Overview

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):

1. The dynamic models SAFE and VSD (very simple dynamic model) were used for assessing acidifying effects of air pollutants on forest soils. The multi-layer model SAFE was calibrated and applied on 260 sites, where full soil profiles were available. For calculating critical loads of acidity and target loads, the input data of SAFE were aggregated to one layer in order to run the VSD model.

2. The SMB method for calculating critical loads of nutrient nitrogen \( CL_{\text{nut}}(N) \) was applied on 10,434 forest sites (managed forests) of the National Forest Inventory (LFI 1990/92), which is based on a 1×1 km \(^2\) raster.

3. The empirical method for mapping \( CL_{\text{nut}}(N) \) 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 1×1 km raster combining several input maps of nature conservation areas and vegetation types. The total sensitive area amounts to 16,373 km \(^2\).

4. 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).

5. The data layers of the SMB method and the empirical method partially cover the same areas. Therefore, the results of both methods were combined by choosing the minimum \( CL_{\text{nut}}(N) \) per grid cell. The final data set contains 22,790 records with \( CL_{\text{nut}}(N) \) on the 1×1 km raster.

The main results of the four modelling approaches are shown in Figure CH-2 as cumulative frequency distributions: \( CL_{\text{nut}}(N) \) for forests (SMB method), \( CL_{\text{nut}}(N) \) for (semi-)natural ecosystems (empirical method) as well as the maximum critical load of sulphur, \( CL_{\text{nat}}(S) \), for forests (SAFE/VSD models) and Alpine lakes (FAB model).
The dynamic modelling of critical loads and target loads of acidity was based on samples from 260 soil profiles consisting of 2 to 9 layers each. Table CH-1 lists the sources of all input data required for the SAFE model runs. At 21 sites, also measurements of soil water chemistry are available (Braun, 2004). Those were used to check plausibility of the results for single soil layers. The multi-layer data were transformed to the one-layer input files.
for VSD according to Kurz and Posch (2002). VSD was used to calculate critical loads, target loads and scenarios demanded by the data call.

The sampling sites are not regularly distributed within the country (Figure CH-1). Therefore, the area of forest represented by one site (EcoArea) was calculated per EMEP-cell dividing the total forested area by the number of sampling points.

Table CH-1. Data sources for the SAFE/VSD model application. Abbreviations: *: time-series parameter; #: soil layer specific parameter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments/Derivation method</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>infiltration rate (P)*</td>
<td>amount of precipitation infiltrating the soil and amount of water leaving the soil at the base of the soil profile (or rooting zone), respectively</td>
<td>base data from Zierl (2000)</td>
</tr>
<tr>
<td></td>
<td>site specific time series for the period 1969-1998 from the hydrological model WAWAHAMO</td>
<td>processed data</td>
</tr>
<tr>
<td>percolation rate (Q)*</td>
<td>P and Q extended to the past and future using the average of the modelled period</td>
<td></td>
</tr>
<tr>
<td></td>
<td>for CL/TL calculations P is the average P of the rotation period containing the biomass key year (1995)</td>
<td></td>
</tr>
<tr>
<td>evapo-transpiration fraction#</td>
<td>(time-invariant) fraction of evapotranspiration from a particular soil layer</td>
<td>base data (fine-root distribution) from Zimmermann (2004) and Braun (2004)</td>
</tr>
<tr>
<td></td>
<td>estimated from classified fine-root distribution; transfer function</td>
<td></td>
</tr>
<tr>
<td>soil moisture#</td>
<td>layer specific bulk soil water content</td>
<td>Arbeitsgruppe Bodenkunde (1982)</td>
</tr>
<tr>
<td></td>
<td>calculated from layer specific available water capacity (AWC) which in turn is estimated according to AG Bodenkunde; transfer function</td>
<td>base data (AWC) from Zimmermann (2004) and Braun (2004)</td>
</tr>
<tr>
<td>soil temperature</td>
<td>average annual soil temperature at 0.2 m soil depth</td>
<td>FOEFL (1994, p. 45)</td>
</tr>
<tr>
<td></td>
<td>extrapolated from measurements as a function of altitude; transfer function</td>
<td>processed data</td>
</tr>
<tr>
<td>Deposition parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>wet and dry deposition</td>
<td>see following chapter on deposition data</td>
<td>processed data</td>
</tr>
<tr>
<td>throughfall deposition (key year)</td>
<td>mean annual throughfall deposition for a specified year</td>
<td>SAEFL (1998, Table 3.3, p.37)</td>
</tr>
<tr>
<td></td>
<td>estimated by means of a regression model (Ca, Mg, K) or a fraction of the deposition (NO\textsubscript{x}, NH\textsubscript{3}); key year 2000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>for SO\textsubscript{x}, Cl and Na, throughfall deposition equals total deposition</td>
<td></td>
</tr>
<tr>
<td>canopy exchange (key year)</td>
<td>mean annual canopy exchange for a specified year</td>
<td>Alveteg et al. (2002)</td>
</tr>
<tr>
<td></td>
<td>calculated by PRESAFE from wet, dry and throughfall deposition input</td>
<td></td>
</tr>
<tr>
<td>'sea-salt' correction</td>
<td>not considered in Switzerland</td>
<td>Alveteg et al. (2002)</td>
</tr>
<tr>
<td>total deposition time series*</td>
<td>annualized gridded (EMEP50) average total deposition time-series for all ions (absolute or relative figures) and the simulation period</td>
<td>Schöpp et al. (2003); Slootweg (2004)</td>
</tr>
<tr>
<td></td>
<td>SO\textsubscript{x}, NO\textsubscript{x} and NH\textsubscript{3} deposition trends 1880-2030 after Schöpp et al. (2003). Constant background deposition prior to 1700 (smoothly approached from 1880 values). Constant 2010 deposition after 2010</td>
<td>BUWAL (1995)</td>
</tr>
</tbody>
</table>
### Parameter Comments/Derivation method Sources

- **Cl deposition trends** adopted from Cl emission trends compiled in BUWAL (1995). Trends outside of the investigated period as for SO$_x$, NO$_x$, and NH$_y$
- 80% of Bc and Na deposition kept constant (national average). 20% varied according to total dust emission trends from BUWAL (1995). Trends outside of the investigated period SO$_x$, NO$_x$, and NH$_y$

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments/Derivation method</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vegetation parameters</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>biomass</strong></td>
<td>any year(s) (growing) biomass for minimum 2 (lumped wood and canopy) up to 5 tree compartments (e.g. stem, root, bark, branch and canopy) of 2 (coniferous and deciduous) or more tree species groups</td>
<td>base data (compartment masses for 12 Swiss major tree species) from Kaufmann (WSL, 2004)</td>
</tr>
<tr>
<td></td>
<td>for sites not on the National Forest Inventory grid intersections, the nearest meaningful (regarding altitude) neighbour is allocated</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‘species’ mass data are lumped to stand and compartment specific biomass</td>
<td></td>
</tr>
<tr>
<td><strong>nutrient content</strong></td>
<td>minimum and maximum Ca-, Mg-, K- and N-contents of the tree compartments considered</td>
<td>measurements from Braun (2004)</td>
</tr>
<tr>
<td></td>
<td>foliage macro nutrient content ranges generalized from measurements and literature for species with no available measurements</td>
<td>Bergmann (1993)</td>
</tr>
<tr>
<td></td>
<td>empirically derived proportionality factors to estimate nutrient contents in wood compartments from foliage levels</td>
<td></td>
</tr>
<tr>
<td></td>
<td>the 5 (compartments) times 12 (species) times 8 (min/max macro-nutrients) matrix recalculated to stand and compartment specific min/max nutrient contents</td>
<td></td>
</tr>
<tr>
<td><strong>logistic growth function</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>bonity</strong></td>
<td>bonity and respective n and k values of a n$^{th}$ order Mikaelis-Menten equation fitted to the data of respective yield tables (bonity and n are site and species specific while k ('half-time') is additionally compartment specific)</td>
<td>Badoux (1966-1969)</td>
</tr>
<tr>
<td></td>
<td>n and k of the Mikaelis-Menten function fitted to the tabulated values in yield tables for managed spruce (coniferous) and beech (deciduous) stands with different bonity</td>
<td>bonity from LFI data extract (WSL, 2004) and Braun (2004)</td>
</tr>
<tr>
<td></td>
<td>all compartments are modelled with the same n (stem) but different k which are (empirical, fixed) fractions of k (stem)</td>
<td></td>
</tr>
<tr>
<td><strong>land-use history</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>annualized national, regional or local fraction of the stands' (growing) biomass cut down and removed from the stand, respectively, for all compartments and the simulation period, assuming all stem wood felled removed from the stand and compartment removal as fraction of the material of the other compartments</strong></td>
<td>SAEFL (1998)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>national stem removal trends from SAEFL (1998) updated with recent years harvesting figures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>average regional harvesting rates (from NFI 1982-1986) scaled with national stem removal trends (continuous harvesting)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>removal of other compartments than stem simplified from SAEFL (1998)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>stands assumed to be forested since 1600</td>
<td></td>
</tr>
<tr>
<td>Parameter</td>
<td>Comments/Derivation method</td>
<td>Sources</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
</tbody>
</table>
| litterfall fraction           | • site specific average fraction of canopy shed every year  
• assumed base rates: 1.0 (deciduous canopies) and 0.143 (coniferous canopies)  
• base rates corrected for nutrient retention before leaf/needle fall (-30% for deciduous and -10% for coniferous canopies) | measured nutrient contents of fresh foliage and leaf litter from Braun (2004) |
| mineralization rate           | • site specific annual average fraction of pooled harvest residues and pooled canopy litter mineralized  
• assumed base rates: 0.10 (harvest litter) and 0.70 (canopy litter) at an average annual air temperature of 7°C  
• base rates corrected for site specific annual average air temperature | average annual air temperature from Zierl (2000)                        |
| relative base cation uptake#  | • base cation and nitrogen uptake in each soil layer within the rooting zone as fraction of total base cation and nitrogen uptake  
• estimated from classified fine-root distribution; transfer function (cp. evapotranspiration fraction) | base data (fine-root distribution) from Zimmermann (2004) and Braun (2004) |
| relative nitrogen uptake#     |                                                                                                                                                                                                                           | base data (fine-root distribution) from Zimmermann (2004) and Braun (2004) |

|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------|
| layer thickness#              | • ‘field’ (bulk) thickness of a soil layer considered  
• adopted from field measurements | base data from Zimmermann (2004) and Braun (2004)                        |
| bulk soil density#            | • (dry) density of the bulk soil of a layer considered  
• estimated from measured densities of the bulk soil or fine earth and classified layer specific coarse contents  
• missing densities of the fine earth are estimated using curve fits (power functions) derived from classified (BEK) measurements | base data from Zimmermann (2004) and Braun (2004)                        |
| coarse content#              | • layer specific content (volume fraction) of inorganic components > 2 mm (‘stones’) in the (bulk) soil  
• derived from field classification | base data from Zimmermann (2004) and Braun (2004)                        |
| grain size distribution#     | • layer specific relative contents (wt. fraction) of sand (2000 - 50 µm), silt (50 - 2 µm) and clay (< 2 µm) in the inorganic fine-earth  
• measured according to Gee and Bauder (1986) | Gee and Bauder (1986).  
| surface area#                | • (total) mineral surface area subject to chemical weathering in a soil layer considered  
• calculated from grain size distribution using a sieve curve to surface area transfer function  
• corrected (lowering) for high clay contents  
• adjusted to the bulk framework | Jönsson et al. (1995)                                                   |
| cation exchange capacity#     | • (any years) cation exchange capacity (CEC) of a soil layer considered  
• contents of the fine-earth’s exchangeable Al, Fe, Ca, Mg, K and Na measured after ammonium-chloride extraction  
• contents of the fine-earth’s exchangeable acidity  
• missing values either adopted from the above or below layer or, in case of $H^+$, estimated from the relationship of measured exchangeable acidity with pH(CaCl₂)  
• CEC adjusted to the bulk framework | Yuan (1959)  
<p>| base saturation# (*)         | • (any years, see below) base saturation for all soil layers considered | base data from Zimmermann (2004) and Braun (2004)                        |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Comments/Derivation method</th>
<th>Sources</th>
</tr>
</thead>
</table>
| soil sampling year      | • fraction of exchangeable cations Ca, Mg and K in respect of CEC  
• key year to which the base saturation refers to is the soil sampling year                                                                                                                                  | Braun (2004)                                 |
| mineral contents#       | • layer specific quantitative mineralogical composition of the fine-earth (up to 14 weatherable minerals)  
• derived from total elemental analysis of the fine earth, qualitative mineralogy and assumed mineral stoichiometries using a mass balance method  
• extra parameters used for this procedure: total elemental analysis (e.g. SiO$_2$, TiO$_2$, Al$_2$O$_3$, Fe$_2$O$_3$, MnO, MgO, CaO, Na$_2$O, K$_2$O, P$_2$O$_5$, LOI); qualitative mineralogy (e.g. from thin section analysis) oxalate-extractable Al and Fe; HNO$_3$-extractable Ca and Mg of calcareous soils mineral stoichiometry database.  
• quantitative mineralogy corrected for mineral specific surface area and adjusted to the bulk framework                                                                                           | total elemental analyses from Zimmermann (2004) and Braun (2004) |
| soil solution DOC#      | • mean (annual) dissolved organic carbon (DOC) concentration in the soil solution of all layers  
• forcing function; based on generalized data from a Ticino research site                                                                                                                            | measurements from Blaser (1993)             |
| soil solution pCO$_2$#  | • mean (annual) layer specific soil partial CO$_2$ pressure (expressed as multiple of the ambient pCO$_2$)  
• generalized forcing function (polynomial) fitted to literature data (ref)                                                                                                                                 | basic values from Solomon and Cerling (1987) |
| soil solution logK$_{Gibbs}$# | • soil-layers specific log of apparent gibbsite equilibrium constant  
• generalized forcing function in relation to organic matter content                                                                                                                   | basic values from Mapping Manual, UBA (1996) |
| type of layer#          | • type of layer according to field classification  
• used as classification variable                                                                                                                                                                                     | base data from Zimmermann (2004) and Braun (2004) |
| BEK classification      | • classification of the sites according to the Map of Suitability of Soils of Switzerland 1:200:000                                                                                                                   | EJPD, EVD and EDI (1980)  
Input for critical loads of nitrogen ($C_{\text{lnut}}(N)$)

The SMB method was applied for forests according to the Mapping Manual with the input data listed in Table CH-2.

Table CH-2. Input data for calculating $C_{\text{lnut}}(N)$ with the SMB method (FOEFL 1996, with updates).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{de}$</td>
<td>0.3 dry soils, 0.5 moist soils, 0.7 moderate wet soils, 0.8 wet soils</td>
<td>data from soil map 1:200,000 (EIPD, EVD and EDI 1980)</td>
</tr>
<tr>
<td>$N_{le(acc)}$</td>
<td>4 kg N ha(^{-1}) a(^{-1}) at 500m altitude, 2 kg N ha(^{-1}) a(^{-1}) at 2000m altitude</td>
<td>linear interpolation in-between. Acceptable leaching mainly occurs by management (after cutting), which is more intense at lower altitudes. $Q$ and $[N]_{le}$ are not used.</td>
</tr>
<tr>
<td>$N_i$</td>
<td>3 kg N ha(^{-1}) a(^{-1}) at 500m altitude, 5 kg N ha(^{-1}) a(^{-1}) at 1500m altitude</td>
<td>linear interpolation in-between. At high altitudes the decomposition of organic matter slows down due to lower temperatures and therefore the accumulation rates of N and C are naturally higher.</td>
</tr>
<tr>
<td>$N_u$</td>
<td>0.7 – 7.0 kg N ha(^{-1}) a(^{-1})</td>
<td>present uptakes calculated on the basis of estimated long-term harvesting rates and average element contents in stems</td>
</tr>
</tbody>
</table>

The application of the empirical method is based on vegetation data compiled from various sources (Hegg et al., 1993; EDI, 1991; WSL, 1993). 25 Sensitive vegetation types were identified and included in the critical load map (Table CH-3). If more than one type occurs within a 1×1 km grid-cell the lowest value of $C_{\text{lnut}}(N)$ was selected for this cell.

Table CH-3. The empirical method: selected ecosystems, critical load values applied in Switzerland (kg N ha\(^{-1}\) a\(^{-1}\)) and EUNIS codes.

<table>
<thead>
<tr>
<th>Ecosystem</th>
<th>CLN range</th>
<th>Relevant vegetation types in Switzerland</th>
<th>$C_{\text{lnut}}(N)$</th>
<th>EUNIS code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acidic coniferous forests</td>
<td>10-20</td>
<td>Molinio-Pinetum (Pfeifengras-Föhrenwald)</td>
<td>17 G3.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ononido-Pinion (Hauhechel-Föhrenwald)</td>
<td>12 G3.43</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cytiso-Pinion (Geissklee-Föhrenwald)</td>
<td>12 G3.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Calluno-Pinetum (Heidekraut-Föhrenwald)</td>
<td>12 G3.3</td>
<td></td>
</tr>
<tr>
<td>Acidic deciduous forests</td>
<td>10-20</td>
<td>Quercion robior-petraeae (Traubeneichenwald)</td>
<td>15 G1.7</td>
<td></td>
</tr>
<tr>
<td>Calcereous forests</td>
<td>10-20</td>
<td>Quercion pubescentis (Flaumeichenwald)</td>
<td>15 G1.71</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fraxino ornio-Ostryon (Mannaeschen-Hopfenbuchwald)</td>
<td>15 G1.73</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erico-Pinion mugi (Ca) (Erika-Bergföhrenwald aufKalk)</td>
<td>15 G3.44</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Erico-Pinion sylvestris (Erika-Föhrenwald )</td>
<td>15 G3.44</td>
<td></td>
</tr>
<tr>
<td>Arctic and alpine heaths</td>
<td>5-15</td>
<td>Juniperion nanae (Zwergwachholderheiden)</td>
<td>10 F2.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Loiseleurio-Vaccinion (Alpenazaleenheiden)</td>
<td>10 F2.21</td>
<td></td>
</tr>
<tr>
<td>Calcereous species-rich grassland</td>
<td>15-25</td>
<td>Mesobromion (erecti) (Trespen-Halbtrockenrasen)</td>
<td>20 E1.26</td>
<td></td>
</tr>
<tr>
<td>Neutral-acid species-rich grassland</td>
<td>15-25</td>
<td>Molinion (caeruleae) (Pfeifengrasrieder)</td>
<td>25 E3.51</td>
<td></td>
</tr>
<tr>
<td>Montane-(sub)alpine</td>
<td>10-20</td>
<td>Chrysopogonetum grylli (Goldbart-</td>
<td>15 E1.2</td>
<td></td>
</tr>
</tbody>
</table>
In 2004, critical loads of acidity for alpine lakes were calculated with a generalised FAB-model (Posch, 2004) and supplied to the CCE (see CCE Progress Report, 2004). The model was run for the catchments of 100 lakes in Southern Switzerland at altitudes between 1650 and 2700 m (average 2200 m).

By the end of February 2005, a revised data set was supplied with improved input data, i.e. deposition, BC uptake, catchment borders.

**Deposition data**

The deposition of BC, N and S was calculated with a generalised combined approach (FOEFL, 1994 and 1996; Thimonier et al., 2004), for the reference year 2000.

Wet deposition is calculated by combining the concentration field of sulphate, nitrate and ammonium compounds in rain water with a precipitation map. Wet concentration measurements are relatively homogenous below an altitude of 1000 m. At higher altitudes concentrations decrease. In southern Switzerland, a detailed study on wet deposition patterns was carried out (SAEFL, 2001).

Resistance analogue models are used for assessing the dry deposition of NH$_3$ and NO$_2$ gas and aerosols. For these compounds, the concentration fields are calculated from emission inventories with a resolution of 200m (NH$_3$ 100m) by applying statistical dispersion models (e.g. Thoeni et al., 2004). For HNO$_3$, the concentration field is calculated as a function of altitude. For SO$_2$, the concentration field is determined by geo-statistical interpolation of monitoring results. For BC, gridded bulk deposition data from CCE are used in combination with filtering factors for forests and average ratios of individual base cations in bulk deposition measurements.

The concentration fields are multiplied by deposition velocities, which depend on the reactivity of the pollutant, surface roughness and climatic parameters. Deposition velocity values were taken from literature (FOEFL, 1996, with modifications).

As an example, Fig. CH-3 shows the resulting spatial pattern of total nitrogen deposition, characterised by a general decrease with altitude, relatively low deposition in inner-Alpine valleys and areas with high depositions due to local ammonia emissions (e.g. in central Switzerland) or by import (in southern Switzerland).
Figure CH-3. Nitrogen deposition (in kg N ha\(^{-1}\) a\(^{-1}\)) for the year 2000 in a perspective view (model results with a resolution of 1x1 km\(^2\); the EMEP 50x50km\(^2\) grid is drawn at an altitude of 1000 m).

Acknowledgements

This work is financed by the Swiss Agency for the Environment, Forest and Landscape (National Focal Centre for modelling and mapping activities under the Convention on Long-range Transboundary Air Pollution).

For the implementation of the VSD- and generalized FAB-model, M. Posch from the CCE provided helpful support and Fortran routines. We thank Stefan Zimmermann (WSL) and Sabine Braun (IAP) for supplying the soil profile data as well as Edgar Kaufmann (WSL) for calculating the biomass in tree compartments.

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