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Project Coordinator: Helmut Hojesky

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CRITICAL LOADS OF ACIDITY FOR HIGH PRECIPITATION AREAS

Results from a Workshop held in Vienna, March 9-10 1992 on the Modifications of Austrian, German and Swiss Maps of Critical Loads of Acidity.

by Umweltbundesamt/Federal Environmental Agency (Austria)

Introduction

There have been some problems using the originally proposed simplified mass balance equations of the Mapping Manual for calculating critical loads of acidity in high precipitation areas. The simplified equation appears to be biased towards the runoff rate. This results in unrealistic critical loads values for alpine areas in Austria and Switzerland as well as in the Harz mountains of Germany and the German Erzgebirge. The values obtained with the simplified equation indicate, that areas known to be sensitive to acid deposition appear as insensitive.

Objective

The objective was to modify the simplified mass balance equations, to remove simplifications not valid, and thereby remove the runoff bias observed for high precipitation areas. The modified versions of the critical loads equations were used to reculculate the critical loads of acidity for Austria, Germany and Switzerland, and to draw modified maps.

The old equation

As it appears in the critical loads mapping manual and related documentation, the originally proposed simplified mass balance equations (SMB) were derived on a basis of a series of assumptions and simplifications. These assumptions and simplifications have been worked through and checked, whether they apply under alpine conditions.

In Austria, Germany and Switzerland, where the runoff varies from 0,3 to 3,5 m/yr, the originally proposed SMB gives critical loads values, which are obviously too high. Areas known to be sensitive to acidification appear as being insensitive. That means, that - according to the critical loads calculations - they are are allowed to receive significantly more acid deposition than they can tolerate. This can be illustrated by the table below, where the results of the originally proposed SMB and the results of PROFILE, which is a complex multi-layer model working on the same mass balance principles, are compared for 3 Swedish sites using different runoff rates in the calculation of critical loads:

Q m/yr	PROFILE keq/ha yr	SMB keq/ha yr	Site and input data
0.15	0.45	0.67	Sandvatten:
0.55	0.41	1.03	W = 0.15
1.15	0.21	1.57	D = 0.6
2.15	0.20	2.47	U = 0.5
0.15	1.00	1.80	Gårdsjön:
0.55	1.06	2.30	W = 0.68
1.15	1.20	2.92	D = 0.55
2.15	1.06	3.90	U = 0.5

0.15	2.25	4.95	Skåne no. 7:
0.55	2.45	5.30	W = 2.0
1.15	2.75	6.00	D = 0.75
2.15	3.10	6.74	U = 0.7

W = weathering rate of Ca + Mg + K + Na [eq/(ha.yr)]
D = base cation deposition [eq/(ha.yr)]
U = base cation uptake [eq/(ha.yr)]

The formula applied in the originally proposed SMB was

$$CL = W + 0.09 \cdot Q + 1.5 \cdot \left(\frac{W + D - U}{(BC/Al)_{crit}}\right) \quad (1)$$

CL = critical load of actual acidity [eq/(ha.yr)]
Q = runoff rate [m^3/(ha.yr)]
$(BC/Al)_{crit}$ = critical base cation : aluminium rate

As critical chemical criterion the BC/Al-ratio = 1,0 was used.

The new equation

By deriving the equation from the complete mass balance, but not making the same simplifications as for the old equation, one can derive a different formula for the calculation of critical loads starting with the definition of the critical load of actual acidity:

$$CL = W - ANC_{l(acc)} \quad (2)$$

ANC = acid neutralizing capacity = alkalinity [eq/m^3]

$ANC_{l(acc)}$ = acceptable alkalinity leaching [eq/(ha.yr)]

In this equation the limiting ANC leaching is determined by the maximum permitted leaching of H^+ and AL^{3+}:

$$ANC_{l(acc)} = -H^{+}_{limit} - Al^{3+}_{limit} \quad (3)$$

The limiting Al-flux is determined by the molar BC/Al-ratio applied, which depends on a mass balance of available base cations. The simplified SMB had assumed, that all the production of alkalinity due to weathering is equivalent to the base cation production involved in the BC/Al-ratio. This is different from nature, because approximately 20-40% or more of the base cations produced by weathering is Na, providing no protection against Al and thus not participating in the BC/Al-ratio:

$$W(Ca+Mg+K) = (1-X_{Na}) \; . \; W(Ca+Mg+K+Na) \quad (4)$$

$1 - X_{Na} = X_{BC}$

X_{BC} = Fraction of weathering excluding Na = 0,6-0,8

This leads to:

$$Al^{3+}_{limit} = \frac{BC}{(BC/Al)} = 1.5 \; . \; \frac{(1-X_{Na}).W + D - U - L_{min}}{(BC/Al)_{crit}} \quad (5)$$

L_{min} = min. leaching of base cations [eq/(ha.yr)]

The factor 1.5 derives from the conversion of critical loads

and base cation concentrations in equivalents to the molar ratio. L_{min} is the minimum leaching of base cations, corresponding to the leaching caused by the residual concentration of base cations that the trees cannot take up. The limiting BC concentration is in the range 10-20 µeq/l; an average of 15 µeq/l has been used:

$$L_{min} = Q \cdot 0{,}015 \qquad (6)$$

Operationally the H^+-concentration can be calculated using the gibbsite equation:

$$[H^+] = \left(\frac{Al^{3+}}{K_{gibb}}\right)^{1/3} \qquad (7)$$

K_{gibb} = Gibbsite coefficient = 300 m^6/eq^2

Accordingly the limiting H^+-concentration corresponding to a certain Al^{3+}-concentration in the soil is calculated from the Al-limiting flux (equation 5), divided by the runoff rate and the gibbsite coefficient:

$$[H^+]_{limit} = \left(\frac{Al^{3+}_{limit}}{Q \cdot K_{gibb}}\right)^{1/3} \qquad (8)$$

By inserting the expression for the Al-limiting flux (equation 5) in equation 8 and multiplying with the runoff rate to get from H^+-concentration to flux, one gets:

$$H^+_{limit} = \left(1.5 \cdot \frac{(1-X_{Na}) \cdot W + D - U - Q \cdot 0.015}{(BC/Al)_{crit} \cdot Q \cdot K_{gibb}}\right)^{1/3} \cdot Q \qquad (9)$$

Using equations 2, 3, 5 and 9, the modified SMB equation for

the critical loads of actual acidity becomes:

$$CL = W + \left(1.5 \cdot \frac{X_{BC} \cdot W + D - U - Q \cdot 0.015}{(BC/Al)_{crit} \cdot K_{gibb}}\right)^{1/3} \cdot Q^{2/3} + 1.5 \cdot \left(\frac{X_{BC} \cdot W + D - U - Q \cdot 0.015}{(BC/Al)_{crit}}\right) \quad (10)$$

For units of critical loads in eq/(ha.yr) and Q in m^3/(ha.yr), the gibbsite coefficient takes the value 300 m^6/eq^2. This corresponds to $-pK_{gibb} = 8.5$. In the modified SMB equation, the dilution of acidity with increasing runoff has been taken into account. Empirically derived values of $-pK_{gibb}$ are 6.5 for the O/A-layer, 7.5 for the E-layer and 8.5 for the B-layer. The modified equation also takes into account, that approximately 20-40% of the base cations produced by weathering is Na, not participating in the BC/Al-ratio. Hence the factor X_{BC} is 0.8, which is a maximum value. The factor varies depending on soil mineralogy.

The simplified expression implies by setting H^+-leaching to 0,09.Q, that there is no large variation of the runoff rates between sites. This is not true for alpine regions, whereas it is correct for the northern European plain. Furthermore the term (W+D-U) is not constant between different sites in the alpine region. Hence it can be concluded, that the simplified SMB equations were neither valid for the alpine region nor any other region with high precipitation and runoff rates.

Results

The modified simple mass balance equations for calculating critical loads of actual acidity were applied to the Austrian, German and Swiss datasets for a comparison with the old calculations. The existing databases were used for the calculations; new data were not required, except annual average temperature.

For the Austrian and Swiss datasets additional changes were made. The weathering rate was set proportional to temperature, using an Arrhenius relationship with A=3500. The formula used was:

$$W = W_0 \cdot 10^{\left(\frac{A}{281} - \frac{A}{273 + T}\right)} \qquad (11)$$

Rooting depth was assumed to decline from 50cm at 1500m above sea level to 10cm at 2500m above sea level.

The figures 1-3 show the Austrian, German and Swiss critical loads maps calculated with the originally proposed simple mass balance equations and the modified ones. It can be seen that the very high critical loads in high precipitation areas have disappeared.

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Acknowledgements:

This report was jointly prepared by (in alphabetical order):

Beat ACHERMANN (Federal Office of Environment, Forests and Landscape, Bern, Switzerland)
Helmut HOJESKY (Umweltbundesamt, Vienna, Austria)
Beat RIHM (Meteotest AG, Bern, Switzerland)
Harald SVERDRUP (Dept. of Chemical Engineering, LTH Lund, Sweden)

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Annex: List of Participants of the Workshop on the Modifications of Austrian, German and Swiss Maps of Critical Loads of Acidity

Dr.Beat ACHERMANN
BUWAL
Abt.Luftreinhaltung

CH - 3003 BERN
Schweiz
Tel: +41-31-61 99 78
Fax: +41-31-26 15 46

Dr.Markus AMANN
IIASA
Dep. TAP
Schloßplatz 1
A - 2361 LAXENBURG
Österreich
Tel: +43-2236-71521-432
Fax: +43-2236-71313

Dr.Ruth BAUMANN
UBA
Abt. Lufthygiene
Spittelauer Lände 5
A - 1090 W I E N
Österreich
Tel: +43-1-31 30 4-852
Fax: +43-1-31 30 4-400

Dr.Peter BLASER
Eidg. Forschungsanstalt
f.Wald, Schnee u.Lands.

CH - 8903 BIRMENSDORF
Schweiz
Tel: +41-1-739-2265
Fax: +41-1-739-2215

Dr.Heinz-Detlef GREGOR
UBA I 3.3

Bismarckplatz 1
W - 1000 BERLIN 33
Deutschland
Tel: +49-30-23-145 846/844
Fax: +49-30-23-156 38

Dipl.Ing.Friedl HERMAN
FBVA

Seckendorff-Gudent Weg 8
A - 1131 W I E N
Österreich
Tel: +43-1-87 838-105
Fax: +43-1-87 75 907

Dr.Jean-Paul HETTELINGH
RIVM
Coord.Center for Effects
A. van Leeuwenhoeklaan 9
NL - 3720 BA BILTHOVEN
Niederlande
Tel: +31-30-74 35 29
Fax: +31-30-25 07 40

Dr.Helmut HOJESKY
UBA
Abt.Lufthygiene
Spittelauer Lände 5
A - 1090 W I E N
Österreich
Tel: +43-1-31 30 4-862
Fax: +43-1-31 30 4-400

Dr.Charlotta JÖNSSON
Lund University
Dep.Chem.Engineering II
P.O. Box 124 Chem. Center
S - 22100 LUND
Schweden
Tel: +46-46-108 274
Fax: +46-46-146 030

Dipl.Ing.Anne KASPER
TU Wien
Inst.f. Analyt. Chemie
Getreidemarkt 9
A - 1060 W I E N
Österreich
Tel: +43-1-58 801-4979
Fax: +43-1-56 78 13

Dr.Markus KNOFLACHER
ÖFZS
Abt. Umweltplanung

A - 2444 SEIBERSDORF
Österreich
Tel: +43-2254-80-2181
Fax: +43-2254(4)-80-2118

Renate KÖBLE
Univ. Stuttgart
Institut f.Navigation
Keplerstr.11
D - 7000 STUTTGART 1
Deutschland
Tel: +49-711-121-2166
Fax: +49-711-121-3500

Andreas KOVAR
TU Wien
Inst.f. Analyt. Chemie
Getreidemarkt 9/151
A - 1060 W I E N
Österreich
Tel: +43-1-58 801-4830
Fax: +43-1-56 78 13

Ir.Hans KROS
Winand Staring Centre

P.O.Box 125
NL - 6700 AC WAGENINGEN
Niederlande
Tel: +31-8370-74 366
Fax: +31-8370-24 812

Dr.Wolfgang LOIBL
ÖFZS
Abt. Umweltplanung

A - 2444 SEIBERSDORF
Österreich
Tel: +43-2254-80-2167
Fax: +43-2254-80-2118

Dr.Hans-Dieter NAGEL
Inst.f. Ökosystemforsch.
Magdalenenstr. 17-19
Postfach 120
O - 1130 BERLIN
Deutschland
Tel: +37-2-2372-8070
Fax: +37-2-2372-2034

Dr.Horst NOWAK
UBA
Abt.Umweltplanung
Spittelauer Lände 5
A - 1090 W I E N
Österreich
Tel: +43-1-31 30 4-412
Fax: +43-1-31 30 4-400

Univ.Prof. Hans PUXBAUM
TU Wien
Inst. f. Analyt. Chemie
Getreidemarkt 9/1514
A - 1060 W I E N
Österreich
Tel: +43-1-58 801-4839
Fax: +43-1-56 78 13

Dr.Klaus RADUNSKY
UBA
Abt.Lufthygiene
Spittelauer Lände 5
A - 1090 W I E N
Österreich
Tel: +43-1-31 30 4-863
Fax: +43-1-31 30 4-400

Beat RIHM
METEOTEST

Fabrikstr. 29
CH - 3012 BERN
Schweiz
Tel: +41-31-23 74 17
Fax: +41-31-23 42 64

Dipl.Ing. Wolfgang SCHÖPP
IIASA
Dep. TAP
Schloßplatz 1
A - 2361 LAXENBURG
Österreich
Tel: +43-2236-71 52 1-309
Fax: +43-2236-71 313

Dipl.Ing.Sigrid SCHWARZ
UBA
Abt.Ökologie
Spittelauer Lände 5
A - 1090 W I E N
Österreich
Tel: +43-1-31 30 4-320
Fax: +43-1-31 30 4-400

Dr.Gerhard SMIATEK
Univ. Stuttgart
Inst. f. Navigation
Keplerstr. 11
D - 7000 STUTTGART
Deutschland
Tel: +49-711-121-3745
Fax: +49-711-121-3500

Dr.Stefan SMIDT
FBVA

Seckendorff-Gudent-Weg 8
A - 1131 W I E N
Österreich
Tel: +43-1-87 838-124
Fax: +43-1-87 75 907

Dr.Christian SMOLINER
BM f. Wissenschaft &
Forschung, Abt. 23
Freyung 1
A - 1010 W I E N
Österreich
Tel: +43-1-53 120-6353
Fax: +43-1-53 120-6480

Dipl.Ing.Wolfgang SPANGL
UBA
Abt. Lufthygiene
Spittelauer Lände 5
A - 1090 W I E N
Österreich
Tel: +43-1-31 30 4-861
Fax: +43-1-31 30 4-400

Dr.Harald SVERDRUP
Lund University
Dep.Chem.Engineering II
P.O. Box 124 Chem. Center
S - 22100 LUND
Schweden
Tel: +46-46-108 274
Fax: +46-46-146 030

Dr.Richard VOLZ
BUWAL
Eidg. Forstdirektion

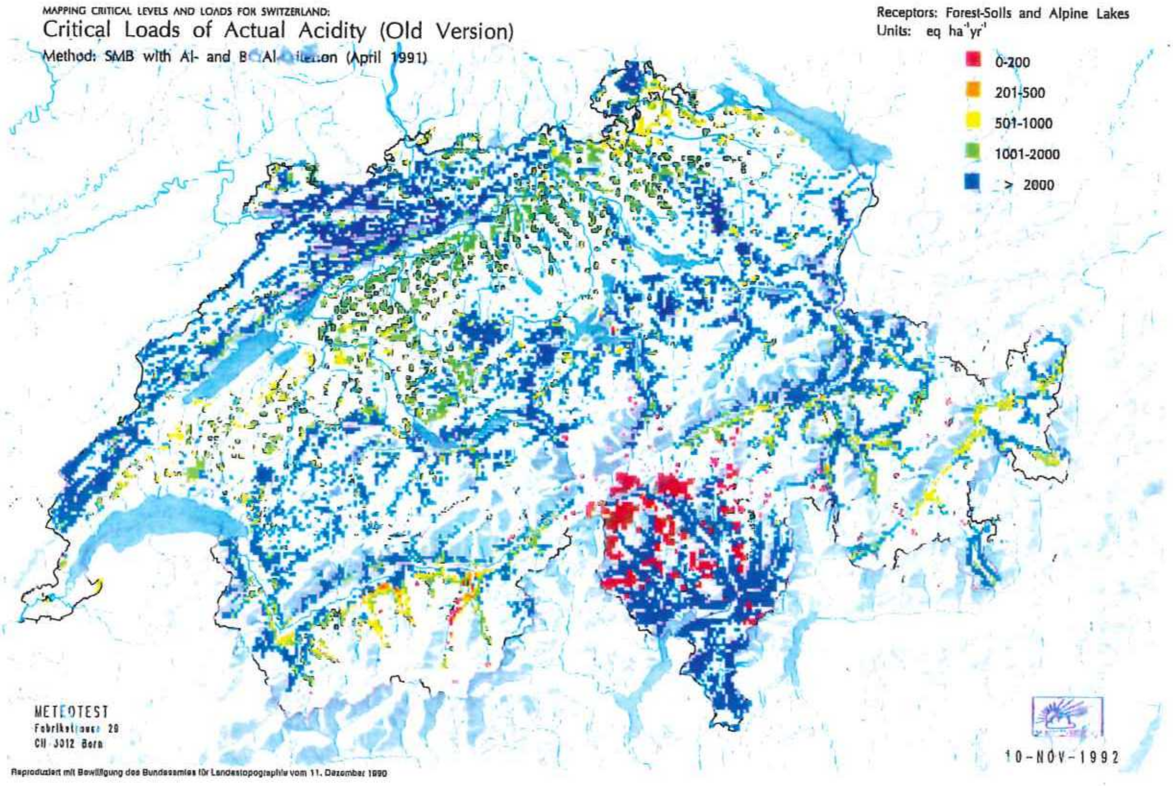
CH - 3003 BERN
Schweiz
Tel: +41-31-67 77 86
Fax: +41-31-26 15 46

Peter WEISS
UBA
Abt. Ökologie
Spittelauer Lände 5
A - 1090 W I E N
Österreich
Tel: +43-1-31 30 4-316
Fax: +43-1-31 30 4-400

Dr.Walter WENZEL
Univ. f. Bodenkultur
Inst. f. Bodenforschung
Gregor Mendel-Str. 33
A - 1180 W I E N
Österreich
Tel: +43-1-34 25 00-306
Fax: +43-1-310 60 27

Beate WERNER
Inst.f. Ökosystemforsch.
Magdalenenstr. 17-19
Postfach 120
O - 1130 BERLIN
Deutschland
Tel: +37-2-2372-3987
Fax: +37-2-2372-2034

Dr.Lutz WERNER
Inst.f. Ökosystemforsch.
Magdalenenstr. 17-19
Postfach 120
O - 1130 BERLIN
Deutschland
Tel: +37-2-2372-5237
Fax: +37-2-2372-2034



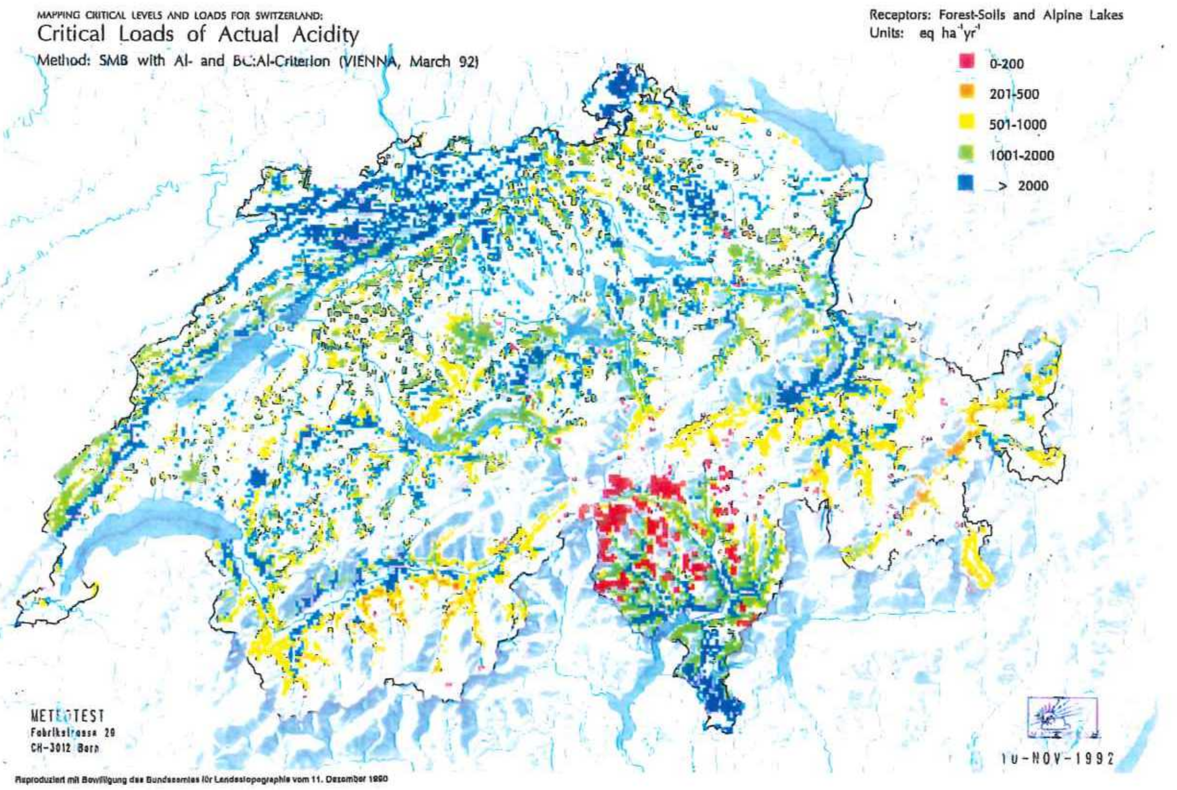
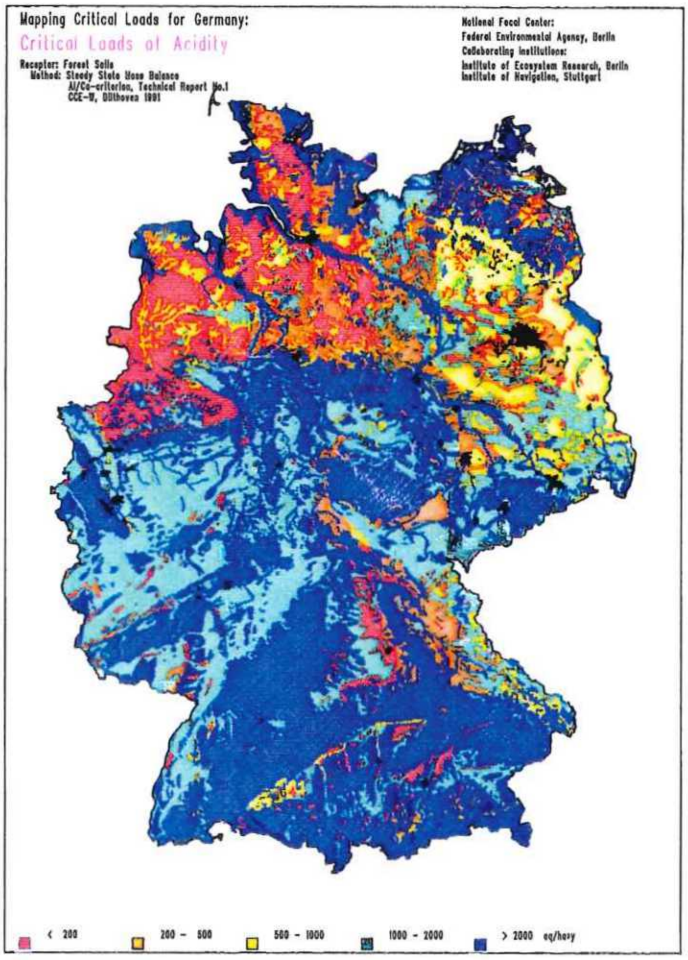


Figure 1: Comparison of the two maps of critical loads of actual acidity for Austria. The map on the top is the old map using the simplified equation; the map on the bottom is the new map using the modified equation. Because of the large bias towards high precipitation – especially in the Alpine regions of Austria – the old map has never been used. The full equation has been applied at an early stage. The only modification done for the new map was the inclusion of the effect of temperature on weathering and the linear decrease of soil rooting depth above 1.500 m a.s.l.



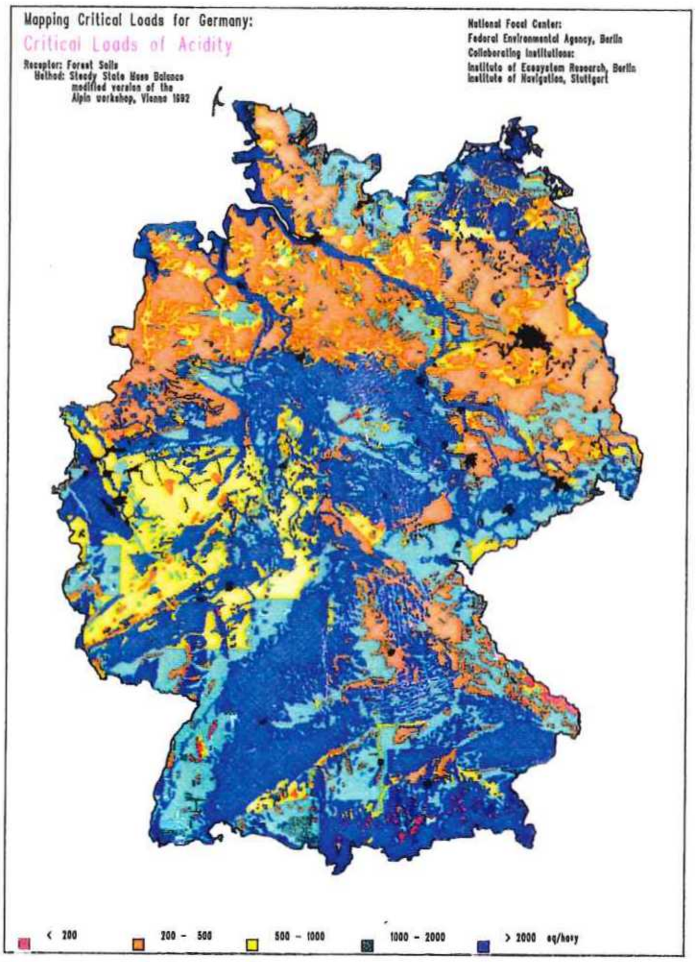


Figure 2: Comparison of the two maps of critical loads of actual acidity for Germany. The map on the top is the old map using the simplified equation; the map on the bottom is the new map using the modified equation. The old map shows some ambiguities (especially in the Harz and Fichtel mountains). The new map shows a more diverse picture; areas with forest damage appear as sensitive. The bias towards high precipitation is not longer present.

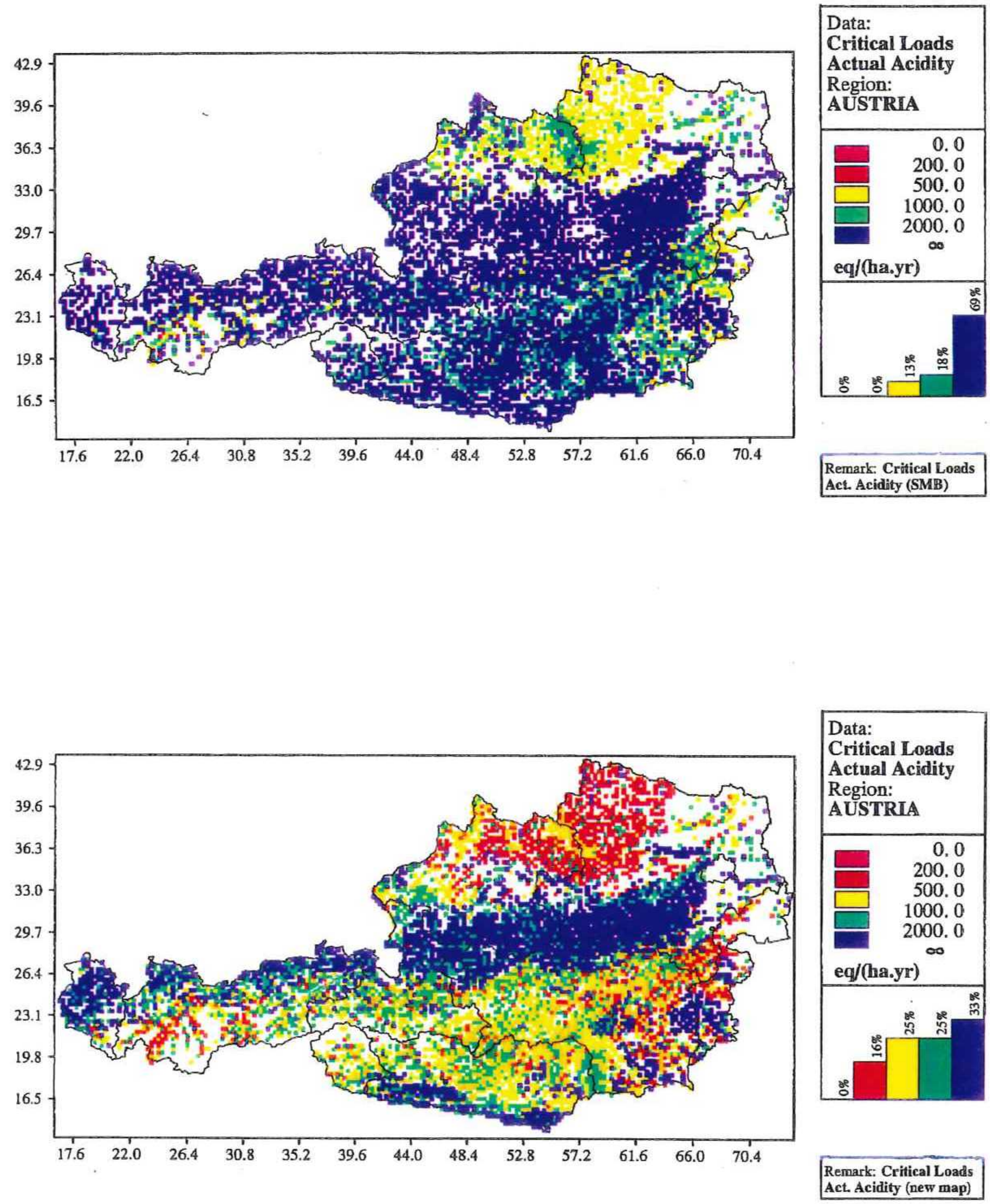


Figure 3: Comparison of the two maps of critical loads of actual acidity for Switzerland. The map on the top is the old map using the simplified equation; the map on the bottom is the new map using the modified equation. It can be seen in the old map, that large parts of Switzerland remain very acid tolerant. Even areas with well documented forest damage such as Jura, Lower Alps, Alps and Ticino remain unsensitive. With the new map there is much better correspondence between the spatial distribution of critical loads and areas known to be sensitive to acidic deposition.