Final report

Further development of the MONERIS Model with particular focus on the application in the Tisza river basin, for the implementation of JOINTISZA project (project code: DTP1-152-2.1)

Client:

Permanent Secretariat of the International Commission for the Protection of the Danube River (ICPDR)

Contractor

Leibniz-Institute for Freshwater Ecology and Inland Fisheries (IGB)

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1. Rationale

The aim of this work is to quantify nutrient emission patterns in the Tisza river basin (TRB) as part of the JOINTISZA project and the updated Tisza River Management Plan. We build on the MONERIS (Modelling nutrient emissions in river catchments, Venohr et al. 2011) application for the 2nd DRBMP (ICPDR 2015). The focus is on revising the input data for land use, soil erosion, and nitrogen surplus and integrating them into the latest MONERIS version in order to harmonize the results with the current European-wide model application within the MARS project (www.mars-project.eu) and to improve the estimation of nutrient fluxes for the time period 2009-2012. The new database also serves to update three scenario calculations for future nutrient emissions.

To foster the acceptance of the model outcome, it was agreed that the Tisza countries provide national data until 31st of October 2018. Since then, two short interim reports were delivered in order to keep the contract partners updated about the ongoing work and receive feedback regarding the setup of the model. On 8th of February and after the meeting in Vienna on 12th of March 2018 additional hydrological data was delivered by Hungary and Romania and included in the hydrological calibration.

2. Model setup of MONERIS and manual

Venohr et al. (2011) provide a comprehensive overview of the MONERIS including model structure, algorithms and implementation of measures (see attachment). Over the recent years MONERIS has been modified including a new P retention approach (see description in Gericke and Venohr 2015a) and a new approach of modelling of dissolved P concentrations in surface runoff (see 3.5). Furthermore, the uptake of N in the root zone has been adapted (Heidecke et al. 2014). The latest user manual of the model is attached to this report (see chapter 8.).

3. Input data

In the following, a documentation of the database updates in comparison to the Danube 2014 model setup (Gericke and Venohr 2015a) is given. Note, the appendix provides further information which were delivered as short reports to the ICPDR on 1st of December 2017 and 1st of February 2018.

3.1. Hydrology

Romania and Slovak Republic provided new hydrological and water quality data. Hungary provided new hydrological data. The new data were checked for plausibility and included in the model calibration and validation. Four Hungarian gauges were replaced by near-by Slovakian and Romanian stations in agreement with the ICPDR (more detailed explanation see appendix 6.3). A map of the former and new hydrological stations included in the hydrological calibration is given in Fig. 1.

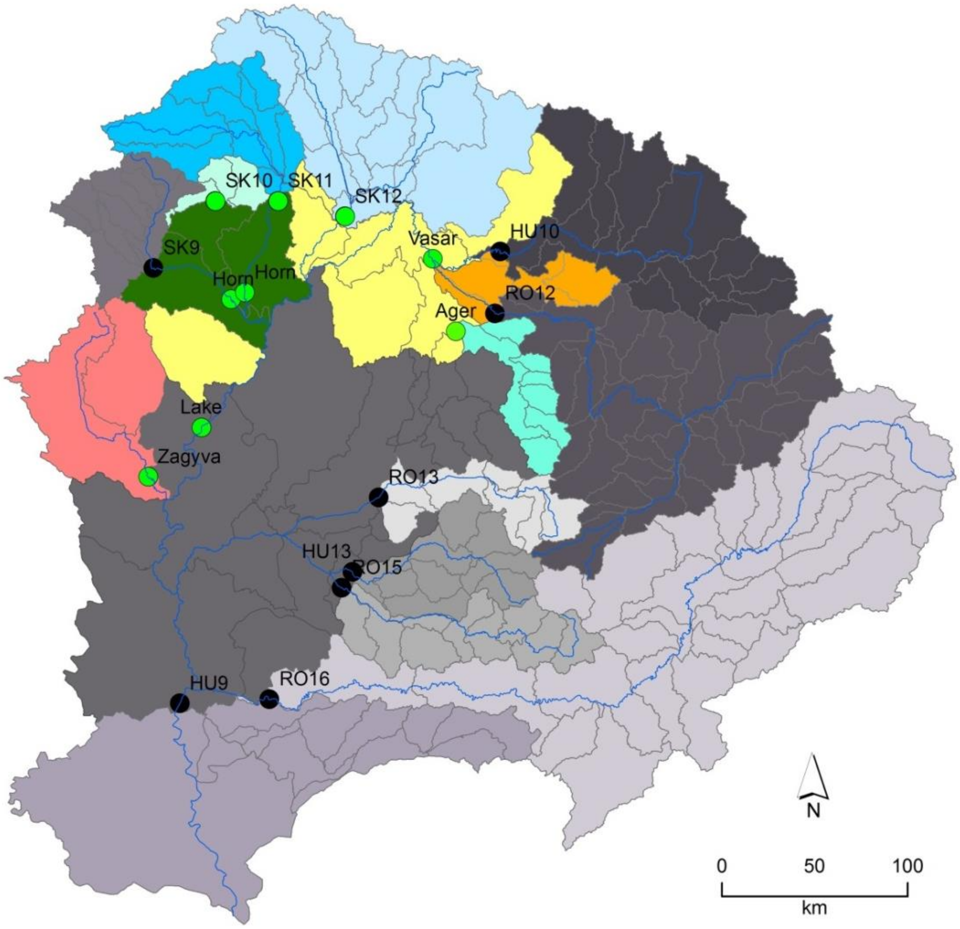


Figure 1: Hydrological stations used for hydrological setup. Color schemes indicate the groups of analytical units (AUs) which are connected to the same gauge, bright colors represent new hydrological sub-catchments derived for new implemented stations (green): gauges SK9, RO12, RO13, RO15 are substituting former Hungarian gauges (more detailed information: see attachment); blue lines represent major rivers of the catchment.

Due to the new stations, the water rich upper part of the basin could be much better described and considered. In turn, a partly negative water balance (Fig. 2) became apparent calculated as difference between the discharges observed at HU9 and the sum of discharges of upstream gauges. Partly negative water balances were also observed between discharges at hydrological station Lake and its upstream gauges. These observations were not explainable by precipitation and evapotranspiration (see Fig.2, appendix 6.3).

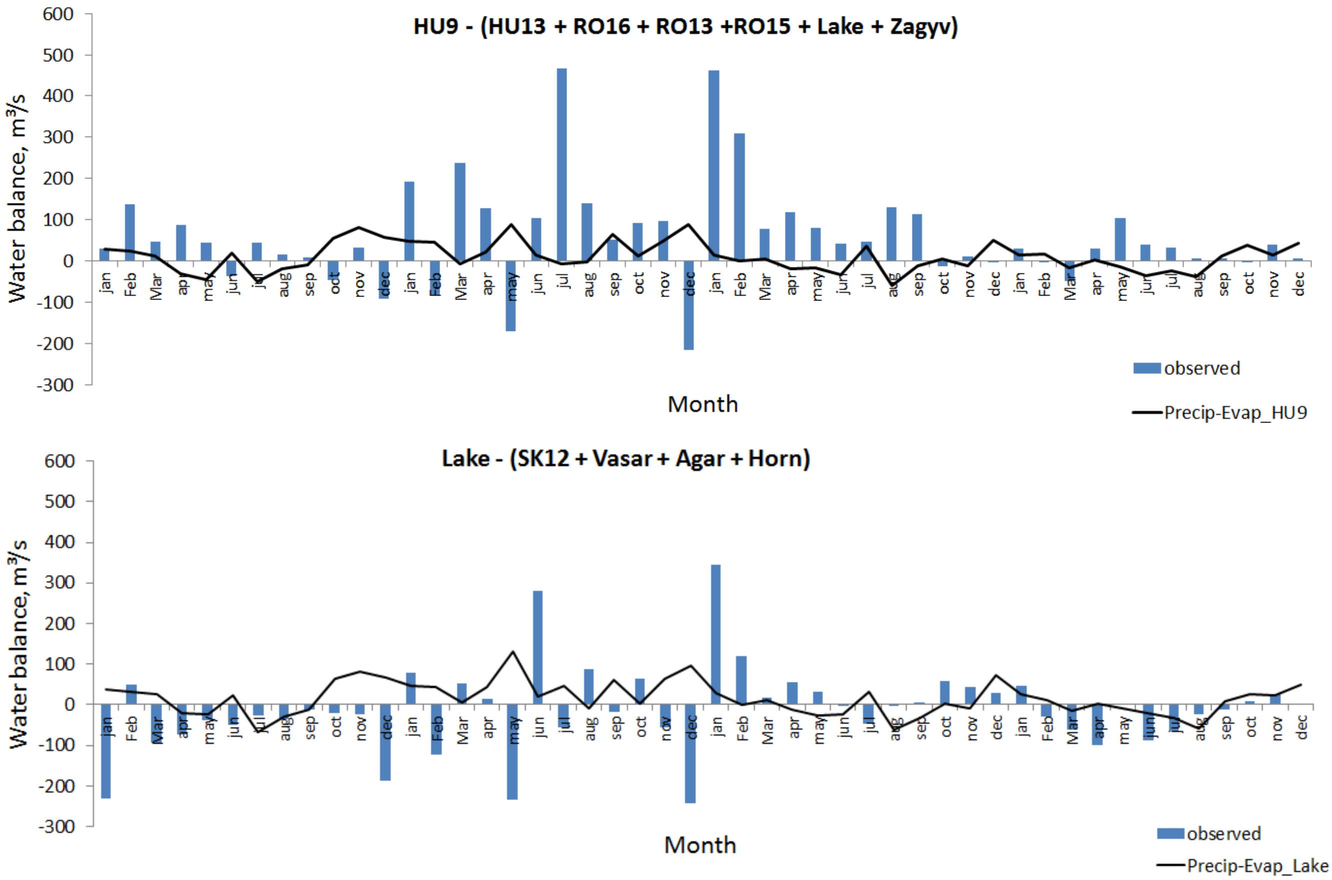


Figure 2: Monthly water balances as difference between a) hydrological station HU 9 and its upstream hydrological stations and b) hydrological station Lake and its upstream hydrological stations

The strong negative balance between monitoring stations are assumed to originate from increase of evaporation in lakes and reservoirs, water abstractions or inundation of riparian wetlands and result in a complex hydrological situation which is difficult to be modelled without detailed information on the water management in the Tisza basin. We modified our run-off calibration approach in order to reflect these hydrological conditions (Fig.3). It consists of following principal elements:

1) Monitoring stations were allocated to AUs for which they best represent run-off at the outlet. Un-monitored AUs were allocated to the next downstream located monitoring station or to a station of neighboring sub-catchment showing similar conditions in precipitation, evaporation and topography.
2) The observed run-off of neighboring monitoring stations was compared. In particular the sum of run-off from HU10 and RO12 was in individual winter month considerably higher than such observed at the next downstream station Vasar, indicating a water release from the various upstream located reservoirs. To generate realistic run-off values we calculated the mean annual ratio Vasar/(HU10+RO12) and applied this for monthly ratios larger than 1.1. The residual run-off was considered as water addition from the reservoirs.

3) Water balances were calculated as precipitation minus evaporation. For each AU allocated to a monitoring station an additive parameter was calibrated to derive a complete agreement with the observed monthly runoff. This additive parameter represents e.g. snow storage, groundwater recharge, but could also indicate an erroneous evaporation rate.
4) If negative water balances were derived a minimum run-off was calculated as
   $Q_{min} = \frac{WB_{AU}}{WB_{mean}} q_{mean} area_{AU} \cdot 0.001$
   With:
   Qmin = minimum monthly run-off per AU in m³/s
   WBAU = monthly water balance (Precipitation – Evaporation) in AU in mm/month
   WBmean = monthly water balance (Precipitation – Evaporation) in Tisza basin in mm/month
   qmean = mean monthly specific fun-off derived from first calibration run in l/s/km²
   areaAU = area of AU in km²
5) Remaining negative balances were replaced by a run-off of 0.01 m³/s. Due to this artificial increase in run-off an overestimate of observed run-off occurred. This was counterbalanced by a water abstraction term. This term, however, can still represent different causes for reduced run-off, such as, flooding of polders, or the loosing phenomenon.

This approach lead to a complete agreement between modelled and observed run-off (mean absolute deviation 0 %, $r^2 = 1$), non-negative run-off generation per AU (pre-requisite for MONERIS) and a realistic spatial pattern of a climate driven run-off generation (see appendix 6.1).

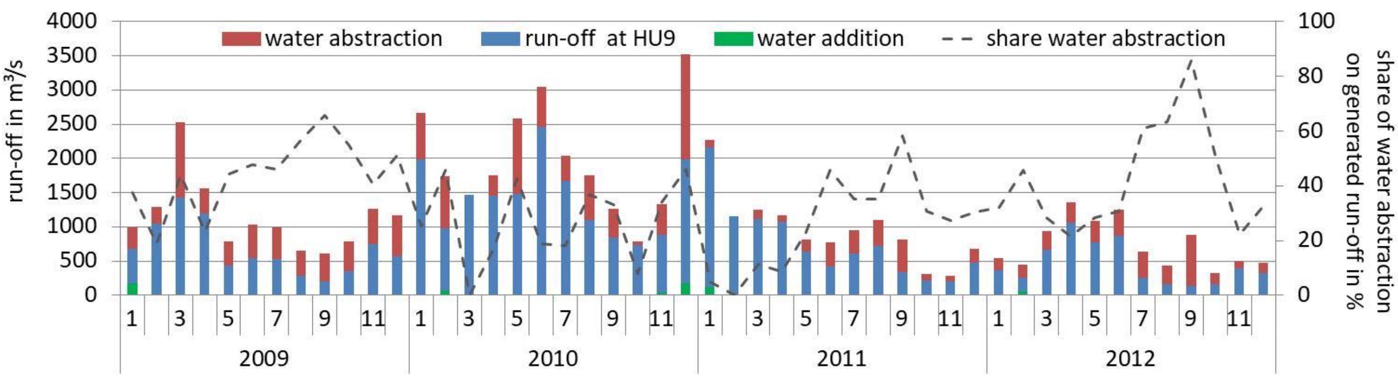


Figure 3: Principal elements considered for Hydrological calibration in Tisza catchment

3.2. Land use

For EU countries, the latest version of Corine Land Cover (CLC 2012) was used to update the land use data. The differences are negligible (Fig. 4) as the DRBMP is based on a preliminary version of CLC 2012. However, we integrated the ECRINS dataset (EEA 2012) which increased the water surface area in the model setup. More significant differences occur in the Ukraine where the former rather old dataset was replaced by the latest data available from GlobCorine (2009) resulting in a decrease of grassland and naturally covered area and an increase of arable land compared to the setup of Gericke and Venohr 2015a. More details are provided in appendix 6.3.

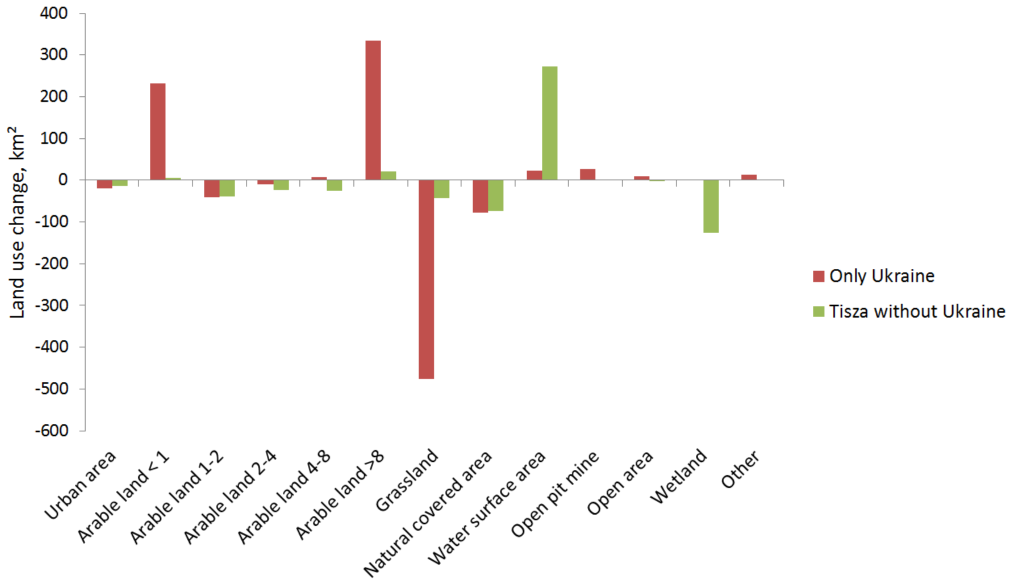


Figure 4: Changes in land use input data in comparison to MONERIS setup for Danube 2014.

3.3. Nitrogen surplus

N surplus is a key input dataset for modelling of nutrient emissions in the Tisza basin. MONERIS needs two datasets: values at AU level for a reference year to describe the spatial variability (ideally derived from regional data) and a national time-series to describe the inter-annual variability.

In the meeting on 10th of March, it was agreed on using the same N surplus data for reference year 2012 as used in the Danube 2014 MONERIS setup (Gericke and Venohr 2015a). However, since then the time series of national N surplus was revised by EUROSTAT (EC-EUROSTAT 2018). The new values differed for HU, SK, and RO in comparison to the data available in 2015 – indicating methodological updates (Fig. 5). Especially for RO, the new values are considerably higher than before. For SK, we observed that the new national value for 2012 (41 kg/ha) matches much better the estimated area-weighted mean of the regional data (46 kg/ha) than before (31 kg/ha).

Similar to the Danube, we used the same time-series for UA and RO. As no time-series was available for Serbia, we used the (slightly changed) time-series from Slovenia in combination with regional data provided by Serbia for 2012.

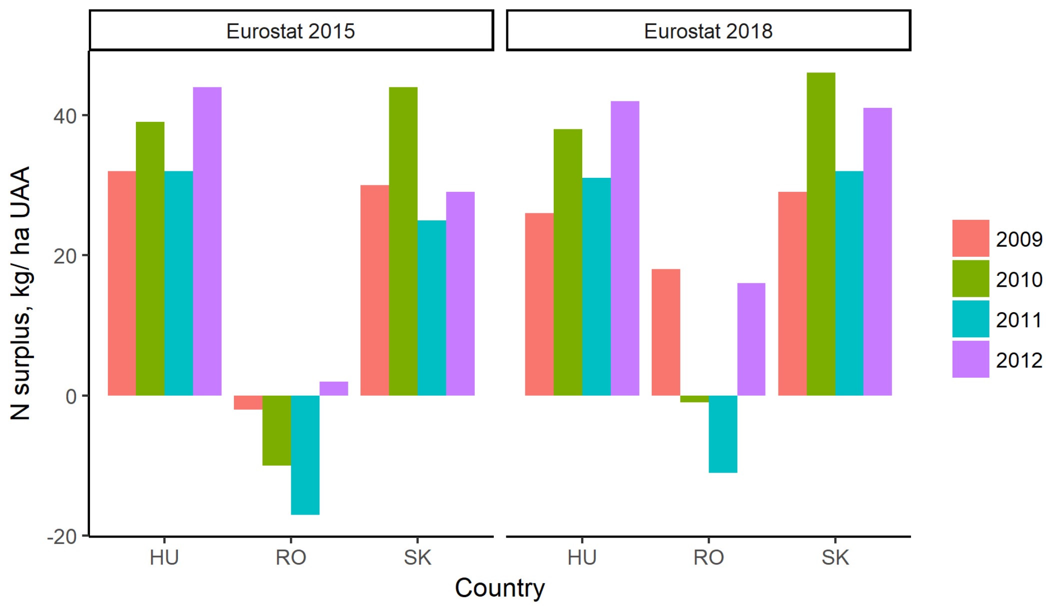


Figure 5: N surplus data on national level for the years 2009 to 2012 according to EUROSTAT 2015 and EUROSTAT 2018. UAA = utilized agricultural land.

3.4. Soil loss and C factor

The update of the soil loss values in the database considers the new land use input data as well as a new soil loss map (Fig. 6) derived in the MARS project (Venohr et al. 2018a) based on Gericke (2015). Firstly, the R factor (rainfall erosivity) of the USLE was derived from long-term average annual precipitation from 1975-1999 (Vogt et al. 2007) instead of 1961-1990. More important, the R factors were also estimated from published regression models from various countries instead of a single relationship established in Germany. These new regression models result in 50% higher R factors. Secondly, the new K factor (soil erodibility) was derived from the Harmonized World Soil Database (HWSD) considering not only the silt content to estimate K factors (as originally derived by Strauss et al. 2005) but also clay, sand, and stoniness.

Given the multiplicative character of the USLE, the new estimations of R and K factors resulted in an average increase of 100% for the whole Tisza compared to earlier application. Note, this increase is not related to any changes in management. In fact, the USLE C factors were left unchanged. It should rather be seen as a revision of the input data similar to the revision of the nitrogen surplus. Although the revised soil loss map might better reflect the variability of rainfall erosivity and soil erodibility than the original soil loss map, the resolution of European data and the USLE are inherent limitations. The effect of soil protection is separately considered in MONERIS (see chapter 5 – scenarios for the effect of measures on nutrient losses).

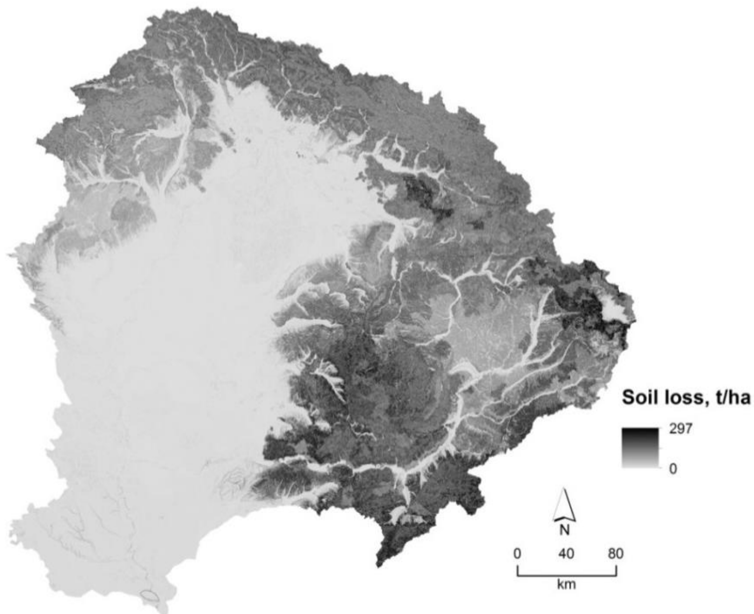


Figure 6: Potential soil loss per year (without C-factor) in Tisza catchment (Venohr et al. 2018a).

3.5. Deriving P losses by surface runoff through degree of phosphorus saturation

Together with nitrogen agricultural soils are usually fertilized with phosphorus. In contrast to nitrogen, phosphorus (P) easily sorbs to soil particles and thus accumulates in the soils. At the same total P content stored in soils the share of easily available P to plants and surface runoff can vary considerably depending on the soil type. Sandy soils have much lower sorption capacities than loamy soils, calcareous and decomposed peat soils and thus are more vulnerable to P losses (Pöthig et al. 2010). The amount of P which is easily available to surface runoff depends on the share of sorption sites occupied by phosphorus on all available P sorption sites in the soils. This percentage is commonly expressed as degree of phosphorus saturation (DPS, Nair 2014). Unfortunately, DPS is not a standard method in soil analyses but can be directly derived from a standard soil test method of water soluble phosphorus (WSP, Pöthig et al. 2010, Fischer et al. 2018). As WSP is also a good predictor of P losses by e.g. surface runoff a method was established to derive WSP and DPS values from P content in soils.

WSP was calculated as weighted mean per 500 m grid cell according to results by (Pöthig, Behrendt, Opitz, & Furrer, 2010) and Pöthig (unpublished data). For loamy and silty soils the correlation found for loamy soils was applied (as no equation for silty soils was available, Fig. 7 and Equation 1). WSP values calculated by Equation 1 were limited to a maximum of 60 mg/kg, as the range of observed WSP did not exceed this value in the former studies.

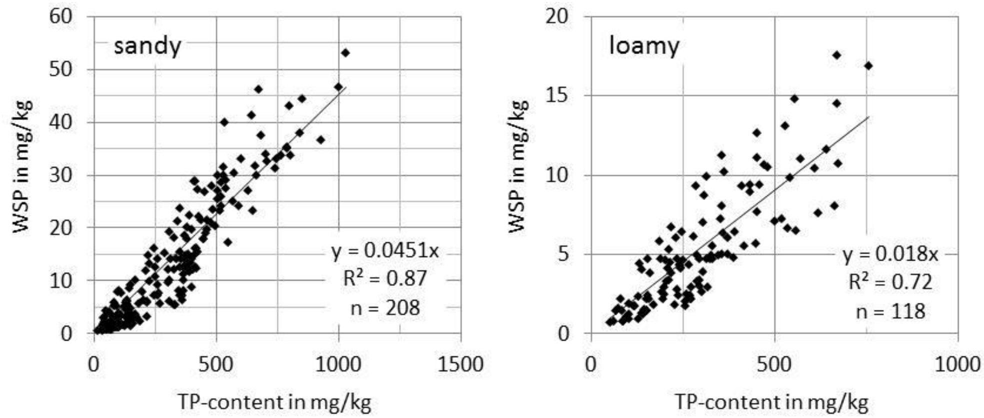


Figure 7: Correlation between P-content in soils and measured WSP in soil samples of Germany and Switzerland (Pöthig unpublished data).

Equation 1: $$\mathbf{WSP} = \frac{((\mathbf{P{-}content} \times \mathbf{0.0451} \times \mathbf{Sand}) + ([\mathbf{P{-}content}] \times \mathbf{0.018} \times [\mathbf{Clay}]) + ([\mathbf{P{-}content}] \times \mathbf{0.018} \times [\mathbf{Silt}]))}{([\mathbf{Silt}] + [\mathbf{Sand}] + [\mathbf{Clay}])}$$

With: WSP = water soluble phosphorus, mg/kg
Sand = share of sand fraction in soils, in %
Clay = share of clay fraction in soils, in %
Silt = share of silt fraction in soils, in %
P-content = Phosphorus content in upper 30 cm soil layer, in mg/kg

As a prerequisite, we derived the spatially distributed P content in agricultural soils using the country wide P-accumulations, to calibrate the total P content and using the N-surplus described above to derive the spatial distribution of applied fertilizers. This approach was developed, tested and calibrated for agricultural soils in Germany and subsequently applied to European data.

In a first step country wide P balance data on agricultural areas were collected from EUROSTAT (EC-EUROSTAT), and area corrected as described before (Fig. 8). The longest time series ranged from 1985 to 2014, whereas the shortest time series only covered data after 2004. To estimate the P-accumulation, we considered also fertilisation from earlier years. From a reconstruction of historic nutrient balances in central Europe (Gadegast & Venohr, in prep.) we know that intensive fertilisation already took place in the 1960ies and often found its maximum in the 1980ies. From this we derived following rules of thumb:

1) P-balances in 1960 equal the earliest reported available value per country (between 1985 and 2004)
2) In 1950 P-balances accounted for 10 % of the values in 1975 (for this year P balances in all countries were positive, but not at their maximum)
3) In 1980 P-balances were 20 % higher than in 1960. These values were corrected for Estonia and Hungary, to ensure, that P-accumulation remained positive for all years.

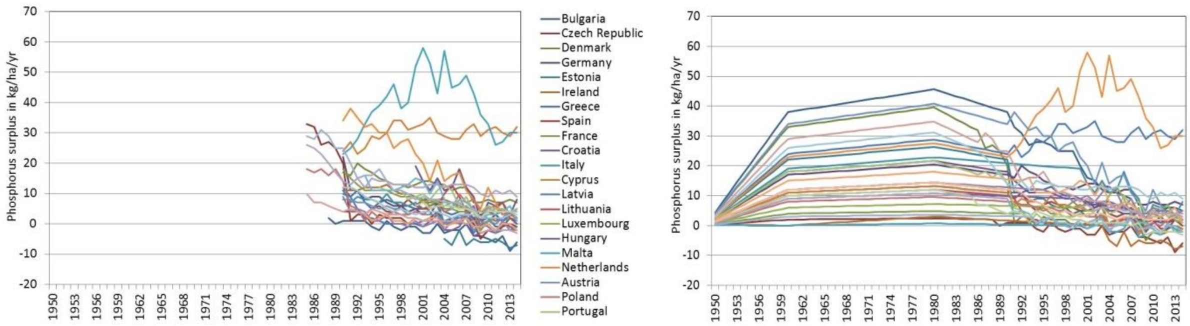


Figure 8: Available P-balance on country (left) and the accomplished time series (right).

The P-accumulation was calculated as the accumulative sum of P-balances over the years (Fig.9).

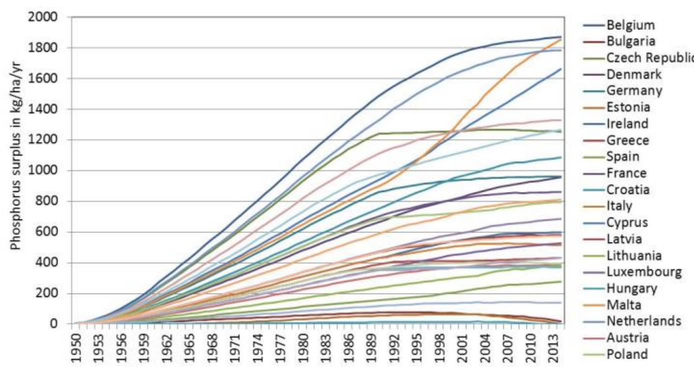


Figure 9: P-accumulation on agricultural land per country in the period from 1950 and 2014.

P-accumulation was distributed following the approach described in Venohr et al. (2018b) for nitrogen surplus, without taking atmospheric deposition into account, as no spatially distributed P deposition information was available.

P-content was derived from bulk density information by the LUCAS physical top soil information map (Ballabio, Panagos, & Monatanarella, 2016). The LUCAS topsoil dataset was made available by the European Commission through the European Soil Data Centre (ESDAC) managed by the Joint Research Centre (EC-JRC, http://esdac.jrc.ec.europa.eu/).

First the soil weight of the top 30 cm soil layer (ploughing horizon) was calculated (Equation 2).

Equation 2: $$\mathbf{Soil\ weight} = \mathbf{BulkDensity} \times \mathbf{LayerDepth} \times \mathbf{UCF}$$

With: soil weight = soil weight of the top 30 cm soil layer, kg/ha
Bulk density = Bulk density, in g/cm³
LayerDepth = 30 cm
UCF = unit correction factor (g/cm² → kg/ha) = 100000

By dividing the corrected and spatially distributed P-accumulation by the derived soil weight the mean P-content in top soils was estimated (Equation 3).

Equation 3: $$\mathbf{P\_content} = \frac{[\mathbf{p_{acc}}]}{[\mathbf{Soil\ weight}]\times \mathbf{1000000}}$$

With: P-content = Phosphorus content in upper 30 cm soil layer, in mg/kg
P-acc = P-accumulation, in kg/ha
soil weight = soil weight of the top 30 cm soil layer, kg/ha

DPS was estimated considering the soil type information by LUCAS and considering the transformation function from Pöthig, Behrendt, Opitz, & Furrer (2010, Fig. 10).

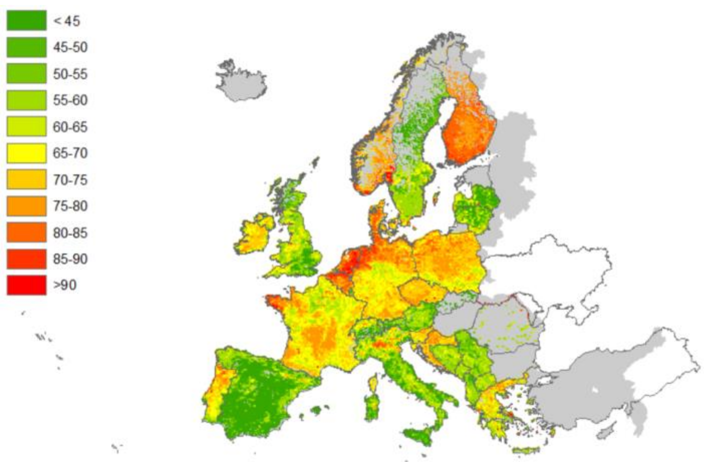


Figure 10: Degree of phosphorus saturation (DPS) in % derived for Europe.

P-concentrations in surface run-off was finally calculated according to Vadas et al. (2005), which was corrected on basis of findings by Fischer et al. (2017), to eliminate effects originating from different soil to water ratios used by Vadas et al. (2005) and Pöthig et al. (2010, Equation 4).

Equation 4: $$\boldsymbol{PconcSR} = \left(\frac{\mathbf{11.2} * \mathbf{WSP\_arable} + \mathbf{66.9}}{\mathbf{1000}}\right) \times \mathbf{WSP\_corr}$$

With: PconSR = P-concentration in surface run-off, in mg/l
WSP = water soluble phosphorus, mg/kg
WSP_corr = WSP correction factor, without uni

4. Results

4.1. Overall emissions in Tisza catchment

The updated database and the new modelling approaches resulted in average total emissions of 95 kt/yr TN and 4.7 kt/yr TP for the Tisza catchment (Fig. 11). This corresponds to an increase of 45% of TN emissions and 10% of TP emissions compared to Gericke and Venohr 2015a.

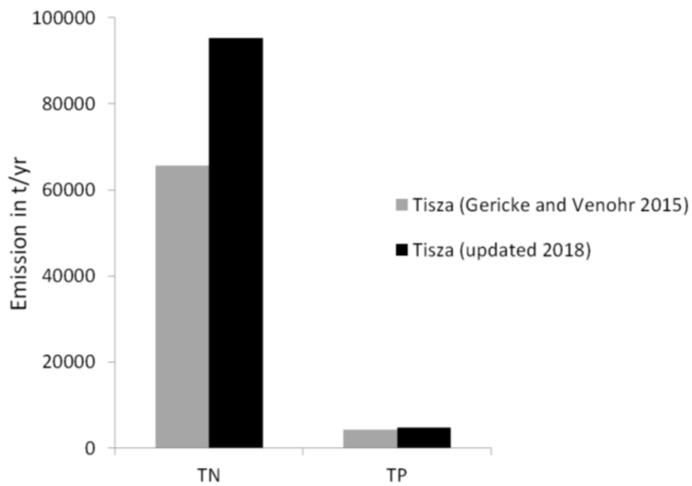


Figure 11: Average yearly nutrient emissions (2009-2012) in the Tisza basin in comparison to the last MONERIS application (Gericke and Venohr 2015a).

The increase in N emission is the consequence of the revised N surplus values which affect the emissions via groundwater, interflow and tile drainage (Fig. 5, Fig. 12). The updated potential soil loss (Fig. 6) contributes to an overall increase in P emissions to surface waters via soil erosion (soil erosion is of minor importance for TN emissions) in the northern part of the catchment. The percentage of P emissions by surface runoff increased due to changes in the model setup (see 3.5., Fig. 12, Gericke and Venohr 2015a).

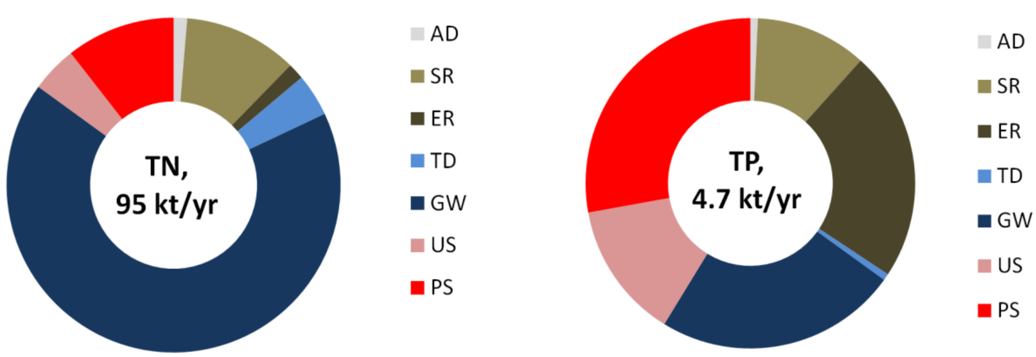


Figure 12: Mean share of the pathways on the total nutrient emissions in the Tisza catchment during 2009-2012: AD=atmospheric deposition, SR=surface runoff, ER=erosion, TD=tile drainage, GW=groundwater, US=urban systems, PS=point sources

Table 1: Share of both nitrogen and phosphorus emissions from different land-use types and via considered pathways in Tisza river basin for the reference status (long-term 2012).

Area specific emission for nitrogen in kg/ha and for phosphorus in kg/km², numbers in brackets represent the share on the total nitrogen or phosphorus emissions. WSA = water surface area; specific emissions on surface waters can be higher than considered in the input data, as we used, for reasons of data consistency, the original water surface area derived from the land-use maps. This does not include areas of smaller rivers, which were supplemented by MONERIS.

Land-use	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
area	1565.1	75598.8	14374.01	56774.2	7133.0	776.0	156221.1
area share	1.0	48.4	9.2	36.3	4.6	0.5	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	8.2 (1.3)						0.1 (1.3)
surface run-off		0.8 (6.2)	0.6 (0.9)	0.7 (4.3)		0.6 (0)	0.7 (11.4)
erosion		0.1 (1.1)	0 (0)	0.1 (0.4)		0 (0)	0.1 (1.6)
tile drainages		0.6 (4.6)	0.1 (0.1)				0.3 (4.7)
groundwater		4.2 (33.3)	4.2 (6.3)	3.2 (19)	9.3 (6.9)	7.3 (0.6)	4.1 (66.1)
urban systems					5.9 (4.3)		0.3 (4.3)
sewer systems					4.4 (3.2)		
DCTP					1.5 (1.1)		
point sources					14.1 (10.5)		0.6 (10.5)
Total	**8.2 (1.3)**	**5.8 (45.2)**	**4.9 (7.4)**	**4 (23.8)**	**29.3 (21.7)**	**7.9 (0.6)**	**6.2 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.7)						0.2 (0.7)
surface run-off		3.7 (5.9)	3.3 (1)	3.2 (3.8)		1.8 (0)	3.2 (10.8)
erosion		10.3 (16.6)	2.3 (0.7)	4.5 (5.5)		0 (0)	6.8 (22.7)
tile drainages		0.4 (0.6)	0.3 (0.1)				0.2 (0.7)
groundwater		6.5 (10.4)	6.5 (2)	5 (6)	35.6 (5.4)	5 (0.1)	7.2 (23.9)
urban systems					87.1 (13.2)		4 (13.2)
sewer systems					53.7 (8.2)		
DCTP					33.5 (5.1)		
point sources					184.4 (28)		8.4 (28)
Total	**21.9 (0.7)**	**20.8 (33.4)**	**12.5 (3.8)**	**12.6 (15.3)**	**307.1 (46.7)**	**6.8 (0.1)**	**30.1 (100)**

Table 1 provides an overview of the shares of different land-use types and pathways on overall nutrient emissions in the Tisza basin for the average reference status (henceforth “long-term 2012”). TN emissions by interflow and groundwater from arable land, grassland and forests contribute to more than 58% of total TN emissions in Tisza basin. For TP emissions, urban areas contain major pathways contributing to almost half of the total emissions.

4.2. Yearly differences in nutrient emissions

While point sources and urban systems remain almost constant, emissions via groundwater, surface runoff, and erosion are influenced by precipitation and hydrology and vary from year to year (Fig. 13). Despite the changes in the hydrological input data, the inter-annual variability is similar to the last Danube application.

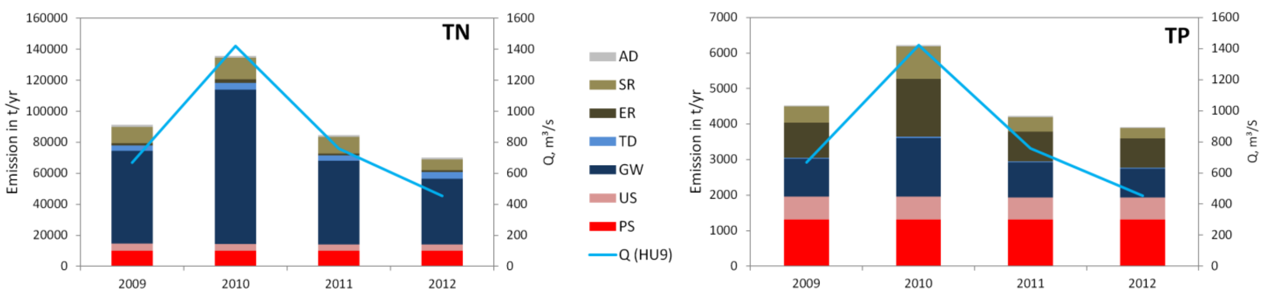


Figure 13: Annual variability of TN and TP emissions for different pathways, Q (HU9) is the mean discharge at HU9.

4.3. Spatial distribution of nutrient emissions in the catchment

4.3.1 Emissions in countries

More than half of both total TN and total TP emissions are emitted from the Hungarian and Romanian part of the catchment. The share on the total emissions by both countries together is 66% and 64% for TP and TN, respectively (Fig. 14).

Figure 14: Share of nutrient emissions from the Tisza countries on overall TP and TN emissions (2009-2012).

Nonetheless, the area-specific emissions in both countries are on average comparatively low (Fig. 15).

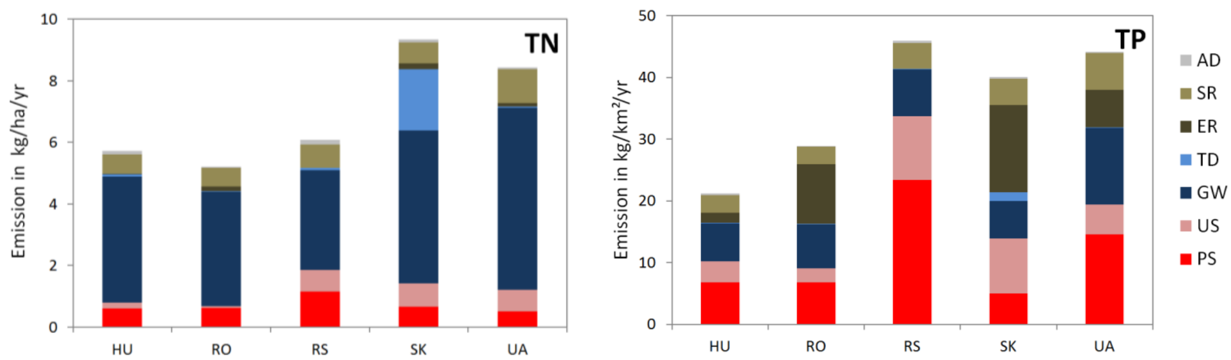


Figure 15: Area specific emissions per emission pathway in the different countries (2009-12)

These area-specific emissions are substantially higher in the northern part of the basin, where the specific runoff is also highest (appendix 6.1: Fig. 23). In these countries also the area specific emissions of pathway erosion are relatively high. Point sources and urban areas are the dominating pathways in Serbia. An overview of the shares of different land-use types and pathways on overall nutrient emissions in the different countries is provided in the appendix (chapter 6.2).

4.3.2. Emissions per analytical unit and land use specific nutrient emissions

TN emissions increased in comparison to the Danube application (Fig. 11, 16). Changes in Romania are mainly caused by the revision of the former low N surplus of 2 kg/ha in 2012 to the recent 16 kg/ha. With the new Slovak and Hungarian hydrological data, the calibrated runoff in the mountainous Sajo/Hornad subbasin increased significantly and, accordingly, the TN emissions. Although, the TP emissions increased only by 10% compared to the Danube application, the spatial pattern changed as a result of new implemented data of soil loss and hydrology (Fig. 16). For instance, the revised runoff in the upper Sajo/Hornad subbasin resulted in similarly higher TP emissions.

Landuse-specific emissions vary substantially between different countries (appendix 6.2). For instance, urban areas having a similar share on area in Hungary and Serbia differ by a factor of 3 in their land-use specific TP emissions and also differ significantly in their overall contribution to total TP emissions (appendix 6.2: tables 5,7). TN emissions from arable land are relatively low when compared to intensively used agricultural areas in central Europe (Fig. 17, appendix 6.2 and section 4.4).

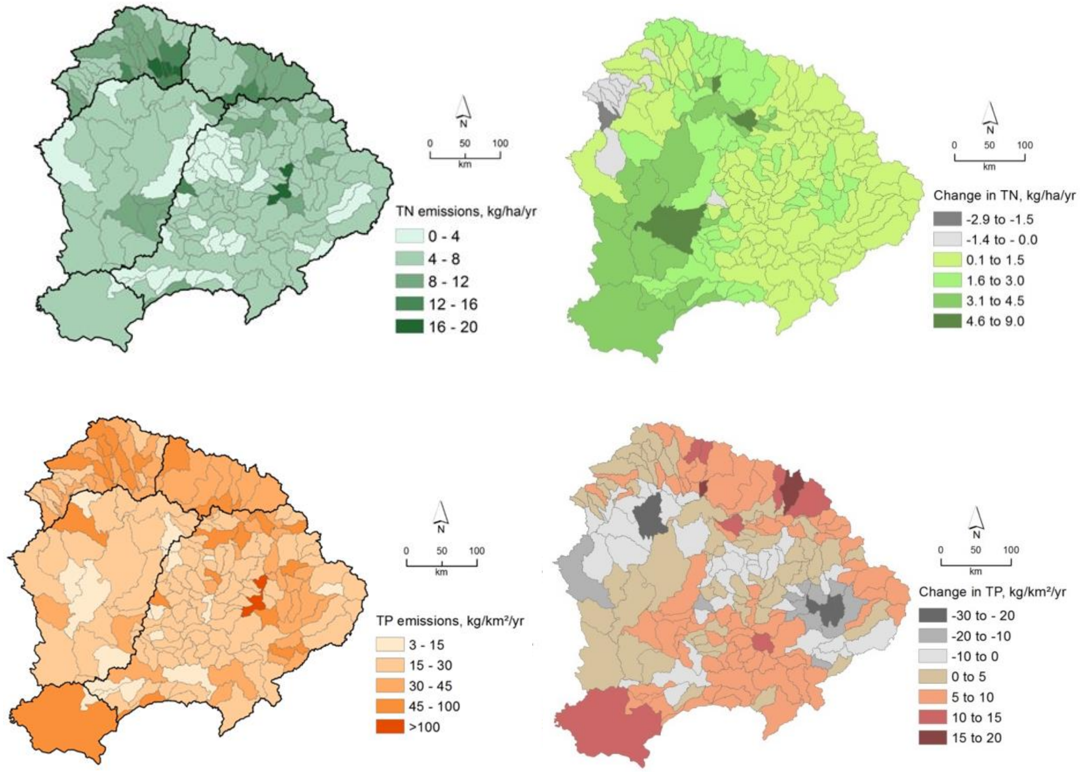


Figure 16: TP and TN emissions per analytical unit in the TRB (left side) and changes in nutrient emissions in comparison to the Danube 2014 setup (right side, Gericke and Venohr 2015a), arithmetic means of 2009-12 are shown.

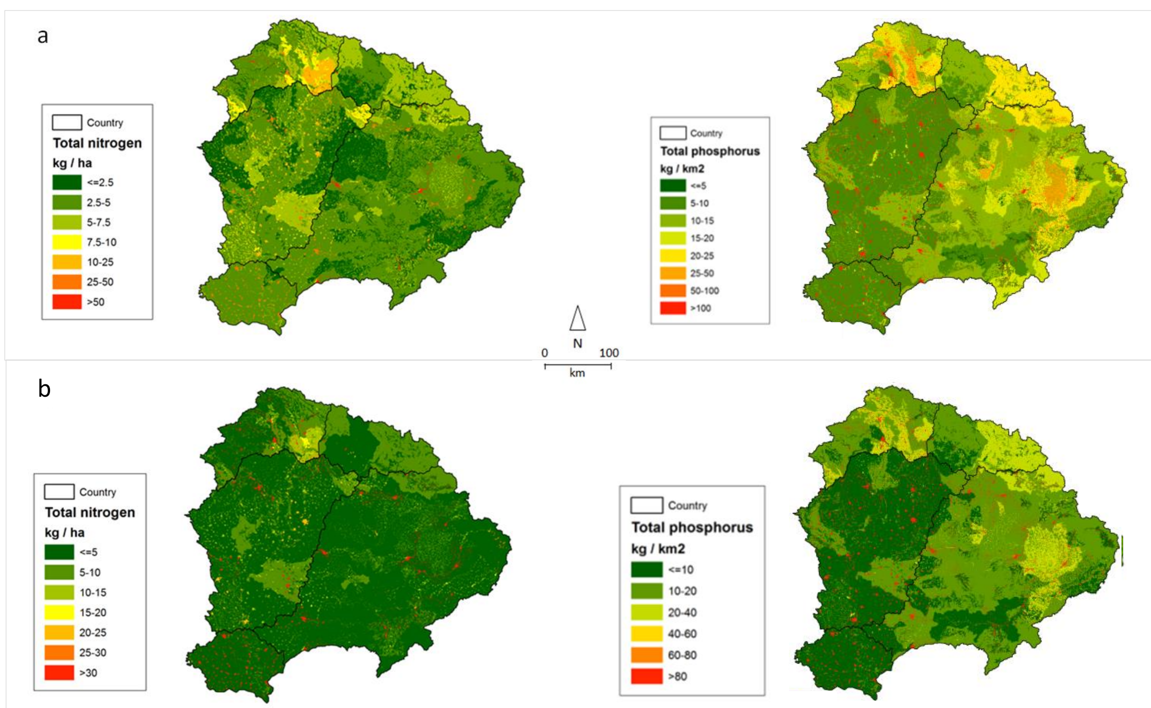


Figure 17: a) TN and TP emissions per land use (average 2009-2012) b) same as above but with classification similar to European maps in Venohr et al. 2018a (maps available online: http://www.mars-project.eu/files/download/deliverables/MARS_D7.2_MARS_suite_of_tools_2.pdf, p.44: a,b).

4.4. Comparison to nutrient emissions on an European scale

Nutrient emissions in the Tisza catchment were compared with emissions calculated for Europe in the context of the EU-Project MARS. European wide modelling was conducted for the period 2001-2010 using the same version of MONERIS as used for the Tisza basin. The comparison shows that for both, TN and TP, the Tisza has a higher share of specific emissions between 5-10 kg/ha/yr and 20-40 kg/km²/yr (Fig. 18).

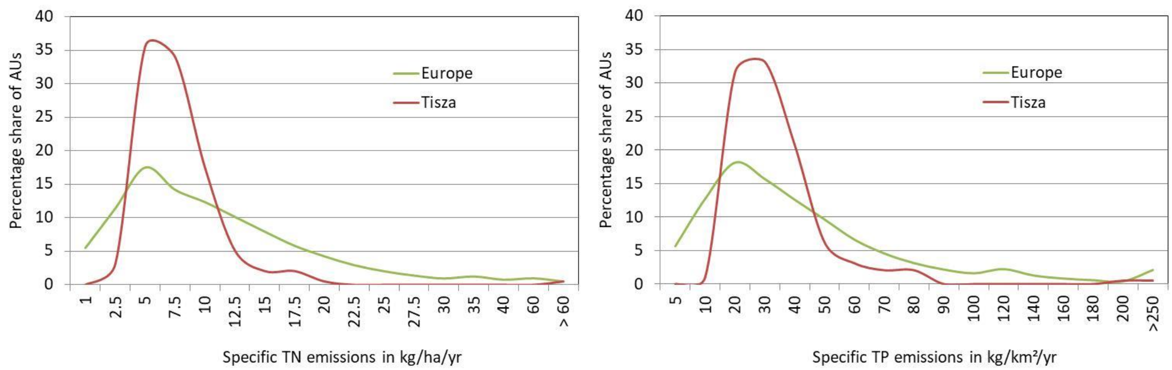
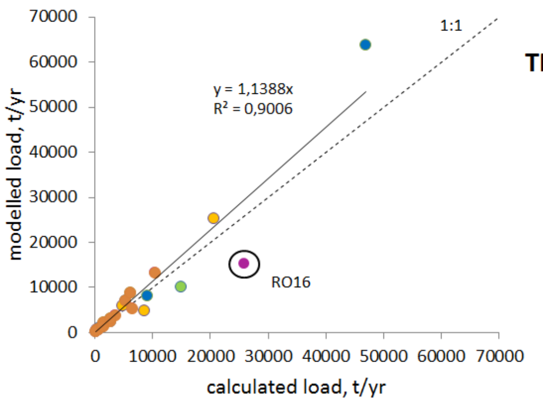


Figure 18: Comparison of mean specific TN and TP emissions calculated for Europe (2001-2010, Venohr et al 2018a) and for Tisza (present report).

In contrast, high specific emissions (TN: >12.5 kg/ha/yr and TP: 50 kg/km²/yr) have a significantly lower share than the European wide mean. This is also reflected in the area weighted mean specific TN and TP emissions, amounting 6.5 kg/ha/yr and 31.4 kg/km²/yr in the Tisza compared to 10.8 kg/ha/yr and 47.7 kg/km²/yr in Europe, respectively.

4.5. Load comparison

To validate and assess the model results we compared modelled loads provided by MONERIs with observed loads, calculated from monitored monthly nutrient concentrations and run-off data. Similar to the last Danube model run we used monthly disaggregated emissions and combined it with a monthly retention and transport modelling (Gericke and Venohr 2015a). This data was subsequently aggregated to annual values for the comparison with observed data. For deriving observed loads only stations with at least 12 monitored concentrations per year were considered.



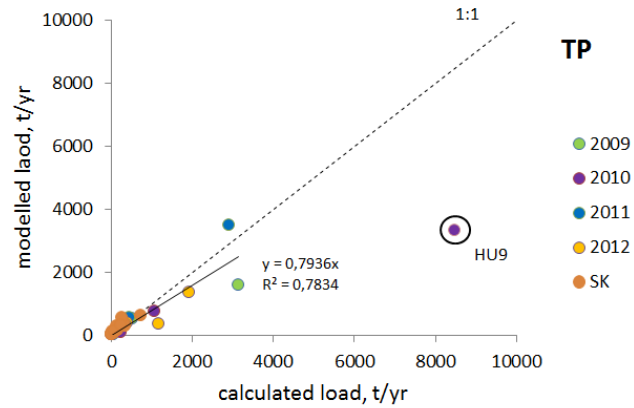


Figure 19: Comparison of modelled and observed loads, 2009-2012 (load of HU9 in 2010 not considered in linear regression).

The load comparison revealed a generally good agreement with deviations in the range of assumed uncertainty in monitoring data (Fig. 19). However, the modelled TN and TP loads for hydrological stations RO16 and HU9 were underestimated for the year 2010. The underestimation at RO 16 occurred due to an extraordinary high TN concentration in July 2010, contributing 25% of annual load (Gericke and Venohr 2015b). The floods in Tisza river basin in 2010 (ICPDR 2012) was accompanied with discharges about twice as high as in the other years. These distinct, extreme conditions cannot be modelled without further adaptions of the model and are probably the reason for deviations between modelled and observed load. Furthermore, upstream region of HU9 is characterized by a complex hydrological situation (see section 3.1) hindering an accurate calculation of loads. The exclusion of station HU 9 results in a regression line between measured and calculated loads almost perfect fitting the 1:1 line (modelled load=0.97 x measured load, R^2=0.87, not shown).

5. Scenarios

Based on the updated database for the TRB, three DRB scenarios were calculated: Baseline and two long-term scenarios Intensification and Vision 2. All scenarios were calculated using average hydrological conditions. WSP values were calculated by using equation: WSP (scenario year) = WSP (reference status) * P-accumulation (scenario year)/ P-accumulation (2012). Detailed information on the three scenarios are available in the 2015 update of the Danube River Basin Management plan (Gericke and Venohr 2015a, p. 86-87). Results of the scenario calculations are presented in in Figures 20-22 and in Tables 8-32 in the appendix (aggregated for whole Tisza and per country).

5.1. Baseline scenario

The baseline scenario was developed from a questionnaire initiated by the ICPDR and covers land use change, improved wastewater treatment, and changes in agricultural activities (Table 2). It also considers an increase of buffer strips in nitrate vulnerable zones (NVZ) and inhabitant-specific TP emissions such as 1.6 g TP / PE and day in UA. Baseline scenario was calculated for two years: 2021 and 2062[1].

[1] Similar to the DRBMP (ICPDR 2015) whose next update is due in 2021. 2062 is fictitious and used to avoid any influence of the past, i.e. to get the full effect of the assumptions on N surplus.

Table 2: Baseline scenario according to Gericke and Venohr 2015a (p.86).

Measure / tendency	Unit	DE	AT	CZ	SK	HU	HR	RO	MD	UA
Arable to grassland[*]	%	0.5	2.5	1.44	0.5	3	0	1	3	0.05
Forest to grassland[*]	%	0	(0)	-0.6	0	0	0	-1	0	-0.09
N-surplus[*]	%	0	0	5	5	0	0	0	0	0
Modified crop rotation	%	13	75	5	5	2	0	0	9	0
No-tillage farming	%	9	10	12	0	2	0	3	16	1
Riparian buffers	%	13	1	10	38[#]	5	100[**]	5	15.5	26
Tile drained areas[*]	%	0	0	-1.5	0	2	0	0	14[+]	5.5
Retention ponds in tile drained areas	%	0	0	0	0	0	0	0	1.5	5
Unpaved to paved[*]	%	1	3.5	0.6	0.5	1	0	0.5	2	0.2
Additional storage volume combined sewers	%	0	90	85	0	0		5	45	0
Inhabitants with transport from septic tanks to WWTPs	%	0	100	0	15	5		15	20	0

[*] change / tendency, [**] 100% values is unrealistic, [#] including buffer strips NVZ, [+] absolute value

5.2. Intensification and Vision 2 scenario

Intensification and Vision 2 scenario were derived from the baseline scenario. The first scenario assumes an intensification of agricultural activities resulting in an annual surplus of minimum 55 kg/ha/yr and a P balance of 5 kg/ha/yr in all analytical units. Vision 2 scenario assumes moderate N surpluses of 15 kg/ha/yr and P balances of 1 kg/ha/yr, respectively. Furthermore, a combination of measures aiming on the reduction of nutrient losses (100% connection to sewers and WWTP in agglomerations, buffer strips for steep slopes, soil protection on steep slopes, expansion of NVZ, no TP emissions laundry and dishwashers) and land-use changes are included. We calculated both with the fictitious year 2062 to exclude the effect of differences in the groundwater residence time within the TRB.

An increase of ca. 38 % of total TN emissions (36287 t/yr) was calculated for the intensification scenario (Fig.20). Total TP emissions remained almost constant as a strong decrease in urban sources emissions is compensated by the increase in pathways erosion and point sources (Fig. 21). In contrast, the Vision 2 scenario results in an overall decrease of ca. 16% (15001 t/yr) TN and ca. 12% (541 t/yr) for TP (Fig. 20, 21, 22), respectively.

While reducing N surplus (fertilizer application) has the highest reduction potential for TN emissions most of the TP reduction occurs in urban areas and is related to the connection of households to (improved) wastewater treatment plants. This accounts for ca. 60% of the total TP reduction. Measures in the agricultural sector like intercropping, buffer strips and reduced fertilizer application are responsible for the remaining 40% of total TP reduction (Fig. 21, 22).

The effect of measures implemented in the scenario analyses varies in the different regions and countries. For example in the analytical unit where Romanian city Cluj-Napoca is included, all scenarios result in a strong reduction of TP emissions of up to 67% (123 kg/km²/yr) because of investments in the wastewater sector. In contrast, in some rural parts TN emissions increase by 55% in the intensification scenario but decrease by 20% in the vision 2 scenario because of the high influence of different N surpluses on total TN emissions. More detailed information on effects of scenarios on overall nutrient emissions per country are presented in the appendix (6.2).

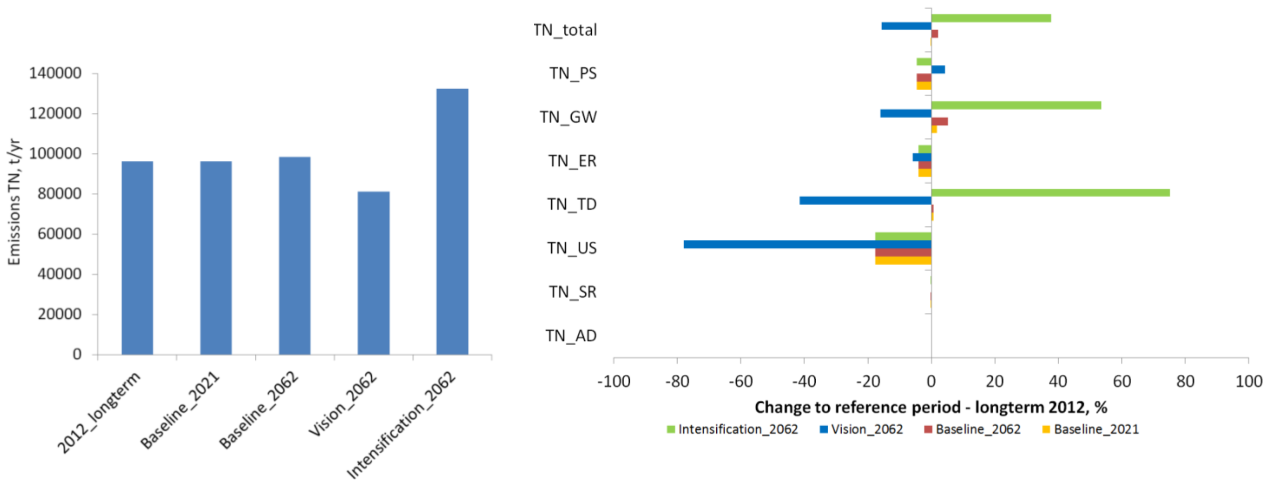


Figure 20: TN emissions in the Tisza river basin calculated for different scenarios and relative changes in emission pathways in comparison to the reference period – long-term 2012.

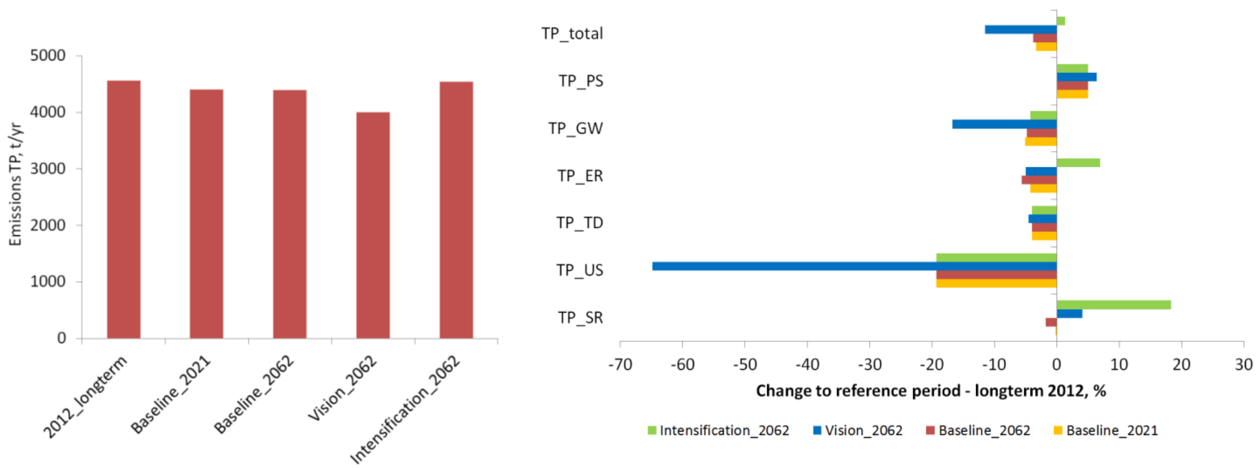


Figure 21: TP emissions in the Tisza river basin calculated for different scenarios and relative changes in emission pathways in comparison to the reference period – long-term 2012.

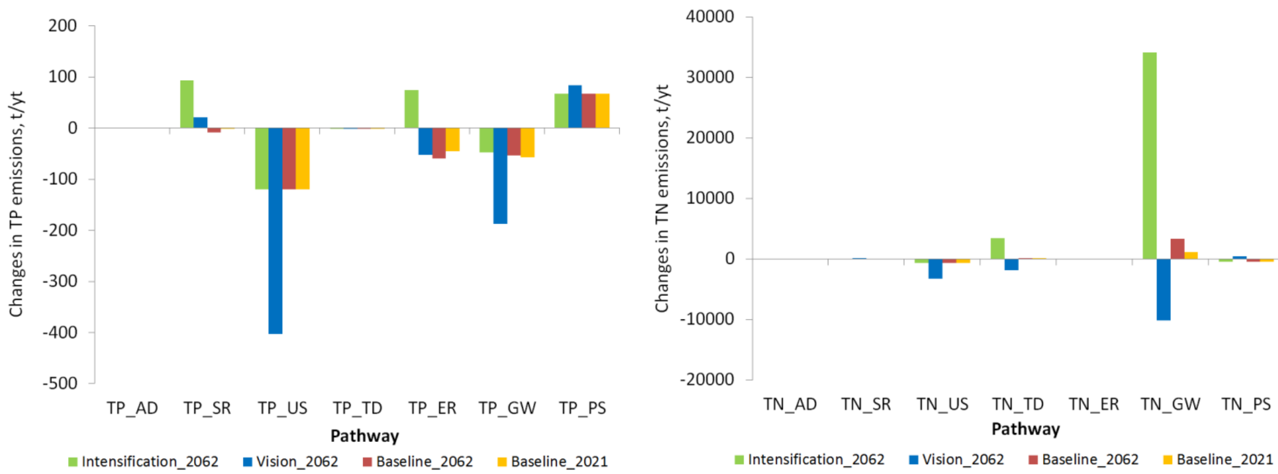


Figure 22: Absolute changes in TP and TN emissions in comparison to the reference period – long-term 2012 in the different scenarios.

6. Appendix 1

6.1. Modelled discharges per analytical unit in Tisza catchment

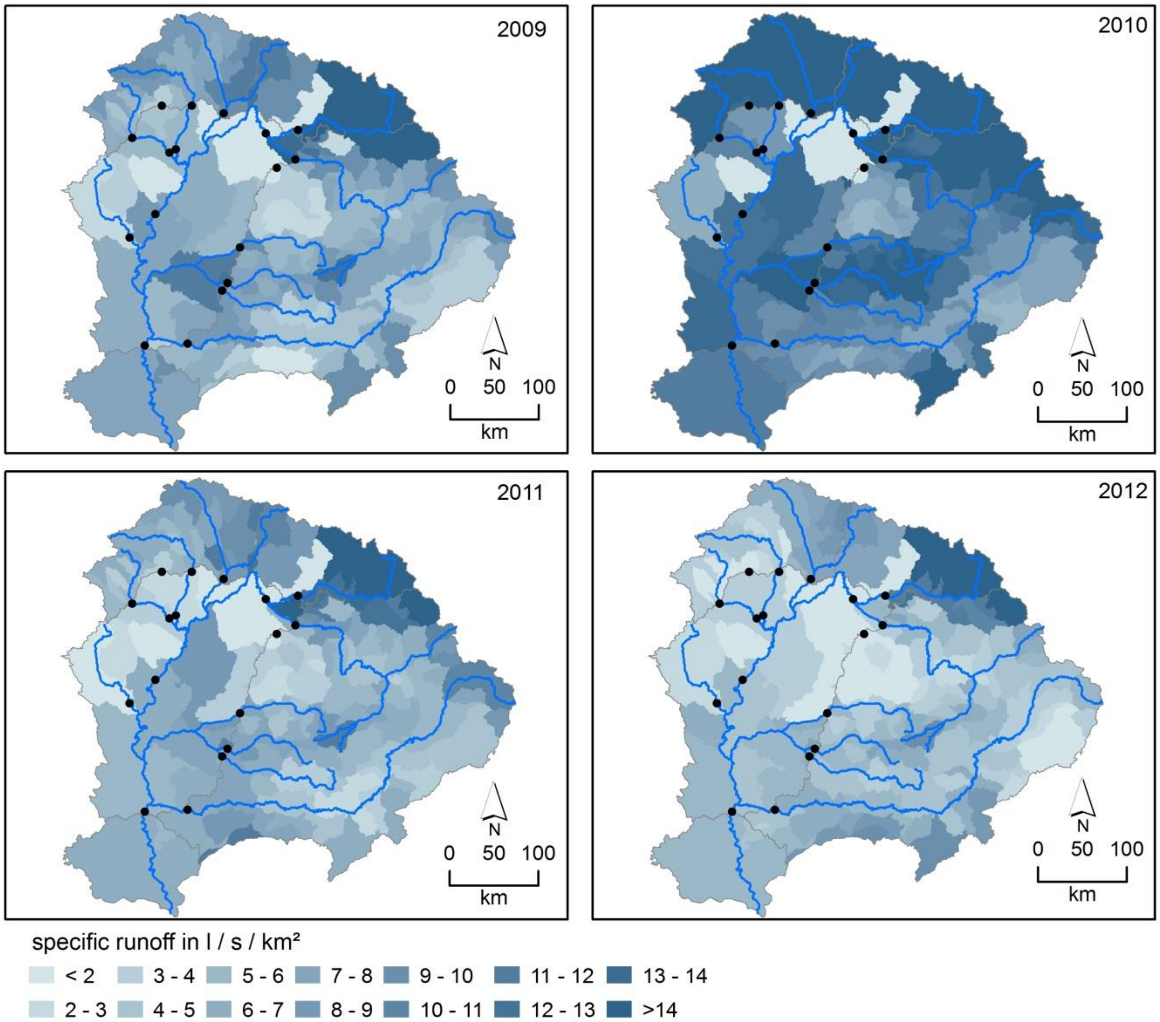


Figure 23: Calibrated specific runoff in Tisza catchment in the year 2009-2012 according to approach described in chapter 3.1.

6.2. Share of nitrogen and phosphorus emissions from different land-use types and via considered pathways: Long-term 2012, Baseline 2021, Baseline 2062, Intensification, Vision 2

6.2.1. Long-term 2012

Table 3-31: Share of both nitrogen and phosphorus emissions from different land-use types and via considered pathways, area specific emission for nitrogen in kg/ha and for phosphorus in kg/km², numbers in brackets represent the share on the total nitrogen or phosphorus emissions, WSA = water surface area. Specific emissions on surface waters can be higher than considered in the input data, as we used for reasons of data consistency the original water surface area derived from the land-use maps. This does not include areas of smaller rivers which were supplemented by MONERIS.

Table 3: Slovak Republic –long-term 2012

Land/use	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
are in km²	80.4	6167.6	834.5	7871.9	795.8	51.3	15801.5
area share in %	0.5	39.0	5.3	49.8	5.0	0.3	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.2 (0.9)						0.1 (0.9)
surface run-off		0.9 (3.6)	0.7 (0.4)	0.7 (3.6)		0.6 (0)	0.7 (7.6)
Erosion		0.3 (1.4)	0.1 (0)	0.1 (0.4)		0 (0)	0.2 (1.9)
tile drainages		5.4 (22.1)	0.8 (0.5)				2.2 (22.6)
groundwater & interflow		6.1 (24.7)	5.7 (3.1)	3.9 (20.4)	7.4 (3.9)	8.5 (0.3)	5 (52.4)
urban systems					14.8 (7.8)	0 (0)	0.7 (7.8)
sewer systems					13.8 (7.2)		
DCTP					1 (0.5)		
point sources					13.1 (6.9)		0.7 (6.9)
Total	**17.2 (0.9)**	**12.7 (51.8)**	**7.3 (4)**	**4.7 (24.4)**	**35.3 (18.5)**	**9.1 (0.3)**	**9.6 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	41.9 (0.5)						0.2 (0.5)
surface run-off		5.9 (5.7)	5.7 (0.8)	3.1 (3.8)		1.4 (0)	4.1 (10.4)
Erosion		29.2 (28.7)	4.2 (0.6)	5.1 (6.4)		0 (0)	14.2 (35.6)
tile drainages		3.1 (3)	2.7 (0.4)				1.4 (3.4)
groundwater & interflow		5.4 (5.3)	5.6 (0.7)	5 (6.2)	24.6 (3.1)	5.5 (0)	6.1 (15.4)
urban systems					173.7 (22)	0 (0)	8.7 (22)
sewer systems					152.7 (19.3)		
DCTP					21 (2.7)		
point sources					100.2 (12.7)		5 (12.7)
Total	**41.9 (0.5)**	**43.6 (42.8)**	**18.2 (2.4)**	**13.1 (16.4)**	**298.5 (37.8)**	**6.9 (0.1)**	**39.8 (100)**

Table 4: Ukraine –long-term 2012

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	27.7	3309.6	67.0	9299.7	34.7	26.7	12765.3
area share in %	0.2	25.9	0.5	72.9	0.3	0.2	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	34.5 (0.9)						0.1 (0.9)
surface run-off		1.3 (3.9)	1.2 (0.1)	1.1 (9.7)		0.6 (0)	1.2 (13.7)
Erosion		0.2 (0.7)	0 (0)	0.1 (0.6)		0 (0)	0.1 (1.3)
tile drainages		0.4 (1.2)	0.1 (0)				0.1 (1.2)
groundwater & interflow		5 (15.2)	5.9 (0.4)	4.8 (40.8)	396.2 (12.6)	1.4 (0)	5.9 (69)
urban systems					257.6 (8.2)	0 (0)	0.7 (8.2)
sewer systems					50.5 (1.6)		
DCTP					207.1 (6.6)		
point sources					185.9 (5.9)		0.5 (5.9)
Total	**34.5 (0.9)**	**6.9 (21)**	**7.3 (0.4)**	**6 (51)**	**839.6 (26.6)**	**1.9 (0)**	**8.6 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	95.6 (0.5)						0.2 (0.5)
surface run-off		6.1 (3.6)	7.4 (0.1)	5.8 (9.5)		3 (0)	5.8 (13.2)
Erosion		12 (7)	1.8 (0)	4 (6.6)		0 (0)	6 (13.7)
tile drainages		0.4 (0.2)	0.4 (0)				0.1 (0.2)
groundwater & interflow		9.9 (5.8)	12.4 (0.1)	7.6 (12.6)	1582.7 (9.8)	3.9 (0)	12.5 (28.3)
urban systems					1775.8 (10.9)	0 (0)	4.8 (10.9)
sewer systems					855.9 (5.3)		
DCTP					919.9 (5.7)		
point sources					5361.7 (33)		14.6 (33)
Total	**95.6 (0.5)**	**28.5 (16.7)**	**22 (0.3)**	**17.4 (28.8)**	**8720.2 (53.7)**	**7 (0)**	**44.1 (100)**

Table 5: Hungary –long-term 2012

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	741.5	28278.7	3974.8	9667.3	2370.9	336.4	45369.5
area share in %	1.6	62.3	8.8	21.3	5.2	0.7	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.9 (2)						0.1 (2)
surface run-off		0.8 (8)	0.6 (0.9)	0.5 (2)		0.6 (0.1)	0.6 (11)
Erosion		0 (0.3)	0 (0)	0 (0.1)		0 (0)	0 (0.3)
tile drainages		0.1 (1.6)	0 (0)				0.1 (1.6)
groundwater & interflow		5.1 (54.4)	5.3 (8)	1.6 (5.7)	2.7 (2.4)	8.2 (1)	4.2 (71.6)
urban systems					3.5 (3.2)	0 (0)	0.2 (3.2)
sewer systems					2.8 (2.5)		
DCTP					0.7 (0.7)		
point sources					11.5 (10.3)		0.6 (10.3)
Total	**6.9 (2)**	**6 (64.3)**	**5.9 (8.9)**	**2.1 (7.8)**	**17.7 (15.9)**	**8.7 (1.1)**	**5.8 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	18.3 (1.4)						0.3 (1.4)
surface run-off		3.2 (9.5)	3.1 (1.3)	2 (2.1)		1.7 (0.1)	2.7 (13)
Erosion		2.2 (6.4)	0.5 (0.2)	1.3 (1.3)		0 (0)	1.7 (7.9)
tile drainages		0.1 (0.2)	0.1 (0)				0 (0.2)
groundwater & interflow		6.6 (19.6)	6.5 (2.7)	4.2 (4.3)	10.6 (2.6)	5.2 (0.2)	6.2 (29.4)
urban systems					62.9 (15.6)	0 (0)	3.3 (15.6)
sewer systems					36.6 (9.1)		
DCTP					26.3 (6.5)		
point sources					130.9 (32.5)		6.8 (32.5)
Total	**18.3 (1.4)**	**12 (35.7)**	**10.1 (4.2)**	**7.5 (7.6)**	**204.3 (50.8)**	**6.9 (0.2)**	**21 (100)**

Table 6: Romania –long-term 2012

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	491.5	28754.4	9201.6	29351.8	3356.7	256.2	71412.1
area share in %	0.7	40.3	12.9	41.1	4.7	0.4	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	7.9 (1)						0.1 (1)
surface run-off		0.7 (5.6)	0.6 (1.5)	0.7 (5.3)		0.6 (0)	0.6 (12.5)
erosion		0.2 (1.8)	0 (0.1)	0.1 (0.7)		0 (0)	0.1 (2.7)
tile drainages		0.2 (1.2)	0 (0.1)				0.1 (1.3)
groundwater & interflow		3.4 (26.2)	3.6 (9)	3.1 (24.5)	10.3 (9.3)	5.4 (0.4)	3.6 (69.3)
urban systems					1.5 (1.3)	0 (0)	0.1 (1.3)
sewer systems					1.2 (1.1)		
DCTP					0.3 (0.2)		
point sources					13.1 (11.9)		0.6 (11.9)
Total	**7.9 (1)**	**4.5 (34.8)**	**4.3 (10.7)**	**3.9 (30.6)**	**24.9 (22.5)**	**6 (0.4)**	**5.2 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.5)						0.2 (0.5)
surface run-off		3 (4.3)	3.2 (1.4)	2.7 (3.9)		1.8 (0)	2.8 (9.6)
Erosion		17.3 (24.2)	3.1 (1.4)	5.7 (8.1)		0 (0)	9.7 (33.6)
tile drainages		0.1 (0.2)	0.2 (0.1)				0.1 (0.3)
groundwater & interflow		6.3 (8.8)	6.6 (3)	4.4 (6.2)	39.4 (6.4)	4.7 (0.1)	7 (24.5)
urban systems					48.2 (7.9)	0 (0)	2.3 (7.9)
sewer systems					14.5 (2.4)		
DCTP					33.7 (5.5)		
point sources					144.4 (23.6)		6.8 (23.6)
Total	**21.9 (0.5)**	**26.7 (37.4)**	**13 (5.8)**	**12.8 (18.2)**	**232.1 (37.9)**	**6.4 (0.1)**	**28.8 (100)**

Table 7: Serbia –long-term 2012

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	224.2	9088.54	296.17	583.6	574.81	105.4	10872.8
area share in %	2.1	83.6	2.7	5.4	5.3	0.97	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.7 (2.3)						0.1 (2.3)
surface run-off		0.8 (11.7)	0.7 (0.3)	0.7 (0.6)		0.6 (0.1)	0.8 (12.7)
erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (1.1)	0 (0)				0.1 (1.1)
groundwater & interflow		2.8 (39.1)	2.8 (1.3)	2.4 (2.1)	10.4 (9.1)	10.2 (1.6)	3.2 (53.2)
urban systems					13.4 (11.7)	0 (0)	0.7 (11.7)
sewer systems					13.4 (11.7)		
DCTP					0 (0)		
point sources					21.7 (18.9)		1.1 (18.9)
Total	**6.7 (2.3)**	**3.8 (51.9)**	**3.6 (1.6)**	**3.1 (2.8)**	**45.5 (39.7)**	**10.9 (1.7)**	**6.1 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.5 (0.8)						0.4 (0.8)
surface run-off		4.6 (8.4)	4.6 (0.3)	2.5 (0.3)		2 (0)	4.1 (9)
Erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (0.2)	0.1 (0)				0.1 (0.2)
groundwater & interflow		6.1 (11.1)	6.1 (0.4)	4.1 (0.5)	38.8 (4.5)	5.1 (0.1)	7.6 (16.5)
urban systems					192.7 (22.3)	0 (0)	10.2 (22.3)
sewer systems					167.2 (19.3)		
DCTP					25.5 (3)		
point sources					442.2 (51.2)		23.4 (51.2)
Total	**17.5 (0.8)**	**10.7 (19.7)**	**10.8 (0.6)**	**6.6 (0.8)**	**673.7 (78)**	**7.1 (0.2)**	**45.7 (100)**

6.2.2 Baseline 2021

Table 8: Whole Tisza – baseline 2021

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	1565.1	75598.8	14281.9	56866.3	7133.1	775.9	156221.1
area share in %	1.0	48.4	9.1	36.4	4.6	0.5	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	8.2 (1.3)						0.1 (1.3)
surface run-off		0.8 (6.1)	0.7 (1)	0.7 (4.3)		0.6 (0)	0.7 (11.5)
erosion		0.1 (1)	0 (0)	0.1 (0.4)		0 (0)	0.1 (1.5)
tile drainages		0.6 (4.6)	0.1 (0.1)				0.3 (4.8)
groundwater & interflow		4.5 (35.2)	4.9 (7.3)	3.2 (18.7)	7.5 (5.6)	7.3 (0.6)	4.1 (67.4)
urban systems					4.8 (3.6)		0.2 (3.6)
sewer systems					3.4 (2.5)		
DCTP					1.4 (1.1)		
point sources					13.5 (10)		0.6 (10)
Total	**8.2 (1.3)**	**6 (46.9)**	**5.7 (8.5)**	**4 (23.5)**	**25.8 (19.1)**	**7.9 (0.6)**	**6.2 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.8)						0.2 (0.8)
surface run-off		3.6 (6)	3.6 (1.1)	3.2 (4)		1.8 (0)	3.2 (11.1)
Erosion		9.7 (16.2)	2.4 (0.7)	4.5 (5.6)		0 (0)	6.5 (22.5)
tile drainages		0.3 (0.6)	0.3 (0.1)				0.2 (0.7)
groundwater & interflow		6.3 (10.5)	6.9 (2.2)	4.9 (6.2)	28.7 (4.5)	5 (0.1)	6.8 (23.5)
urban systems					70.3 (11.1)		3.2 (11.1)
sewer systems					42.7 (6.7)		
DCTP					27.6 (4.3)		
point sources					193.7 (30.4)		8.8 (30.4)
Total	**21.9 (0.8)**	**19.9 (33.2)**	**13.2 (4.2)**	**12.6 (15.7)**	**292.8 (46)**	**6.7 (0.1)**	**29 (100)**

Table 9: Slovak Republic– baseline 2021

Land/use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
are in km²	80.4	6167.6	834.5	7871.9	795.8	51.3	15801.5
area share in %	0.5	39.0	5.3	49.8	5.0	0.32	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.2 (0.9)						0.1 (0.9)
surface run-off		0.9 (3.7)	0.7 (0.4)	0.7 (3.7)		0.6 (0)	0.7 (7.8)
erosion		0.3 (1.5)	0.1 (0)	0.1 (0.5)		0 (0)	0.2 (2)
tile drainages		5.5 (23.3)	0.9 (0.5)				2.2 (23.8)
groundwater & interflow		6.5 (27.4)	6.3 (3.6)	3.9 (20.9)	9.2 (5)	8.4 (0.3)	5.3 (57.1)
urban systems					4.8 (2.6)	0 (0)	0.2 (2.6)
sewer systems					3.5 (1.9)		
DCTP					1.3 (0.7)		
point sources					10.4 (5.7)		0.5 (5.7)
Total	**17.2 (0.9)**	**13.3 (55.9)**	**8 (4.6)**	**4.7 (25)**	**24.4 (13.3)**	**9 (0.3)**	**9.3 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	41.9 (0.6)						0.2 (0.6)
surface run-off		5.8 (6.6)	5.9 (0.9)	3.1 (4.4)		1.4 (0)	4.1 (11.9)
Erosion		29.4 (33)	4.3 (0.7)	5.1 (7.3)		0 (0)	14.2 (40.9)
tile drainages		3 (3.3)	2.8 (0.4)				1.3 (3.7)
groundwater & interflow		5.4 (6.1)	5.8 (0.9)	5 (7.1)	33.3 (4.8)	5.5 (0.1)	6.6 (18.9)
urban systems					68 (9.8)	0 (0)	3.4 (9.8)
sewer systems					33.8 (4.9)		
DCTP					34.2 (5)		
point sources					96.9 (14)		4.9 (14)
Total	**41.9 (0.6)**	**43.6 (48.9)**	**18.9 (2.9)**	**13.1 (18.8)**	**198.2 (28.7)**	**6.9 (0.1)**	**34.8 (100)**

Table 10: Ukraine– baseline 2021

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	27.7	3309.6	66.9	9299.7	34.8	26.6	12765.3
area share in %	0.2	25.9	0.5	72.9	0.3	0.2	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	34.5 (0.8)						0.1 (0.8)
surface run-off		1.3 (3.8)	1.2 (0.1)	1.1 (9.4)		0.6 (0)	1.2 (13.3)
erosion		0.2 (0.6)	0 (0)	0.1 (0.6)		0 (0)	0.1 (1.1)
tile drainages		0.4 (1.1)	0.1 (0)				0.1 (1.1)
groundwater & interflow		6.4 (18.8)	7.8 (0.5)	4.7 (38.6)	372.1 (11.5)	1.3 (0)	6.1 (69.4)
urban systems					256 (7.9)	0 (0)	0.7 (7.9)
sewer systems					54.6 (1.7)		
DCTP					201.3 (6.2)		
point sources					202.9 (6.3)		0.6 (6.3)
Total	**34.5 (0.8)**	**8.3 (24.3)**	**9.2 (0.5)**	**5.9 (48.5)**	**830.9 (25.7)**	**1.9 (0)**	**8.8 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	95.6 (0.5)						0.2 (0.5)
surface run-off		6.1 (3.7)	7.5 (0.1)	5.8 (9.9)		3 (0)	5.8 (13.7)
erosion		10.4 (6.4)	1.8 (0)	4 (6.9)		0 (0)	5.6 (13.3)
tile drainages		0.4 (0.2)	0.5 (0)				0.1 (0.2)
groundwater & interflow		9.9 (6.1)	12.6 (0.2)	7.6 (13.1)	1677 (10.8)	3.9 (0)	12.8 (30.2)
urban systems					1686 (10.8)	0 (0)	4.6 (10.8)
sewer systems					688.9 (4.4)		
DCTP					997.1 (6.4)		
point sources					4852.1 (31.2)		13.2 (31.2)
Total	**95.6 (0.5)**	**26.8 (16.4)**	**22.4 (0.3)**	**17.4 (30)**	**8215.2 (52.8)**	**7 (0)**	**42.3 (100)**

Table 11: Hungary – baseline 2021

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	741.5	28278.7	3974.8	9667.3	2370.9	336.4	45369.5
area share in %	1.6	62.3	8.8	21.3	5.2	0.7	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.9 (1.9)						0.1 (1.9)
surface run-off		0.7 (7.6)	0.7 (1.1)	0.5 (1.9)		0.6 (0.1)	0.6 (10.7)
erosion		0 (0.2)	0 (0)	0 (0.1)		0 (0)	0 (0.3)
tile drainages		0.1 (1.5)	0 (0)				0.1 (1.5)
groundwater & interflow		5.4 (56.2)	6.9 (10.2)	1.5 (5.4)	2.6 (2.3)	8.1 (1)	4.5 (75.1)
urban systems					3.5 (3.1)	0 (0)	0.2 (3.1)
sewer systems					2.8 (2.5)		
DCTP					0.7 (0.6)		
point sources					8.4 (7.4)		0.4 (7.4)
Total	**6.9 (1.9)**	**6.3 (65.5)**	**7.7 (11.3)**	**2.1 (7.4)**	**14.6 (12.8)**	**8.7 (1.1)**	**6 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	18.3 (1.6)						0.3 (1.6)
surface run-off		3.1 (10.3)	3.8 (1.8)	2 (2.3)		1.7 (0.1)	2.7 (14.4)
erosion		1.9 (6.2)	0.5 (0.2)	1.2 (1.4)		0 (0)	1.5 (7.9)
tile drainages		0.1 (0.2)	0.1 (0)				0 (0.2)
groundwater & interflow		6.4 (21.1)	7.9 (3.7)	4.2 (4.8)	10.2 (2.8)	5.2 (0.2)	6.2 (32.6)
urban systems					62.6 (17.3)	0 (0)	3.3 (17.3)
sewer systems					36.5 (10.1)		
DCTP					26.2 (7.2)		
point sources					94.1 (26)		4.9 (26)
Total	**18.3 (1.6)**	**11.5 (37.8)**	**12.3 (5.7)**	**7.5 (8.5)**	**166.9 (46.2)**	**6.9 (0.3)**	**18.9 (100)**

Table 12: Romania – baseline 2021

Land-use	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
area in km²	491.5	28754.4	9109.5	29443.8	3356.7	256.2	71412.1
area share in %	0.7	40.3	12.8	41.2	4.7	0.4	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	7.9 (1.1)						0.1 (1.1)
surface run-off		0.7 (5.6)	0.6 (1.6)	0.7 (5.4)		0.6 (0)	0.7 (12.6)
erosion		0.2 (1.7)	0 (0.1)	0.1 (0.7)		0 (0)	0.1 (2.6)
tile drainages		0.2 (1.2)	0 (0.1)				0.1 (1.3)
groundwater & interflow		3.5 (27.4)	3.9 (9.7)	3.1 (24.5)	6.3 (5.7)	5.3 (0.4)	3.5 (67.7)
urban systems					1.6 (1.5)	0 (0)	0.1 (1.5)
sewer systems					1.5 (1.4)		
DCTP					0.1 (0.1)		
point sources					14.6 (13.3)		0.7 (13.3)
Total	**7.9 (1.1)**	**4.6 (35.9)**	**4.6 (11.5)**	**3.8 (30.6)**	**22.5 (20.5)**	**6 (0.4)**	**5.2 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.5)						0.2 (0.5)
surface run-off		3 (4.1)	3.2 (1.4)	2.7 (3.8)		1.8 (0)	2.7 (9.3)
Erosion		16.1 (22)	3.1 (1.3)	5.6 (7.8)		0 (0)	9.2 (31.1)
tile drainages		0.1 (0.2)	0.2 (0.1)				0.1 (0.2)
groundwater & interflow		6 (8.2)	6.6 (2.9)	4.3 (6)	21.8 (3.5)	4.6 (0.1)	6.1 (20.6)
urban systems					38 (6)	0 (0)	1.8 (6)
sewer systems					20.6 (3.3)		
DCTP					17.4 (2.8)		
point sources					202 (32.1)		9.5 (32.1)
Total	**21.9 (0.5)**	**25.3 (34.4)**	**13.1 (5.6)**	**12.7 (17.7)**	**261.8 (41.6)**	**6.4 (0.1)**	**29.6 (100)**

Table 13: Serbia – baseline 2021

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	224.2	9088.5	296.2	583.6	574.8	105.4	10872.8
area share in %	2.1	83.6	2.7	5.4	5.3	1.0	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.7 (2.4)						0.1 (2.4)
surface run-off		0.8 (12.1)	0.7 (0.3)	0.7 (0.7)		0.6 (0.1)	0.8 (13.2)
Erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (1.1)	0 (0)				0.1 (1.1)
Groundwater & interflow		2.6 (37.6)	2.6 (1.2)	2.5 (2.3)	10.7 (9.7)	10.3 (1.7)	3.1 (52.5)
urban systems					13.7 (12.4)	0 (0)	0.7 (12.4)
sewer systems					13.7 (12.4)		
DCTP					0 (0)		
point sources					20.3 (18.4)		1.1 (18.4)
Total	**6.7 (2.4)**	**3.5 (50.8)**	**3.4 (1.6)**	**3.2 (3)**	**44.7 (40.5)**	**11 (1.8)**	**5.8 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.5 (0.8)						0.4 (0.8)
surface run-off		4.6 (8.7)	4.6 (0.3)	2.5 (0.3)		2 (0)	4.1 (9.4)
Erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (0.2)	0.1 (0)				0.1 (0.2)
groundwater & interflow		6.1 (11.5)	6.1 (0.4)	4.1 (0.5)	39.7 (4.8)	5.1 (0.1)	7.6 (17.2)
urban systems					196.5 (23.5)	0 (0)	10.4 (23.5)
sewer systems					171.3 (20.5)		
DCTP					25.2 (3)		
point sources					408.3 (48.9)		21.6 (48.9)
Total	**17.5 (0.8)**	**10.8 (20.4)**	**10.8 (0.7)**	**6.6 (0.8)**	**644.5 (77.2)**	**7.1 (0.2)**	**44.1 (100)**

6.2.3 Baseline 2062

Table 14: Whole Tisza – baseline 2062

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	1565.1	75598.8	14281.9	56866.3	7133.1	775.9	156221.1
area share in %	1.0	48.4	9.1	36.4	4.6	0.5	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	8.2 (1.3)						0.1 (1.3)
surface run-off		0.8 (6)	0.7 (1)	0.7 (4.2)		0.6 (0)	0.7 (11.2)
erosion		0.1 (1)	0 (0)	0.1 (0.4)		0 (0)	0.1 (1.5)
tile drainages		0.6 (4.5)	0.1 (0.1)				0.3 (4.7)
groundwater & interflow		4.7 (36.5)	5.3 (7.6)	3.1 (18.1)	7.4 (5.4)	7.2 (0.6)	4.3 (68.1)
urban systems					4.8 (3.5)		0.2 (3.5)
sewer systems					3.4 (2.5)		
DCTP					1.4 (1)		
point sources					13.5 (9.8)		0.6 (9.8)
Total	**8.2 (1.3)**	**6.2 (47.9)**	**6 (8.8)**	**3.9 (22.7)**	**25.7 (18.6)**	**7.8 (0.6)**	**6.3 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.8)						0.2 (0.8)
surface run-off		3.5 (5.9)	3.5 (1.1)	3.2 (4)		1.8 (0)	3.2 (11)
erosion		9.5 (15.9)	2.3 (0.7)	4.5 (5.6)		0 (0)	6.4 (22.3)
tile drainages		0.3 (0.6)	0.3 (0.1)				0.2 (0.7)
groundwater & interflow		6.3 (10.6)	7 (2.2)	5 (6.2)	28.4 (4.5)	5 (0.1)	6.8 (23.6)
urban systems					70.3 (11.1)		3.2 (11.1)
sewer systems					42.7 (6.7)		
DCTP					27.6 (4.4)		
point sources					193.7 (30.6)		8.8 (30.6)
Total	**21.9 (0.8)**	**19.7 (33)**	**13.1 (4.1)**	**12.6 (15.8)**	**292.5 (46.2)**	**6.8 (0.1)**	**28.9 (100)**

Table 15: Slovak Republic – baseline 2062

Land/use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
are in km²	80.4	6167.6	834.5	7871.9	795.8	51.3	15801.5
area share in %	0.5	39.0	5.3	49.8	5.0	0.3	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.2 (0.9)						0.1 (0.9)
surface run-off		0.9 (3.7)	0.7 (0.4)	0.7 (3.7)		0.6 (0)	0.7 (7.8)
erosion		0.3 (1.5)	0.1 (0)	0.1 (0.5)		0 (0)	0.2 (1.9)
tile drainages		5.5 (23.1)	0.9 (0.5)				2.2 (23.6)
groundwater & interflow		6.7 (28.1)	6.6 (3.7)	3.8 (20.5)	9.1 (4.9)	8.4 (0.3)	5.4 (57.5)
urban systems					4.8 (2.6)	0 (0)	0.2 (2.6)
sewer systems					3.5 (1.9)		
DCTP					1.3 (0.7)		
point sources					10.4 (5.6)		0.5 (5.6)
Total	**17.2 (0.9)**	**13.5 (56.4)**	**8.3 (4.7)**	**4.6 (24.6)**	**24.3 (13.1)**	**9 (0.3)**	**9.3 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	41.9 (0.6)						0.2 (0.6)
surface run-off		5.8 (6.6)	5.9 (0.9)	3.1 (4.4)		1.4 (0)	4.1 (11.9)
erosion		29.4 (33)	4.3 (0.7)	5.1 (7.3)		0 (0)	14.2 (41)
tile drainages		3 (3.3)	2.8 (0.4)				1.3 (3.7)
Groundwater & interflow		5.4 (6.1)	5.8 (0.9)	5 (7.1)	33 (4.8)	5.5 (0.1)	6.6 (18.9)
urban systems					68 (9.9)	0 (0)	3.4 (9.9)
sewer systems					33.8 (4.9)		
DCTP					34.2 (5)		
point sources					96.9 (14)		4.9 (14)
Total	**41.9 (0.6)**	**43.6 (49)**	**18.9 (2.9)**	**13.1 (18.8)**	**197.9 (28.7)**	**6.9 (0.1)**	**34.8 (100)**

Table 16: Ukraine – baseline 2062

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	27.7	3309.6	66.9	9299.7	34.8	26.6	12765.3
area share in %	0.2	25.9	0.5	72.9	0.3	0.2	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	34.5 (0.8)						0.1 (0.8)
surface run-off		1.3 (3.8)	1.2 (0.1)	1.1 (9.4)		0.6 (0)	1.2 (13.2)
erosion		0.2 (0.6)	0 (0)	0.1 (0.6)		0 (0)	0.1 (1.1)
tile drainages		0.4 (1.1)	0.1 (0)				0.1 (1.1)
groundwater & interflow		6.6 (19.2)	7.9 (0.5)	4.7 (38.4)	370.8 (11.4)	1.3 (0)	6.1 (69.5)
urban systems					256 (7.9)	0 (0)	0.7 (7.9)
sewer systems					54.6 (1.7)		
DCTP					201.3 (6.2)		
point sources					202.9 (6.2)		0.6 (6.2)
Total	**34.5 (0.8)**	**8.4 (24.7)**	**9.3 (0.6)**	**5.9 (48.3)**	**829.6 (25.6)**	**1.9 (0)**	**8.8 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	95.6 (0.5)						0.2 (0.5)
surface run-off		5.4 (3.3)	6.8 (0.1)	5.8 (10)		3 (0)	5.6 (13.4)
erosion		10.1 (6.2)	1.8 (0)	4 (7)		0 (0)	5.6 (13.2)
tile drainages		0.4 (0.2)	0.5 (0)				0.1 (0.2)
groundwater & interflow		9.9 (6.1)	12.6 (0.2)	7.6 (13.2)	1671.1 (10.8)	3.9 (0)	12.7 (30.3)
urban systems					1686 (10.9)	0 (0)	4.6 (10.9)
sewer systems					688.9 (4.5)		
DCTP					997.1 (6.5)		
point sources					4852.1 (31.4)		13.2 (31.4)
Total	**95.6 (0.5)**	**25.8 (15.9)**	**21.6 (0.3)**	**17.4 (30.2)**	**8209.3 (53.2)**	**7 (0)**	**42.1 (100)**

Table 17: Hungary – baseline 2062

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	741.5	28278.7	3974.8	9667.3	2370.9	336.4	45369.5
area share in %	1.6	62.3	8.8	21.3	5.2	0.7	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.9 (1.8)						0.1 (1.8)
surface run-off		0.7 (7.3)	0.7 (1)	0.5 (1.8)		0.6 (0.1)	0.6 (10.2)
erosion		0 (0.2)	0 (0)	0 (0.1)		0 (0)	0 (0.3)
tile drainages		0.1 (1.4)	0 (0)				0.1 (1.4)
groundwater & interflow		5.8 (57.6)	7.4 (10.5)	1.5 (5)	2.5 (2.1)	8 (1)	4.7 (76.2)
urban systems					3.5 (3)	0 (0)	0.2 (3)
sewer systems					2.8 (2.4)		
DCTP					0.7 (0.6)		
point sources					8.4 (7.1)		0.4 (7.1)
Total	**6.9 (1.8)**	**6.6 (66.5)**	**8.2 (11.6)**	**2 (6.9)**	**14.5 (12.1)**	**8.6 (1)**	**6.2 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	18.3 (1.6)						0.3 (1.6)
surface run-off		3.1 (10.4)	3.8 (1.8)	2 (2.3)		1.7 (0.1)	2.7 (14.5)
erosion		1.9 (6.3)	0.5 (0.2)	1.2 (1.4)		0 (0)	1.5 (7.9)
tile drainages		0.1 (0.2)	0.1 (0)				0 (0.2)
groundwater & interflow		6.4 (21.1)	7.9 (3.7)	4.2 (4.8)	10 (2.8)	5.2 (0.2)	6.1 (32.5)
urban systems					62.6 (17.3)	0 (0)	3.3 (17.3)
sewer systems					36.5 (10.1)		
DCTP					26.2 (7.2)		
point sources					94.1 (26)		4.9 (26)
Total	**18.3 (1.6)**	**11.5 (37.9)**	**12.3 (5.7)**	**7.5 (8.5)**	**166.7 (46.1)**	**6.9 (0.3)**	**18.9 (100)**

Table 18: Romania – baseline 2062

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	491.5	28754.4	9109.5	29443.8	3356.7	256.2	71412.1
area share in %	0.7	40.3	12.8	41.2	4.7	0.4	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	7.9 (1)						0.1 (1)
surface run-off		0.7 (5.5)	0.6 (1.5)	0.7 (5.3)		0.6 (0)	0.7 (12.3)
erosion		0.2 (1.7)	0 (0.1)	0.1 (0.7)		0 (0)	0.1 (2.5)
tile drainages		0.2 (1.2)	0 (0.1)				0.1 (1.3)
groundwater & interflow		3.8 (28.9)	4.2 (10.3)	3 (23.5)	6.1 (5.4)	5.3 (0.4)	3.6 (68.4)
urban systems					1.6 (1.4)	0 (0)	0.1 (1.4)
sewer systems					1.5 (1.3)		
DCTP					0.1 (0.1)		
point sources					14.6 (13)		0.7 (13)
Total	**7.9 (1)**	**4.9 (37.2)**	**5 (12)**	**3.8 (29.5)**	**22.3 (19.9)**	**5.9 (0.4)**	**5.3 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.5)						0.2 (0.5)
surface run-off		2.8 (3.8)	3 (1.3)	2.7 (3.8)		1.8 (0)	2.6 (9)
erosion		15.7 (21.5)	3 (1.3)	5.6 (7.9)		0 (0)	9 (30.7)
tile drainages		0.1 (0.2)	0.2 (0.1)				0.1 (0.2)
groundwater & interflow		6.2 (8.5)	6.7 (2.9)	4.3 (6.1)	21.4 (3.4)	4.7 (0.1)	6.2 (21)
urban systems					38 (6.1)	0 (0)	1.8 (6.1)
sewer systems					20.6 (3.3)		
DCTP					17.4 (2.8)		
point sources					202 (32.4)		9.5 (32.4)
Total	**21.9 (0.5)**	**24.8 (34)**	**12.9 (5.6)**	**12.7 (17.9)**	**261.5 (41.9)**	**6.4 (0.1)**	**29.3 (100)**

Table 19: Serbia – baseline 2062

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	224.2	9088.5	296.2	583.6	574.8	105.4	10873
area share in %	2.1	83.6	2.7	5.4	5.3	1.0	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.7 (2.4)						0.1 (2.4)
surface run-off		0.8 (12.1)	0.7 (0.3)	0.7 (0.7)		0.6 (0.1)	0.8 (13.3)
erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (1.1)	0 (0)				0.1 (1.1)
groundwater & interflow		2.6 (37.3)	2.6 (1.2)	2.5 (2.3)	10.8 (9.8)	10.3 (1.7)	3 (52.3)
urban systems					13.7 (12.4)	0 (0)	0.7 (12.4)
sewer systems					13.7 (12.4)		
DCTP					0 (0)		
point sources					20.3 (18.5)		1.1 (18.5)
Total	**6.7 (2.4)**	**3.5 (50.6)**	**3.3 (1.6)**	**3.2 (3)**	**44.8 (40.7)**	**11 (1.8)**	**5.8 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.5 (0.8)						0.4 (0.8)
surface run-off		4.7 (9)	4.7 (0.3)	2.5 (0.3)		2 (0)	4.2 (9.6)
Erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (0.2)	0.1 (0)				0.1 (0.2)
groundwater & interflow		6.1 (11.4)	6.1 (0.4)	4.1 (0.5)	39.9 (4.8)	5.1 (0.1)	7.6 (17.2)
urban systems					196.5 (23.5)	0 (0)	10.4 (23.5)
sewer systems					171.3 (20.5)		
DCTP					25.2 (3)		
point sources					408.3 (48.8)		21.6 (48.8)
Total	**17.5 (0.8)**	**10.9 (20.6)**	**10.9 (0.7)**	**6.6 (0.8)**	**644.7 (77)**	**7.1 (0.2)**	**44.3 (100)**

6.2.4 Intensification

Table 20: Whole Tisza – intensification

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	1565.1	75598.8	14281.9	56866.3	7133.1	775.9	156221.1
area share in %	1.0	48.4	9.1	36.4	4.6	0.5	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	8.2 (1)						0.1 (1)
surface run-off		0.8 (4.4)	0.7 (0.7)	0.7 (3.1)		0.6 (0)	0.7 (8.3)
erosion		0.1 (0.7)	0 (0)	0.1 (0.3)		0 (0)	0.1 (1.1)
tile drainages		1 (5.9)	0.1 (0.1)				0.5 (6)
groundwater & interflow		8.5 (48.8)	10.1 (10.9)	2.5 (10.7)	5.6 (3)	6.9 (0.4)	6.3 (73.8)
urban systems					4.8 (2.6)		0.2 (2.6)
sewer systems					3.4 (1.8)		
DCTP					1.4 (0.8)		
point sources					13.5 (7.2)		0.6 (7.2)
Total	**8.2 (1)**	**10.5 (59.8)**	**10.9 (11.7)**	**3.3 (14.2)**	**23.9 (12.8)**	**7.5 (0.4)**	**8.5 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.7)						0.2 (0.7)
surface run-off		4.6 (7.3)	4.7 (1.4)	3.2 (3.8)		1.8 (0)	3.8 (12.6)
erosion		11.2 (17.8)	2.8 (0.8)	4.5 (5.3)		0 (0)	7.3 (24)
tile drainages		0.3 (0.5)	0.3 (0.1)				0.2 (0.6)
groundwater & interflow		6.8 (10.8)	7.5 (2.3)	5 (6)	22.5 (3.4)	5.1 (0.1)	6.9 (22.6)
urban systems					70.3 (10.5)		3.2 (10.5)
sewer systems					42.7 (6.4)		
DCTP					27.6 (4.1)		
point sources					193.7 (29)		8.8 (29)
Total	**21.9 (0.7)**	**23 (36.5)**	**15.3 (4.6)**	**12.7 (15.1)**	**286.5 (42.9)**	**6.9 (0.1)**	**30.5 (100)**

Table 21: Slovak Republic – intensification

Land/use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	80.4	6167.6	834.5	7871.9	795.8	51.3	15801.5
area share in %	0.5	39.0	5.3	49.8	5.0	0.3	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.2 (0.7)						0.1 (0.7)
surface run-off		0.9 (2.8)	0.7 (0.3)	0.7 (2.8)		0.6 (0)	0.7 (5.9)
erosion		0.3 (1.1)	0.1 (0)	0.1 (0.3)		0 (0)	0.2 (1.5)
tile drainages		8.8 (27.7)	1.1 (0.5)				3.5 (28.1)
groundwater & interflow		11.5 (36.1)	13.2 (5.6)	3.2 (12.6)	7.7 (3.1)	7.9 (0.2)	7.2 (57.6)
urban systems					4.8 (2)	0 (0)	0.2 (2)
sewer systems					3.5 (1.4)		
DCTP					1.3 (0.5)		
point sources					10.4 (4.2)		0.5 (4.2)
Total	**17.2 (0.7)**	**21.5 (67.6)**	**15.1 (6.4)**	**3.9 (15.7)**	**22.9 (9.3)**	**8.5 (0.2)**	**12.4 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	41.9 (0.6)						0.2 (0.6)
surface run-off		6.8 (7.3)	6.8 (1)	3.1 (4.2)		1.4 (0)	4.5 (12.5)
erosion		32.9 (35.3)	4.9 (0.7)	5.1 (7)		0 (0)	15.6 (43)
tile drainages		3 (3.2)	2.8 (0.4)				1.3 (3.6)
groundwater & interflow		5.4 (5.8)	5.8 (0.8)	5 (6.8)	28.4 (3.9)	5.5 (0)	6.3 (17.5)
urban systems					68 (9.4)	0 (0)	3.4 (9.4)
sewer systems					33.8 (4.7)		
DCTP					34.2 (4.7)		
point sources					96.9 (13.4)		4.9 (13.4)
Total	**41.9 (0.6)**	**48 (51.6)**	**20.3 (3)**	**13.1 (18)**	**193.3 (26.8)**	**6.9 (0.1)**	**36.3 (100)**

Table 22: Ukraine – intensification

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	27.7	3309.6	66.9	9299.7	34.8	26.6	12765.3
area share in %	0.2	25.9	0.5	72.9	0.3	0.2	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	34.5 (0.7)						0.1 (0.7)
surface run-off		1.3 (3)	1.2 (0.1)	1.1 (7.4)		0.6 (0)	1.2 (10.5)
erosion		0.2 (0.5)	0 (0)	0.1 (0.4)		0 (0)	0.1 (0.9)
tile drainages		1.1 (2.5)	0.2 (0)				0.3 (2.6)
groundwater & interflow		17.5 (40.6)	22.4 (1.1)	3.9 (25.4)	294.7 (7.2)	1.3 (0)	8.3 (74.2)
urban systems					256 (6.2)	0 (0)	0.7 (6.2)
sewer systems					54.6 (1.3)		
DCTP					201.3 (4.9)		
point sources					202.9 (4.9)		0.6 (4.9)
Total	**34.5 (0.7)**	**20.1 (46.6)**	**23.8 (1.1)**	**5.1 (33.2)**	**753.6 (18.4)**	**1.8 (0)**	**11.2 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	95.6 (0.5)						0.2 (0.5)
surface run-off		8.1 (4.9)	9.8 (0.1)	5.8 (9.9)		3 (0)	6.3 (15)
erosion		12.3 (7.5)	2.2 (0)	4 (6.9)		0 (0)	6.1 (14.4)
tile drainages		0.4 (0.2)	0.5 (0)				0.1 (0.2)
groundwater & interflow		9.9 (6.1)	12.6 (0.2)	7.6 (13.1)	1329.4 (8.5)	3.9 (0)	11.8 (27.9)
urban systems					1686 (10.8)	0 (0)	4.6 (10.8)
sewer systems					688.9 (4.4)		
DCTP					997.1 (6.4)		
point sources					4852.1 (31.2)		13.2 (31.2)
Total	**95.6 (0.5)**	**30.6 (18.7)**	**25.1 (0.3)**	**17.4 (29.9)**	**7867.5 (50.5)**	**7 (0)**	**42.4 (100)**

Table 23: Hungary – intensification

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	741.5	28278.7	3974.8	9667.3	2370.9	336.4	45369.5
area share in %	1.6	62.3	8.8	21.3	5.2	0.7	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.9 (1.6)						0.1 (1.6)
surface run-off		0.7 (6.5)	0.7 (0.9)	0.5 (1.7)		0.6 (0.1)	0.6 (9.2)
erosion		0 (0.2)	0 (0)	0 (0.1)		0 (0)	0 (0.3)
tile drainages		0.2 (1.5)	0 (0)				0.1 (1.6)
groundwater & interflow		6.7 (60.5)	8.7 (11)	1.3 (4.1)	2.3 (1.7)	8 (0.9)	5.4 (78.3)
urban systems					3.5 (2.7)	0 (0)	0.2 (2.7)
sewer systems					2.8 (2.1)		
DCTP					0.7 (0.6)		
point sources					8.4 (6.4)		0.4 (6.4)
Total	**6.9 (1.6)**	**7.6 (68.8)**	**9.5 (12)**	**1.9 (5.8)**	**14.3 (10.8)**	**8.5 (0.9)**	**6.9 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	18.3 (1.5)						0.3 (1.5)
surface run-off		3.7 (11.8)	4.6 (2)	2 (2.2)		1.7 (0.1)	3.2 (16)
erosion		2.1 (6.7)	0.6 (0.3)	1.2 (1.3)		0 (0)	1.6 (8.2)
tile drainages		0.1 (0.2)	0.1 (0)				0 (0.2)
groundwater & interflow		6.9 (21.7)	8.3 (3.7)	4.4 (4.7)	9.6 (2.5)	5.2 (0.2)	6.5 (32.7)
urban systems					62.6 (16.5)	0 (0)	3.3 (16.5)
sewer systems					36.5 (9.6)		
DCTP					26.2 (6.9)		
point sources					94.1 (24.8)		4.9 (24.8)
Total	**18.3 (1.5)**	**12.8 (40.3)**	**13.5 (6)**	**7.6 (8.2)**	**166.3 (43.8)**	**6.9 (0.3)**	**19.8 (100)**

Table 24: Romania – intensification

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	491.5	28754.4	9109.5	29443.8	3356.7	256.2	71412.1
area share in %	0.7	40.3	12.8	41.2	4.7	0.4	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	7.9 (0.7)						0.1 (0.7)
surface run-off		0.7 (3.6)	0.6 (1)	0.7 (3.5)		0.6 (0)	0.7 (8.2)
erosion		0.2 (1.1)	0 (0.1)	0.1 (0.5)		0 (0)	0.1 (1.7)
tile drainages		0.4 (2.2)	0.1 (0.1)				0.2 (2.3)
groundwater & interflow		9.1 (46.1)	10.4 (16.7)	2.3 (11.9)	4.3 (2.6)	4.8 (0.2)	6.1 (77.5)
urban systems					1.6 (1)	0 (0)	0.1 (1)
sewer systems					1.5 (0.9)		
DCTP					0.1 (0.1)		
point sources					14.6 (8.6)		0.7 (8.6)
Total	**7.9 (0.7)**	**10.5 (53.1)**	**11.1 (17.9)**	**3.1 (15.9)**	**20.5 (12.2)**	**5.4 (0.2)**	**7.9 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.9 (0.5)						0.2 (0.5)
surface run-off		4.2 (5.3)	4.5 (1.8)	2.7 (3.6)		1.8 (0)	3.4 (10.7)
erosion		18.9 (24)	3.6 (1.5)	5.6 (7.3)		0 (0)	10.4 (32.8)
tile drainages		0.1 (0.2)	0.2 (0.1)				0.1 (0.2)
groundwater & interflow		6.9 (8.8)	7.4 (3)	4.5 (5.8)	16.3 (2.4)	4.9 (0.1)	6.4 (20.1)
urban systems					38 (5.6)	0 (0)	1.8 (5.6)
sewer systems					20.6 (3.1)		
DCTP					17.4 (2.6)		
point sources					202 (30)		9.5 (30)
Total	**21.9 (0.5)**	**30.1 (38.3)**	**15.7 (6.3)**	**12.8 (16.7)**	**256.4 (38.1)**	**6.7 (0.1)**	**31.7 (100)**

Table 25: Serbia – intensification

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	224.2	9088.5	296.2	583.6	574.8	105.4	10872.8
area share in %	2.1	83.6	2.7	5.4	5.3	1.0	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.7 (1.4)						0.1 (1.4)
surface run-off		0.8 (7.2)	0.7 (0.2)	0.7 (0.4)		0.6 (0.1)	0.8 (7.9)
erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.3 (2.6)	0 (0)				0.3 (2.6)
groundwater & interflow		7.3 (62.6)	7.3 (2)	1.4 (0.8)	6.1 (3.3)	9.4 (0.9)	6.8 (69.6)
urban systems					13.7 (7.4)	0 (0)	0.7 (7.4)
sewer systems					13.7 (7.4)		
DCTP					0 (0)		
point sources					20.3 (11)		1.1 (11)
Total	**6.7 (1.4)**	**8.4 (72.4)**	**8.1 (2.3)**	**2.1 (1.2)**	**40.1 (21.8)**	**10 (1)**	**9.7 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.5 (0.8)						0.4 (0.8)
surface run-off		6.1 (11.4)	6.1 (0.4)	2.5 (0.3)		2 (0)	5.4 (12.1)
erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (0.2)	0.1 (0)				0.1 (0.2)
groundwater & interflow		6.1 (11.4)	6.1 (0.4)	4.1 (0.5)	24.1 (2.9)	5.1 (0.1)	6.8 (15.2)
urban systems					196.5 (23.3)	0 (0)	10.4 (23.3)
sewer systems					171.3 (20.3)		
DCTP					25.2 (3)		
point sources					408.3 (48.4)		21.6 (48.4)
Total	**17.5 (0.8)**	**12.2 (22.9)**	**12.2 (0.7)**	**6.6 (0.8)**	**628.8 (74.6)**	**7.1 (0.2)**	**44.6 (100)**

6.2.5 Vision 2

Table 26: Whole Tizsa – vision 2

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	1587.2	75887.3	14603.9	55727.3	7690.5	725.0	156221.1
area share in %	1.0	48.6	9.3	35.7	4.9	0.5	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	8.1 (1.6)						0.1 (1.6)
surface run-off		0.8 (7.3)	0.7 (1.2)	0.7 (5)		0.7 (0.1)	0.7 (13.6)
erosion		0.1 (1.2)	0 (0.1)	0.1 (0.5)		0 (0)	0.1 (1.7)
tile drainages		0.3 (3.2)	0.1 (0.1)				0.2 (3.3)
groundwater & interflow		3.5 (32.2)	4 (7.2)	3.3 (22.5)	3.3 (3.1)	8.1 (0.7)	3.4 (65.8)
urban systems					1.2 (1.1)		0.1 (1.1)
sewer systems					0.9 (0.9)		
DCTP					0.3 (0.2)		
point sources					13.7 (12.9)		0.7 (12.9)
Total	**8.1 (1.6)**	**4.7 (43.8)**	**4.8 (8.6)**	**4.1 (28)**	**18.2 (17.2)**	**8.8 (0.8)**	**5.2 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.6 (0.8)						0.2 (0.8)
surface run-off		3.8 (7)	3.9 (1.4)	3.2 (4.2)		1.9 (0)	3.4 (12.7)
erosion		9.5 (17.4)	2.5 (0.9)	4.6 (6.1)		0 (0)	6.5 (24.4)
tile drainages		0.3 (0.6)	0.3 (0.1)				0.2 (0.7)
groundwater & interflow		6.4 (11.6)	7.1 (2.5)	4.9 (6.6)	9.1 (1.7)	5.3 (0.1)	6 (22.5)
urban systems					28.4 (5.3)		1.4 (5.3)
sewer systems					21.2 (3.9)		
DCTP					7.2 (1.3)		
point sources					181.9 (33.7)		9 (33.7)
Total	**21.6 (0.8)**	**20.1 (36.6)**	**13.8 (4.9)**	**12.6 (17)**	**219.3 (40.6)**	**7.2 (0.1)**	**26.6 (100)**

Table 27: Slovak Republic– vision 2

Land/use	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
are in km²	81.4	6080.7	833.7	7788.1	969.5	48.2	15801.5
area share in %	0.5	38.5	5.3	49.3	6.1	0.3	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17 (1.2)						0.1 (1.2)
surface run-off		0.9 (4.9)	0.7 (0.6)	0.7 (4.9)		0.7 (0)	0.7 (10.3)
erosion		0.4 (2)	0.1 (0)	0.1 (0.6)		0 (0)	0.2 (2.6)
tile drainages		2.9 (15.9)	0.7 (0.5)				1.2 (16.5)
groundwater & interflow		4.4 (23.9)	4.8 (3.6)	4.1 (29.1)	4.7 (4.1)	9.9 (0.4)	4.3 (61.2)
urban systems					0.8 (0.7)	0 (0)	0 (0.7)
sewer systems					0.5 (0.5)		
DCTP					0.3 (0.2)		
point sources					8.6 (7.5)		0.5 (7.5)
Total	**17 (1.2)**	**8.5 (46.7)**	**6.3 (4.7)**	**4.9 (34.5)**	**14.1 (12.3)**	**10.6 (0.5)**	**7 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	41.4 (0.7)						0.2 (0.7)
surface run-off		6.1 (7.3)	6.1 (1)	3.1 (4.8)		1.5 (0)	4.2 (13.2)
erosion		31.4 (38)	4.4 (0.7)	5 (7.7)		0 (0)	14.8 (46.5)
tile drainages		2.9 (3.6)	2.8 (0.5)				1.3 (4)
groundwater & interflow		5.4 (6.6)	5.8 (1)	5 (7.8)	10.8 (2.1)	6.3 (0.1)	5.6 (17.5)
urban systems					14.5 (2.8)	0 (0)	0.9 (2.8)
sewer systems					7.3 (1.4)		
DCTP					7.2 (1.4)		
point sources					79.5 (15.4)		4.9 (15.4)
Total	**41.4 (0.7)**	**45.9 (55.5)**	**19.2 (3.2)**	**13.1 (20.3)**	**104.9 (20.2)**	**7.8 (0.1)**	**31.8 (100)**

Table 28: Ukraine – vision 2

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	27.7	3312.9	67.1	9311.5	34.8	11.3	12765.3
area share in %	0.2	26.0	0.5	72.9	0.3	0.1	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	34.4 (0.9)						0.1 (0.9)
surface run-off		1.3 (4.2)	1.2 (0.1)	1.1 (10.4)		1.4 (0)	1.2 (14.7)
erosion		0.1 (0.5)	0 (0)	0.1 (0.6)		0 (0)	0.1 (1.1)
tile drainages		0.4 (1.2)	0.1 (0)				0.1 (1.2)
groundwater & interflow		6.2 (20.2)	7.5 (0.5)	4.7 (42.8)	50.1 (1.7)	3.2 (0)	5.2 (65.3)
urban systems					35.2 (1.2)	0 (0)	0.1 (1.2)
sewer systems					8.2 (0.3)		
DCTP					26.9 (0.9)		
point sources					458.2 (15.6)		1.2 (15.6)
Total	**34.4 (0.9)**	**8 (26.1)**	**8.9 (0.6)**	**5.9 (53.8)**	**543.5 (18.5)**	**4.5 (0.1)**	**8 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	95.4 (0.5)						0.2 (0.5)
surface run-off		6.5 (4)	8 (0.1)	5.8 (9.9)		7.2 (0)	6 (14)
erosion		8 (4.9)	1.9 (0)	4 (6.9)		0 (0)	5 (11.8)
tile drainages		0.4 (0.2)	0.5 (0)				0.1 (0.2)
groundwater & interflow		10 (6.1)	12.7 (0.2)	7.6 (13.1)	199.3 (1.3)	9.3 (0)	8.8 (20.6)
urban systems					235.8 (1.5)	0 (0)	0.6 (1.5)
sewer systems					111.9 (0.7)		
DCTP					123.9 (0.8)		
point sources					8014.1 (51.3)		21.8 (51.3)
Total	**95.4 (0.5)**	**24.9 (15.2)**	**23.1 (0.3)**	**17.4 (29.9)**	**8449.2 (54.1)**	**16.5 (0)**	**42.5 (100)**

Table 29: Hungary – vision 2

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	748.3	28359.4	3984.0	9511.6	2439.8	326.5	45369.5
area share in %	1.6	62.5	8.8	21.0	5.4	0.7	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.9 (2.8)						0.1 (2.8)
surface run-off		0.7 (11.3)	0.7 (1.6)	0.5 (2.8)		0.6 (0.1)	0.6 (15.9)
erosion		0 (0.3)	0 (0)	0 (0.1)		0 (0)	0 (0.4)
tile drainages		0.1 (0.9)	0 (0)				0 (0.9)
groundwater & interflow		2.8 (43.8)	3.6 (7.9)	2 (10.4)	2 (2.7)	8.9 (1.6)	2.7 (66.5)
urban systems					1.9 (2.5)	0 (0)	0.1 (2.5)
sewer systems					1.7 (2.2)		
DCTP					0.2 (0.3)		
point sources					8.2 (11)		0.4 (11)
Total	**6.9 (2.8)**	**3.6 (56.4)**	**4.4 (9.6)**	**2.6 (13.3)**	**12.1 (16.2)**	**9.5 (1.7)**	**4 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	18.1 (1.7)						0.3 (1.7)
surface run-off		3.3 (11.5)	4 (2)	2 (2.4)		1.7 (0.1)	2.8 (16)
erosion		1.8 (6.5)	0.5 (0.3)	1.2 (1.5)		0 (0)	1.5 (8.2)
tile drainages		0.1 (0.2)	0.1 (0)				0 (0.2)
groundwater & interflow		6.3 (22.2)	7.7 (3.8)	4 (4.8)	5.7 (1.7)	5.2 (0.2)	5.8 (32.8)
urban systems					43.4 (13.2)	0 (0)	2.3 (13.2)
sewer systems					36 (11)		
DCTP					7.4 (2.3)		
point sources					91.4 (27.9)		4.9 (27.9)
Total	**18.1 (1.7)**	**11.4 (40.4)**	**12.3 (6.1)**	**7.3 (8.7)**	**140.5 (42.8)**	**6.9 (0.3)**	**17.6 (100)**

Table 30: Romania – vision 2

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	505.4	29035.3	9422.7	28531.9	3670.9	245.9	71412.1
area share in %	0.7	40.7	13.2	40.0	5.1	0.3	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	7.7 (1.1)						0.1 (1.1)
surface run-off		0.7 (5.9)	0.6 (1.7)	0.7 (5.3)		0.7 (0)	0.7 (12.9)
erosion		0.2 (1.7)	0 (0.1)	0.1 (0.8)		0 (0)	0.1 (2.6)
tile drainages		0.1 (1.2)	0 (0.1)				0.1 (1.3)
groundwater & interflow		3.7 (29.5)	4.1 (10.7)	3 (24)	3.4 (3.4)	5.7 (0.4)	3.4 (68.1)
urban systems					0.4 (0.5)	0 (0)	0 (0.5)
sewer systems					0.4 (0.4)		
DCTP					0 (0)		
point sources					13.3 (13.6)		0.7 (13.6)
Total	**7.7 (1.1)**	**4.7 (38.2)**	**4.8 (12.6)**	**3.8 (30.1)**	**17.2 (17.5)**	**6.4 (0.4)**	**5 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	21.3 (0.5)						0.2 (0.5)
surface run-off		3.3 (4.8)	3.6 (1.7)	2.7 (3.8)		1.8 (0)	2.9 (10.3)
erosion		15.6 (22.4)	3.3 (1.5)	5.8 (8.2)		0 (0)	9.1 (32.2)
tile drainages		0.1 (0.2)	0.2 (0.1)				0.1 (0.3)
groundwater & interflow		6.3 (9.1)	7 (3.3)	4.3 (6.1)	9.1 (1.7)	5 (0.1)	5.7 (20.2)
urban systems					16.1 (2.9)	0 (0)	0.8 (2.9)
sewer systems					10.1 (1.8)		
DCTP					6 (1.1)		
point sources					184.7 (33.6)		9.5 (33.6)
Total	**21.3 (0.5)**	**25.4 (36.5)**	**14 (6.5)**	**12.9 (18.2)**	**209.9 (38.2)**	**6.8 (0.1)**	**28.3 (100)**

Table 31: Serbia – vision 2

Land-use	WSA	Arable	Grassland	Forest	Urban area	Other Areas	Total
area in km²	224.5	9099.0	296.5	584.2	575.5	93.1	10872.8
area share in %	2.1	83.7	2.7	5.4	5.3	0.9	100
Nitrogen	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	6.7 (2.6)						0.1 (2.6)
surface run-off		0.8 (13.4)	0.7 (0.4)	0.7 (0.7)		0.7 (0.1)	0.8 (14.7)
erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (1.6)	0 (0)				0.1 (1.6)
groundwater & interflow		3.2 (50.1)	3.2 (1.6)	2.2 (2.3)	3 (3)	11.5 (1.9)	3.1 (58.8)
urban systems					1.7 (1.7)	0 (0)	0.1 (1.7)
sewer systems					1.7 (1.7)		
DCTP					0 (0)		
point sources					20.5 (20.6)		1.1 (20.6)
Total	**6.7 (2.6)**	**4.1 (65)**	**3.9 (2)**	**2.9 (3)**	**25.2 (25.3)**	**12.2 (2)**	**5.3 (100)**
Phosphorus	**WSA**	**Arable**	**Grassland**	**Forest**	**Urban area**	**Other Areas**	**Total**
atmospheric deposition	17.5 (1.4)						0.4 (1.4)
surface run-off		4.9 (15.3)	4.9 (0.5)	2.5 (0.5)		2.2 (0.1)	4.4 (16.4)
erosion		0 (0)	0 (0)	0 (0)		0 (0)	0 (0)
tile drainages		0.1 (0.3)	0.1 (0)				0.1 (0.3)
groundwater & interflow		6.1 (19)	6.1 (0.6)	4.1 (0.8)	8.7 (1.7)	5.8 (0.2)	6 (22.4)
urban systems					53.9 (10.7)	0 (0)	2.9 (10.7)
sewer systems					47.6 (9.4)		
DCTP					6.3 (1.3)		
point sources					246.3 (48.9)		13 (48.9)
Total	**17.5 (1.4)**	**11 (34.6)**	**11.1 (1.1)**	**6.6 (1.3)**	**308.9 (61.3)**	**8 (0.3)**	**26.7 (100)**

6.3. Short report from 1st of December 2017

- Data input for MONERIS –
1) Hydrological data
2) Land use data
3) Next steps

1) Hydrological data

New hydrological data was provided by Romania and Slovak Republic. In table 1, locations of the new stations and the neighboring stations of the 2014 Danube project are shown. The comparison of monthly means of the neighbor stations revealed strong deviations (Fig. 1) which are apparently not explainable by the hydrology but rather by differing measuring methods of the different countries.

Table 1: New hydrological stations

Hydrological station	Country	Analytical unit ID	Temporal resolution of discharges	Adjacent Hungarian hydrological station downstream	Approx. distance between hydrological stations, km
RO12	Romania	324	Daily	HU11	4.0
RO13	Romania	410	Daily	HU12	3.0
RO15	Romania	430	Daily	HU14	0.4
SK9	Slovak Republic	4062	Daily	HU8	1.0

In order to be able to proceed with the setup of the model a decision is needed how to handle these inaccuracies. The inconsistency in the data needs to be taken into account in the setup of the model. Following options are possible to deal with the inconsistencies:

1) Neglect the differences and use the old stations used in the Danube project for hydrological calibration
2) Use the new stations for hydrological calibration of the model
3) Use arithmetic means of both stations for the hydrological calibration of the model

An advantage of the use of the new hydrological stations is the higher resolution of water quality data available for the Romanian stations (24 values per year) in comparison to the stations in Hungary (12 values per year). Additionally, new hydrological data was delivered for the Slovakian stations SK10, SK11, SK12 (corresponding analytical unit IDs: 4065, 4074, 4088). A comparison of the measured discharges with the modeled discharges revealed partly high deviations. Thus, we would suggest a new hydrological calibration also including stations SK10, SK11 and SK12.

IMPORTANT: Please inform us until 15th of December 2017: 1) which option we should choose and 2) whether we should include stations SK10, SK11 and SK12 in the hydrological calibration.

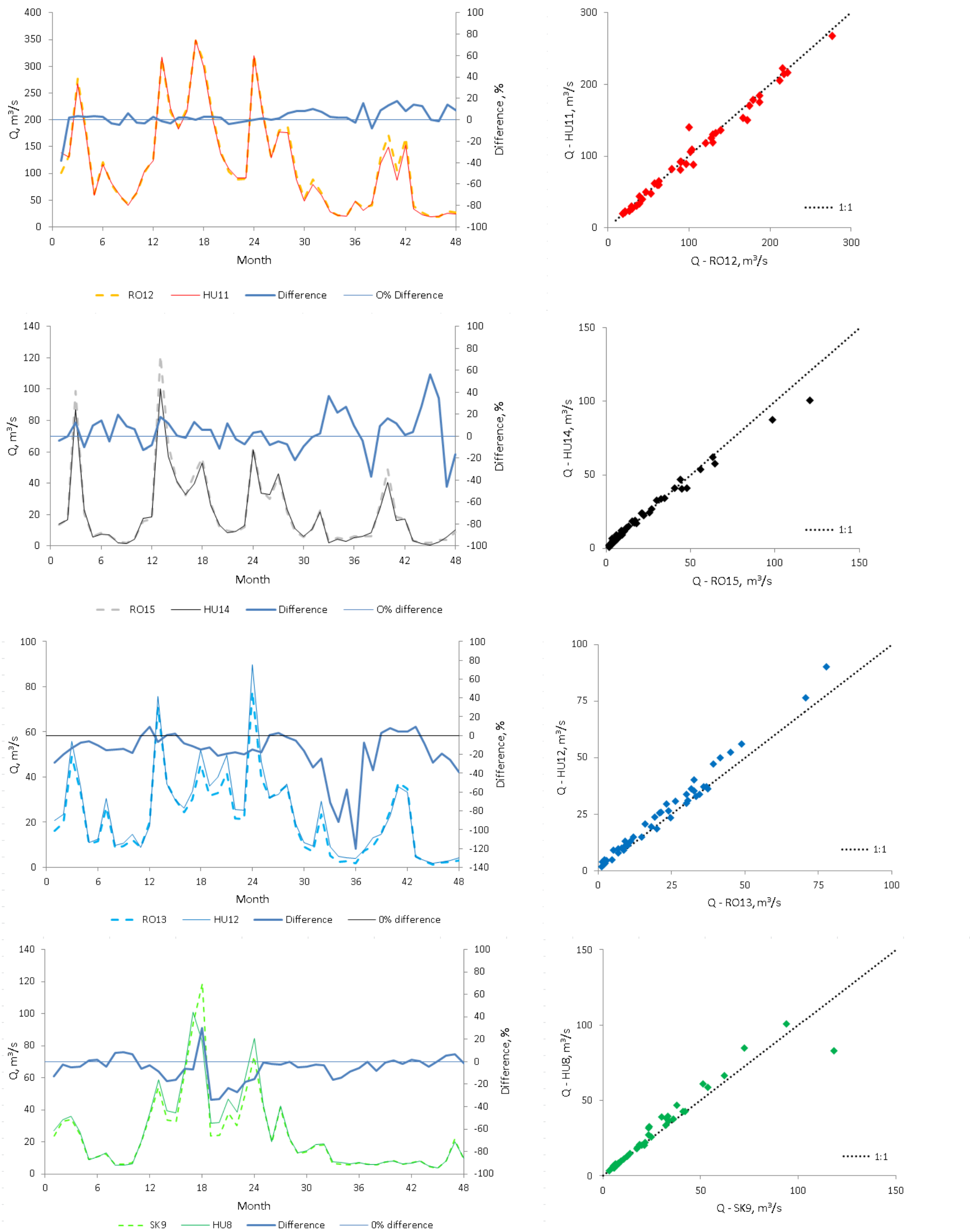


Figure 1: Comparison of average monthly discharges in neighbor stations (see Table 1): Q=discharge, difference = ($Q_{upstream}$-$Q_{downstream}$)/ ($Q_{upstream}$/100), Month 1 = January 2009, Month 48 =December 2012.

2) Land use

We compared the newest land use datasets available for the Tisza region with the input data used for the Danube 2014 setup of MONERIS. Differences were predominantly found in Romania and Serbia (Fig. 2). They are due to technical reasons rather than changes in land use (data shift in Serbia, vector instead of raster data in Romania) and provide a more precise dataset than the one used in the Danube 2014 setup. Therefore, we decided to update the land use and soil loss values in the MONERIS database

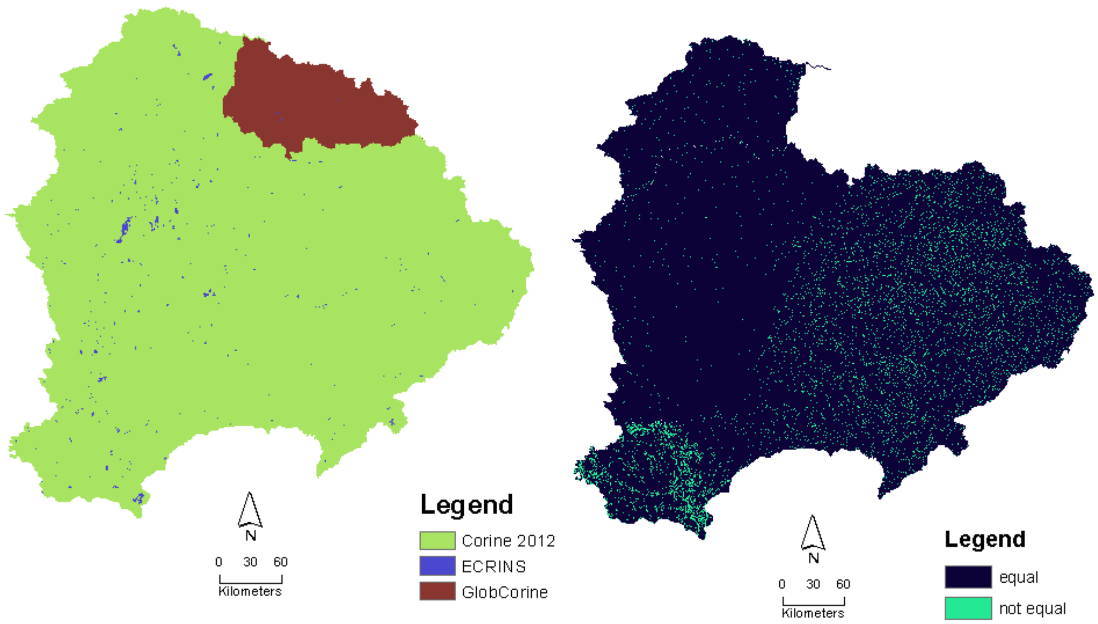


Figure 2: Land use data: a) Overview over data sources b) Difference of Corine Land Cover 2012 in comparison to the Danube 2014 project.

Table 2: Land use datasets used as input data

Dataset	Spatial resolution	URL	Used for
Corine Land Cover (CLC) 2012, Version 18.5.1	100m	http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012/view	All Tisza, except Ukraine
GlobCorine 2009	300m	http://dup.esrin.esa.int/page_project114.php	Ukraine
ECRINS		https://www.eea.europa.eu/data-and-maps/data/european-catchments-and-rivers-network#tab-gis-data	All Tisza

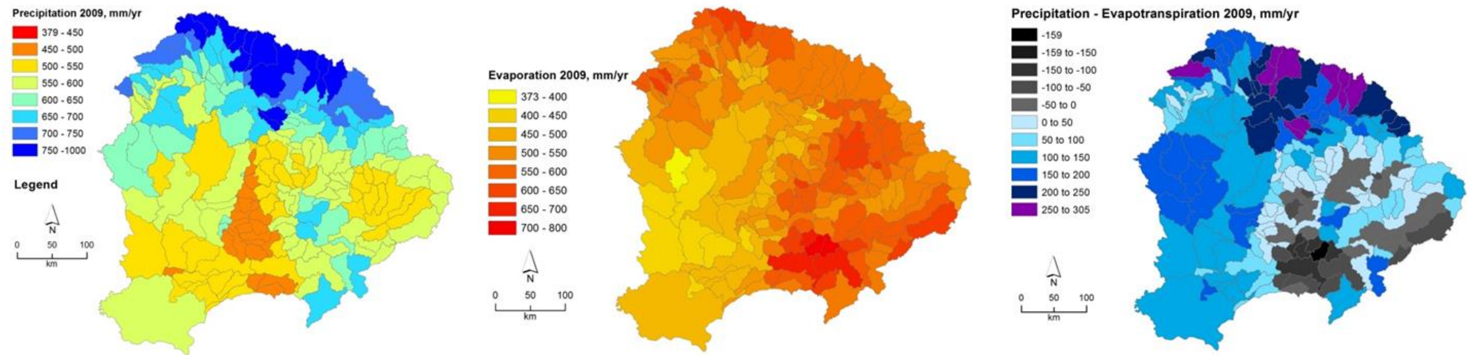
3) Next steps

In accordance with latest approaches used in the MARS project, the next steps will be:

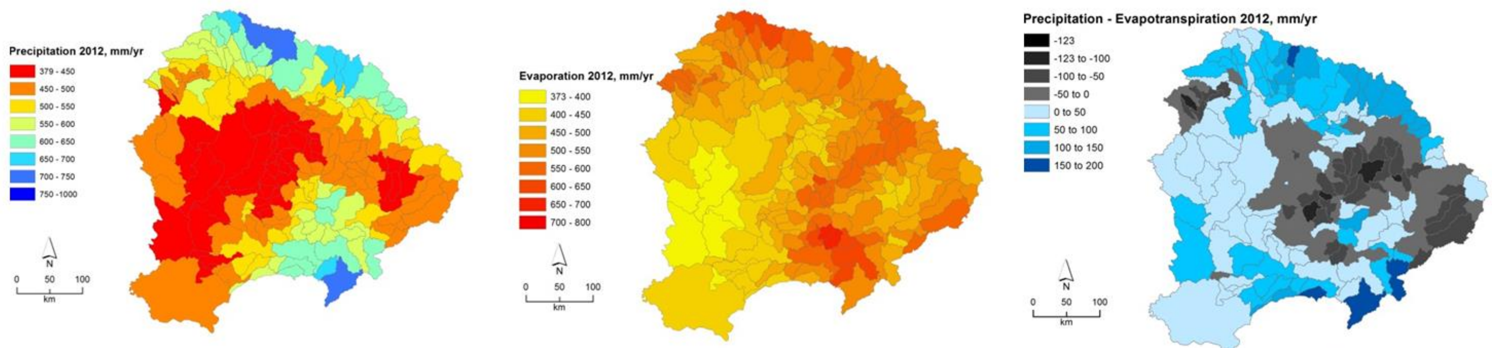
1) Update of the land use and soil loss values in the MONERIS database
2) Derivation of N surplus

6.4. Short report from 1st of February 2018

Precipitation, Evapotranspiration and Precipitation – Evapotranspiration 2009



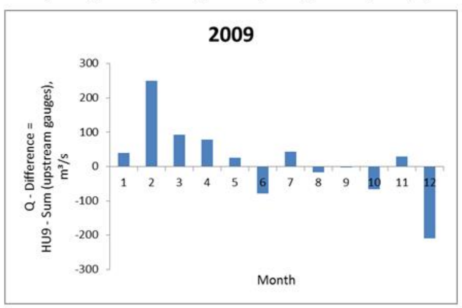
Precipitation, Evapotranspiration and Precipitation – Evapotranspiration 2012

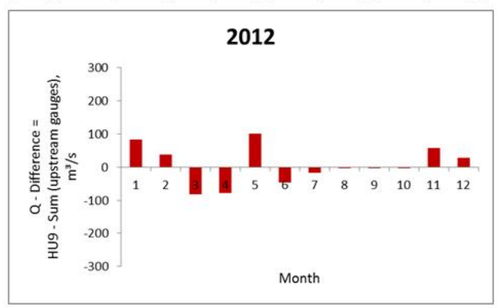


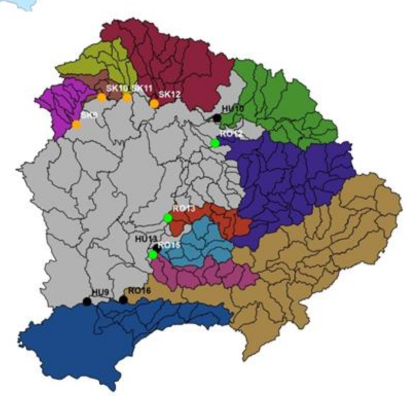
Water balances for 2009 and 2012 between HU9 and upstream gauges (monthly means):

Q-difference=

Q(HU9)- [(Q(HU10) + Q(RO12) + Q(RO13) + Q(HU13) + Q (RO15)+ Q (RO16) + Q (SK9) + Q (SK10) + Q (SK11) + Q (SK12)]

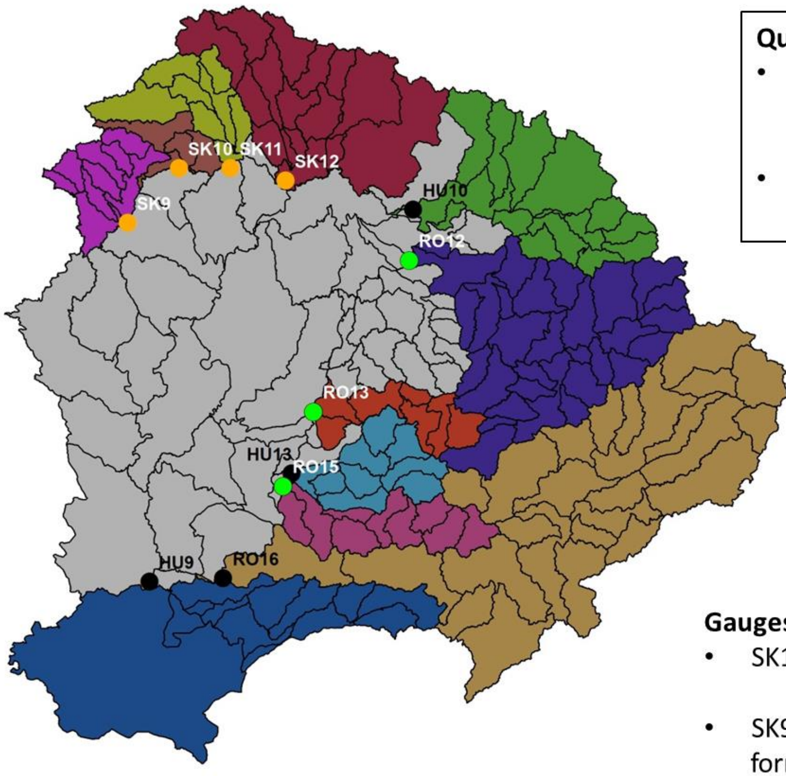






(larger figure: see next slide)

Gauges with corresponding analytical units



Questions:

- Are the negative water balances explainable by water extractions (e.g. by agriculture) in the grey marked analytical units?
- Could you provide or indicate us a dataset to verify this assumption?

Gauges:

- SK10, SK11, SK12: new implemented gauges
- SK9, RO12, RO13, RO15 : gauges that are substituting former Hungarian gauges
- HU9, RO16, HU13, HU10: gauges also used in Danube 2014 model setup

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Pöthig, R., H. Behrendt, D. Opitz, and G. Furrer. 2010. A universal method to assess the potential of phosphorus loss from soil to aquatic ecosystems. Environmental Science and Pollution Research 17:497-504.

Strauss,P., Wolkerstorfer,G., Buzos, K., Kovacs, A., Clement, A. 2005. Deliverable 2.1 – evaluated model on estimating nutrient flows due to erosion/runoff in the case study areas selected, Deliverable 2.1, DaNUbs, EVK1-CT-2000-00051, 90 pp.

Vadas, P. A., P.J.A. Kleinman, A. N. Sharpley, B. L. Turner (2005): Relating soil phosphorus to dissolved phosphorus in runoff: a single extraction coefficient for water quality modeling. Jornal of Environmental Quality 34 (2), 572-580.

Venohr, M., U. Hirt, J. Hofmann, D. Opitz, A. Gericke, A. Wetzig, S. Natho, F. Neumann, J. Hurdler, M. Matranga, J. Mahnkopf, M. Gadegast, and H. Behrendt. 2011. Modelling of Nutrient Emissions in River Systems - MONERIS - Methods and Background. International Review of Hydrobiology 96:435-483.

Venohr M, Birk S, Bremerich V, Gericke A, Globevnik L, Koprivšek M, Mahnkopf J, Panagopoulos Y, Snoj L, Faneca Sànchez M, Stefanidis K and Sperna Weiland F 2018a MARS Deliverable 7.2 - Scenario Analysis Tool (SAT), Report on data, scientific methods and tool implementation. Available online: http://www.mars-project.eu/files/download/deliverables/MARS_D7.2_MARS_suite_of_tools_2.pdf (accessed 04/2018).

Venohr, M. et al. 2018b. Distributed Nitrogen surplus derived from European national statistics. Submitted to Hydrological processes

Vogt J., Soille P., de Jager A., Rimaviciute E., Mehl W., Foisneau S., Bodis K., Dusart J., Paracchini M-L., Haastrup P., Bamps C. 2007. A pan-European river and catchment database. Luxembourg: Office for Official Publications of the European Communities. Available online: http://ccm.jrc.ec.europa.eu/php/index.php?action=view&id=23 (last accessed 04/2018).

8. Appendix 2: MONERIS manual and MONERIS publication

MONERIS manual

- Online help tool as available in MONERIS version 3.0 beta -

Preface

This online help is intended to support you in working with the MONERIS software und its user interfaces. It is accessed via the HELP button.
In the following running text names for menu bars and their functions are printed in italics and the buttons (and other control elements of MONERIS) are printed in bold face.
In addition, the help points out tooltips belonging to the user interfaces. These tooltips provide you with extra information on which working steps are necessary for each task whenever the mouse hovers above the task.

To support user, red background color of fields is used as follow:

- Red background color in empty fields on the MONERIS user interface shows you, these fields are necessary to fill
- If you define an invalid value by filling packing of measures, this field is marked with red background color

Contents

1. Introduction

MONERIS (MOdelling Nutrient Emissions in RIver Systems) is a semi-empirical, conceptual model for the quantification of nutrient emissions from point and diffuse sources in river catchments (Behrendt et al., 2000; 2002a; 2002b). MONERIS now has a new model surface programmed in C#, which we implemented in 2012, (previously EXCEL/VBA was used for all calculations). In MONERIS results are presented for total nitrogen (TN), total phosphorus (TP) and dissolved silicium (Si). Furthermore, a scenario manager has been developed to calculate the effects of measures on the nutrient emissions for different pathways and spatial units.

The model is based on data for runoff and water quality for the study area, along with a Geographical Information System (GIS), thus bringing together digital maps as well as statistical information for different administrative levels. The application of MONERIS allows regionally differentiated quantification of nutrient emissions into a river system on the level of an analytical unit. The results can be visualised in GIS generated maps.

Figure 1 gives an overview of the main pathways and processes in MONERIS. There are seven pathways for nutrient emission into surface waters:

here are seven pathways for nutrient emission into surface waters:

- point sources (from municipal waste water treatment plants and direct industrial discharge)
- atmospheric deposition on water surface areas
- groundwater
- tile drainages
- urban areas (sealed)
- erosion
- overland flow (dissolved nutrients

Whereas point emissions from waste water treatment plants and industrial sources are directly discharged into the rivers, diffuse emissions into surface waters come from different pathways, represented by separate flow components. The direct and diffuse components must be separated, since the underlying processes and the nutrient concentrations are different.

The model facilitates beneath the calculations of emissions into surface waters, calculations of nutrient retention in surface waters, and allows a comparison between the calculated and the observed loads.

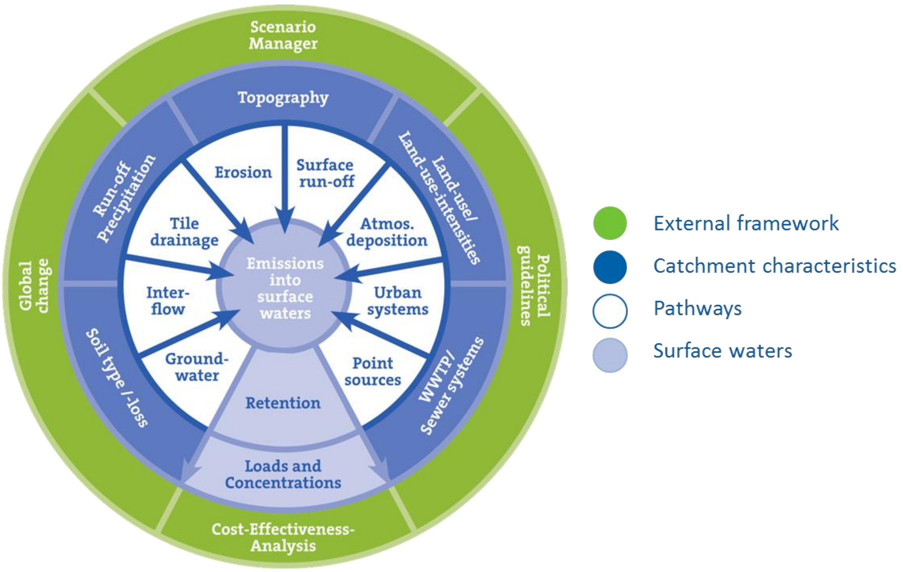


Figure 1: Structure of the MONERIS model showing the external framework, catchment characteristics, pathways, and surface waters (Venohr et al 2011).

2. First steps

System requirements

Following system requirements must be fulfilled to work with MONERIS 3.0:

Software:

MONERIS 3.0

- Systems Software Microsoft Windows XP or Windows 7
- Microsoft .NET Framework 2.0

MONERIS Import Tool

- ArcGIS 9.3.1, ArcGIS 10.0 ,
- Spatial Analyst extension

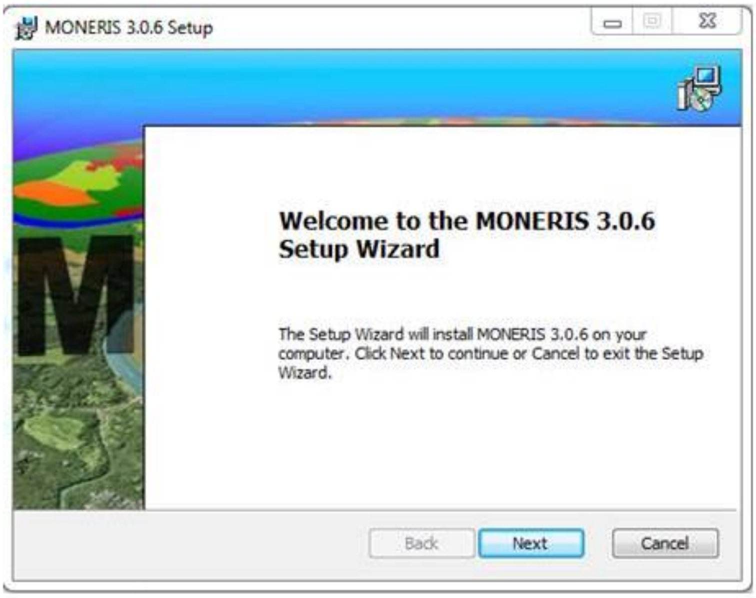
Hardware:

- 4 GB RAM memory
- About 100 MB free hard disc (without Data)
- Display resolution of 1024 x 768

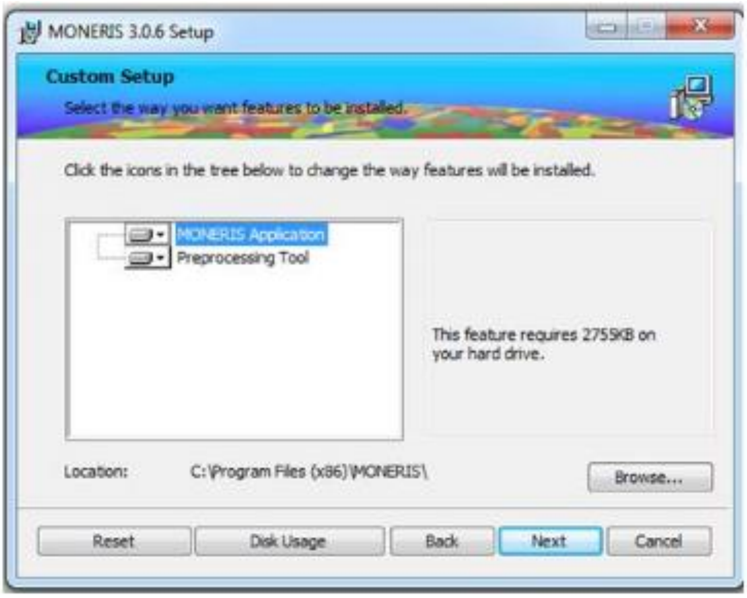
Notes on installing and starting the program

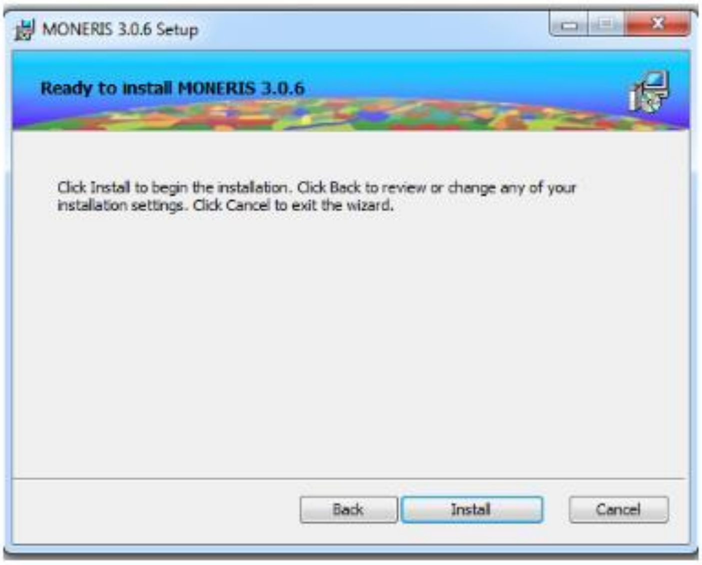
Starting the setup

The setup to install MONERIS is started by double clicking on **IGB.Monerisv3.0_w7_x86. msi**.

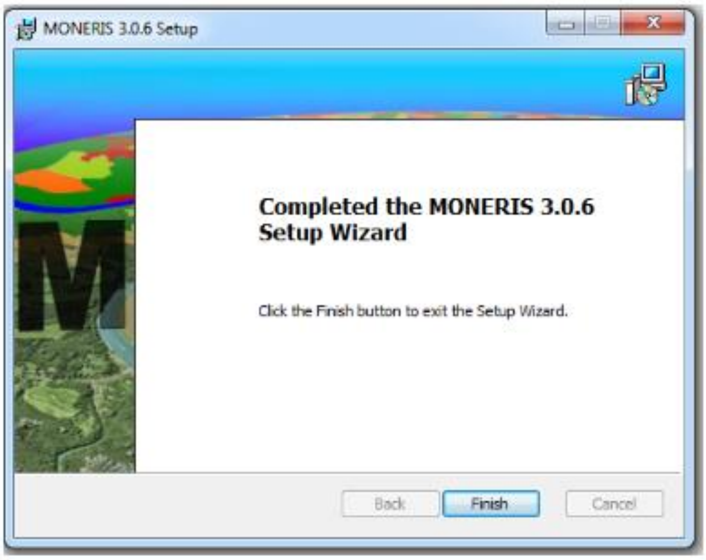


After accepting the licensing agreement, both the components to be installed and the target directory for installation are selected.





After installation, end the setup by clicking **Finish**.



The links to MONERIS Program and preprocessing tool will appear on the desktop after installation.

Start

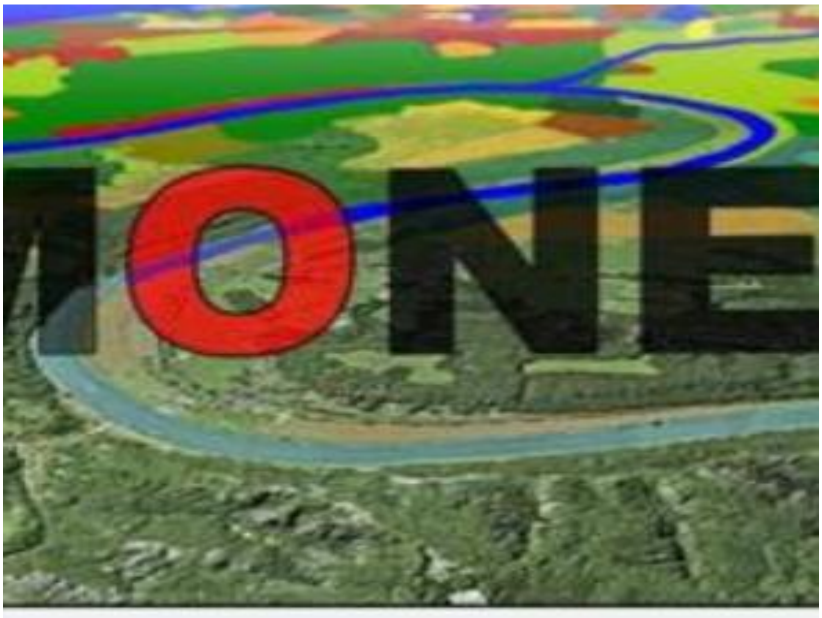
To start MONERIS, double click on the **MONERIS** icon. The user interface is opened.

3. MONERIS main menu

User surface design

The user surface in MONERIS comprises the following four menu points:

- Model setup
- Management alternative settings
- Calculate settings
- Results

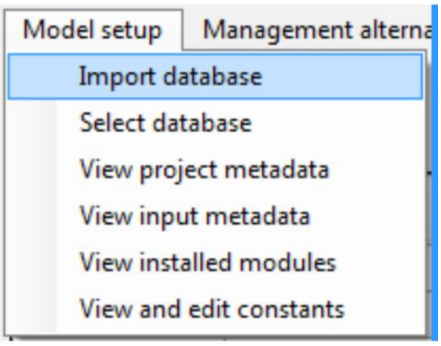


Your first step as a user is to connect to the input and output databases (MONERIS-in.mdb, MONERIS-out.mdb and optionally MONERIS-Scenario.mdb). Depending on the extent of your calculations, calculations can be carried out for single years already in the second step using the **Calculate settings menu item** (see section **Calculate single years**), or you can start calculations considering specific hydrological conditions (dry or wet years, long term means) after defining management alternatives (see sections **Management alternative settings** and **Calculate hydrological conditions**).
Using the Elbe Expert Toolbox, an input scenario set can be prepared for the Elbe river basin. An input scenario set is related to scenario data in scenario database (MONERIS_Scenario.mdb).
The scenario data will be used instead of the standard input data if connection to scenario database has been established using **Model setup → Select Database**.

4. Model setup

Importing a database

Via the menu **Model setup → Import Database** the user can import input data from database format of version 2.16.018 to a MONERIS-In.mdb database of the current version.



Note: A tooltip guides the user through the necessary steps and gives helpful explanations on the menu point. To export results in to a VBA/Excel-MONERIS database: see section **Export results**.

To import input data from database format of version 2.16.018:

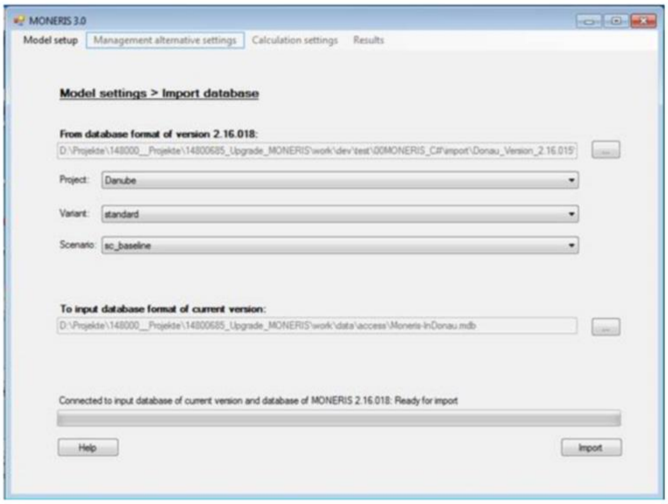
1. Use browse button to select the database of version 2.16.018.
2. Use appropriate combo box to select desired project, variant and scenario.
3. Use browse button to select an empty input database of the current MONERIS version.
4. Press the **Import** Button.
5. The selected input database of the current MONERIS version is now filled with data from the database of version 2.16.018.
6. Optionally, proceed with the Model setup > Select Database menu option in order to continue working with the freshly filled input database.

Note: Data of only one variant can be imported into a database of current version. If data of more than one variant shall be imported, different copies of current version ‘s database has to be used.

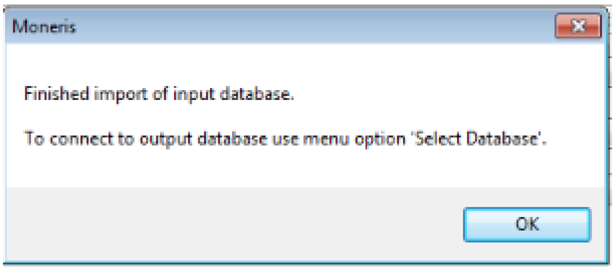
If your data is stored in a database of an older version, the data has to be copied into a database of version 2.16.018.

An empty database of version 2.16.018 (Moneris-IGB.mdb is available in **<installation directory>template\mdb**.

It is recommended to work with a local copy of this database.

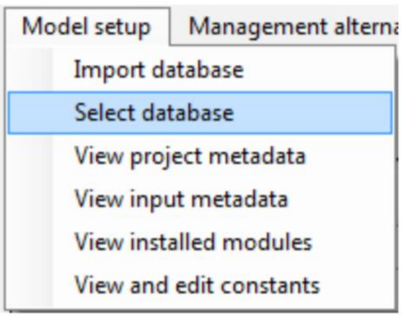


After the import process is finished, a message box will appear. The message box reminds you that you still have to connect to output database. Therefore, you have to switch to menu option **Select database**.



Selecting a database

Via the menu **Model setup → Select Database** the user can select databases.



The output database can be empty while the input database has to contain the complete data required for the MONERIS calculation. The input database can be filled with input data either:

- by importing data from a database format of version 2.16.015 or
- by using the pre-processing tools of MONERIS.

An empty input database (Moneris-In.mdb) and an empty output database (Moneris-Out.mdb) of current version is available in **<installation directory>template\mdb**.
It is recommended to work with a local copy of these databases.

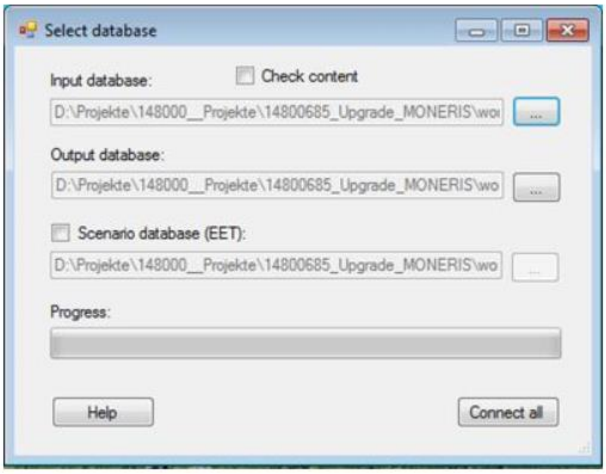
You can navigate to the input, output and optionally scenario databases via the **OPEN** dialog. The connection path to the selected database is shown in the appropriate text box.

Using the Elbe Expert Toolbox, an input scenario set can be prepared for the Elbe river basin. An input scenario set is related to scenario data in scenario database (MONERIS_Scenario.mdb).

The scenario data will be used instead of the standard input data if connection to scenario database has been established using **Model setup Select Database**.
The database path is stored as user setting. If you start MONERIS next time, these database path’s appear in the related text boxes.

Under the precondition that the database is not moved or renamed you can use **CONNECT ALL** Button to connect to all databases.

A progress bar shows the successful import of the input data tables.



Tables of the input and output databases

Table 1: Tables of input database

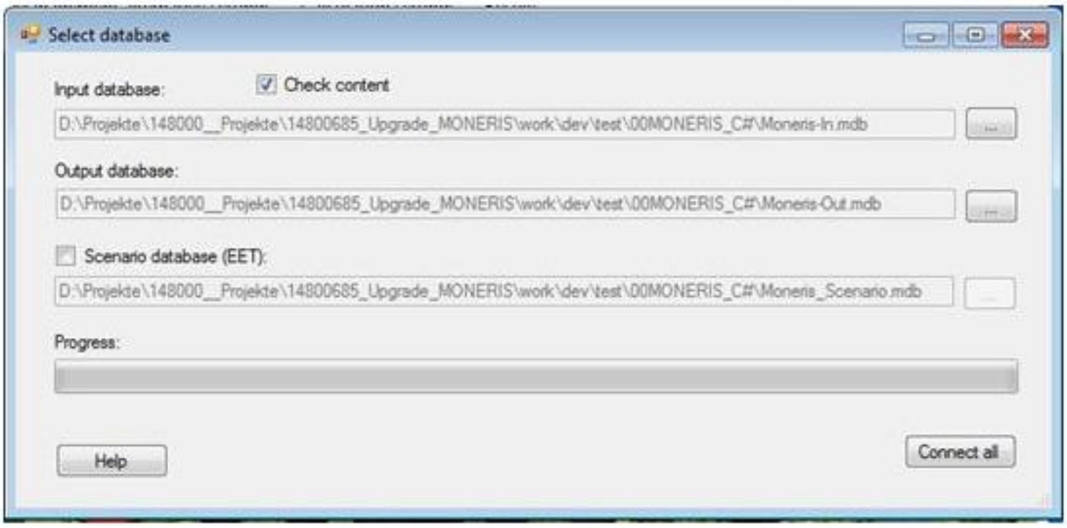
No.	Table name	Explanation	Table in DB of VBA-Version
1	CoordinationArea	Name, keyfield	Name in basicinfo (BI_WA)
2	Country	Country name	Name in basicinfo (BI_Country)
3	RiverBasinDistrict	River basin district	Name in basicinfo (BI_RBD)
4	State	State	Name in basicinfo (BI_State), IDs in country_meta
5	TimeSeries	Parameter names, frequency and units of periodical data	Attributes in periodical_data, monthly_hydrology_optional, country_data, monitoring station
6	TimeSeriesValue	Periodical values	Values of periodical_data, monthly_hydrology_optional, country_data, monitoring station
7	DischargePoint	Discharge point	individuell_wwtp (TS_1≠ "Y")
8	MonitoringStation	Name of Monitoring station	monitoring_data (staticvalues)
9	WasteWaterTreatmentPlant	Waste water treatment plant	individuell_wwtp (TS_1 = "Y")
10	AnalyticalUnit	EMEP parameter, elevation information, nitrogen surplus and area topology based on each individual area	basicinfo
11	Hydrogeology	Hydrogeological data, mean groundwater residence time	basicinfo
12	Hydrology	Data on evapotranspiration and precipitation	basicinfo
13	InputMetadata	more information about e.g. institution provided data, download link from data	project_meta
14	LandUse	Land use data; nitrogen surplus	basicinfo
15	ProjectMetadata	Modeler name, river system, Reference year N surplus, Scale factor	
16	Scenario		
17	Soil	Soil data, phosphorus accumulation; Nitrogen and clay contents in the soil	basicinfo
18	SoilLoss	Soil loss on arable land with slope less and soil loss on Grassland and natural covered area	basicinfo
19	SurfaceWater	Flow length of main river and tributary; Area of lakes in main river and tributary	basicinfo
20	SurfaceWaterMapLookup	as Basis for Scale factor	

Table 2: Tables of outputdatabase

Nr	Table name	Explanation	Table in DB of VBA-Version
1	ChangedConstants	Constants can be changed by modeler	Constants.mdb
2	ChangedModules	Modules can be changed by modeler	
3	ChangeNSurplusLookup	How can Nsurplus changed	
4	Constants	standard value are saved in source code	
5	ConstantsSettings		
6	InputScenarioSet	Can be filled in EET,manages scenario data from other models (SWIM, LUS, RAUMIS)	
7	ManagementAlternative	Name of management alternative	New attribute in scenario_settings
8	ManagementOption	Properties of package of measures	measure_groups
9	ManagementSetting	Spatial assignment of package of measures to analytical units	scenario_settings
10	ModuleSettings	Coded value domain	
11	ProjectMetadata		
12	Scenario	Master table of result metadata (related to TimeSeriesValue, InputScenarioSet, ManagementAlternative, ChangedConstants, ChangedModules	
13	StaticResults	Result table for static results	
14	TimeSeries	Parameter names of periodical results	Attributes of results, results_monthly, results_CEA
15	TimeSeriesValue	Periodicalresults	Values of results, results_monthly, results_CEA

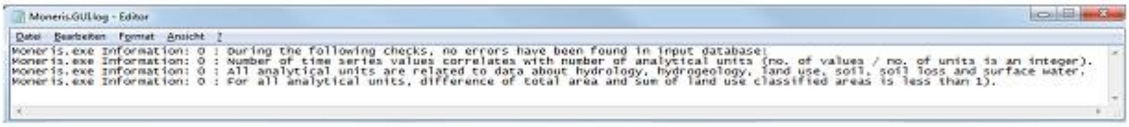
Check of databases

By clicking the **Check content** box a brief check of the input database is automatically performed when connecting with the database.

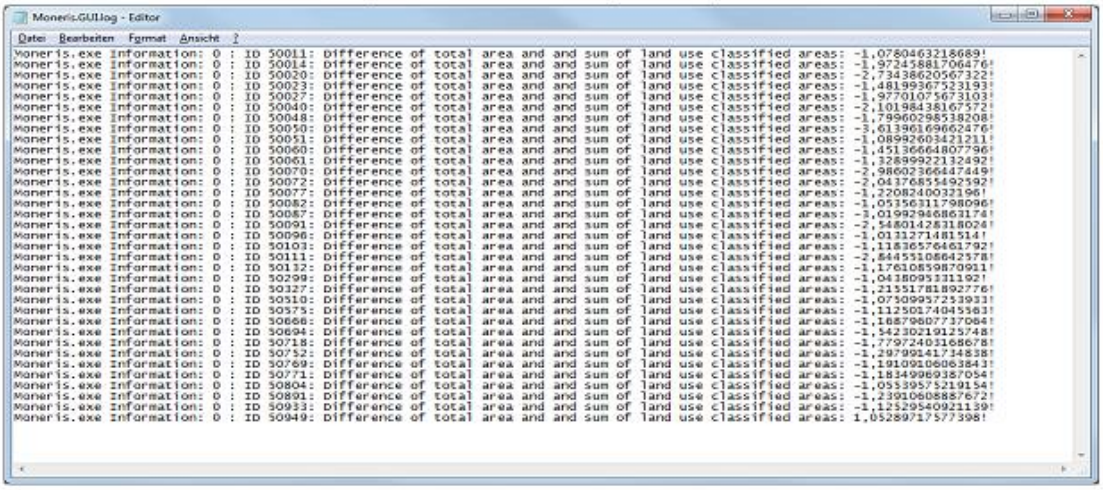


The result is then saved in a log file in the user´s Windows Temp-directory, e.g.
C:\Users\userxyz\AppData\Local\Temp\Moneris.GUI\Moneris.GUI.log

The file is automatically opened after being checked. In case no errors were found, the types of checks performed are listed.



In case errors were found, they are listed according to AnalyticalUnits IDs:



The following tests are performed:

For every Time Series entry for AnalyticalUnits:

- Does the number of related TimeSeriesValues correspond with the number of Analytical Units, and is the TimeSeriesValues / AnalyticalUnits number thus an integer?

For every Analytical Unit:

- Does is have related entries in the tables Hydrology, Hydrogeology, Land Use, Soil, Soil Loss und Surface Water?
- Does the total area equal the sum of areas of the single land use classes? Thus is total area minus land use areas <= absolute value of 1 Parameter?

In case errors were found, the menu option Calculation settings stays disabled. If you decide to calculate with this input data anyway, you have to establish the connection to input database again - but without ticking Check content check box.

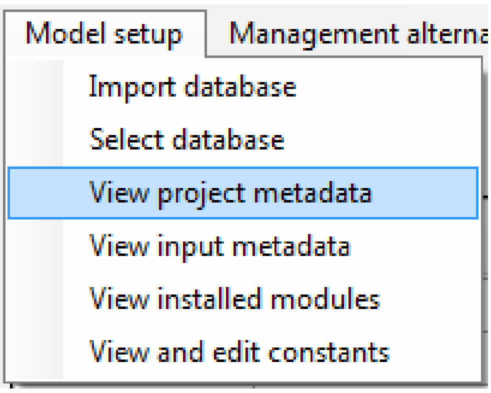
View project metadata

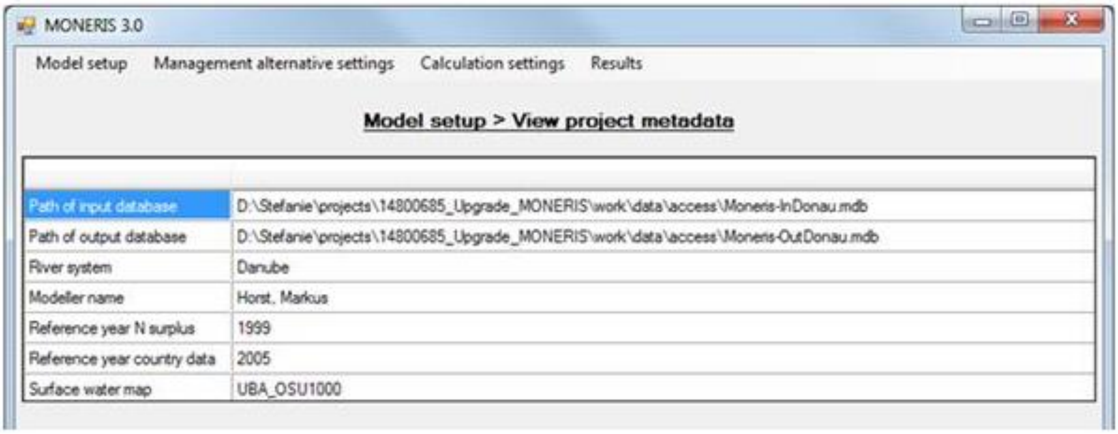
The modeler may describe the project and configure the model via metadata. To this end, open the input database via Access and enter the desired parameter into the **PROJECTMETADATA** table.
The **PROJECTMETADATA** table of the input database enables to set the following parameters:

Table 3: Parameters of inputdatabase

<table>
<tr><th>Parameter</th><th>Description</th></tr>
<tr><td>FirstSetup</td><td>Date of the first model setup</td></tr>
<tr><td>LastUpdate</td><td>Date of the last model setup</td></tr>
<tr><td>ModellerName</td><td>Name of the modeler</td></tr>
<tr><td>RiverSystem</td><td>Name of the river system
When model results are saved to the output database, the name of the river system is copied to the PROJECTMETADATA table of the output database.
This is important for the following executions of MONERIS. By mistake it might happen that this output database is selected together with an input database of another river system. Then, the user is informed by a message box and can select the appropriate input database of the matching river system.</td></tr>
<tr><td>RefYearNSurplus</td><td>Regarding country wise input data, it is possible to choose one reference year by which to investigate temporal changes of nutrient surpluses. This is necessary when the model is calculated for hydrological conditions (long term mean, dry or wet conditions). When 2015is chosen as reference year, development of the nitrogen surplus until 2015 is used for the calculation. This can be important for calculation of the mean nitrogen surplus during the groundwater residence time.</td></tr>
<tr><td>ScaleFactor</td><td>According to the surface water map used during preprocessing of input data, a scale factor has to be chosen. This scale factor influences the later calculation of surface areas from main rivers and tributaries.
Possible scale factors are stored in the SURFACEWATERMAPLOOKUP table of the input database.
<table>
<tr><th colspan="2">SurfaceWaterMapLookup</th></tr>
<tr><th>SurfaceWaterMapID</th><th>SurfaceWaterMap</th></tr>
<tr><td>0</td><td>DTK25</td></tr>
<tr><td>1</td><td>UBA1000</td></tr>
<tr><td>2</td><td>UBA_OSU1000</td></tr>
<tr><td>3</td><td>DLM250</td></tr>
<tr><td>4</td><td>DLM1000</td></tr>
<tr><td>5</td><td>BART1000</td></tr>
<tr><td>6</td><td>DCW1000</td></tr>
</table></td></tr>
<tr><td>ReferenceYearCountry</td><td>The country wise input data does not contain time series values for hydrological conditions. Therefore, a reference year has to be chosen. When the model is calculated for hydrological conditions, country wise input data of the chosen reference year are used.</td></tr>
</table>

By the menu point **Model setup → View project metadata**, the user is shown the project metadata.

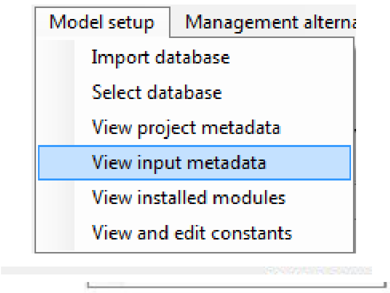


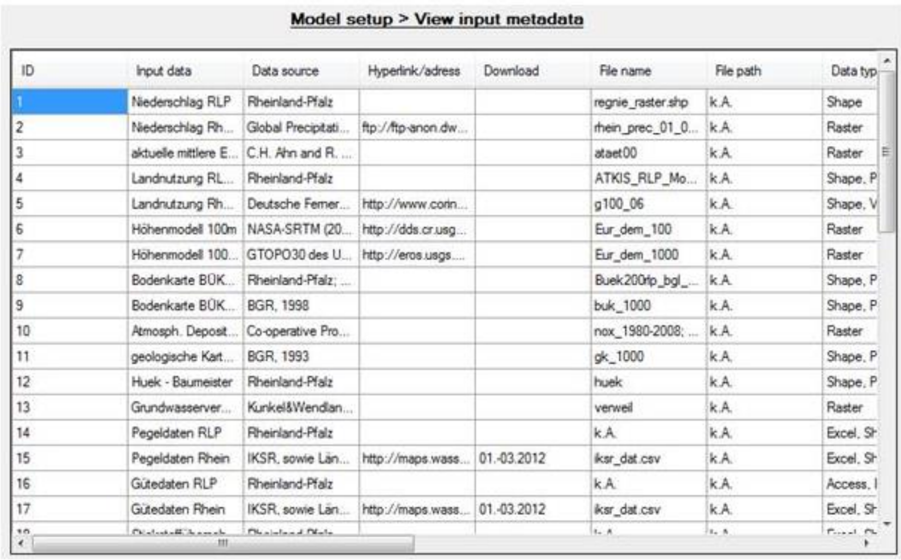


View input metadata

The modeler may describe input data via metadata. To this end, open the database via Access and enter the desired parameter into the **INPUTMETADATA**table.

By the menu point **Model setup → View input metadata**the user is shown the metadata.





ID	Input data	Data source	Hyperlink/adress	Download	File name	File path	Data typ
1	Niederschlag RLP	Rheinland-Pfalz			regnie_raster.shp	k.A.	Shape
2	Niederschlag Rh...	Global Precipitati...	ftp://ftp-anon.dw...		rhein_prec_01_0...	k.A.	Raster
3	aktuelle mittlere E...	C.H. Ahn and R. ...			ataet00	k.A.	Raster
4	Landnutzung RL...	Rheinland-Pfalz			ATKIS_RLP_Mo...	k.A.	Shape, P
5	Landnutzung Rh...	Deutsche Ferner...	http://www.corin...		g100_06	k.A.	Shape, V
6	Höhenmodell 100m	NASA-SRTM (20...	http://dds.cr.usg...		Eur_dem_100	k.A.	Raster
7	Höhenmodell 100...	GTOPO30 des U...	http://eros.usgs....		Eur_dem_1000	k.A.	Raster
8	Bodenkarte BÜK...	Rheinland-Pfalz; ...			Buek200rlp_bgl_...	k.A.	Shape, P
9	Bodenkarte BÜK...	BGR, 1998			buk_1000	k.A.	Shape, P
10	Atmosph. Deposit...	Co-operative Pro...			nox_1980-2008; ...	k.A.	Raster
11	geologische Kart...	BGR, 1993			gk_1000	k.A.	Shape, P
12	Huek - Baumeister	Rheinland-Pfalz			huek	k.A.	Shape, P
13	Grundwasserver...	Kunkel&Wendlan...			verweil	k.A.	Raster
14	Pegeldaten RLP	Rheinland-Pfalz			k.A.	k.A.	Excel, Sh
15	Pegeldaten Rhein	IKSR, sowie Län...	http://maps.wass...	01.-03.2012	iksr_dat.csv	k.A.	Excel, Sh
16	Gütedaten RLP	Rheinland-Pfalz			k.A.	k.A.	Access, I
17	Gütedaten Rhein	IKSR, sowie Län...	http://maps.wass...	01.-03.2012	iksr_dat.csv	k.A.	Excel, Sh

View installed modules

The model core is split into several exchangeable modules. This way, MONERIS modelers with basic knowledge of the computer language .NET C# can make model changes in the source code and test them on their own. To this end, the core module you intend to modify must be loaded into a separate C# project and compiled in a program library (dll) after reediting. You can pass this program library on to other MONERIS users. All you need to do is copy the program library to the PlugIn directory. MONERIS will recognize the module at next application and use it instead of the standard implementation. The PlugIn directory is made up of sub directories assembled in the directory of generic program libraries. Depending on the operation system, it can be called different names:

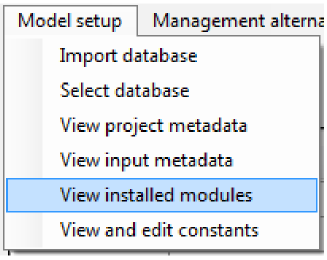
Windows7/ English:

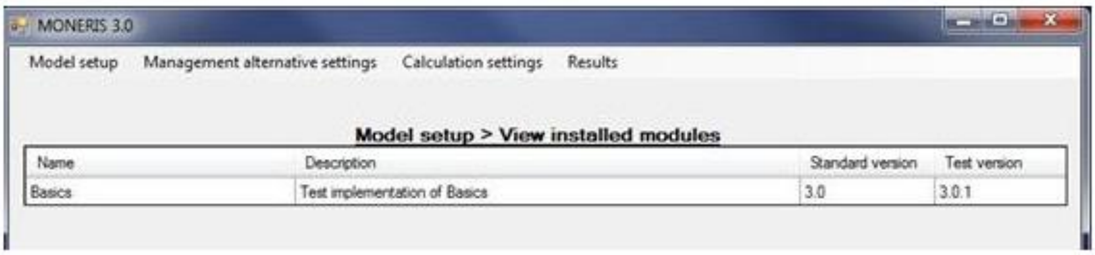
C:\Program Files (x86)\Common Files\MONERIS\DotNet\PlugIns\Engines\Test

Windows XP/ German:

C:\Programme\Gemeinsame Dateien\MONERIS\DotNet\PlugIns\Engines\Test

By **Model setup > View changed modules** the modules present in the PlugIn directory are indicated:





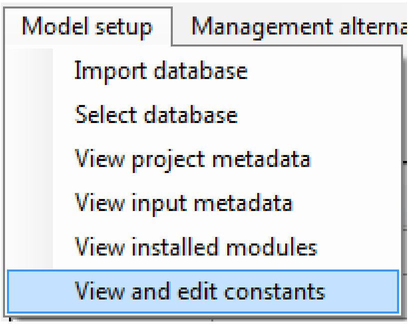
Due to the modular manner of the model core, the basic calculations concerning areas, water, etc. are detached from the actual calculation of nutrients. In addition to this basis module for every nutrient (nitrogen, phosphorus, silicium), there is an individual module which accesses the basic calculation results via interfaces. Further, separate modules exist for calculation of the retention and the cost-benefit-analysis of measures, as well as monthly disaggregation of the annual results. In detail these are the following modules:

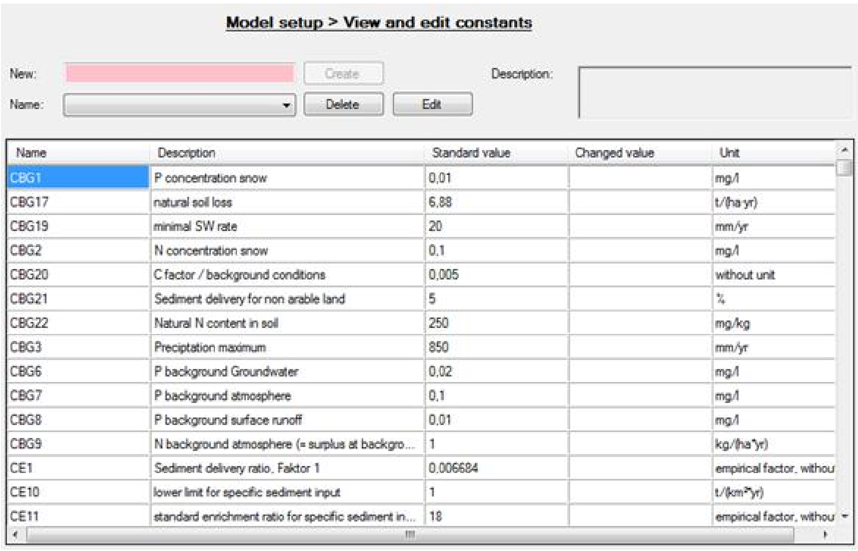
Table 4: Separate modules

Name	Content
Basics	General calculations of areas, water, non-specific emissions, as well as summation of point sources input data
EmissionsNitrogen	Emissions nitrogen
EmissionsPhosphorus	Emissions phosphorus
EmissionsSilicium	Emissions silicium
Retention	Retention
CostEffectivenessAnalysis	Cost-benefit-analyses for measures
MonthlyDisaggregation	Disaggregation of annual results into monthly results

View and edit constants

Within the model core of MONERIS, the standard values of constants are hard-coded.
By the menu point **Model setup → View changed constants** the user is shown the standard values of the constants.





Name	Description	Standard value	Changed value	Unit
CBG1	P concentration snow	0,01		mg/l
CBG17	natural soil loss	6,88		t/(ha·yr)
CBG19	minimal SW rate	20		mm/yr
CBG2	N concentration snow	0,1		mg/l
CBG20	C factor / background conditions	0,005		without unit
CBG21	Sediment delivery for non arable land	5		%
CBG22	Natural N content in soil	250		mg/kg
CBG3	Preciptation maximum	850		mm/yr
CBG6	P background Groundwater	0,02		mg/l
CBG7	P background atmosphere	0,1		mg/l
CBG8	P background surface runoff	0,01		mg/l
CBG9	N background atmosphere (= surplus at backgro...	1		kg/(ha*yr)
CE1	Sediment delivery ratio, Faktor 1	0,006684		empirical factor, withou
CE10	lower limit for specific sediment input	1		t/(km²*yr)
CE11	standard enrichment ratio for specific sediment in...	18		empirical factor, withou

The modeler may change constants if necessary. To this end, constant settings can be created and used as calculation setting.

To create a new setting of constants:

1. Type name and description of a new setting of constants.
2. Press the '**Create**' button.
3. Enter the new values in the '**ChangedValue**' column of the data grid.
4. Press the '**Save**' button.

To edit an existing setting of constants:

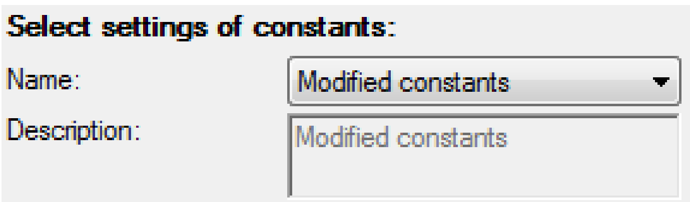
1. Select the setting of constants
2. Press the '**Edit**' button.
3. Enter the new values in the '**ChangedValue**' column of the data grid.
4. Press the '**Save**' button.

To delete an existing setting of constants:

1. Select the setting of constants.
2. Press the '**Delete**' button.

To use an existing setting of constants as calculation setting:

1. Use the menu point **Calculation setting > Calculate hydrological conditions** (or **> Calculate single years**) to open the respective calculation dialog.
2. Select the setting of measures.



5. Management alternative settings

Via the menu point **Management alternative settings**, the user can:

- Define packages of measures
- Define management alternatives
- View management alternatives.

Defining packages of measures

The first step to define a new package of measures is entering a name and a brief description. If the description or the name is missing, the **Select a combination of measures** tab control and the **Save** button are not activated.

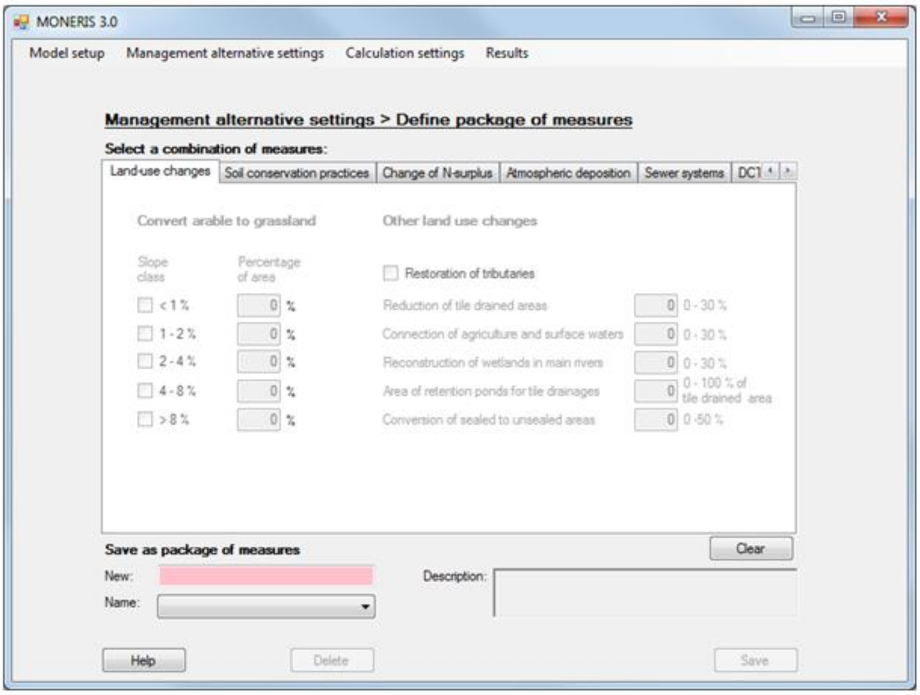
The next step is choosing one or a combination of measures. The combination of settings can be saved as a new package of measures by clicking the **Save** button.

Existing POM cannot be edited but deleted only.

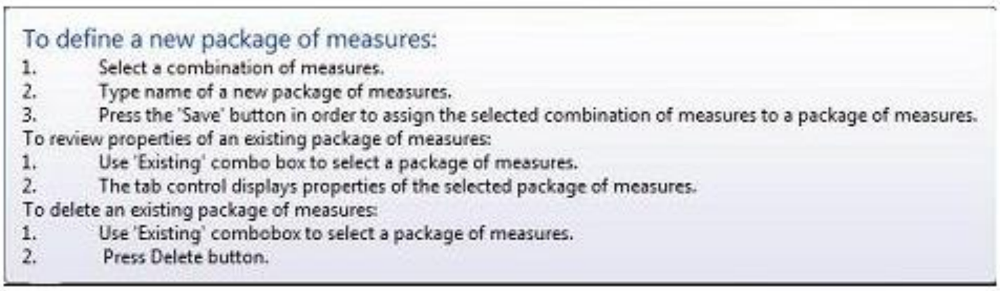
If the output database contains model results or management settings based on that POM, you will be informed by a message box. If you decide to delete the POM anyway, related results and management settings are deleted too.

To delete a package of measures, use the **Existing** combo box to select it and click the **Delete** button on the bottom.

To review a package of measures, select the name in the **existing** combo box.



Note: A tooltip guides the user through the necessary steps and gives helpful explanations on the menu point where needed.

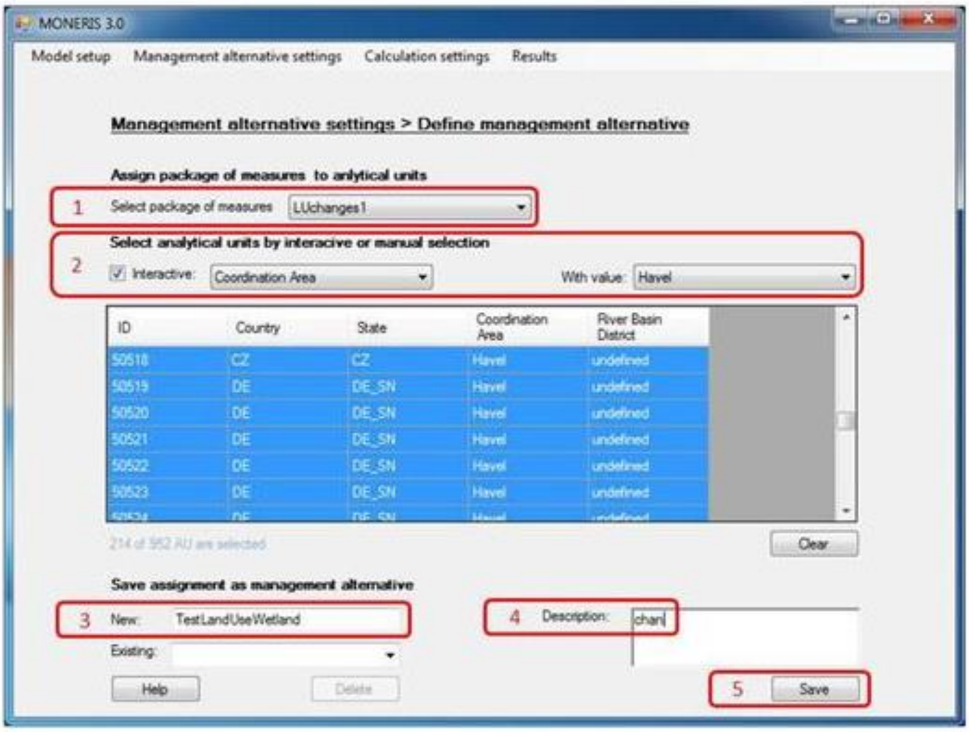

To define a new package of measures:
1. Select a combination of measures.
2. Type name of a new package of measures.
3. Press the 'Save' button in order to assign the selected combination of measures to a package of measures.

To review properties of an existing package of measures:
1. Use 'Existing' combo box to select a package of measures.
2. The tab control displays properties of the selected package of measures.

To delete an existing package of measures:
1. Use 'Existing' combobox to select a package of measures.
2. Press Delete button.

Defining management alternatives

To apply a package of measures to one or more analytical units, a spatial allocation has to be made. This occurs by defining a management alternative. After selecting packages **(1.)** of measures, the user must select an analytical unit **(2.)**. Enter a new name for the management alternative and write a description or select an existing one **(3., 4.)**.



Manual selection of an AU:

Select AUs by clicking onto one or several row headers. You can select all existing AUs at once by clicking on the left table head.

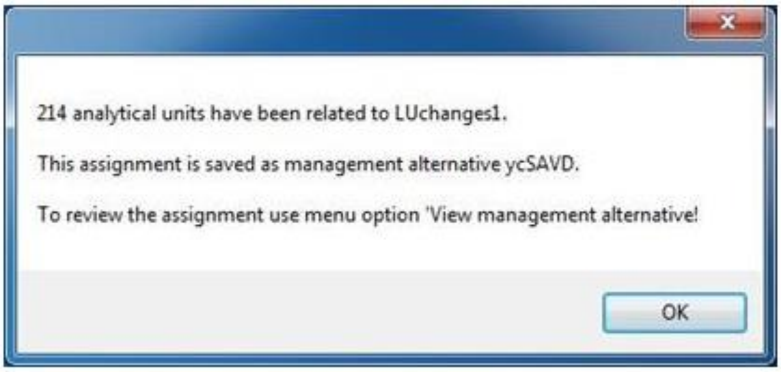
Interactive selection of an AU:

By ticking the Interactive checkbox, AUs can be aggregated on different levels. Depending on the value selected from the dropdown list on the top right, you can set one or more elements as belonging to the aggregation level.

- Country: includes AUs inside a country´s administrative borders
- State: includes AUs inside a state´s administrative borders
- Coordination area: includes connecting AUs inside a working area according to the European WFD
- River Basin District: includes AUs inside a river basin
- Catchment: includes all sub catchments in its boundaries
- ID: AUs can be selected by their ID numbers
- All: All AUs in the project.

To select all AUs at once, select Interactive: **All**.

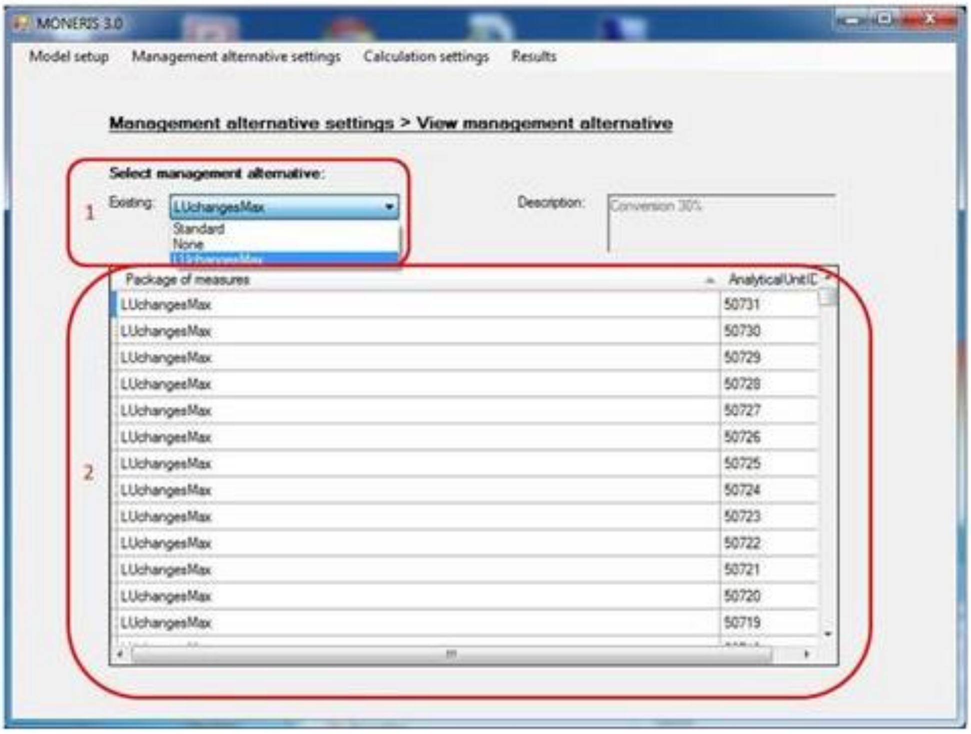
By clicking the **SAVE** button, the selected package of measures is assigned to the selected analytical unit. A message box will inform you about this action and the review option.



Note: A tooltip guides the user through the necessary steps and gives helpful explanations on the menu point where needed.

View management alternative

The user can select a management alternative via an existing combobox **(1.)**.
The data grid displays the assignment **(2.)**.



Selectable measures

In the following, the selectable measures are described in more detail:

Land use changes

These measures take into account:

- Conversion of arable land to grassland
- Restoration of tributaries
- Reduction of drainage areas
- Connection of agricultural areas to surface waters
- Retention ponds for drainageflows
- Conversion of paved surfaces to unpaved surfaces.

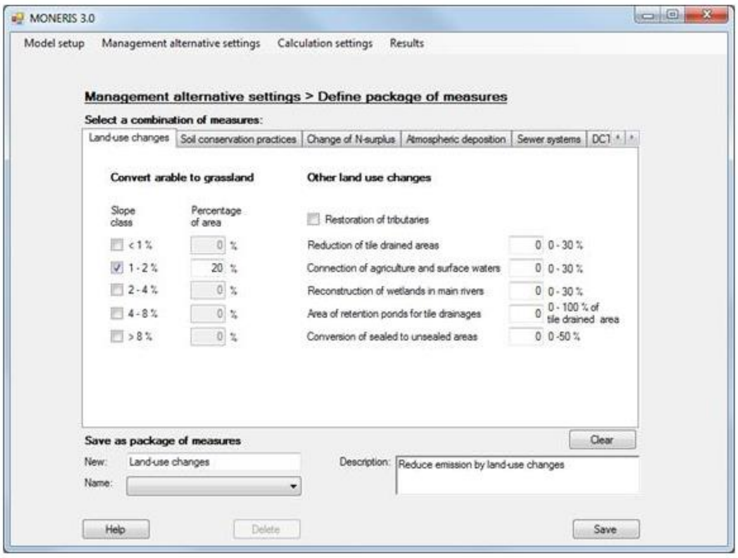
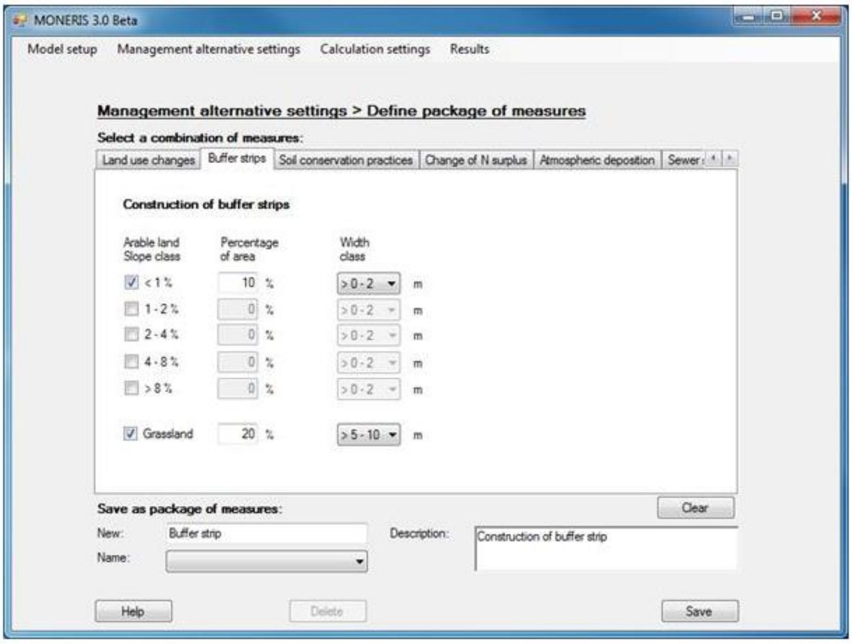


Table 5: Description of measures in the section Land use changes

Measure	Description
Conversion arable land to grassland	Simulates the conversion of arable land to grassland. Influences the pathways of erosion, overland flow and tile drainages. The percentage of arable land to be converted can be determined for different slope classes. A conversion of grassland to arable land (negative area portions) is not possible and could lead to errors in the calculation.
Reduction of tile drained areas	Reduces the tile drained areas, given by the basic information table in %. It is possible to choose a percentage between 0 and 30%. This value refers to the currently given tile drained area.
Connection of agriculture and surface water	The reduction of emissions via overland flow and erosion is simulated by this measure, for example by buffer strips. The user can reduce the percentage of agricultural land which contributes eroded matter directly into the surface water. It is possible to choose a number between 0 and 30%. This number refers to the percentage of total agricultural area in the analytical unit.
Retention ponds for tile drained areas	This measure simulates that discharges from tile drainages enter into retention ponds before they enter surface waters. The area of retentions ponds is given as the hectare pond area per km² tile drained area It is possible to choose a value between 0 and 100%. Considering tile drainage discharges, the hydraulic load of retention ponds is calculated and used for the calculation of retention in retention ponds.
Conversion of sealed to unsealed areas	The calculated impervious urban area can be reduced with this measure. The reduction does not depend on the population density. This new not impervious area is not linked to any land use. It is possible to choose a value between 0 and 50%.

Buffer strips

These measures enable the construction of buffer strips for arable land and grassland.



Soil conservation practices on arable land

These measures take into account:

- Soil conservation
- Contour ploughing
- Intercropping

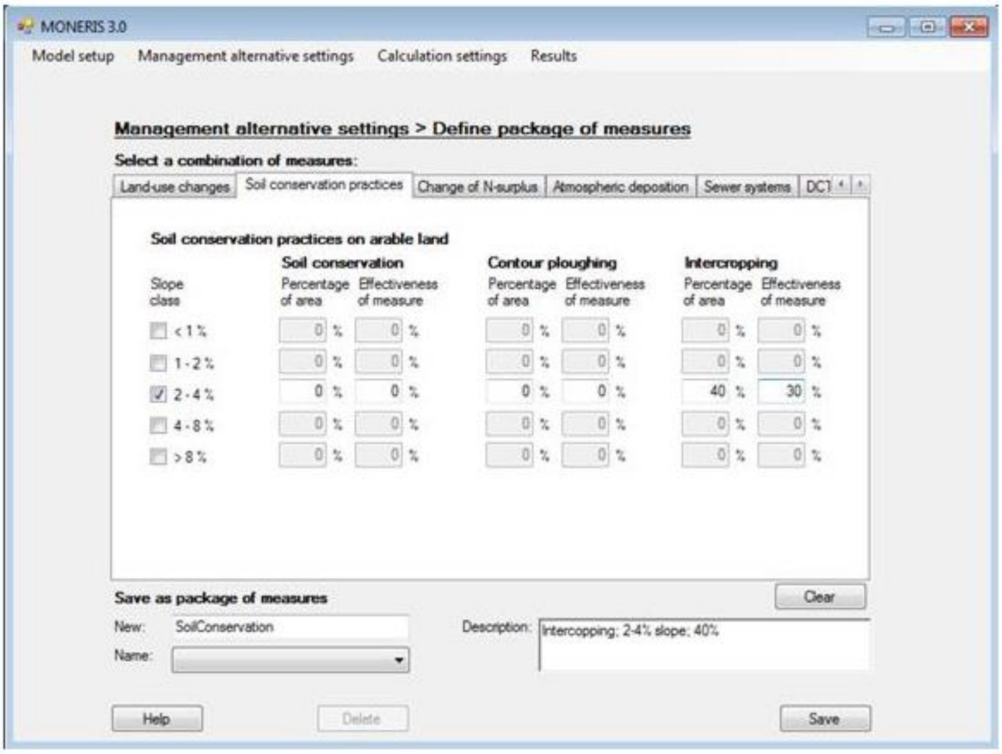


Table 6: Description of measures in the section Soil conservation practices

Measure	Description
Soil conservation practices reduction on arable land	This measure describes the reduction of soil loss on arable land. This adjustment allows the conversion of conventionally used arable land, of different slope classes, into sustainable practice. The estimated reduction can be evaluated for each slope class in %.

Change of nitrogen surplus

These measures take into account:

- Reduction of the nitrogen surplus
  - Maximum of fertilizer and manure
  - Reduction by agri-environmental measures (AEM), e.g.:
- Soil conservation
- Intercropping
- Extensified grassland
- AEMx: others.

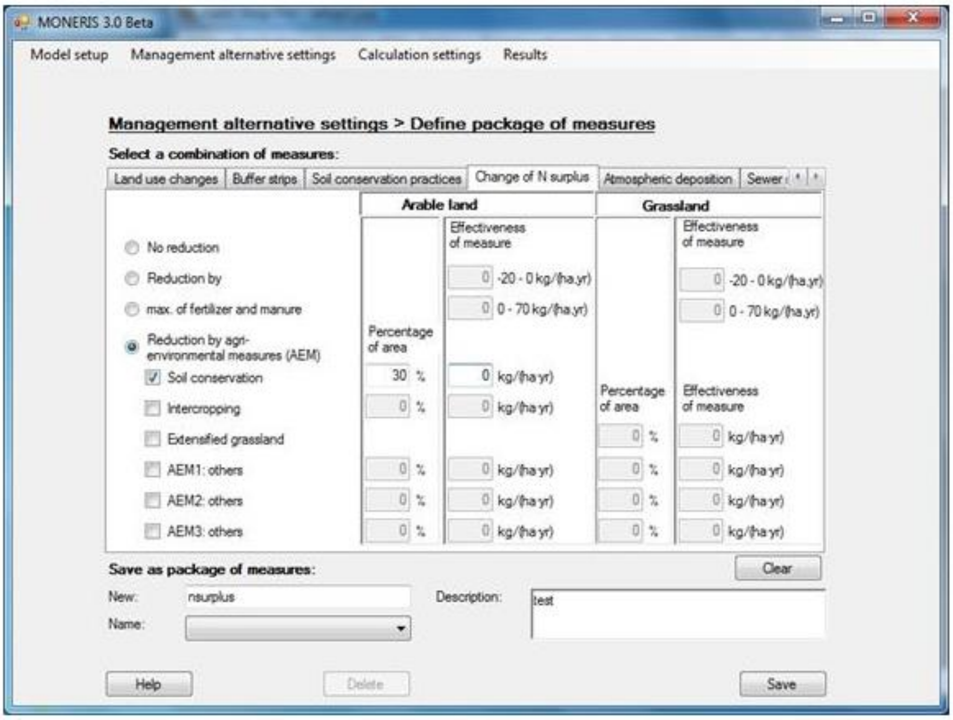


Table 7: Description of measures in the section Change of N surplus

Measure	Description
Reduction of the nitrogen surplus	Applying this scenario, the user can reduce the mean nitrogen surplus of the calculation year (the reference year for scenarios) by a certain amount. The unit is kg/(ha·yr), and refers to the nitrogen surplus.
Max. of fertilizer and manure	This measure states that a certain nitrogen surplus on agricultural land is not exceeded (without the share of atmospheric deposition).

Atmospheric deposition

These measures take into account:

- Reduction of atmospheric NHy und NOx depositions

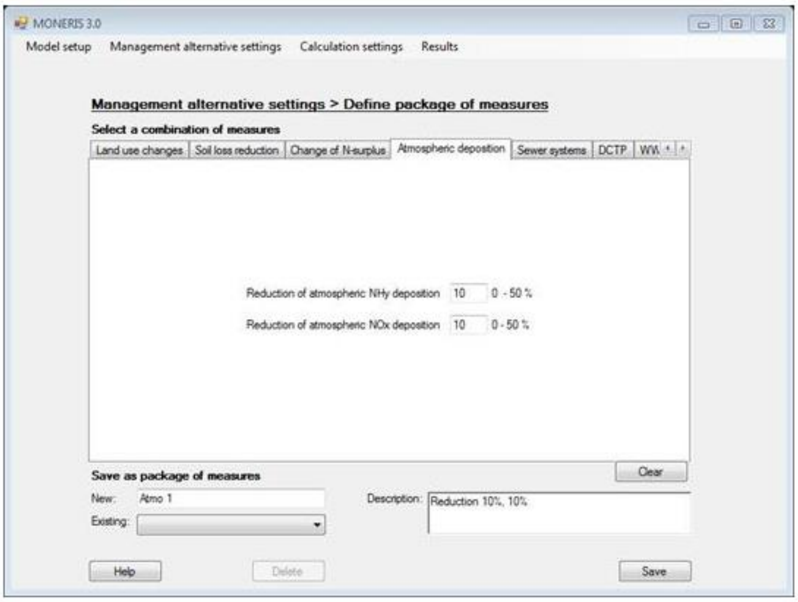


Table 8: Description of measures in the section Atmospheric deposition

Measure	Description
Reduction of atmospheric NHy deposition	Using this measure, the atmospheric deposition of NHy is reduced within the selected analytical unit. This measure is calculated before any other pathways, and thus influences all relevant pathways as well as measures such as maximum nitrogen surplus caused by fertilizer and manure.
Reduction of atmospheric NOx deposition	This measure reduces the atmospheric NOx deposition within the selected analytical unit. In the MONERIS calculation this measure is calculated before any other pathways und thus influences all relevant pathways as well as measures like maximum of nitrogen surplus caused by fertilizer and manure.

Sewer systems

Here, various parameters can be modified that affect nutrient emissions from urban systems, such as:

- Increase of storage volume in combined sewer systems
- Clearing basins for separate sewer discharges
- Soil retention filters for separate sewer discharges
- Inhabitants connected to sewer systems and WWTPs
- Phosphate-free laundry detergents
- Phosphate-free dishwashing detergents

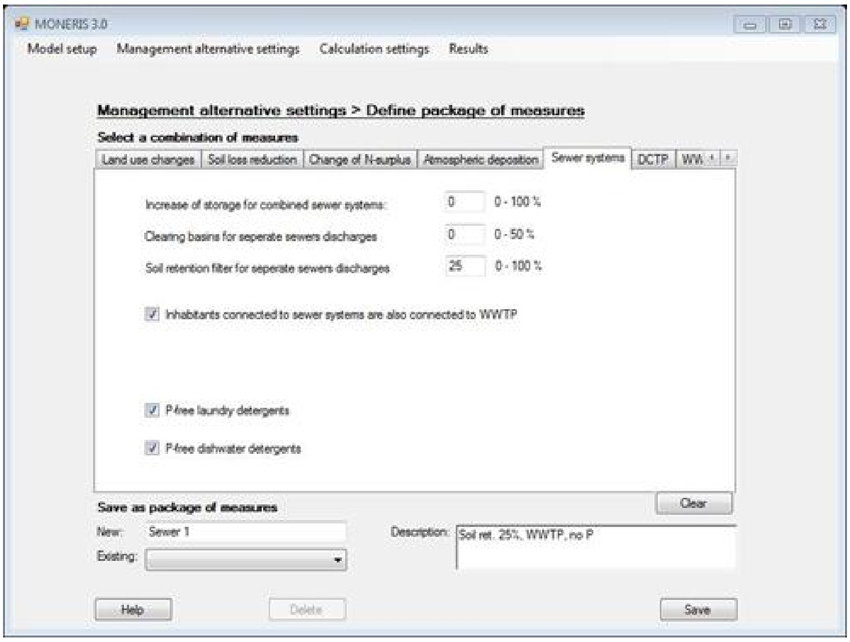


Table 9: Description of measures in the section Sewer system

Measure	Description
Increase of storage for combined sewer systems	This measure simulates the increase of storage volume for combined sewer systems. 100% represents a volume of 23.3 m³/ha of impervious urban area.
Clearing basins for separate sewer discharges	This measure determines which share of the rainwater, transported in separate sewer systems, is treated in storm water sedimentation tanks before it enters the surface water. For storm water sedimentation tanks, a retention of 35% for nitrogen and 35% for phosphorus is estimated.
Soil retention filters for separate sewer discharges	This measure states which share of the rainwater transported in separate sewer systems is treated in soil retention filters before it enters the surface water. For soil retention filters, retention of 80% for nitrogen and 45% for phosphorus is estimated.
Portion of inhabitants connected to sewers and WWTP	This measure expects that all inhabitants connected to sewer systems are also connected to WWTP. This measure does not consider inhabitants that are connected to DCTP or septic tanks.

Small waste water treatment plants

The tab **DCTP** contains measures to reduce the nutrient emissions via decentralized treatment plants.

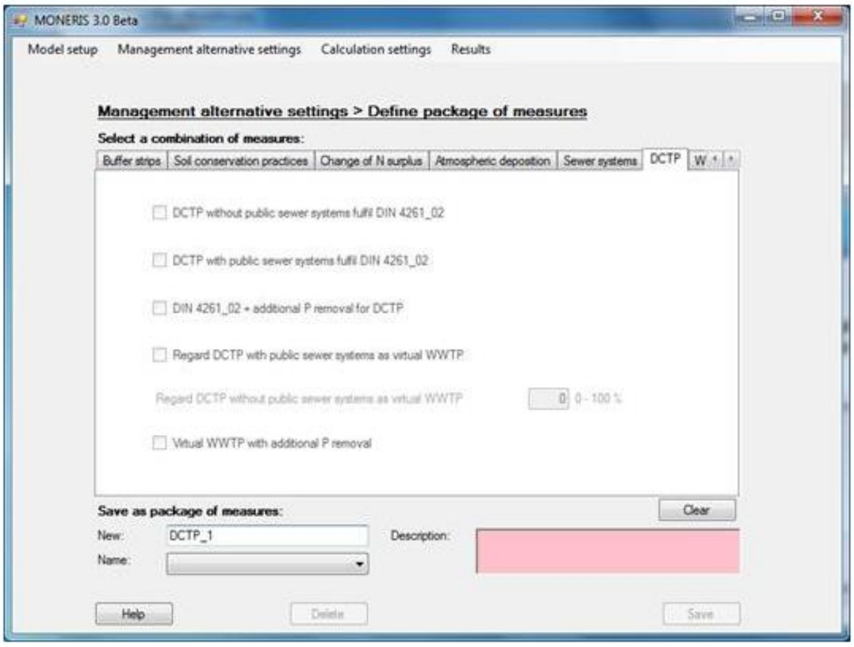


Table 10: Description of measures in the section DCTP (decentralized treatment plants)

Measure	Description
DCTP **without** or **with** public sewer systems fulfil DIN2	Some older DCTPs do not fully comply with the current standards (DIN2), but operate according to DIN1 (TGL). "Standard" means that the current technical status is not changed. "DIN2fulfilled" implies that the older DCTP operates according to the newer DIN2. For DIN1/TGL a retention rate of 10% for nitrogen and 7% for phosphorus is assumed, whereas for DIN2 the retention rates of 15% and 13% respectively are assumed.
DIN2 + additional phosphorus-removal for DCTP	This measure assumes that all DCTPs are run according to DIN 2, and that they have phosphorus elimination.
DCTP with public sewer systems, transformed to virtual WWTP	For this measure it is estimated that all inhabitants connected to DCTPs (and thus to a public sewer system) are also connected to a WWTP, which might be virtual, as it is not yet built.
DCTP without public sewer systems, transformed to virtual WWTP	This measure is analogous to the previous measure, except that it is valid for the sewer systems that are not connected to a public sewer system. As the connection of virtual WWTP is not always possible, the user can set the percentage of inhabitants.
Virtual WWTP with additional phosphorus-removal	If the above mentioned measure "DCTP with/ without public sewer systems, transformed to virtual WWTP" apply (meaning virtual WWTPs exist), this measure implies phosphorus removal for these WWTPs.

Wastewater treatment plants (P and N concentrations)

In the tabs **WWTP P** and **WWTP N**, the effluent concentrations for single WWTPs of a certain size (referring to the number of connected inhabitants) can be defined.
The user can only set concentrations in the range of suggested values. Generally, the concentrations should correspond to the target values of the EU directive for waste water.

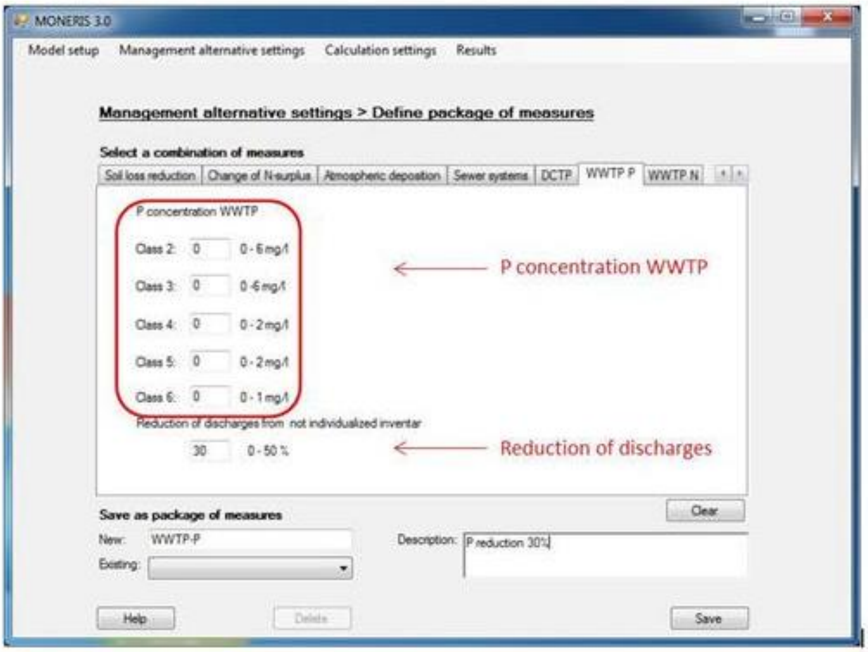


Table 11: Description of measures in the section WWTP-P (wastewater treatment plants – phosphorus):

Measure	Description
P concentrations according to quality classes	This measure assumes that waste water treatment efficiency is increased and concentrations are reduced. If concentrations are already lower than an assumed threshold, they will remain unchanged.

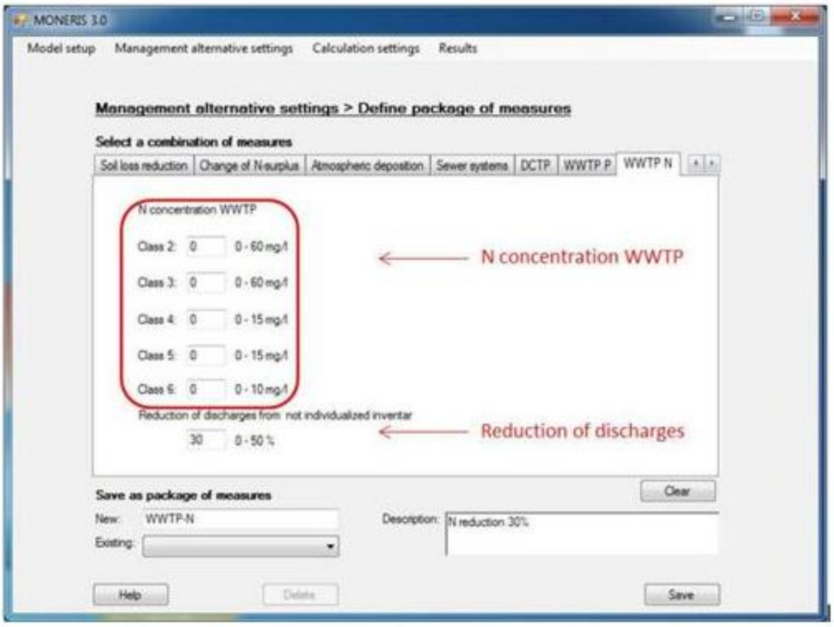


Table 12: Description of measures in the section WWTP-N (wastewater treatment plants – nitrogen)

Measure	Description
N concentrations according to quality classes	This measure assumes that waste water treatment efficiency is increased and concentrations are reduced. If concentrations are already lower than an assumed threshold, they will remain unchanged.

6. Calculation settings

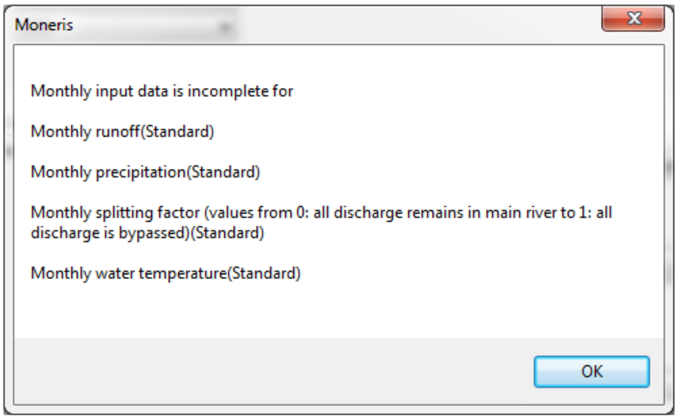
Via the menu **Calculate settings** the user can choose between:

- Calculate single years
- Calculate hydrological conditions.

The following calculation settings can be set for both options:

Monthly Results

Optionally, the annual results can be disaggregated to monthly results. Therefore, the input database has to include monthly input data. If the option **Monthly results** is activated and monthly input data is missing, a message box will appear:



Write results to text files

Optionally, text files with temporary results can be created. The text files are saved in a sub directory of the directory where the output database is stored (Moneris-Out.mdb). Using select all, copy and paste (**Crtl +A**, **Crtl +C**and**Crtl +V**), the content of these files can be moved to an Excel sheet easily.

The following text files are created in sub directory **Results_<Date>_<Time>**:

Table 13: Text files

Name	Description
BasicsLongTerm.txt	Basic calculation for long term conditions (calculated by Basics module).
Basics.txt	Basic calculation for selected years (calculated by Basics module).
Nitrogen.txt	Temporary results calculated by module Emission Nitrogen module.
Phosphorus.txt	Temporary results calculated by module Emission Phosphorus module.
AnnualResults.txt	Annual results
MonthlyResults.txt	Monthly results

Outlet for impact ratio calculation:

To enable calculation of the impact ratios, the user needs to select an analytical unit to serve as the outlet area. This is not necessarily the area located at the outlet of the total river basin, because, for example in case of the Odra, emissions or loads entering the backwater can be more interesting.

Impact ratios for both nitrogen and phosphorus are calculated for each analytical unit. This ratio between load and emission serves to establish the impact of each AU with respect to the total nutrient burden in a river system.

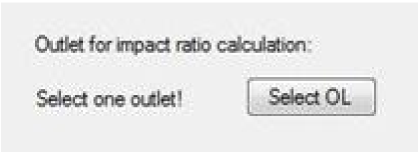
Calculation uses the following formula:

Load (analytical unit)/ Total load at outlet

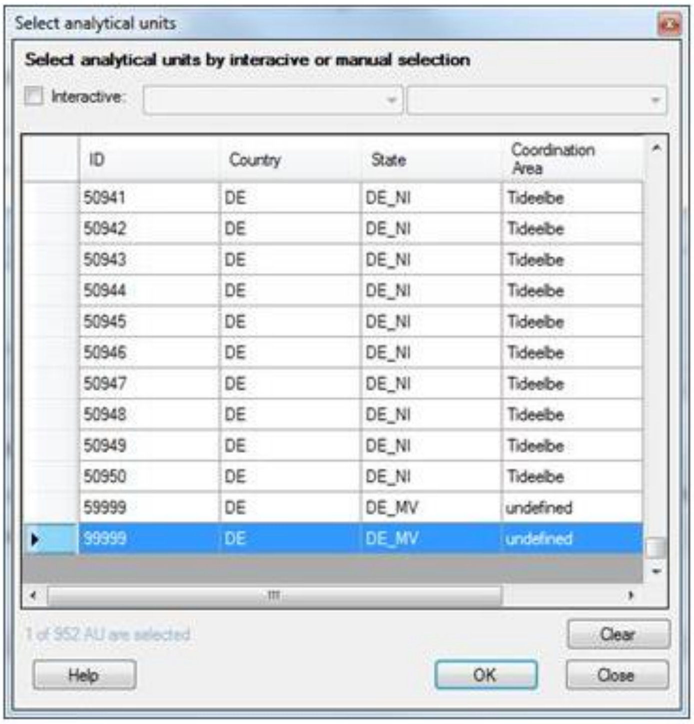
Emission (AU)/ Sum of emissions in the outlet´s total river basin

Selection of area outlet in the GUI:

The **Select OL** button in the dialogs Calculate hydrological conditions or Calculate single years opens a dialog to select an analytical unit. Impact ratios for all analytical units in the total river basin of the selected outlet are calculated with the above mentioned formula.



Selection of analytical units: refer to section **Defining management alternatives**.



Constants setting

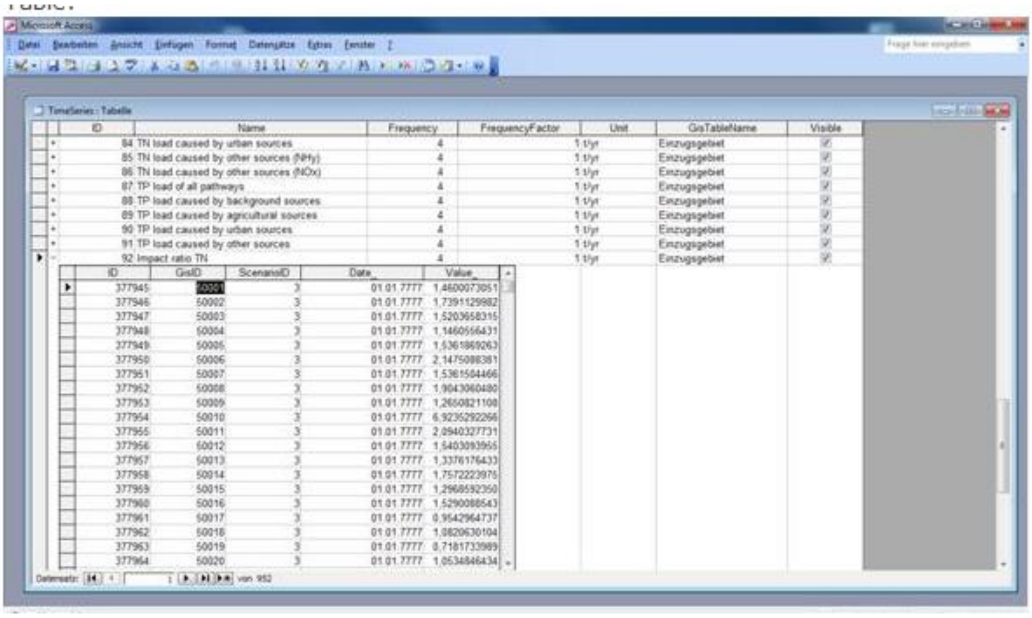
Chapter View and edit constants describes how to modify the standard values of constants and save them as a re-usable setting of constants. Optionally, one of the pre-defined setting of constants can be used for the model run.

Reference year for N surplus calculation

Regarding country wise input data, it is possible to choose one reference year by which to investigate temporal changes of nutrient surpluses. When 2005 is chosen as reference year, development of the nitrogen surplus until 2005 is used for the calculation. This can be important for calculation of the mean nitrogen surplus during the groundwater residence time.

Saving results to the database:

Calculation results can be filed to the results database via Results > Save results (see chapter 7). They are written to the tables TimeSeries and TimeSeriesValue. For example, the impact ratios are filed to TimeSeries.NameImpact ratio TN or Impact ratio TP, respectively, and their according values are laid down in the TimeSeriesValue-Table:

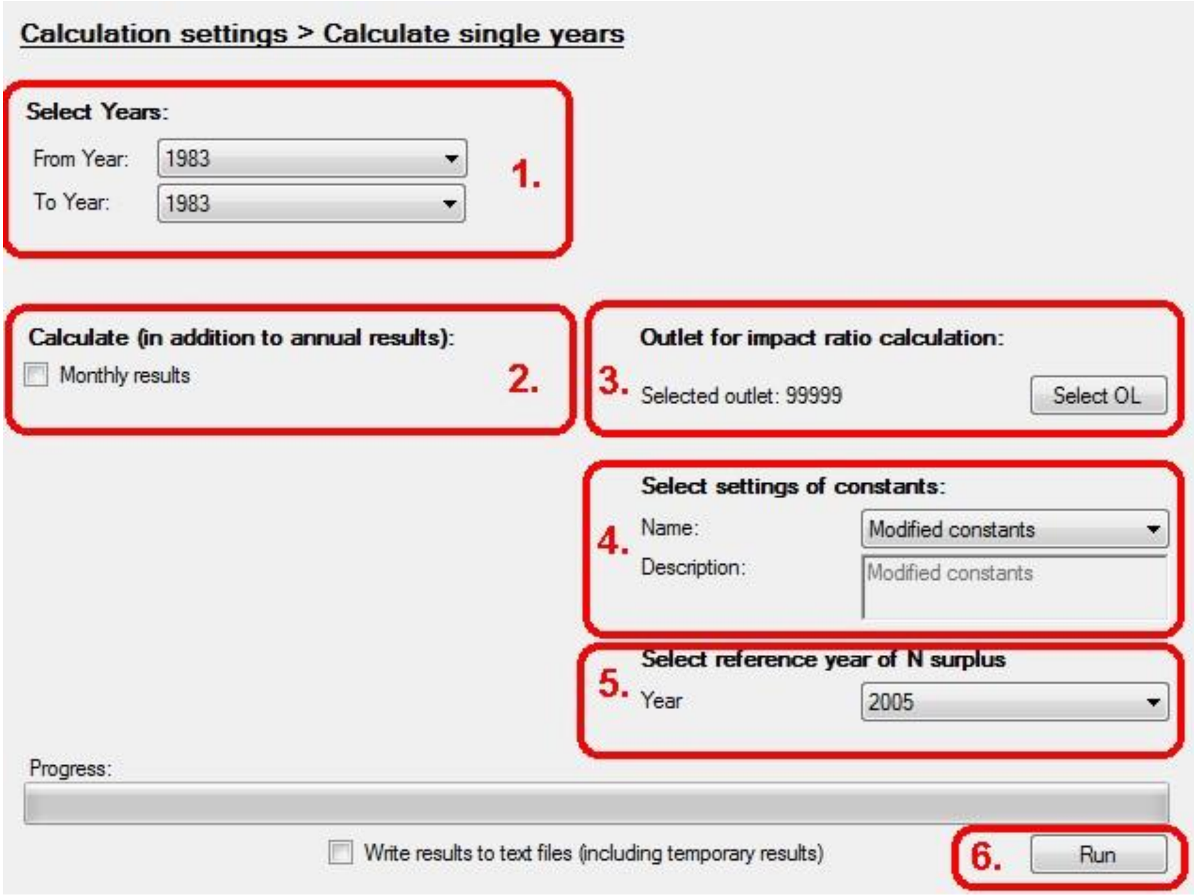


Calculation of single years

Only those years for which input data are available are offered in the drop down menus **(1.)**. Management alternatives are not considered in calculations based on single years.
In a second step, additional result types are selected via checkboxes **(2.)**. Based on single years, only monthly results can be calculated additionally.
Then, one analytical unit has to be selected as the reference outlet to calculate the impact ratio **(3.)**. Optionally, a pre-defined setting of constants can be selected **(4.)**.
As a last step, a reference year for N surplus calculation has to be selected **(5.)**.The drop down menu offers the end years of available country-wise N surplus time series with a minimum length of 55 years.

To create text files with temporary results, tick Write results to text files (including temporary results) check box.

Finally the model run can be started **(6.)**.



Calculate hydrological conditions

In the first step the user must select the management alternative to be applied from the drop down menu **(1.)**.

In a second step the result types (e.g. Target concentration) are selected via checkboxes, and one analytical unit is selected as the reference outlet to calculate the impact ratio(see below) **(2.)**.

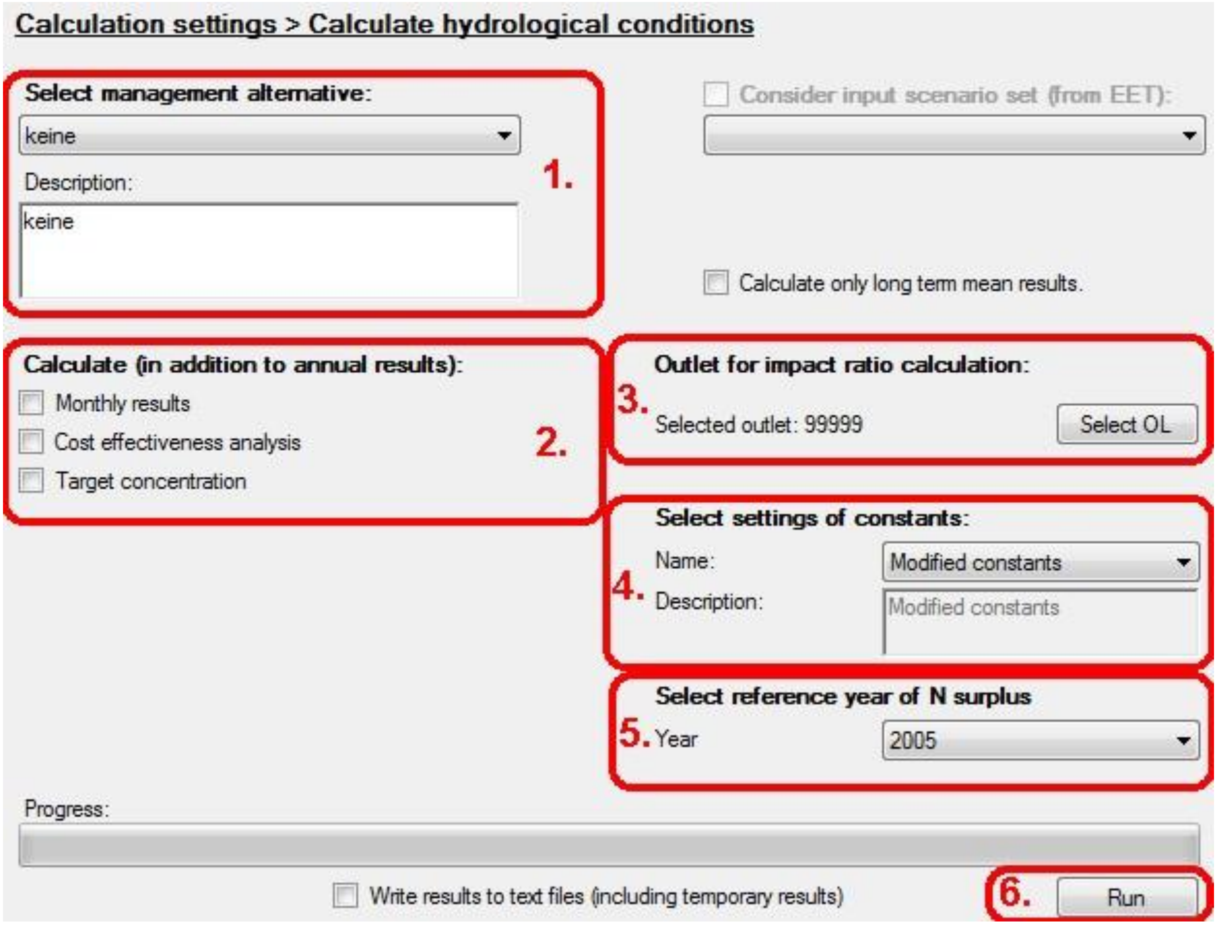
Then, one analytical unit has to be selected as the reference outlet to calculate the impact ratio **(3.)**.

Optionally, a pre-defined setting of constants can be selected **(4.)**.

As a last step, a reference year for N surplus calculation has to be selected **(5.)**.The drop down menu offers the end years of available country-wise N surplus time series with a minimum length of 55 years.

To create text files with temporary results, tick **Write results to text files (including temporary results)** check box.

Finally the user can start the model run **(6.)**.



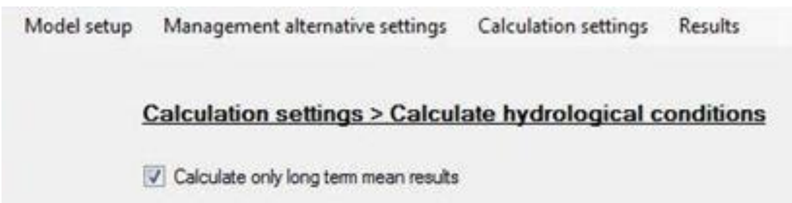
In addition to the general calculation settings described in the beginning of the chapter, the following settings can be set only for hydrological conditions:

Calculate only long term mean results

By default, three different long-term hydrological conditions are calculated:

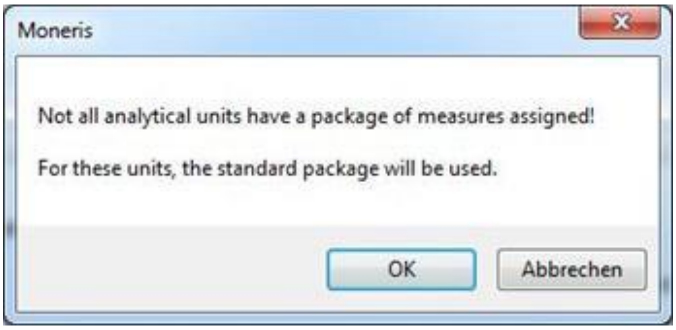
- Medium (mean years, ID 7777)
- Minimum (dry years, ID synthetic year= 8888)
- Maximum (wet years, ID synthetic year= 9999).

If calculation is to be based on medium long term means only, activate the check box



Calculate only long term mean results.

The standard package will be applied to those analytical units that are not contained in the selected management alternative. The user is informed by the following message:



Consider input scenario set (from EET):

Using the Elbe Expert Toolbox, an input scenario set can be prepared for the Elbe river basin. An input scenario set is related to scenario data in scenario database (MONERIS_Scenario.mdb).
The scenario data will be used instead of the standard input data if connection to scenario database has been established using **Model setup → Select Database**.

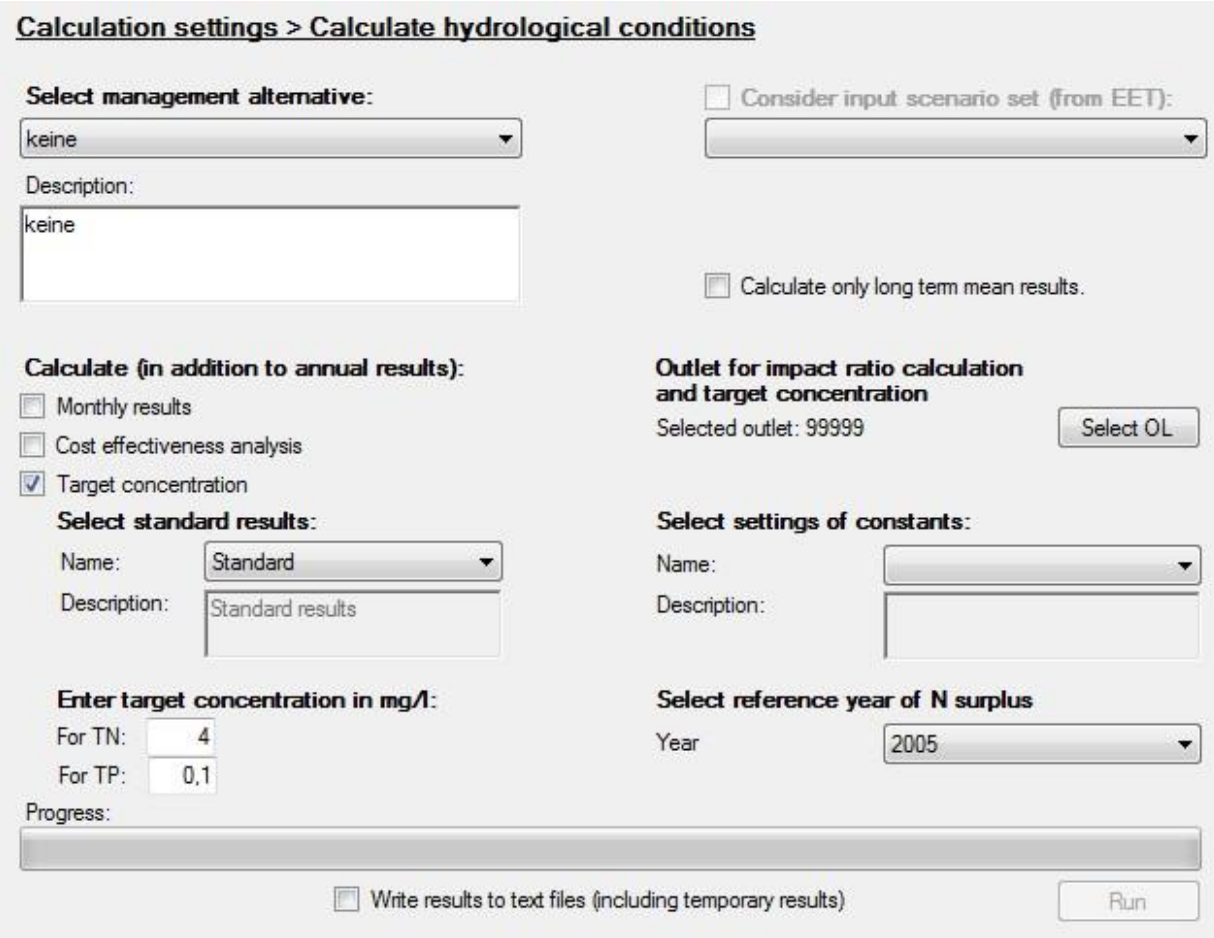
Target concentration:

Optionally, target concentrations for nitrogen and phosphorus can be calculated. Thereby, results of standard calculation are compared with results based on measures reducing urban and point emissions.
Before target concentrations can be calculated, the following working steps are required:

1. To create standard results for long term conditions, calculate hydrological conditions with management alternative **None**.
2. Save these standard results to database.
3. Create and save a package of measures. Effective measures to reduce emission of urban and point sources can be selected on the tabs **Sewer Systems**, **DCTP**, **WWTP N** and **WWTP P**.
4. Create and save a management alternative by assigning this package of measures to analytical units.

Based on this data, target concentration can be calculated:

1. Select the management alternative prepared to model the reduction of urban and point emissions.
2. Tick **Target concentration** check box.
3. Enter values for target concentrations in the appearing text boxes(**For TN** and **For TP)**.
4. Load **Standard** results from database.
5. Select an outlet.
6. Press **Run**.
7. To view the calculated results, use the menu option **Results > View tables**.

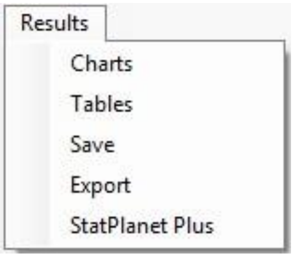


Cost effectiveness analysis

If a management alternative is applied, the cost effectiveness of the related measures can be calculated.

7. MONERIS Results

Via the **Results** menu the user can view, save or export results of the model run.

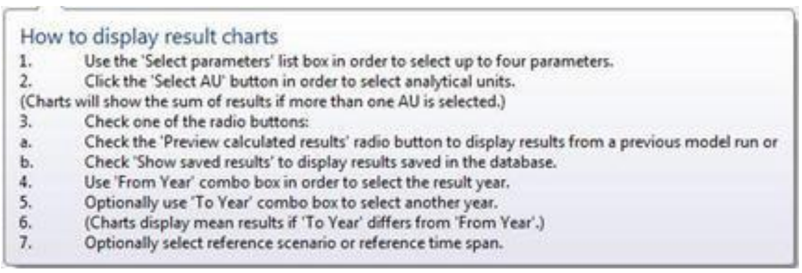


View charts

In this menu point, the user specifies which results are shown and how there are displayed. The following steps are taken:

- Select the agent group
- Select the relevant parameter(s)
- Select AU(s)
- Select results
- Display the results
- Select a reference
- Select the time period.

Note: A tooltip guides the user through the necessary steps and gives helpful explanations on the menu point where needed.


How to display result charts

1. Use the 'Select parameters' list box in order to select up to four parameters.
2. Click the 'Select AU' button in order to select analytical units.

(Charts will show the sum of results if more than one AU is selected.)

3. Check one of the radio buttons:

a. Check the 'Preview calculated results' radio button to display results from a previous model run or
b. Check 'Show saved results' to display results saved in the database.

4. Use 'From Year' combo box in order to select the result year.
5. Optionally use 'To Year' combo box to select another year.
6. (Charts display mean results if 'To Year' differs from 'From Year'.)
7. Optionally select reference scenario or reference time span.

1. Select agent group:

The drop down box shows available agent groups. Depending on the selected parameter, the available diagram types are listed in the list below.

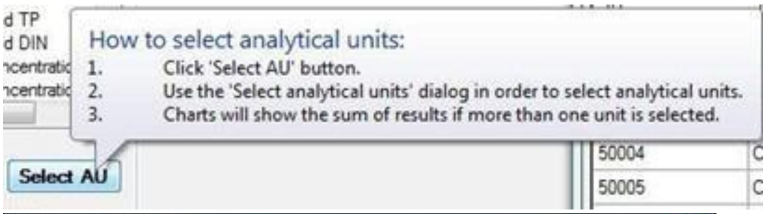
2. Select parameters:

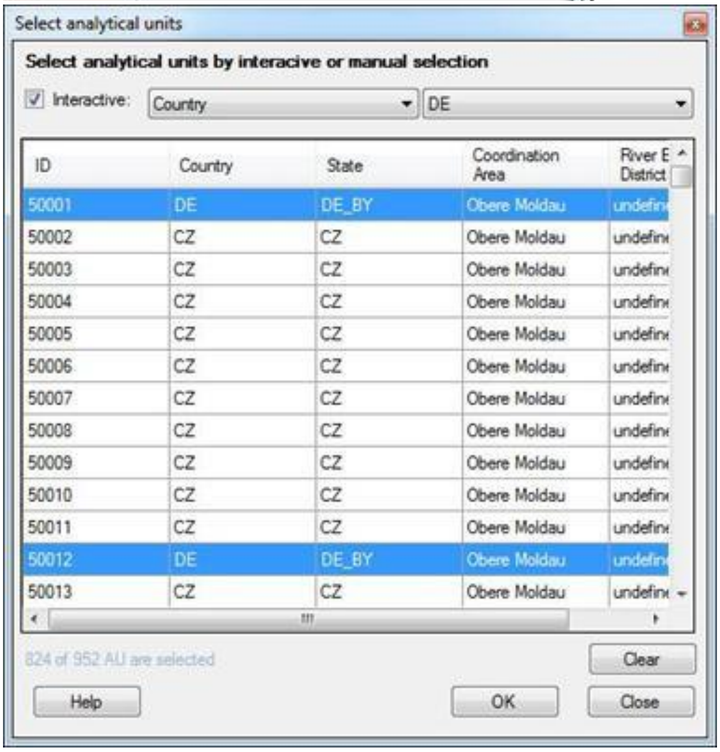
The list specifies available diagram types. Depending on the selected parameter, results are shown as bar charts, pie or point charts. Up to four diagrams can be displayed simultaneously.

3. Select analytical units/ how to sum results:

By clicking the button, the analytical units to be considered can be determined either manually in the table, or interactively by aggregating state, river basins and other analytical units.

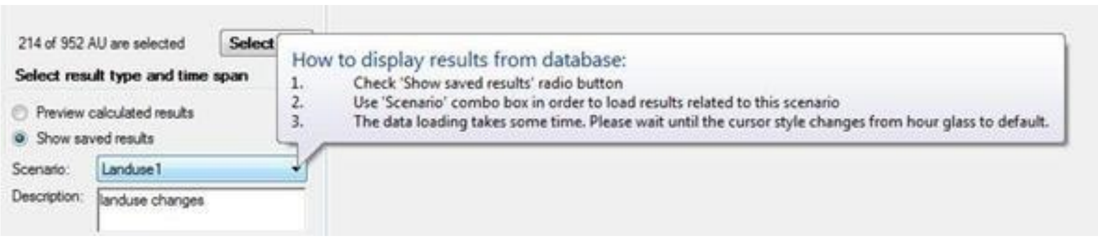
Selection of analytical units: refer to section **Defining management alternatives.**





4. Select the results:

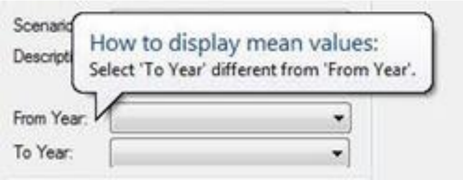
Check the **Preview calculated results** button to display results from the preceding model run, or check 'Show saved results' to display results you have previously saved as scenarios in the database (see “Save results”).



5. Select the time period/ how to display mean values:

Via the combo boxes From Year and To Year, a time period for the results wished to be displayed can be defined. If From Year and To Year are not identical, the diagrams will display mean values for the indicated time span.

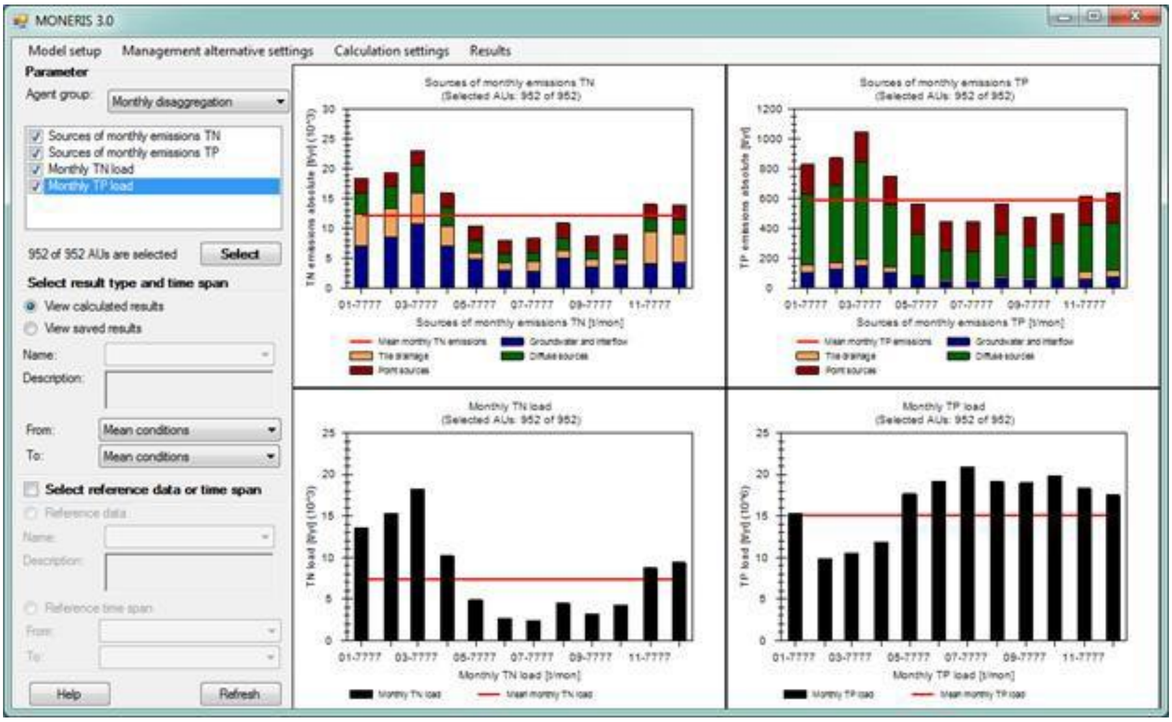
Note: A tooltip gives helpful explanations on the selection of years.



6. Selecting a reference:
   Several diagram types give you the option to show a reference value. Either the results from a different time span or the results from a different scenario can be chosen as reference values.
7. Displaying the results:
   Diagrams are displayed after all necessary dialog entries, have been set. The diagrams can be updated by clicking the Refresh button.

Monthly charts

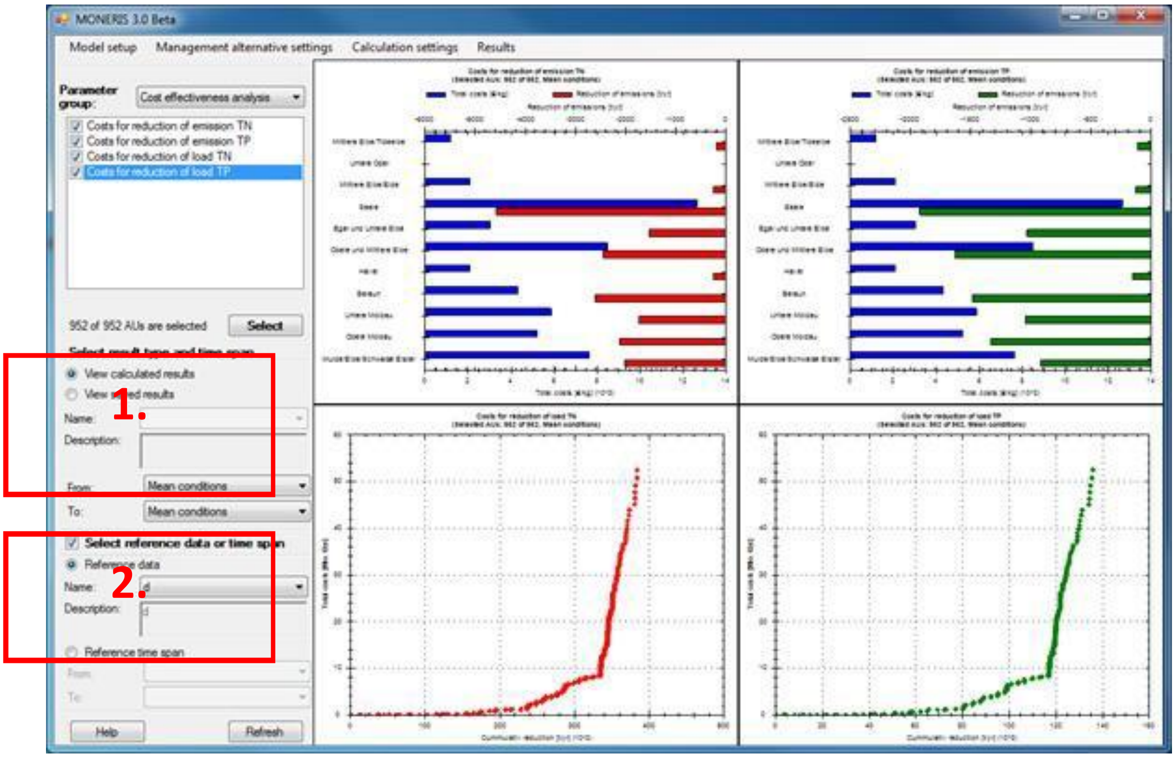
If annual results have been disaggregated monthly, monthly charts visualize sources of monthly emissions and monthly loads.



Cost effectiveness analysis charts

These charts display the reduction of TN and TP emission and load in relationship to the costs of the applied management alternative. Therefore, the results of two model runs have to be selected or loaded from the database:

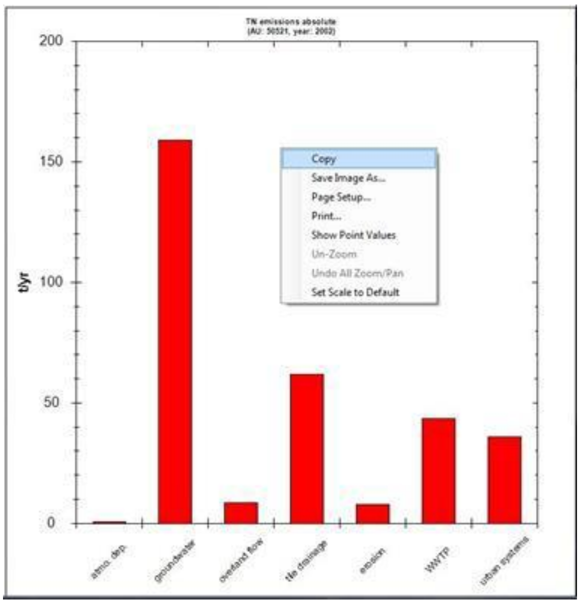
1. CEA results: Cost effectiveness results for a management alternative
2. Reference results: Standard results without management alternative

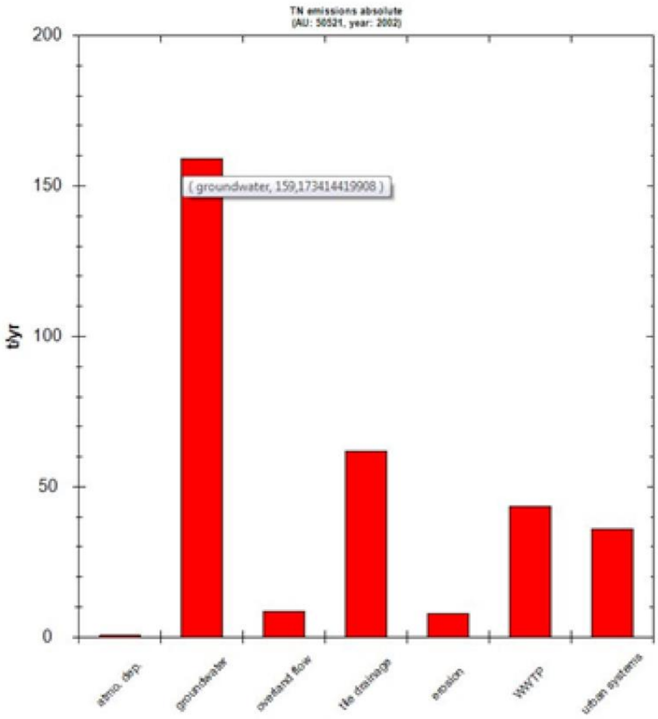


Working with diagrams

Via context menu the diagram you can

- Copy diagram
- Save as Image
- Change the page setup
- Print diagram
- Show point Values
- Use zoom functions
- Show point Values





View tables

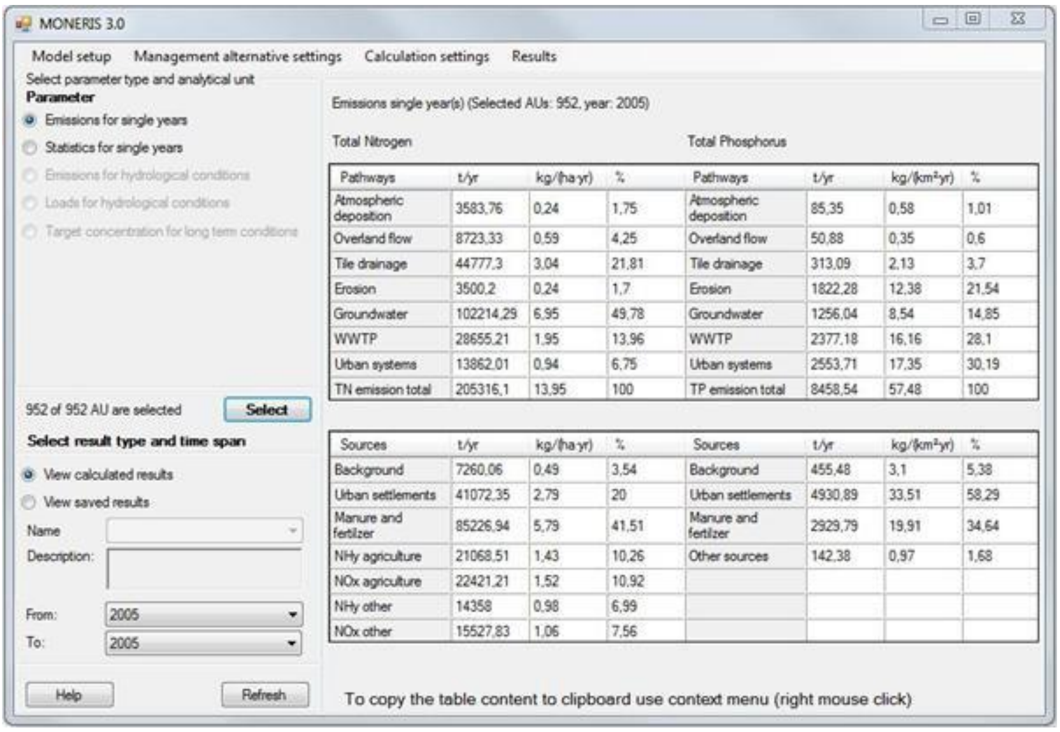
Nutrient emissions and loads can also be shown as tables. Depending on the available results, the radio buttons are enabled or not. Depending from selected **Parameter** check boxes, results are visualized in different ways.

Emissions for single years

This option shows emissions for single years – separated in pathways and sources. At least one analytical unit has to be selected.

Results are displayed

- as **sum** if more than one analytical unit is selected and
- as **mean** if more than one year is selected.

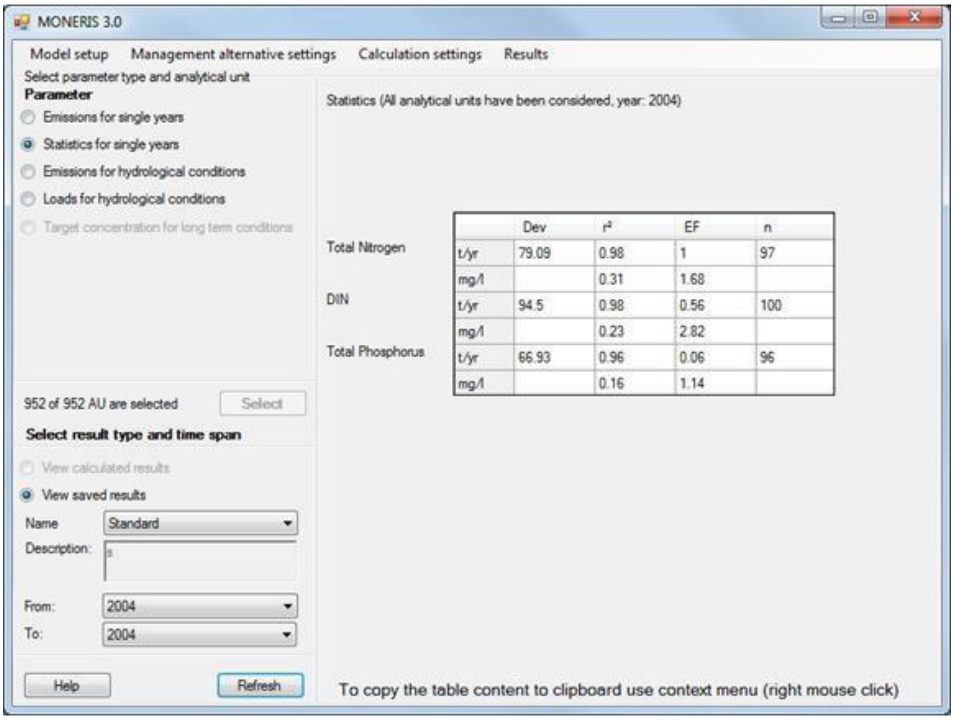


Pathways	t/yr	kg/(ha·yr)	%	Pathways	t/yr	kg/(km²yr)	%
Atmospheric deposition	3583,76	0,24	1,75	Atmospheric deposition	85,35	0,58	1,01
Overland flow	8723,33	0,59	4,25	Overland flow	50,88	0,35	0,6
Tile drainage	44777,3	3,04	21,81	Tile drainage	313,09	2,13	3,7
Erosion	3500,2	0,24	1,7	Erosion	1822,28	12,38	21,54
Groundwater	102214,29	6,95	49,78	Groundwater	1256,04	8,54	14,85
WWTP	28655,21	1,95	13,96	WWTP	2377,18	16,16	28,1
Urban systems	13862,01	0,94	6,75	Urban systems	2553,71	17,35	30,19
TN emission total	205316,1	13,95	100	TP emission total	8458,54	57,48	100

Sources	t/yr	kg/(ha·yr)	%	Sources	t/yr	kg/(km²yr)	%
Background	7260,06	0,49	3,54	Background	455,48	3,1	5,38
Urban settlements	41072,35	2,79	20	Urban settlements	4930,89	33,51	58,29
Manure and fertilizer	85226,94	5,79	41,51	Manure and fertilizer	2929,79	19,91	34,64
NHy agriculture	21068,51	1,43	10,26	Other sources	142,38	0,97	1,68
NOx agriculture	22421,21	1,52	10,92				
NHy other	14358	0,98	6,99				
NOx other	15527,83	1,06	7,56				

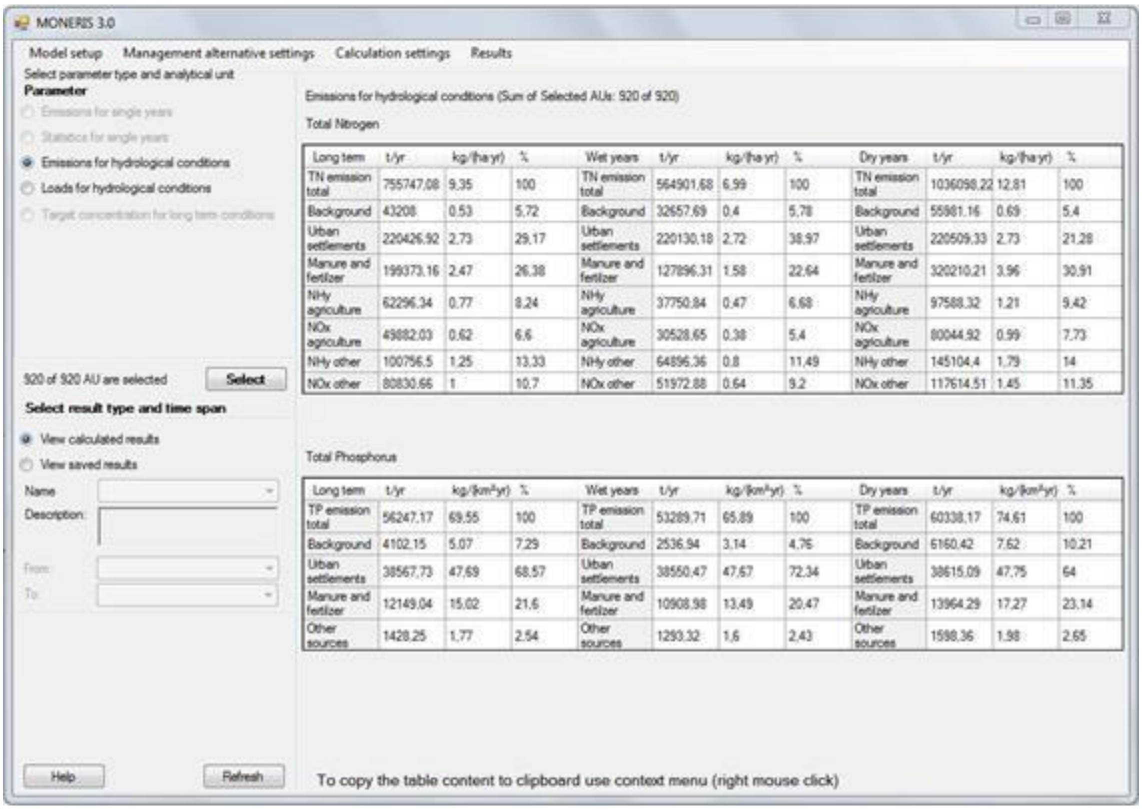
Statistics for single years

This option visualizes statistics to compare modeled results with input data from monitoring stations. Statistics is calculated for all analytical units with related monitoring data.
Results are displayed as **mean** if more than one year is selected.



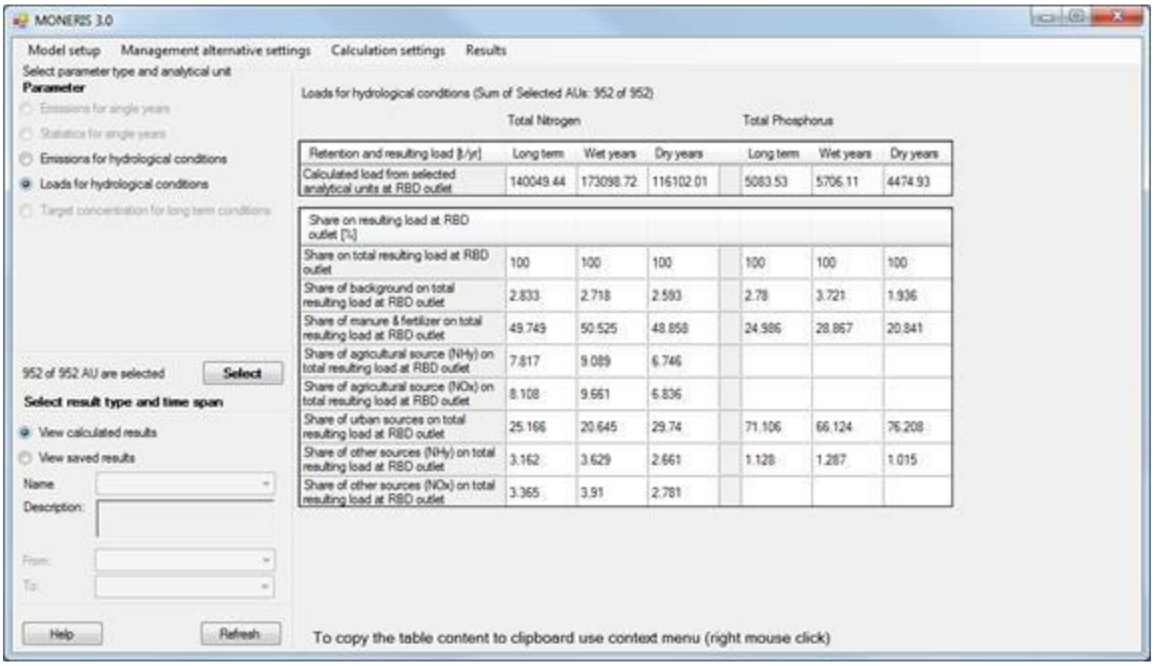
Emissions for hydrological conditions

This option shows emissions for hydrological conditions – separated in pathways and sources.
At least one analytical unit has to be selected.
Results are displayed as **sum** if more than one analytical unit is selected.



Loads for hydrological conditions

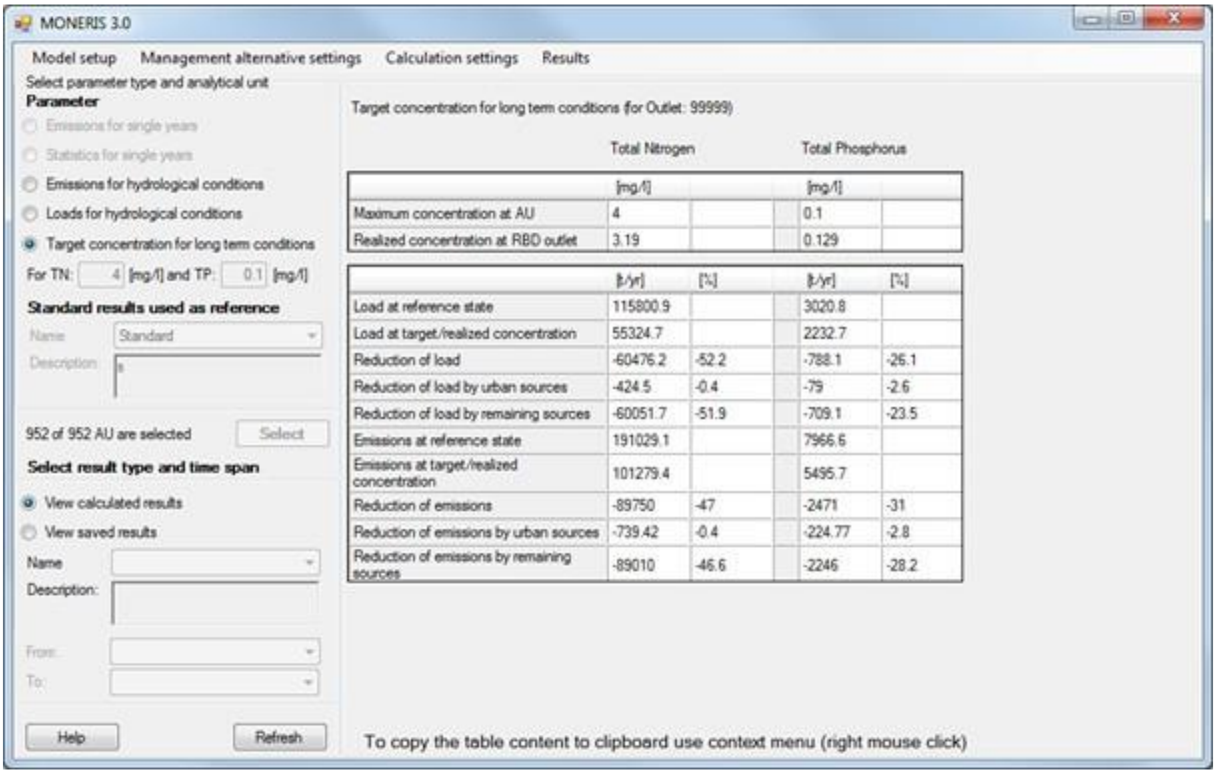
For hydrological conditions, this option visualizes the share of loads from different sources on the total load at river basin district outlet.



Target concentration for hydrological conditions

This option shows the results of calculations of target concentration. The base data of the target concentration calculations are displayed as well:

- Outlet (in brackets of table title)
- Target concentration for TN and TP (below **Target concentration** check box)
- Standard results (below **Target concentration** text boxes)



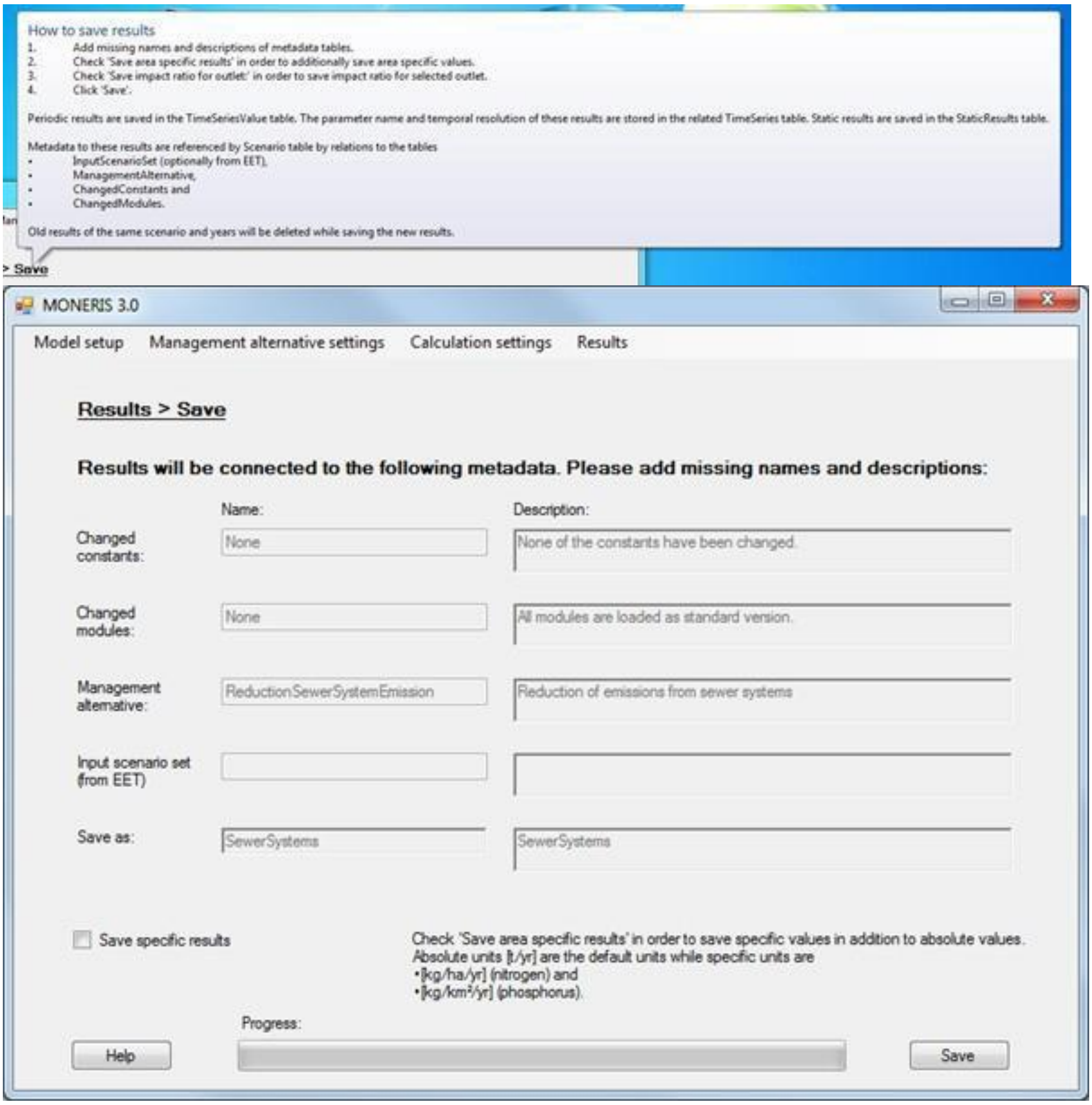
Note: A tooltip guides the user through the necessary steps and gives helpful explanations on the menu point.

Save Results

Results from calculation runs can be saved as scenarios. This way they can be recalled at a later point and/ or serve for comparison with current model runs.

Before scenario results are saved, missing names and descriptions of metadata tables must be defined. These might be references to the applied management alternative, input scenario set (alternative input data from other models) or references to changed modules and changed constants. If the database contains results with the same metadata constellation (same management alternative, same constants and modules settings), these metadata tables already exist. Then the controls for the metadata tables are disabled and serve for information purpose only. Old results of the same scenario and years will be deleted while saving the new results.

Note: Tooltips guide the user through the necessary steps and give information on the metadata tables.



How to save results:

1. Enter name and description for results.
2. Add missing names and descriptions of metadata tables.
3. Check **Save area specific** results in order to additionally save area specific values.

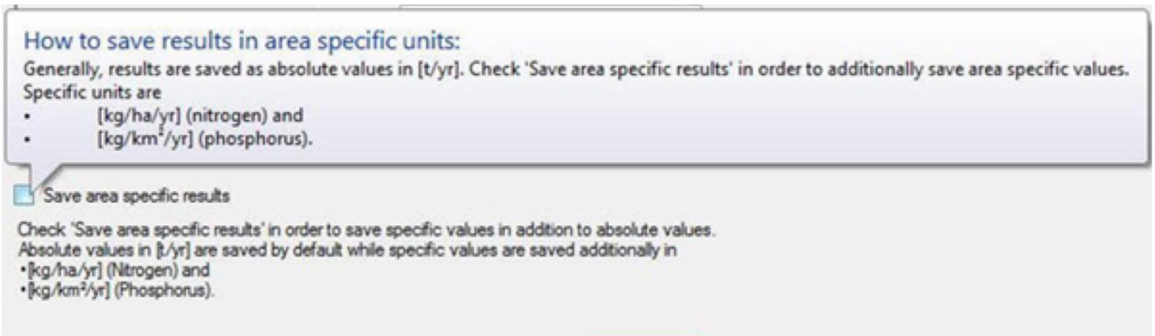
4. Click **Save**.

How to save results in area specific units:

Generally, results are saved as absolute values in [t/yr]. Check **'Save area specific results**' in order to additionally save area specific values.

Specific units are:

- [kg/ha/yr] (nitrogen) and
- [kg/km²/yr] (phosphorus).

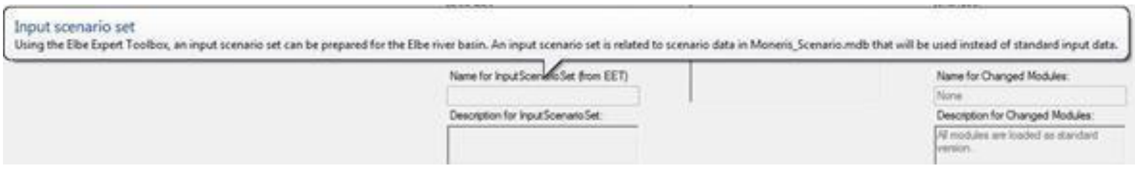


Input scenario set:

An input scenario set prepared using the Elbe Expert Toolbox will be used instead of the standard input data.

Using the Elbe Expert Toolbox, an input scenario set can be prepared for the Elbe river basin. An input scenario set is related to scenario data in scenario database (MONERIS_Scenario.mdb).

The scenario data will be used instead of the standard input data if connection to scenario database has been established using **Model setup → Select Database**.



Result tables

Periodic results are saved in **Time Series Value table**. The parameter name and temporal resolution of these results are stored in related **Time Series table**. Static results are saved in **Static Results** table.

Units of results

Results by default refer to the respective MONERIS analytical units and are saved as absolute values in [t/yr]. Tick **Save area specific results** in order to additionally save area specific values. Specific results are saved in:

- kg/ha/yr (nitrogen) or, respectively in
- kg/km²/yr (phosphorus).

Saving specific results will take longer, since twice the number of results is filed compared with the default option.

Metadata tables of results

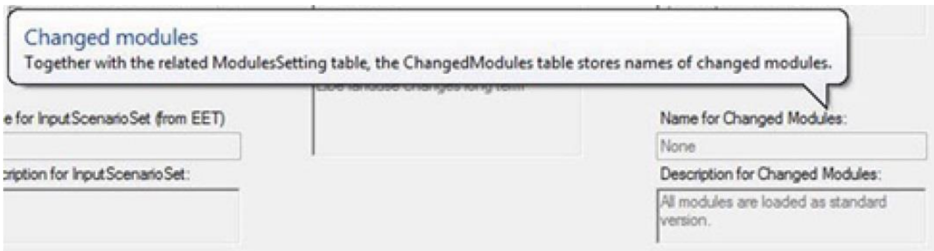
Each result stored in **Time Series Value table** has a relation to a row in **Scenario table**. The **Scenario table** is the master table for result metadata. The Scenario table is related to other sub metadata tables like Input Scenario Set (optionally from EET), Management Alternative, Changed Constants and Changed Modules.

Changed constants

Together with the related **Constants Setting table**, the **Changed Constants table** stores the changed constants. Constants can be changed in the Constants table of the output database.

Changed modules

Together with the related **Modules Setting table**, the **Changed Modules table** stores names of changed modules.



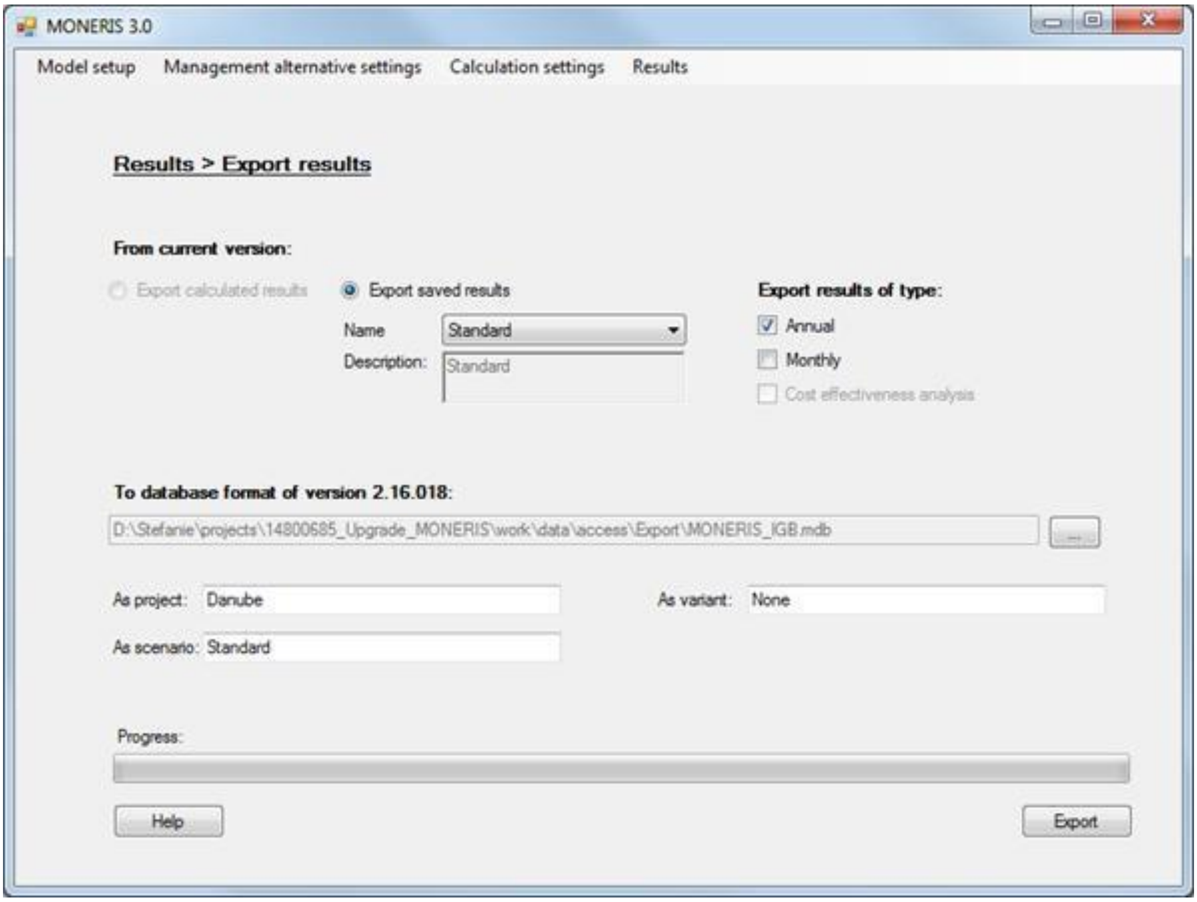
Export Results

Results from a current calculation run or results saved in the MONERIS-Out.mdb database can be exported to the database format of version 2.16.018. To achieve this, the results produced in the current MONERIS version need to be converted to the according database format.

The background to this is that to visualize their results, IGB had another company develop the so-called PrestoCatch-Viewer. In order for this particular viewer to visualize the results generated in the current MONERIS version, they first need to be exported into the database format of **version 2.16.018.**

An empty database of version 2.16.018 (Moneris-IGB.mdb) is available in **<installation directory>template\mdb\.**

It is recommended to use a local copy of this database to export results from current version.



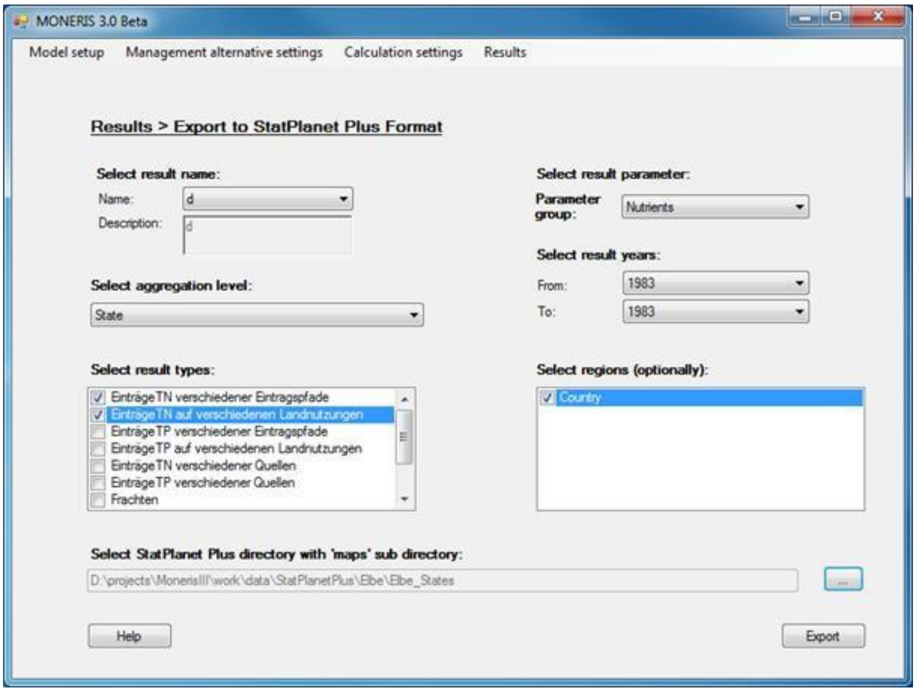
Note: A tooltip guides the user through the necessary steps and gives helpful

explanations on the menu point.

To export results to database format of version 2.16.018:

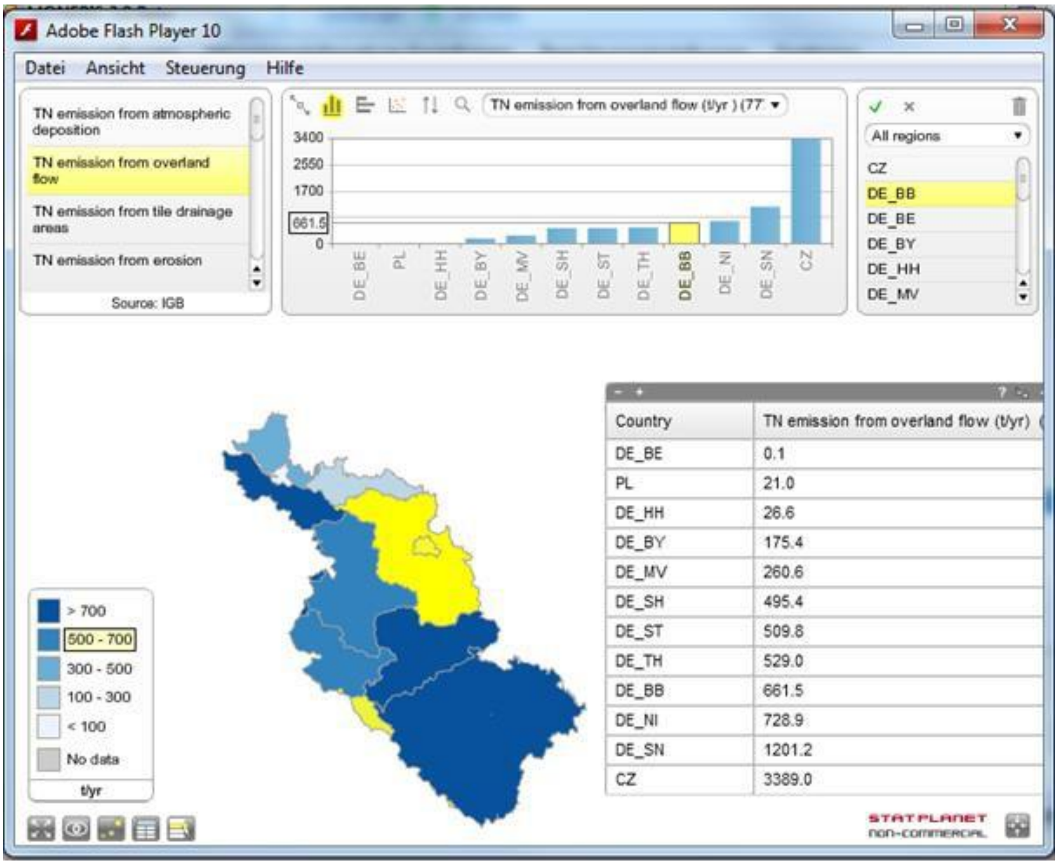
1. Check the respective radio button
   a. To export currently calculated model results or
   b. To export results saved in a currently connected output database.
2. Select result types in the respective list box
3. Use browse button to select an empty database of version 2.16.018.
4. Enter project, variant and scenario names in the appropriate text boxes.
5. Click Export. Results will be saved in result tables of the selected database.

StatPlanet Plus



Calculated or loaded results can be exported to display them with the StatPlanet Plus viewer. The viewer can be downloaded from http://www.statsilk.com.

After Export of results StatPlanetPlus.exe starts automatically and creates highly interactive Flash maps.



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Research Paper

Modelling of Nutrient Emissions in River Systems – MONERIS – Methods and Background

key words: nitrogen, phosphorus, in-stream retention, river basin management

Abstract

MONERIS is a semi-empirical, conceptual model, which has gained international acceptance as a robust meso- to macro scale model for nutrient emissions. MONERIS is used to calculate nitrogen (N) and phosphorus (P) emissions into surface waters, in-stream retention, and resulting loads, on a river catchment scale. This paper provides the first (i) comprehensive overview of the model structure (both the original elements and the new additions), (ii) depiction of the algorithms used for all pathways, and for retention in surface waters, and (iii) illustration of the monthly disaggregation of emissions and the implementation of measures. The model can be used for different climatic conditions, long term historical studies, and for future development scenarios. The minimum validated spatial resolution is 50 km^2, with a temporal resolution of yearly or monthly time steps. The model considers seven emission pathways (atmospheric deposition on surface waters, overland flow, erosion, tile drainage, groundwater, emissions from sealed urban areas, and point sources), and six emission sources (natural background, fertilizer application, nitrogen atmospheric deposition on arable land and other areas, urban sources, and point sources); and these are calculated separately for different land-uses. The pathway and source-related approach is a prerequisite for the implementation of measures to reduce non-point and point-source emissions. Therefore, we have modified MONERIS by the addition of a "management alternative" tool which can identify the potential effectiveness of nutrient reduction measures. MONERIS is an appropriate tool for addressing the scientific and political aspects of river basin management in support of a good surface water quality.

1. Introduction

The international North Sea Conference (NSC) and the Helsinki-Commission (HELCOM) enacted a 50% reduction of nitrogen (N) and phosphorus (P) loads from 1985 and 1987 to 1995 in the North Sea and the Baltic Sea. Despite this, water quality remains insufficient in European rivers, and consequently legislative initiatives have been put in place. Most important among them is the European Water Framework Directive (WFD), which came into force in 2000, to bring about good ecological and chemical conditions of water quality in groundwater and surface water bodies until 2015 (European Parliament and Council of the European Union, 2000; Rekolainen *et al.*, 2003).

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To determine effective measures for reducing emissions to, and loads in, surface waters, we can use tools that model nutrient sources and emission pathways, and scenarios for land use and management options (CHAPLOT *et al.*, 2004; KERSEBAUM *et al.*, 2003; KRAUSE *et al.*, 2008; VOLK *et al.*, 2008, 2009). Examples of such models include HSPF (BICKNELL *et al.*, 2001), AGNPS (YOUNG *et al.*, 1987), MIKE-SHE (REFSGARD, 1997), Soil and Water Assessment Tool (SWAT) (ARNOLD *et al.*, 1998; GASSMAN *et al.*, 2007), SWIM (KRYSANOVA *et al.*, 1998), GROWA/WEKU (WENDLAND and KUNKEL, 1999) and STOFFBILANZ (GEBEL *et al.*, 2010a, b). Overviews of different eco-hydrological models are given in ARNOLD and FOHRER (2005); HORN *et al.* (2004); KRYSANOVA and HABERLANDT (2002) and VOLK and STEINHARDT (2001).

Within the EU-project EUROHARP, eight nitrogen models and five phosphorous models were applied to 17 European catchments, to compare the models from the viewpoint of the calculated net nutrient loads and the partitioning of nutrient emissions at the catchment scale (KRONVANG *et al.*, 2009). This comparison was conducted because nutrient emissions on a catchment scale cannot be measured. In general, in the tested models although there was good agreement between observed and modelled nutrient loads, there were very large differences among the models in the modelled values for nutrient emissions and retention. Neither the simple, nor the complex, models were more consistent, nor in other terms delivered better results than the others; the limitations were those posed by the simplicity, or the data demand of the models.

The MONERIS model is described in detail in BEHRENDT (1988, 1996), BEHRENDT *et al.* (2000, 2002a); BEHRENDT and DANNOWSKI (2005); FUCHS *et al.* (2010) and VENOHR *et al.* (2009, 2010a).

Compared to other models like SWAT (ARNOLD *et al.*, 1998), SWIM (KRYSANOVA *et al.*, 1998), GROWA/WEKU (KUNKEL and WENDLAND, 2002, 1997) and STOFFBILANZ (GEBEL *et al.*, 2010a, b), our MONERIS model (MOdelling Nutrient Emissions in RIver Systems; BEHRENDT *et al.*, 2000) works with a moderate demand of input data, requires only a short computing time and is applicable to large river basins. Approaches used in recent models, range from export coefficients to detailed physically based equations. Consequently, model results vary from lumped total figures, to detailed information of a high temporal and spatial resolution. In these terms, MONERIS represents a good compromise between detailed, process-based models, and the application of simple approaches.

MONERIS calculates nutrient emissions for seven different emission pathways and six different emission sources (VENOHR *et al.*, 2010b). With this model, it is possible to identify long-term pathway- or source-related changes, as well as management options including cost-effectiveness-analysis. However, depending on the scientific task, other models might be chosen, such as SWAT or SWIM (higher temporal resolution) or GROWA/WEKU (focus on groundwater).

For the first version of MONERIS, the temporal resolution was 5-year periods, and the spatial resolution was 500 km^2. The main driver for the first development of MONERIS was to identify sources and pathways of nutrient emissions for hydrological sub-catchments, later called analytical units (AU). The approaches for the considered pathways have been developed and calibrated separately from each other, and no further inter-calibration was made during later model runs. The approaches for calculation of in-stream retention have been calibrated with observed values or with data from models other than MONERIS. Thus we ensured that the calibrated retention approach did not include a systematic error of MONERIS, by filling the gap between the modelled emissions and the observed loads.

Since its inception in 1999, MONERIS has been applied to the whole of Germany (BEHRENDT *et al.*, 2000; VENOHR *et al.*, 2008a, b), numerous European river systems (*e.g.*, Axios, Danube, Daugava, Elbe, Odra, Po, Rhine, Vistula, see BEHRENDT *et al.*, 2000, 2003a; 2003b, BEHRENDT and DANNOWSKI, 2005; SCHREIBER *et al.*, 2005), and to river catchments in Canada (VENOHR *et al.*, 2010b), Brazil (VON SPERLING and BEHRENDT, 2007), Mongolia (HOFMANN *et al.*, 2010; HOFMANN *et al.*, 2011; MENZEL *et al.*, 2011) and China (XU, 2004).

The international application of MONERIS facilitates its continuous testing and development. The recent version of MONERIS works with a minimum spatial resolution of 50 km^2, and calculates in yearly or monthly time steps. Emissions can be calculated on a land-use basis, rather than as a sum for the respective analytical unit. MONERIS has been extended by a “management alternative” tool, so that it can also be used to identify the potential of measures to reduce emissions and loads. The model includes a module, developed under the lead and in cooperation with the Technical University of Berlin, to calculate the costs originating from the implementation of measures, thus allowing cost-effectiveness-analysis (CEA). The description of the CEA module is in preparation, and will be published subsequently to the present model description. Completed by the “management alternative” tool and the CEA module, the model provides a comprehensive framework for river basin management.

The three objectives of our present paper are to: (i) provide a comprehensive overview of the MONERIS model and its new developments, including the methods, formulas and model parameters for all pathways, and for the in-stream retention, (ii) illustrate the monthly disaggregation of emissions, and (iii) to describe the “management alternatives” tool for the simulation of the impact of management changes on the nutrient emissions into surface waters.

The paper begins with a general overview of the model, and then proceeds to detailed description of the methods, including the algorithms for calculation of each pathway and those for retention in surface water; the paper is completed by presentation of two new features: the newly developed method to disaggregate the yearly results into monthly results, and the “management alternatives” tool.

2. General Model Descriptions

MONERIS has been developed at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB; BEHRENDT *et al.*, 2000) as a semi-empirical, conceptual model for the quantification of nutrient emissions from point and diffuse sources into surface waters of river

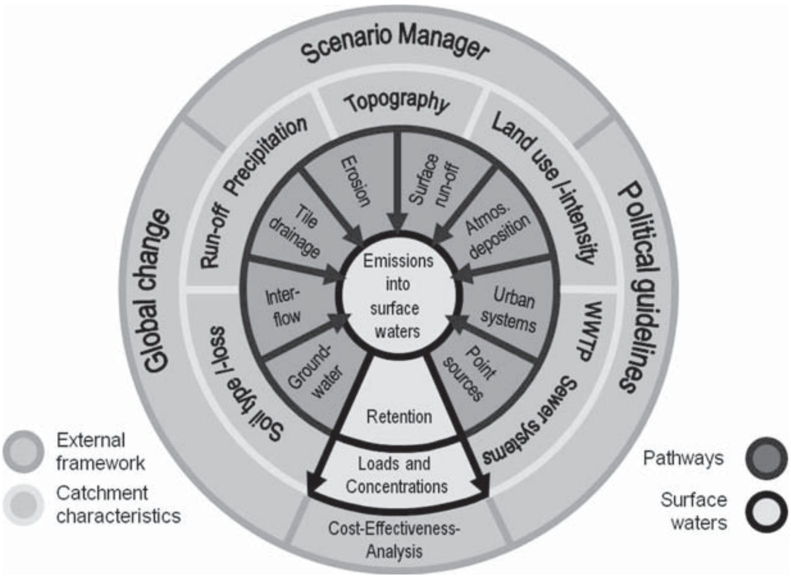

Figure 1. Structure of the MONERIS model showing the external framework, catchment characteristics, pathways, and surface waters.

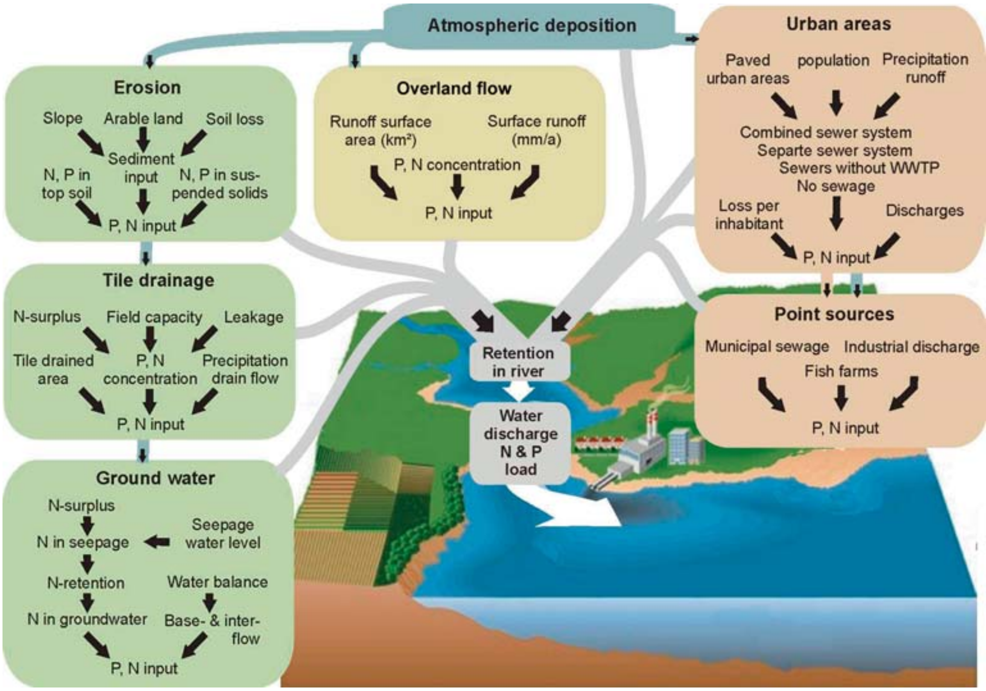

Figure 2. Pathways and processes for nutrient emission into surface waters (background picture modified after LOICZ, TURNER *et al.,* 1998).

systems (BEHRENDT *et al.*, 2000, Fig. 1). The model is based on catchment characteristics (Fig. 2) derived from digital maps and statistical reports. The application of MONERIS allows the regionally differentiated quantification of nutrient emissions into and the resulting loads in surface waters.

MONERIS considers six diffuse nutrient emissions pathways: direct emissions via atmospheric deposition on surface waters, overland flow, erosion, emissions via tile drainages, emissions via groundwater and interflow from unsealed areas and finally emissions from sealed urban areas and households (Fig. 2). Emissions from point sources are considered for municipal waste water treatment plants (WWTP) and industrial discharges.

For each pathway, the water component (for the erosion pathway the sediment yield) and the nutrient concentration for the different pathways are calculated separately. MONERIS calculates the total resulting net emissions entering surface waters, including retention and transformation processes in soils and groundwater. Subsequently, in-stream retention in surface waters is calculated separately for tributaries, main rivers and selected lakes to finally describe resulting loads in the surface waters of a river system. The basis for a model evaluation is the comparison of observed and calculated nutrient loads in the surface waters.

3. Methodology to Calculate Nutrient Emissions

Analytical units (AU) are the smallest modelling unit and represent the basis for the calculation of nutrient emissions and in-stream retention. Analytical units describe hydrological sub-catchments (based on the topography). For each analytical unit the hydrological connection to a downstream analytical unit has to be defined and is considered in MONERIS by the ‘flow-net-equation’ (FNE). Artificial divides, *e.g.* by channels, of the river system (splittings) can be implemented in the FNE and are considered for the calculation of the in-stream retention and load. Due to the resolution of the input data analytical units must not be smaller than 1 km^2. The validated minimum size for analytical units is 50 km^2.

MONERIS requires the total runoff as input data. The runoff for every diffuse pathway except groundwater recharge is determined separately as a function of precipitation, while the groundwater recharge is calculated as the difference of the total runoff and the sum of the runoff from the other diffuse pathways.

The following land use categories are considered in MONERIS: arable land, grassland, natural covered areas (incl. forests), urban areas, wetlands, open land areas, open pit mine, water surface areas and other areas.

3.1. Calculation of the Water Surface Area

The area of surface water is needed to model the atmospheric deposition on surface waters as well as the later in-stream nutrient retention. Information on the lake area is in general available from topographical maps, whereas the surface area of river is, if at all, only given for large streams. An approach to calculate the surface area of (smaller) rivers was implemented in MONERIS.

The water surface area of rivers is calculated as a product of the mean width and the flow length for individual analytical units. For a subsequent calculation of in-stream retention, water surface areas of main rivers, tributaries, and lakes, have to be determined separately (Fig. 3). The calculation of river width is based on VENOHR *et al.* (2005), but was re-calibrated with an extended and modified data set. VENOHR *et al.* (2005) calculated the flow-

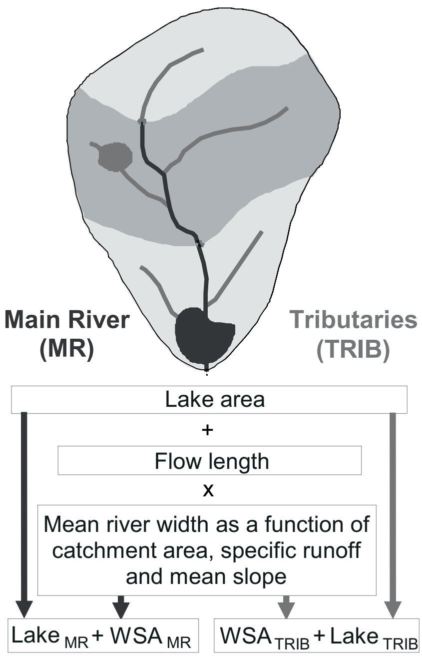

Figure 3. Calculation of the water surface area (WSA) of main rivers (MR) and tributaries (TRIB) in river systems.

length-weighted mean width of all tributaries within one analytical unit. In contrast to the approach by VENOHR *et al.* (2005), for the present calibration, the width has been classified in steps of 0.1 m, as the widths in maps were only given as classified data.

VENOHR *et al.* (2005) derived river widths from topographical maps and statistical reports, but the width of main rivers wider than 42 m were missing. In the recent, extended data set, 184 additional river stretches of large German rivers with widths up to 380 m have been added from Google-Maps. By combining both data sets, for main rivers, the widths of 462 river stretches have been now considered, and for tributaries the mean widths of rivers and ditches in 259 analytical units have been now considered. After classification of the width of tributaries into 0.1 m steps, there were 20 groups available for calibration of tributary widths.

The river width is calculated based on catchment area, specific runoff, and mean slope of the catchment (Eq. 1) and (Eq. 2). As the width of tributaries is only influenced by the local conditions, the calculation is based on catchment area, specific runoff and slope of the respective analytical unit. For main rivers, the entire hydrological catchment and the according mean specific runoff have to be considered, whereas the mean slope of the respective analytical unit is used.

$$W_{TRIB} = 0.082 \cdot A_{AU}^{\ 0.0395} \cdot q_{AU}^{\ 1.545} \cdot sl^{-0.025} \qquad \text{(Eq. 1)}$$

W_{TRIB} = calculated mean river width of the tributaries, in m
A_{AU} = area of the analytical unit, in km^2
q_{AU} = specific runoff of the analytical unit, in l/(s · km^2)
sl = mean slope (1000 m GRID) in analytical unit, in %

$$W_{MR} = 0.26 \cdot A_{CAT}^{\ 0.49} \cdot q_{tot}^{\ 0.45} \cdot sl^{-0.025} \qquad \text{(Eq. 2)}$$

W_{MR} = calculated mean river width of the main river, in m
A_{CAT} = area of the total catchment, in km^2
q_{tot} = mean specific runoff of the total catchment, in l/(s · km^2)

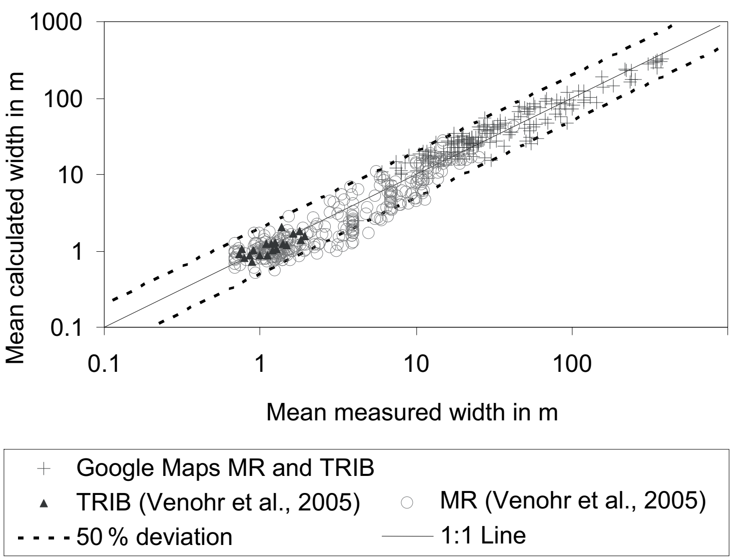

Figure 4. Comparison of measured and calculated widths for main rivers (MR) and tributaries (TRIB).

Table 1. Mean absolute deviation, r^2, and modelling efficiency (EF) of the calibration for main 462 rivers and 259 tributaries grouped in 20 classes.

	Main rivers $N = 462$	Tributaries $N = 20$
Mean absolute deviation in %	30.3	15.3
r^2	0.96	0.58
EF	0.94	0.50

Measured and calculated river widths are compared in Figure 4. The measured mean width varied between 0.7 m and 380 m for main rivers, and between 0.7 m and 1.9 m for tributaries. A mean deviation of 30.3% for main rivers, and 15.3% for tributaries, and as well as high regression coefficients (Table 1), document a good statistical agreement between measured and calculated widths.

We calculated the individual water surface area of main rivers and tributaries for a specific analytical unit, by multiplying the river width with the flow length. The flow length was derived from topographical maps, and was subsequently corrected according to the scale-dependent generalization of the map. With increasing scale, generalisation increases, such that smaller rivers and meanders are missing; thus the real length of the river, and consequently the water surface area, will be underestimated. Therefore, for 87 German catchments, we compared the lengths of rivers derived from maps with four different scales (1 : 25,000; 1 : 100,000; 1 : 250,000; 1 : 1,000,000), and derived scale factors for the main rivers (S_{MR}) and tributaries (S_{TRIB}) (Table 2) (VENOHR, 2006). For large scale maps the scaling factor can vary considerably, *e.g.*, between DLM1000 and Bartholomew (BART1000). As the DLM1000 has been corrected with information from the DLM250 map, its scale factor is much smaller than that of the BART1000 map. Consequently, the detailedness of maps is not only dependent on the scale but also on the respective methods and data, which were used to generate the map. Scale factors thus cannot be transferred to other maps of the same scale.

Table 2. Scale factors for tributaries (S_{TRIB}) and main rivers (S_{MR}) for maps of different scales, based on 87 German catchments.

Maps	Scale	Scale factor	
		S_{MR}	S_{TRIB}
DTK25	1 : 25,000	1.00	1.00
UBA1000	1 : 100,000	1.11	1.83
UBA-OSU1000	1 : 100,000	1.11	2.10
DLM250	1 : 250,000	1.11	3.23
DLM1000	1 : 1,000,000	1.13	2.99
BART1000	1 : 1,000,000	1.18	8.40
DCW1000	1 : 1,000,000	1.17	6.28

3.2. Nutrient Emissions via Atmospheric Deposition on Water Surface Areas

In MONERIS, atmospheric deposition on water surface areas is calculated as a product of the water surface area and the area-specific atmospheric deposition rate of N and P. Atmospheric N deposition is considered separately for different land uses or as a mean value per analytical unit, whereas for P deposition, only a mean deposition rate per analytical unit is considered. For a subsequent calculation of the total water balance in an analytical unit, the precipitation on, and the potential evaporation from, water surface areas are balanced.

3.3. Nutrient Emissions via Overland Flow

Emissions of dissolved fractions of nutrients via overland flow from unsealed areas is calculated separately for different land uses (arable land, grassland, naturally covered areas, open land areas, wetlands, open pit mine areas, and snow and ice covered areas) (Fig. 5).

Basis for the overland flow calculation is the specific runoff from these areas (Eq. 3).

$$q_{spec} = \frac{Q_{AU} - Q_U - Q_{WSA}}{A_{GL} + A_{AL} + A_{NC} + A_{OA} + A_S + A_{WL} + A_{OPM}} 1000 \qquad \text{(Eq. 3)}$$

q_{spec} = specific runoff, in $l/(s \cdot km^2)$
Q_{AU} = mean annual runoff from analytical unit, in m^3/s
Q_U = mean annual runoff from sealed urban areas, in m^3/s
Q_{WSA} = annual precipitation on water surface areas, in m^3/s
A_{GL} = grassland, in km^2
A_{AL} = arable land, in km^2
A_{NC} = naturally covered areas, in km^2
A_{OA} = open land areas, in km^2
A_S = snow and ice covered areas, in km^2
A_{WL} = wetlands, in km^2
A_{OPM} = open pit mine areas, in km^2

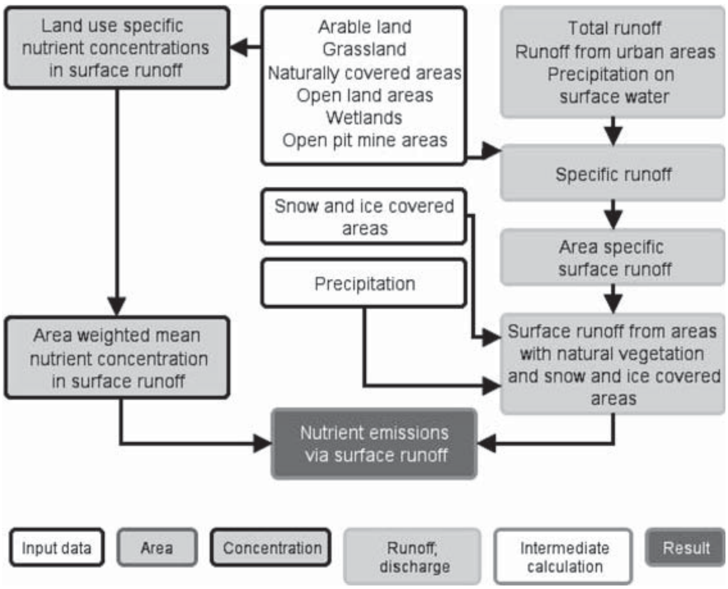

Figure 5. Basic scheme for calculation of dissolved nutrient emissions via overland flow.

The surface runoff is calculated as a function of the specific runoff of an analytical unit, following the approach by CARL and BEHRENDT (2006, 2008) and CARL *et al.* (2008) (Eq. 4). The use of this approach for test regions in the Danube catchment proved its applicability, and delivered results similar to those of hydrological models such as SWAT and DIFGA (CARL *et al.*, 2008).

$$q_{SR} = 0.0426 \cdot (q_{spec} \cdot 86.4 \cdot 0.365)^{1.2461} \qquad \text{(Eq. 4)}$$

q_{SR} = specific surface runoff, in mm/yr

Equation 4 has not been validated for calculation of runoff from glaciers and snow-covered areas, and has to be considered by a separate approach. The US SOIL CONSERVATION SERVICE (1972) developed an approach to describe runoff from snow and ice covered areas (Eq. 5). Using data from Austrian alpine regions, ZESSNER *et al.* (2010) re-calibrated this approach and derived an exponent of 0.6, instead of the original value of 0.45.

$$Q_S = 4 \cdot A_S \cdot (PR_{yr} - 850)^{0.6} \frac{1000}{86\,400 \cdot 365} \qquad \text{(Eq. 5)}$$

Q_S = surface runoff from snow and ice covered areas, in m^3/s
PR_{yr} = annual precipitation, in mm/yr

Equation 5 is only valid for annual precipitation exceeding 850 mm; in cases of lower precipitation, no runoff from snow and ice covered areas is assumed. Based on the specific surface runoff (Eq. 4), as well as runoff from snow and ice covered areas (Eq. 5) the total surface runoff from unsealed areas is calculated using equation 6.

$$Q_{SR} = q_{SR} \cdot (A_{GL} + A_{AL} + A_{NC} + A_{WL} + A_{OPM}) \frac{1000}{86\,400 \cdot 365} + Q_S \qquad \text{(Eq. 6)}$$

Q_{SR} = total surface runoff from unsealed areas, in m^3/s

3.3.1. Phosphorus

An extensive study on the P content and P absorption capacity of soils in the north-east German flatlands was conducted by PÖTHIG and BEHRENDT (1999), based on BRAUN *et al.* (1991) and WERNER *et al.* (1991). This study showed that the water soluble P concentration depends very strongly on the P saturation of the soil. PÖTHIG *et al.* (2010) made measurements at 429 sites in Germany and Switzerland, and derived an equation to calculate the dissolved P concentrations dependent upon the P saturation in soils (Fig. 6).

Since the P saturation in soils varies spatially and temporally, we modified the approach by PÖTHIG *et al.* (2010) for use in MONERIS. To consider changing P saturation in soils and the situation in a respective analytical unit, the ratio between the mean P accumulation and the maximum P accumulation during the entire calculation period is considered on an administrative unit level (Eq. 7).

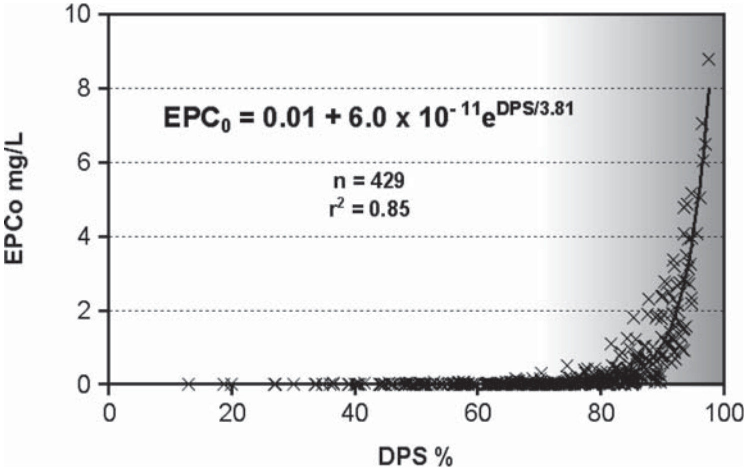

Figure 6. Dependence of the equilibrium P concentration (EPCo) on the degree of P saturation in the soil (DPS) (PÖTHIG *et al.,* 2010).

$$PA_{AU\text{-}COR} = PA_{AU\text{-}RY} \frac{PA_{AM\text{-}SY}}{PA_{AM\text{-}MAX}} \qquad \text{(Eq. 7)}$$

$PA_{AU\text{-}COR}$ = corrected P accumulation of a specific calculation year for each analytical unit, in kg/(ha · yr)
$PA_{AU\text{-}RY}$ = individual P accumulation for each analytical unit, considering the spatial distribution of P accumulation, in kg/(ha · yr)
$PA_{AM\text{-}SY}$ = mean P accumulation, on the level of an administrative unit, for the calculation year, in kg/(ha · yr)
$PA_{AM\text{-}MAX}$ = maximum P accumulation on the level of an administrative unit during the entire modelling period, in kg/(ha · yr)

Finally, a P change correction factor is calculated by equation 8.

$$PA_{AU\text{-}CF} = \frac{PA_{AU\text{-}COR}}{PA_{AM\text{-}MAX}} \qquad \text{(Eq. 8)}$$

$PA_{AU\text{-}CF}$ = correction factor to consider the temporal and spatial variability of P saturation in soils, in kg/(ha · yr)

In order to avoid unrealistically high P concentrations in surface runoff, a maximum P saturation of 97% is assumed, and the ratio of $PA_{AU\text{-}CF}$ will therefore be limited by the model. Equation 9 calculates the P concentration in surface runoff, according to the approach by PÖTHIG *et al.* (2010) on the basis of temporarily and spatially corrected P accumulation.

$$P_{SR\text{-}AL} = 0.01 + 6 \cdot 10^{-11} \cdot \mathrm{Exp}^{\left[PA_{AU\text{-}CF} \cdot \frac{DPS}{3.81}\right]} \qquad \text{(Eq. 9)}$$

$P_{SR\text{-}AL}$ = P concentration in surface runoff from arable land, in mg/l
DPS = degree of P saturation in soils with arable land, in %

Using DPS values of 90% for arable land and 80% for grassland, at a correction factor $PA_{AU\text{-}CF} = 1$, the corresponding P concentrations of 1.1 mg/l and 0.1 mg/l in surface runoff are calculated by equation 9. These calculated concentrations correspond well to concentrations observed during storm water events (Gelbrecht *et al.*, 1996). For open land areas, naturally covered areas, open pit mine areas, wetlands, and for natural background conditions, a P saturation of less than 50% is assumed. This corresponds to a P concentration in surface runoff of 0.01 mg/l, following the approach by Pöthig *et al.* (2010). For snow and ice covered areas, a P concentration of 0.005 mg/l is assumed.

3.3.2. Nitrogen

In MONERIS, the N concentration in surface runoff from arable land is calculated on basis of the approach by Werner *et al.* (1991). Werner *et al.* (1991) did not take into account the N by atmospheric deposition (in form of NO_x and NH_y), thus we make an addition to compensate for this (Eq. 10). For snow and ice covered areas, an N concentration of 0.1 mg/l is assumed. For land use other than arable land or snow and ice covered areas, the N concentrations in surface runoff are derived only from the atmospheric deposition.

$$C_{SR\text{-}N\text{-}AL} = 0.3 + \frac{AD_{NHy} + AD_{NOx}}{PR_{yr}} \qquad \text{(Eq. 10)}$$

$C_{SR\text{-}N\text{-}AL}$ = N concentration in surface runoff from arable land, in mg/l
AD_{NHy} = atmospheric deposition of NH_y fractions on arable land in $kg/(km^2 \cdot yr)$
AD_{NOx} = atmospheric deposition of NO_x fractions on arable land in $kg/(km^2 \cdot yr)$

The emissions via surface runoff are calculated by multiplying the respective P and N concentrations with the surface runoff for each land use type. The sum of these land use specific emissions is the total emission via surface runoff.

3.4. Nutrient Emissions via Erosion

The quantification of N and P emissions, via erosion, into surface waters is based on four parameters: (i) soil loss, (ii) slope, (iii) nutrient content in top soils, and (iv) land use. The erosion pathway of MONERIS follows two empirical approaches. First, MONERIS calculates sediment input as the product of the soil loss, and an empirical sediment delivery ratio (SDR, according to Walling (1983, 1996)). Second, the modelled sediment input is multiplied with the nutrient content in the topsoil and an empirical enrichment ratio (ENR) (Fig. 7).

Soil loss data for arable land, grassland, naturally covered areas, and snow and ice covered areas, are considered separately and are usually generated based on the Universal Soil Loss Equation (USLE; DIN 19708, 2005, Wishmeier and Smith, 1978). To calculate the long term annual mean soil loss, this equation requires additional geo-referenced input data, such as that on precipitation, soil, and land management practices. Although the underlying concept of the USLE was criticized (*e.g.*, Novotny and Chesters, 1989), we use this approach in MONERIS because alternatives are data-demanding and often limited to small areas (de Vente *et al.*, 2007; Volk *et al.*, 2010). The long term annual mean soil loss is used as input data in MONERIS and has to be derived in advance of a model setup.

Soil loss and sediment input are highly variable in space and in time. In MONERIS, the long term mean soil losses from arable land, grassland, and naturally covered areas are corrected by the precipitation ratio PR_{CF}, between the actual and the long term mean USLE R factor (Eq. 11). The R factor is calculated according to Deumlich (1993).

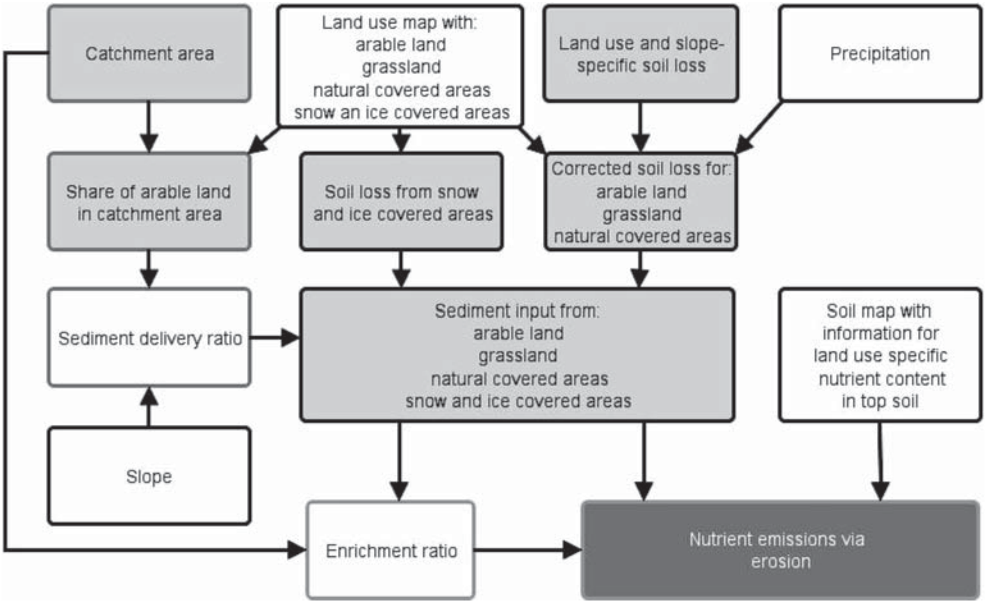

Figure 7. Main steps for calculating nutrient emissions via erosion.

$$PR_{CF} = \frac{0.152 \cdot PR_{S\text{-}SY} - 6.88}{0.152 \cdot PR_{S\text{-}LT} - 6.88} \quad \text{(Eq. 11)}$$

PR_{CF} = precipitation ratio as correction factor, dimensionless
$PR_{S\text{-}SY}$ = summer precipitation in specific study year, in mm/yr
$PR_{S\text{-}LT}$ = long term mean summer precipitation, in mm/yr

Not all areas are directly connected to surface waters and only a small fraction of eroded particles actually reaches the surface waters. Therefore, the share of areas that contribute to sediment input has to be defined, and is described by the Sediment Delivery Ratio (SDR). The SDR equation was derived from a detailed mapping in 29 catchments in eastern Germany. In a first step areas directly located at a surface water and with a slope orientated to it were derived as critical source areas. In empirical models, the spatial variability of SDR is usually explained by simple parameters such as average slope or area (DE VENTE *et al.*, 2007; WALLING, 1983, 1996). Accordingly, MONERIS uses the average slope and the proportion of arable land in each analytical unit to estimate the long term mean SDR (Eq. 12). Like this the share of areas contributing to emissions via soil erosion could be determined.

$$SDR_{AG} = 0.006684 \cdot (sl - 0.25)^{0.3} \cdot (20 + A_{AL\,\%})^{1.5} \quad \text{(Eq. 12)}$$

SDR_{AG} = sediment delivery ratio, in %
sl = mean slope from 1000 m-DEM, in %
$A_{AL\%}$ = proportion of arable land, in %

Equation 12 is only suitable for agricultural areas with sheet erosion as the dominant erosion process (*i.e.*, the scope of the USLE). In case of no arable area (scenario on background conditions) it is assumed that on 20% of the catchment area erosion still occurs. Erosion may occur on arable land and on grassland but the spatial origin can often not clearly be distinguished. Equation 12 therefore has been re-calibrated under consideration of this share of 20% and to give the total share of arable land and grassland contributing to erosion. Equation 12 is applied when average slope angles are above 0.25%. For areas with a slope of < 0.25%, no erosion is considered in MONERIS and the SDR is set to 0. The approaches in MONERIS were calibrated with land use date derived from the Corine Land Cover Map (Deutsches Zentrum für Luft- und Raumfahrt, 2000).

In a second step the actual amount of eroded matter reaching surface waters had to be quantified. Therefore annual sediment loads (yields) at 23 gauges in southern Germany were used. At low flow conditions sediment loads to a considerable share consist of autochthonous material. USLE-based soil erosion data therefore were compared to long term mean annual critical sediment yields, following the method by Behrendt *et al.* (2000). Critical suspended sediment yields were calculated as the discharge-dependent fraction of total suspended solid yields (SSY) (Fig. 8).

From multi-year time-series of daily data on water runoff (Q) and suspended-solid concentrations (SSC), the mean values of SSY and SSC were obtained for runoff classes. Generally, these mean values of SSY and SSC increased above gauge-specific critical runoff (Qcrit), and the critical yields were defined as the difference between regression models describing the SSY-Q and SSC-Q relationships for high and low discharge classes (Fig. 8; Eq. 13). Alpine catchments are very effective sediment suppliers, and the USLE underestimates their

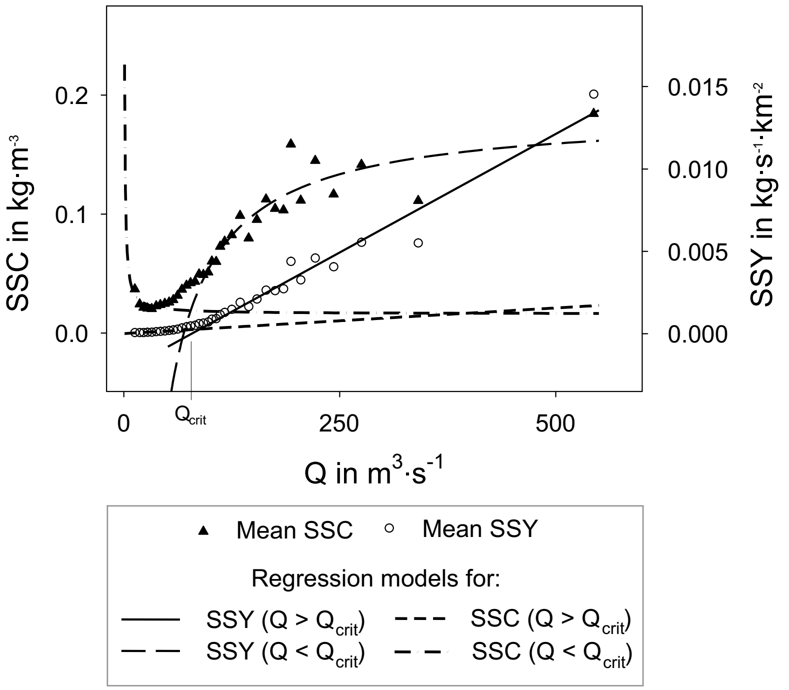

Figure 8. Calculation of critical suspended solids yields (Q = water discharge, SSC = suspended solids concentration, SSY = suspended solids yield, Qcrit = gauge-specific critical runoff) (adapted from Behrendt *et al.*, 2000).

soil loss. On basis of monitored suspended solid loads in alpine regions Behrendt *et al.* (2000) derived a soil loss from snow and ice covered areas of 400 t/(km^2 · yr) (Eq. 13). The suspended solid yield by erosion from arable land, grassland, naturally covered areas, and snow and ice covered areas, is finally calculated by equation 13.

$$SSY = (SL_{AL} \cdot A_{AL} + SL_{GL} \cdot A_{GL}) \cdot PR_{CF} \cdot SDR_{AG} + SL_{NC} \cdot A_{NC} \cdot PR_{CF} + SL_S \cdot A_S \quad \text{(Eq. 13)}$$

SSY = suspended-solids yield, in t/yr
A_{AL} = arable land, in km^2
A_{GL} = grassland, in km^2
A_{NC} = naturally covered areas, in km^2
A_S = snow and ice covered areas, in km^2
SL_{AL} = soil loss from agricultural land, in t/(km^2 · yr)
SL_{GL} = soil loss from grassland, in t/(km^2 · yr)
SL_{NC} = soil loss from naturally covered areas, in t/(km^2 · yr)
SL_S = soil loss from snow and ice covered areas, in t/(km^2 · yr)
PR_{CF} = see equation 11

Soil erosion and sediment transport are selective processes in respect to particle size (Sharpley, 1980). Fine soil particles are preferentially transported to, and within surface waters, and are usually richer in adsorbed nutrients (nutrient content NC_{TS}), than is the case with coarser soil particles (Scheffer and Schachtschabel, 1989). As P accumulates in soils, Behrendt *et al.* (2000) developed an approach to estimate the P content in top soils, assuming an initial value of 150 mg/kg (soil mass) and a mean clay content of 21%. Top soil contents for open land, and snow and ice covered areas are assumed to be 150 mg/kg for P and 250 mg/kg for N.

The modelled sediment input is multiplied with the nutrient content of the topsoil and with an empirical enrichment ratio (ENR), to obtain the nutrient emission via soil erosion. The enrichment ratio is defined as the ratio of the nutrient content in suspended sediments to that in the bulk soil. For P, the variation of the calculated ENR in 27 catchments in the Danube basin is well explained by modelled sediment input (Behrendt *et al.*, 2000) (Eq. 14); this was in agreement with Auerswald (1989) and Sharpley (1980). Equation 14 is valid where $SSY/A_{AU} \leq 1.0$, otherwise ENR_P is set to 18.

$$ENR_P = 18 \cdot \left(\frac{SSY}{A_{AU}}\right)^{-0.47} \quad \text{(Eq. 14)}$$

ENR_P = enrichment ratio for P, dimensionless
A_{AU} = analytical unit area, in km^2

For N, an indirect approach had to be chosen because there were no data available on N content in suspended solids. From a study of 17 catchments Werner and Wodsak (1994) determined that the mean N-P ratio of eroded soil and bulk soil was 2.35 and (Eq. 15) was adapted accordingly to estimate ENR_N, the enrichment ratio for N.

$$ENR_N = \frac{18}{2.35} \cdot \left(\frac{SSY}{A_{AU}}\right)^{-0.47} = 7.7 \cdot \left(\frac{SSY}{A_{AU}}\right)^{-0.47} \quad \text{(Eq. 15)}$$

ENR_N = enrichment ratio for N, dimensionless

The total nutrient emissions via erosion are calculated using the respective values for N and P, and for different land uses, by equation 16.

$$ER = \frac{NC_{TS}}{1000\,000} \cdot SL \cdot ENR \qquad \text{(Eq. 16)}$$

ER = nutrient emissions via erosion, in t/yr
NC_{TS} = nutrient content (N or P) in top soils, in mg/kg
SL = soil loss from different land uses, in $t/(km^2 \cdot yr)$
ENR = N or P enrichment ratio, dimensionless

3.5. *Nutrient Emissions via Tile Drainage Flow*

N and P emissions, via tile drainages into surface waters, are calculated for tile-drained arable land and grassland, respectively. Three parameters are considered in MONERIS: (i) tile drain flow rate, (ii) size of tile drained areas, and (iii) mean nutrient concentration of the tile drain flow; the main calculation steps for nutrient emissions via tile drainages are shown in Figure 9.

3.5.1. *Tile Drainage Flow Rate*

The tile drainage discharge rate is calculated as 50% of the winter precipitation and 10% of the summer precipitation following Kretschmar (1977, Eq. 17). These values were supported by analysis of data for tile drainage from monitoring stations (Hirt *et al.*, 2011).

$$TD_{q\text{-}spec} = 0.5 \cdot PR_{WI} + 0.1 \cdot PR_{SU} \qquad \text{(Eq. 17)}$$

$TD_{q\text{-}spec}$ = area specific drain flow, in mm/yr
PR_{WI} = precipitation in winter, in mm/yr
PR_{SU} = precipitation in summer, in mm/yr

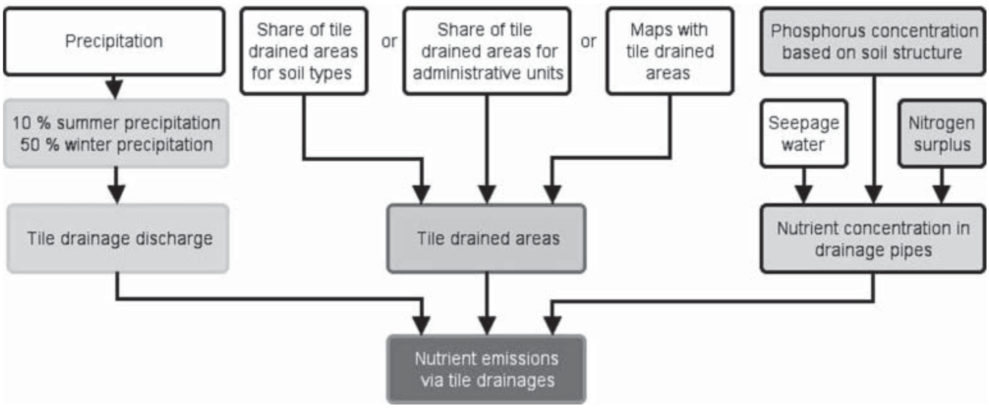

Figure 9. Main steps for calculation of N emissions via tile drainages.

3.5.2. Size of Tile Drained Areas

To determine the size of tile drained areas in an analytical unit, three different kinds of input data are used: (a) maps of tile drained areas (b) statistics on tile drained areas at an administrative level, and (c) calculated percentage of tile drained areas for different soil and site conditions.

In many areas, especially in Western Europe, there are little data available on location of tile drained areas (maps or statistics), and assessment of the percentage of tiled drained areas for different soil and site properties is the only way to derive the size of tile drained areas in an analytical unit. The percentage of tiled drained areas can be derived from digitalised tile drained data for representative areas. Based on spatial analysis of the soil and site properties on these representative tile drained areas, the percentage of tile drained areas could be transferred to a whole catchment area (BALZER, 2010; BEHRENDT *et al.*, 2000; HIRT *et al.*, 2005a, b).

3.5.3. Mean Nutrient Concentration in Tile Drainage Runoff

The N concentration in tile drain outlets (Eq. 18), and the potential nitrate concentration in the seepage water, is calculated based on the approach of FREDE and DABBERT (1998) using the regionally differentiated N surplus. The nutrient concentration of seepage water is expected to correlate with those of the tile drainage flow. The soil boundary condition is that net mineralization and net immobilisation are both negligible. To consider denitrification in soils the nitrate concentration in the tile drainage flow is reduced by an exponent of 0.85 for arable land, and 0.7 for grassland (BEHRENDT *et al.*, 2000). The calculated N concentrations in the tile drainage runoff, according to (Eq. 18), correspond to BEHRENDT *et al.* (2000).

$$TD_{TNC} = \frac{\left(IM_{Nsurp}\right)^{0.85}}{TD_{q\text{-}spec}} \cdot 100 \qquad \text{(Eq. 18)}$$

TD_{TNC} = N concentration in tile drainage flow under arable land (for grassland the denitrification exponent of 0.85 has to be substituted by 0.7), in mg/l
IM_{Nsurp} = N surplus, in kg/(ha · yr)

The P concentration in tile drainage discharge for different soil structures was determined based on a literature study by BEHRENDT *et al.* (2000), and is summarized here in Table 3. Tile drained fens and bogs are expected to be degraded ecosystems where mineralisation of organic matter occurs, and thus they are treated as nutrient sources rather than as nutrient sinks. The phosphorous concentration in tile drainage runoff from bogs varies significantly according to regional conditions, and has been calibrated for different model applications.

Table 3. P concentrations in tile drainage runoff in four different soil structures.

Soil structure	P-concentration in mg/l
Sandy	0.20
Loamy	0.06
Fen	0.30
Bog	2.00

3.6. Nutrient Emissions via Groundwater

Nutrient emissions via groundwater are calculated as the product of area weighted land use and soil structure specific groundwater concentrations, and the groundwater discharge rate, defined as the sum of natural interflow and base flow.

3.6.1. Nitrogen

The N surplus on agricultural land and its change during groundwater residence time is the dominating parameter for calculating the N concentration in groundwater. In MONERIS, the mean N concentrations in the groundwater are calculated based on mean long term conditions. Here, the groundwater residence time can either be estimated based on mean long term conditions (Eq. 21) or is considered as external derived input data. The modelled N concentration in groundwater also consider N uptake in the root-zone, later retention in groundwater, as well as the seepage water quantity in the individual analytical units (Fig. 10). The N emissions via groundwater to the surface waters are calculated as the product of the groundwater N concentrations, and the groundwater flow, calculated for the respective year.

Groundwater recharge is calculated for all unsealed areas, except water surface areas, open pit mine areas and tile drained areas (Eq. 19). The groundwater recharge is calculated for each analytical unit, as the difference between the mean long term total runoff (input data of MONERIS) and the calculated mean long term runoff from diffuse pathways (Eq. 19).

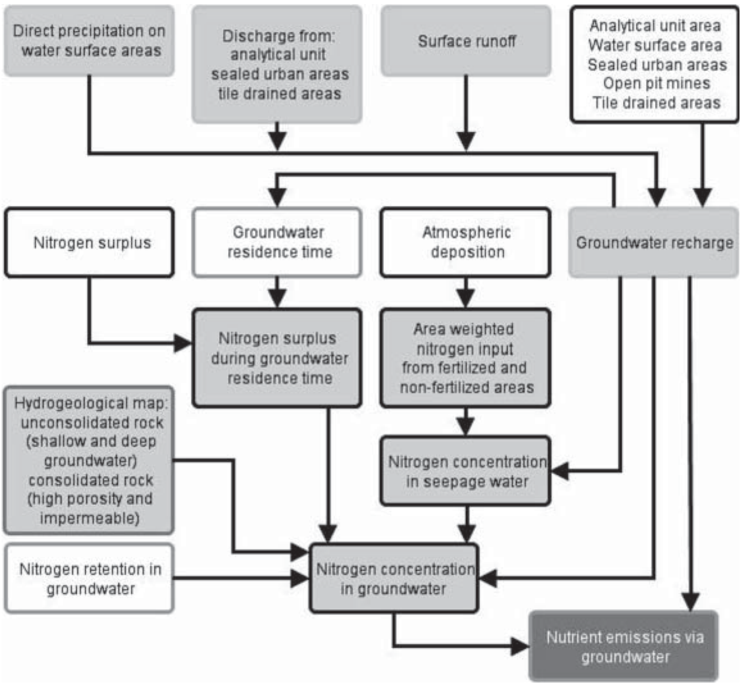

Figure 10. Main steps for calculation of N emission via groundwater.

$$q_{GW} = \frac{Q_{AU} - Q_{WSA} - Q_{SR} - Q_{TD} - Q_{urban}}{A_{AU} - A_{WSA} - A_{urban} - A_{OPM} - A_{TD}} \cdot \frac{86400 \cdot 365}{1000} \quad \text{(Eq. 19)}$$

q_{GW} = mean long term groundwater recharge, in mm/yr
Q_{AU} = mean long term runoff from an analytical unit, in m^3/s
Q_{WSA} = mean long term direct precipitation on surface waters, in m^3/s
Q_{SR} = mean long term surface runoff from unsealed areas, in m^3/s
Q_{TD} = mean long term discharge from tile drainages, in m^3/s
Q_{urban} = mean long term discharge from sealed urban areas, in m^3/s
A_{AU} = analytical unit area, in km^2
A_{WSA} = water surface areas, in km^2
A_{urban} = sealed urban areas, in km^2
A_{OPM} = open pit mine areas, in km^2
A_{TD} = tile drained areas, in km^2

By calculating groundwater recharge as a residual of the remaining flow components, the water balance in an analytical unit should not be altered. However, in some cases, precipitation and runoff show inconsistencies, and the runoff from the diffuse pathways is higher or much lower than the total runoff in an analytical unit, resulting in negative or very high groundwater recharges. In order to avoid large deviations from the runoff (input data of MONERIS), a corrected groundwater recharge ($q_{GW\text{-}corr}$) is defined by a maximum value of 1.5 times the sum of interflow and base flow calculated by CARL *et al.* (2008) (Eq. 20), and a minimum value of 25 mm/yr.

However, the total runoff per analytical unit is considered as input data in MONERIS. The simple approach to calculate the groundwater recharge avoids, in most cases, a modification of the total runoff by the model, that can be applied to any river system and supports the link to hydrological models.

$$q_{GWmax} = 0.146 \left[\frac{Q_{AU} - Q_{SR}}{A_{AU}} \cdot 86.4 \cdot 365 \right]^{1.1247} + 1.176 \left[\frac{Q_{AU} - Q_{SR}}{A_{AU}} \cdot 86.4 \cdot 365 \right]^{0.8535} \quad \text{(Eq. 20)}$$

q_{GWmax} = groundwater recharge, in mm/yr

The mean groundwater residence time for each analytical unit is considered to reflect the change of land use intensities, in other words, the N surplus on agricultural areas. If groundwater residence time data are not available, they will be estimated by MONERIS using equation 21 (SCHREIBER *et al.*, 2003). Equation 21 has been derived from the long term comparison of N surpluses and N concentrations for groundwater monitoring stations in the Rhine, Elbe and Odra basins (BEHRENDT *et al.*, 2000). Depending on the period for which data were available, this correlation is only valid for a maximum of 50 years (SCHREIBER *et al.*, 2003), which is supposed to be long enough to reflect recent land use changes. Calculated groundwater residence times are aggregated into five-year classes, due to the simple approach (Eq. 21) and the limited availability of spatially distributed data for N surpluses.

$$GW_{RT} = \frac{3000}{q_{GW\text{-}corr}} \quad \text{(Eq. 21)}$$

GW_{RT} = groundwater residence time, in yr
$q_{GW\text{-}corr}$ = corrected mean long term groundwater recharge, in mm/yr

For the groundwater residence time, a mean N surplus is calculated. Because spatially distributed data on annual N surplus is often not available, MONERIS considers two different sources for N surplus data: (i) N surplus for each analytical unit for a specific year (N_{SY}), and (ii) annual time series of N surplus on a sub-national or national administrative level (N_{AM}).

For modelling the mean N surplus in an analytical unit during the groundwater residence time, the mean N_{AM} during the groundwater residence time is compared to N_{AM} of the specific calculation year. The change of N surplus on an administrative level ($N_{AM\text{-}GR}/N_{AM\text{-}SY}$ ratio) is also for the respective analytical unit (Eq. 22).

$$N_{AU\text{-}GR} = N_{AU\text{-}SY} \cdot \frac{N_{AM\text{-}GR}}{N_{AM\text{-}SY}} \qquad \text{(Eq. 22)}$$

$N_{AU\text{-}GR}$ = mean N surplus in an analytical unit during groundwater residence time, in kg/(ha · yr)
$N_{AU\text{-}SY}$ = N surplus in an analytical unit for a specific calculation year, in kg/(ha·yr)
$N_{AM\text{-}GR}$ = mean N surplus in the respective administrative level during groundwater residence time, in kg/(ha · yr)
$N_{AM\text{-}SY}$ = N surplus in the respective administrative level for a specific calculation year, in kg/(ha · yr)

For non-fertilized areas (naturally covered areas, wetlands, open land areas, open pit mine areas, snow and ice covered areas and unsealed urban areas), the mean N surplus is not used for the calculations; instead the mean long term atmospheric deposition is used. From this, the area-weighted mean N input of fertilized and non-fertilized agricultural areas is calculated. The mean N concentration in the seepage water is calculated by equation 23.

$$C_{N\text{-}LW} = \frac{N_{in}}{q_{GR\text{-}corr}} 100 \qquad \text{(Eq. 23)}$$

$C_{N\text{-}LW}$ = mean N concentration in seepage water, in mg/l
N_{in} = mean N input on soils, as the area-weighted mean of fertilized and non-fertilized agricultural areas, in kg/(ha · yr)

Estimation of the nitrate concentration in groundwater requires a catchment-specific model for N retention in the unsaturated and saturated vadose zone. To determine this, BEHRENDT *et al.* (2000) compared the nitrate concentration in seepage water to the groundwater nitrate concentrations of 217 monitoring stations in Germany. The N retention rates were shown to depend on the seepage water rate and on hydro-geological conditions, and led to the development of equation 24. Significant differences in the groundwater concentrations in different hydro-geological rock types could be shown and have been considered in the constants k_1 and k_2 of equation 24 and Table 4.

$$C_{GW\text{-}NO3} = \left[\sum_{i=1}^{4} \frac{1}{1 + k_1 \cdot q_{GR\text{-}corr}^{k_2}} \cdot \frac{A_{HG_i}}{A_{AU}} \right] \cdot C_{N\text{-}LW}^{0.637} \qquad \text{(Eq. 24)}$$

$C_{GW\text{-}NO3}$ = nitrate concentration in groundwater, in mg/l
A_{HGi} = areas of hydro-geological rock types, in km^2
k_1, k_2 = model constants for different hydro-geological conditions, dimensionless

Table 4. Two model constants (Eq. 24) used to estimate N retention in four hydro-geological rock types according to BEHRENDT *et al.* (2000).

Hydro-geological rock types	k_1	k_2
Unconsolidated rock, shallow groundwater	2752.221	–1.54004
Unconsolidated rock, deep groundwater	68 561.63	–1.95861
Consolidated rock, high porosity	60.22649	–0.90311
Consolidated rock, impermeable	0.012733	0.661513

The seepage water concentrations for different land use categories are modelled following equation 23. The resulting groundwater concentrations for different land uses are calculated by applying the mean groundwater N retention (Eq. 24).

Additionally to the N emissions described above, dissolved organic N (DON) emissions via groundwater from wetlands and forests are calculated. DON is calculated using the corrected values for groundwater recharge underneath naturally covered areas and wetlands. VENOHR (2006) and VENOHR *et al.* (2010a) derived DON concentrations of 2–6 mg/l for wetlands, and of 0.5–2.5 mg/l for forests, based on studies in Irish, German and Canadian river systems. In spite of large differences in DON concentrations between different catchments, VENOHR (2006) and VENOHR *et al.* (2010a) observed a strong increase of DON concentrations with decreasing temperatures.

3.6.2. Phosphorus

The mean dissolved reactive phosphorus (SRP) concentrations in groundwater are calculated as the area-weighted mean of sandy, silty and loamy soils, and fens and bogs, in the respective analytical unit. The share of degraded and natural fens and bogs is considered separately for each analytical unit. Model parameters for mean SRP concentrations in water from different soil structures and from fens and bogs have been derived by BEHRENDT *et al.* (2000) from data for 217 groundwater monitoring stations in Germany, published data by BRAUN *et al.* (1991), DRIESCHER and GELBRECHT (1993) and WERNER *et al.* (1991) (Eq. 25).

For arable land and grassland (without tile-drained areas) the mean P groundwater concentration is calculated by equation 25. For naturally covered areas, wetland, open land areas and unsealed urban areas, the mean concentration of SRP in the groundwater is set to 0.02 mg/l also derived on basis of data published by BRAUN *et al.* (1991), DRIESCHER and GELBRECHT (1993) and WERNER *et al.* (1991).

$$C_{GWAGRI\text{-}P} = \frac{0.1 \cdot A_S + 0.03 \cdot (A_C + A_L + A_{SI}) + 0.1 \cdot A_{FD} + 0.02 \cdot A_{FN} + 0.5 \cdot A_{BD} + 0.035 \cdot A_{BN}}{A_S + A_L + A_{FD} + A_{FN} + A_{BD} + A_{BN}} \quad \text{(Eq. 25)}$$

$C_{GWAGRI\text{-}P}$ = P concentration in groundwater under agricultural land use, in mg/l
A_S = areas of sandy soil, in km^2
A_C = areas of clay soil, in km^2
A_L = areas of loamy soil, in km^2
A_{SI} = areas of silty soil, in km^2
A_{FD} = areas of degraded fens, in km^2
A_{FN} = areas of natural fens, in km^2
A_{BD} = areas of degraded bogs, in km^2
A_{BN} = areas of natural bogs, in km^2

In aerated groundwater, there are usually only small differences between the total P concentration and the SRP concentration. In contrast, in anaerobic groundwater, the total P concentrations can be up to five times higher than the SRP concentration (Behrendt, 1996; Driescher and Gelbrecht, 1993). To distinguish between aerobic and anaerobic conditions, the ratio between nitrate concentrations in groundwater and in seepage water is used. If this ratio is less than 0.1, indicating anaerobic conditions, the total P concentration in the groundwater is assumed to be 2.5 times higher than the SRP concentration (Behrendt *et al.*, 2000). For aerobic conditions the total P concentration is assumed to equal the SRP concentration.

3.7. Nutrient Emissions via Urban Systems

Nutrient emissions from urban systems are calculated for sealed urban areas connected or not connected to sewer systems, as well as for households not being connected to sewer systems or waste water treatment plants (WWTP). Households connected to sewer systems and to WWTP are not accounted for in the calculated emissions from urban systems as they should be considered in the WWTP inventory. Storm water events generating high runoff from sealed areas are crucial for emissions from urban systems. Here, the increased discharges from combined sewers can often not be handled by WWTP and have to be stored in the sewer systems. If the storage capacity in combined sewer systems is exceeded, the excessive water amount is bypassed directly, allowing raw sewage from households, commercial use, and streets to reach surface waters during overflow events. Beyond combined sewer systems, MONERIS considers four more pathways for nutrient emissions from urban areas (Fig. 11): rainwater collected via separate sewer systems, decentralized treatment plants, sewer systems without WWTP, and not connected inhabitants and areas.

For calculation of the N and P concentrations in sewages from households, MONERIS uses inhabitant-specific emissions. For N, inhabitant-specific emissions (Inh_N) vary between 9 and 12 g/(inhabitant · d) (ATV, 1997, Lindtner and Zessner, 2003; Werner *et al.*, 1991), and can be adapted to the situation in the particular river system. For P, inhabitant-specific P emissions are set to 1.65 g/(inhabitant · d), excluding phosphates from laundry and dishwashers. Since the usage of phosphates in dishwasher and laundry detergents varies from country to country, the total specific values for dissolved P emissions from humans and detergents are considered on a country level.

For calculation of N emissions, MONERIS uses the area-specific value of 4 kg/(ha · yr) from litter and excrements, in addition to the values for atmospheric deposition. The area-specific P emission from sealed urban areas by atmospheric deposition, litter, and excrement, amounts to 2.5 kg/(ha · yr) (Brombach and Michelbach, 1998).

3.7.1. Calculation of Sealed Urban Areas

The total urban area can be deduced from a land use map. The percentage of this urban area that is sealed can then be calculated based on the population density, using the approach of Heaney *et al.* (1976) (see Eq. 26). For equation, a maximum population density of < 150 inhabitants/ha is defined, which corresponds to a maximum of 92% of sealed urban areas.

$$A_{SUA} = 9.6 \cdot (0.4047 \cdot POP_{DENS})^{(0.573-0.0391 \cdot \log \cdot (0.4047 \cdot POP_{DENS}))} \quad \text{(Eq. 26)}$$

A_{SUA} = sealed urban areas, in %
POP_{DENS} = population density, in inhabitants/ha for $POP_{DENS} < 150$/ha

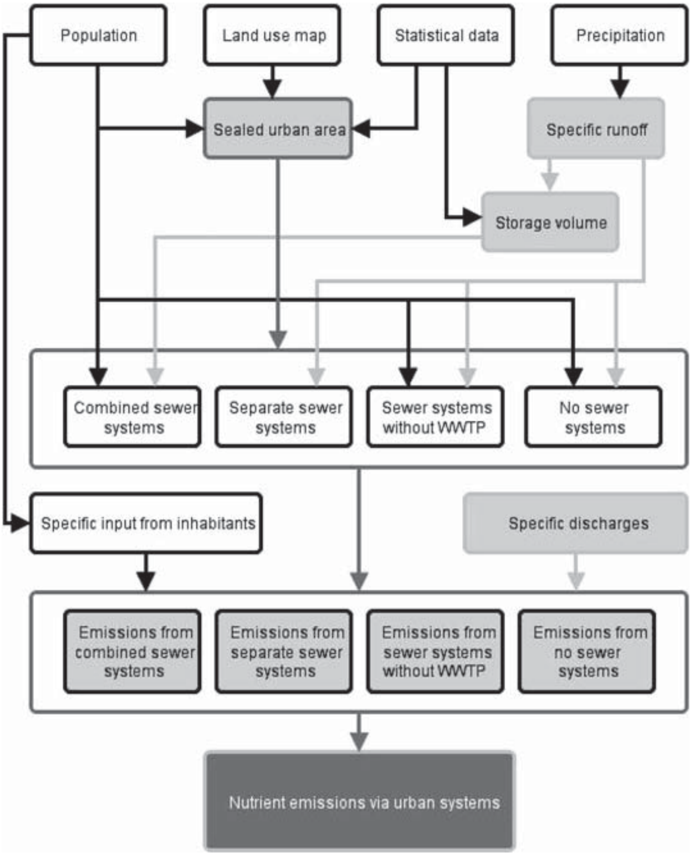

Figure 11. Main steps for calculation of nutrient emissions via urban systems (diagram excludes the pathway for decentralized treatment plants).

Percentages of the sealed urban areas are proportionally allocated to the corresponding sewer systems, according to the length of the combined and separate sewer systems, and the connection rates of inhabitants.

3.7.2. Runoff from Sealed Urban Areas

The runoff rate from sealed urban areas that is generated from precipitation is calculated according to HEANEY *et al.* (1976) (Eq. 27). The higher the percentage of the area that is sealed, the larger is the runoff rate, and thus the larger the part of precipitation reaching the sewer systems.

$$Q_{R\text{-}SUA} = 0.15 + 0.75 \cdot A_{SUA} \cdot 0.01 \qquad \text{(Eq. 27)}$$

$Q_{R\text{-}SUA}$ = runoff rate from sealed urban areas, dimensionless

Accordingly, the area-specific runoff from sealed urban areas can be calculated, depending on the size of the sealed urban area, the runoff rate, and the annual precipitation. The total runoff from sealed urban areas is calculated as the sum of runoff from all urban pathways.

3.7.3. Nutrient Emissions via Combined Sewer Systems

During heavy rainfall events, WWTP cannot handle the entire water coming from combined sewer systems and have to be stored in the sewer systems itself. Is the storage volume of the combined sewer system exceeded, excess water is bypassed directly, without treatment, into surface waters via the combined sewer overflow (CSO).

The discharge rate during CSO events depends on the storage volume in the combined sewer system. BROMBACH and MICHELBACH (1998) and MEISSNER (1991) anticipated that a storage volume of 23.3 m^3/ha corresponds to a storage capacity of 100%. The precipitation-runoff rate is assumed to be 1 l/(ha · s) (q_R) for all analytical units. The discharge rate according to MEISSNER (1991) is described in equation 28:

$$Q_{R\text{-}CSO} = \left[\left(\frac{\dfrac{4000+25\cdot q_R}{0.551+q_R}}{\dfrac{CSV}{100}\cdot 23.3+\dfrac{36.8+13.5\cdot q_R}{0.5+q_R}}\right)-6+\frac{PR_{yr}-800}{40}\right] \qquad \text{(Eq. 28)}$$

$Q_{R\text{-}CSO}$ = discharge rate via CSO, in %
PR_{yr} = annual precipitation, in mm/yr
q_R = precipitation-runoff rate, in l/(ha · s)
CSV = storage volume of combined sewer systems, in %

For calculating the discharge by CSO events, the number of days with heavy rainfall events is calculated according to MOHAUPT *et al.* (1998) on the basis of the annual precipitation (Eq. 29).

$$DHR = PR_{yr}^{2.5}\cdot 0.0000012 \qquad \text{(Eq. 29)}$$

DHR = number of heavy rainfall events, in d/yr

The effective number of heavy rainfall days (Eq. 30) describes the number of days, which actually cause a CSO event. Here, the discharge rate via CSO is calculated with and without (CSV = 0) considering the storage volume in the combined sewer system. Consequently, in combined sewer systems with a high storage volume, heavy rainfall events less often cause an overflow event.

$$DHR_{EFF} = DHR\cdot\frac{Q_{SP}}{Q_{SP\text{-}nostorage}} \qquad \text{(Eq. 30)}$$

DHR_{EFF} = effective number of days of heavy rainfall events, in d/yr
Q_{SP} = CSO discharge rate with consideration of storage volume in sewer systems, in %
$Q_{SP\text{-}nostorage}$ = CSO discharge rate without consideration of storage volume in sewer system, in %

Calculation of the nutrient emission via CSO uses the nutrient loads in the combined sewer systems of an entire day. Although a CSO event may not be of an entire day's duration, sewage from households stays in the combined sewer systems for several hours or even days.

To calculate the total discharge during CSO events, three sources are taken into account: (i) water from households (inhabitants), (ii) water from commercial areas, and (iii) precipitation on areas connected to combined sewer systems. The total annual discharge in combined sewer systems generated by precipitation is calculated by equation 31.

$$Q_{CSO\text{-}P} = A_{CS} \cdot PR_{yr} \cdot Q_{R\text{-}SUA} \cdot 1000 \qquad \text{(Eq. 31)}$$

$Q_{CSO\text{-}P}$ = discharge in combined sewer systems generated by precipitation, in m^3/yr
A_{CS} = sealed urban areas connected to combined sewer systems, in km^2
$Q_{R\text{-}SUA}$ = see (Eq. 27)

For calculating the amount of waste water from commercial areas, the approach of BROMBACH and MICHELBACH (1998) and MOHAUPT *et al.* (1998) is applied. This approach assumes that 0.8% of the total urban area is commercial area, having a runoff rate of 1 l/(ha · s) for 10 hours after heavy rainfall events (Eq. 32).

$$Q_{CSO\text{-}CA} = \left(1 \cdot 0.8 \cdot A_{CS} \cdot \frac{10}{24} \cdot \frac{86\,400}{1000}\right) \qquad \text{(Eq. 32)}$$

$Q_{CSO\text{-}CA}$ = discharge in combined sewer systems generated from precipitation on commercial areas, in m^3/d

The discharges from inhabitants in households connected to combined sewers are calculated on basis of an inhabitant-specific daily waste water production, which is assumed to be 130 l/(inhabitants · d) (Eq. 33) (BROMBACH and MICHELBACH, 1998; MOHAUPT *et al.*, 1998).

$$Q_{CSO\text{-}Inh} = Inh_{CS} \cdot \frac{130}{1000} \qquad \text{(Eq. 33)}$$

$Q_{CSO\text{-}Inh}$ = discharge in the combined sewer system generated from inhabitants, in m^3/d
Inh_{CS} = number of inhabitants in households connected to combined sewer systems

The total discharge from inhabitants and from precipitation from sealed urban areas emitted via CSO events is calculated using equation 34. The influence of external water intrusion into sewer systems is excluded, as it is assumed that the sewer systems act as donors of water during heavy rainfall events.

$$Q_{CSO\text{-}total} = ((Q_{CSO\text{-}Inh} + Q_{CSO\text{-}CA}) \cdot DHR_{EFF} + Q_{CSO\text{-}P}) \cdot \frac{Q_{R\text{-}CSO}}{100} \qquad \text{(Eq. 34)}$$

$Q_{CSO\text{-}total}$ = total discharge via spillways during CSO, in m^3/yr
DHR_{EFF} = see equation 30

For the calculation of the P concentration in combined sewer systems during overflow events, the P emissions from commercial areas are also considered. The N and P concentrations in combined sewer systems at overflow events are calculated according to equations 35 and 36 respectively.

$$TNC_{CSO} = \frac{\left(Inh_{CS} \cdot Inh_N + (AD_N + SUA_N \cdot 100)\frac{Q_{R\text{-}SUA} \cdot A_{CS} \cdot 10}{365}\right) \cdot DHR_{EFF}}{Q_{CSO\text{-}total} \cdot \frac{100}{Q_{R\text{-}CSO}} + \frac{A_{CS} \cdot 23.3}{100\,000} \cdot DHR_{EFF} \cdot \frac{CSV}{100}} \quad \text{(Eq. 35)}$$

TNC_{CSO} = TN concentration during CSO, in mg/l
Inh_N = inhabitant-specific N emissions, in g/(inhabitant · d)
AD_N = atmospheric NO_x and NH_y deposition on urban areas, in $kg/(km^2 \cdot yr)$
SUA_N = specific TN emissions from sealed urban areas by litter, animal excrement, and traffic, in kg/(ha · yr) (currently set to 4 kg/(ha · yr))
$Q_{R\text{-}SUA}$ = see equation 27
CSV = storage volume of combined sewer systems, in %
DHR_{EFF} = see equation 30
$Q_{R\text{-}CSO}$ = see equation 28

$$TPC_{CSO} = \frac{\left(Inh_{CS} \cdot Inh_P + SUA_P \cdot 100\frac{Q_{R\text{-}SUA} \cdot A_{CS} \cdot 10}{365}\right) \cdot DHR_{EFF}}{Q_{CSO\text{-}total} \cdot \frac{100}{Q_{R\text{-}CSO}} + \frac{A_{CS} \cdot 23.3}{100\,000} \cdot DHR_{EFF} \cdot \frac{CSV}{100}} \quad \text{(Eq. 36)}$$

TPC_{CSO} = TP concentration during CSO, in mg/l
Inh_P = inhabitant-specific P emissions, in g/(inhabitant · d)
AD_P = atmospheric P deposition on urban areas, in $kg/(km^2 \cdot yr)$
SUA_P = specific TP emissions from sealed urban areas by litter, animal excrement, and traffic, in kg/(ha · yr) (currently set to 2.5 kg/(ha · yr))
DHR_{EFF} = see equation 30
$QR_{\text{-}CSO}$ = see equation 28

Finally the nutrient emissions via combined sewer systems during overflow events is calculated as the product of the nutrient concentration in combined sewer systems at overflow events and the total discharge via CSO from sealed urban areas and households connected to combined sewer systems.

3.7.4. Nutrient Emissions via Rainwater-Collecting Separate Sewer Systems

Separate sewer systems collecting black water from households and industries are connected to WWTPs, and the waste water of such separate sewer systems is considered within the pathway point sources. Discharge from sealed urban areas including commercial areas connected to separate sewer systems collecting rain water is calculated in equation 37.

$$Q_{SS\text{-}total} = A_{SS} \cdot PR_{yr} \cdot Q_{R\text{-}SUA} \cdot 1000 \quad \text{(Eq. 37)}$$

$Q_{SS\text{-}total}$ = total discharge from rainwater-collecting sewer systems, in m^3/yr
A_{SS} = sealed urban areas connected to separate sewer systems, in km^2
$Q_{R\text{-}SUA}$ = see equation 27
PR_{yr} = annual precipitation, in mm/yr

Loads from rainwater-collecting separate sewer systems are partly treated in clarifier basins and in retention soil filters before being discharged to surface waters. Information about the share of the clarifier basins and retention soil filters has to be given as input data in MONERIS. The emissions finally depend on the subsequent retention in the clarifier basins and in retention soil filters. The retention in clarifier basins and in retention soil filters are set to 35% and 85% for N, and 35% and 45% for P, respectively.

Nutrient emissions via separate sewer systems are calculated based on area-specific emissions and atmospheric deposition by equations 38 and 39.

$$TNC_{SS} = \left(\frac{AD_N}{PR_{yr}} + \frac{SUA_N \cdot 10\,000}{PR_{yr} \cdot Q_{R\text{-}SUA}}\right) \cdot \left(1 - \frac{0.35 \cdot RCB}{100}\right) \cdot \left(1 - \frac{0.85 \cdot RSF}{100}\right) \quad \text{(Eq. 38)}$$

TNC_{SS} = N concentration from separate sewer systems after retention, in mg/l
RCB = share of retention clarifier basins in separate sewer system, in %
RSF = share of retention soil filter in separate sewer system, in %
$Q_{R\text{-}SUA}$ = see equation 27

$$TPC_{SS} = \left(\frac{SUA_P \cdot 10\,000}{PR_{yr} \cdot Q_{R\text{-}SUA}}\right) \cdot \left(1 - \frac{0.35 \cdot RCB}{100}\right) \cdot \left(1 - \frac{0.45 \cdot RSF}{100}\right) \quad \text{(Eq. 39)}$$

TPC_{SS} = N concentration from separate sewer systems after retention, in mg/l

The nutrient emissions via separate sewer systems are calculated as product of the nutrient concentration from separate sewer systems after treatment, and the discharge from rainwater-collecting separate sewer systems.

3.7.5. Nutrient Emission from Sealed Urban Areas and Inhabitants that Are Connected to Sewer Systems, but not to Municipal WWTP

The calculation of emissions from areas and households connected to sewer systems but not to WWTPs, (in the following called "connected to sewer systems only (OS)"), are conducted analogous to the approaches used for combined and separate sewer systems. In contrast to separate sewer systems, no treatment in clarifier basins and in retention soil filters is assumed (these treatments apply only in separate sewer systems). Also in contrast to combined sewer systems, in OS systems the total discharge is considered (not only the discharge at overflow events). Discharge from sealed urban areas connected to sewer systems only is calculated in equation 40.

$$Q_{OS\text{-}total} = A_{OS} \cdot PR_{yr} \cdot Q_{R\text{-}SUA} + \left(Inh_{OS} \cdot \frac{130}{1000}\right) \cdot 365 \quad \text{(Eq. 40)}$$

$Q_{OS\text{-}total}$ = discharge from sealed urban areas and inhabitants that are connected to sewer systems only, in m^3/yr
A_{OS} = sealed urban areas connected to sewer system only, in km^2

Inh_{OS} = number of inhabitants connected to sewer systems only
$Q_{R\text{-}SUA}$ = see equation 27

Nutrient concentrations from sealed urban areas and from inhabitants connected to sewer systems only are calculated with equations 41 and 42.

$$TNC_{OS} = \frac{(Inh_{OS} \cdot Inh_N) \cdot 365 + (AD_N + SUA_N \cdot 100) \cdot Q_{R\text{-}SUA} \cdot A_{OS} \cdot 10}{Q_{OS\text{-}total} \cdot 86\,400 \cdot 365} \qquad \text{(Eq. 41)}$$

TNC_{OS} = TN concentration in discharge from inhabitants and sealed urban areas connected to sewer systems only, in mg/l
$Q_{R\text{-}SUA}$ = see equation 27

$$TPC_{OS} = \frac{(Inh_{OS} \cdot Inh_N) \cdot 365 + SUA_N \cdot Q_{R\text{-}SUA} \cdot A_{OS} \cdot 1000}{Q_{OS\text{-}total} \cdot 365 \cdot 86\,400} \qquad \text{(Eq. 42)}$$

TPC_{OS} = TP concentration in discharge from inhabitants and sealed urban areas connected to sewer systems only, in mg/l
$Q_{R\text{-}SUA}$ = see equation 27

3.7.6. Nutrient Emission from Sealed Urban Areas and Inhabitants that are Connected to DCTP with or without Sewer Systems

Decentralised wastewater treatment plants (DCTP) are onsite or cluster wastewater systems that are used to treat and dispose relatively small volumes of wastewater, generally originating from individual or groups of dwellings and businesses that are located relatively close together. Onsite and cluster systems are commonly used in combination. Different DCTP are distinguished in the model, according to their technical status and how loads are discharged to the surface waters. The DCTP can be constructed according to different legal regulations. In Germany under DIN 4261 01 (1991) (DIN = German industry norm), without wastewater aeration, a retention capacity of 10% for N and 7% for P can be achieved, and according to DIN 4261 02 (1984) with wastewater aeration, a retention capacity of 15% for N and 13% for P can be achieved. Emissions can be discharged directly via sewer systems or pipes and ditches, or indirectly via infiltration to soil and groundwater. In the first case, no further retention subsequent to the DCTP is assumed. For the second case, additionally to the retention in the DCTP, retention during the soil and groundwater passage is considered. The retention in soil and groundwater is calculated following the method described for the groundwater pathway. Analogous to the calculation for the other sewer systems, inhabitant-specific TN and TP are considered for DCTP (Eq. 43).

$$TN/TP_{DCTP} = \frac{RN/P_{SGW}}{100} \cdot Inh_{DCTP} \cdot Inh_N \cdot 0.365 \cdot \left(1 - \frac{R_{DCTP}}{100}\right) \qquad \text{(Eq. 43)}$$

TN/TP_{DCTP} = nutrient emissions from DCTP, in t/yr
RN/P_{SGW} = nutrient retention in soil and groundwater analogue to equation 24, in %
Inh_{DCTP} = inhabitants connected to one of the different DCTP types (as described above)
R_{DCTP} = nutrient retention capacity of DCTP, distinguished for DCTP with or without waste water aeration, in %

3.7.7. Nutrient Emissions from Sealed Areas and Households neither Connected to Sewer Systems nor to WWTP

In rural areas or in older settlements, households are sometimes neither connected to a sewer system nor to WWTP. Households, should, nevertheless, be connected to a septic tank. For this it is assumed that 90% of the dissolved inhabitant-specific emissions are transported to a WWTP (Eqs. 44 and 45). For the remaining 10% from septic tanks, and for emissions from not connected sealed urban areas, the retention in soil and groundwater is taken into account.

$$TN_{NC} = \frac{RN_{SGW}}{100} \cdot \left(Inh_{ST} \cdot Inh_{N} \cdot \frac{0.365}{1000} \cdot \left(1 - \frac{FR_{WWTP}}{100}\right) + \left(\frac{AD_{N} + SUA_{N} \cdot 100}{1000}\right) \cdot A_{NC} \right) \quad \text{(Eq. 44)}$$

TN_{NC} = TN emissions from households and sealed urban areas neither connected to sewer systems or WWTP, in t/yr
Inh_{ST} = number of inhabitants in households connected to septic tanks
FR_{WWTP} = fraction of dissolved specific inhabitant emissions transported to WWTP, in %
A_{NC} = sealed urban areas neither connected to sewer system nor to WWTP, in km^2

$$TP_{NC} = \frac{RP_{SGW}}{100} \cdot \left(Inh_{ST} \cdot Inh_{P} \cdot \frac{0.365}{1000} \cdot \left(1 - \frac{FR_{WWTP}}{100}\right) + \left(\frac{SUA_{P} \cdot 100}{1000}\right) \cdot A_{NC} \right) \quad \text{(Eq. 45)}$$

TP_{NC} = TP emissions from households and sealed urban areas neither connected to sewer systems or to WWTP, in t/yr

3.8. *Nutrient Emissions via Point Sources*

Nutrient emissions via point sources are taken from an inventory with information on individual waste water treatment plants (WWTP). Additionally, lumped discharges from industrial direct dischargers and remaining smaller point sources can be considered for each analytical unit. For the WWTP inventory data on the discharge, the TN and TP concentrations and the size as inhabitant equivalents are needed. Temporal changes in discharges from waste water treatment plants can be considered by factors for individual years in each analytical unit. For the later calculation of retention in surface waters it can also be considered whether point sources discharge into tributaries or directly into the main river of an analytical unit. In MONERIS usually all emissions are assumed to first reach the tributaries. In reality, WWTPs are normally located at large streams and therefore discharge into these main rivers. In case that it is known whether the WWTP discharge into the tributaries or the main river, it can be separately considered for the calculations.

3.9. *Retention in Surface Waters*

In surface waters, retention – which is the sum of all nutrient transformation and loss processes – is an important element of the nutrient cycle. In MONERIS we consider net nutrient retention rather than the contribution of individual chemical and biological transformation, or non-permanent retention processes.

Retention processes include nitrification-denitrification, plant uptake, sedimentation, and decomposition of dissolved organic matter. For N, the dominant retention process is denitrification, whereas for P it is sedimentation (MULHOLLAND *et al.*, 2000; SAUNDERS and KALFF, 2001b; SEITZINGER, 1988; SVENDSEN and KRONVANG, 1993; TRISKA *et al.*, 1994; VENOHR, 2006). For dissolved organic nitrogen (DON), retention in surface waters is assumed to be negligible.

For the retention calculation, it is assumed that: (i) nutrient emissions are evenly distributed throughout the catchment, (ii) all emissions reach the tributaries before the main rivers, and (iii) tributaries discharge into the main river at the outlet of the respective analytical unit. Thus, nutrient loads coming from upstream catchments are subject to the retention in the main river of the downstream analytical unit. In addition, for the situation where lakes are flushed by the main river at the outlet of an analytical unit, an additional retention can be considered for all incoming loads from tributaries and main rivers.

To model N retention, the THL-approach by VENOHR (2006) is used, which considers water temperature (T) and hydraulic load (HL) (Eq. 46). The P retention in tributaries is calculated using the approaches developed by BEHRENDT and OPITZ (2000) and BEHRENDT *et al.* (2000), which quantifies the retention as a function either of the hydraulic load or of the specific runoff, and calculates a mean retention based on both of these parameters. The P retention in main rivers is calculated according to the hydraulic load only (specific runoff is not suitable for the retention calculation in main rivers, as it does not change with the length of the respective river stretch (VENOHR, 2006).

The retention processes in specific lakes or river stretches are closely related to the nutrient residence time, and thus also to the flow velocity (Eq. 46). As shown in equation 46, residence time and flow velocity can mathematically be transferred into the hydraulic load, which is used for the retention calculation with MONERIS. Water depth and flow velocity are both needed to calculate the residence time and are difficult to model, even on a large scale, in contrast to the water surface area, which can be easily calculated and is often also available from maps or statistical reports (see Chapter 3.1). Consequently, the hydraulic load has been chosen as modelling parameter for the retention calculation, to allow a wider applicability of the model.

$$\frac{z}{\tau} = \frac{z}{\frac{V}{Q_a}} = \frac{z}{\frac{WSA \cdot z}{Q_a}} = \frac{Q_a}{WSA} = HL \qquad \text{(Eq. 46)}$$

z = mean depth of a water body, in m
τ = mean residence time in a water body, in yr
V = mean volume of a water body, in m^3
Q_a = specific runoff, in m^3/yr
WSA = water surface areas, m^2
HL = hydraulic load, in m/yr

3.9.1. Basic Approach to Model Retention in Surface Waters

The retention is based on a general mass balance equation for mixed reactors (Eq. 47).

$$\frac{dC(t)}{dt} = \frac{Q}{V} \cdot (C_{in}(t) - C(t)) - C(t) \cdot k \qquad \text{(Eq. 47)}$$

$C(t)$ = calculated nutrient concentration as a function of time, in mg/l
$C_{in}(t)$ = mean nutrient concentration of emissions, in mg/l
Q = runoff, in m^3/s
k = retention rate, in s^{-1}

If the speed of the contributing retention processes is much higher than the mean residence time in a surface water body, steady state conditions can be assumed for the retention calculation. Under these conditions, equation 47 can be simplified to:

$$\frac{Q}{V} \cdot (C_{in} - C) - C \cdot k = 0 \qquad \text{(Eq. 48)}$$

If we assume that $Q \cdot C_{in}$ are the emissions, $Q \cdot C$ is the load and $C \cdot V \cdot k$ is the retention. Equation 48 can also be written as in equation 49, which is the basic structure for the retention approach in MONERIS.

$$L = \frac{1}{1 + R_L} E \qquad \text{(Eq. 49)}$$

L = load in surface waters, in t/yr
E = emissions to surface waters, in t/yr
R_L = load-weighted retention coefficient (R/L)

If steady state conditions are given, N retention can be calculated with equation 50. On an annual basis this approach is used to calculate TN and DIN retention.

$$R_{L\text{-TN/DIN}} = 1 - \frac{1}{1 + a \cdot e^{bT} \cdot HL^{-1}} \qquad \text{(Eq. 50)}$$

$R_{L\text{-TN/DIN}}$ = load weighted retention for TN and DIN, in %
T = water temperature, in °C
a = constant, in yr/m
b = constant, in K^{-1}

For P only TP retention is calculated. As discussed above, BEHRENDT and OPITZ (2000) used hydraulic load and specific runoff for the P retention approach (Eqs. 51 and 52), and the mean of both is used in MONERIS.

$$R_{L\text{-PHL}} = 1 - \frac{1}{1 + a_1 \cdot HL^{-1}} \qquad \text{(Eq. 51)}$$

$$R_{L\text{-Pq}} = 1 - \frac{1}{1 + a_2 \cdot q^{-1}} \qquad \text{(Eq. 52)}$$

$R_{L\text{-PHL}}$ = load weighted P retention, using HL as driving parameter, in %
$R_{L\text{-Pq}}$ = load weighted P retention, using specific runoff as driving parameter, in %
q = area specific runoff, in $l/(s \cdot km^2)$
a_1 = constant, yr/m
a_2 = constant, in $(s \cdot km^2)/l$

3.9.2. Calibration of the Retention Approaches

Parameter b (Eq. 50) describes the temperature dependence of N retention, reflecting the increase in biological activity with increasing temperature. Different methodological approaches have determined values for parameter b of between –0.04 and –0.11 (HILL, 1983; MOHAUPT, 1985; SAUNDERS and KALFF, 2001b; TOMS *et al.*, 1975; VAN LUIJN *et al.*, 1999), with a mean of –0.067.

To verify the values for b described in the literature, VENOHR (2006) statistically analysed the change of N concentrations with temperature at 49 monitoring sites in Germany from 1983 to 1997 (Fig. 12). Figure 12 shows the ratio between the N concentration at a given temperature and the concentration at the mean temperature, and shows how this ratio changes with changing water temperature. The average ratio of all available measurements for all monitoring stations was calculated subsequently for groups of 0.5 °C steps, resulting in 54 classes. The statistical analysis delivered a value of –0.056 for b ($r^2 = 0.86$; $N = 54$, not shown in Figure 12), which is in the lower range of published mean value of b (see above). However, VENOHR (2006) showed that a value for b of –0.067 does not deliver results significantly different from those using –0.056 for b. Finally, –0.067 for b is used in MONERIS to represent the temperature dependence of N retention.

The N retention approach ($R_{L\text{-}DIN/TN}$) was calibrated based on N concentration and temperature measurements from 59 catchments in Germany (39 (DIN) and 20 (TN)) for 1993–1997 (VENOHR, 2006). The 5-year mean nutrient emissions calculated with MONERIS compared with the 5-year mean of observed loads were used to calibrate the N retention approach (Table 5).

According to (VENOHR, 2006), the exponent for the hydraulic load or the specific runoff used to calculate $R_{L\text{-}DIN}$, $R_{L\text{-}TN}$, $R_{L\text{-}Pq}$, $R_{L\text{-}PHL}$, has been set to a value of –1 in order to avoid scaling effects, when applying the approaches to river catchments of different size. This was considered for the calibration of the N retention approaches. For P BEHRENDT and OPITZ (2000) derived exponents for q and HL different from 1. Therefore, for the application in MONERIS the approaches were re-calibrated with the dataset described by BEHRENDT and OPITZ (2000).

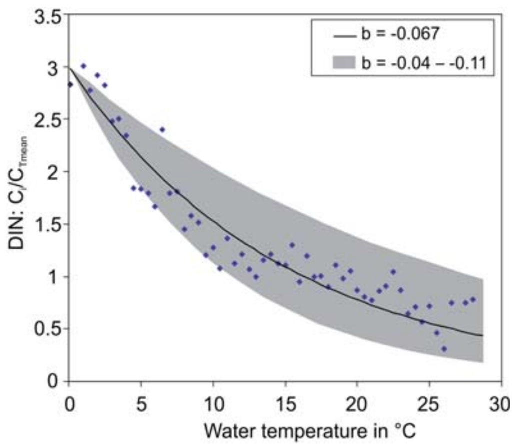

Figure 12. Dependence of the ratio DIN C_i : DIN C_{Tmean} (DIN concentrations of an individual measurement (C_i), and the DIN concentration at the mean water temperature (C_{Tmean}) of a monitoring station), on the water temperature. Temperatures grouped in 0.5 °C classes (VENOHR, 2006).

Table 5. Parameter for calculating DIN, TN and TP retention with Eqs. 51–53.

Retention approaches	a	Mean absolute Deviation in%	r^2	Modelling Efficiency	*N*	Equation
$R_{L\text{-}DIN}$	8.58	22.3	0.71	0.57	38	51
$R_{L\text{-}TN}$	4.74	26.9	0.76	0.67	20	51
$R_{L\text{-}Pq}$	8.77	21.6	0.98	0.84	89	52
$R_{L\text{-}PHL}$	15.91	31.0	0.97	0.73	89	53

3.10. Monthly Disaggregation of Emissions

MONERIS disaggregates annual emissions to monthly values, rather than calculating monthly emissions directly. This is appropriate because many area-covering input data (such as N surplus, inhabitants, and atmospheric deposition) are only available on an annual basis or only show a small inner-annual variation. The MONERIS approach to disaggregate the emissions describes the total monthly emissions and the resulting monthly loads, rather than modelling dynamics of the individual pathways.

For tile drainages, groundwater, and other diffuse pathways, the mean annual concentrations calculated by MONERIS are used. For the disaggregation of nutrient emissions from annual to monthly values, it is assumed that the nutrient concentrations do not change within years. Consequently, precipitation and runoff are the main driving factors for the seasonal variability of nutrient emissions. For runoff and precipitation, monthly input data is considered. Water temperature and incoming short wave radiation at ground level are used for the monthly retention calculation.

For diffuse pathways, the mean annual concentrations have been calculated based on annual diffuse emissions and mean annual runoff (Eq. 53).

$$C_a = \frac{E_a}{Q_a} \cdot \frac{1\,000\,000}{86\,400 \cdot 365} \qquad \text{(Eq. 53)}$$

C_a = mean annual concentration from pathway(s), in mg/l
E_a = annual emissions from pathway(s), in t/yr
Q_a = mean runoff from pathway(s), in m^3/s

To calculate monthly runoff for the pathways, a variety of approaches are used. Monthly surface runoff, runoff from urban systems, and precipitation on surface waters, is estimated according to the distribution of runoff during the year (Eq. 54). Although, these pathways are driven by precipitation, for the disaggregation to monthly values the generated runoff has to be taken into account.

$$Q_{diff\text{-}M} = Q_{diff\text{-}Y} \cdot \frac{Q_M}{Q_Y} \qquad \text{(Eq. 54)}$$

$Q_{diff\text{-}M}$ = monthly runoff as the sum of monthly runoffs from surface runoff, urban systems, and direct precipitation on surface waters, in m^3/s
$Q_{diff\text{-}Y}$ = annual runoff as the sum of annual runoffs from surface runoff, urban systems, and direct precipitation on surface waters, in m^3/s
Q_M = monthly runoff, in m^3/mo
Q_Y = annual runoff, in m^3/yr

Note that Q_{diff} is the part of total runoff without the runoff from tile drainages and groundwater.

Monthly flow rates from tile drainages are calculated as a percentage of the monthly precipitation (Eq. 55), based on HIRT *et al.* (2011) following KRETSCHMAR (1977). There is marked seasonal variation in the percentage of precipitation leading to tile drainage runoff, being much higher in winter than in summer; for sites in north-west Europe, this is shown in Figure 13. In case, the annual flow from tile drainages is calculated according to (Eq. 17), it is obligatory to use this equation also on a monthly basis to avoid differences between the annual sum and the sum of the monthly tile drainage flows.

$$Q_{TD\text{-}M} = RR_{TD} \cdot PR_M \cdot A_{TD} \cdot 1000 \qquad \text{(Eq. 55)}$$

$Q_{TD\text{-}M}$ = monthly runoff from tile drainages, in m^3/mo
RR_{TD} = share of the monthly runoff rate on the monthly precipitation, in %
A_{TD} = tile drained areas, in km^2
PR_M = monthly precipitation, in mm/mo

Runoff from groundwater is calculated as a residual of the total runoff from an analytical unit, minus the discharge originating from surface runoff, urban areas, direct precipitation on surface waters, and from tile drainages (Eq. 56). If the total monthly runoff is not available from other sources, *i.e.* models, it can be calculated by using the mean yearly runoff corrected by the ratio of mean monthly to mean yearly runoff for the next representative gauging station.

Equation 17 can be used for an annual model application. For the monthly disaggregation however, equation 55 should be applied. In this case the annual sum of the monthly tile drainage flow should be used instead.

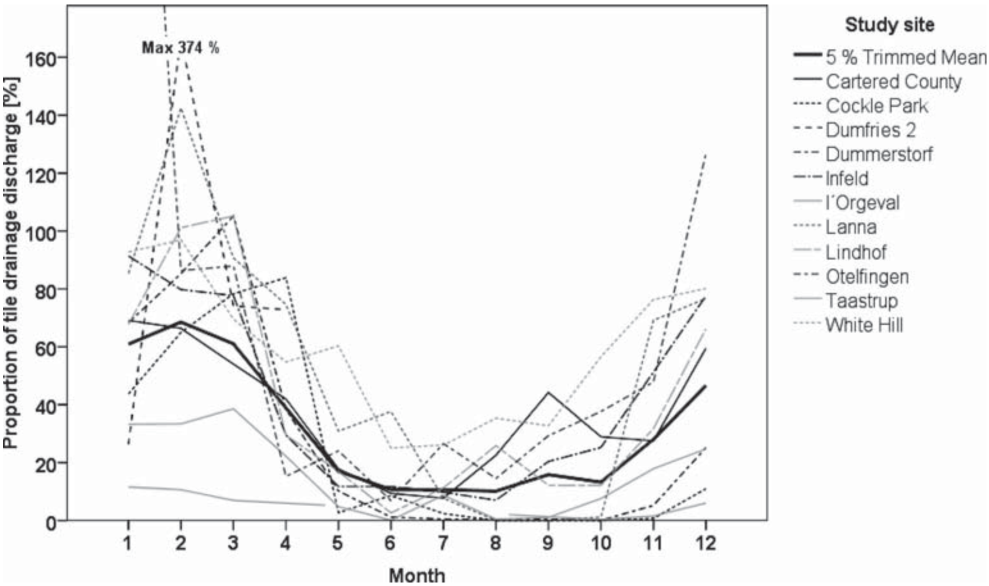

Figure 13. Monthly changes in percentage of precipitation leading to runoff from tile drainages; data is for 11 sites in north-west Europe, and their mean (solid black line) (HIRT *et al.*, 2011).

$$Q_{GW\text{-}M} = Q_{tot\text{-}M} - Q_{diff\text{-}M} - Q_{TD\text{-}M} \quad \text{(Eq. 56)}$$

$Q_{GW\text{-}M}$ = mean monthly discharge from groundwater, in m^3/s
$Q_{tot\text{-}M}$ = mean total runoff from sub-catchment, in m^3/s
$Q_{diff\text{-}M}$ = mean monthly runoff as the sum of monthly runoffs from surface runoff, urban systems, and direct precipitation on surface waters, in m^3/s

Emissions from point sources, (waste water treatment plants and industrial direct dischargers), were assumed to remain constant during the year and be equally distributed among the twelve months.

3.10.1. Monthly Retention Calculation

For TN, the major retention processes considered in the monthly calculations are the coupled nitrification-denitrification. For DIN other transformation processes like plant uptake and subsequent mineralisation are considered, too. The involved aquatic organisms can vary from phytobenthos, to macrophytes in smaller rivers and ditches, and phytoplankton in larger rivers and lakes. The transformation process between DIN (dissolved inorganic nitrogen) and PON (particulate organic nitrogen) are reversible, and can have a major influence on the fractioning of N in surface waters. On an annual basis, however, the resulting net effect is assumed to be negligible (SAUNDERS and KALFF, 2001b; SVENDSEN and KRONVANG, 1993; VENOHR, 2006).

The transformation of DIN to PON by uptake and the later mineralisation back to DIN does not effect the TN concentrations. For calculating monthly TN retention, the coupled nitrification-denitrification is considered to be the only relevant process. For calculating monthly DIN retention, uptake by aquatic organisms must also be considered. N uptake by aquatic organisms increases with increasing water temperature, decreasing flow velocity, and with available sunlight (LAMPERT and SOMMER, 1993; MULHOLLAND *et al.*, 2001). The available sunlight for a water body can vary widely, and is dependent on the local conditions, (for example shadows from clouds, trees, and houses, and self-shading by macrophytes within the water body, can retard much of the available sunlight). In general, the available sunlight is strongly correlated with the incoming short wave radiation at surface level. Hence, in MONERIS, calculation of the monthly DIN retention uses the incoming short wave radiation at surface level as the parameter representing monthly differences in available sunlight; differences in shading are neglected. Data on incoming short wave radiation for Europe, is available as a 15 km grid, with monthly values for May 2007 to April 2010, from the European-wide CM-SAF map provided by the German Weather Service (Deutscher Wetterdienst, DWD) (www.cmsaf.eu).

For the calculation of monthly DIN-retention, we used the annual THL-approach for the calculation of TN-retention (Eq. 50 TN retention) to describe the dominant nitrification-denitrification, and the minor share of retention accounted for by sedimentation. In addition to the existing THL approach, a new term has been introduced to describe the N uptake by aquatic organisms. Water temperature, hydraulic load, and global radiation are used as parameters in the new Temperature-Hydraulic-Load-Radiation (THLR)-approach (Eq. 57).

$$RM_{THLR\text{-}DIN} = \frac{1}{1 + (5.7 + 0.025 \cdot R) \cdot e^{0.067 \cdot T} \cdot HL^{-1}} \cdot 100 \quad \text{(Eq. 57)}$$

$RM_{THLR\text{-}DIN}$ = monthly DIN retention calculated with the THLR approach, in %
R = incoming short wave radiation at surface level, in W/m^2

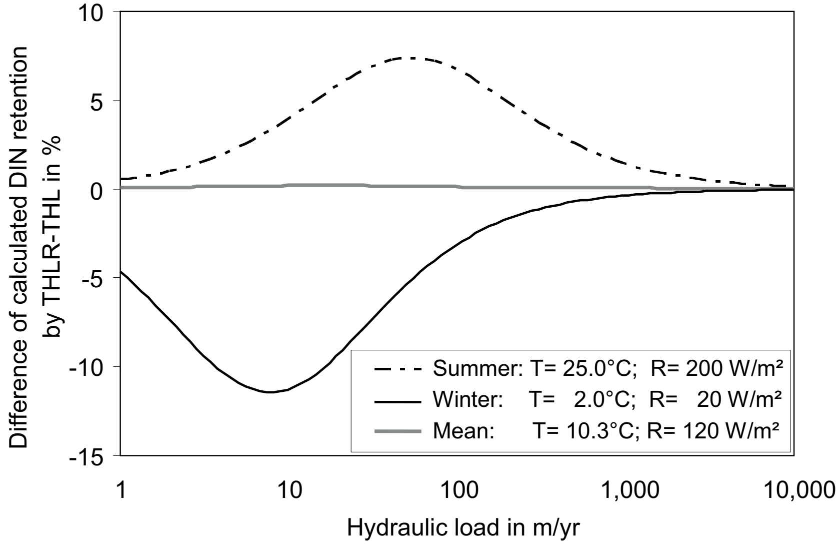

Figure 14. Comparison of DIN retention calculated with the THLR (Temperature Hydraulic Load Radiation) and THL (Temperature Hydraulic Load) at different hydraulic loads: data presented for summer (dashed line), winter (solid black line), and annual mean conditions.

From the CM-SAF map, the mean monthly radiation over the period from May 2007 to April 2010 was calculated for Germany. By calculating an area weighted mean, a mean monthly radiation of 120 W/m^2 was derived.

Calibration of the THLR-approach assumed that the mean annual DIN retention of the THL-approach equals the monthly DIN retention of the THLR-approach at mean annual conditions. This is the case when using 120 W/m^2 as the mean monthly Radiation, 10.3 °C as the mean water temperature, and factors of 5.7 and 0.025 for the THLR-approach.

Compared to the THL-approach, the THLR-approach delivers a higher DIN retention in summer, especially for hydraulic loads between 10 and 200 m/yr. In summer, for low hydraulic loads (<10 m/yr, which are favourable conditions for N uptake by aquatic organisms); the two approaches deliver about the same retention, as radiation apparently does not limit the N uptake by aquatic organisms. At medium hydraulic loads (10 m/yr to 200 m/yr), the increased radiation of summer has the strongest effect on the modelled retention, and the THLR-approach delivers a 7.5% higher retention than the THL approach. At high hydraulic loads (> 200 m/yr), flow conditions are increasingly unfavourable for N uptake by aquatic organisms, and the differences between the retention calculated by the two approaches decrease. During winter, the situation is reversed, and the THLR-approach delivers a lower retention than does the THL approach, as low radiation limits N uptake by aquatic organisms at low hydraulic loads (Fig. 14).

For P, sedimentation is the dominant retention process. Only total P retention is calculated, and thus the changing shares of the P fractions that are accounted for by other processes, such as uptake by aquatic organisms, are omitted. The same equation (Eqs. 51 and 52) and parameters are used for calculation of both the monthly and the annual P retention.

4. Implementation of Measures in MONERIS

MONERIS uses integrated "management alternative" settings in order to calculate the potential of regionally differentiated measures to reduce nutrient emissions and resulting loads. Hereby it is possible to select or combine one or more measures, which can be implemented to individual or groups of analytical units. The measures implemented in MONERIS are considered by their net effect on the nutrient emissions, rather than the change in the respective transformation or transport processes.

In order to distinguish between the effect of the measure and the hydrological conditions of a specific year, the measures are only considered in the model for mean long-term dry and wet hydrological conditions. For the three hydrological conditions annual precipitation and runoff data are differentiated, all remaining input data, however, refer to the most recent available calculation year.

For the calculation of the N emissions, the development of the N surplus on agricultural land during the groundwater residence time has to be considered. Thus, the development of future N surpluses can be considered by the model.

The modelled potential of measures to reduce emissions can serve as basis for the development of management alternatives with a minimum resolution of an analytical unit. MONERIS, however, does not consider the technical, temporal or spatial feasibility of these measures, hence boundary conditions for the implementation of measures need to be reviewed with the appropriate national and state authorities or catchment area commissions and organisations.

The implemented measures are grouped into five categories: changes in land use (a), land use intensity (b), sewer systems (c), DCTP (d), and WWTP P or N (e). All given figures on the reduction potential or efficiency of certain measures can be changed by model users and can only be understood as a value to begin analysis for a certain study catchment.

4.1. Changes in Land Use

Measures from this category change the distribution or the management of a certain land use, such as tile drained areas or sloping areas prone to erosion.

4.1.1. Conversion of Sealed to Unsealed Urban Areas (in %)

This measure simulates a reduction of the sealed urban areas. By this measure the discharge in sewer systems generated from precipitation is reduced and also the occurrence of combined sewer systems overflow events is reduced. Consequently, the groundwater recharge will increase by the same amount as discharge in sewer systems is decreased. The considered nutrient retention in the soil and groundwater leads to an additional reduction of the emissions. The discharge from WWTP is not affected by this measure.

4.1.2. Conversion of Arable Land to Grassland

This measure assumes the conversion from arable land to grassland. A conversion of grassland to arable land (negative area portions) is not implemented in the model. The share of arable land to be converted to grassland can be defined separately for the slope classes <1%, 1–2%, 2–4%, 4–8%, >8%. By converting arable land to grassland nutrient emissions via erosion and overland flow will be reduced. For the converted arable land the standard approaches and model parameters used for grassland are applied. This measure should preferably be applied for areas with steep slopes.

If the share of tile drained areas is different for arable land and grassland this measure will also change the emissions via tile drainages. This does not affect the N surplus or P accumulation on agricultural land.

4.1.3. Reduction of Tile Drained Areas on Agricultural Used Areas

The reduction of tile drained areas can be considered separately for arable land and grassland, but it cannot be defined for specific soils or slope classes. Tile drainages act like a short cut in the water circle and lead to an increased (artificial) interflow, delivering high nutrient loads. By this measure the leakage to the soils and groundwater increases, accompanied by an increased retention, compared to interflow.

The effects of rewetting of intensively used arable land, such as increased risk of P redissolution (GELBRECHT *et al.*, 1996), is not considered within the model.

4.1.4. Soil Loss Reduction on Arable Land

By this measure the application of existing practises to reduce soil loss, such as conservation tillage and contour ploughing, can be simulated. Practices to reduce soil loss differ in their effectiveness, in dependence on the site characteristics like soil type, slope or precipitation (SCHMIDT *et al.,* 2002). Therefore, the effect of the soil loss reduction can be defined separately for the slope classes < 1%, 1–2%, 2–4%, 4–8%, > 8% and for each analytical unit. The reduction efficiency of such measures, directly reducing the calculated soil loss, can separately by defined by the model user for any slope class and analytical unit.

4.1.5. Construction of Buffer Stripes

By applying this measure, the model simulates the construction of buffer stripes in order to reduce the share of eroded material entering surface waters. The user can define the share of agricultural land in a respective analytical unit, for which the emissions via erosion should be reduced. Consequently, the sediment delivery ratio (SDR, see Eq. 12) is reduced by this share. In dependence of the assumed width of the buffer stripe erosion will be reduced by 10 to 100% (RADERSCHALL *et al.*, 1996).

This measure does not consider any land use changes, for example to substitute the area need to construct buffer stripes. It is also not possible to select specific areas within a respective analytical unit, for which an increased soil loss was found. For this measure the percentage share of tributaries for which buffer stripes are assumed and the respective width of the buffer stripe can be defined.

When combining measures to reduce soil loss from arable land and the construction of buffer stripes, both measures are considered in addition to each other, and cannot be applied beside of each other for selected parts of arable land separately.

4.1.6. Retention Ponds for Tile Drained Areas

This measure assumes that discharges from tile drainages enter a retention pond before being released to surface waters. N and P retention in retention ponds are calculated considering the tile drainage discharges, the retention pond size and the hydraulic load of retention ponds. The sufficient N retention capacity can be attained by adjusting the area of retention ponds in relation to the tile drained areas. Research results suggest that a retention pond size of 150 m^2 per ha tile drained arable land provides a sufficient retention capacity.

Although this measure has been implemented in the model to calculate the effect of retention ponds, also other practices, such as in-field groundwater denitrification reactors, bioreactors or reactive swales and grassed waterways can be considered with this measure. This measure does not consider any land use changes, for example to substitute the area need to construct retention ponds.

4.1.7. Reconstruction of Wetlands in Main Rivers

The reconstruction of wetlands, for example by dike back-shifting, is only possible for very few selected locations. The retention on wetlands, when being flooded, or in wetlands, when being flushed by groundwater, is very complex and difficult to model. In MONERIS only the first situation of flooding wetlands is implemented and considered by an increase of water surface areas. This leads to an increased retention due to reduced hydraulic load. The dyke back shift area as well as the gained water surface areas can be defined for each analytical unit separately. In the model the grassland of the respective analytical unit will be reduced by the amount of gained water surface areas. If the grassland area is exceeded, arable land will be reduced respectively.

4.1.8. Stream Flow Restoration in Tributaries

By the stream flow restoration the flow length of tributaries will be increased, which in turn leads to an increased water surface area and an increased in-stream nutrient retention. The increase of the flow length can be defined for this measure.

4.2. Changes in Land Use Intensities

This category contains measures to reduce N surplus, N deposition and the ban of phosphate in detergents.

4.2.1. Reduction of the Nitrogen Surplus and Maximum Use of Fertilizer and Manure

By the reduction of N surplus on agricultural land the N concentrations in tile drainages and in the groundwater will be reduced. While the N concentration in tile drainages could be reduced immediately, the groundwater concentration will be reduced delayed, in dependence of the groundwater residence times.

Three options can be chosen for this measure: 1. the reduction of N surplus in percent, 2. the reduction of N surplus in kg (ha · yr) and 3. defining a maximum N surplus allowed on the agricultural land. The first two options reflect the effect of good farming practices, which will reduce N surplus by a certain amount. The 3rd option can be selected to model the effect of the fulfilment of legal frameworks like the EU-Nitrate Directive.

The model is not able to consider negative N surplus. If the measure settings for option two would result in negative N surplus, the model replaces these N surpluses by a value of zero. If the N surplus in a specific analytical unit is lower than the maximum N surplus assumed for option three, the original value will be used by the model.

4.2.2. Reduction of Atmospheric NH_y and NO_x Deposition

By this measure, the atmospheric deposition of NH_y and NO_x can be reduced separately, reflecting the different main sources for NH_y (agriculture) and NO_x (traffic, households, burning). The reduction of atmospheric deposition affects directly the N surplus on agricultural land, N concentrations in surface runoff, emissions from sealed urban areas and the deposition on water surface areas. Major restriction of this measure is that the causers of atmospheric emissions are often located outside of the studied river catchment.

4.2.3. Use of Phosphate-Free Detergents

While phosphate in laundry detergents in most European countries is already banned, phosphates in automatic dishwasher detergents are increasingly used, with increasing numbers of sold dishwashers. The EC plans to prohibit all use of phosphates in detergents by 2013, European countries outside the EU at least plan the ban of phosphates in laundry detergents. By this measure a full ban of phosphates in the respective detergents is assumed and is reflected in the reduction of inhabitant specific P emissions (BEHRENDT, 1994). The amount of reduction depends on the level of usage, which is considered on countrywide basis in the model. Moreover P concentration from waste water treatment plants with less than 10,000 population equivalents is reduced by the share of phosphates from detergents.

4.3. Measures to Reduce Discharge Volumes from Sewer Systems

This category offers measures to reduce untreated discharge from urban systems via sewer systems by increasing the share of areas connected to sewer systems, the increase of storage volumes in combined sewer systems and additional constructions to treat loads from rainwater collecting separate sewer systems.

4.3.1. Increased Storage of Combined Sewer Systems

This measure assumes the increase of storage volume in combined sewer systems to decrease the risk of overflow events resulting from storm water events. 100% of storage equals a water storage volume of 23.3 m^3/ha (of sealed urban areas) in combined sewer systems (see Chapter 3.7.). For this measure the storage volume should be given in percent in relation to a storage volume of 23.3 m^3/ha. If the original storage volume in a specific analytical unit is higher than the storage volume assumed for the measure, the original value will be used by the model.

4.3.2. Filtration of Water from Separate Sewer Systems

This measure defines the share of loads in rainwater collecting separate sewer systems, which is treated in soil retention filters or clarifier basins before discharged to surface waters. For soil retention filters, a retention capacity of 80% for N and 45% for P is used as a standard value. For clarifier basins N and P retention is set to 35% of the incoming load. If the original share of treated loads in a specific analytical unit is higher than assumed for the measure, the original value will be used by the model.

4.3.3. People Connected to Sewer Systems are also Connected to WWTP

This measure expects that all households and areas (inhabitants) connected to sewer systems are also connected to a WWTP. This measure does not consider households and areas that are unconnected, connected to DCTP or septic tanks. The measure defines the number of inhabitants in households only connected to sewer systems as zero. By this measure households and areas only connected to sewer systems will be connected to a virtual WWTP (sewer category 4).

4.3.4. Portion of People Connected to Sewer Systems and WWTP

With this measure the minimum share of households and areas (inhabitants) connected to sewer systems and WWTP on the total inhabitants is defined. If the original share of connected households and areas (inhabitants) in a specific analytical unit is higher than assumed for the measure, the original value will be used by the model. If the share of connected households and areas (inhabitants) is increasing, the share of households and areas (inhabitants) connected to decentralized treatment plants DCTP or to septic tanks will be reduced respectively. Measure 4.3.3 is calculated first and will be considered in the calculated share of connected inhabitants.

4.4. Measures for Decentralized Treatment Plants (DCTP)

Measures from this category reduce the nutrient emissions via decentralized treatment plants. DCTP are small-scale WWTPs and differ according to the technical treatment status between older systems without waste water aeration (DIN 4261 Part 1) and the recent standards with waste water aeration (DIN 4261 Part 2) (see urban systems).

4.4.1. Technical Status of the DCTP

This measure simulates that all DCTPs are constructed according to the standards of DIN 4261 Part 2, for which retention rates of 15% for N and 13% for P are assumed. This measure does not change the type how loads are discharged to the surface water (sewer system, pipes/ditches, or soil/groundwater).

4.4.2. DIN2 with Additional Phosphorus-Removal for DCTP

With this measure it is simulated that for all DCTPs constructed according to DIN 4261 Part 2 an additional P-removal is implemented. Thus P will be further reduced by 80% in the biological and mechanical pre-treated waste water of the DCTP.

4.4.3. DCTP Transformed to Virtual WWTP

With this measure it is simulated that all DCTPs in a respective analytical unit will be converted into new, to be built WWTPs (virtual WWTP). In MONERIS the measure can be applied separately for DCTPs either discharging via sewer systems or via pipes/ditches or soil/groundwater. The strongest improvement will result for DCTP discharging via sewer systems and pipes/ditches, whereas for DCTP discharging via soil/groundwater the effect

Table 6. Maximum concentrations of P and N for 5 WWTP size classes according to the EC Urban Waste Water Treatment Directive (European Parliament and Council of the European Union (Ed), 1991).

WWTP size class	Inhabitant equivalents	Phosphorus mg/l	Nitrogen mg/l
2	2,000–5,000	≤ 6.0	≤ 60.0
3	5,000–10,000	≤ 6.0	≤ 60.0
4	10,000–50,000	≤ 2.0	≤ 15.0
5	50,000–00,000	≤ 2.0	≤ 15.0
6	> 100,000	≤ 1.0	≤ 10.0

might be negative, as retention in soils and groundwater can be higher than in the virtual WWTP.

4.4.4. Virtual WWTP with Additional Phosphorus-Removal

Additionally to the previous measure for the virtual WWTP a P removal is assumed with this measure. Like this, the minimum nutrient reduction of the virtual WWTP is 80% for P and 40% for N.

4.5. Measures for the Reduction of Phosphorus and Nitrogen Concentrations from WWTPs

Measures from this category define the N and P effluent concentrations for WWTPs larger than 2,000 population equivalents. Generally, in EU-countries N and P concentrations should correspond to the target values of the EC Urban Waste Water Treatment Directive (European Parliament and Council of the European Union, 1991, Table 6). Maximum outlet concentrations can be defined separately for different size classes. If the original outlet concentration of an individual WWTP is lower than the assumed maximum concentration, the original value will be used by the model.

If no individual WWTP inventory is available, a reduction of loads from non-classified WWTP in percent can be defined. The N and P loads from WWTPs are calculated as the product of discharge and concentration (see point sources). The discharge of a WWTP will not be changed by this measure.

5. Validation

The validation of models like MONERIS is difficult as areas covering information on emissions and retention (in the catchment and in surface waters) are usually not available. Monitoring data, (*e.g.,* concentrations, runoff, matter fluxes) in surface waters or for a specific pathway always reflect the situation at a specific location and time. An up-scaling of these values to an analytical unit level and to a month or a year is difficult and is not always representative for the whole period and area.

For developing of MONERIS the approaches for the different pathways have been derived and calibrated separately, and if data were available, validated against these. A determination of an absolute error of emissions calculated for a specific analytical unit is therefore in most cases not possible.

A model comparison conducted in the EU-project EUROHARP (see introduction) showed that MONERIS compared to the other models delivered balanced results, often close to the mean values of all models (KRONVANG *et al.*, 2009). Nevertheless, none of the models delivered more consistent or in other terms better results than the other models.

Consequently, the validation of MONERIS results is often restricted to a comparison of modelled and observed loads. Observed loads are calculated on base of measured runoff and nutrient concentration at the gauging stations (BEHRENDT, 2000). In Figure 15 mean calculated loads of the single years 2003–2005 were compared to the observed loads for German river basins (FUCHS *et al.*, 2010). Due to a uniform deviation at the 1 : 1-line, no systematic error is detectable. A comparison of modelled and observed loads from MONERIS applications all over the world delivered mean deviations between 15% and 35%. This equals the error to be expected in the observed loads (ZWEYNERT, 2009).

The load comparison in general shows higher deviations for small (< 50 km^2) analytical units. Two reasons can be found to explain this: (i) data or (ii) model insufficiencies. In smaller analytical units individual site conditions (*e.g.*, soil, slope, and location of tile drained areas) and events (*e.g.*, heavy rainfall) stronger influences the total emissions than in larger catchments. Area covering input data, *e.g.*, precipitation or atmospheric deposition, are often results from other models transferring point information to the area. In case data from administrative units (statistical reports) are used the spatial resolution of these units is coarser than for the analytical units. In this case the specific situation in different analytical units might not be explained by the input data. On the other hand, if detailed information is available, the approaches used in MONERIS, developed to describe mean situations in river systems, are not able to consider these data and to model the specific situation.

Spatial resolution of MONERIS is limited to ca. 10 km^2, but the validated minimum size for analytical units is 50 km^2 (BEHRENDT *et al.* 2003b; ZWEYNERT, 2009). On a temporal scale a monthly resolution can be achieved. The quality of results is profoundly dependent on the resolution and quality of input data. Not for all countries the data quality is as high as in the EU countries. Thus, MONERIS can display only a part of its potential, if only a data set of reduced data quality is available. MONERIS was tested successfully in different climatic regions. Nevertheless, geographical limitations are given for areas under arid condition, since MONERIS is not able to calculate emissions with a negative groundwater discharge.

6. Conclusions

The motivation for this first complete description of the nutrient emission model MONERIS, and its methods and algorithms, was the need to provide an up-to-date comprehensive and scientific-based overview for modellers and model users. The model MONERIS is based on data for river flow and water quality, as well as a set of geo-referenced data including digital maps and extensive statistics. Whereas diffuse emissions into surface waters are calculated as the sum from different pathways and their individual flow components, the point emissions from wastewater treatment plants and industrial sources are taken from an inventory. The particular value of the MONERIS model concept is the strictly separated calibration and validation of the approaches for the different emissions pathways, which is achieved by using data sets independent from other results of MONERIS, thus avoiding the effect of inter-calibration.

Due to its flexibility, the MONERIS model was extended, in collaboration with the Karlsruhe Institute of Technology (FUCHS *et al.*, 2010), to allow calculation of heavy metals and polycyclic aromatic hydrocarbons. An additional improvement has been the enhancement of temporal and spatial resolution. On a temporal scale, a monthly resolution is now possible, and the spatial resolution has been enhanced to a validated minimum size of 50 km^2

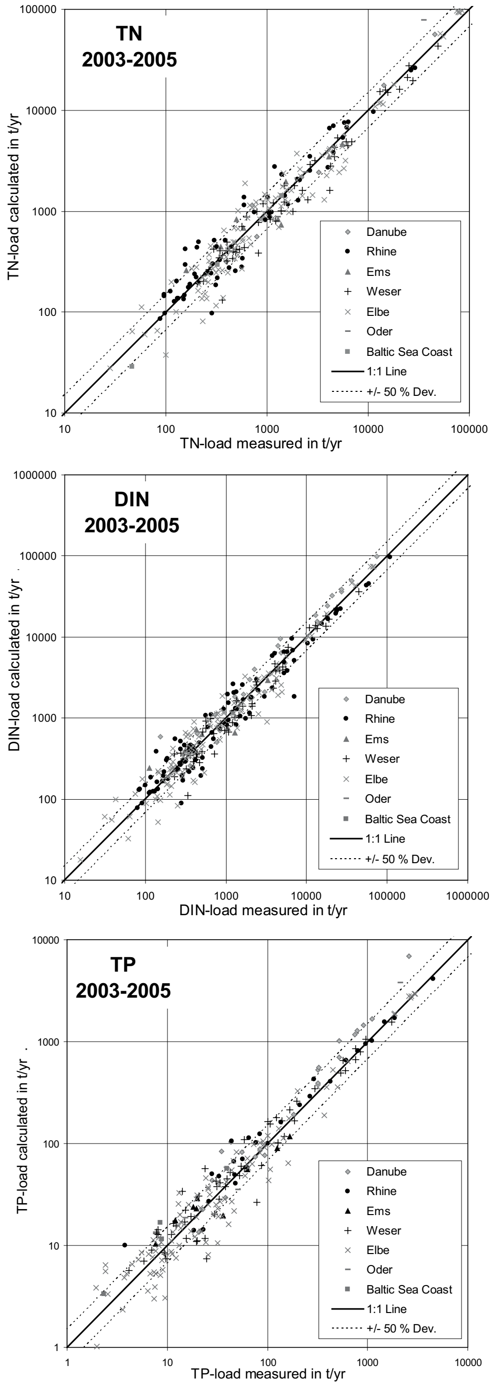

Figure 15. Comparison of calculated and observed annual loads for total nitrogen (TN), dissolved inorganic nitrogen (DIN), and total phosphorus (TP), for 6 rivers and two coastal areas for 2003–2005.

(BEHRENDT *et al.* 2003b; ZWEYNERT, 2009). Initially, MONERIS was created to calculate nutrient emissions in meso- to macroscale river basins, on a temporal resolution between 5-year mean values and yearly values.

The quality of model results is strongly dependent on the resolution and quality of the input data. In EU countries, the quality of the data input is high. However, this is not always the case for data from some non-EU countries. Even if there is limited data available for some catchments, MONERIS can still be applied, contrasting with the very detailed, process-based models which could not be used in such circumstances. The application of MONERIS was successful in a wide range of catchments, including those with cool-humid or hot-dry climates, intensively to extensively used landscapes, and highly populated to scarcely populated.

With the "management alternative" tool, MONERIS can calculate the effect of measures. However, there are restrictions for deriving detailed management plans, because MONERIS works on the level of an analytical unit, and does not consider whether site conditions are suitable for a particular management alternative. Nevertheless, information from management plans (such as those proposed by local studies or by Federal States) can be aggregated, and taken into account for scenario calculations.

Further developments for MONERIS may include calculating with negative water balances (such as occur under dry climate conditions), and with negative nitrogen surpluses (as could be used for historical modelling, or extensively used areas), and bridging the gap between abiotic drivers (flow velocity and light availability) and the response of aquatic biota. Beyond that, currently new approaches are under development, *e.g.,* to consider the effect of wetlands on the nutrient balance, to improve the SDR-approach for erosion, and to extend the catalogue of management options.

After 15 years of development, and numerous international applications, the MONERIS model is confirmed as an appropriate tool for nutrient emission modelling and river basin management on large scales, and under a wide range of different catchment characteristics.

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