Switzerland

National Focal Centre

Federal Office for the Environment (FOEN)
Air Pollution Control and Chemicals Division
Beat Achermann, Reto Meier
CH-3003 Bern
tel: +41 58 462 99 78 / +41 58 463 07 99
beat.achermann@bafu.admin.ch
reto.meier@bafu.admin.ch

Collaborating Institutions

Beat Rihm, Meteotest, Bern
Dani Kurz, EKG Geo-Science, Bern
Sabine Braun, Institute for Applied Plant Biology, Schönenbuch
Lukas Kohli and Tobias Roth, Hintermann & Weber AG, Bern

Overview of Critical Load Data

This document gives a summary of data sources and methods used to calculate Swiss critical loads, and highlights changes since the previous data submission (Achermann et al. 2011). As in 2011, the Swiss data set on critical loads of acidity and nutrient nitrogen is compiled from the output of four modelling and mapping approaches (see Figure CH.1). For the CCE data call 2014/15 all methods and data were updated, except the critical loads for alpine lakes did not change:

The SMB method for calculating critical loads of nutrient nitrogen (CLnutN) was applied on 10,632 forest sites. 10,331 of these sites originate from the National Forest Inventory (NFI 1990/92), which is based on a 1x1 km^2 grid. They are complemented by 301 sites with soil profiles (which are partly identical with the NFI-sites).

The empirical method for mapping critical loads of nutrient nitrogen (CLempN) includes different natural and semi-natural ecosystems, such as raised bogs, fens, species-rich grassland, alpine heaths and poorly managed forest types with rich ground flora. The mapping was done on a 1x1 km^2 grid combining several input maps of nature conservation areas and vegetation types. The total sensitive area amounts to 14,532 km^2.

A variant of the SMB was used for assessing critical loads of acidity on 301 forest sites, where full soil profiles were available. Net-uptake fluxes were modelled with the model MakeDep.

Critical loads of acidity were calculated for 100 sensitive alpine lakes in Southern Switzerland applying a generalized version of the FAB model (first order acidity balance).

With regard to the use of the "Habitat Suitability Index" progress was made in gathering input data but no results could be submitted so far.

The Swiss critical loads database is constructed on the base of sampling points and modelling sites in such a way that ecosystem areas are consistent with the new EMEP longitude-latitude grids (0.50° x 0.25° or 0.1° x 0.1°). Figure CH.1 gives an overview of the ecosystems and methods used for mapping.

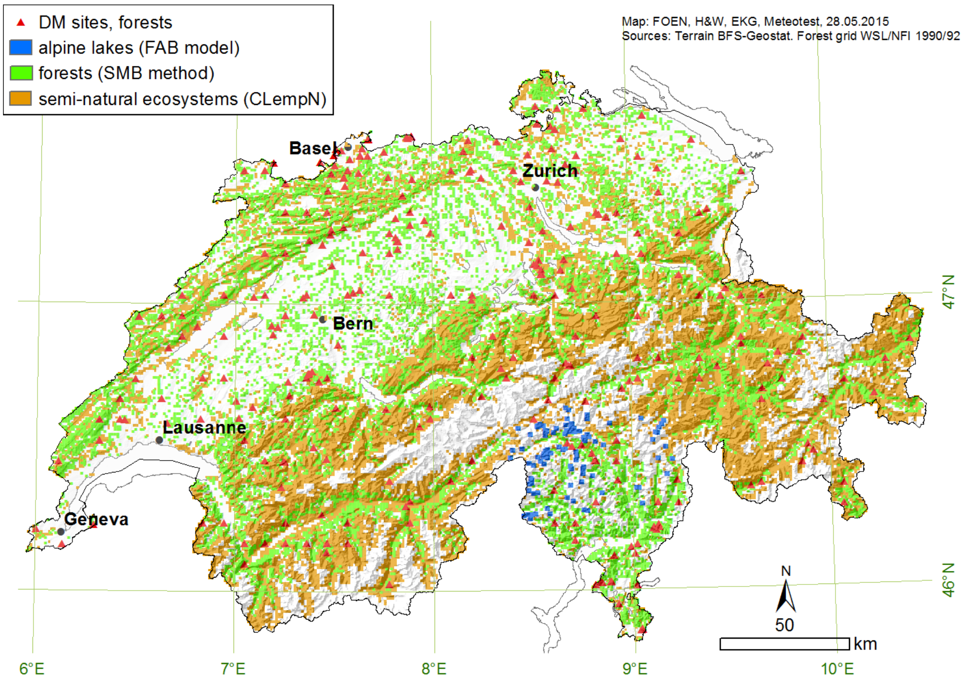

Figure CH.1 Overview of ecosystems: forest monitoring sites used for dynamic modelling (DM sites), alpine lakes, forest sites from the NFI and semi-natural ecosystems from various data sources (Hegg et al. 2003; national inventories of raised bogs, fens and dry grassland (TWW), biodiversity monitoring network (BDM)).

Some essential results of the update are shown in Figure CH.2 as cumulative frequency distributions: CLnutN for forests (SMB method), CLnutN for (semi-)natural ecosystems (empirical method) as well as the maximum critical load of sulphur (CLmaxS) for forests (MakeDep/SMB models) and Alpine lakes (FAB model).

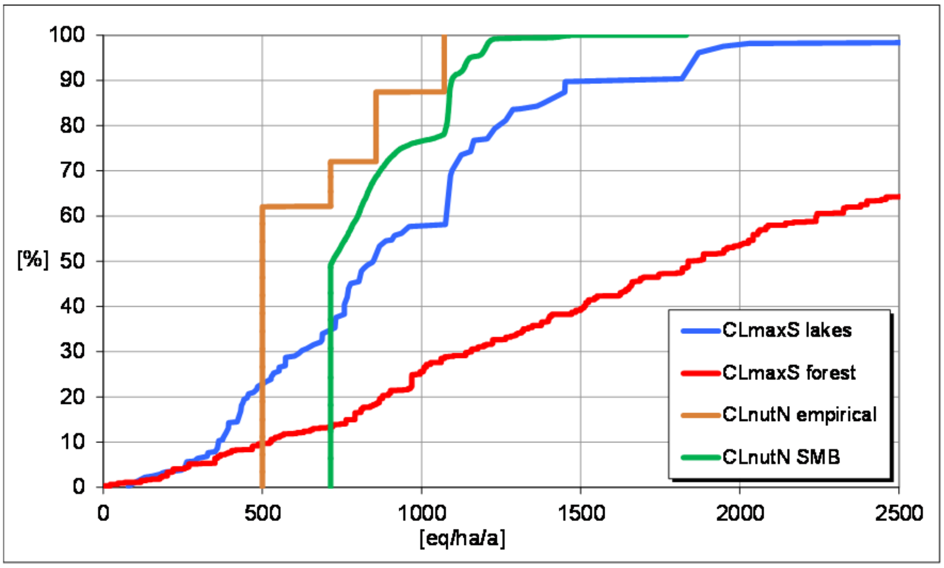

Figure CH.2 Cumulative frequency distributions of CLnutN (SMB and empirical method) and CLmaxS (forests and alpine lakes).

Critical loads of nutrient nitrogen (SMB method)

Procedure

In a first step, CLnutN was calculated by the SMB method for 301 forest sites used in dynamic modelling and for 10,331 sites of the National Forest Inventory (NFI). Table CH.1 gives a summary of the input parameter values. Thereby, only NFI-sites with a defined mixing ratio of deciduous and coniferous trees are included (NFI 1990/92). This corresponds approximately to the managed forest area as brush forests and inaccessible forests are excluded.

In a second step, the lower limit of CLnutN calculated by the SMB was set to 10 kg N ha^{-1} a^{-1} (corresponding to the lower limit of CLempN used for forests). This means, all values of CLnutN below 714 eq ha^{-1} a^{-1} were set to 714. This is done with respect to the fact that so far no empirically observed harmful effects in forest ecosystems were published for depositions lower than 10 kg N ha^{-1} yr^{-1} and for latitudes and altitudes typical for Switzerland. Therefore, the critical loads calculated with the SMB method were adjusted to empirically confirmed values.

Table CH.1 Range of input parameters used for calculating CLnutN with the SMB method.

Para-meter	Values	Comment
Nle (acc)	4 kg N ha^{-1} yr^{-1} at 500 m, 2 kg N ha^{-1} yr^{-1} at 2000 m altitude, linear interpolation in-between	Acceptable N leaching. Leaching mainly occurs by management (after cutting), which is more intense at lower altitudes.
Ni	1.5 kg N ha^{-1} yr^{-1} at 500 m, 2.5 kg N ha-1 yr^{-1} at 1500 m altitude, linear interpolation in-between	N immobilization in the soil. At low temperature (correlated with high altitude) the decomposition of organic matter slows down and therefore the accumulation rates of N are naturally higher.
Nu	0.5 – 14.7 kg N ha^{-1} yr^{-1}	N uptake calculated on the basis of long-term harvesting rates.
fde	0.2 – 0.7 depending on the wetness of the soil	Denitrification fraction. For NFI-sites, information on wetness originates from soil map 1:200'000. For DM-sites it is a classification according to the depth of the saturated horizon.

Acceptable nitrogen leaching

Instead of using precipitation surplus (Q) and acceptable N concentrations in soil water ([N]acc) as proposed in the mapping manual, Nle(acc) was calculated as a function of altitude (see Table CH.1). The rationale for this procedure was presented in a former CCE Status Report (Achermann et al. 2007). The proposed values for [N]acc were tested with the Swiss dataset. Some of the proposed values led to implausible high N leaching and CLnutN, mainly in high precipitation areas, which was judged to be unacceptable with respect to the risk of acidification and concomitant nutrient (base cation) losses.

Therefore it was decided to continue using the acceptable N leaching rates (Nle(acc)), which were used already in former data submissions. They are basically drawn from the 1996 version of the Mapping Manual

(UBA, 1996). They reflect an average long-term N leaching rate which is caused by management, mainly after cutting or other disturbances. Forest management is generally more intense at lower altitude than at high altitude (see also Section Nitrogen Uptake).
The submitted values of acceptable N concentration were calculated as: [N]acc = Nle(acc) / Q.

Nitrogen immobilization
At high altitudes, the decomposition of organic matter slows down due to lower temperatures and therefore the accumulation rates of N in the soil are naturally higher. The values shown in Table CH.1 are somewhat higher than the proposal in the Mapping Manual. This means that a 'conservative' calculation of CLnutN is made.

Net growth uptake of nitrogen
For the DM-sites, net-uptake fluxes were modelled with MakeDep (Alveteg et al., 2002) using biomass data from the 3rd National Forest Inventory (http://lfi.ch, WSL, 2013), tree genera-specific logistic growth curves, site productivity index, nutrient contents in the various compartments of the tree, and average annual harvesting rates stratified according to the five NFI-regions (Table CH.2).
The uptake for the other forest sites was derived from the DM-sites by a linear regression with altitude (z) within each region (Table CH.2).

Table CH.2 Net nitrogen uptake (Nu) in the five NFI-regions (kg N ha^{-1} a^{-1}).

Region	**Average**	**Function of altitude z (m a.s.l.)**
1. Jura	5.3	6.99 - 0.00300 z
2. Central Plateau	8.5	--
3. Pre-Alps	4.3	7.60 - 0.00322 z
4. Alps	2.9	3.58 - 0.00064 z
5. Southern Alps	1.6	2.29 - 0.00056 z
Average CH	4.4	--

Denitrification fraction
For calculating CLnutN, fde was determined according to wetness class information from the digital soil map BEK (SFSO, 2000) as shown in Table CH.3. On the DM-sites, information from the soil profiles was used to determine the depth of the water saturated horizon.

Table CH.3 Values of fde selected for the BEK classes of soil wetness.

Wetness class BEK	Description	Depth of saturated horizon	fde
0	Unknown	--	0.2
1	No groundwater	--	0.2
2	Moist	below 90 cm, but capillary rise	0.3
3	Slightly wet	60-90 cm	0.4
4	Wet	30-60 cm	0.6
5	Very wet (not occurring on the digital map)	<30 cm	0.7

Empirical critical loads of nutrient nitrogen

The application of the empirical method is based on vegetation data compiled from various sources and aggregated to a 1x1 km^2 raster (see Figure CH.1). Overall, 44 sensitive vegetation types were identified and included in the critical load data set:

- 1 type of raised bog; source Federal Inventory of Raised and Transitional Bogs of National Importance (EDI 1991), see Table CH.4;
- types of fens; source Federal Inventory of Fenlands of National Importance (WSL 1993), see Table CH.4;
- 21 types with various vegetation worthy of protection (Hegg et al. 1993) including rare and species-rich forest types, grasslands and alpine heaths, see Table CH.4;
- 1 type of mountain hay meadow in montane to sub-alpine altitudinal zones with more than 35 species $(10\ m2)^{-1}$ (Roth et al. 2013), source Biodiversity Monitoring (BDM, http://www.biodiversitymonitoring.ch/en/data/indicators/z/z9.html), see Table CH.4.
- 18 types of dry grassland; source National Inventory of Dry Grasslands of National Importance (TWW, FOEN 2007); see Table CH.5.

The values for the empirical critical loads for nitrogen (CLempN) have been based on the outcome of the Workshop in Noordwijkerhout (Bobbink and Hettelingh 2011). In addition, the relative sensitivity of the ecosystems was reassessed by Burnand (2011).

On the basis of recent results from the assessment of relationships between nitrogen deposition and species diversity in mountain hay meadows (EUNIS class E2.3) and (sub-)alpine scrub habitats (EUNIS class F2.2) in Switzerland it was concluded that the empirical critical loads for nitrogen proposed for these habitats at the workshop in Noordwijkerhout (Bobbink and Hettelingh 2011) should be set at lower values (Roth et al 2013, Achermann et al 2014). For mountain hay meadows a range for CLempN of 10-15 kg N $ha^{-1}yr^{-1}$ (instead of 10-20 kg N $ha^{-1}yr^{-1}$) and for (sub)alpine scrub habitats a range of 5-10 kg N $ha^{-1}yr^{-1}$ (instead of 5-15 kg N $ha^{-1}yr^{-1}$) is used now.
The critical loads database was adapted accordingly and complemented with new sites of the BDM. Furthermore, EUNIS codes and empirical critical loads were specified for some grassland ecosystem types.
The TWW data set complements well the grassland types mapped by Hegg et al. (1993). It contains 18 vegetation groups, which partially also occur in the inventory of Hegg et al. The two inventories are used here in a complementary way, because they answer different purposes: the atlas of Hegg et al. gives an overview of the occurrence of selected vegetation types, while TWW focuses on the precise description of objects with national importance.
If more than one sensitive ecosystem type occurs within a 1x1 km^2 grid-cell the lowest value of CLempN was selected for this cell.

Table CH.4 The empirical method: selected ecosystems, critical load values applied in Switzerland (kg N ha^{-1} a^{-1})

Ecosystem type	CLN range	Relevant vegetation types in Switzerland	CLempN	EUNIS code
Coniferous forests	5-15	Molinio-Pinetum (Pfeifengras-Föhrenwald) Ononido-Pinion (Hauhechel-Föhrenwald) Cytiso-Pinion (Geissklee-Föhrenwald) Calluno-Pinetum (Heidekraut-Föhrenwald) Erico-Pinion mugi (Ca) (Erika-Bergföhrenwald auf Kalk) Erico-Pinion sylvestris (Erika-Föhrenwald)	12 12 12 10 12 12	G3.44 G3.43 G3.4 G3.3 G3.44 G3.44
Deciduous forests	10-20	Quercion robori-petraeae (Traubeneichenwald) Quercion pubescentis (Flaumeichenwald) Fraxino orno-Ostryon (Mannaeschen-Hopfenbuchwald)	15 15 15	G1.7 G1.71 G1.73
Arctic and (sub)- alpine scrub habitats	5-10	Juniperion nanae (Zwergwacholderheiden) Loiseleurio-Vaccinion (Alpenazaleenheiden)	7 7	F2.23 F2.21
Sub-atlantic semi-dry calcareous grassland	15-25	Mesobromion (erecti) (Trespen-Halbtrockenrasen)	15	E1.26
Molinia caerulea meadows	15-25	Molinion (caeruleae) (Pfeifengrasrieder)	15	E3.51
Mountain hay meadows	10-15	Grassland types 4.5.1-4.5.4 (Delarze et al. 2008)	12	E2.3
(sub)-alpine grassland	5-10	Chrysopogonetum grylli (Goldbart- Halbtrockenrasen) Seslerio-Bromion (Koelerio-Seslerion) (Blaugras-Trespen- Halbtrockenrasen) Stipo-Poion molinerii (Engadiner Steppenrasen), sub-alpine Elynion (Nacktriedrasen), alpine	10 10 10 7	E4.3 E4.4 E4.4 E4.42
Shallow soft-water bodies	3-10	Littorellion (Strandling-Gesellschaften)	7	C1.1
Poor fens	10-15	Scheuchzerietalia (Scheuchzergras) Caricion fuscae (Braunseggenried)	10 12	D2.21 D2.2
Rich fens	15-30	Caricion davallianae (Davallsseggenried)	15	D4.1
Raised bogs	5-10	Sphagnion fusci (Hochmoor)	7	D1.1

Table CH.5 Empirical critical loads for nitrogen assigned to 18 types of dry grasslands (TWW) of the national inventory of dry grasslands (FOEN 2007), in kg N ha^{-1} a^{-1}. Some types are also included in the dataset by Hegg et al. (2003), see remarks.

TWW-code		Vegetation type	EUNIS	Remarks	CLempN
1	CA	Caricion austro-alpinae	E4.4	(sub-)alpine grassland	8
2	CB	Cirsio-Brachypodion	E1.23	similar to TWW 18, also used as hay meadow	12
3	FP	Festucion paniculatae	E4.3	similar to TWW 13; also mapped by Hegg et al.	7
4	LL	(low diversity, low altitude)	E2.2	contains different types, promising diversity when mown, therefore lower range chosen	15
5	AI	Agropyrion intermedii	E1.2	transitional type	15
6	SP	Stipo-Poion	E1.24	pastures/fallows in large inner-alpine valleys; CLempN based on national expert-judgment (Hegg et al. 1993)	10
7	MBSP	Mesobromion / Stipo-Poion	E1.26	similar to TWW 18, pastures	15
8	XB	Xerobromion	E1.27	meadows/pastures/fallows in large inner-alpine valleys; CLempN based on national expert-judgment (Hegg et al. 1993)	12
9	MBXB	Mesobromion / Xerobromion	E1.26	similar to TWW 18	12
10	LH	(low diversity, high altitude)	E2.3	contains different types of dry grassland at high altitude	12
11	CF	Caricion ferrugineae	E4.41	(sub-)alpine grassland; also mapped by Hegg et al.	7
12	AE	Arrhenatherion elatioris	E2.2	often used as meadows, lower range chosen as it occurs at all altitude levels	12
13	FV	Festucion variae	E4.3	(sub-)alpine grassland, middle of the range chosen	7
14	SV	Seslerion variae	E4.43	alpine grassland, middle of the range chosen; also mapped by Hegg et al.	7
15	NS	Nardion strictae	E1.71	meadows, subalpine	12
16	OR	Origanietalia	E2.3	meadows/fallows	15
17	MBAE	Mesobromion / Arrhenatherion	E1.26	similar to TWW 18, slightly more nutrient-rich than Mesobromion	15
18	MB	Mesobromion	E1.26	genuine semi-dry grassland	12

Critical loads of acidity for forests

Critical loads of acidity were assessed by means of a variant of the Simple Mass Balance (SMB) model also considering the extensions listed in the Mapping Manual (Chapter 5.3, UNECE, 2004). To allow weathering rates to be consistently calculated for conditions at critical load, the Sverdrup-Warfvinge Weathering (SWW) algorithm (i.a. Sverdrup & Warfvinge, 1995) was linked to the SMB (version March 23, 2013, M. Posch, CCE, pers. comm.).

Critical chemical limits
On the basis of results from the long-term monitoring of forest sites (inter-cantonal long-term forest monitoring network, including i.a. soil profile analysis, soil solution analysis, forest condition assessment, ground vegetation relevés) and on the basis of published results on relationships between base saturation and storm-induced forest damages as well as fine root conditions (Braun et al. 2003, Braun et al. 2005) we came to the conclusion that a critical limit value of the Bc/Al ratio of 1 allows for too much acidification and weakening of forests stands in Switzerland. Taking the Bc/Al ratios resulting from soil solution monitoring and considering its relation to base saturation (Braun 2013) we concluded that a critical limit value for Bc/Al of 5-10 would be more appropriate to protect forests from acidification since it would not allow, like for Bc/Al=1, a development of base saturation towards values substantially below 20%. Thus, our revised critical loads of acidity for forests are based on calculations with a critical limit value for Bc/Al ratio of 7.

Input
Due to the extension of the SMB with the SWW algorithm, the list of needed input parameters got slightly larger than in earlier assessments (see Table CH.6). Compared to the submission in 2011, an additional 51 sites (current total 311) were considered in the modelling and a series of basic data was brought up-to-date in recent years entailing changes in the model input.
Climate input was drawn from revised site-specific monthly climate data (Remund et al., 2014) for a past 1961-1990 and future 2045-2074 period adopting an IPCC A1B scenario. For critical loads calculations the data were annualized for each of the 30 years period (i.e. input is 30 years annual average).
Wet and dry deposition rates for base cations (Bc), Na and Cl were interpolated by spatial regression on the basis of monitoring results from the Long-term Forest Ecosystem Research Programme of WSL (http://www.wsl.ch/info/organisation/fpo/lwf/index_EN). They represent an average of the period 2006-2009 (Rihm et al. 2013). Deposition of base cations is input to MakeDep, which was used to simulate forest growth and management and resulting nutrient cycle. Annual harvest and corresponding nutrient contents were taken from an up-to-date MakeDep run. Net uptake of base cations and nitrogen was calculated as the sum of tree compartment mass removed from the plot (harvest) times the average nutrient contents of the compartments. Since critical loads are being used to set future emission/deposition targets and to remain consistent with the climate input, it was decided to use average annual deposition and nutrient flux output from MakeDep for the period 2045-2074.
In the course of integrating the 51 new sites into the database and in conjunction with the implementation of the weathering calculation routine, soil input required by the extended SMB was completely

revised. For the current submission we considered (cp. Phelan et al., 2014)

- a modification of the assessment of the major rooting zone, which defines the single soil compartment required by the SMB,
- a modification of the weatherable surface area estimation,
- a modification of the area weighting of the mineralogy,
- the introduction of a stoichiometry correction for base cation depleted clay minerals,
- a harmonisation of the assessment of long-term average soil moisture content and porosity, which determine water saturation and thereby wetted mineral surface.
- Finally, instead of averaging the layered soil input within the rooting zone, transfer functions used to get from soil raw data to the requested soil input were now applied to averaged raw data.

Table CH.6 List of input parameters required to run the SWW/SMB.

Key word	**Unit**	**Comment**
SiteInfo	-	string with info on the site (max.128 chars)
useSWW	-	flag; 0=weathering rates given; 1=steady-state weathering rates computed with SWW
AciCrit	-	Criterion for acidity CLs; 1=Al:Bc (mol mol^{-1}); 2=[Al] (molc m^{-3}); 3=bsat (fraction); 4=pH (mol L^{-1}); 5=[ANC] (molc m^{-3})
Vacicrit	-	Critical value for criterion 'AciCrit'; units as given under 'AciCrit'
NutCrit	-	Criterion for CLnutN; 1=[N]acc (mgN L^{-1}); 2=Nle,acc (molc m^{-2} a^{-1})
Vnutcrit		Critical/acceptable value for criterion 'NutCrit'; units as given under 'NutCrit'
thick	M	thickness of the soil compartment
porosity	m^3 m^{-3}	porosity of the soil
Theta	m^3 m^{-3}	volumetric water content of the soil
lgKAlox	(mol $L^{-1})^{-2}$	log10 of equilibrium constant in [Al] = KAlox*$[H]^3$
lgKAlBC	-	log10 of Gapon selectivity constant for Al-Bc exchange
lgKHBC	-	log10 of Gapon selectivity constant for H-Bc exchange
pCO2fac	-	CO_2 pressure in soil solution as multiple of pCO_2(atm) in air
cRCOO	mol m^{-3}	total concentration of organic acids (m*DOC); (0=no organic acids simulated)
TempC	°C	soil temperature
percol	m a^{-1}	percolation (precipitation surplus) (m/a)
f_de	-	denitrification fraction (0<=f_de<=1)
Nim_acc	molc m^{-2} a^{-1}	'constant' (acceptable, minimum) N immobilized
Ca_dep	molc m^{-2} a^{-1}	deposition of Ca
Mg_dep	molc m^{-2} a^{-1}	deposition of Mg
K_dep	molc m^{-2} a^{-1}	deposition of K
Na_dep	molc m^{-2} a^{-1}	deposition of Na
Cl_dep	molc m^{-2} a^{-1}	deposition of Cl
Ca_upt	molc m^{-2} a^{-1}	net uptake of Ca
Mg_upt	molc m^{-2} a^{-1}	net uptake of Mg
K_upt	molc m^{-2} a^{-1}	net uptake of K

Key word	Unit	Comment
N_gupt	molc m^{-2} a^{-1}	net uptake of N
Ca_we	molc m^{-2} a^{-1}	weathering rate for Ca
Mg_we	molc m^{-2} a^{-1}	weathering rate for Mg
K_we	molc m^{-2} a^{-1}	weathering rate for K
Na_we	molc m^{-2} a^{-1}	weathering rate for Na
surface	m^2 m^{-3}	soil particle surface area
MinDat	-	Path to PROFILE-style 'mineraldata' file {mineraldata}
M_groups	-	number of mineral groups used (first M_groups of those in MinDat)
M_fracts	m^2 m^{-2}	surface area fractions of minerals in M_groups

Determining the ecosystem area

Critical loads of acidity were successfully calculated for 301 DM-sites. These are not regularly distributed within the country. The NFI-sites (National Forest Inventory), however, are a systematic sample, each representing a forest area of 1 km^2. Therefore, the area of forest represented by one DM-site was determined by those NFI-sites situated within the respective Thiessen-polygon constructed for the DM-sites, and all acidity parameters were copied from a DM-site to the affiliated NFI-sites. In consequence, EcoArea was set to 1.0 km^2 for all resulting sites with critical loads for acidity.

However, if a NFI-site was situated on a 1x1 km grid cell containing also a site with empirical critical loads, EcoArea was set to 0.8 km^2 for the NFI-site and to 0.2 km^2 for the empirical site. Thus, double area counts were excluded.

Critical loads of acidity for alpine lakes

Critical loads of acidity for alpine lakes were left unchanged. They were calculated with a generalised FAB-model (Posch et al. 2007). The model was run for the catchments of 100 lakes in Southern Switzerland (see Figure CH.1) at altitudes between 1650 and 2700 m (average 2200 m). To a large extent the selected catchments consist of crystalline bedrock and are therefore quite sensitive to acidification.

Habitat Suitability Index

Progress was made in preparing the required vegetation data for the well-monitored forest sites. Well-monitored sites were selected with the purpose to be able to compare modelling results with field observations. There are now two sets of vegetation data, one showing the current site-specific vegetation composition according to recent relevés and the other highlighting the vegetation composition reflecting the natural "undisturbed" situation for the respective habitat type according to expert judgement. The plant species were parameterized according to the ecological indicator values given in the Swiss Flora Indicativa (Landolt et al 2010). A customised Veg database will be established on the basis of this parameterization. Dynamic modelling with VSD-Veg and VSD+-Veg, respectively, and calculation of biodiversity critical loads with SMB-Veg is planned.

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