Commentary

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1 Introduction

Pollution of ground and surface water from point and non-point sources via the different input pathways are still evident in the intensively used regions in Middle Europe. It should be minimized in order to get a good ecological state according to the Water Framework Directive (EU 2000).

Diffuse inputs of nitrogen (N) and phosphorus (P) in waters are realized via the different runoff components (1). N and P are certainly different in respect to their bindings and physical / chemical character. Dislocation of P is often determined by a particle-bound transport, which depends on soil erosion and surface runoff.

Figure 1: Sources and pathways of nutrient inputs into waters in river basins

Nitrogen is chiefly washed out as dissolved nitrate via interflow and groundwater flow. Processes of turnover (mobilization, immobilization, denitrification) as well as residence times of water fluxes should be taken into consideration whenever possible.

Modelling tools, like the model STOFFBILANZ, are used to generate these inputs of sediment and nutrients in river catchments according to their origin and quantity.
Therefore we have to consider diffuse and point source inputs into waters as well as processes of retention during the residence time in groundwater and surface water.

According to the Water Framework Directive water management programs are chiefly established on a regional scale. Thus we have to use emission-based modelling tools, which are able to identify diffuse and point source inputs even in larger river basins, considering main sources, pathways and sinks in accordance to land use and location.

The following methods and algorithms only refer to a modelling in one year time steps. Daily based modelling routines are also available in the STOFFBILANZ approach for evapotranspiration, and deep percolation (Crop Evapotranspiration $ET_{adj}$, see Allen et al. 1998), for direct runoff (Curve Number approach, see NRCS 2004, Hawkins et al. 2009), and for soil loss by stormwater runoff (USLE-M, see Kinnell 2001, Yu & Rosewell 1996), sediment input, as well as particulate P input, but not described in detail in this commentary. All these daily based modelling was done outside Europe, especially in China and South-Africa (Gebel et al. 2016, 2017, Meissner et al. 2016).

2 The philosophy of the STOFFBILANZ model

2.1 Principles

The STOFFBILANZ model is a Web based tool to quantify nitrogen, phosphorus and sediment emissions in surface water. The main sources and pathways are identified and calculated for land use types and user specific area units. The results show the nutrient and sediment inputs according to the different areas as annual balance. The model mediates between a large and small scale approach and is therefore especially suitable for use in the field of regional (mesoscale) river basin management. Here the method is especially useful as a component for the realization of the EU water framework directive.

Using scientifically validated methods in accordance to the state of the art the model allows to generate flow and mass balances for different states of landscape and land use (current state, target state, scenarios):

- Analysis of origin (sources)
- Analysis of pathways
- Identification of risk areas and source areas
- Aggregation at different spatial levels

To quantify diffuse nutrient and sediment loadings it is first necessary to obtain and work up parameters of landscape, land use and farming, which are listed in 17, appendix). To compare the calculated loadings with real measured data we need information to point source inputs and water quality measurements (compare 18, appendix).
In order to link user friendliness, technical aspects and requirements to the river basin management, GALF bR has developed the Web based model STOFFBILANZi. The Web service consists of the model itself and various tools for data import and export, data analysis and visualisation. The storage of spatial and technical data is done in a PostgreSQL / POSTGIS database. Modern web technologies enable the development of a desktop-like user interface. An important element is the implementation of the UMN-Mapserver, which supports the dynamic visualization of model data and results. Users are thus able to monitor and to evaluate the parameters and results in a cartographic mode, but also to make their own modelings. Statistic tools are supporting the evaluation of the model data and the comparison of scenarios (2 and 3).

A demo version with limited functions is disposable at viewer.stoffbilanz.de (see also www.stoffbilanz.de).

Figure 2: The modular construction of the web based STOFFBILANZ model
3 Water balance

The determination of total runoff $R$ is realized as the sum of the runoff components surface runoff $RO$, rain discharge (runoff from sealed areas) $RS$, drainage rate $RD$, interflow $RI$ and groundwater runoff $RG$:

$$R = RO + RD + RI + RG + RS \ [\text{mm yr}^{-1}]$$

The determination of surface runoff and rain discharge respectively is done according to the modified Curve Number Method (adapted from US Soil Conservation Service 1972, Halbfaß 2004). Surface runoff is only calculated for areas with a hydraulic connection to the river net.

*Interflow and groundwater runoff* are calculated on the basis of percolation rates taking into account the runoff quotient and the sun exposure (Ad-hoc-AG Boden 2003, modified according to Röder 1997, Wessolek 1997, Wessolek et al. 2008).

Calculation of drainage rates on drained areas is similar to the determination of percolation (Ad hoc-AG Boden 2003), whereby capillary rise is not included.

3.1 Surface runoff

The determination of the surface runoff $RO$ and the rain discharge $RV$ respectively is done according to the modified Curve Number Method (adapted from US Soil Conservation Service (SCS), 1972), which has been developed in the USA. Based on flood data and measurements of percolation in small river basins characteristics of runoff have been investigated considering land use, soil tillage, soil texture, soil moisture and intensity of rainfall. The resulting Curve number (CN) gives a measure for the maximum storage capacity taking into account land use and preliminary rainfall...
Chapter 3: Water balance

(indicated by three classes of soil moisture). The influence of soil characteristics on the capacity of percolation is determined in the SCS-method considering four hydrological soil classes, modified for the calculation in the STOFFBILANZ model as seen in 1 (adapted from US Soil Conservation Service 1972, Halbfaß 2005).

The CN₅-value will be corrected by the slope as follows:

$$CN_{slp} = \left( \frac{(CN_5 \cdot e^{0.00673(100-CN_5)}) - CN_5}{3} \right) \cdot (1 - 2 \cdot e^{-13.86 \cdot slp}) + CN_5$$

where slp is the slope [m · m⁻¹].

The storage capacity S [mm] and the initial loss Iₐ [mm] are determined by the following equations:

$$S = \left( \frac{1000}{CN} - 10 \right) \cdot 25.4$$

$$I_a = 0.03 \cdot S$$

Table 1: Derivation of CN-values (medium soil moisture, 5% slope)

<table>
<thead>
<tr>
<th>main form of land use</th>
<th>soil texture (compare 20, appendix)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ss</td>
</tr>
<tr>
<td>arable land (conventional)</td>
<td>67</td>
</tr>
<tr>
<td>arable land (conservation tillage)</td>
<td>62</td>
</tr>
<tr>
<td>grassland</td>
<td>39</td>
</tr>
<tr>
<td>forest</td>
<td>36</td>
</tr>
<tr>
<td>fruit-growing</td>
<td>36</td>
</tr>
<tr>
<td>viticulture</td>
<td>64</td>
</tr>
<tr>
<td>settlement</td>
<td></td>
</tr>
<tr>
<td>waters</td>
<td></td>
</tr>
<tr>
<td>undefined land use</td>
<td></td>
</tr>
</tbody>
</table>

We are calculating the mean annual surface runoff as follows below considering the mean annual number of rainy days dₚ and the mean daily sum of rainfall Pₐ for these rainy days:

$$RO, RS = \frac{(P_d - I_a)^2}{(P_d - I_a + S)} \cdot d_p \ [\text{mm yr}^{-1}]$$
A calculation of the surface runoff in respect of the main land use types *arable land*, *grassland*, *fruit-growing*, *viticulture*, *forest* and *undefined land use* is always done if the area has a hydraulic connection. The surface runoff is however not calculated on areas with a missing connection. For *settlement* areas a calculation of the surface runoff from the unsealed part $RO$ is done, as well as a calculation of the rain discharge $RS$ from the sealed part.

Surface runoff is not calculated for areas with a slope more less than 0.5°, water surfaces and drained areas respectively (siehe 3.3).

### 3.2 Percolation rates

#### 3.2.1 Arable land, grassland, forest

The determination of long-year percolation rates is based on the TUB-BGR-methodology, (Ad-hoc-AG Boden 2003, Wessolek et al 2008) considering a land use-specific statistical regression (22, appendix). Parameters of land use, soil and soil water are included in the regression as well as the plant available soil water in the effective root zone $WV$. The necessary parameters are listed below:

- soil texture in order to derive the field capacity in the effective root zone $nFKWe$ and the climate controlled capillary rise $KA_{kli}$ from April to September,
- land use type (*arable land*, *grassland*, *coniferous forest*, *deciduous forest*),
- climate data: potential FAO-grass reference evapotranspiration $ET0$, precipitation in summer $P_{summer}$ and winter $P_{winter}$.

Following the TUB-BGR-procedure percolation rate from the rooted soil zone is derived from the difference of mean annual precipitation $P_{year}$ and actual evapotranspiration $Eta$ in dependence on $ET0$ and $WV$.

$WV$ is determined by $KA$, $nFKWe$, $P_{summer}$, $P_{year}$ and $RO$ (Ad-hoc-AG Boden 2003) as follows:

$$WV = nFKW + KA_{kli} \cdot P_{summer} \cdot \left( 1 - \frac{RO}{P_{year}} \right) \,[\text{mm yr}^{-1}]$$

The capillary rise is calculated by the following equations in 2, considering different land use types (Ad-hoc AG Boden 2003):

#### Table 2: Calculation of climate controlled capillary rise

<table>
<thead>
<tr>
<th>Land use type</th>
<th>$KA_{kli}$ [mm a$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable land</td>
<td>$KA_{kli} = 1.05 \cdot ET0_{summer} - P_{summer} + 0.5 \cdot nFKWe$</td>
</tr>
<tr>
<td>Grassland</td>
<td>$KA_{kli} = 1.05 \cdot ET0_{summer} - P_{summer} + 0.5 \cdot nFKWe$</td>
</tr>
<tr>
<td>Forest</td>
<td>$KA_{kli} = 1.05 \cdot ET0_{summer} - P_{summer} + 0.5 \cdot nFKWe$</td>
</tr>
<tr>
<td></td>
<td>$KA_{kli} + ET0_{summer} = 0.72 \cdot ET0 + 48$</td>
</tr>
</tbody>
</table>

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The capillary rise $KA$ is derived from $KA_{kli}$ as follows:

(a) $KA = 0$ if $KA_{kli} = 0$
(b) $KA = KA_{kli}$ if $KA_{max} > KA_{kli}$
(c) $KA = KA_{max}$ if $KA_{max} \leq KA_{kli}$

The maximum capillary rise $KA_{max}$ is a function of mean daily capillary rise $KR$ [mm/d] and the corresponding mean daily length of time of capillary rise $ta$ [d] (according to Ad-hoc-AG Boden 2003):

$$KA_{max} = KR \cdot ta \quad [\text{mm yr}^{-1}]$$

In the STOFFBILANZ model we assume that $KR$ mainly depends on soil texture and type of crop and is only relevant on hydromorphic soil types. Otherwise we are neglecting the derivation of $KR$.

3.2.2 settlement, viticulture, fruit-growing, undefined land use

We are calculating the percolation rate for these land use types according to Liebscher & Keller (1979, modified by Wendland et al. 1993):

$$SW = 0.86 \cdot P_{year} - 111.6 \cdot \left( \frac{P_{summer}}{P_{winter}} \right) - 120 \cdot \log (KA+nFKW_e) \quad [\text{mm yr}^{-1}]$$

3.3 Drainage rates

The portion of drained areas $F_d$ for arable land and grassland can be derived (according to Behrendt et al. 1999) from the soil type (SS-##, S#: 50%, GG-##, G#, HN, HH, A#: 10%). It is also possible to use alternative procedures with a higher resolution (e.g. Hirt et al. 2005) or a more sensitive dataset, if available.

The derivation of drainage rates on drained areas is similar to the determination of percolation, whereby capillary rise is not included in general:

$$RD = \frac{A_d \cdot SW}{100} \quad [\text{mm yr}^{-1}]$$

On drained areas we have no calculation of RG, RO and RI.

3.4 Groundwater runoff and interflow

The percolation rate is separated into the interflow $RI$ and groundwater runoff $RG$ according to Röder (1997), using a runoff quotient $f_q$ in dependence on the site slope and grade of hydromorphy (3):
Table 3: Determination of the runoff quotient

<table>
<thead>
<tr>
<th>grade of hydro-morphy</th>
<th>slope class [°]</th>
<th>mgwtd(^1) [m]</th>
<th>soil types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤1</td>
<td>&gt;1-2</td>
<td>&gt;2-5</td>
</tr>
<tr>
<td>terrestrial</td>
<td>1,1</td>
<td>1,2</td>
<td>1,4</td>
</tr>
<tr>
<td>semi hydromorphic</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>hydromorphic</td>
<td>2,5</td>
<td>2,5</td>
<td>2,5</td>
</tr>
</tbody>
</table>

The factor of sun exposure \(f_{\text{exp}}\) (modified from Wessolek, 1997) describes the influence of exposure and slope on the intensity of evaporation on arable land. Consequently the runoff is higher on north, north-west and north-east exposed slopes and lower on south, south-west and south-east exposures. This factor is only used for the calculation of the groundwater runoff and the interflow from arable land (4).

Table 4: Influence of exposure and slope on the intensity of evaporation on arable land

<table>
<thead>
<tr>
<th>exposure</th>
<th>slope [°]</th>
<th>≤1</th>
<th>&gt;1-2</th>
<th>&gt;2-5</th>
<th>&gt;5-10</th>
<th>&gt;10-15</th>
<th>&gt;15</th>
</tr>
</thead>
<tbody>
<tr>
<td>north</td>
<td></td>
<td>1</td>
<td>1,03</td>
<td>1,06</td>
<td>1,13</td>
<td>1,2</td>
<td>1,32</td>
</tr>
<tr>
<td>north-east</td>
<td></td>
<td>1</td>
<td>1,02</td>
<td>1,05</td>
<td>1,09</td>
<td>1,18</td>
<td>1,23</td>
</tr>
<tr>
<td>north-west</td>
<td></td>
<td>1</td>
<td>1,02</td>
<td>1,05</td>
<td>1,09</td>
<td>1,18</td>
<td>1,23</td>
</tr>
<tr>
<td>south</td>
<td></td>
<td>1</td>
<td>0,97</td>
<td>0,94</td>
<td>0,89</td>
<td>0,79</td>
<td>0,72</td>
</tr>
<tr>
<td>south-west</td>
<td></td>
<td>1</td>
<td>0,98</td>
<td>0,95</td>
<td>0,9</td>
<td>0,81</td>
<td>0,75</td>
</tr>
<tr>
<td>south-east</td>
<td></td>
<td>1</td>
<td>0,98</td>
<td>0,95</td>
<td>0,9</td>
<td>0,81</td>
<td>0,75</td>
</tr>
<tr>
<td>east, west</td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Groundwater runoff and interflow are computed as follows, considering the portion of drainage \(A_d\) and the grade of sealing \(A_{\text{seal}}\) [%]:

\[
RG = \frac{SW \cdot RO \cdot f_{\text{exp}} \cdot \left( 1 - \frac{A_d}{100} \right) \cdot \left( 1 - 0,75 \cdot \frac{A_{\text{seal}}}{100} \right)}{P_{\text{year}}} \cdot f_q \ [\text{mm yr}^{-1}]
\]

\[
RI = (f_q - 1) \cdot RG \ [\text{mm yr}^{-1}]
\]

We assume that sealed areas have a permeability of 25%. There is no calculation of \(RI\) and \(RG\) on drained areas.

---

\(^1\) mean groundwater table depth
4 Soil erosion and sediment input

4.1 Soil erosion from rainfall and runoff

Soil erosion from rainfall and runoff is computed according to the Universal Soil Loss Equation USLE (Wischmeier & Smith 1978) considering sheet and rill erosion, but no stream channel and gully erosion (compare Auerswald & Schwertmann 1988, Auerswald 2000, Wiegand 2002).

\[ A = R \cdot K \cdot C \cdot S \cdot L \cdot P \]

- **A**: computed soil loss per unit area \([t\, ha^{-1}\, yr^{-1}]\),
- **R**: rainfall and runoff factor: the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water, where such runoff is significant,
- **K**: soil erodibility factor: soil loss rate per erosion index unit,
- **L**: slope-length factor: ratio of soil loss from the field slope length to that from a 22 m length,
- **S**: slope-steepness factor: ratio of soil loss from the field slope gradient to that from a 9% slope,
- **C**: cover and management factor: ratio of soil loss from an area with specified cover and management to that from an identical area in tilled, continuous fallow,
- **P**: support practice factor: ratio of soil loss with a support practice like contour disking to that with straight-row farming up and down the slope.

The C-factor is computed municipality based considering data from the agricultural statistic (e.g. InVeKoS-data) according to Auerswald (2002) for arable land as follows:

\[ C = \left[ 83 - 1.58 \cdot (c + ms + fc) + 0.0082 \cdot (c + ms + fc)^2 \right] \cdot \left( 1 - 0.03 \cdot fc \right) + 0.01 \cdot fc - 0.05 \cdot ms \]

with **c** as the portion of cereals (including rape, excluding maize) [% of cropland], **ms** as the portion of root crops and cereals (including rape and maize) in conservation tillage [% of cropland], **fc** as the portion of perennial feed cropsf several years [% of cropland].

The coefficients **c**, **ms** and **fc** are computed from the agricultural statistic per municipality. We are able to consider 91% of the real C-factors’ variance (Auerswald 2000). The methodology should not be used if a dominance of vegetables, perennial cultures (hop, viticulture, fruit-growing) or crop feed (> 30%) or combinations of crop feed and root crops in conservation tillage are given, because negative C-factors could be computed. We recommend to set in an estimated value of 0.01 in these cases, which corresponds to a 1% soil loss of an area in tilled, continuous fallow.

If we only know the shares of conservation tillage at all, but information about the corresponding fruit types are missing, we recommend to choose a C-factor value of 0.06. The recommended values for the following land use types are: 0.1 on viticulture.
and fruit-growing, 0.004 on grassland and forest. We do not calculate any C-factors on further land use types.

It should be taken into account, that the chosen size of the grid significantly influences the modelling of soil loss. Larger grid sizes show a tendency to underestimate soil loss, because the spatial variability of slope is decreasing, caused by aggregation (Wu et al. 2005).

4.2 Sediment input

Soil accumulation is close connected to soil erosion. Only a smaller part of soil loss is carried in into surface water in larger river basins. Sediment input is often limited to smaller areas, but can be very intensive on those „hotspot“-sites. We assume, that approximately 90% of the sediment input into surface water is realized on 10% of a catchment ‘s area (see COST Action 869 2006, Voges 1999). Driving forces are the distances to the watercourse, transportation capacity of surface runoff and the deposition of soil in landscape.

Sediment loadings in watercourses may also be caused by many other factors, for example:
- lateral or vertical erosion within watercourses,
- sediment input from urban areas / settlement (substances filtered off),
- mudflows, solifluction, gelifluction,
- sediment input from coal mining, building of roads, houses etc.
- forest routes.

Car Traffic and industrial washing off are the main sources of sediment input in urban areas with approximately 0.2 to 1 t ha⁻¹ yr⁻¹. Particle-bound input is of minor importance on this land use type (z.B. Carter et al. 2003, Kiehlhorn 2005, University of Wisconsin-Extension 1997). Soil losses from building-sites have been estimated up to 14-18 t ha⁻¹ a⁻¹, filtered off substances with concentrations between 100 to 340 mg l⁻¹ have been mentioned by Kiehlhorn (2005). In the STOFFBILANZ model we cannot consider these sources at the moment in an adequate way.

Empirical based modellings often use the sediment delivery ratio SDR to compute the relation between soil erosion from rainfall and runoff and sediment input in the watercourse. In the model STOFFBILANZ we use a methodology to estimate sediment input, which has been adapted to regional scale (Veith 2002, Halbfaß 2005, Halbfaß & Grunewald 2006, 2008, Voges 1999). Main targets are:
- the spatial differentiated computation of sediment delivery considering the main driving forces,
- the calculation of sediment input in the whole river basin,
- the computation of hotspot and source areas of sediment input in detail.
The methodological approach is explained in 4. First we have to do a separation between connected areas and those areas, who have no hydraulic connection to the river net using GIS-functions (Halbfaß 2006). Barriers on the flow path, like roads, railways, etc. are considered in the modelling of sediment input, non-connected areas will be neglected.

The sediment delivery ratio $SDR$ is calculated as follows:

$$ SDR = \chi \left( \frac{s}{l_{flow}} \right)^{(1-P)} $$

where $\chi$ is a coefficient of land use, $s$ is the slope [m m$^{-1}$], $l_{flow}$ is the average distance to the watercourse [m] and $P$ is the likeliness of connectivity$^3$.

The coefficient $\chi$ is derived from the C-factor:

$$ \chi = 1.43 \cdot \ln (C \text{ factor}) + 9.49 \quad R^2=0.89 $$

$P$ is calculated using the different probabilities (according to Voges 1999, see 5) for the distance to the watercourse $p_{lgf}$, soil erosion $p_A$ and surface runoff $p_{RO}$ as follows: $(0 \leq P \leq 1)$

with

$$ P_{lgf} = -0.1358 \cdot \ln (l_{flow}) + 0.9717 \quad R^2=0.94 \quad (0 < \chi \leq 1000 \text{ m}) $$

$^3$ the likeliness of connectivity describes the probability and the intensity of an area to participate on sediment dislocations up to the watercourse (Halbfaß 2005)
Chapter 4: Soil erosion and sediment input

\[ P_A = 0.0671 \cdot \ln (A) + 0.1557 \quad R^2=0.85 \ (\chi \geq 0.1 \ \text{t ha}^{-1} \ \text{yr}^{-1}) \]

\[ P_{RO} = 0.0386 \cdot \ln (RO) + 0.0994 \quad R^2=0.96 \ (\chi \geq 0.1 \ \text{mm yr}^{-1}) \]

and:

\[ p_{\text{flow}} = 0 \quad \text{v} \quad p_A = 0 \quad \text{v} \quad p_{RO} = 0 \quad \rightarrow \quad P = 0 \]

\[ \text{lflow} > 1000 \ \text{m} \quad \rightarrow \quad p_{\text{flow}} = 0 \quad \rightarrow \quad P = 0 \]

\[ A < 0.1 \ \text{t ha}^{-1} \ \text{a}^{-1} \quad \rightarrow \quad p_A = 0 \quad \rightarrow \quad P = 0 \]

\[ RO < 0.1 \ \text{mm a}^{-1} \quad \rightarrow \quad p_{RO} = 0 \quad \rightarrow \quad P = 0 \]

Figure 5: The derivation of likeliness of connectivity in principle

Sediment input in the watercourses is derived as follows:

\[ SE = SDR \cdot A \cdot a \]

where \( SE \ [\text{t yr}^{-1}] \) is the use specific sediment input, \( A \ [\text{t ha}^{-1} \ \text{yr}^{-1}] \) is the soil erosion and \( a \ (0 \leq a \leq 1) \) is the portion of an area where a hydraulic connection is given.

Sediment hotspots are computed by an estimation formula considering the relation between \( P \) and \( SDR \):

\[ f\ (P) = SDR = a \cdot P^b \]

The coefficients \( a \) and \( b \) of this function are determined by the Least Square Method.

Sediment hotspot areas are defined, if the increase \( f'(P_0) \) of tangent at \( P_0 \geq 1 \).

\( P_0 \) is derived as follows:

\[ P_0 = \left( \frac{(f'(P_0))}{(a \cdot b)} \right)^{\frac{1}{(b-1)}} \quad \text{with} \quad f'(P_0) = 1 \]
5 P-balance

5.1 Diffuse P-input

The P-balancing is influenced by P-inputs, P-transformations and P-losses. A complete modelling of this soil-water-plant system on regional scale might be very difficult, because of the physical / chemical character of phosphorus and its strong binding to the sediment. P-transformations are therefore not adequately computable. In the STOFFBILANZ model we focus on the derivation of particle-bound (via soil erosion and surface runoff) and dissolved P-losses (via percolation) considering pathways, sources and sinks of phosphorus in river basins. Particle bound phosphorus $PP_{SE}$ and dissolved P-losses $DP$ are summarized to $TP_{diff}$:

$$TP_{diff} \,[kg \, ha^{-1} \, a^{-1}] = PP_{SE} + DP$$

5.1.1 Particle-bound phosphorus

Particle bound P-input in surface waters $PP_{SE}$ are calculated for the land use types arable land, grassland, deciduous forest, coniferous forest, viticulture and fruit-growing (emmission) considering sediment input $SE$, nutrient enrichment $ER$ and the P-content $P_t$ in topsoil:

$$PP_{SE} \,[kg \, ha^{-1} \, a^{-1}] = SE \,[t \, ha^{-1} \, a^{-1}] \cdot ER \cdot P_t \,[mg \, kg^{-1}]$$

The P-content in topsoil is derived from land use type and soil texture (e.g. according to Freistaat Sachsen 1999). P-contents are rather uncertain because of their site specific high variability (Halbfaß & Grunewald 2004).

The nutrient enrichment $ER$ is derived from the soil loss rate $A$ (compare Auerswald 1989).

$$ER = 2.53 \cdot A^{-0.21} \quad R^2 = 0.981$$

Thus we have an increasing $ER$ if soil erosion sinks, because of the selective transport process, preferring the dislocation of silt and clay. P is mainly adsorbed to these soil textures, thus we have an enrichment of sorbed substances in the sediment load of the surface runoff in comparison to the soil (Lammers 1997). The enrichment is based on the splash-effect of rainfall. Soil aggregates are destroyed and soil particles are dislocated selectively. Thus enrichment ratio increases in combination with a sinking soil loss because the portion of smaller soil particles, being dislocated, increases (Ghadiri & Rose 1991a, b). In literature we find different enrichment ratio values, corresponding to regional characteristics up to 6.0. Mean values about 1.8 are typical for Mid european conditions (Sharpley et al. 1993, Schaub & Wilke 1996, Duttmann 1999).
5.1.2 Dissolved P-inputs

The dissolved P-inputs $DP$ into the tributary – for areas of arable land, grassland, fruit-growing, viticulture and deciduous / coniferous forest - are calculated as the product of the average runoff of the respective runoff component and the corresponding P-concentration in surface runoff, drain discharge, groundwater runoff and interflow.

Table 5: P-concentrations [mg/l] in the runoff components

<table>
<thead>
<tr>
<th>land use type</th>
<th>surface runoff</th>
<th>drain discharge</th>
<th>interflow</th>
<th>groundwater runoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>arable land</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- conventional tillage</td>
<td>0.2</td>
<td>0.2$^1$ / 0.06$^2$</td>
<td>0.06$^3$ / 0.01 – 0.05$^4$</td>
<td>0.01 – 0.05$^5$</td>
</tr>
<tr>
<td>- conservation tillage</td>
<td>0.6</td>
<td>0.6$^2$ / 0.18$^2$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>grassland</td>
<td>0.8</td>
<td>0.8</td>
<td>0.06$^3$ / 0.01 – 0.05$^4$</td>
<td>0.01 – 0.05$^5$</td>
</tr>
<tr>
<td>deciduous / coniferous forest</td>
<td>0.025</td>
<td>-</td>
<td>0.01 – 0.03</td>
<td>0.01 – 0.03$^3$</td>
</tr>
<tr>
<td>fruit-growing</td>
<td>1.2</td>
<td>-</td>
<td>0.01 – 0.05</td>
<td>0.01 – 0.05$^5$</td>
</tr>
<tr>
<td>viticulture</td>
<td>0.8</td>
<td>-</td>
<td>0.01 – 0.05</td>
<td>0.01 – 0.05$^5$</td>
</tr>
</tbody>
</table>

$^1$ soil texture ss, ls, us / $^2$ soil texture lt, tl, sl, ut, su, lu, tu / $^3$ semihydromorphic and hydromorphic soils / $^4$ terrestrial soils / $^5$ regional differentiated

At the moment we have a discussion about the influences of conservation tillage on P-concentrations. According to Zimmermann (2003) strong macropore fluxes are possible on these sites, if the percolation capacity is exceeded. The risk of a P-dislocation via macropores even depends on many other soil characteristics. We assume that there is no significant increasing of P-dislocation via macropore on terrestrial soil types (compare Schmidt 2006).

5.1.3 Further P-inputs

P-inputs $TP_{diff}$, which cannot be calculated according to their pathway of input (particle-bound, dissolved) are summarized in the following chapter. In the modelling we use export coefficients, which have been derived from literature.

5.1.3.1 Diffuse sources in urban areas / settlement

Diffuse sources from urban areas / settlement are considered in the modelling via the following pathways using export coefficients:

- housings without a connection to a public sewage treatment plant, direct discharger to the sewage system, small sewage works possible, no cesspit
- housings without a connection to a sewage system, cesspit or a small sewage works available
- stormwater overflow discharge
• atmospheric deposition (unsealed area)

In the estimation of diffuse inputs from housings, population equivalents in raw water and mean values of retention are included.

P-inputs via stormwater overflow discharges are only determined on the sealed area.

For the computation of atmospheric P-deposition on unsealed areas we use a mean value of 0.5 kg P ha\(^{-1}\) yr\(^{-1}\). We assume additionally that only 10 % (0.05 kg P ha\(^{-1}\) yr\(^{-1}\)) will be washed out into surface water because of the high P-sorption in the unsaturated zone.

**Pathway unsealed settlement / urban area**

Spatial scale: grid

Input data

- Export coefficient for P \(c_p\) [kg ha\(^{-1}\) yr\(^{-1}\)]
- grade of sealing \(A_{seal}\) [%]
- retention coefficient in soil \(r_{soil}\) for P 90%
- permeability of sealing: 25%

Modelling

\[
DP_{urb} = c_p \left( \frac{100 - r_{soil}}{100} \right) \left( \frac{100 - A_{seal} \cdot 0.75}{100} \right) \text{[kg ha}\(^{-1}\) yr\(^{-1}\) ]}
\]

**Pathway storm water discharge**

Spatial scale: grid

Input data

- export coefficient for P \(c_p\) [kg ha\(^{-1}\) yr\(^{-1}\)]
- grade of sealing \(A_{seal}\) [%]
- permeability of sealing: 25%

Modelling

\[
DP_{seal} = c_p \left( \frac{A_{seal} \cdot 0.75}{100} \right) \text{[kg ha}\(^{-1}\) yr\(^{-1}\) ]}
\]

**Pathway housings without a sewer system**

Spatial scale: varying

Input data
Chapter 5: P-balance

- export coefficient for P \( c_{\text{Pinh}} \) [kg inhabitants\(^{-1}\) yr\(^{-1}\)]
- inhabitants \( n_{\text{inh}} \) [-]
- grade of connection to the sewage treatment plant \( n_{\text{STP}} \) [%]
- portion of the inhabitants without a connection to the sewer system to the sum of inhabitants with a direct discharge and inhabitants without a connection to the sewer system \( n_{\text{wSTP}} \) [%]
- settlement area \( A_{\text{urb}} \) [ha]

Modelling

\[
DP_{\text{seal}} = c_{\text{Pinh}} \cdot \frac{n_{\text{inh}}}{100} \cdot \left[ \frac{100 - n_{\text{STP}}}{100} \cdot \frac{n_{\text{wSTP}}}{100} \right] \left[ \text{kg ha}^{-1} \text{ yr}^{-1} \right]
\]

Pathway housings with a direct discharge

Spatial scale: varying

Input data

- export coefficienten for P \( c_{\text{Pinh}} \) [kg inhabitants\(^{-1}\) yr\(^{-1}\)]
- inhabitants \( n_{\text{inh}} \) [-]
- grade of connection to the sewage treatment plant \( n_{\text{STP}} \) [%]
- portion of the inhabitants without a connection to the sewer system to the sum of inhabitants with a direct discharge and inhabitants without a connection to the sewer system \( n_{\text{wSTP}} \) [%]
- settlement area \( A_{\text{urb}} \) [ha]

Modelling

\[
DP_{\text{seal}} = c_{\text{Pinh}} \cdot \frac{n_{\text{inh}}}{100} \cdot \left[ \frac{100 - n_{\text{STP}}}{100} \cdot \frac{n_{\text{wSTP}}}{100} \right] \left[ \text{kg ha}^{-1} \text{ yr}^{-1} \right]
\]

Diffuse P-input \( TP_{\text{diff}} \) from settlement / urban area in surface waters is realized as the sum of all export coefficient of each pathway..

5.1.3.2 Diffuse sources for waters and undefined land use types

We do not make any differentiation between particle-bound and dissolved inputs on the land use types waters and Undefined land use, because variabilities are hardly to compute. Diffuse P-input \( TP_{\text{diff}} \) for undefined land use is estimated to 0.5 kg P ha\(^{-1}\) yr\(^{-1}\).
On the land use type *waters* we determine the diffuse phosphorus input $TP_{diff}$ according to the atmospheric $P$-deposition, varying according to literature data from 0,04 to 1,5 kg $P$ ha$^{-1}$ yr$^{-1}$. We recommend to use the 0,4 value for eastern Germany regions with precipitations about 660 mm a$^{-1}$, according to Behrendt et al. (1999).

5.2 **Point-related P-inputs**

Besides the diffuse $P$-input we have an additional pollution of waters by point-related loadings $TP_{point}$, which can be quantified using datasets of public and industrial sewage treatment plants.
Chapter 6: N-balance

6 N-balance

6.1 Diffuse N-input

6.1.1 N-balances on arable land, grassland and viticulture, fruit-growing

The nitrogen balance can be computed in a simplifying way as the result of inputs and outputs being done in the present regional scale by different modelling tools (e.g. Behrendt et al. 2002, Bach et al. 2003). Processes of mobilisation and immobilisation of nitrogen are additionally considered by applications with a more detailed site specific view (e.g. Hülsbergen & Diepenbrock 1997, Brisson et al. 1998) In the STOFFBILANZ model these processes are included for cropland sites using indicators of mineralisation and immobilisation in dependence on soil and fruit specific coefficients. Thus we are able to give an estimation to the status of N-humus (decreasing or increasing) in addition. Focusing on these phenomena will become more important in the future because of an increasing cultivation of energy crops. Effects of special measurements like intercrop cultivation, changes in livestock or consequences of climate change can be computed in a more sufficient way. The different parameters of this „extended“ N-balancing are included in 6 (Gebel et al. 2010, 2013)

Figure 6: Derivation of the N-balance on cropland
Chapter 6: N-balance

Calculation of input, output, mobilisation and immobilisation is derived from the following equations considering the respective spectrum of crop types:

\[
\text{Import} = F_{\text{min}} + f_l \cdot F_{\text{org}} + F_{\text{leg}}
\]

\[
\text{Mobilisation} = f_{\text{mob}} \cdot F_{\text{org}} + M_{\text{root}} + M_{\text{ic}} + M_{\text{soil}} \quad \text{[kg N ha}^{-1} \text{yr}^{-1}]\]

\[
\text{Immobilisation} = f_{\text{org}} \cdot F_{\text{org}} + I_{\text{root}} + I_{\text{ic}}
\]

\[
\text{Export} = E_{\text{harv}} + E_{\text{root}}
\]

where \( F_{\text{min}} \) is mineral fertilizer, \( F_{\text{org}} \) is farm manure, \( F_{\text{leg}} \) is N-fixing of legumes, \( M_{\text{root}} \) is N-mobilisation from crop residues of the preliminary crop in the year of calculation, \( I_{\text{ic}} \) is N-immobilisation by inter crops, \( M_{\text{ic}} \) is N-mobilisation from inter crops of the previous year, \( M_{\text{soil}} \) is long year N-mobilisation from organic soil matrix, \( E_{\text{harv}} \) is harvest withdrawal of the main product, \( I_{\text{root}} \) is N-immobilisation by root and by-product, \( E_{\text{root}} \) is exported by-product, \( f_l \) is coefficient to consider losses of \( F_{\text{org}} \), \( f_{\text{mob}} \) is the coefficient to consider N-mobilisation from \( F_{\text{org}} \) in the year of calculation, \( f_{\text{org}} \) is the coefficient to determine the organic part of \( F_{\text{org}} \).

Information to the atmospheric deposition \( N_{\text{atm}} \) and denitrification in topsoil \( D_{\text{soil}} \) will be given in chapter 6.1.3 and 6.1.4.

6.1.1.1 N-import on arable land

Mineral fertilizer and farm manure

Data to mineral fertilizer \( F_{\text{min}} \) are given in dependence on fruit types and regional specification. Farm manure \( F_{\text{org}} \) is determined in dependence on the regional livestock considering losses of storage and deposition of liquid manure and dung by the help of a coefficient \( f_l \).

N-fixing by legumes

N-fixing rates \( F_{\text{leg}} \) are determined in dependence on the type of fruit and the respective yield (nach SfL 2007).

6.1.1.2 N-mobilisation on cropland

N-mobilisation from farm manure

The N-mobilisation from the organic farm manure part is calculated via the coefficient \( f_{\text{mob}} \) considering dung and liquid manure.

N-mobilisation from inter crops

Effects of the cultivation of inter crops of the previous year are considered by additional coefficients of N-immobilisation and mobilisation. In the modelling we assume that the N-mobilisation from inter crops in spring is about 75% of the total immobilisation of the inter crops \( M_{\text{ic}} \) in autumn / winter of the previous year (compare Schliepha-ke & Albert 2003, chapter 6.1.1.3).
N-mobilisation from crop residues and roots

N-mobilisation from crop residues and roots $M_{root}$ are considered in the modeling according to SLfL (2007) and Arman et al. (2002).

N-mobilisation from organic soil matrix

The long time mobilisation of nitrogen from the organic soil matrix $M_{soil}$ is determined as described above (7). N-mobilisations resulting from the recent year calculation are not included in this part of the modeling. They are calculated in addition (see $M_{root}$).

In the framework of the development of the model STOFFBILANZ_BW in cooperation with the authorities of the federal state of Baden-Württemberg we have modified the methodology to derive the N-mobilisation based on the Henin & Dupuis concept. N-mobilisation is calculated according to Mary & Guérif (1994) and Meynard et al. (1996), considering content of humus, C/N-ratio, contents of clay, lime and skeleton, average annual temperature and fruit type specific management practice. Thus we get a differentiation including variabilities of soil texture and soil type specifics of N-mobilisation in an adequate way.

\[ \text{Figure 7: Derivation of the N-mobilisation from the organic soil matrix} \]

First we have to determine the organic N-content in topsoil $N_t$ using the humus content $c_{humus}$ [%], raw density $\text{SBD} \ [\text{g/cm}^3]$ and C/N-ratio in topsoil as follows (Mary & Guérif 1994, Meynard et al. 1996):

\[ N_t = \frac{c_{humus} \cdot \text{SBD} \cdot 3 \cdot 10000}{1,72 \cdot C/N} \quad [\text{kg N ha}^{-1} \text{ yr}^{-1}] \]

The potential N-mobilisation from soil matrix $M_{soil}$ is determined as follows considering $N_t$, the coefficient $K_2$ and the content of skeleton $c_{sk}$ in topsoil [%]:
\[ M_{\text{soil}} = N_t \cdot K_2 \cdot 1.3 \cdot (1 - \frac{c_{sk}}{100}) \quad [\text{kg N ha}^{-1} \text{ yr}^{-1}] \]

The coefficient \( K_2 \) is calculated by content of clay \( c_{\text{clay}} \) and lime \( c_{\text{lime}} \) in topsoil [%] and the average annual temperature \( T_{\text{avg}} \) [°C] via the coefficient \( f_t \). The intensity of farm manure use and the frequency of an export of crop residues is taken into account for each type of fruit via the coefficient \( f_s \) to characterize the cultivation system (6, according to Arman et al. 2002, Mary & Guérif 1994, Meynard et al. 1996):

\[
K_2 = \frac{1200 \cdot f_s \cdot f_t}{(c_{\text{clay}} \cdot 10 + 200) \cdot (0.3 \cdot c_{\text{lime}} \cdot 10 + 200)}
\]

\[ f_t = 0.15 \cdot T_{\text{avg}} - 0.5 \]

**Table 6: Definition of the coefficient \( f_s \) to characterize the cultivation practice**

<table>
<thead>
<tr>
<th>Crop residues being exported</th>
<th>frequency of farm manure practice</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt; every 10 years</td>
</tr>
<tr>
<td>... always</td>
<td>0,8</td>
</tr>
<tr>
<td>... sometimes</td>
<td>0,9</td>
</tr>
<tr>
<td>... never</td>
<td>1</td>
</tr>
</tbody>
</table>

**6.1.1.3 N-immobilisation on arable land**

**N-immobilisation by the organic part of farm manure**

We calculate the organic part of farm manure which will be included in the humus-pool in the year of calculation using the coefficient \( f_{\text{org}} \).

**N-immobilisation by crop residues and root**

The N-immobilisation in crop residues and root on arable land is given by \( I_{\text{root}} \) in relation to the fruit type specific yield and the coefficient of withdrawal for the by-product (SflL 2007, LAP 2004). Crop residues being exported are excluded in the calculation (see \( E_{\text{root}} \)).

**N-immobilisation by inter crops**

Effects of the cultivation of inter crops are considered by additionally coefficients of N-immobilisation and mobilisation. In the modelling we assume that the N-immobilisation by inter crops \( I_{\text{i}} \) in autumn / winter is about 20 kg N ha\(^{-1}\) yr\(^{-1}\) higher than the N-mobilisation in spring of the calculation year from the intercrop of the previous year. We are estimating the N-immobilisation to 80 kg N ha\(^{-1}\) yr\(^{-1}\) and the N-mobilisation to 60 kg N ha\(^{-1}\) yr\(^{-1}\) respectively (see chapter 6.1.1.2, compare to Schliephake & Albert 2003).
6.1.1.4 N-export on arable land

**Harvest withdrawel**

The N-withdrawel by harvest is given by $E_{\text{harv}}$ in relation to the fruit type specific yield and the coefficient of withdrawel for the main product (SLfL 2007).

**Crop residues being exported**

This part of crop residues $E_{\text{root}}$ is considered in dependence on the fruit type specific yield, the coefficient of withdrawel for the by-product and the portion of crop residues being exported (SLfL 2007).

6.1.1.5 **Interim balance**

The interim balance ($N_{\text{surplus}}$) on arable land is calculated as follows, considering sources (input, mobilisation) and sinks (immobilisation, output):

$$N_{\text{surplus}} = F + M - I - E \quad [\text{kg N ha}^{-1} \text{yr}^{-1}]$$

6.1.1.6 **Interim balance on grassland**

We calculate the interim balance (= N-surplus) on grassland as follows:

$$N_{\text{surplus}} = F_{\text{leg}} + F_{\text{min}} + (f_{\text{f}} - f_{\text{org}} + f_{\text{mob}}) \cdot F_{\text{org}} - E_{\text{harv}} \quad [\text{kg N ha}^{-1} \text{yr}^{-1}]$$

The N-fixing of legumes on grassland is determined according to Weissbach (1995). All other parameters are derived analogous to cropland whereby we do not consider N-transformations.

6.1.1.7 **Interim balance on viticulture and fruit-growing**

We estimate the interim balance value (= surplus) on viticulture to 0 kg N ha$^{-1}$ yr$^{-1}$, on fruit-growing areas a 10 kg N ha$^{-1}$ yr$^{-1}$ value is given. These values should be adapted if necessary.

6.1.2 N-balance on forest land

6.1.2.1 **N net-uptake rate**

While calculating the data for forest land first the weathering class and N-net-uptake rate have to be computed. We derive the data following the critical-load-concept (according to Nagel & Gregor 1999, UBA 1996). For the use in the model STOFFBILANZ they have been accordingly adapted (Kaiser 2002). The weathering rate is classified according to the soil texture and parent rock derived from the soil type (adapted from Nagel & Gregor 1999, 7).
Table 7: Derivation of the weathering class on forest land

<table>
<thead>
<tr>
<th>soil type</th>
<th>soil texture</th>
<th>Hn, Hh</th>
<th>ss, ls, us, su</th>
<th>sl, lu</th>
<th>tl</th>
<th>tu</th>
<th>ut</th>
<th>lt</th>
</tr>
</thead>
<tbody>
<tr>
<td>HN, HH</td>
<td>Hn, Hh</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>F#, O#, RN, RQ, P#, B#, PP-BB</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>D#, L#, SS-##, GG-##, A#, S#, G#, T#, Y#</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

The yield type can be deduced from the weathering class while taking into consideration the average annual temperature as well as the average percolation rate (adapted from Nagel & Gregor 1999, 8).

Table 8: Derivation of the yield type on forest land

<table>
<thead>
<tr>
<th>temperature [°C]</th>
<th>weathering class 3 + 4</th>
<th>weathering class 1 + 2</th>
<th>weathering class 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥9</td>
<td>Ia</td>
<td>Ia</td>
<td>Ia</td>
</tr>
<tr>
<td>8</td>
<td>I</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>7</td>
<td>II</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>6</td>
<td>IV</td>
<td>IV</td>
<td>IV</td>
</tr>
<tr>
<td>5</td>
<td>≥5</td>
<td>≥5</td>
<td>≥5</td>
</tr>
<tr>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>SW [mm/ yr⁻¹]</td>
<td>yield type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>≥1000</td>
<td>Ia</td>
<td>Ia</td>
<td>Ia</td>
</tr>
<tr>
<td>&lt;1000-800</td>
<td>la</td>
<td>la</td>
<td>la</td>
</tr>
<tr>
<td>&lt;800-600</td>
<td>la</td>
<td>la</td>
<td>la</td>
</tr>
<tr>
<td>&lt;600-400</td>
<td>la</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>&lt;400-200</td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>&lt;200</td>
<td>III</td>
<td>III</td>
<td>III</td>
</tr>
</tbody>
</table>

The net removal of N on biomass (uptake) which is harvested can be derived from the yield type (adapted from Nagel & Gregor 1999, 9).
Table 9: Derivation of the N net-uptake on forest land

<table>
<thead>
<tr>
<th>yield type</th>
<th>deciduous forest</th>
<th>coniferous forest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>15</td>
<td>10</td>
</tr>
<tr>
<td>I</td>
<td>13,5</td>
<td>8,5</td>
</tr>
<tr>
<td>II</td>
<td>11,5</td>
<td>6,5</td>
</tr>
<tr>
<td>III</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>IV</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>V</td>
<td>3,5</td>
<td>2</td>
</tr>
</tbody>
</table>

6.1.2.2 N-Immobilisation on forest land

The N-immobilisation rate \(I_{\text{humus}}\) is found with the help of the average annual temperature (adapted from Nagel & Gregor 1999, 10).

Table 10: Derivation of N-immobisation rate on forest land

<table>
<thead>
<tr>
<th>average annual temperature [°C]</th>
<th>≤4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>≥9</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-immobilisation rate [kg N ha(^{-1}) yr(^{-1})]</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1,5</td>
<td>1</td>
</tr>
</tbody>
</table>

6.1.3 Atmospheric N-deposition

The data of total atmospheric deposition (dry and wet) \(N_{\text{atm}}\) are considered in the modelling according to land use type for each grid cell (compare Gauger et al. 2002, 2008).

6.1.4 Denitrification in topsoil

6.1.4.1 Arable land, grassland, fruit-growing, viticulture, settlement, undefined land use

We calculate the denitrification of the top soil according to the method of Wendland (1992), considering the Michaelis-Menten-kinetics. Here the different parts of the interim balance are used. In addition to that we determine the maximum denitrification rate as well as the coefficient \(K\) which depends on the conditions of denitrification (good / moderate / poor) and the soil type (11):

\[
D_{\text{soil}}[\text{kg N ha}^{-1} \text{a}^{-1}] = \frac{D_{\text{max}} \cdot \left( \frac{N_{\text{surplus}} + N_{\text{atm}}}{7,5} \right)}{K + \frac{N_{\text{surplus}} + N_{\text{atm}}}{7,5}}
\]
Chapter 6: N-balance

Table 11: Conditions of denitrification derived from the soil type

<table>
<thead>
<tr>
<th>Conditions of denitrification</th>
<th>D(\text{max}[\text{kg N ha}^{-1}\text{yr}^{-1}])</th>
<th>K</th>
<th>Bodentypen</th>
</tr>
</thead>
<tbody>
<tr>
<td>good</td>
<td>50</td>
<td>6,7</td>
<td>S#, G#, HN, HH</td>
</tr>
<tr>
<td>moderate</td>
<td>30</td>
<td>4</td>
<td>RR, RZ, T#, D#, L#, SS-##, GG-##, C#, A#</td>
</tr>
<tr>
<td>poor</td>
<td>10</td>
<td>2,5</td>
<td>F#, O#, RN, RQ, P#, B#, PP-BB, UA, Y#</td>
</tr>
</tbody>
</table>

The conditions of denitrification in the top soil require though a more differentiated view in addition to the values in 11. So the conditions for the soil type luvisol (L#) in combination with the soil textures ss and ls are assumed as poor (instead of moderate). For the soil type cambisol (B#) the conditions of denitrification of the soil textures tl, lt and ut are categorized as moderate (instead of poor). The reason for these differentiations is that we as well as Wendland (1992) distinguish between cambisols that are poor in base and those that are rich in base. Areas with the above mentioned soil textures are mainly classified as cambisols rich in base. Here we also find particularly high field capacity values, comparatively low values of effective field capacity and field capacity in the effective root depth and low kf and soil porosity values, which increase denitrification. Furthermore the assessment of the conditions of denitrification on soils with a skeleton content higher than 30% is always changed from good to moderate respectively from moderate to poor. We assume that the conditions of denitrification in areas of settlements and in of those of viticulture are generally poor independent on the soil type and the soil texture. The reason for these modifications is that these soils have a sufficient porosity and a greater distance to groundwater table, so that higher rates of denitrification need not be expected.

6.1.4.2 Forest land

For the land use types deciduous and coniferous forest the denitrification rate is determined according to the critical-load-concept (see Kaiser & Gebel 2003, adapted from Nagel & Gregor 1999). Here data for the atmospheric deposition, the N net-uptake rate \(I_{\text{uptake}}\) (9), the N immobilization rate \(I_{\text{humus}}\) (10) and a denitrification coefficient \(f_{de}\) (12) are necessary:

\[
\text{D}_{\text{soil}}[\text{kg N ha}^{-1}\text{a}^{-1}] = f_{de}(N_{\text{atm}} - I_{\text{uptake}} - I_{\text{humus}})
\]

Table 12: Derivation of the coefficient \(f_{de}\)

<table>
<thead>
<tr>
<th>Soil texture</th>
<th>ss, ls, us, su, si, lu</th>
<th>tl, tu</th>
<th>tl, ut, lt</th>
<th>Hn, Hh</th>
</tr>
</thead>
<tbody>
<tr>
<td>(f_{de})</td>
<td>0,1</td>
<td>0,2</td>
<td>0,3</td>
<td>0,8</td>
</tr>
</tbody>
</table>
6.1.5 Diffuse N-leaching from the rooted soil zone

N-leaching rate $DN_{soil}$ on arable land, grassland, viticulture, fruit-growing and undefined land use is determined as follows considering the interim balance, $N_{atm}$ and the denitrification $D_{soil}$:

$$DN_{soil} [\text{kg N ha}^{-1} \text{a}^{-1}] = N_{\text{surplus}} + N_{atm} - D_{soil}$$

On the land use type waters the leaching corresponds to the atmospheric deposition.

On forest land we compute the N-leaching in dependence on N net-uptake rate, N-immobilisation and denitrification as follows (according to Nagel & Gregor 1999):

$$DN_{soil} [\text{kg N ha}^{-1} \text{a}^{-1}] = N_{atm} - D_{soil} - I_{\text{uptake}} - I_{\text{humus}}$$

On the land use type settlement the N-leaching is only calculated on the unsealed area. We assume that the permeability on the sealed area $A_{seal}$ [%] is about 75% (compare to Sukopp & Wittig 1998).

$$DN_{soil} [\text{kg N ha}^{-1} \text{a}^{-1}] = (N_{atm} - D_{soil}) \cdot \left(1 - \frac{0.75 \cdot A_{seal}}{100}\right)$$

The diffuse loadings from sealed areas $DN_{RS}$ are washed out directly into the tributary (see below).

6.1.6 N-input in surface waters from sealed areas

The N-inputs from the sealed area $DN_{RS}$ are calculated analogous to the derivation of P-inputs.

Pathway storm water discharge

Spatial scale: grid

Input data

- export coefficient for N $c_N$ [kg ha$^{-1}$ yr$^{-1}$]
- grade of sealing $A_{seal}$ [%]
- permeability of sealing: 25%

Modelling

$$DN_{seal} = c_N \cdot \left(100 \cdot \frac{A_{seal}}{0.75} \cdot \frac{0.75}{100}\right) [\text{kg N ha}^{-1} \text{yr}^{-1}]$$
Pathway housings without a sewer system

Spatial scale: varying

Input data

- export coefficient for N $c_{\text{Ninh}}$ [kg inhabitants$^{-1}$ yr$^{-1}$]
- inhabitants $n_{\text{inh}}$ [-]
- grade of connection to the sewage treatment plant $n_{\text{STP}}$ [%]
- portion of the inhabitants without a connection to the sewer system to the sum of inhabitants with a direct discharge and inhabitants without a connection to the sewer system $n_{\text{wSTP}}$ [%]
- settlement area $A_{\text{urb}}$ [ha]

Modelling

$$DN_{\text{scale}} = \frac{c_{\text{Ninh}} \cdot n_{\text{inh}} \cdot 100 - n_{\text{STP}} \cdot n_{\text{wSTP}}}{100 \cdot 100} \cdot \frac{1}{A_{\text{urb}}} \text{ [kg ha}^{-1} \text{ yr}^{-1}]$$

Pathway housings with a direct discharge

Spatial scale: varying

Input data

- export coefficient for N $c_{\text{Ninh}}$ [kg inhabitants$^{-1}$ yr$^{-1}$]
- inhabitants $n_{\text{inh}}$ [-]
- grade of connection to the sewage treatment plant $n_{\text{STP}}$ [%]
- portion of the inhabitants without a connection to the sewer system to the sum of inhabitants with a direct discharge and inhabitants without a connection to the sewer system $n_{\text{wSTP}}$ [%]
- settlement area $A_{\text{urb}}$ [ha]

Modelling

$$DN_{\text{scale}} = \frac{c_{\text{Ninh}} \cdot n_{\text{inh}} \cdot 100 - n_{\text{STP}} \cdot 100 - n_{\text{wSTP}}}{100 \cdot 100} \cdot \frac{1}{A_{\text{urb}}} \text{ [kg ha}^{-1} \text{ yr}^{-1}]$$

Diffuse N-input from sealed areas in surface waters $DN_{\text{RS}}$ is realized as the sum of all leachings of each pathway.
6.1.7 Separation of the N-leaching to the runoff components

Nitrate-N being readily soluable in water is extremely apt to be washed out because of its high mobility. The emissions from an area are transfered from the rooted soil matrix by the way of percolation (DN_{SW}), drain discharge (DN_{RD}) and the surface runoff (DN_{RO}). We assume that for water areas the loads are only transfered by the surface runoff.

The partitioning of N_{anSW} in N_{anRG} and N_{anRB} is done for each runoff component. The loads for the groundwater runoff, interflow, surface runoff and drain discharge are calculated as follows:

\[
\begin{align*}
DN_{SW} [kg \ N ha^{-1} a^{-1}] &= DN_{soil} \cdot \frac{SW}{(R-0.75 \cdot RS)} \\
DN_{RD} [kg \ N ha^{-1} a^{-1}] &= DN_{soil} \cdot \frac{RD}{(R-0.75 \cdot RS)} \\
DN_{RO} [kg \ N ha^{-1} a^{-1}] &= DN_{soil} \cdot \frac{RO}{(R-0.75 \cdot RS)} \\
DN_{RI} [kg \ N ha^{-1} a^{-1}] &= DN_{soil} \cdot \frac{RI}{(R-0.75 \cdot RS)} \\
DN_{RG} [kg \ N ha^{-1} a^{-1}] &= (DN_{SW} - DN_{RI}) \cdot r_{gw}
\end{align*}
\]

Residence time of groundwater runoff and denitrification in the upper aquifer is computed in the modelling in dependence on groundwater structure (see below). We assume that for water areas the loads are only transfered by the surface runoff. Therefore a possible transfer of nitrogen from the water into the ground water is not taken into account.

The nitrate concentration in percolation water C_{NO3SW} is calculated according to the following algorithm:

\[
C_{NO3SW} [mg \ l^{-1}] = \frac{DN_{SW} \cdot 4.43 \cdot 100}{SW}
\]

6.1.8 Residence time and denitrification in the upper aquifer

The nitrate emissions which are detectable in the surface water have reduced themselves because of denitrification processes during the runoff passage in the groundwater system. The nitrate loss by denitrification r_{gw} in the upper aquifer (groundwater path) is computed in dependence on groundwater structure. Considering half-value time of denitrification and residence time of groundwater, a significant reduction of the N-input into groundwater is possible. The detection of flow-paths and the calculation of distance ground-water velocity is only possible in loose rock. Total residence time and retention of the emitted load per grid cell is then determined on the integral interaction of residence time and half-value time of all grid cells corresponding to the flow path until the contact to surface water is realized (compare to chapter 6.1.8.2, 8).
Flow paths and residence time are not numerically considered in regions with solid rock or loose over solid rock aquifers because of the very complex hydraulic, which can not be explained by the Darcy-algorithm. Thus we have to make an estimation of the respective values (see chapter 6.1.8.1, 13 and 14).

6.1.8.1 Solid rock aquifers and loose over solid rock aquifers

We have to estimate residence time and half-time value of denitrification in these regions, based on the investigations of Wendland & Kunkel (1999) and Kunkel & Wendland (1999). The methodology has exemplary been adapted by Ullrich (2006) for Saxony considering the hydro-chemical character of groundwater and present literature and isotope data to groundwater dating (e.g. Schwarze 2004) (13, 14).

The coefficient \( r_{gw} \) is considered in dependence on half-value time of denitrification and groundwater residence time (upper aquifer) as follows (Wendland & Kunkel 1999, Wendland 1992):

- **good or moderate conditions of denitrification:**
  \[
  r_{gw} = \exp(-0,267 \cdot t_{gw})
  \]

- **poor conditions of denitrification:**
  \[
  r_{gw} = \exp(-0,034 \cdot t_{gw})
  \]

- **denitrification might be insignificant:**
  \[
  r_{gw} = \exp(-0,02 \cdot t_{gw})
  \]

---

**Table 13: Derivation of denitrification in the upper aquifer, e.g. for Saxony**

<table>
<thead>
<tr>
<th>upper aquifer</th>
<th>half-value time of denitrification [yr]</th>
<th>hydro-chemical character of groundwater</th>
<th>conditions of denitrification</th>
</tr>
</thead>
<tbody>
<tr>
<td>quarternary and tertiary loose rock</td>
<td>ca. 1,2 bis 4</td>
<td>mainly reducing</td>
<td>good or moderate</td>
</tr>
<tr>
<td>loose rock over solid rock</td>
<td>ca. 20</td>
<td>oxidising / reducing</td>
<td>poor</td>
</tr>
<tr>
<td>limestone, conglomerate, metamorphic, plutonic, volcanic, sandstone, silt and clay rock</td>
<td>ca. 35</td>
<td>oxidising</td>
<td>insignificant</td>
</tr>
</tbody>
</table>
Table 14: Estimation of ground water residence time (solid rock, e.g. Saxony)

<table>
<thead>
<tr>
<th>groundwater structure / soil type</th>
<th>estimation of average groundwater residence time [yr]</th>
</tr>
</thead>
<tbody>
<tr>
<td>sandstone</td>
<td>20</td>
</tr>
<tr>
<td>loose rock over solid rock</td>
<td>15</td>
</tr>
<tr>
<td>metamorphic, plutonic</td>
<td>7</td>
</tr>
<tr>
<td>volcanic</td>
<td>6.5</td>
</tr>
<tr>
<td>limestone, conglomerate, silt- and claystone, quaternary valleys</td>
<td>5</td>
</tr>
<tr>
<td>soil types G#, GG-##, A#, HN</td>
<td>1</td>
</tr>
</tbody>
</table>

6.1.8.2 Loose rock aquifers

The calculation is based on a compartment model which has been developed by Uhlig (2008) according to the WEKU-methodology (Kunkel & Wendland 1999) using a multiple-flow algorithm (8).

Necessary input data are coefficients of permeability taken from the HÜK 200, a digital groundwater table of the upper aquifer, the river net and an elevation model. We use these data to generate the distance ground-water velocity, flow paths and the transfers of nitrate for each grid cell of the upper aquifer. The exfiltration in surface water is determined on the distance between elevation model and groundwater-head. The transfer of groundwater runoff and nitrate load to the exfiltration zone stops if stationary conditions are fulfilled.

Figure 8: Derivation of groundwater residence time and denitrification
Denitrification is simulated via a first order degradation, using a coefficient of degradation of 0.267/yr (compare to Wendland 1992).

Transport of groundwater runoff and nitrate load is realized by a multiple-flow algorithm (MFA). According to the hydraulic gradient, waters and loads are separated into different directions. Finally we are able to compute nitrate load and nitrate concentration for each grid cell up to the exfiltration zone (Uhlig et al. 2010).

6.1.9 Dissolved N-input from diffuse sources

The total dissolved N-input $DN_R$ from diffuse sources considering denitrification in groundwater is calculated as follows:

$$DN_R [kg \, N \, ha^{-1} \, a^{-1}] = DN_{RO} + DN_{RS} + DN_{RD} + DN_{RI} + DN_{RG}$$

6.1.10 Particle-bound N-input

Besides the dissolved N-input, we can have particle-bound dislocations of nitrogen which are generally of minor importance. We calculate these inputs $PN_{SE}$ in combination with the modeling of soil erosion considering the organic N-content of topsoil $N_t$ and the sediment input $SE$ as follows:

$$PN_{SE} [kg \, N \, ha^{-1} \, a^{-1}] = \frac{N_t \cdot SE}{3000}$$

6.1.11 Total diffuse N-input

The total diffuse N-input $TN_{diff}$ is finally calculated as the sum of dissolved and particle-bound loads:

$$TN_{diff} [kg \, N \, ha^{-1} \, a^{-1}] = PN_{SE} + DN_R$$

6.2 Point-related N-inputs

Besides the diffuse N-input $TN_{point}$ we have an additionally pollution of waters by point-related loadings, which can be quantified using datasets of public and industrial sewage treatment plants.
Chapter 7: Long lasting nutrient retention in river basins


Dealing with the nutrient retention phenomenon we should take into account, that many effects are short time related, especially controlled by hydrological variability (flood, low water). A long lasting retention for P especially exists in flooding areas and reservoirs (Walling u. He 1994, Guhr u. Meissner 2000, Venterink et al. 2003, Withers u. Jarvie 2008). The most important N-removal is caused by denitrification in river bed (z.B. Donner et al. 2004). At the moment there is still a lack of plausible methods to derive process-orientated retention rates in the meso- or macroscale catchment modelling.

Our computation of an average long-term retention of nitrogen and phosphorus in surface waters is based on generally available data and should only be used in a regional river basin modeling.

7.1 Retention of phosphorus

7.1.1 Retention of phosphorus in rivers

The spatial and temporal dynamic of transformation, transport and retention of phosphorus is generated using the spiralling concept (Newbold et al. 1983). Thus processes in the river continuum are changing from source to mouth (e.g. Bowes et al. 2003).

Important processes in rivers in respect to a reflection of sources and sinks are listed as follows (e.g. House 2002, Haggard u. Sharpley 2007, Withers u. Jarvie 2008):

(a) sinks

1. deposition of sediment adsorbed phosphorus on the river bed;
2. sorption of phosphorus to the bed sediment;
3. phosphorus uptake by macrophytes and algues;
4. precipitations of phosphorus in combination with calcite, iron and hydroxides in oxidised interstitial water.

(b) sources
1. flood related remobilisation / resuspension of phosphorus from bed and bank sediments;
2. desorption and solution of phosphorus from the sediment;
3. mineralisation of organic phosphorus;
4. solution of phosphorus in reduced interstitial water.

The processes mentioned above are generally relevant as short-term or medium-range sources and sinks, controlled by the temporal dynamic of runoff (low water, flood). Long-term retention of phosphorus is chiefly relevant in the inundation zone of rivers and in reservoirs, being controlled by sedimentation of suspended particles (Walling u. He 1994, Guhr u. Meissner 2000, Venterink et al. 2003, Withers u. Jarvie 2008). P-desorption from sediment into waters is neglectable as long as the interstitial water is oxidised (Schonlau 2007).

The computation of phosphorus retention in the STOFFBILANZ model only considers the average long-term sedimentation of suspended loads in the flooding zone of surface waters. Sorption/desorption in the flooding zone, resuspension and short-term respectively medium-range processes are neglected.

The sedimentation areas $A_i$ per surface water body (OWK) are generated using GIS-technologies (e.g. processing of flooding zone, elevation model, soil mapping). Average annual long-term rates of sedimentation $s_i$ are defined to the LAWA-river typology. For the Lower Elbe river a value of 1 mm yr$^{-1}$ has been exemplarily investigated (z.B. Schwartz et al. 2004, Krüger et al. 2006). Arguments by analogy have been used to determine sedimentation rates for smaller rivers because corresponding investigations are missing. The compactness $SBD$ is assumed to be 1,5 g/cm$^3$ uniformly (15).
Chapter 7: Long lasting nutrient retention in river basins

Table 15: Generating of parameters acc. to the LAWA-river typology e.g. for Saxony

<table>
<thead>
<tr>
<th>LAWA-type</th>
<th>description</th>
<th>$k_{ST}$</th>
<th>$s$ mm a$^{-1}$</th>
<th>SBD g/cm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>silicic mountain brooks</td>
<td>20 to 22</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>6</td>
<td>calcic mountain brooks</td>
<td>22</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>9</td>
<td>silicic mountain rivers</td>
<td>28</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>10</td>
<td>mountain streams</td>
<td>30</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>14</td>
<td>lowland brooks with sandy sediment</td>
<td>40</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>15</td>
<td>lowland rivers with sandy-loamy sediment</td>
<td>40</td>
<td>0,5</td>
<td>1,5</td>
</tr>
<tr>
<td>16</td>
<td>lowland brooks with gravel sediment</td>
<td>35</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>17</td>
<td>lowland rivers with gravel sediment</td>
<td>35</td>
<td>0,5</td>
<td>1,5</td>
</tr>
<tr>
<td>18</td>
<td>lowland brooks with silty sediment</td>
<td>35</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>20</td>
<td>lowland streams</td>
<td>40</td>
<td>1,0</td>
<td>1,5</td>
</tr>
<tr>
<td>11</td>
<td>brooks with organic sediment</td>
<td>30</td>
<td>0,1</td>
<td>1,5</td>
</tr>
<tr>
<td>19</td>
<td>watercourses of flatland</td>
<td>35</td>
<td>0,1</td>
<td>1,5</td>
</tr>
</tbody>
</table>

The average annual sedimentation rate being potentially deposited is determined per surface water body considering sedimentation area and rate as well as the coefficient of compactness. The retention of suspended loads in lakes and reservoirs is assumed to be 75%. The surface water bodies are joined together by a routing from source to mouth. Thus the suspended loads of the tributaries also include the respective loads of the upstream residents. The suspended load is reduced by the calculated sediment retention. The load consists of:

- sediment input caused by soil erosion from rainfall and runoff,
- sediment input via drain discharges: 50% of P-input is assumed to be particle-bound, corresponding sediment rate is derived, P-concentration in sediment: 1000 mg kg$^{-1}$,
- sediment input on settlement areas and undefined land use areas are estimated to 0,2 t ha$^{-1}$ yr$^{-1}$ (low limited).

In relation to the suspended load we have a potential particle-bound P-rate, consisting of the following components:

- particle-bound P-input, caused by sediment input via soil erosion,
- particle-bound P-input via drain discharges, assumed to be 50% of the total input via drain discharges,
- particle-bound P-input from settlement and undefined land use, assumed to be 50% of the total input from these land use types.

The long-term average annual retention of phosphorus in the flooding zone is derived from the sedimentation rate and the corresponding particle-bound P-concentration in sediment per surface water body. Long-term effects of bank erosion is not included in
the modelling as well as we have no limitation of particle-bound P-concentration in the suspended load.

7.1.2 Retention of phosphorus in lakes and reservoirs

Retention in lakes and reservoirs \( r_{\text{res}} \) is done according to Maniak (2005) considering the coefficient of phosphorus net transfer \( s_{\text{P}} \), average depth of the water body \( z \) and the hydraulic residence time \( \tau \):

\[
r_{\text{res}} = \frac{s_{\text{P}}}{s_{\text{P}} + \frac{z}{\tau}}
\]

A net transfer coefficient of 16 is given in Maniak (2005). We have made an adaption of the net transfer coefficient for the use in saxonian reservoirs considering the investigations of Frank (2007).

7.1.3 Calculation within the river net

We determine a specific retention for each surface water body (OWK). The corresponding load per OWK \( L_i \) consists of the catchment related input within the OWK area \( TP_i \) multiplied with the specific coefficient of retention \( r \) and the sum of inputs \( L_j \) from the upstream residents multiplied with \( r \):

\[
L_{i,P} = (TP_{\text{diff, point }, i} + \sum L_j) \times (1-r)
\]

Tributaries and upstream residents are joined by a routing.

7.2 Retention of nitrogen

7.2.1 Retention of nitrogen in rivers

The most important mechanism of nitrogen retention in surface waters is the denitrification in the contact zone of water and sediment, being controlled by hydraulic and micro-biological processes. According to the Nutrient Spiralling – concept (Stream Solute Workshop, 1990) modelling of retention \( r_{\text{riv}} \) of a river section is done in dependence on a time-specific N-uptake rate \( k_i \) (biological aspect) and the water residence time \( \tau \) (hydraulic Aspect) as follows:

\[
r_{\text{riv}} = 1 - \exp(-k_i \cdot \tau)
\]

Water residence time is derived from the river section length and the average flow velocity with

---

The flow velocity is generated in a simplified way according to Mischke et al. (2005), considering the hydraulic gradient I, discharge Q, river width w and Manning-Strickler-coefficient $k_{ST}$:

$$v = k_{ST} \left( \frac{Q}{(k_{ST} \cdot w \cdot \sqrt{I})^{(\frac{3}{2}) \cdot \sqrt{I}}} \right)$$

N-uptake rate depends on the discharge according to literature data (Wollheim et al. 2006). Thus we have a decreasing uptake rate with an increasing discharge, because the relationship between contact zone of water and sediment and the discharge becomes more disadvantageous. The dependency of the uptake rate to nitrate concentration and water temperature is not considered at the moment. The implementation of these parameters should be strived for in order to optimise the retention modelling especially for point-related inputs.

River length is derived using GIS-technologies for each surface water body (OWK). The discharge of a surface water body includes the discharges of the surface water bodies above, thus the whole catchment is considered. The Manning-Strickler-coefficient is taken from literature (LAWA-Fließgewässertypen), as well as the average river width (mapping of river structure).

### 7.2.2 Retention of nitrogen in lakes and reservoirs

Retention modelling in lakes and reservoirs $r_{res}$ is done according to Maniak (2005) considering the coefficient of nitrogen net transfer $s_N$, average depth of the water body $z$ and the hydraulic residence time $\tau$:

$$r_{res} = \frac{s_N}{s_N + \frac{z}{\tau}}$$

### 7.2.3 Calculation within the river net

We determine a specific retention for each surface water body (OWK). The corresponding load per OWK $L_i$ consists of the catchment related input within the OWK area $T_{N_i}$ multiplied with the specific coefficient of retention $r$ and the sum of inputs $L_j$ from the upstream residents multiplied with $r$ (Halbfaß el al. 2010):

$$L_{i,N} = (T_{N_{diff,point,i}} + \sum L_j) \times (1 - r)$$

Tributaries and upstream residents are joined by a routing.
8 Decision support / scenarios

There is much space to use the STOFFBILANZ modelling as a decision support tool for river basin management as well as the defining, calculating and interpretation of special scenarios in comparison is possible. A collection of scenario options, which is extendable in cooperation to the developers, is presented in 16 (see detailed information in Gebel et al. 2015, 2016).

<table>
<thead>
<tr>
<th>target parameter</th>
<th>controlling factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>diffuse input</td>
<td></td>
</tr>
<tr>
<td>soil erosion / sediment input / PP\textsubscript{SE} / PN\textsubscript{SE}</td>
<td>conservation tillage / mulch seed / direct seed inter crop cultivation crop sequence eduction of slope length structure of edges (cropland, waters) land use change</td>
</tr>
<tr>
<td>dissolved N-input DN</td>
<td>inter crop cultivation mineral fertilizers / farm manure crop sequence organic farming</td>
</tr>
<tr>
<td>humus-N</td>
<td>temperature (climate change) live stock management of by-product management of fermenting residues (energy crops)</td>
</tr>
<tr>
<td>diffuse input on sealed areas</td>
<td></td>
</tr>
<tr>
<td>dissolved P-input DP/ dissolved N-input DN</td>
<td>grade of connection to public sewage treatment plant share of housings with direct discharge, small sewage works, cesspit P elimination of small sewage works, sewage treatment plants additional building of sewage treatment plants</td>
</tr>
<tr>
<td>point-related inputs</td>
<td></td>
</tr>
<tr>
<td>sewage treatment plants</td>
<td>design capacity</td>
</tr>
<tr>
<td>demographic change</td>
<td>decreasing number of inhabitants</td>
</tr>
</tbody>
</table>
Chapter 8: Decision support / scenarios

9 References


Chapter 9: References


Veith, T.L. (2002): Agricultural BMP placement for cost-effective pollution control at the watershed level, Virginia Polytechnic Institute and State University.


Chapter 9: References


10 Appendix

Table 17: Input parameters in the STOFFBILANZ model

<table>
<thead>
<tr>
<th>Parameter</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land use type</td>
<td>Main land use type⁵</td>
</tr>
<tr>
<td>Grade of sealing $A_{\text{Seal}}$</td>
<td>Grade of sealing [%]</td>
</tr>
<tr>
<td>Soil texture</td>
<td>Main soil texture⁶</td>
</tr>
<tr>
<td>Soil type</td>
<td>Main soil type⁷</td>
</tr>
<tr>
<td>Skeleton content $c_{\text{sk}}$</td>
<td>Average content of skeleton in topsoil [%]</td>
</tr>
<tr>
<td>$P_t$</td>
<td>P-content in topsoil [mg kg⁻¹]</td>
</tr>
<tr>
<td>Content of humus $C_{\text{humus}}$</td>
<td>Content of humus in topsoil [%]</td>
</tr>
<tr>
<td>C/N-ratio</td>
<td>C/N-ratio in topsoil</td>
</tr>
<tr>
<td>Raw density SBD</td>
<td>Raw density [%]</td>
</tr>
<tr>
<td>slope</td>
<td>Average slope [°]</td>
</tr>
<tr>
<td>exposure</td>
<td>Main exposure</td>
</tr>
<tr>
<td>Precipitation in winter $P_{\text{winter}}$</td>
<td>Precipitation in winter (okt. - march) [mm yr⁻¹]</td>
</tr>
<tr>
<td>Precipitation in summer $P_{\text{summer}}$</td>
<td>Precipitation in summer (april– sept.) [mm yr⁻¹]</td>
</tr>
<tr>
<td>$\text{ET}_{\text{p}}$</td>
<td>FAO-grass-reference precipitation [mm yr⁻¹]</td>
</tr>
<tr>
<td>Average annual temperature $T_{\text{avg}}$</td>
<td>Average annual temperature [°C]</td>
</tr>
<tr>
<td>$N_{\text{atm}}$</td>
<td>Atmospheric deposition (dry and wet)</td>
</tr>
<tr>
<td>elevation</td>
<td>Average elevation [m above NN]</td>
</tr>
<tr>
<td>Distance to waters</td>
<td>Average distance to the next tributary [m]</td>
</tr>
<tr>
<td>Hydraulic connection</td>
<td>Hydraulic connection (GIS-preprocessing)</td>
</tr>
<tr>
<td>Rainy days</td>
<td>Average number of rainy days with a precipitation ≥ 1mm</td>
</tr>
<tr>
<td>Mineral fertilizer $F_{\text{min}}$</td>
<td>Fruit type specific mineral fertilizer [kg N ha⁻¹ yr⁻¹]</td>
</tr>
<tr>
<td>Farm manure $F_{\text{org}}$</td>
<td>Farm manure [kg N ha⁻¹ yr⁻¹])</td>
</tr>
<tr>
<td>yield</td>
<td>Fruit type specific yield [dt/ha]</td>
</tr>
</tbody>
</table>

---

5 Cropland, grassland, fruit-growing, viticulture, deciduous forest, coniferous forest, settlement/urban area, waters, undefined land use
6 According to Ad-hoc-AG Boden (2005)
7 According to Ad-hoc-AG Boden (2005)
### Table 18: Input data of validation

<table>
<thead>
<tr>
<th>data</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point-related nutrient inputs</td>
<td>Data to public and industrial sewage treatment plants</td>
</tr>
<tr>
<td>Measured data in surface waters</td>
<td>N- und P-loads and concentrations</td>
</tr>
<tr>
<td>Measured runoff data</td>
<td>Discharges</td>
</tr>
<tr>
<td>Reservoirs / lakes</td>
<td>Characterising data (e.g. mean depth, hydraulic res-</td>
</tr>
<tr>
<td></td>
<td>idence time)</td>
</tr>
<tr>
<td>Measured data in groundwater</td>
<td>Nitrate concentrations in upper aquifers</td>
</tr>
</tbody>
</table>

### Table 19: Types of fruit and prefixes

<table>
<thead>
<tr>
<th>Parameter</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter wheat (qw)</td>
<td>Winter wheat (14-16% crude protein)</td>
</tr>
<tr>
<td>Winter wheat (ww)</td>
<td>Winter wheat (12% crude protein)</td>
</tr>
<tr>
<td>Winter barley (wb)</td>
<td>Winter barley</td>
</tr>
<tr>
<td>Winter rye (wr)</td>
<td>Winter rye, triticale</td>
</tr>
<tr>
<td>Summer cereal (sc)</td>
<td>Summer wheat, durum wheat, oats, summer rye, summer barley, spelt</td>
</tr>
<tr>
<td>Silo maize (sm)</td>
<td>Silomaize, corn-cob-mix</td>
</tr>
<tr>
<td>Grain maize (gm)</td>
<td>Grain maize</td>
</tr>
<tr>
<td>Rape (r)</td>
<td>Rape</td>
</tr>
<tr>
<td>Further oil seeds (os)</td>
<td>Mustard, linseed</td>
</tr>
<tr>
<td>potatoe (p)</td>
<td>Potatoe</td>
</tr>
<tr>
<td>Root crops (rc)</td>
<td>Sugar beet</td>
</tr>
<tr>
<td>sunflower (sf)</td>
<td>Sunflower</td>
</tr>
<tr>
<td>Grain legumes (gl)</td>
<td>Pea, lupin, bean</td>
</tr>
<tr>
<td>Fodder legumes (fl)</td>
<td>Clover-gras, luceme-gras</td>
</tr>
<tr>
<td>Crop grass (cg)</td>
<td>Cropgrass</td>
</tr>
<tr>
<td>Intensive vegetables (iv)</td>
<td>Intensive vegetables</td>
</tr>
<tr>
<td>Virginia-tobacco (vt)</td>
<td>Virginia-tobacco</td>
</tr>
<tr>
<td>Dark air dried tobacco, burley-tobacco (dt)</td>
<td>Dark air dried tobacco, burley-tobacco</td>
</tr>
<tr>
<td>strawberries (st)</td>
<td>Strawberries</td>
</tr>
<tr>
<td>asparagus (as)</td>
<td>Asparagus</td>
</tr>
<tr>
<td>Intensive grassland (ig)</td>
<td>Intensive meadows, pasture, grassland</td>
</tr>
<tr>
<td>Extensive grassland (eg)</td>
<td>Extensive meadows, meadow orchard</td>
</tr>
<tr>
<td>Fallow</td>
<td>Fallow</td>
</tr>
</tbody>
</table>
Table 20: Soil textures in the STOFFBILANZ model (comp. Ad-hoc-AG Boden, 2005)

<table>
<thead>
<tr>
<th>Soil textures, used in the STOFFBILANZ model (prefixes, description)</th>
<th>Corresponding soil textures according to Ad-hoc AG Boden (2005) (prefixes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ss, sandy sand</td>
<td>Ss, gS, mS, fS, ffS</td>
</tr>
<tr>
<td>Is, loamy sand</td>
<td>Su2, Si2, Sl3, Sl2</td>
</tr>
<tr>
<td>us, silty sand</td>
<td>Su3, Su4</td>
</tr>
<tr>
<td>sl, sandy loam</td>
<td>Slu, St3, Sl4</td>
</tr>
<tr>
<td>su, sandy silt</td>
<td>Us, Uu</td>
</tr>
<tr>
<td>lu, loamy silt</td>
<td>Uls, Ut2, Ut3</td>
</tr>
<tr>
<td>ll, loamy loam</td>
<td>Ls2, Ls3, Ls4, Lt2</td>
</tr>
<tr>
<td>tu, clay silt</td>
<td>Ut4, Lu</td>
</tr>
<tr>
<td>tl, clay loam</td>
<td>Ts3, Ts4, Lts</td>
</tr>
<tr>
<td>ut, silty clay</td>
<td>Tu3, Tu4, Lt3</td>
</tr>
<tr>
<td>lt, loamy clay</td>
<td>Ts2, Ti, Tu2, Tt</td>
</tr>
<tr>
<td>Hn, low moor</td>
<td>-</td>
</tr>
<tr>
<td>Hh, peat bog</td>
<td>-</td>
</tr>
<tr>
<td>F#, subhydric</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 21: Soil types in the STOFFBILANZ model (compare Ad-hoc-AG Boden, 2005)

<table>
<thead>
<tr>
<th>Prefixes of soil types</th>
<th>Corresponding soil types (FAO-Unesco 1974)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F#</td>
<td>Skeleton soil</td>
</tr>
<tr>
<td>O# / I</td>
<td>Lithosol</td>
</tr>
<tr>
<td>RN / N</td>
<td>Leptosol</td>
</tr>
<tr>
<td>RQ / R</td>
<td>Regosol</td>
</tr>
<tr>
<td>T# / C</td>
<td>Chernozem</td>
</tr>
<tr>
<td>P# / P</td>
<td>Podzol</td>
</tr>
<tr>
<td>RR, RZ / E</td>
<td>Rendzina, calcaric regosol</td>
</tr>
<tr>
<td>D# / V</td>
<td>Vertisol</td>
</tr>
<tr>
<td>B# / B</td>
<td>Cambisol</td>
</tr>
<tr>
<td>PP-BB / dystric B</td>
<td>Podzolic cambisol</td>
</tr>
<tr>
<td>L# / L, D</td>
<td>Luvisol, Podzoluvisol</td>
</tr>
<tr>
<td>C# / R</td>
<td>Calcaric regosol</td>
</tr>
<tr>
<td>Y#</td>
<td>Anthrosol, rigosol</td>
</tr>
<tr>
<td>SS-## / stagnic G-B</td>
<td>Subtype with properties of stagnic gleysol (e.g. SS-BB)</td>
</tr>
<tr>
<td>GG-## / gleyic B</td>
<td>Subtype with properties of gleysol (e.g. GG-BB)</td>
</tr>
<tr>
<td>A# / J</td>
<td>Fluvisol</td>
</tr>
<tr>
<td>S# / stagnic G</td>
<td>Stagnic gleysol</td>
</tr>
<tr>
<td>G#</td>
<td>Gleysol</td>
</tr>
<tr>
<td>HN, HH / O</td>
<td>Histosol</td>
</tr>
<tr>
<td>J#</td>
<td>Subhydric soil</td>
</tr>
</tbody>
</table>
Table 22: Derivation of percolation rate SW (according to Ad-hoc AG Boden 2003)

<table>
<thead>
<tr>
<th>Land use type</th>
<th>WV</th>
<th>Regression formula</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cropland</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater influence</td>
<td>&gt; 700 mm</td>
<td>$SW = \frac{P_{\text{year}} - ET0}{[0.61 \times \log(1/ET0) + 2.66]}$</td>
</tr>
<tr>
<td></td>
<td>≤ 700 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [0.61 \times \log(nFKWe + KA + P_{\text{summer}}) - 3.08]$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\times [0.61 \times \log(1/ET0) + 2.66]$</td>
</tr>
<tr>
<td>No groundwater influence</td>
<td>&gt; 700 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [0.76 \times \log (1/ET0) + 3.07]$</td>
</tr>
<tr>
<td></td>
<td>≤ 700 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [1.45 \times \log(nFKWe + P_{\text{summer}}) - 3.08] \times [0.76 \times \log(1/ET0) + 3.07]$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Grassland</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater influence</td>
<td>&gt; 700 mm</td>
<td>$SW = \frac{P_{\text{year}} - ET0}{[0.40 \times \log(1/ET0) + 2.07]}$</td>
</tr>
<tr>
<td></td>
<td>≤ 700 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [1.79 \times \log(nFKWe + KA + P_{\text{summer}}) - 3.89] \times [0.40 \times \log(1/ET0) + 2.07]$</td>
</tr>
<tr>
<td>No groundwater influence</td>
<td>&gt; 700 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [0.66 \times \log (1/ET0) + 2.79]$</td>
</tr>
<tr>
<td></td>
<td>≤ 700 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [1.79 \times \log(nFKWe + P_{\text{summer}}) - 3.89] \times [0.66 \times \log(1/ET0) + 2.79]$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Coniferous forest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater influence</td>
<td>&gt; 750 mm</td>
<td>$SW = \frac{P_{\text{year}} - ET0}{[0.81 \times \log(1/ET0) + 3.20]}$</td>
</tr>
<tr>
<td></td>
<td>≤ 750 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [1.68 \times \log(nFKWe + KA + P_{\text{summer}}) - 3.53] \times [0.81 \times \log(1/ET0) + 3.20]$</td>
</tr>
<tr>
<td>No groundwater influence</td>
<td>&gt; 750 mm</td>
<td>$SW = \frac{P_{\text{year}} - ET0}{[0.92 \times (1/ET0) + 3.52]}$</td>
</tr>
<tr>
<td></td>
<td>≤ 750 mm</td>
<td>$SW = P_{\text{year}} - ET0 \times [1.68 \times \log(nFKWe + P_{\text{summer}}) - 3.53] \times [0.92 \times \log(1/ET0) + 3.52]$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Deciduous forest</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Groundwater influence</td>
<td>&gt; 750 mm</td>
<td>$SW = \frac{P_{\text{year}} - 0.90 \times ET0}{[0.81 \times \log(1/ET0) + 3.20]}$</td>
</tr>
<tr>
<td></td>
<td>≤ 750 mm</td>
<td>$SW = P_{\text{year}} - 0.90 \times ET0 \times [1.68 \times \log(nFKWe + KA + P_{\text{summer}}) - 3.53] \times [0.81 \times \log(1/ET0) + 3.20]$</td>
</tr>
<tr>
<td>No groundwater influence</td>
<td>&gt; 750 mm</td>
<td>$SW = \frac{P_{\text{year}} - 0.90 \times ET0}{[0.92 \times (1/ET0) + 3.52]}$</td>
</tr>
<tr>
<td></td>
<td>≤ 750 mm</td>
<td>$SW = P_{\text{year}} - 0.90 \times ET0 \times [1.68 \times \log(nFKWe + P_{\text{summer}}) - 3.53] \times [0.92 \times \log(1/ET0) + 3.52]$</td>
</tr>
</tbody>
</table>