3.282	0.517	0.845	2.360	0.393	0.578
815	0.82	0.399	0.720	5.459	1.334	1.077	2.360	0.393	0.578
816	1.02	0.492	0.895	2.921	1.204	0.666	3.691	0.160	0.584
817	0.95	0.490	0.830	2.709	0.920	0.918	3.931	1.303	1.036
818	1.25	0.546	1.095	3.998	1.228	0.897	3.931	1.303	1.036
819	1.40	0.640	1.225	2.394	1.095	0.520	1.190	0.470	0.410
820	1.42	0.800	1.245	3.080	1.180	0.630	1.190	0.470	0.410
821	1.50	0.740	1.315	1.390	0.760	0.290	1.740	0.940	0.550
822	0.98	0.350	0.860	2.920	1.610	0.530	2.040	1.120	0.620
823	1.10	0.520	0.965	0.710	0.440	0.250	2.040	1.120	0.620
824	1.25	0.550	1.095	0.530	0.280	0.320	1.000	0.600	0.800
825	1.05	0.440	0.920	0.510	0.220	0.330	0.580	0.240	0.580
826	0.80	0.320	0.700	0.740	0.310	0.290	1.200	0.700	0.520
827	0.73	0.150	0.640	2.320	1.010	1.110	1.200	0.700	0.520
828	0.66	0.100	0.580	5.150	2.460	1.580	1.200	0.700	0.520
829	0.63	0.120	0.550	5.794	3.387	1.677	1.200	0.700	0.520
830	0.62	0.113	0.545	6.543	4.101	1.962	6.543	4.101	1.962
848	0.95	0.351	0.830	3.441	0.766	0.715	3.458	0.996	0.689
849	0.96	0.545	0.840	2.819	0.680	0.547	3.498	0.971	0.614
850	1.00	0.483	0.875	3.964	0.912	0.659	3.413	1.012	0.627
851	1.05	0.601	0.920	3.197	1.186	0.773	3.691	0.983	0.584
852	1.20	0.730	1.050	1.745	0.583	0.407	2.850	0.640	0.647
853	0.98	0.525	0.860	3.321	1.515	0.648	2.526	0.763	0.811
854	1.05	0.600	0.920	1.788	0.966	0.406	2.396	1.406	0.483
855	0.98	0.560	0.860	2.291	1.346	0.821	0.320	0.320	0.190
856	1.60	0.900	1.400	0.740	0.450	0.320	1.490	0.880	0.600

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
857	0.96	0.530	0.840	2.400	1.080	0.620	1.120	0.700	0.360
858	0.90	0.420	0.790	1.040	0.770	0.220	4.880	2.090	4.150
859	1.05	0.410	0.920	0.510	0.290	0.270	4.880	2.090	4.150
860	1.15	0.500	1.000	0.640	0.230	0.290	0.580	0.240	0.580
861	0.87	0.390	0.760	0.520	0.310	0.300	0.580	0.240	0.580
862	0.76	0.230	0.665	0.700	0.330	0.390	0.580	0.240	0.580
863	0.67	0.120	0.585	4.110	1.840	1.080	0.580	0.240	0.580
864	0.64	0.110	0.560	7.333	4.177	4.588	0.580	0.240	0.580
865	0.63	0.100	0.550	7.996	4.588	3.452	1.811	1.052	0.839
883	0.96	0.612	0.840	3.204	0.754	0.642	3.448	0.831	0.729
884	1.00	0.590	0.875	1.909	0.506	0.465	1.909	0.506	0.465
885	1.20	0.688	1.050	2.804	0.491	0.550	2.087	0.270	0.478
886	1.20	0.653	1.050	3.667	1.003	0.532	2.087	0.270	0.478
887	1.10	0.621	0.965	2.929	1.194	0.569	2.151	0.749	0.627
888	0.95	0.374	0.830	3.829	1.635	0.894	2.494	0.835	0.923
889	0.75	0.327	0.655	4.437	1.782	1.383	3.095	0.990	0.830
890	0.78	0.409	0.685	5.302	1.694	2.597	3.095	0.990	0.830
891	1.30	0.880	1.140	1.680	0.890	1.130	0.710	0.370	0.380
892	1.20	0.980	1.050	0.860	0.540	0.370	1.020	0.600	0.400
893	0.88	0.400	0.770	1.340	0.700	0.280	1.670	0.800	0.550
894	0.90	0.310	0.790	0.850	0.390	0.330	1.100	0.600	0.570
895	1.25	0.470	1.095	1.450	0.540	0.380	1.100	0.600	0.570
896	0.90	0.250	0.790	1.120	0.480	0.480	1.980	0.900	0.810
897	0.76	0.200	0.665	1.767	0.793	0.748	1.980	0.900	0.810
898	0.69	0.160	0.605	2.535	1.046	0.606	2.121	1.234	1.005
899	0.66	0.130	0.580	7.263	3.580	4.756	2.121	1.234	1.005
900	0.62	0.110	0.550	7.949	4.203	3.438	2.121	1.234	1.005
901	0.61	0.080	0.535	8.086	3.946	4.702	2.757	1.181	1.103
921	1.25	0.670	1.095	2.488	0.626	0.572	2.087	0.681	0.478
922	1.20	0.650	1.050	2.889	0.808	0.748	2.774	0.913	0.612
923	0.84	0.427	0.735	4.619	1.535	1.338	2.665	0.856	0.658
924	0.85	0.436	0.745	5.018	1.575	2.179	3.095	0.990	0.830
925	0.70	0.221	0.615	4.893	2.132	3.310	3.095	0.990	0.830
926	1.10	0.390	0.965	2.846	1.325	0.985	0.750	0.390	0.380
927	1.55	0.960	1.355	0.950	0.560	0.270	0.570	0.350	0.290
928	1.40	0.720	1.225	0.690	0.460	0.340	1.080	0.440	0.400
929	0.95	0.400	0.830	0.720	0.360	0.320	1.990	1.050	0.480
930	1.25	0.500	1.095	2.130	0.890	0.810	1.100	0.600	0.570
931	0.91	0.370	0.795	1.489	0.572	0.463	1.100	0.600	0.570
932	0.78	0.250	0.685	1.141	0.603	0.509	1.023	0.556	0.598
933	0.73	0.160	0.640	3.922	1.306	1.670	3.922	1.306	1.670
934	0.67	0.140	0.585	5.474	2.312	1.931	5.474	2.312	1.931
935	0.65	0.110	0.570	7.847	3.731	3.799	2.757	1.181	1.103
956	0.97	0.610	0.850	2.709	0.753	0.578	2.709	0.752	0.577
957	0.98	0.590	0.860	2.982	0.859	0.628	2.982	0.859	0.623
958	1.05	0.620	0.920	4.189	1.093	1.364	4.188	1.092	1.363
959	1.10	0.590	0.965	2.876	1.146	0.799	2.876	1.145	0.798
960	0.79	0.405	0.690	4.486	1.506	1.541	1.777	1.053	0.457
961	0.79	0.430	0.690	3.555	1.840	1.055	1.777	1.053	0.457

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
962	1.00	0.440	0.875	2.309	1.594	0.593	1.220	0.460	0.320
963	1.45	0.600	1.270	1.310	0.590	0.300	1.220	0.560	0.350
964	1.10	0.460	0.965	1.270	0.590	0.230	1.420	0.540	0.360
965	1.10	0.500	0.965	2.082	0.519	0.954	1.420	0.540	0.360
966	0.95	0.390	0.830	2.085	0.721	0.759	2.591	1.350	0.874
967	0.78	0.290	0.685	2.004	1.028	1.143	2.591	1.350	0.874
968	0.74	0.180	0.650	4.307	2.441	1.463	2.591	1.350	0.874
969	0.67	0.160	0.585	6.076	1.627	1.793	6.076	1.627	1.793
970	0.66	0.125	0.580	4.437	1.531	1.433	2.441	0.933	0.953
991	0.98	0.619	0.860	2.925	0.952	0.570	1.916	0.905	0.627
992	0.82	0.580	0.720	3.487	0.944	0.734	1.946	1.012	0.621
993	0.88	0.596	0.770	3.252	1.026	0.755	2.077	0.415	0.620
994	1.00	0.566	0.875	1.879	0.795	0.582	0.848	0.197	0.231
995	1.50	1.027	1.315	0.472	0.184	0.210	0.449	0.164	0.231
996	0.92	0.627	0.805	0.982	0.402	0.329	0.360	0.160	0.170
997	0.78	0.360	0.685	3.533	1.603	0.635	0.991	0.355	0.413
998	0.85	0.470	0.745	1.747	0.960	0.663	0.991	0.355	0.413
999	1.25	0.610	1.100	1.400	0.598	0.237	1.370	0.826	0.285
1000	1.20	0.700	1.050	0.533	0.223	0.451	0.556	0.224	0.294
1001	1.10	0.669	0.965	1.502	0.512	0.465	2.200	0.880	1.078
1002	0.86	0.480	0.755	1.152	0.477	0.778	1.152	0.477	0.778
1003	0.76	0.240	0.665	2.563	1.053	0.891	2.563	1.053	0.891
1004	0.68	0.170	0.595	6.000	0.695	0.916	6.000	0.695	0.916
1005	0.69	0.200	0.605	7.197	1.968	1.842	7.197	1.968	1.842
1026	1.10	0.652	0.965	3.352	0.919	0.606	3.352	0.919	0.606
1027	0.80	0.620	0.700	2.457	0.700	0.536	2.457	0.700	0.536
1028	0.78	0.615	0.685	3.137	0.977	0.994	3.137	0.977	0.993
1029	1.05	0.790	0.920	2.063	0.800	0.659	2.063	0.799	0.659
1031	1.60	1.060	1.360	0.518	0.212	0.167	0.518	0.212	0.167
1032	0.93	0.593	0.815	2.872	0.923	0.496	1.013	0.369	0.428
1033	0.74	0.305	0.650	3.558	1.811	0.757	1.013	0.369	0.429
1034	0.76	0.330	0.665	1.469	0.777	0.593	1.438	0.877	0.324
1035	1.20	0.580	1.050	1.187	0.855	0.270	1.557	1.253	0.867
1036	1.30	0.700	1.095	2.061	0.845	0.494	2.290	1.064	0.660
1037	0.88	0.370	0.770	1.703	0.860	0.545	2.256	1.305	0.876
1038	0.79	0.270	0.690	1.820	0.681	0.666	1.738	0.796	0.921
1039	0.68	0.163	0.595	3.784	0.686	0.993	1.925	0.825	0.951
1040	0.68	0.250	0.595	6.205	0.536	1.138	6.205	0.536	1.138
1067	1.65	1.280	1.445	0.407	0.125	0.117	0.150	0.099	0.162
1068	0.75	0.520	0.655	2.745	1.143	1.031	0.195	0.099	0.636
1069	0.65	0.290	0.570	2.656	1.751	0.796	1.581	0.936	0.587
1070	0.70	0.345	0.615	2.408	1.302	1.119	1.557	1.253	0.867
1071	0.95	0.550	0.830	2.600	0.987	0.477	1.944	1.164	0.646
1072	1.05	0.470	0.920	1.099	0.764	0.709	1.944	1.164	0.646
1073	1.10	0.410	0.965	0.508	0.306	0.397	1.944	1.164	0.646
1074	0.95	0.370	0.830	0.748	0.359	0.440	2.257	1.305	0.876
1075	0.72	0.260	0.630	4.450	0.696	0.894	4.450	0.696	0.894
1102	1.60	1.548	1.400	0.604	0.305	0.291	0.155	0.091	0.217
1103	0.90	0.618	0.790	2.219	0.699	1.040	0.215	0.806	0.636

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
1104	0.67	0.255	0.585	7.731	3.354	3.131	1.986	0.929	0.317
1105	0.64	0.236	0.560	7.190	3.255	3.299	2.090	0.831	0.317
1106	0.69	0.300	0.610	5.788	2.126	1.802	3.150	1.810	1.127
1107	0.79	0.250	0.690	2.034	1.334	0.876	2.636	1.515	1.597
1108	0.96	0.320	0.840	0.709	0.411	0.405	0.776	0.378	0.496
1109	1.05	0.380	0.920	0.680	0.357	0.571	0.520	0.283	0.357
1110	1.00	0.370	0.875	2.216	0.792	1.187	1.554	0.596	0.572
1111	0.65	0.230	0.570	6.306	1.544	1.953	3.004	1.435	1.979
1137	1.25	0.921	1.095	2.520	1.063	0.694	0.170	0.074	0.164
1138	0.75	0.233	0.655	3.393	1.209	1.182	2.974	1.062	1.751
1139	0.74	0.290	0.650	5.157	1.995	1.725	2.299	1.062	1.573
1140	0.71	0.270	0.620	4.458	1.880	1.425	2.246	0.996	1.564
1141	0.66	0.186	0.580	6.559	2.707	2.378	2.250	1.012	1.584
1142	0.68	0.170	0.600	5.010	2.261	1.662	4.543	2.579	2.071
1143	0.80	0.290	0.700	1.939	1.107	0.783	1.592	1.562	0.860
1144	0.90	0.310	0.790	1.058	0.579	0.832	0.667	0.427	0.550
1145	0.90	0.280	0.790	1.037	0.540	0.572	0.960	0.499	0.522
1146	0.68	0.190	0.595	4.039	1.069	1.120	2.482	0.712	0.874
1147	0.64	0.120	0.560	4.432	1.546	1.804	2.700	1.162	1.387
1148	0.65	0.200	0.570	5.187	2.306	1.806	4.119	1.774	3.061
1172	0.92	0.646	0.805	2.938	1.046	0.991	2.600	0.889	1.543
1173	0.69	0.350	0.605	4.340	1.795	1.452	5.190	1.744	1.759
1174	0.72	0.292	0.630	2.955	1.190	0.985	2.299	1.062	1.573
1175	0.82	0.405	0.720	3.180	1.365	1.073	2.500	0.979	1.439
1176	0.70	0.260	0.615	4.931	2.164	1.627	2.485	1.029	1.464
1177	0.65	0.160	0.570	6.525	2.548	1.963	5.801	3.227	2.487
1178	0.69	0.142	0.605	3.068	1.940	1.475	2.719	2.263	1.715
1179	0.78	0.280	0.685	1.199	1.631	0.715	0.997	1.265	0.598
1180	0.90	0.460	0.790	1.115	0.696	0.409	0.750	0.655	0.623
1181	0.70	0.280	0.615	1.760	0.952	0.868	0.750	0.655	0.623
1182	0.67	0.230	0.585	4.206	2.079	1.931	0.750	0.655	0.623
1183	0.65	0.155	0.570	6.168	2.764	3.779	2.966	1.837	1.491
1207	0.80	0.486	0.700	2.841	1.423	0.814	3.164	1.103	1.266
1208	0.70	0.375	0.615	3.842	1.427	1.012	3.648	1.053	1.476
1209	0.79	0.341	0.690	2.007	0.786	0.643	3.084	1.103	1.476
1210	0.78	0.374	0.685	2.679	1.133	0.956	3.663	0.955	0.930
1211	0.69	0.228	0.595	4.022	1.837	1.043	3.748	1.021	0.930
1212	0.76	0.247	0.665	2.431	1.527	1.070	2.167	1.423	1.044
1213	0.69	0.190	0.605	3.871	2.318	1.535	3.053	1.699	1.423
1214	0.66	0.210	0.580	2.246	1.608	1.068	1.733	1.291	0.919
1215	0.72	0.250	0.630	2.345	1.645	0.717	1.995	1.216	0.765
1216	0.69	0.350	0.605	2.746	1.946	1.236	2.110	1.817	1.205
1217	0.66	0.200	0.580	4.741	3.319	2.633	2.883	1.857	1.474
1218	0.68	0.100	0.595	6.735	3.578	2.871	2.966	1.837	1.491
1243	0.80	0.366	0.700	3.614	1.172	0.765	3.199	1.144	1.476
1244	0.69	0.322	0.605	3.681	1.437	0.944	3.413	1.218	1.476
1245	0.68	0.352	0.595	4.043	1.668	1.197	3.508	1.119	1.437
1246	0.65	0.204	0.570	5.278	2.306	1.549	3.283	0.741	1.111
1247	0.64	0.269	0.560	5.483	2.466	1.550	3.508	0.732	1.111

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
1248	0.63	0.183	0.550	6.851	3.377	2.772	4.585	2.194	1.361
1249	0.66	0.200	0.580	4.802	2.229	1.546	4.884	2.194	1.361
1250	0.67	0.150	0.585	3.971	2.742	1.558	3.537	2.389	1.378
1251	0.66	0.140	0.580	6.397	2.887	2.714	5.225	2.630	2.531
1252	0.68	0.150	0.595	6.389	3.012	2.218	4.234	1.805	1.544
1253	0.72	0.130	0.630	4.789	2.168	1.718	3.272	1.552	1.346
1254	0.66	0.130	0.580	4.459	2.313	1.410	2.033	1.148	1.198
1255	0.64	0.053	0.560	6.690	3.009	2.776	3.286	1.820	2.195
1256	0.62	0.070	0.545	5.877	2.900	1.908	5.877	2.900	1.908
1257	0.58	0.060	0.510	6.808	3.259	2.837	6.808	3.259	2.837
1280	0.69	0.341	0.605	3.035	1.096	0.645	3.249	0.790	1.054
1281	0.80	0.344	0.700	3.399	1.533	0.865	3.174	0.831	1.111
1282	0.68	0.209	0.595	6.763	2.687	2.181	2.475	0.560	1.166
1283	0.63	0.167	0.550	6.897	2.811	2.580	2.575	0.609	1.166
1284	0.65	0.151	0.570	6.119	2.505	1.623	7.075	2.775	1.448
1285	0.67	0.230	0.585	3.339	1.451	1.420	4.169	1.894	1.381
1286	0.71	0.234	0.620	3.514	1.599	1.151	4.234	1.805	1.544
1287	0.75	0.220	0.655	3.459	1.499	0.914	2.305	1.024	0.791
1288	0.72	0.225	0.630	2.368	0.992	1.239	1.617	0.759	0.771
1289	0.65	0.070	0.570	6.778	2.982	2.119	2.428	1.190	1.353
1290	0.58	0.035	0.510	8.555	3.190	2.968	9.363	4.300	3.441
1291	0.57	0.060	0.500	7.603	2.734	3.057	7.603	2.734	3.057
1292	0.61	0.048	0.535	7.638	2.414	2.897	3.275	1.409	1.311
1293	0.62	0.030	0.545	7.391	2.865	3.827	7.391	2.865	3.827
1316	0.82	0.416	0.720	2.688	1.051	0.551	3.258	1.325	1.181
1317	0.82	0.421	0.720	4.038	1.560	1.025	3.258	1.185	1.189
1318	0.66	0.212	0.580	5.802	1.985	1.610	3.244	1.316	1.302
1319	0.68	0.207	0.595	5.701	2.497	2.439	3.244	1.398	1.302
1320	0.72	0.393	0.630	1.251	0.770	0.708	4.169	1.894	1.381
1321	0.82	0.330	0.720	1.740	0.903	1.243	1.225	0.637	1.545
1322	0.70	0.270	0.615	1.969	0.807	0.563	4.104	1.582	1.174
1323	0.67	0.150	0.585	3.785	1.738	1.487	1.536	0.594	0.601
1324	0.62	0.057	0.545	7.093	3.054	2.895	7.093	3.054	2.895
1325	0.61	0.047	0.535	8.041	3.435	3.238	8.041	3.435	3.238
1326	0.61	0.036	0.535	8.808	4.404	3.187	2.573	1.475	1.827
1327	0.63	0.043	0.545	6.616	2.786	3.117	1.896	0.946	0.600
1328	0.63	0.061	0.550	6.447	3.400	3.820	6.447	3.400	3.820
1350	0.79	0.327	0.690	3.501	1.555	0.797	3.293	1.399	0.614
1351	0.72	0.254	0.630	4.846	1.506	0.939	3.254	1.472	0.737
1352	0.68	0.240	0.600	5.723	1.593	1.693	3.254	1.471	0.737
1353	0.68	0.226	0.595	5.997	2.159	1.620	3.293	1.399	1.302
1354	0.65	0.233	0.570	5.873	2.745	1.622	3.981	1.744	1.183
1355	0.66	0.129	0.580	4.955	2.610	1.394	3.981	1.744	1.183
1356	0.67	0.137	0.585	5.064	1.971	1.404	4.104	1.582	1.174
1357	0.66	0.110	0.580	6.309	2.612	2.208	4.104	1.582	1.174
1358	0.65	0.100	0.570	6.121	2.068	2.037	3.370	1.280	1.434
1359	0.66	0.138	0.580	5.943	1.763	1.759	2.015	1.477	1.673
1360	0.64	0.102	0.555	7.645	2.788	3.195	1.978	1.517	1.709
1361	0.63	0.090	0.550	8.919	2.996	4.008	8.919	2.996	4.008

No.				Ground water			Surface water		
	P	Q	S _{dep}	Ca	Mg	SO _{4r}	Ca	Mg	SO _{4r}
	m.yr ⁻¹		keq.ha ⁻¹ .yr ⁻¹	meq.l ⁻¹			meq.l ⁻¹		
1362	0.65	0.103	0.570	5.960	2.851	2.715	1.896	0.946	0.600
1363	0.63	0.107	0.550	5.744	2.075	1.760	1.896	0.946	0.600
1386	0.74	0.363	0.650	3.692	1.385	0.690	3.254	1.472	0.737
1387	0.70	0.325	0.615	4.635	1.915	0.935	3.254	1.472	0.737
1388	0.69	0.218	0.605	5.673	2.067	1.820	3.656	1.661	1.123
1389	0.67	0.208	0.585	4.950	2.107	1.543	3.293	1.563	0.625
1390	0.69	0.205	0.605	4.909	2.252	1.543	3.293	1.481	1.127
1391	0.69	0.171	0.605	5.490	2.452	1.331	3.293	1.481	1.025
1392	0.69	0.148	0.605	5.960	2.121	1.618	5.960	2.121	1.618
1393	0.70	0.243	0.615	5.982	2.068	1.968	5.982	2.068	1.968
1394	0.71	0.200	0.620	5.000	1.968	2.043	2.015	1.477	1.673
1395	0.67	0.105	0.585	5.551	2.310	1.897	5.551	2.310	1.897
1396	0.66	0.064	0.580	6.623	2.889	2.509	1.808	0.875	0.544
1397	0.68	0.063	0.590	5.910	2.810	2.479	1.808	0.875	0.544
1422	0.75	0.334	0.650	3.839	1.460	0.938	3.169	1.480	0.820
1423	0.71	0.259	0.620	4.030	1.391	0.803	3.209	1.317	0.862
1424	0.69	0.252	0.605	5.161	1.641	1.447	3.343	1.177	0.833
1425	0.78	0.252	0.685	7.003	1.771	4.019	3.189	1.267	1.220
1426	0.72	0.214	0.630	4.815	1.840	1.713	3.358	1.152	1.718
1427	0.70	0.280	0.615	5.513	1.862	1.929	3.318	1.136	1.634
1428	0.75	0.327	0.655	4.839	2.216	1.143	4.839	2.216	1.143
1429	0.88	0.501	0.770	0.878	0.405	0.262	2.000	1.314	1.579
1430	0.69	0.227	0.600	3.241	1.971	1.371	2.000	1.314	1.579
1431	0.69	0.190	0.605	4.149	1.870	1.726	4.149	1.870	1.726
1432	0.69	0.180	0.605	3.189	1.258	1.016	3.189	1.258	1.016
1457	0.84	0.388	0.735	3.642	0.898	0.731	3.298	1.119	0.862
1458	0.84	0.350	0.735	4.514	1.000	1.439	3.184	1.053	0.734
1459	0.82	0.311	0.720	5.825	1.556	2.335	1.239	0.536	0.689
1460	0.80	0.300	0.700	5.553	1.818	2.529	2.600	0.872	0.668
1461	0.76	0.270	0.665	4.299	1.288	1.276	2.695	0.930	0.714
1462	0.73	0.312	0.635	4.845	1.525	1.132	2.864	1.078	0.797
1463	0.76	0.364	0.665	4.552	1.928	1.619	4.414	1.650	1.212
1464	0.96	0.693	0.640	0.669	0.365	0.232	0.669	0.365	0.232
1465	0.81	0.519	0.710	0.713	0.357	0.349	0.713	0.357	0.349
1466	0.84	0.325	0.735	1.731	0.823	0.459	1.731	0.823	0.459
1494	0.83	0.404	0.725	4.491	1.505	1.845	2.146	0.848	1.496
1495	0.89	0.391	0.780	4.013	0.970	0.775	2.086	0.790	1.496
1496	0.85	0.360	0.745	3.739	1.100	0.997	2.156	0.831	1.418
1497	0.80	0.350	0.700	3.592	1.105	0.737	2.086	0.806	1.439
1498	0.78	0.310	0.685	3.043	0.932	0.628	2.255	0.815	1.368
1499	0.85	0.495	0.745	2.590	0.816	0.482	1.452	0.819	1.228
1500	0.88	0.470	0.770	2.868	1.186	0.644	1.452	0.819	1.228
1532	1.02	0.486	0.895	1.877	0.420	0.392	1.751	0.946	1.141
1533	0.92	0.451	0.805	1.981	0.507	0.402	1.448	0.783	1.199
1534	0.92	0.520	0.805	2.273	0.591	0.364	1.452	0.818	1.228
1569	1.05	0.710	0.920	1.581	0.303	0.348	1.911	1.070	1.183

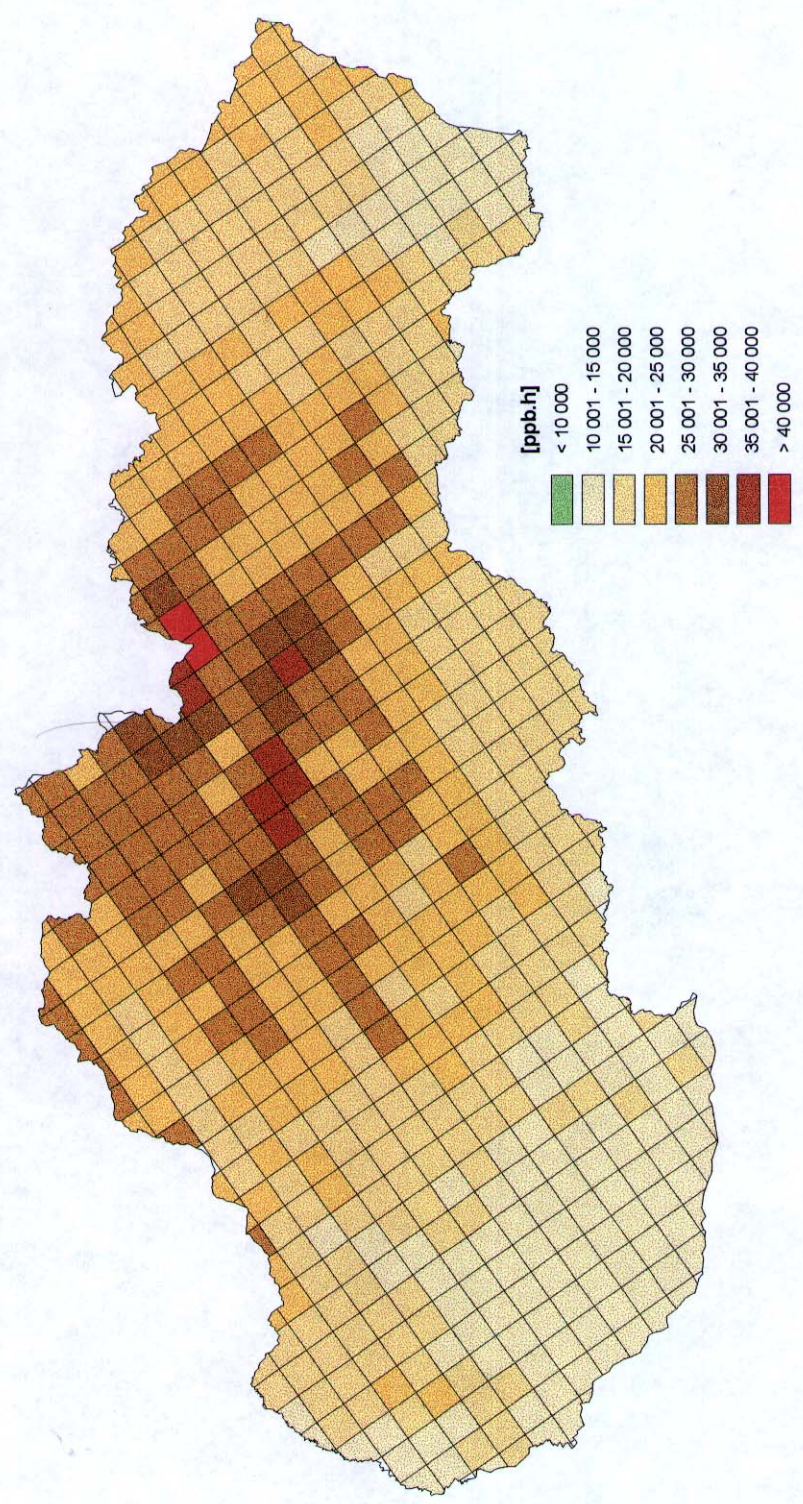
ANNEX 5

**Critical loads/levels and their exceedance
for the Slovak Republic**

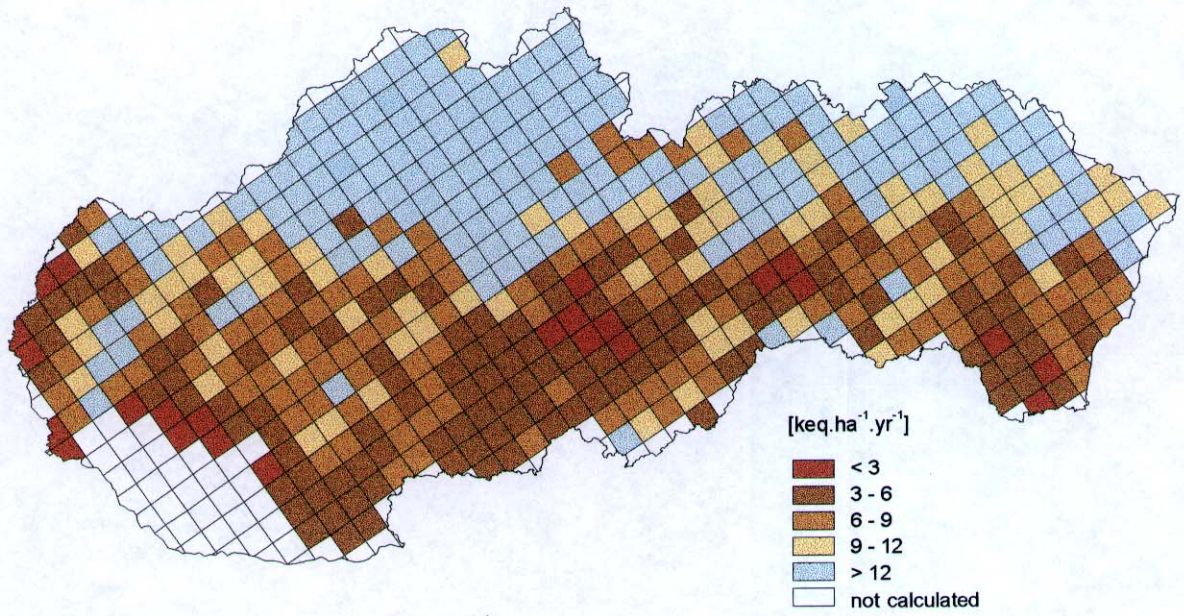
OZONE LEVELS IN THE SLOVAK REPUBLIC

AOT 40 FOR FOREST AREAS 1995

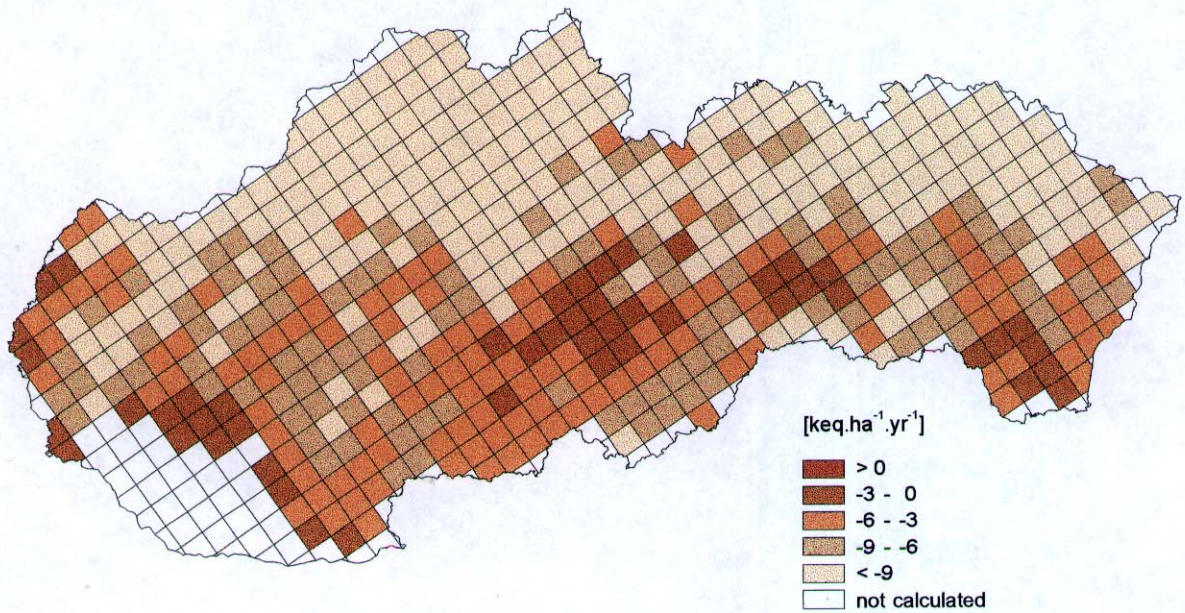
Accumulated Exposure over Threshold of 40 ppb, April-September, over whole days



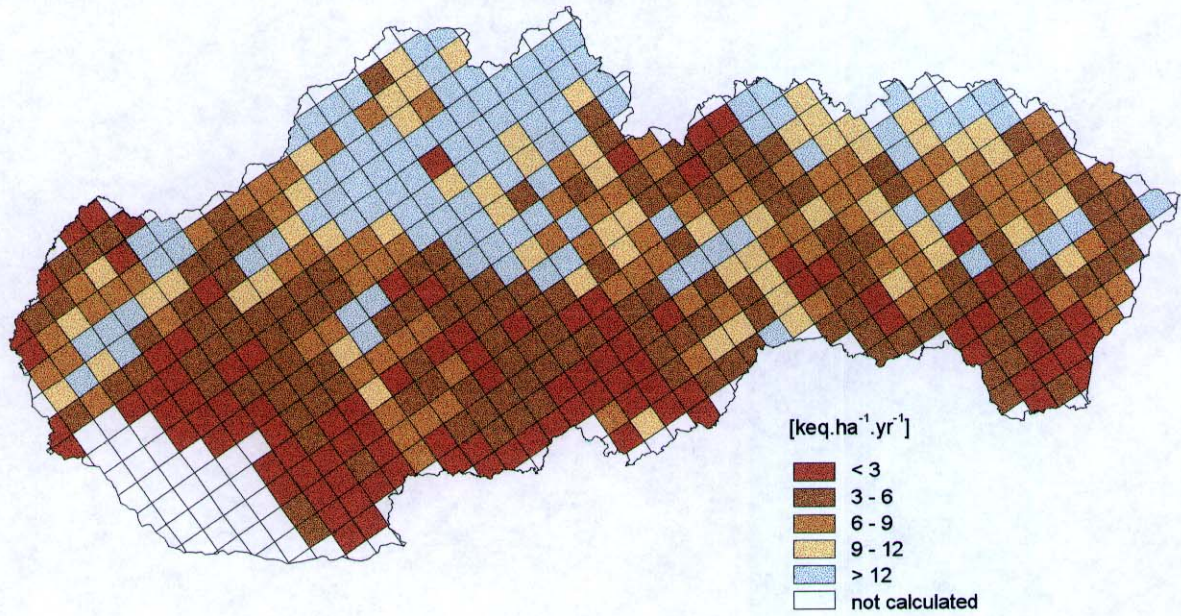
Critical loads of acidity Receptor: Ground water



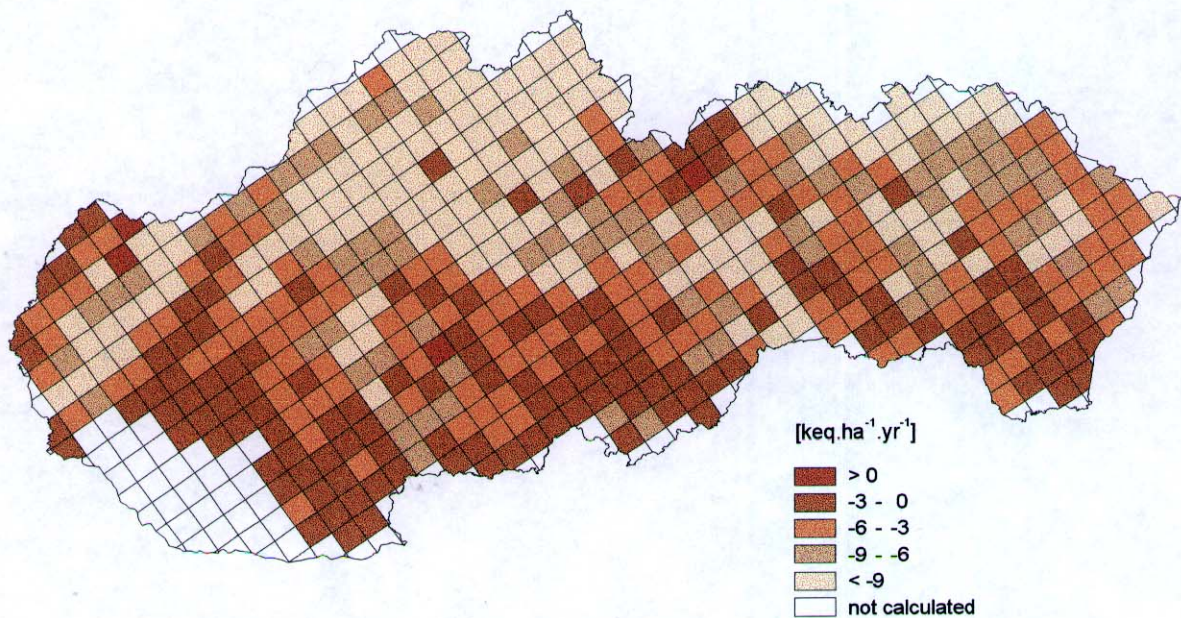
Exceedance of critical loads of acidity Receptor: Ground water Year: 1995



Critical loads of acidity
Receptor: Surface water

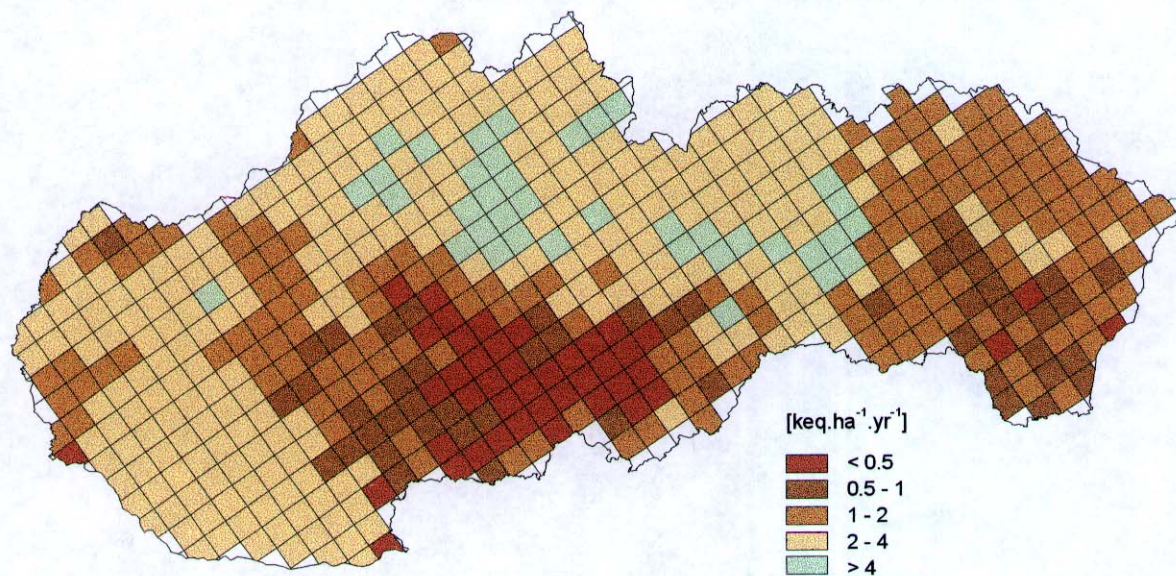


Exceedance of critical loads of acidity
Receptor: Surface water Year: 1995



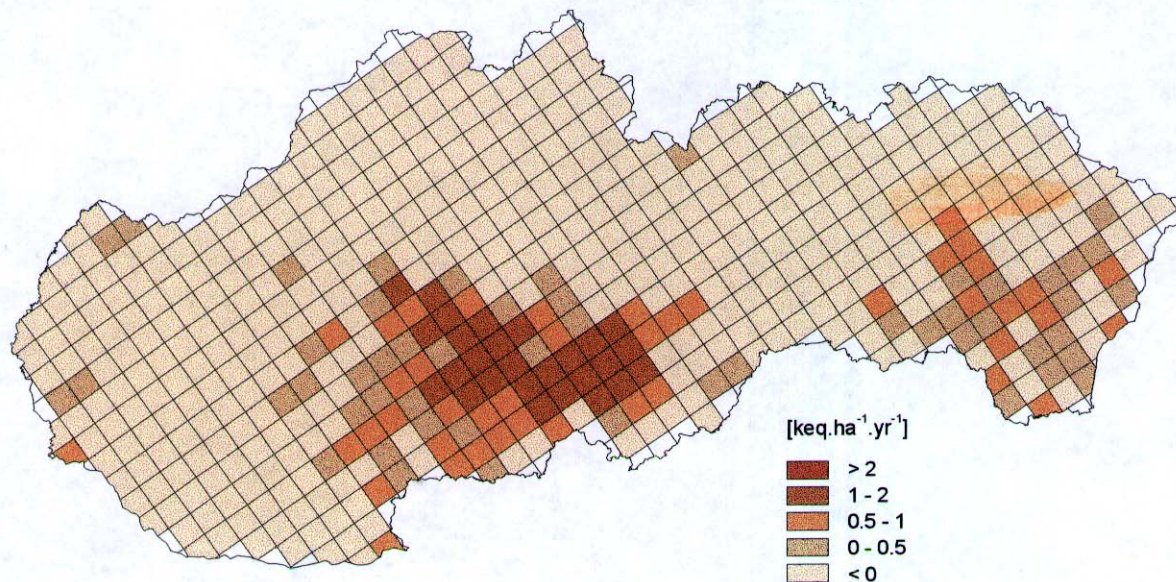
Critical sulphur deposition (5 percentile)

Receptor: Forest soils Year: 1995



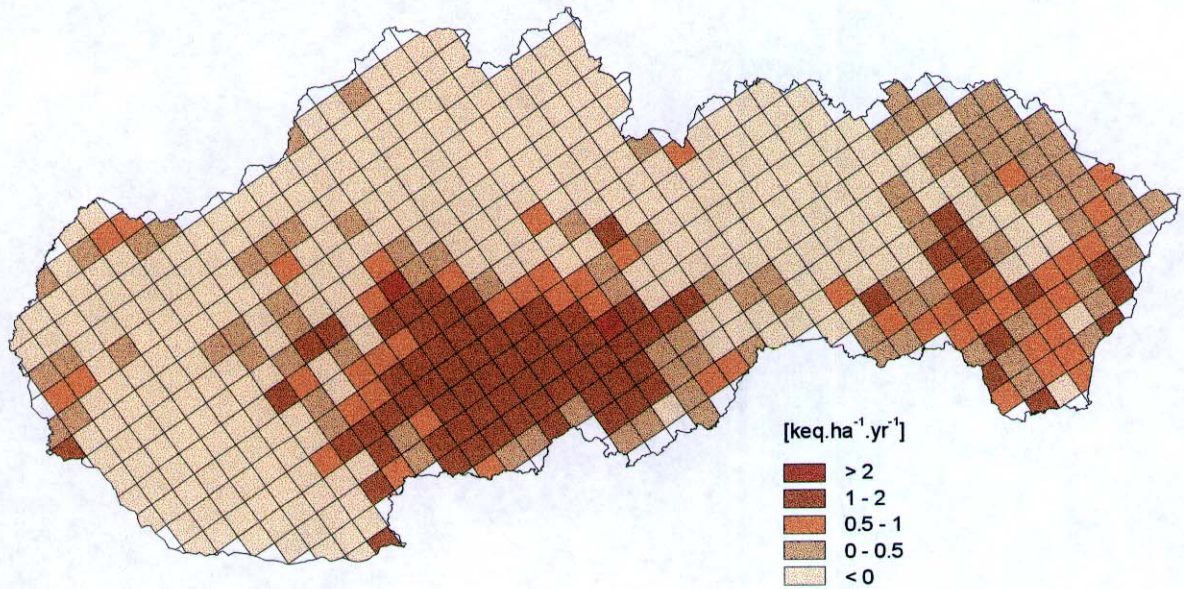
Exceedance of critical sulphur deposition (5 percentile)

Receptor: Forest soils Year: 1995



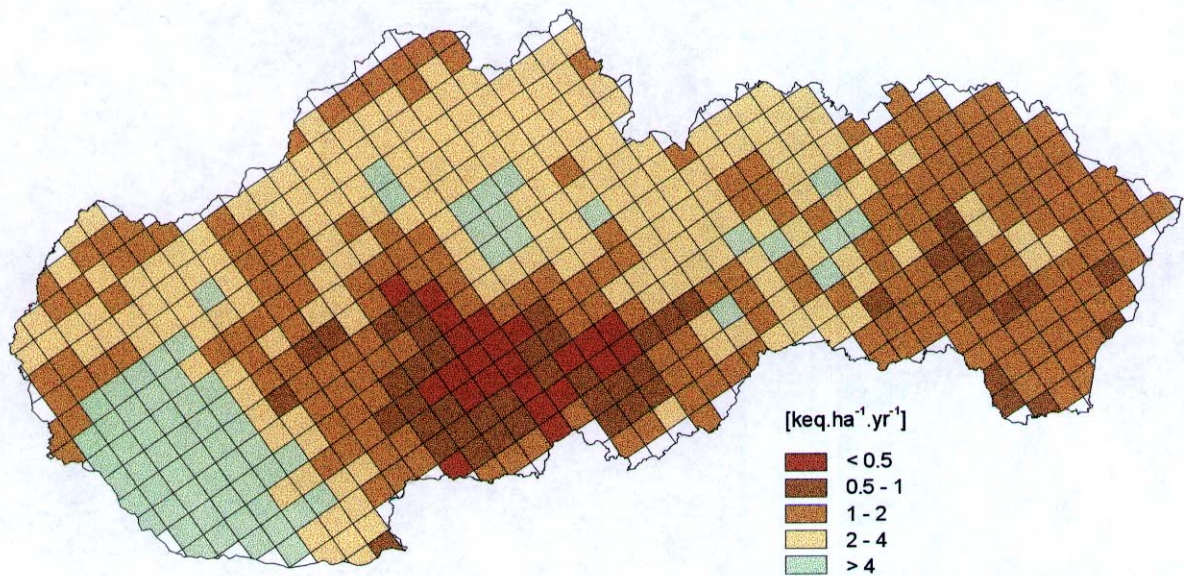
Exceedance of critical loads of potential acidity (5 percentile)

Receptor: Forest soils Year: 1995



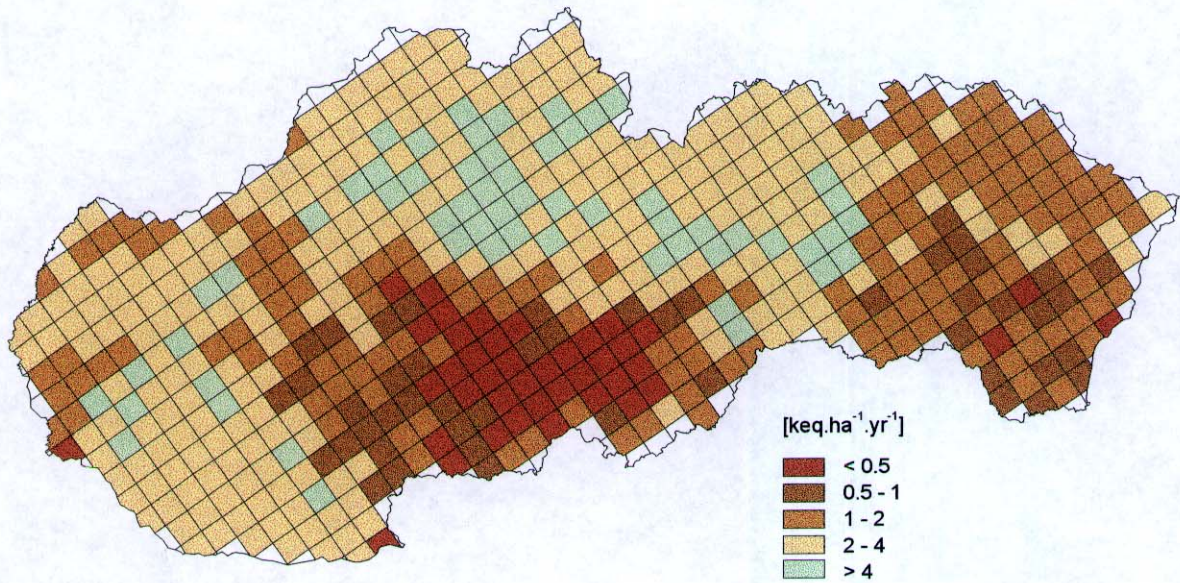
Critical loads of sulphur (5 percentile)

Receptor: Forest soils Year: 1995



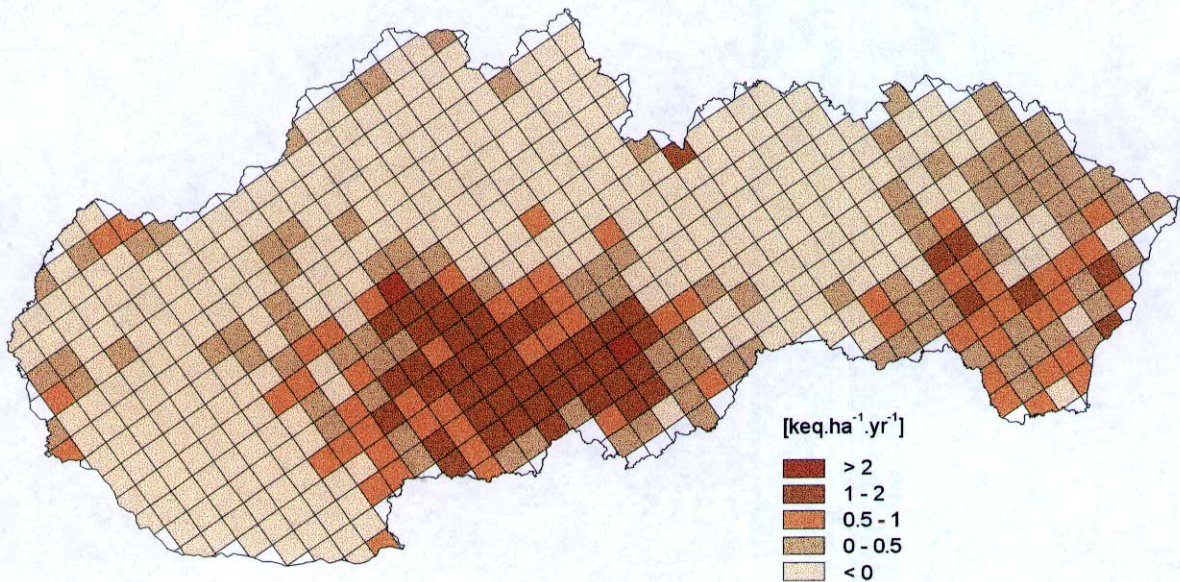
Critical sulphur deposition (5 percentile)

Receptor: Forest soils Year: 1990



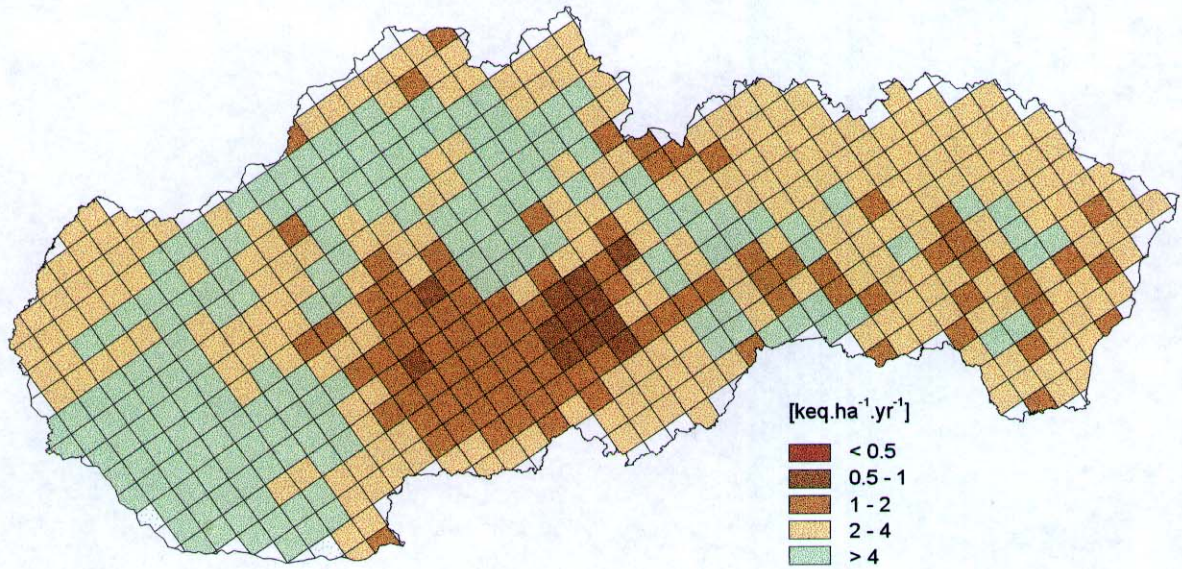
Exceedance of critical sulphur deposition (5 percentile)

Receptor: Forest soils Year: 1990



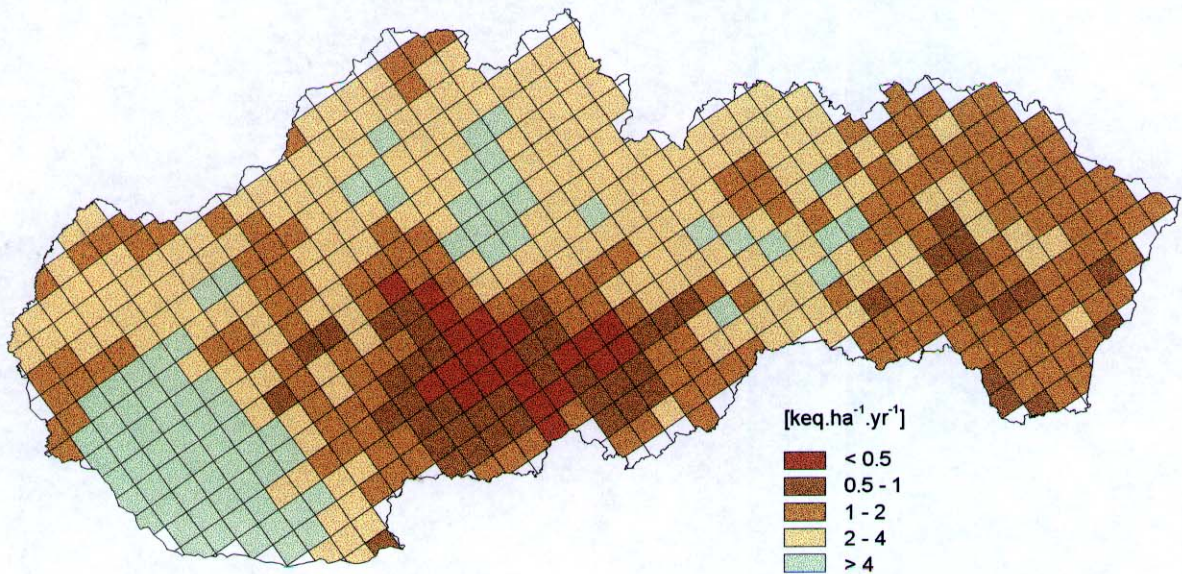
Critical loads of actual acidity (5 percentile)

Receptor: Forest soils (Czech Republic approach)



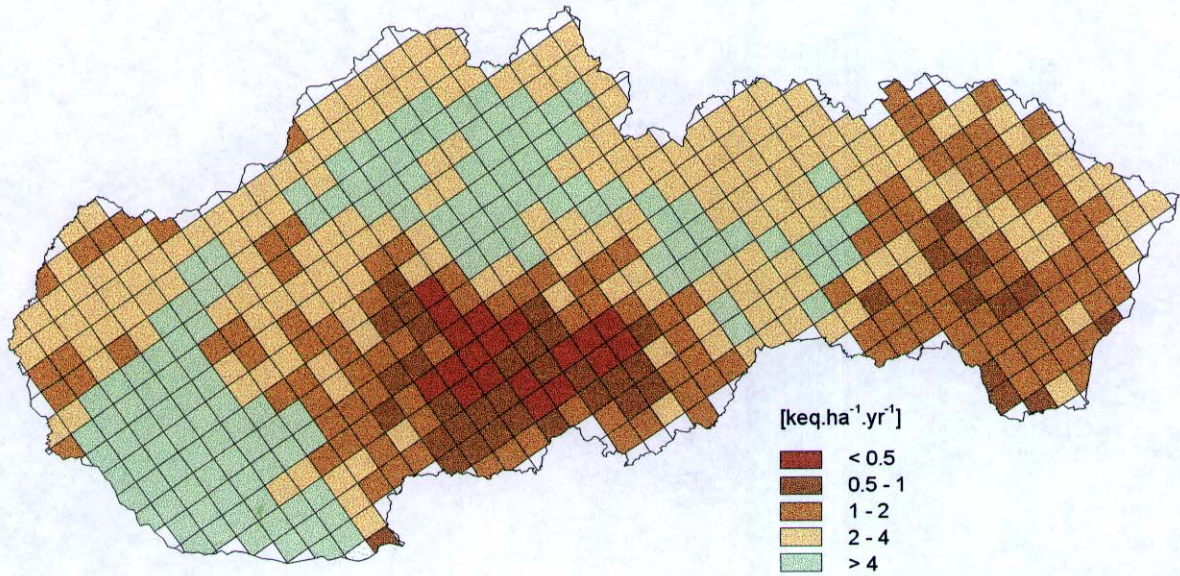
Critical loads of sulphur (5 percentile)

Receptor: Forest soils Year: 1990



Critical loads of potential acidity (5 percentile)

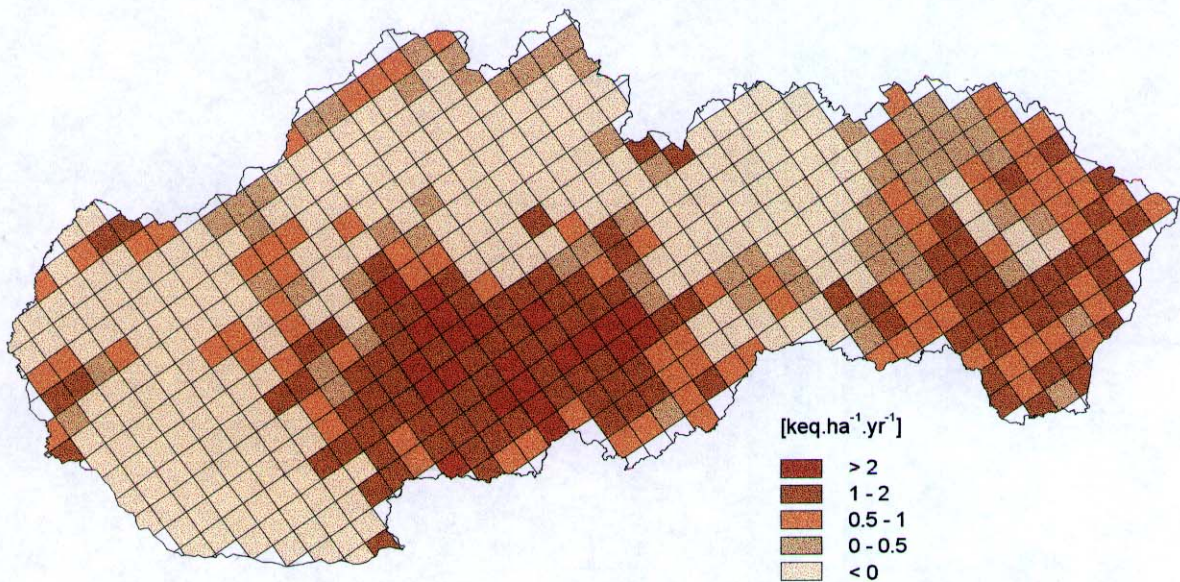
Receptor: Forest soils



Exceedance of critical loads of potential acidity (5 percentile)

Receptor: Forest soils

Year: 1990



ANNEX 6

Description of PROFILE model

CALCULATING CRITICAL LOADS OF ACID DEPOSITION WITH PROFILE - A STEADY-STATE SOIL CHEMISTRY MODEL

PER WARFVINGE and HARALD SVERDRUP

*Department of Chemical Engineering II, Lund Institute of Technology, P.O. Box 124,
S-221 00 Lund, Sweden*

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Abstract. A steady state soil chemistry model was used to calculate the critical load of acidity for forest soils and surface waters at Lake Gärdsjön in S.W. Sweden. The critical load of all acid precursors (potential acidity) for the forest soil is $1.64 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$, and $1.225 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$ for surface waters. For the most sensitive receptor, the critical load is exceeded by $1.0 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$, and a 80% reduction in S deposition is required, if N deposition remains unchanged. The critical load is largely affected by the present immobilization of N in the terrestrial ecosystem which is higher than the base cation uptake. The model, PROFILE, is based on mass balance calculations for the different soil layers. From measurable soil properties, PROFILE reproduces the present stream water composition as well as present soil solution chemistry. The model calculates the weathering rate from independent geophysical properties such as soil texture and mineral composition.

1. Introduction

With the objective to assess the environmental impact of S and N emission, the various bodies within the United Nations Economic Commission for Europe (UN/ECE) is carrying out the task of assessing the 'Critical Load' of acidifying compounds. The Critical Load is defined as:

The maximum deposition of acidifying compounds that will not cause chemical changes leading to long term harmful effects on ecosystem structure and function

The Critical Load is thus a property of the ecosystem, independent of present acid status.

Within the Critical Load exercise, in which all European countries as well as the United States and Canada participate, the levels of tolerance should be assessed for three receptors, forest soils, surface waters and groundwater. For each receptor, a chemical criteria is applied, which, if violated, corresponds to the exceedence of the Critical Load (Sverdrup *et al.*, 1990). As a part of the political process, the levels of exceedence will be calculated to provide foundations for political decisions on abatement measures.

There are basically two different ways to assess the impact of acid deposition on the development of soil chemistry parameters by means of model estimates. First, one may try to reproduce the entire process of acidification by calculating how key soil chemistry quantities have changes from the point in time when the soil was in a pre-industrial steady-state situation with the prevailing ambient

conditions such as precipitation, climatological factors, land use as well as chemical constitution of the precipitation. During the last decade, a number of models directed to assess the long-term impact of acid rain on catchments have been developed. Examples include ILWAS (Chen *et al.*, 1983), MAGIC (Cosby *et al.*, 1985) and Trickle-Down (Schnoor *et al.*, 1984) and SMART (de Vries *et al.*, 1989). These models rely on estimates of pristine conditions. Among these are intensity factors such as deposition composition, soil pH and base saturation, and also capacity factors such as mineral abundance and the cation exchange capacity. One features of dynamic models are that they serve to indicate time scale of the recovery if emission control efforts are implemented.

All dynamic models used for calculating changes in soil chemistry must be triggered from an equilibrium situation. They should also be expected to converge towards a steady-state solution if that the acid deposition is brought to a constant value. The terminal soil chemistry reached in for a constant deposition demonstrates the inherent ability to withstand ultimate acidification of soils and runoff, and reflects the Critical Load of different soil systems.

The modeling strategy adopted in this paper is to make a short-cut past the acidification process itself and directly evaluate the soil's final chemical status for a given set of conditions. With this method the Critical Load of a soil system can be calculated directly, as related to the soil solution composition, groundwater quality, and the acidification and increase in Al content of surface waters. This modeling method does not, however, give any answer to questions regarding the rates of acidification and recovery of soil profiles. By comparing model output for present deposition with soil data, it is possible to evaluate whether the system has reached a steady-state with the present acid deposition or is still undergoing acidification. From the steady-state approach follows some assumptions that must be stressed:

- The magnitude of capacity factors such as mineral abundance and cation exchange capacity is constant.
- Long term average values for precipitation, uptake etc. must be used as input.
- The effect of seasonal variations in input variables such as soil CO₂ pressure, nitrification rate and soil moisture content can not be addressed.
- The rate of change in soil chemistry over time can not be assessed.

The soil chemistry model PROFILE has been developed as a tool for calculating Critical Loads for the three receptors mentioned above. The objective with this paper is to provide a comprehensive description of the model, the underlying principles and to demonstrate the use of the model. A previous publication (Sverdrup and Warfvinge, 1988a) does not describe the present state of the model.

Despite that a number of chemical model already have developed to assess the environmental impact of acid deposition, the existence of PROFILE is justified for the following reasons:

- The model translates to the Critical Loads concepts due to the steady-state approach

- The weathering rates are calculated from independent geophysical soil data
- The data acquisition is supported by the state-of-the-art review in the document 'Mapping Critical Loads' (Sverdrup *et al.*, 1990), available through the Environmental Protection Board of all UN/ECE countries.

The chemistry of the PROFILE model has also been implemented as a dynamic model. That model has been given the acronym SAFE. Soil Acidification in Forested Ecosystems (Warfvinge and Sverdrup, 1990a). In a comparative study (Warfvinge and Sverdrup, 1990b) three model, SAFE, SMART and MAGIC have been applied to historical soil data from sites in Southern Sweden.

2. Materials and Methods

Since PROFILE is designed to calculate the steady-state chemistry of soils, groundwater recharge as well as surface waters, the model operates with different system boundaries. The smallest subsystem is a soil horizon as shown in Figure 1. The soil profile itself is divided into compartments corresponding to the natural soil stratification. Within each of these the mixing of the liquid phase is assumed to correspond to a mixed bucket model. It is a formal requirement that each compartment in the model is chemically isotropic, and the division of the soil profile according to the horizons represents an attempt to meet this.

In each of the soil compartments, a number of chemical reactions are included, represented either by equilibrium relationships or kinetic equations. The reaction systems considered are soil solution equilibrium reactions, silicate weathering, uptake of nutrient cations, NO_3^- and NH_4^+ , nitrification and cation exchange reactions (Figure 1). All processes interact via the soil solution. For instance, there is no mechanism for roots to strip nutrients directly from weathering materials.

These reactions only represent a selection of chemical processes in the soil

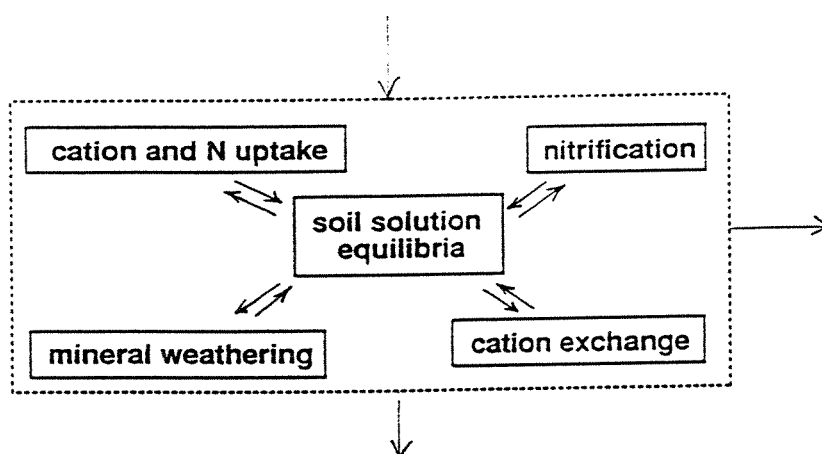


Fig. 1. The conceptual structure of one compartment in the PROFILE model.

environment. Consequently a number of general assumptions have been made. The most important of these are:

- Each soil compartment is chemically isotropic and the soil solution perfectly mixed.
- Sulfur reactions do not serve as a net sink or source of acid neutralizing capacity.
- N immobilization can be lumped with N uptake reactions.
- Internal element cycling of elements such as K in the upper soil layers is not modeled.
- Organic complexing of metals such as Al is not modeled.

The first condition is justified by the mere existence of soil horizons, while assuming complete mixing in a soil layer is less obvious. Recent isotope studies in undisturbed soil columns cite 544 show that a mixed bucket series model can be used to describe the water flow through the unsaturated part of a Swedish forest soil. Sulfuric acid adsorption may buffer soil acidification and recovery for a period of a few decades, and in lakes sulfate reduction is a long term source of alkalinity. In acidified soils close to a steady-state, the role of S mineralization affecting the acidity balance of the terrestrial ecosystem is quite unclear (Nilsson, 1985). The last three simplifications are due to the present lack of suitable models for these reaction systems.

The soil column may also be viewed as one unit, as the system boundary in Figure 2 shows. Thereby, the run-off chemistry can be assessed as the integrated result of chemical reactions in the entire soil column. The water leaving a layer may either percolate vertically or flow horizontally. Changing the proportions between these flow paths will alter the relative importance of different soil layers for the chemistry of the drainage water. The effect of acid precipitation on groundwater formation could also be assessed. The PROFILE model can be used for this purpose by calculating the soil water composition down to the groundwater table.

2.1. SOIL SOLUTION MASS BALANCES

For a chemically isotropic soil horizon, one may derive a mass balance for acid neutralizing capacity. It states that the change in ANC must equal the net difference between what enters a soil layer, what leaves it and the rate by which ANC is produced from different sources. In the model, the processes considered include cation exchange reactions involving H, Al base cations (BC), silicate weathering as well as biological processes that may serve as sinks and sources of ANC. The key mass balance constituting the basis for the soil chemistry model is:

$$\frac{d[\text{ANC}]}{dt} = \frac{1}{z\Theta} (Q_0[\text{ANC}]_0 - \left(Q + z \frac{d\Theta}{dt} \right) [\text{ANC}]) + R_w + R_{\text{exc}} + R_{\text{BC}} + R_{\text{N}} \quad (1)$$

where

- z = soil layer height (m)
- Θ = soil water content ($\text{m}^3 \text{m}^{-3}$)

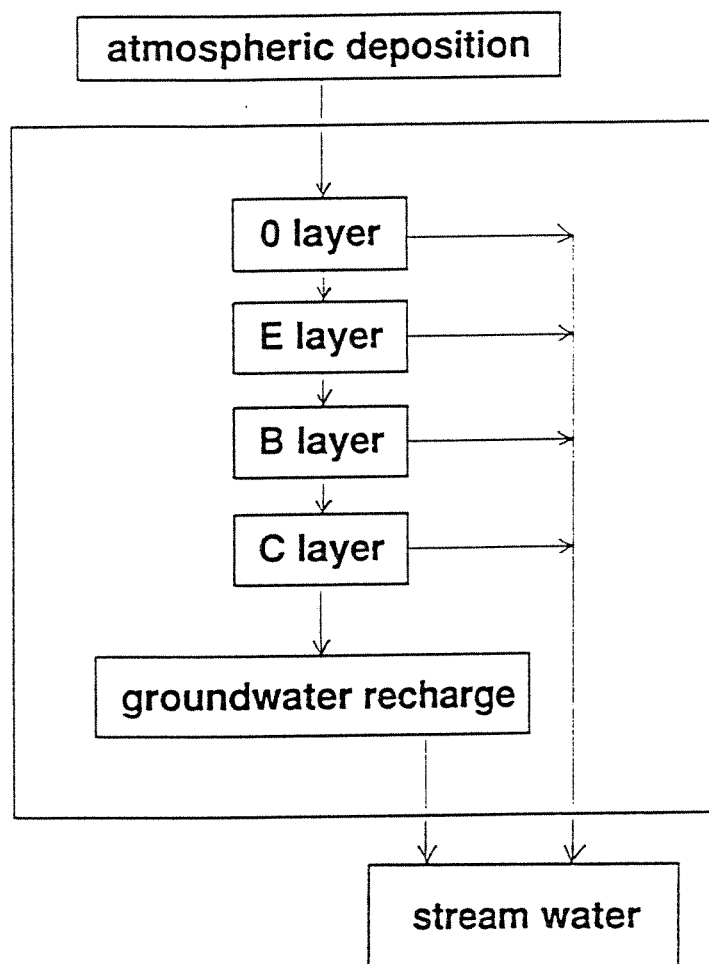


Fig. 2. Water routes possible in the PROFILE model.

- Q = Flow rate ($\text{m}^3 \text{m}_s^{-2} \text{yr}^{-1}$)
 R_W = rate of ANC production from weathering ($\text{kmol}_c \text{m}^{-3} \text{yr}^{-1}$)
 R_{exc} = rate of ANC production from cation exchange ($\text{kmol}_c \text{m}^{-3} \text{yr}^{-1}$)
 R_{BC} = rate of base cation uptake ($\text{kmol}_c \text{m}^{-3} \text{yr}^{-1}$)
 R_N = rate of ANC production by N reactions and uptake
 ($\text{kmol}_c \text{m}^{-3} \text{yr}^{-1}$).

No subscript refers to condition in the soil layer, and consequently also the leachate from a soil layer. Subscript 0 denotes concentrations in the inflow to the layer, while subscript s refers to bulk volume of soil rather than volume of soil water.

If the path of acidification was to be simulated, this differential equation would be solved together with corresponding equations for other soil components. However, when the 'Critical Load' of a soil system is assessed it may not be necessary to reproduce the entire acidification process, but sufficient to regard only the steady-

state solution to Equation (1), accordingly solving Equation (1) for:

$$\frac{d[\text{ANC}]}{dt} = 0. \quad (2)$$

As obvious from the mass balance for ANC, this solution may be obtained even if the cation exchange phase has not reached a steady state in terms of base saturation. For a soil system to be in true equilibrium however, it is necessary constraint that the distribution of cations on the solid phase should not vary with time. Mathematically, this corresponds to a situation where:

$$R_{\text{exc}} \propto \frac{d}{dt} (\text{CEC} (\bar{X}_{\text{BC}} - \bar{X}_{\text{H}} - \bar{X}_{\text{Al}})) = 0 \quad (3)$$

where

$$\begin{aligned} \text{CEC} &= \text{cation exchange capacity in the horizon, arbitrary units} \\ \bar{X}_i &= \text{exchangeable fraction of element } i. \end{aligned}$$

In all systems, the upper limit of removal of any component in solution is the supply. In order to calculate the ANC production from uptake of base cations and N uptake and other reactions, additional mass balances are required. The general form of all these equations are identical to Equation (1). This leads to the following set of equations to be solved simultaneously:

$$0 = \frac{1}{z \Theta} (Q_0[\text{ANC}]_0 - Q[\text{ANC}]) + R_w - R_{\text{BC}} - R_{\text{N}} \quad (4)$$

$$0 = \frac{1}{z \Theta} (Q_0[\text{BC}^{2+}]_0 - Q[\text{BC}^{2+}]) + \frac{R_w - R_{\text{BO}}}{2} \quad (5)$$

$$0 = \frac{1}{z \Theta} (Q_0[\text{NO}_3^-]_0 - Q[\text{NO}_3^-]) - R_{\text{NO}_3^-} + R_{\text{nit}} \quad (6)$$

$$0 = \frac{1}{z \Theta} (Q_0[\text{NH}_4^+]_0 - Q[\text{NH}_4^+]) - R_{\text{NH}_4^+} - R_{\text{nit}} \quad (7)$$

where

$$\begin{aligned} R_{\text{NO}_3^-} &= \text{Rate of } \text{NO}_3^- \text{ uptake (kmol}_c \text{ m}^{-3} \text{ yr}^{-1}) \\ R_{\text{nit}} &= \text{Rate of nitrification, } \text{NH}_4^+ \text{ uptake (kmol}_c \text{ m}^{-3} \text{ yr}^{-1}). \\ R_{\text{NH}_4^+} &= \text{Rate of } \text{NH}_4^+ \text{ uptake (kmol}_c \text{ m}^{-3} \text{ yr}^{-1}). \end{aligned}$$

These first two of these equations must be solved iteratively since the rate of ANC production from weathering, R_w , is a function of pH, which in turn is a non-linear function of the ANC. The solution of Equations (4) to 7 will therefore also include the evaluation of all species that appear in the definition of ANC. With this set of equations, and the functional relationships discussed below, only reacting components in the soil system have to be considered to characterize the soil solution completely. Therefore, the solution of the charge balance becomes redundant, and the fluxes of SO_4^{2-} as well as Cl^- do not have to be included in soil chemistry calculations.

For the uppermost soil layer, the input is the atmospheric deposition.

2.2. SOIL SOLUTION EQUILIBRIUM SUB-MODEL

ANC may be interpreted in terms of dissolved species participating in acid/base transformations in the aqueous phase. In the model it is assumed that the chemical reaction systems of the soil solutions include the auto protolysis of water, the carbonate equilibrium reactions, acid-base reactions of a monovalent organic acid, as well as the precipitation and sub-sequent dissolution reactions of a solid gibbsite phase, producing different charged alumini-hydroxyl species. The solution ANC is defined as:

$$[\text{ANC}] = [\text{OH}^-] + [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [R^-] - [\text{H}^+] - 3[\text{Al}^{3+}] - 2[\text{Al}(\text{OH})^{2+}] - [\text{Al}(\text{OH})_2^+] \quad (8)$$

With this definition, it is clear that ANC is a quantity derived from a reduced charge balance from which all solution components that are not believed to participate in acid-base reactions in the liquid phase have been omitted. Such components include SO_4^{2-} , NH_4^+ and BC^{2+} . In an equilibrium situation, each species on the right hand side of Equations (8) can be explicitly calculated from the solution H^+ -concentration, and ANC will therefore be a unique function of the solution pH and, most important, *vice versa*. Numerically, ANC may be calculated explicitly from a given pH, while the H^+ -concentration corresponding to a given ANC must be calculated iteratively. This is performed by finding the root to the equation:

$$0 = [\text{OH}^-] + [\text{HCO}_3^-] + 2[\text{CO}_3^{2-}] + [R^-] - [\text{H}^+] - 3[\text{Al}^{3+}] - 2[\text{Al}(\text{OH})^{2+}] - [\text{Al}(\text{OH})_2^+] - [\text{ANC}] \quad (9)$$

The concentrations of the components evolving from the carbonate buffering system can be calculated after introducing the equilibrium equations of the protolysis reactions of CO_2 and Henry's law for gaseous and liquid phase CO_2 -equilibrium.

In the organic soil layers, the buffering reaction of organic components may be important. In PROFILE, dissolved organic carbon (DOC) is modeled as a monovalent organic acid. The dissociation of the acid functional groups of the DOC is quantified using an expression as proposed by Oliver (Oliver *et al.*, 1983).

The equilibrium expressions controlling the concentration of the Al species considered, have such a form that it may be interpreted as an apparent equilibrium with gibbsite. It must be remembered that this model is a simplification, and that the equilibrium expression probably lumps together several different mechanisms for Al concentration control. Both equilibrium and disequilibrium mechanisms are involved, and gibbsite may not necessarily be a part of any of these processes which are most likely to proceed as long non-ideal reaction paths. Many sensitive soils in Europe do not contain gibbsite in detectable amounts (Melkerud, 1983), but operationally the Al concentration is estimated from an assumed equilibrium with a solid phase in most models. The justification for selecting the gibbsite

dissolution/precipitation reaction as the foundation for modeling the Al equilibrium system is primarily that reasonable titration curves can be derived with this aquatic chemistry model. Future versions of PROFILE will include an Al chemistry model based on the kinetics of dissolution and precipitation of primary and secondary minerals (Olausson *et al.*, 1990).

The complete set of equilibrium equations necessary to solve Equation (9) is:

$$[\text{OH}^-] = \frac{K_W}{[\text{H}^+]} \quad (10)$$

$$[\text{HCO}_3^-] = \frac{K_{\text{H}_2\text{CO}_3} K_{\text{Henry}} P_{\text{CO}_2}}{[\text{H}^+]} \quad (11)$$

$$[\text{CO}_3^{2-}] = [\text{HCO}_3^-] \frac{K_{\text{HCO}_3}}{[\text{H}^+]} \quad (12)$$

$$[\text{R}^-] = 1 \times 10^{-6} [\text{DOC}] \frac{K_{\text{org}}}{K_{\text{org}} + [\text{H}^+]} \quad (13)$$

$$[\text{Al}^{3+}] = K_G [\text{H}^+]^4 \quad (14)$$

$$[\text{Al}(\text{OH})_2^+] = K_{\text{Al}(\text{OH})_2^+} K_G [\text{H}^+]^2 \quad (15)$$

$$[\text{Al}(\text{OH})_3] = K_{\text{Al}(\text{OH})_3} K_G [\text{H}^+] \quad (16)$$

where

P_{CO_2} = CO_2 partial pressure (atm)

DOC = dissolved organic carbon in solution (mg L^{-1})

K_W etc = Aqueous equilibrium coefficients as specified in Table I.

The constant 1×10^{-6} that appears in the expression for $[\text{R}^-]$ is an empirical factor

TABLE I

Equilibrium equations and corresponding coefficients included in PROFILE. Units applied are kmol, m^3 and atmospheres. References are made to: 1: (Stumm and Morgan, 1983). 2: (Oliver *et al.*, 1983). 3: (Schecher and Driscoll, 1987).

Equilibrium reaction	Equ. coeff.	Value/function	Ref.
$\text{H}_2\text{O} \rightleftharpoons \text{H}^+ + \text{OH}^-$	K_W	$\exp(-6.09 + 4471/T - 0.0171 \cdot T)$	1
$\text{CO}_2(\text{g}) \rightleftharpoons \text{H}_2\text{CO}_3(\text{aq})$	K_{Henry}	$\exp(-12.59 - 2198/T - 0.0126 \cdot T)$	1
$\text{H}_2\text{CO}_3 + \text{H}_2\text{O} \rightleftharpoons \text{HCO}_3^- + \text{H}_3\text{O}^+$	$K_{\text{H}_2\text{CO}_3}$	$\exp(-14.82 + 3401/T - 0.0327 \cdot T)$	1
$\text{HCO}_3^- + \text{H}_2\text{O} \rightleftharpoons \text{CO}_3^{2-} + \text{H}_3\text{O}^+$	K_{HCO_3}	$\exp(-6.53 + 2906/T - 0.0238 \cdot T)$	1
$\text{RH} + \text{H}_2\text{O} \rightleftharpoons \text{R}^- + \text{H}_3\text{O}^+$	K_{org}	$\exp(-0.96 + \text{pH} - 0.001 \cdot \text{pH}^2)$	2
$\text{Al}(\text{OH})_3 + 3\text{H}^+ \rightleftharpoons \text{Al}^{3+} + 3\text{H}_2\text{O}$	K_G	User specified	
$\text{Al}^{3+} + 2\text{H}_2\text{O} \rightleftharpoons \text{Al}(\text{OH})_2^+ + 2\text{H}^+$	$K_{\text{Al}(\text{OH})_2^+}$	5×10^{-10}	3
$\text{Al}^{3+} + \text{H}_2\text{O} \rightleftharpoons \text{Al}(\text{OH})_3 + \text{H}^+$	$K_{\text{Al}(\text{OH})_3}$	1×10^{-5}	3

that converts DOC expressed in mg L^{-1} to carboxyl groups expressed in $\text{kmol}_c \text{L}^{-1}$ (Ågren and Jacks, 1990).

In general, the pH corresponding to a certain ANC is governed by the carbonate and the organic matter buffer systems at positive values for ANC, i.e. at pH-levels above 5, while the Al buffering system has its effect below this level.

2.3. NITROGEN REACTIONS

In PROFILE, we have not attempted to model the processes that govern the flow of nutrient cations, N compounds and ANC between the soil solution and the roots of the growing plants. PROFILE relies on input data to specify the maximum rates of uptake of different compounds to the vegetation.

Nitrogen reactions are included is that they act as sources or sinks of acidity in the soil (Galloway and Dillon, 1983). The connection to the acidity-alkalinity balance is clear from Equation (9), where the net production is quantified by the term R_N . Considering only uptake of NH_4^+ and NO_3^- as well as nitrification, the net production of ANC from these reactions is:

$$R_N = R_{\text{NO}_3^-} - R_{\text{NH}_4^+} - 2 R_{\text{nitr}} \quad (17)$$

The only biological process that is modeled in terms of a kinetic rate expression is nitrification: Regarding N-uptake, PROFILE relies on input data that specifies the maximum yearly uptake, distributed vertically in the horizon. For each soil layer, the constraint for N-uptake can be defined as:

$$R_{\text{NO}_3^-} + R_{\text{NH}_4^+} \leq R_{\text{Nmax}} \quad (18)$$

where

$$R_{\text{Nmax}} = \text{maximum N uptake from the solution in a layer (kmol m}^{-3} \text{ yr}^{-1}\text{)}.$$

In PROFILE, the assumption is that ammonia and nitrate are taken up in fixed proportions, provided that both components are in supply. This fixed ratio is referred to as $x_{\text{NH}_4^+}$. The rate of nitrification is governed by a kinetic expression:

$$R_{\text{nitr}} = \frac{k_{\text{nitr}} [\text{NH}_4^+]}{K_{\text{nitr}} + [\text{NH}_4^+]} \quad (19)$$

The values of the kinetic rate coefficient k_{nitr} and the Michaelis-Menten saturation constant K_{nitr} are discussed in 'Mapping Critical Loads' (Sverdrup *et al.*, 1990).

It is possible to solve for $[\text{NH}_4^+]$ by combining Equation (7) with Equation (19) and the condition that $R_{\text{NH}_4^+} = x_{\text{NH}_4^+} R_{\text{Nmax}}$. The ammonia concentration is then given as the solution to an ordinary second-order equation:

$$[\text{NH}_4^+] = \frac{K_{\text{nitr}} - \alpha}{2} + \sqrt{\left(\frac{K_{\text{nitr}} - \alpha}{2}\right)^2 + K_{\text{nitr}} \left(\alpha + \frac{k_{\text{nitr}}(\theta z)}{Q}\right)} \quad (20)$$

where

$$\alpha = \frac{[\text{NH}_4^+]_0 Q_0}{Q} - (k_{\text{nit}} + x_{\text{NH}_4} R_{\text{Nmax}}) \frac{\Theta z}{Q}$$

If the ammonia entering a soil layer is sufficient to meet the demand for N we therefore get the following result to enter into the mass balances:

$$[\text{NH}_4^+] > 0 \left\{ \begin{array}{l} R_{\text{NH}_4} = \frac{Q_0[\text{NH}_4^+]_0 - Q[\text{NH}_4^+]}{z\Theta} - R_{\text{nit}} \\ R_{\text{NO}_3} = \min \left(\frac{Q_0[\text{NO}_3^-]}{z\Theta} + R_{\text{nit}}, (1 - x_{\text{NH}_4}) R_{\text{Nmax}} \right) \\ R_{\text{nit}} = \frac{k_{\text{nitr}} [\text{NH}_4^+]}{k_{\text{nitr}} + [\text{NH}_4^+]} \end{array} \right. \quad (21)$$

If the supply of NH_4 does not meet the total N uptake demand, however, the solution to Equation (20) becomes 0.

We then get:

$$[\text{NH}_4^+] = 0 \left\{ \begin{array}{l} R_{\text{NH}_4} = \frac{Q_0[\text{NH}_4^+]_0}{z\Theta} \\ R_{\text{NO}_3} = \min \left(\frac{Q_0[\text{NO}_3^-]}{z\Theta}, R_{\text{Nmax}} - R_{\text{NH}_4} \right) \\ R_{\text{nit}} = 0 \end{array} \right. \quad (22)$$

The 'min' operator means that the lowest value of the two arguments in the parenthesis is chosen. This condition prevents uptake of nitrate to exceed the input to the soil layer, which would result in negative concentrations in the calculations.

2.4. BASE CATION UPTAKE

As the N uptake, base cation uptake is represented by a forcing function rather than a process. Furthermore, there is no constraint in the model that base cation uptake should occur in a certain proportion to the N uptake. The only condition is that the uptake cannot be larger than the supply from internal or external sources within a soil layer.

Based on the steady-state mass balance (Equation 5), the uptake expressed per unit soil solution is given as:

$$R_{\text{BC}} = \min \left(\frac{Q_0[\text{BC}]_0}{z\Theta} + R_w, R_{\text{BCmax}} \right). \quad (23)$$

In this case, the 'min' operator puts a constraint on the uptake the sum of what enters the soil layer by convective flow and what is produced not to exceed by chemical weathering.

Due to internal element cycling the actual uptake activity may be larger than

the net removal from the soil solution. A key process to include into the calculations is mineralization of organic matter, primary in the uppermost horizon. Mineralization can be accounted for by assigning a negative value to the uptake rates. The effect is then that base cations, and ammonia is produced. This should be balanced by increased uptake in lower horizons.

2.5. THE WEATHERING RATE SUB-MODEL

In many types of soil systems, weathering of primary minerals provides the long-term neutralization capacity (Reuss *et al.*, 1986). PROFILE has many elements in common with other contemporary soil acidification models (Sverdrup *et al.*, 1990; de Vries *et al.*, 1989). Regarding weathering reactions, however, PROFILE allows the weathering rate to be calculated explicitly from independent soil properties (Sverdrup and Warfvinge, 1988b), rather than being an input to the model. In this context, weathering refers to the release of alkalinity and base cations, rather than the actual dissociation of the silicate structure. The weathering rate constants used in the model are therefore not comparable with rate coefficients determined from Si and Al production experiments.

Several chemical reactions between the mineral and constituents in the liquid solution contribute to the base cation release rate from chemical weathering of silicate minerals, and the total will be the sum of the rates of the individual elementary reactions. For most minerals several dissolution reactions have been experimentally identified (Sverdrup, 1990). These involve many components in the liquid phase; H^+ , H_2O , OH^- and dissolved CO_2 , as well as Al cations of the parent mineral and strongly complexing organic ligands.

The total base cation release rate is taken to be the sum of the rates of all the chemical reactions taking place to dissolve the mineral minus the rate of precipitation of secondary solid phases. The rate is proportional to the exposed surface area of the mineral, and by inserting the expression for the concentration of activated complex in the rate equation based on the transition state theory, a general equation for the weathering rate at constant temperature may be derived. Under the conditions prevailing in the natural soil environment, the base cation release rate for a single mineral, r , may be approximated by:

$$r = k_H \cdot \frac{[H^+]^{n_H}}{f_H} + \frac{k_{H_2O}}{f_{H_2O}} + k_{CO_2} P_{CO_2}^{n_{CO_2}} \quad (24)$$

where

- k_H = rate coefficient for the reaction with H^+ ($m s^{-1}$)
- k_{H_2O} = rate coefficient for the reaction with H_2O ($kmol_c m^{-2} s^{-1}$)
- k_{CO_2} = rate coefficient for the reaction with CO_2 ($kmol_c atm^{-1} m^{-2} s^{-1}$)
- n_H etc. = reaction order of individual reactions
- f_H, f_{H_2O} = rate reduction factors for product inhibition.

Numerical values for the all coefficients of the minerals at present considered in

TABLE II

Rate coefficients for the base cation release from weathering reactions at a temperature of 8 °C.

Mineral	pK_H	n_H	pK_{H_2O}	pK_{CO}	n_{CO}	k_M	x_{Al}	z_{Al}	k_{Ca}	x_{Ca}	z_{Ca}
K-Feldspar	16.0	0.5	17.2	17.2	0.6	$1 \cdot 10^{-5}$	0.4	0.14	5×10^{-4}	0.15	0.15
Oligoclase	15.9	0.5	17.0	15.8	0.6	$2 \cdot 10^{-5}$	0.4	0.14	1×10^{-3}	0.2	0.15
Albite	15.4	0.5	17.0	15.9	0.6	$1 \cdot 10^{-5}$	0.4	0.14	5×10^{-4}	0.2	0.15
Hornblende	15.4	0.7	17.0	15.9	0.6	$5 \cdot 10^{-5}$	0.3	0.3	2.5×10^{-3}	0.3	0.3
Pyroxene	13.8	0.7	17.5	15.8	0.6	$5 \cdot 10^{-4}$	0.2	0.1	2.5×10^{-2}	0.3	0.3
Epidote	12.6	0.8	16.8	15.8	0.6	$5 \cdot 10^{-4}$	0.3	0.2	2.5×10^{-2}	0.2	0.2
Garnet	12.4	1.0	16.9	15.8	0.6	$1 \cdot 10^{-3}$	0.4	0.2	5×10^{-2}	0.2	0.2
Biotite	15.3	0.6	17.6	15.8	0.5	$1 \cdot 10^{-4}$	0.3	0.2	5×10^{-4}	0.2	0.2
Muscovite	15.2	0.5	17.5	16.5	0.5	$1 \cdot 10^{-6}$	0.4	0.2	5×10^{-5}	0.1	0.1
Chlorite	15.3	0.7	16.7	15.8	0.5	$5 \cdot 10^{-5}$	0.2	0.1	2.5×10^{-3}	0.2	0.11
Vermiculite	14.8	0.6	17.6	16.5	0.5	$1 \cdot 10^{-6}$	0.4	0.1	5×10^{-5}	0.2	0.1
Apatite	12.8	0.7	15.8	-	-	-	-	-	3×10^{-4}	0.4	0.2

PROFILE are given in Table II. Reactions with organic ligands have been lumped with the rate of the reaction with water. The two factors reducing the rate of base cation production due to increased concentrations of weathering products, f_H , f_{H_2O} are defined as:

$$f_H = \left(1 + \frac{[Al^{3+}]}{k_{Al}}\right)^{x_{Al}} + \left(1 - \frac{[BC^{2+}]}{k_{BC}}\right)^{x_{BC}} \quad (25)$$

$$f_{H_2O} = \left(1 + \frac{[Al^{3+}]}{k_{Al}}\right)^{z_{Al}} + \left(1 - \frac{[BC^{2+}]}{k_{BC}}\right)^{z_{BC}} \quad (26)$$

where

k_{Al} , k_{BC} = saturation coefficients for dissolution reduction
($\text{kmol}_c \text{ m}^{-3}$)

x_{Al} , x_{BC} , z_{Al} , z_{BC} = reaction orders.

The rate of weathering reactions in soils are kinetically limited, and hence temperature dependent. The temperature effect is quantified through the Arrhenius equation, stating that the reaction rate coefficient is function of a thermodynamic property the activation energy. In PROFILE, the rate coefficient for a given temperature is calculated as.

$$k_T = k_s \exp \left(- \frac{E_A}{R} \left(\frac{1}{T} - \frac{1}{273.15} \right) \right) \quad (27)$$

where

k_T = rate coefficient at Temperature T
 k_s = rate coefficient at 8 °C (Table I)
 E_A = activation energy (kJ kmol^{-1})
 R = universal gas constant ($\text{kJ kmol}^{-1} \text{ K}^{-1}$).

TABLE III

Lumped activation energies used to calculate the weathering rate coefficient from 8 C to the temperature T, by means of Equation(27), and stoichiometric coefficients representing the relative release of base cations. Source: (Sverdrup, 1990)

Mineral	E_A/R^{-1}			Base cation content			
	pK_H	pK_{H_2O}	pK_{CO_2}	y_{Na}	y_K	y_{Mg}	y_{Ca}
K-Feldspar	3500	2000	1700	0.0	0.90	-	-
Oligoclase	4200	2500	1700	0.45	-	-	0.55
Albite	3800	2500	1700	0.9	-	-	0.1
Hornblende	4300	3800	1700	-	-	0.67	0.33
Pyroxene	2700	3800	1700	-	-	0.50	0.50
Epidote	2500	3800	1700	-	-	-	1.0
Garnet	2500	3500	1700	-	-	0.25	0.75
Biotite	4500	3800	1700	-	0.20	0.80	-
Muscovite	4500	3800	1700	-	0.80	0.20	-
Chlorite	4500	3800	1700	-	-	1.0	-
Vermiculite	4300	3800	1700	-	0.50	0.50	-
Apatite	3500	4000	1700	-	-	-	1.0

Values used for E_A/R are given in Table III. The effect of the temperature on model is output is often quite large. Typically, a change by 4° results in a change in weathering rate by 30%.

In soils the availability of moisture may be limited causing the activity of the exposed mineral surface to be less than unity. The reactions will only take place on wetted surfaces, and the degree of surface wetting is taken to be proportional to the soil moisture saturation. All surfaces to participate in reaction must be wetted, but there must also be sufficient soil solution present for the weathering process to communicate with other soil processes. In PROFILE the activity of the reacting surface is assumed to be proportional to the soil moisture saturation. For dissolution in the natural soil environment, the rate equation for each soil horizon is:

$$R_{H^+} = \sum_i^{\text{minerals}} (1 - y_{Na}) r_i A_{exp} x_i \theta z \quad (28)$$

where

- r_i = rate of base cation production from mineral i (Equation (24))
($\text{kmol}_c \text{m}^{-2} \text{s}^{-1}$)
- y_{Na} = fraction of Na released during weathering of mineral i
- A_{exp} = exposed surface of the mineral matrix ($\text{m}^2 \text{m}_s^{-3}$)
- θ = the soil moisture saturation
- x_i = fraction of mineral i in the mineral matrix of the soil horizon.

The exposed surface in the soil horizon can be approximated from a BET analysis of a particle size distribution and the mineralogy (Sverdrup *et al.*, 1990). The soil moisture saturation is calculated by combining the densities of a solid, an

aqueous, and a gaseous phase with the bulk density ρ_{soil} and the volumetric water content θ :

$$\theta = \frac{2700 \theta}{2700 + 1000 \theta - \rho_{\text{soil}}} \quad (29)$$

2.6. THE ION EXCHANGED SUB-MODEL

With the concentrations of all liquid phase components computed, the composition of the exchanger phase may be determined. Three equations are necessary to calculate the charge fractions; two selectivity equations and one total conditions. With the Gapon exchange equations, the condition given by the definition of charge fraction we get:

$$K_{\text{H/Al}} = \frac{[\text{H}^+]^3 \bar{X}_{\text{Al}}^3}{[\text{Al}^{3+}] \bar{X}_{\text{H}}^3} \quad (30)$$

$$K_{\text{H/BC}} = \frac{[\text{H}^+]^2 \bar{X}_{\text{BC}}^2}{[\text{BC}^{2+}] \bar{X}_{\text{H}}^2} \quad (31)$$

$$1 = \bar{X}_{\text{H}} + \bar{X}_{\text{Al}} + \bar{X}_{\text{BC}} \quad (32)$$

where

$\bar{X}_{\text{H}}, \bar{X}_{\text{BC}}, \bar{X}_{\text{Al}}$ = charge fraction of H, BC and Al on cation exchange matrix

$K_{\text{H/Al}}$ = Gapon selectivity coefficient for H-Al exchange

$K_{\text{H/BC}}$ = Gapon selectivity coefficient for H-Ca exchange.

Solving for \bar{X}_{Al} and \bar{X}_{BC} in Equation (30) and Equation (31) respectively, and substituting these quantities into Equation (32) makes it possible to solve for \bar{X}_{H} explicitly as:

$$\bar{X}_{\text{H}} = \left(1 + \frac{K_{\text{H/Al}}^{1/3} [\text{Al}^{3+}]^{1/3}}{[\text{H}^+]} + \frac{K_{\text{H/BC}}^{1/2} [\text{BC}^{2+}]^{1/2}}{[\text{H}^+]} \right)^{-1} \quad (33)$$

The calculated value of \bar{X}_{H} can now be used with the selectivity equation in order to characterize the exchanger phase completely.

2.7. STREAM WATER COMPOSITION

The composition of the stream water is calculated from a steady-state mass balance, where the system boundary is taken around all soil compartments. This is shown in Figure 3. With this concept it is not necessary to keep track on how water is routed within the soil column. For each component in the solution an equation analogous to Equations (4) to (7) is used. For ANC, the mass balance becomes:

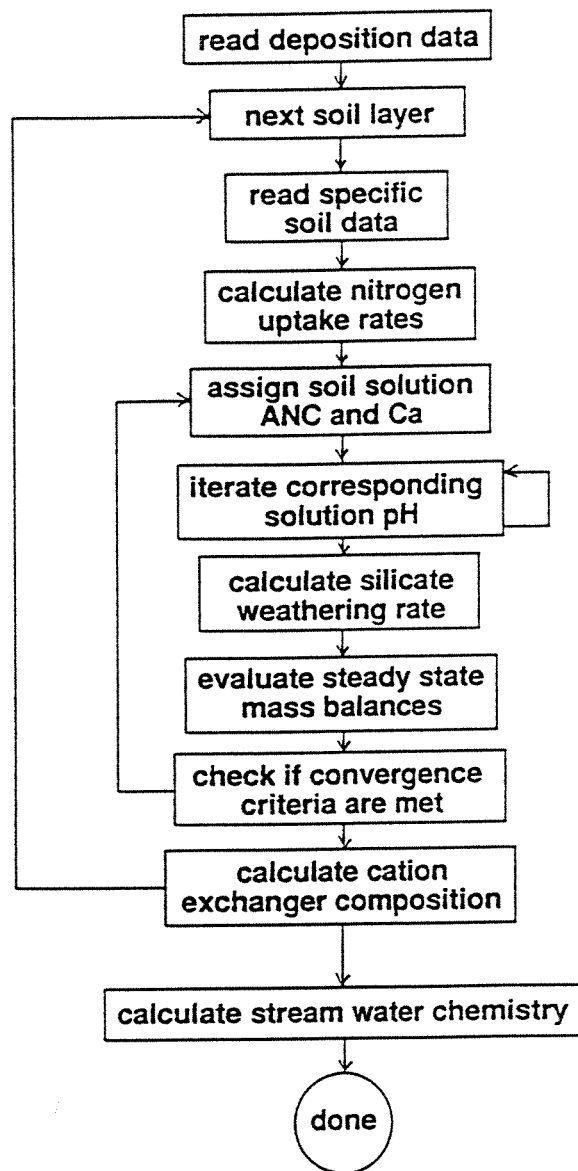


Fig. 3. Calculation order for solving equations in the PROFILE model.

$$Q_{\text{run}} [\text{ANC}]_L = Q_{\text{prec}} [\text{ANC}]_{\text{prec}} + \sum_{\text{layers}} z \theta (R_w - R_{\text{BC}} + R_N) \quad (34)$$

where

$Q_{\text{run}}, Q_{\text{prec}}$ = run-off and precipitation rate (m yr^{-1})
 $\text{ANC}_{\text{run}}, \text{ANC}_{\text{prec}}$ = ANC of run-off and precipitation (kmol m^{-3})

Corresponding balances are evaluated for BC, NO_3^- and NH_4^+ . The pH and the Al

concentration of the run-off is calculated from the ANC by means of Equation (9).

2.8. COMPUTER IMPLEMENTATION

The equations in the PROFILE model are solved according to the flow sheet in Figure 5.1.8. The iterations are carried out with a Regula-Falsi iteration procedure in order to avoid the hazards involved in applying Newton-Raphsons method on these systems of equations.

PROFILE is available as a computer application for Apple Macintosh computers, and requires fractions of a second of computer time. Input data for soil chemistry

The figure displays two screenshots of the PROFILE computer application's data input screens. The top screenshot shows the main configuration window, and the bottom screenshot shows the detailed soil layer input window.

Top Screenshot: Main Configuration Window

Stack: BlankStack/v2.3
 Run ID: Created: 90-10-18

Do Stream Water

Soil temperature (C):

Nitrification rate
 high
 medium
 low
 none

Buttons: Go To Card, Check Input, Import Data, Run PROFILE

Bottom Screenshot: Soil Layer Input Window

Soil layer no:

Buttons: Copy Data, Go To Card, Clear values, Check Input

Soil layer height (m)	<input type="text"/>	<input type="checkbox"/> K-feldspar	<input type="text"/>
Moisture content (m ³ /m ³)	<input type="text"/>	<input type="checkbox"/> Oligoclase	<input type="text"/>
Soil bulk density (kg/m ³)	<input type="text"/>	<input type="checkbox"/> Albite	<input type="text"/>
Surface area (m ² /m ³)	<input type="text"/>	<input type="checkbox"/> Hornblende	<input type="text"/>
CO ₂ pressure (n atm)	<input type="text"/>	<input type="checkbox"/> Pyroxene	<input type="text"/>
% of precipitation entering layer	<input type="text"/>	<input type="checkbox"/> Epidote	<input type="text"/>
leaving layer	<input type="text"/>	<input type="checkbox"/> Garnet	<input type="text"/>
Mg+Ca+K uptake (% of max)	<input type="text"/>	<input type="checkbox"/> Biotite	<input type="text"/>
N-uptake (% of max)	<input type="text"/>	<input type="checkbox"/> Muscovite	<input type="text"/>
DOC (mg/L)	<input type="text"/>	<input type="checkbox"/> Chlorite	<input type="text"/>
log K gibbsite	<input type="text"/>	<input type="checkbox"/> Vermiculite	<input type="text"/>
pK H/Al exchange	<input type="text"/>	<input type="checkbox"/> Apatite	<input type="text"/>
pK H/Ca exchange	<input type="text"/>		

Fig. 4. Data input screens as displayed by the PROFILE computer application.

calculations are entered interactively on two types of screens. On one screen, general data is entered, as shown in the upper part of Figure 4. The nitrification rate is selected according to different classes (Sverdrup *et al.*, 1990). On additional screens, data specific for a each soil horizon is given. Mineralogy is chosen from a selection of twelve common groups of minerals.

A user's manual with cross-references to the 'Mapping Critical Loads' document further facilitates model use. The computer implementation of the model is available through the authors, easy to use and available free of charge for non-commercial use.

Besides calculating soil and stream water chemistry, the model calculates the BC to Al ratio in the soil solution. This quantity is known to serve as an indicator of the potential for forest growth (Huetterman and Ulrich, 1984; and G. van Loenen, 1989). Also, the model summarizes general results such as total weathering rate in the profile, total uptake of N and base cations, acidity produced by N cycling and deposition rates expressed according to different conventions.

3. Results and Discussion

PFOFILE was applied to the research site at Gårdsjön in SW Sweden (Olsson *et al.*, 1985). The model was used to calculate the critical loads of two very similar subcatchment by Lake Gårdsjön, F1 and F3. Calculations were performed with respect to the forest soil and the surface water, applying specific criteria for each system. Input data used for soil chemistry calculations are shown in Table IV. The nitrification rate coefficient was $k_{\text{nitr}}=0.005$, and preference of ammonia to nitrate uptake was set to 2:1, expressed as $x_{\text{NH}_4^+} = 0.67$.

At present, the total deposition of all acid precursors, the potential acidity, amounts to $2.24 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$ (Lövblad *et al.*, 1991). The contribution of total acidity deposited with SO_4^{2-} is 1.27, NO_3^- is 0.72 while NH_3 contribute $0.62 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$. The total atmospheric base cation input is $0.74 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$, of which the non-marine part contributes with a net alkalinity input of $0.37 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$.

Figures 5, 6 and 7 show PROFILE calculations performed for the subcatchments. Soil solution data was taken from Gieser and Lundström (1991). For comparison, pH measured in water suspension (Melkerud, 1983) was included in Figure 5. While the model calculates a long term value for the soil solution, the measurements represent temporal point data. Therefore the model can be said to describe the annual average conditions in the profile. It is clear, however, that the model exhibit the same spatial pattern as the data with lower pH values in the upper soil layers. The internal acidity input in the O horizon is nitrification and NH_4^+ immobilization, while weathering and NO_3^- are sources of alkalinity in the lower layers. While H and Al are strongly coupled via the pH-ANC relationship and the Al equilibrium system, and the value of K_G is therefore an immediate link between pH and calculated

TABLE IV

1: (Melkerud, 1983), 2: (Lundin, 1982), 3: (Castelle and Galloway, 1990), 4: (Jacks and Norrström, 1986), 5: (Raben, 1988), 6: (Persson and Broberg, 1985), 7: (Gieser and Lundström, 1991)

Parameter	Unit	Soil layer					Ref.
		1	2	3	4	5	
Soil layer height	m	0.05	0.10	0.10	0.30	0.15	1
Moisture content	m ³ m ⁻³	0.2	0.2	0.2	0.2	0.2	2
Soil bulk density	kg m ⁻³	800	1200	1400	1600	1600	1
Specific surface area	m ² m ⁻³	5×10 ⁵	1×10 ⁶	1.5×10 ⁶	1.7×10 ⁶	1.7×10 ⁶	1
CO ₂ pressure	times ambient	3	5	10	15	20	3, 4
Inflow	% of precipitation	100	90	80	70	61	^a
Percolation	% of precipitation	90	80	70	61	61	^a
Mg-Ca+K uptake	% of total max	20	20	30	30	0	5
N uptake /	% of total max	20	20	30	30	0	5
Dissolved organic carbon	mg L ⁻¹	34	76	8	5.9	5.9	5
log Gibbsite eq. constant	kmol ² m ⁻³	6.5	8.12	9.05	9.27	9.27	6
		% of total					
Mineral							
K-feldspar		15	15	18	13	19	
Oligoclase		14	14	12	16	14	
Hornblende		0.1	0.5	0.5	1.5	0.5	
Epidote		0.1	0.5	0.5	1.5	0.5	
Garnet		0	0.1	0.1	0.1	0.1	
Biotite		0	0.1	0.5	0.5	0.5	
Chlorite		0	0.4	0.4	0.4	0.4	
Vermiculite		0	3.0	5.0	0	0	
Quartz		70.9	69.0	65.0	63.0	65.0	

^a Pure guess.

Al concentration. To obtain the best values for K_G these were actually calculated from the data. The capability of the model to reproduce pH and Al data is therefore dependent on how well it calculates the ANC. At present PROFILE cannot present the calculations of different base cations separately because the vertical distribution of the uptake and regeneration of different base cations are not known. The comparison between measured Ca and calculated BC should therefore not be brought too far.

Critical loads can be evaluated in different ways, depending on what processes in the ecosystem that are regarded as natural processes. The term 'potential acidity' implies that ammonia deposition results in release of acidity, either by direct uptake or nitrification. It is thus defined as:

$$\text{Potential acidity} = \text{SO}_{4,D}^* + \text{NO}_{3,D} + \text{NH}_{4,D} - \text{BC}_D^* \quad (35)$$

where $\text{SO}_{4,D}^*$, $\text{NO}_{3,D}$, $\text{NH}_{4,D}$, BC_D^* = Atmospheric deposition (kmol_c ha⁻¹ yr⁻¹).

Superscript * refers to deposition from non-marine sources, subscript D denotes deposition.

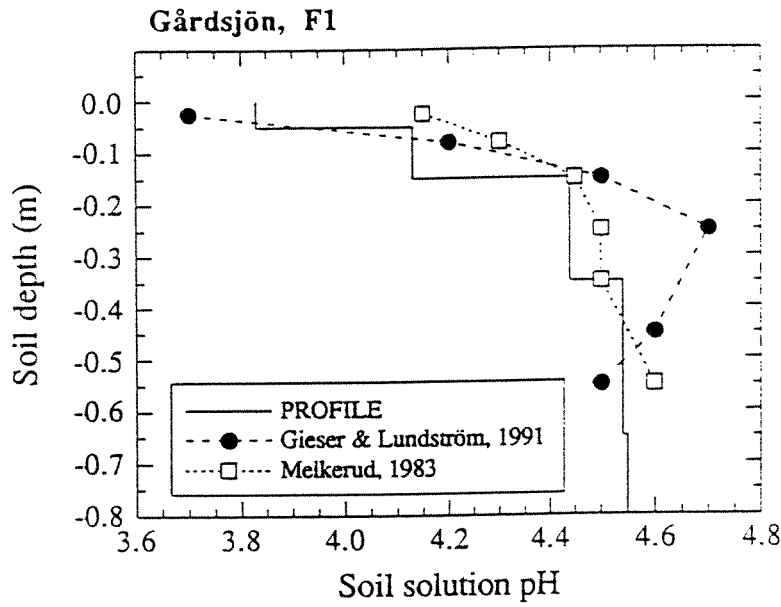


Fig. 5. Calculated soil solution pH and data.

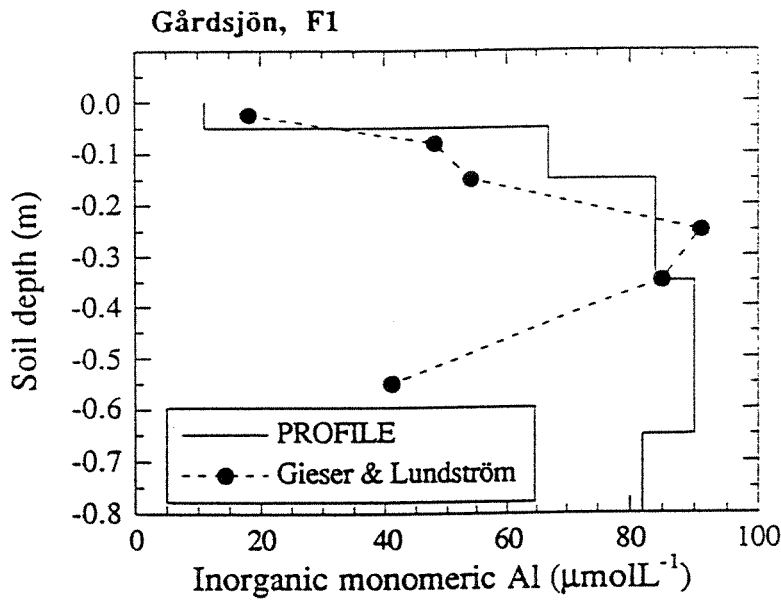


Fig. 6. Calculated soil solution Al and data.

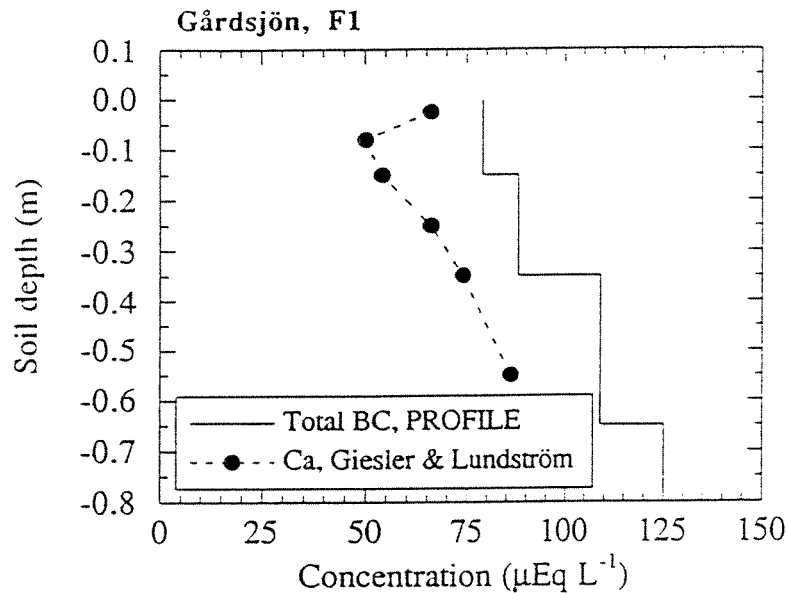


Fig. 7. Calculated soil solution base cation concentration and data.

With this definition, the critical load becomes (Sverdrup *et al.*, 1990):

$$\begin{aligned} \text{Critical load of Potential acidity} &= \\ &= \sum_{\text{layers}} z \theta (R_w - R_{BC} + R_N) - Q_{\text{run}} [\text{ANC}]_L \end{aligned} \quad (36)$$

With this definition, the critical load is assessed under the condition that the influence of land use, quantified in the uptake of base cations and N will remain at present level.

Although the definition of the critical load is independent of which receptor that is considered, the actual value depends on if the soil system or the surface water is considered since different critical criteria are applied. This is because that the biological indicators in the two systems are different. The forest stand is the biological indicator for the soil system, while fish populations should be protected in surface waters.

For forest soil, the Manual on Mapping of Critical Loads' suggests that the molar ratio of Ca to Al in the soil solution is used as criterion. This quantity is known to serve as an indicator of the potential for forest growth. A low ratio of Ca to Al indicates that the uptake of nutrient cations is subject to competition from Al which specifically inhibits the development of active root tips. The model does not distinguish between the nutrients Ca, Mg and K, and PROFILE therefore calculates the molar ratio between 'base' cations, BC to Al^{3+} .

Figure 7 shows the calculated minimum soil solution BC:Al ratio as the bold

line as a function of deposition of potential acidity. Given that the criteria for forest soils is a BC:Al ratio of 1.0, the critical load of the system is $1.64 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$. The S deposition must consequently be reduced by 50% to reach a target deposition corresponding to the critical load for the forest soil, if N deposition remains unchanged. According to concept of potential acidity, however, the relative proportions of change in deposition has no influence, as long as the total reduction in deposition of acid precursors is sufficient.

The critical load can also be calculated directly from PROFILE output according to Equation (36). With a calculated weathering rate of $0.584 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$, and an ANC in the runoff of $-46 \mu\text{mol m}^{-3}$ ($0.252 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$) and additional data from Table V, it is evaluated as:

$$\text{Critical load of Potential acidity} = 0.584 - 0.5 + 1.3 - (-0.252) = 1.64. \quad (37)$$

The data that are foundation for setting the critical BC:Al ratio to 1.0 anywhere in the root zone do leave room for different interpretations (Sverdrup *et al.*, 1990; Sverdrup and Warfvinge, 1990). Applying the more strict criteria of [BC]:[Al] = 1.25 leads to a decrease in critical load by $0.20 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$, a rather small change as compared to other uncertainties involved. With a criteria of 0.75, however, the critical load will increase by $0.35 \text{ kmol}_c \text{ ha}^{-1} \text{ yr}^{-1}$. According to PROFILE calculations the lowest value of the BC:Al ratio in the root zone consistently appears in the B horizon.

The critical load for surface water of the two minicatchments F1 and F3 in the Lake Gårdsjön area was calculated with the same data as for the forest soil. As described above this is performed with Equation (34) and corresponding equations for base cations, NH_4^+ and NO_3^- . Additional input parameters are limited to the K_G , DOC and P_{CO_2} of the stream water. At the pH levels corresponding to the

TABLE V

Parameter	Unit	Value
Precipitation	m yr^{-1}	0.9
Runoff	m yr^{-1}	0.56
Temperature	$^{\circ}\text{C}$	8
Present deposition:		
H_2SO_4	$\text{kEq ha}^{-1} \text{ yr}^{-1}$	1.27
HNO_3	$\text{kEq ha}^{-1} \text{ yr}^{-1}$	0.72
NH_4^+	$\text{kEq ha}^{-1} \text{ yr}^{-1}$	0.62
Ca-Mg+K	$\text{kEq ha}^{-1} \text{ yr}^{-1}$	0.74
Non-marine fraction	%	50
Maximum uptake		
Ca-Mg+K	$\text{kEq ha}^{-1} \text{ yr}^{-1}$	0.50
$\text{NO}_3^- + \text{NH}_4^+$	$\text{kEq ha}^{-1} \text{ yr}^{-1}$	1.30

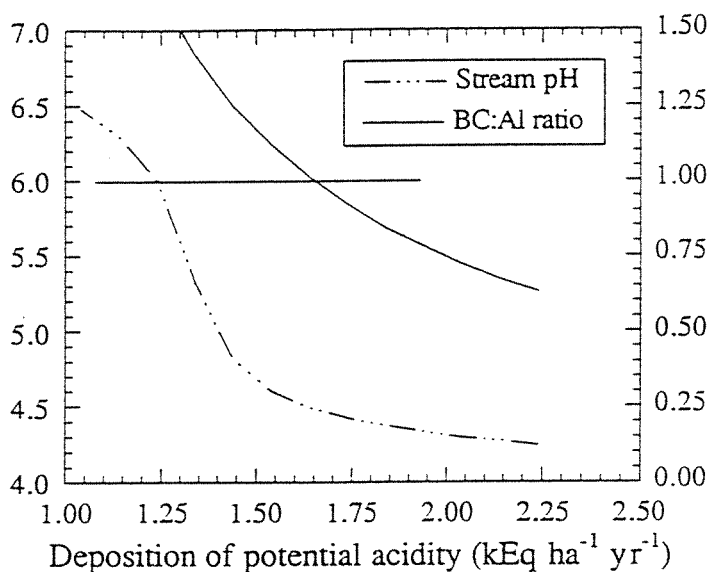


Fig. 8. Soil solution BC:Al ratio and stream pH as a function of deposition rate, as calculated by PROFILE.

Swedish criteria for surface waters, an ANC of 20 mmol m^{-3} , Al buffering is negligible. The DOC in the streams draining F1 and F3 is 7.7 mg L^{-1} (Persson and Broberg, 1985), while the CO_2 pressure in equilibrium with the stream water was estimated to 2 times atmospheric partial pressure.

The results from these calculations are shown in Figure 8. At present, the runoff from these subcatchments are in the range 4.1 to 4.3 (Hultberg, 1985). This corresponds to the model's predictions of the stream water pH at present deposition. This indicates that the catchments are terminally acidified, i.e. the soil have reached a steady-state with the acid deposition. This conclusion is further supported by a proton budget of the catchment (Nilsson, 1985).

The calculations show that the acid deposition at Lake Gårdsjön would have to be decreased even further in order reach a critical loads, as compared to the critical loads of the soil. The difference can be interpreted by means of Equation (36). While leaching of acidity could be tolerated from the forest soil, a positive ANC is necessary to meet the criterion of pH 6.0 in the runoff. Also, the weathering rate is marginally lower at the lower rate of deposition corresponding to the critical load for the stream waer. The calculation becomes:

$$\text{Critical load of Potential acidity} = 0.567 - 0.5 + 1.3 - 0.132 = 1.235. \quad (38)$$

The result that the critical loads for the forest soil and the stream water at Gårdsjön are similar should not be made into a general conclusion. In many regions, such as S. Norway, tills may be even more shallow than at Lake Gårdsjön, and the weathering capability is very small. In such areas, the most sensitive receptor

is therefore most likely to be the surface waters, while the opposite may be case for Central Sweden and S.E. Norway.

It must be pointed out however, that the observed N uptake largely exceeds the rate of base cation uptake. This indicates an imbalance in the ecosystem that may not correspond to a steady-state situation, unless denitrification is the actual cause of the apparently almost complete N uptake in the terrestrial ecosystem. To avoid this effect, the critical load may therefore be 'cleaned' from factors caused by forestry and pseudosteady state by deleting the uptake from the critical loads definition. One can therefore calculate a critical load based on the inherent capability of the system to neutralize acid deposition as:

$$\text{Critical load of acidity} = \sum^{\text{layers}} z \Theta R_w - Q_{\text{run}} [\text{ANC}]_L. \quad (39)$$

With this convention, the critical load of acidity for the forest soil becomes 0.84 and 0.435 for surface waters. With this definition, it becomes more obvious that the present imbalance between base cation and N uptake is a very important source of alkalinity in the system. In a longer perspective, the required reductions in S depositions calculated from the critical load of potential acidity will not suffice to meet the critical load, but N deposition must also be reduced. Mathematically, however, the present exceedance of the critical load is identical with the exceedance of the critical load of potential acidity. This is because the uptake terms then are considered as external loads of acidity or alkalinity, comparable with the atmospheric deposition.

4. Conclusions

PROFILE allows the sensitivity of different ecosystems to be quantified in terms of critical loads. The critical load can thus be calculated from geophysical data, and is not based on information of the present state of acidification of a system. The model requires input data, such as mineralogy, that are not routine measurements in most field projects, and we wish that other researchers in terrestrial sciences are encouraged to consider to put emphasis on gathering such data. The Al chemistry in PROFILE is based on the presence of phase that is still yet to be discovered. PROFILE may provide a framework to explore new hypothesis regarding Al mobility in soils since it makes it possible to separate the primary production of Al from silicate minerals from the influence of secondary phases.

By definition, the critical load should be calculated from long-term conditions. Regarding the N issue, the problem is basically that there is a lack of knowledge how terrestrial ecosystems will respond to high N loads. Here, PROFILE is simple tool for assessing the effects of different N uptake/deposition scenarios.

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References

- Castelle, A. J. and Galloway, J. N.: 1990, 'Carbon Dioxide Dynamics in Acid Forest Soils in Shenandoah National Park, Virginia', *Journal of Soil Science Society of America* **4**, 252.
- Chen, C. J., Gherini, S., Hudson, R. M., and Dean, S.: 1983, *The Integrated Lake-Watershed Acidification Study*, Final Report EPRI EA-3221, Electrical Power Research Institute, Palo Alto, California.
- Cosby, B. J., Wright, R. F., Hornberger, G. M., and Galloway, J. N.: 1985, 'Modeling the Effects of Acid Deposition: Assessment of a Lumped Parameter Model for Soil Water and Stream Water Chemistry', *Water Resources Research* **21**, 51.
- Galloway, J. N. and Dillon, P. J.: 1983, 'Effects of Acid Deposition: The Importance of Nitrogen', in *Ecological Effects of Acid Deposition*, National Swedish Environmental Protection Board, pp. 145-160.
- Giesler, R. and Lundström, U.: 1991, 'The Chemistry of Several Podsol Profile Soil Solutes Extracted with Centrifuge Drainage Technique', in Rosén, K. (eds.), *Chemical Weathering under Field Conditions*, Swedish University of Agricultural Sciences, Department of Forest Soils, Uppsala, Sweden, pp. 157-165.
- Huetterman, A. and Ulrich, B.: 1984, 'Solid Phase-Solution-Root Interaction in Soils Subjected to Acid Deposition', *Phil. Trans. R. Lond.*, **B305**, 352.
- Hultberg, H.: 1985, *Budgets of Base Cations, Chloride, Nitrogen and Sulphur in the Acid Lake Gårdsjön*, Vol. 37 of *Ecological bulletin*, Swedish Natural Science Research Council (NFR), Stockholm, Sweden, pp. 133-157.
- Jacks, G. and Norrström, A.-C.: 1986, *Markkalkning för att ätgärda surt grundvatten (Soil liming for mitigating acid groundwater)*, Progress report, Department of Land Improvement and Drainage, Royal Institute of Technology, Stockholm, Sweden.
- Keltjens, W. G. and Loenen, E. van: 1989, 'Effects of Aluminium and Mineral Nutrition on Growth and Chemical Composition of Hydroponically Grown Seedlings of Live Different Forest Tree Species', *Plant and Soil* **119**, 39.
- Lundin, L.: 1982, *Soil Moisture and Ground Water in Till Soil and Significance of Soil type for Runoff*, UGNI Report No. 56, Dept. of Physical Geography, Uppsala University, Uppsala, Sweden.
- Lövblad, G., Andersen, B., Hovman, M., Joffe, S., Pedersen, U., and Reisell, A.: 1991, *Mapping Deposition of Sulphur, Nitrogen and Base Cations to the Nordic Countries*, Nordic Council of Ministers, Copenhagen (in prep.).
- Melkerud, P. A.: 1983, *Quaternary Deposits and Bedrock Outcrops in an Area Around Gårdsjön, South-West Sweden, with Physical, Mineralogical Geochemical Investigation*, Reports on Forest Ecology and Forest Soils No.: 40, Swedish University of Agricultural Sciences, Uppsala, Sweden.
- Nilsson, I. S.: 1985, *Why is Lake Gårdsjön acid? - An Evaluation of Processes Contributing to Soil and Water Acidification*, Vol. 37 of *Ecological Bulletin*, Swedish Natural Science Research Council (NFR), Stockholm, Sweden, pp. 311-318.
- Olausson, S., Warfvinge, P., and Sverdrup, H.: 1990, *An Aluminium Model Based on the Kinetics of Dissolution and Precipitation in Relation to the Gibbsite Model*, Presented at International Conference on Acidic Deposition, Glasgow 16-21 September 1990.
- Oliver, G. G., Thurman, E. M., and Malcolm, R. L.: 1983, 'The Contribution of Humic Substances to the Acidity of Colored Natural Waters', *Geochimica et Cosmochimica Acta* **47**, 2031.

- Olsson, B., Hallbäck, L., Johansson, S., Melkerud, P.-A., Nilsson, L., and Nilsson, T.: 1985, *The Lake Gårdsjön Area - Physiogeographical and Biological Features*, Vol. 37 of *Ecological Bulletin*, Swedish Science Research Council (NFR), Stockholm, Sweden, pp. 10-28.
- Persson, G. and Broberg, O.: 1985, *Nutrient Concentrations in the Acidified Lake Gårdsjön: The Role of Transport and Retention of Phosphorus, Nitrogen and DOC in Watershed and Lake*, Vol. 37 of *Ecological Bulletin*, Swedish Natural Science Research Council (NFR), Stockholm, Sweden, pp. 158-175.
- Raben, G. H.: 1988, *Untersuchungen zur räumlichen Entwicklung boden- und wurzel-chemischer Stressparameter und deren Einfluss auf die Feindwurzelentwicklung in bodensauren Waldgesellschaften des Hils*, Vol. Reihe A, Bd. 38 of *Berichte des Forschungszentrums Waldökosysteme/Waldsterben*, Göttingen, Germany.
- Reuss, J., Christophersen, N., and Seip, H. M.: 1986, 'A Critique of Models for Freshwater and Soil Acidification', *Water, Air, and Soil Pollution* 30, 909.
- Schecher, W. D. and Driscoll, C. T.: 1987, 'An Evaluation of Uncertainty Associated with Aluminium Equilibrium Calculations', *Water Resources Research* 23, 525.
- Schnoor, G., Palmer Jr., W. D., and Glass, G. E.: 1984, 'Modeling Impacts of Acid Precipitation for Northeastern Minnesota', in Schnoor, G. (ed.), *Modeling of Total Acid Precipitation Impacts*, Butterworth Publishing, London.
- Stumm, W. and Morgan, J. J.: 1983, *Aquatic Chemistry*, Wiley Interscience, New York.
- Sverdrup, H. and Warfvinge, P.: 1988a, 'Assessment of Critical Loads of Acid Deposition on Forest Soils', in Nilsson, J. (ed.), *Critical Loads for Sulphur and Nitrogen*, Nordic Council of Ministers and The United Nations Economic Commission for Europe (ECE), pp. 81-130.
- Sverdrup, H. and Warfvinge, P.: 1988b, 'Weathering of Primary Silicate Minerals in the Natural Soil Environment in Relation to a Chemical Weathering Model', *Water, Air, and Soil Pollution*, 38, 387.
- Sverdrup, H. and Warfvinge, P.: 1992, 'A Model for the Impact of Soil Solution Ca:Al Ratio on Tree Base Cation Uptake', *Water, Air, and Soil Pollution*, 61, 365.
- Sverdrup, H. U., Vries, W. de, and Henriksen, A.: 1990, *Mapping Critical Loads*, Nord 1990:98, Nordic Council of Ministers.
- Sverdrup, H.: 1990, *The Kinetics of Base Cation Release Due to Chemical Weathering*, Lund University, February 1990.
- Vries, W. de, Posch, M., and Kim, J.: 1989, 'Simulation of the Long Term Soil Response to Acid Deposition in Various Buffer Ranges', *Water, Air, and Soil Pollution* 48, 349.
- Warfvinge, P. and Sverdrup, H.: 1990a, *Dynamic Modeling of Acidification of Forest Soils*, Presented at International Conference on Acidic Deposition, Glasgow 16-21 September 1990.
- Warfvinge, P. and Sverdrup, H.: 1990b, 'The SAFE (Soil Acidification of Forested Ecosystems) Model', in Andersen, B. (ed.), *Soil Acidification Models Applied on Swedish Historic Soils Data*, Nordic Council of Ministers, Copenhagen (in prep.).
- Ågren, S. and Jacks, G.: 1990, *Aluminium Mobility and Humic Substances*, Technical Report 1058, Royal Institute of Technology, Stockholm, Sweden.



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- 1/1982 Henriksen, A. 1982. Changes in base cation concentrations due to freshwater acidification. 50 pp. Out of print.
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