The Model System

MONERIS

Version 2.14.1vba

Manual

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In Memory of

Horst Behrendt †

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List of abbreviations

ABAG	Common soil loss equation
ATV	Abwassertechnische Vereinigung e.V. (see DWA)
AU	Analytical Unit
BART	Bartholomew, global base map
BGR	Federal Institute for Geosciences and Natural Resources
BÜK	Soil maps for Germany of the BGR
CAT	Catchment
CL	Calculated load
CLC	CORINE Land Cover
CORINE	Coordinated Information on the European Environment
DCTP	Decentralised waste water treatment plants
DCW	Digital Chart of the World
DIFGA	Hydrologic model
DIN	Dissolved inorganic nitrogen
DLM	Digital landscape model for Germany in different scales 1:25,000; 1:50,000 and 1:1,000,000
DON	Dissolved organic nitrogen
DTK	Digital topographic map for Germany
DWA	German Association for Water, Wastewater and Waste
DY	Dry year
EEA	European Environmental Agency
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
EZG	Total area size of the catchment
FAL	Federal Regional Studies and Planning Research Institute for land use
FAO	Food and Agriculture Organization
FNE	Flow net equation

GB	Giga byte
GHz	Giga hertz
GIS	Geographic Information System
GRID	Raster data
HL	Hydraulic load
ID	Index
IGB	Leibniz-Institute of Freshwater Ecology and Inland Fisheries
ISO	International Organsitation on Standardization
LT	Long term
MMK	Digitale Mittelmaßstäbige landwirtschaftliche Standortkartierung
MONERIS	MOdelling Nutrient Emissions in RIver Systems
MR	Main river
N	Nitrogen
NH_y-N	Atmospheric ammonia deposition
NH_y	Ammonia
NO_x-N	Atmospheric nitric oxides deposition
NO_x	Nitric oxides
OECD	Organization for Economic Co-operation and Development
OL	observed load
OSPAR	OSLO PARIS COMMISSION, 2006
P	Phosphorus
RAM	Random Access Memory
RB	River basin
RBD	River basin district
RIVM	National Institute of Public Health and the Environment

q	Runoff rate
S	Scaling factor
SB	Sub basin
SDR	Sediment delivery ratio
SRP	Soluble reactive phosphorus
SU	Sub unit
SWAT	Hydrologic model
TGL	Technische Normen, Gütevorschriften und Lieferbedingungen
THL-approach	Calculating the retention in surface waters based on temperature and hydraulic load
TN	Total nitrogen
TP	Total phosphorus
TRIB	Tributary
UBA	German Federal Environment Agency
$UBA_{1000/OSU1000}$	Hydrographic maps of the UBA
USLE	Universal Soil Loss Equation
VBA	Visual Basic Application
WFD/ WRRL	Water Framework Directive
WSA	Water surface area
WWTP	Waste water treatment plant
WY	Wet year

1 General model description

MONERIS is a nutrient emission model to be used for regional, national and international studies of water quality in catchment areas. It was developed at IGB-Berlin, to address three goals:

- Identification of the sources and pathways of nutrient emissions at the analytical unit (smallest calculation unit) level
- Analysis of the transport and the retention of nutrients in river systems
- Provision of a framework for examining management alternatives (scenarios)

In order to reach "an acceptable chemical state of water condition" by 2015 as required by the Water Framework Directive (WFD, European Parliament and Council of the European Union 2000) there must be catchment-based approaches for recording the present state of load, and for the development of guidelines.

MONERIS is a very flexible system, and is therefore most suitable to cover these demands, and to support analysis at a variety of scales.

Nutrient emissions of point and diffuse sources into surface waters are evaluated in the model. Point data (e.g. waste water treatment plants), areal information (e.g. soil data), and administrative information (like statistical data for districts), are integrated. The application of geographic information systems (GIS) is essential. Modelling scenarios allows calculation of the efficiency of management measures for reaching prescribed water quality standards (such as target concentrations of surface water quality). The MONERIS approach provides an assignment of the measures applied to the analytical units.

In the model, suitable measures are pre-defined which can be implemented by the user, either as single or combined measures. The measures can be based on analytical units or cover larger areas. Therewith, the resulting effect of measures on loads in the catchment can be tested. By integrating numerous of possible components into the system, complex analysis of effects of measures can be obtained in a short time.

The model was developed in the Department of Limnology of Shallow Lakes and Lowland Rivers, at the Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany (IGB-Berlin). Since its inception in 1999 MONERIS has been applied to numerous European river systems (for example the Axios, Danube, Daugava, Elbe, Odra, Po, Rhine, Vistula, see BEHRENDT et al., 1999; 2003a; 2003b; SCHREIBER et al., 2005a; BEHRENDT & DANNOWSKI, 2005), the whole of Germany (BEHRENDT et al., 2000; VENOHR ET AL., 2008a, b), and river catchments in Canada, Brazil (VON SPERLING & BEHRENDT, 2007) and China (XU PENGZU, 2004).

The MONERIS work group at IGB is looking forward to receiving improvement suggestions and critiques from all of the users of the model.

2 Model structure

2.1 Basic structure

MONERIS (**MO**delling **N**utrient **E**missions in **RI**ver **S**ystems) 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 VBA, which we implemented in 2008, (previously EXCEL 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.

Fig. 1 gives an overview of the main pathways and processes in MONERIS, and these are then detailed in section 4.2.

There 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.

The system boundaries are:

- topsoil (nitrogen surplus on agricultural land)
- groundwater (nutrient output from topsoil into the groundwater)
- surface waters (remaining emissions)

When interpreting the MONERIS model results, the following four issues should be taken into consideration:

- Spatial resolution: the smallest model unit is the analytical unit. Spatial differentiation below this scale is not possible.
- Temporal resolution: MONERIS uses both constant and time-variant input data. Depending on the data base, the resolution for time sequences varies between monthly, one year and long-term.
- Results: All results, if not explicitly shown differently, are model results.
- Model concept: MONERIS is based on the empiric approach to describing complex relationships simply. Thus determination of water balance uses a simplified method, rather than a detailed hydrologic modelling in the classic sense.

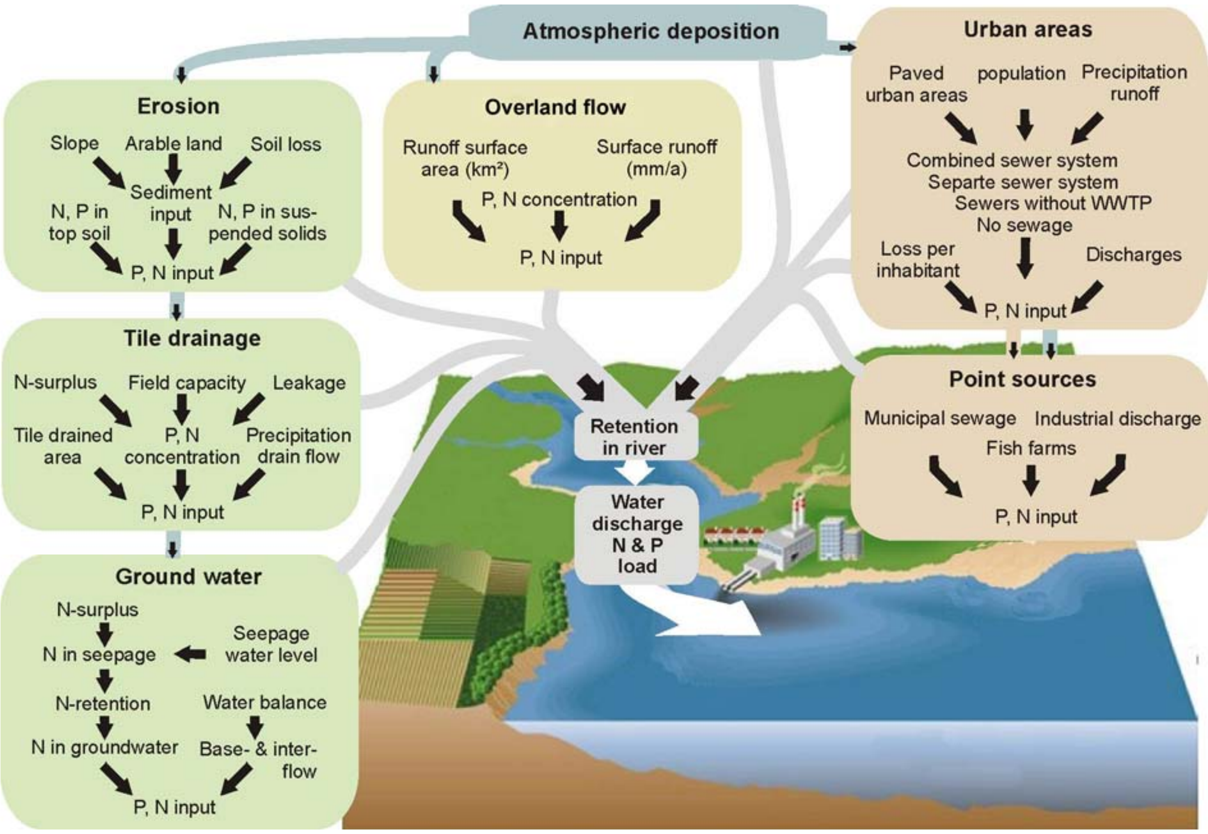


Fig. 1: Pathways and processes for nutrient emission into surface waters (modified after SCHERNEWSKI, 2008).

2.2 Spatial and temporal resolution

The MONERIS approach uses a hierarchic classification of the catchment. The smallest unit is the "Analytical unit" (AU) (Table 1), which is the base of all calculations. Spatial division into analytical units of a minimum size of 50 km² is feasible, and has been validated. Although it is mathematically possible to run the model at a spatial resolution of 1 km², calibration is not possible because gauging stations are not available at this level.

In MONERIS, the catchment is attained by aggregation of all analytical units. Smaller catchments, especially coastal waters could, if necessary, be considered together with larger catchments, to form a river catchment unit. The structure of catchments in MONERIS is shown in Fig. 2.

Table 1: Terminology and hierarchic classification of the catchment

Term	Abbreviation	Definition
Analytical unit	AU	smallest model unit in MONERIS
Catchment of the AU	CAT	total of the analytical units above the selected analytical unit
Sub unit	SU	total of the analytical units of one administrative unit (i.e. Federal State)
Sub basin	SB	WFD, Art. 2, No. 14
River basin	RB	WFD, Art. 2, No. 13
River basin district	RBD	WFD, Art. 2, No. 15

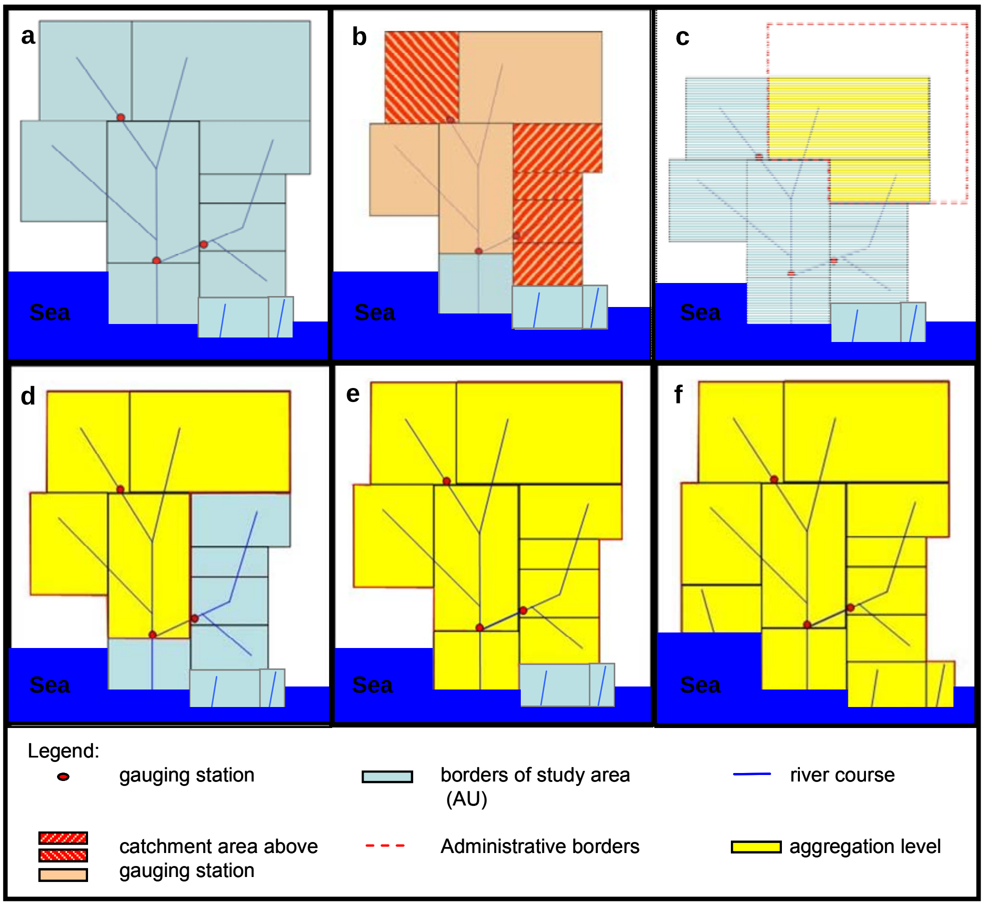


Fig. 2: Schematic classification of the model area and its aggregation levels according to the WFD: a = analytical unit (AU); b = catchment of the AU's; c = sub-unit (SU); d = sub-basin (SB); e = river basin (RB); f = river basin district (RBD).

2.3 Methodological approach of MONERIS

The procedure for the use of MONERIS is shown in Fig. 3.

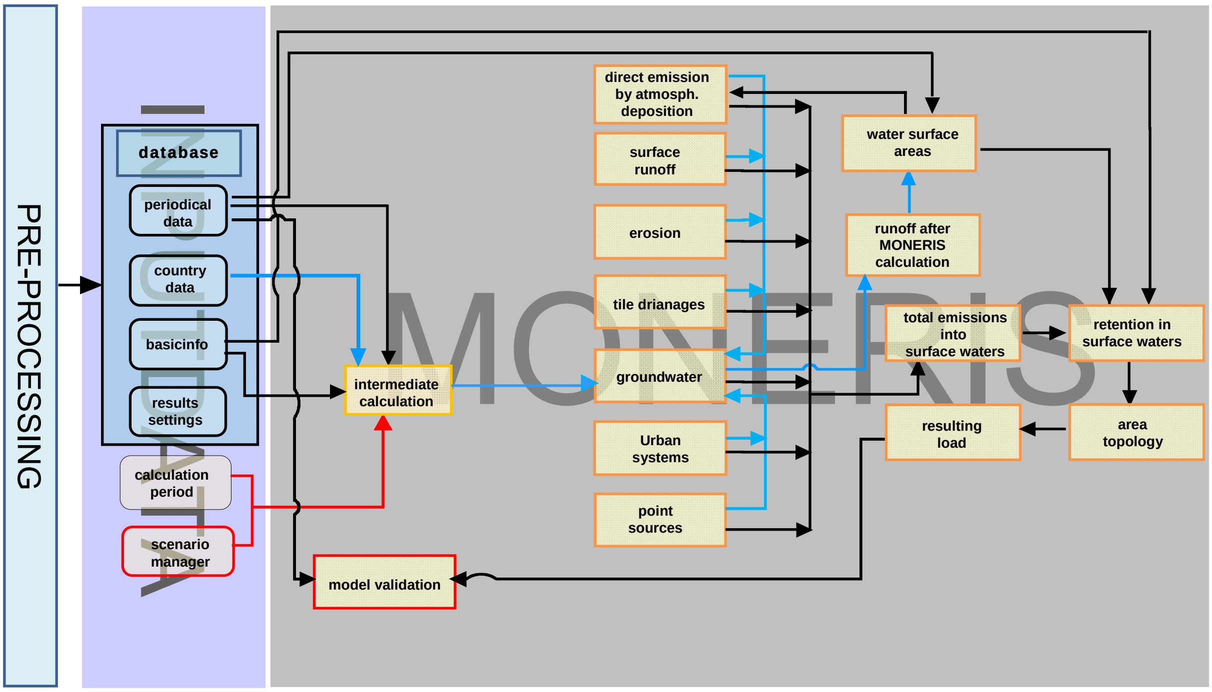


Fig. 3: Model structure of MONERIS.

Initially a data base is created, the complexity of which depends on the questions to be answered and the minimum standards required for the related dataset (see section 3.3 and Annex A). The pre-processing procedure comprises acquisition and preparation of data, and its quality assurance. Established protocols for this are available, although they are not compulsory, and individual users may choose to develop and use their own pre-processing procedures.

Pre-processed data is stored in three tables in the MONERIS database in Access, depending on the spatial and temporal characteristics:

- Basic information, study area-specific and treated as temporally constant data,
- Periodical data, used for study area-specific time sequences, and
- Country data, which is used for country-specific time sequences.

Other data bases include the Meta information, and the user defined settings, for the scenarios. They regulate the further use of input data for every analytical unit of the values in the data base.

Every analytical unit is assigned to corresponding information, including a country code obtained from the country code data table, which includes basic data of the respective country, e.g. special factors for phosphate in detergents. Based on the analytical units, the area topology (Section 4.1.1) defines the hydrological connections of the analytical units (Section 2.2). This hydrological connection is the basis for the creation of the flow net equation to calculate the total runoff (Section 4.1.2).

2.3.1 Point source nutrient emissions

The source of point emissions can usually be identified clearly, and includes nutrient emissions arising from communal waste water treatment plants, and industrial discharges. The amount of point source emissions only varies within a narrow range, since these sources are largely independent of meteorological factors. For the regional calculation of the nutrient emissions of communal waste water treatment plants, an inventory of waste water treatment plants should be used which includes the geographical position of the plants and their discharge points. The calculation of the direct industrial discharges is carried out according to branch-related inventories, which capture the different nitrogen (N) and phosphorus (P) emissions into water bodies from the different branches. These data are usually available from sewage and waste-engineering institutions. In case there is no information available for individual smaller waste water treatment plants, the emissions can be summarized and regarded as a summation for the calculations.

2.3.2 Diffuse nutrient emissions

Nutrient emissions from diffuse sources are characterized by their highly variable matter load, in contrast to the low variability for point sources. This variability can range over orders of magnitude, and is closely related to hydro-meteorological factors, especially precipitation. The locations of the diffuse nutrient emissions usually cannot be identified clearly.

MONERIS considers six pathways of diffuse nutrient emissions:

- Direct emissions via atmospheric deposition into the water body: The bases for calculations are the water bodies of the analytical unit (Section 4.2.2.1) and the annual deposition rates.
- Overland flow: calculation of the nutrient emission is based on the surface runoff (Section 4.2.2.3) and the portion of arable, grass and open land, for which area-specific nutrient concentrations in the surface runoff were defined.
- Erosion: sediment, and thus nutrient emissions, will be calculated only for those areas which are relevant for emissions and surface waters (Section 4.2.2.4). The erosion module was calibrated according to the inorganic suspended load.
- Tile drainage: calculation of nutrient emissions is based on the tile drainage area, the tile drainage runoff in summer and winter, and the nitrogen balance surplus on

agricultural area and for phosphorus: the medium phosphorus concentration depending on the type of soil (Section 4.2.2.5).

- Groundwater: calculation of nutrient emissions in this pathway is carried out together with basic runoff and natural interflow (Section 4.2.2.6). It is based on the nitrogen balance surplus of the agricultural areas, and the mean phosphorus concentration which is dependent on the type of soil. The effective retention in groundwater depends on the hydro geological conditions.
- Sealed urban areas: the nutrient emissions from sealed urban areas are calculated in regard to regional differences in the sewage system, as well as the size of the storage capacities of the combined sewer systems (Section 4.2.2.7).

2.3.3 Retention in surface waters

The nutrient retention in the surface waters is calculated depending on the hydraulic load, the water temperature (for nitrogen) and the runoff rate (for phosphorus) (BEHRENDT ET AL., 2000 and modified by VENOHR, 2006). Therefore, it is possible to compare the calculated nutrient load and the actual nutrient concentration measured at the gauging station.

3 Requirements

3.1 User requirements

For the application and evaluation of the results from MONERIS, the user should have a broad knowledge of physical, chemical and biological processes in river systems. In addition, comprehensive knowledge of Microsoft EXCEL and Microsoft ACCESS software is required. The user should also be able to evaluate the input data for eligibility and reliability.

The reliability of the model results depend upon the quality of the input data, the processing for MONERIS, and on the modellers knowledge. Every application requires careful consideration of the expectations of the model results in relation to the input data, particularly the determination of whether the special features of the modelled river system are considers in an adequate way.

The most up to date version of MONERIS, Version 2.14.1vba, is made for three different application levels. According to individual targets and preconditions, the user can work as:

- VIEWER (selection, combination, and calculation, of predefined scenarios, and consideration and export of application results without the option of changing formulas),
- MODELLER (access to all options of the VIEWER surface, plus options to load new data, set password protection for the input data base, modify scenarios and apply parameters) or
- MODIFIER (access to all options of the VIEWER and MODELLER surface, plus options to modify equations and values used, and to save them as standard values).

This present version of the manual is primarily presented for viewers and modellers. MONERIS modifiers will need additional instructions, which will be provided by the IGB.

3.2 Hardware and software requirements

During the conception and design of MONERIS, special attention was given to a wide range of possible applications based on Microsoft Office software. MONERIS is performed in VBA, and it needs EXCEL for the visualization of the results. Thus, the model can work on all IBM compatible PCs which are equipped with the system requirements shown in Table 2.

Table 2: Recommended hardware and software requirements for MONERIS.

Hardware / software	System requirements
Processor	2 GHz
Virtual memory	1 GB
Random Access Memory (RAM)	2 GB
Operating system	WINDOWS 2000, XP, VISTA
Software	Developed and tested for MS-Office EXCEL 2003.
Data storage	Access Datenbank

3.3 Input data requirements

This section provides a general overview of the requirements for input data; a detailed description is given in Annex B.

Since MONERIS can compute data for small river basins (e.g. river Stör in Northern Germany, catchment size 1,135 km²) and large river basins (e.g. Danube river basin, catchment size 800,000 km²), the amount of effort needed for the data searches depends on the chosen scale, the data requirements, and the desired resolution.

With the support of an external Geographic Information System (GIS), the data have to be managed, processed and transferred into a uniform projection. Data can be in different forms, for example data for waste water treatments plants (WWTP) can be in inventory form with accurate geo-referenced locations for each individual WWTP, or in the form of generalized statistical data on an administrative level.

The following input data are required for the application of MONERIS:

Spatial input data

- Catchment boundaries
- Digital elevation model
- River network
- Location of tile drainages
- Population density
- Land use (according to MONERIS classification)
- Soil
- Soil loss maps
- Hydrogeology
- Hydrometeorology
- Atmospheric deposition

Data for administrative units (derived from statistics)

- Population
- Nitrogen surplus of the soil nutrient balance
- Phosphorus accumulation in the soil
- Agriculture
- Length of sewer system network
- Waste water treatment plants, particularly waste water statistics
- Proportion of the population connected to sewer systems and/or WWTPs
- Share of tile drainages, if not available as spatial data

Data for geo-referred issues

- Inventory of waste water treatment plants
- Data from water quality measuring points
- Data from water discharge measuring points
- Data from precipitation measuring points

4 Methodology to calculate nutrient emissions

4.1 Pre-processing

Pre-processing is needed to prepare the data in a suitable form for use in the model.

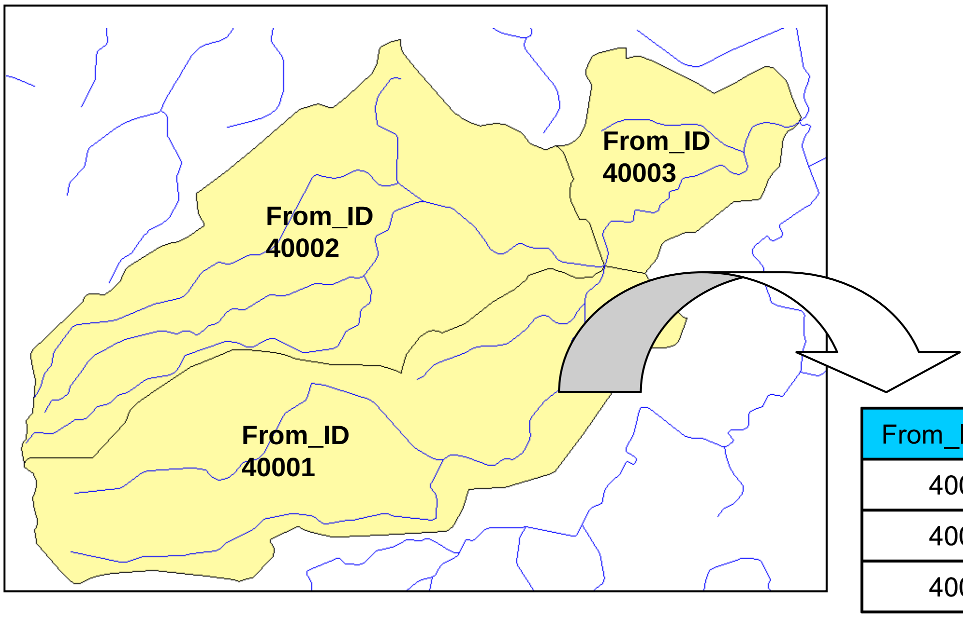
4.1.1 Area topology

Analytical units are the basis for calculation of emissions and retention. They are mainly created according to natural boundaries (over ground catchment boundaries), and sometimes according to administrative boundaries. The boundaries should be based on those officially established; however, if these are not available, then new boundaries should be derived from the elevation and water model. The size of the analytical units is not only dependant on boundaries, but also on the resolution of available data, the desired resolution, and the results sought.

For the analytical units, area topology will be determined by the water topology, i.e. for each analytical unit, the area into which it drains is determined.

The area topology is determined by suitable maps of the analytical units and the river system. Every analytical unit is assigned three attributes, From_ID, To_ID, and Split_ID. The From_ID defines the ratio (ID) of an analytical unit, the To_ID relates to the analytical unit into which the defined analytical unit drains, and the Split_ID relates to second analytical unit if the analytical unit above dewaters into two different lower analytical units. The From_ID should be assigned such that a lower From_ID always drains into a higher To_ID, thus From_ID can also be used as a classification feature (Fig. 4). The runoff of the whole area is characterised by the highest From_ID.

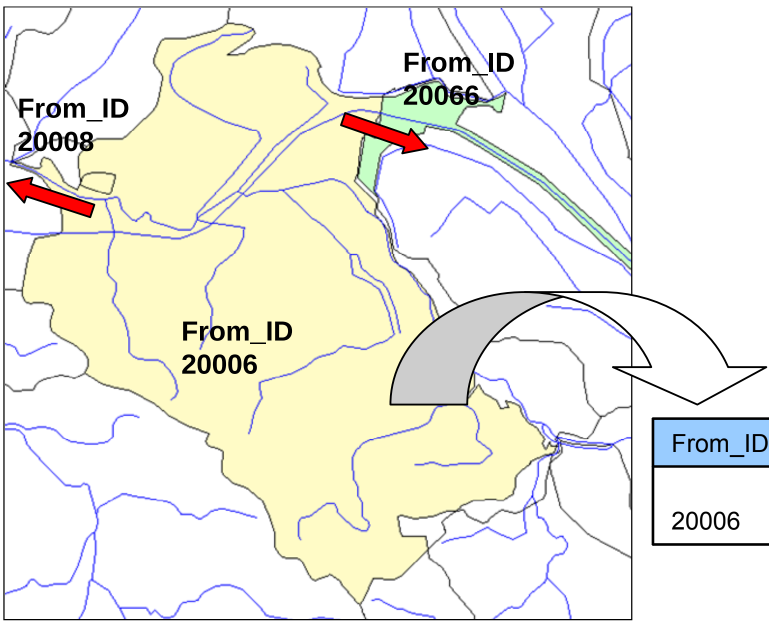
Each of the three ID's of the analytical unit consists of a 5-digit identification number, the first of which indicates the catchment of the river system. For Germany, the catchments are numbered: 1 = Danube, 2 = Rhine, 3 = Ems, 4 = Weser, 5 = Elbe, 6 = Odra, 7 = direct catchments of the North Sea, and 8 = direct catchment of the Baltic Sea. Estuaries are a combination of the number of the catchment, and the identification "9999" (e.g. Rhine estuary = 29999).



From_ID	To_ID
40001	40003
40002	40003
40003	4000?

Fig. 4: GIS-based generation of the IDs.

Should an analytical unit dewater into two different lower analytical units, as may occur because of a channel or a junction, a Split_ID is used. An example of an analytical unit (yellow; From_ID 20006), which through a channel dewaters into the analytical unit with the From_ID 20008 and From_ID 20066 the “splitting” is shown in Fig. 5.



From_ID	To_ID	Split_ID	Comments
20006	20008	20066	Elbe-Weser-Canal

Fig. 5: Splitting of a river course.

If the river course is identical with the course of the borders between two different analytical units, e.g. because of country borders (Fig. 6), the areas will be handled as if the analytical unit drains completely into the catchment on the other side of the river.

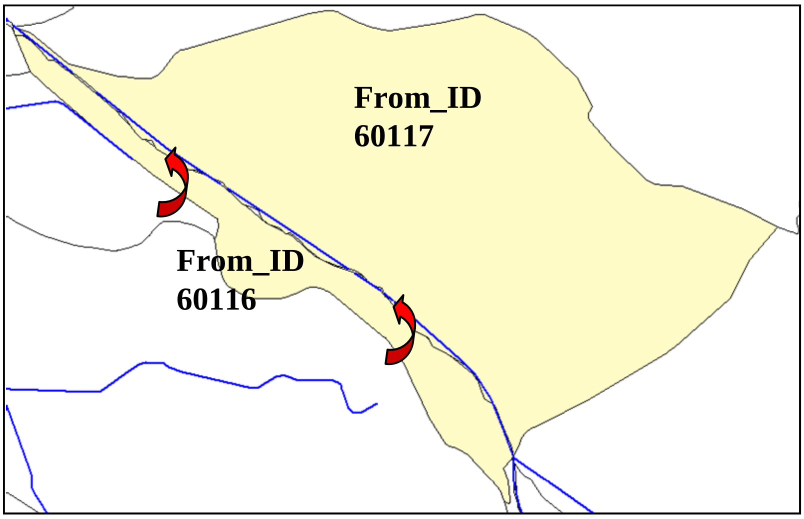


Fig. 6: Definition of the water topology at Border Rivers.

4.1.2 Flow net equation

The flow net equation (FNE), describing the topology of the stream network, is the conversion of area topology into a formula that can be used by MONERIS to calculate the size of catchment areas, total runoff and loads.

The flow net equation is generated in three versions:

- FNE without splitting: e.g. used to determine total size of the catchment.
- FNE with splitting: may be used in calculation of loads, some parts of which are discharged through a channel.
- FNE upper course: may be used to determine, for example, the runoff draining from upper catchments into a particular analytical unit, without consideration of the area runoff of that particular analytical unit. This version also contains splittings.

4.1.3 Runoff calibration

For the application of MONERIS, the average annual runoff data of every analytical unit are needed. They need to be appropriately modelled for all analytical units, and calibrated with available data from monitoring stations.

One option is calculation of a simplified water balance for the analytical units based on runoff values, precipitation and evapotranspiration values. The runoff values provided by the measuring stations determine the amount of runoff. Spatial distribution is determined by precipitation and evapotranspiration.

From the balance of the precipitation minus the evapotranspiration, non-adjusted runoffs for all analytical units can be calculated. On the basis of the runoff equation, the non-adjusted runoffs can then be added up and compared with observed runoffs for each measuring station. Differences can subsequently be levelled with a reduction factor, which is assigned to all analytical units within the catchment of one monitoring station (provided they were not assigned to another upstream measuring station).

4.1.4 Calculation of the water surface area

The water surface area within a catchment should be quantified for calculation of nutrient retention in rivers and lakes, and for calculation of atmospheric deposition on water surfaces. For this purpose, we use the approach of VENOHR ET AL. (2005) for the estimation of the river width of main rivers and tributaries (Fig. 7). Additionally to this method the widths of 184 main river sections were derived from Google-maps. This approach estimates the water surface area as a product of the length of the current and the width of the water surface area.

A distinction is made between a river course which completely runs through an analytical unit, subsequently called the main river, and all remaining streaming waters, which are called tributaries. For analytical units without influxes, that is to say headwaters, no main course is accounted for.

For the calibration and validation of the approach about 500 river systems in Europe with different hydro morphological features were used. The calibration is based both on the measurements of the river width, and on detailed hydrological maps containing information related to the river width. The calculated water surface area was verified by statistical data of the German Federal States.

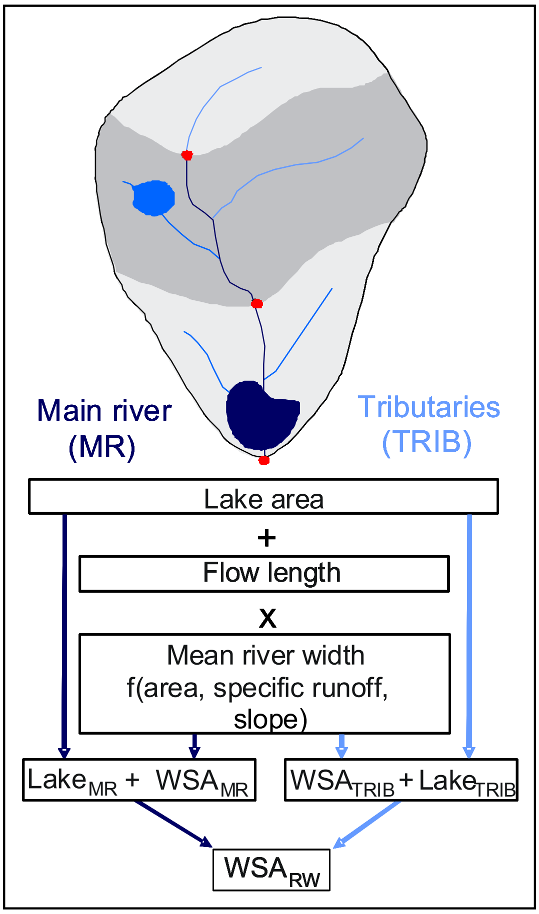


Fig. 7: Calculation of the water surface area (WSA) of main rivers (MR) and tributaries (TRIB) in river systems according to VENOHR ET AL. (2005).

The river width is calculated depending of the total size of the catchment, the area specific runoff, and the mean slope of the particular area of the analytical unit (Eq. 1 and Eq. 2).The flow length of the tributaries is determined for every analytical unit, based of the difference between the total length of all rivers on the map, and the lengths of the main rivers. Differentiated between main river and tributary, the water surface area of the rivers is added to the water surface area of the lakes.

$$width_{TRIB} = WSA1 \cdot BI_{AU_A}^{\;WSA2} \cdot q_{spec}^{\;1WSA3} \cdot BI_{slope_{1000}}^{\;WSA4} \qquad \text{Eq. 1}$$

$width_{TRIB}$	= calculated flow length weighted average river width of the tributaries, in m
BI_AU_A	= area of the analytical unit, in km²
q_{spec}	= area specific discharge of the analytical unit, in l/(s·km²)
BI_slope_{1000}	= mean slope (1000m GRID) in the analytical unit, in %
$WSA1-4$	= Model constants

$$width_{MR} = WSA5 \cdot BI_{AU_A}{}^{WSA6} \cdot q_{spec_{tot}}{}^{WSA7} \cdot BI_{slope1000}{}^{WSA8}$$ Eq. 2

$width_{MR}$	= calculated flow length weighted average river width of the main river, in m
BI_AU_A	= area of the catchment, in km²
$q_{spec_{tot}}$	= area specific discharge of the catchment, in l/(s·km²)
BI_slope_{1000}	= mean slope (1000m GRID) in the catchment, in %
$WSA5-8$	= Model constants

For the calculation of the water surface area, it is important to consider that with an increasing map scale, generalisation also increases, such that smaller rivers and meanders are missing. Thus the real length of the river, and consequently the surface water area, will be underestimated. Therefore the lengths of rivers from maps with four different scales (1:25,000; 1:100,000; 1:250,000; 1:1,000,000) were compared, and scale factors were determined for the main rivers (S_{MR}) and tributaries (S_{TRIB}). The scale factors determined from 87 German catchments are shown in Table 3 (VENOHR, 2006; VENOHR ET AL., 2005; see also Annex B).

Table 3: 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_{TRIB}	S_{MR}
DTK25	1:25,000	1.00	1.00
UBA1000	1:100,000	1.83	1.11
UBA-OSU1000	1:100,000	2.10	1.11
DLM250	1:250,000	3.23	1.11
DLM1000	1:1,000,000	2.99	1.13
BART1000	1:1,000,000	8.40	1.18
DCW1000	1:1,000,000	6.28	1.17

4.2 Approaches of calculation

In the following section, calculation of point and diffuse nutrient emission sources is described.

4.2.1 Nutrient emissions from point sources

For calculation of nutrient emissions from point sources, information is required on location of waste water treatment plants and direct industrial discharges, as well as their assignment to the analytical units. The most significant industrial discharges come from the food, paper, textile, leather, iron and steel, chemical and fertilizer industries, along with mining and large scale agriculture. In addition, the size of the population connected to the sewer systems, in particular to a WWTP should be known.

These data are available from existing public WWTP inventories which contain the following values:

- o geographical position
- o receiving water
- o point of discharge (MR or TRIB)
- o technical status
- o method of purification and levels of further treatment
- o amount of waste water treated annually
- o treated amount of extraneous water
- o nitrogen parameters (concentration, annual load)
- o phosphorus parameters (concentration, annual load)

The size of a WWTP depends on the number of inhabitants (E) connected to the WWTP, including all additional emissions which are calculated in inhabitant equivalents. As a rule, different size groups (levels of upgrade) of WWTPs are related to different purification capacities.

The loads from WWTPs can be calculated from the product of the mean annual nutrient concentration during the runoff and the annual runoff. The nutrient concentration in the discharge of the WWTP is usually measured by the operators. If this is not the case, the nutrient load can be calculated from the population equivalent connected and the estimated elimination capacity of the WWTP. The nitrogen and phosphorus emissions of a WWTP can be determined with different methods depending on the existing data.

For all WWTPs, nutrient emissions can be calculated on the basis of population-specific nutrient emissions and the efficiency of a WWTP. For the Federal Republic of Germany, the procedure is described in BEHRENDT ET AL. (1999).

4.2.2 Nutrient emissions via diffuse sources

4.2.2.1 Nutrient emissions via atmospheric deposition

To calculate the direct atmospheric deposition on water surfaces, the following input data is required:

- o Area of all water surfaces that are connected to the river system within the analytical unit
- o Deposition rates for phosphorus and nitrogen

The calculation of the water surface areas is described in section 4.1.4. The deposition rates of nitrogen in European countries are available through the European Monitoring and Evaluation Programme (EMEP) program. The resolution of the raster grids for NH_y and NO_x deposition (in kg/(ha·yr)) is 50 km. In certain cases, country-specific data with a higher resolution is available, as for example for Germany in 1 km raster (GRID after GAUGER ET AL., 2008).

The phosphorus deposition rate depends on the land use of the specified area. In general this rate varies between 0.3 and 3.0 kg/(ha·yr) (BEHRENDT ET AL., 2002). Having analyzed statistical data, BEHRENDT ET AL. (2002) determined a mean deposition rate of 0.37 kg/(ha·yr) for middle-European catchments. The phosphorus deposition rate can vary for other countries, depending on the statistic data basis.

The nutrient emissions via atmospheric depositions are calculated as product of area-specific deposition and water surface area of the analytical unit.

4.2.2.2 Nitrogen surplus and phosphorus accumulation

The annual nitrogen surplus of agricultural areas is the essential input data for the groundwater, erosion, tile drainage and overland flow pathways. The nitrogen surplus is calculated as the difference between the total emission of nutrients to the soil, and the removal by harvest. A nutrient surplus can be stored in the soil, or transported into the air or via groundwater into surface waters.

The different approaches available for calculation of nutrient balances on national and international scales are based on agricultural statistics and nutrient equivalents for animal species and crops.

The calculation of the annual nitrogen and phosphorus balances for agriculture areas is based on statistical data, for example mineral nitrogen and phosphorus fertilizers or farm fertilizers. The annual removal is calculated in relation to the nutrient content and amount of harvested crops and forage plants.

The nutrient balance in agricultural areas can be calculated on the basis of this information, coefficients for nitrogen fixation and the plant-specific nitrogen and phosphorus uptake:

- Nutrient supply = mineral fertilizer + farm fertilizer + other emissions (e.g. atmospheric deposition, symbiotic nitrogen fixation)
- Nutrient removal = nutrient removal by harvest of crops and forage plants.
- Nutrient balance = nutrient supply – nutrient removal

As agricultural statistics in Germany on district level are available only in four year intervals (NS_C = long time series of nitrogen balances for countries and federal states respectively in kg/(ha·yr)), data have to be transferred into annual values (Eq. 3)

$$NS_{CY} = NS_D \cdot \frac{NS_{CCY}}{NS_{CRY}}$$ Eq. 3

NS_{CY} = calculated nitrogen surplus per year and analytical unit, in kg/(ha·yr)

NS_D = detailed nitrogen surplus for a reference year, in kg/(ha·yr)

NS_{CCY} = country wide nitrogen surplus of the calculated year, in kg/(ha·yr)

NS_{CRY} = country wide nitrogen surplus of the reference year, in kg/(ha·yr)

For districts in other countries there are approaches following the method of the Organisation for Economic Co-operation and Development (OECD, 1997) or using statistical data (FAO, 2007) to calculate nutrient balances on agricultural areas. On the national scale, calculations are already available, for example for Germany by the Federal Regional Studies and Planning Research Institute for land use (FAL) (KREINS & GÖMANN, 2008; LANGE ET AL., 2006) or the University of Giessen (BACH ET AL., 2003).

4.2.2.3 Nutrient emissions via overland flow

Nutrient emissions via overland flow are calculated for arable land, grassland, naturally covered areas, open areas; and snow covered areas. The following input data is required:

- o Land use
- o Mean nutrient content in topsoil
- o Intensity of precipitation

Fig. 8 shows the scheme for calculation of the soluble nutrients via overland flow.

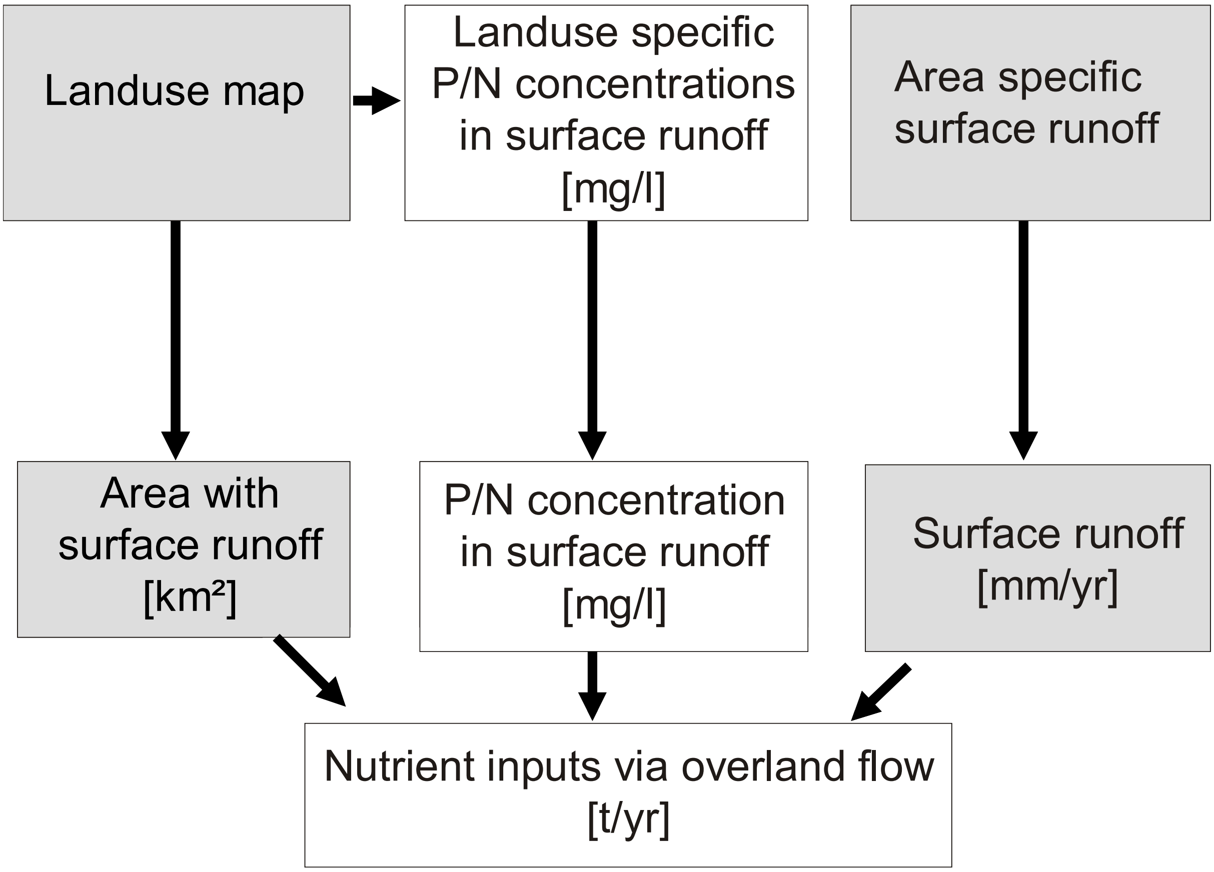


Fig. 8: Nutrient emissions via overland flow.

The surface runoff is calculated as a function of the total discharge of an analytical unit, following the approach by CARL & BEHRENDT described in SCHREIBER ET AL. (2005b), CARL & BEHRENDT (2006, 2008) and CARL ET AL. (2008) (Eq. 4).The results of this conceptual time-series-model are comparable with the results of hydrological models such as SWAT and DIFGA for certain test regions of the daNUbs-project (KROISS et al., 2003).

$$q_{SR_{pre}} = CSR18 \cdot (q_{spec} \cdot 86.4 \cdot 0.365)^{CSR19} \qquad \text{Eq. 4}$$

$q_{SR_{pre}}$ = area specific surface runoff, in mm/a

q_{spec} = area specific discharge, in l/(s·km²)

$CSR18-19$ = model constants

Based on the area specific surface runoff, the surface runoff for all unsealed areas (Eq. 5), as well as for all snow covered areas (Eq. 6), is calculated separately. The sum of these components makes up the relevant surface runoff.

$$Q_{SR_{nsv}} = \frac{\frac{q_{SR_{pre}}}{86.4}}{0.365} \cdot \frac{AU_A}{1000} - US_{Qurb}$$ Eq. 5

$Q_{SR_{nsv}}$ = surface runoff from areas with natural vegetation, in m³/s

$q_{SR_{pre}}$ = area specific surface runoff, in mm/a

AU_A = area of the analytical unit, in km²

US_{Qurb} = surface runoff from sealed urban areas, in m³/s

$$Q_{SR_{sn\_pre}} = CSR15 \cdot \frac{IM_{snow_A} \cdot (PD_{PREC_{yr}} - CSR14)}{1000}$$ Eq. 6

$Q_{SR_{sn\_pre}}$ = surface runoff from snow covered areas, in m³/a

IM_{snow_A} = snow or ice covered areas in the analytical unit, in km²

$PD_{PREC_{yr}}$ = sum of precipitation, in mm/yr

$CSR14-15$ = model constants

Phosphorus

The phosphorus concentrations for arable and grassland are calculated by Eq. 7 and Eq. 8:

$$P_{SR_{arab}} = CSR9 + CSR10 \cdot Exp(P_{acc_{de}} \cdot CSR6 \cdot CSR11)$$ Eq. 7

$P_{SR_{arab}}$ = phosphorus concentration in surface runoff from arable areas, in mg/l

$P_{acc_{de}}$ = phosphorus accumulation-factor, dimensionless

$CSR6;9-11$ = model constants

$$P_{SR_{pasture}} = CSR9 + CSR10 \cdot Exp(P_{acc_{de}} \cdot CSR7 \cdot CSR11)$$ Eq. 8

$P_{SR_{pasture}}$ = phosphorus concentration in surface runoff from grassland, in mg/l

$P_{acc_{de}}$ = phosphorus accumulation-factor, dimensionless

$CSR7;9-11$ = model constants

With

$$P_{acc_{de}} = \frac{CD_{Pacc_{coum}}}{CSR8}$$ Eq. 9

$P_{acc_{de}}$	= phosphorus accumulation factor
$CD_{Pacc_{coum}}$	= phosphorus accumulation of the administrative Catchment or state, in kg/ha
$CSR8$	= model constant

For open areas and naturally covered areas, a phosphorus concentration of 0.035 mg/l is assumed. The four phosphorus concentrations (comp. Eq. 7 and Eq. 8 above) are calculated as area weighted means, depending on the land use. They are then multiplied with the surface runoff, resulting in the phosphorus emission from unsealed areas into surface waters.

For snow covered areas a phosphorus concentration of 0.005 mg/l is assumed. Again the phosphorus concentration is multiplied with the surface runoff, and thus result in the phosphorus emission from snow covered areas into surface waters.

The sum of both phosphorus emissions produces the total phosphorus emission via overland flow.

Nitrogen

For nitrogen, the following concentrations are assumed:

- Arable areas: 0.3 mg/l plus atmospheric deposition concentration
- grassland: atmospheric deposition concentration
- naturally covered areas: atmospheric deposition concentration
- open areas: atmospheric deposition concentration

As for phosphorus, the nitrogen concentrations for unsealed areas are calculated as area weighted means, depending on the land use. Then they are multiplied with the surface runoff, resulting in the nitrogen emission from unsealed areas into surface waters.

For snow covered areas, a nitrogen concentration of 0.1 mg/l is assumed. This concentration, multiplied with the surface runoff, results in the nitrogen emission from snow covered areas into surface runoff.

The sum of both phosphorus emissions produces the total nitrogen emission via overland flow.

4.2.2.4 Nutrient emissions via erosion

For the calculation of the erosion pathway, the following emission data is required:

- o Local soil loss
- o Digital elevation model (slope of 1 km² resolution)
- o Mean nutrient content in top soil
- o Land use

MONERIS calculates the nutrient emissions in surface waters as local soil loss from arable land, grassland, naturally covered areas, and the land use-dependent nutrient content in top soil (Fig. 9). However, the sediment load in rivers originates only from certain parts of the catchments.

Arable land is generally very prone to soil loss. Therefore, it is subdivided into slope classes as the kinetic energy increases with the slope angle. Furthermore, the proportion of fine particles and attached nutrients in the sediment increases while being translocated. In MONERIS, this grain size effect is expressed by nutrient-specific enrichment ratios (Eq. 14).

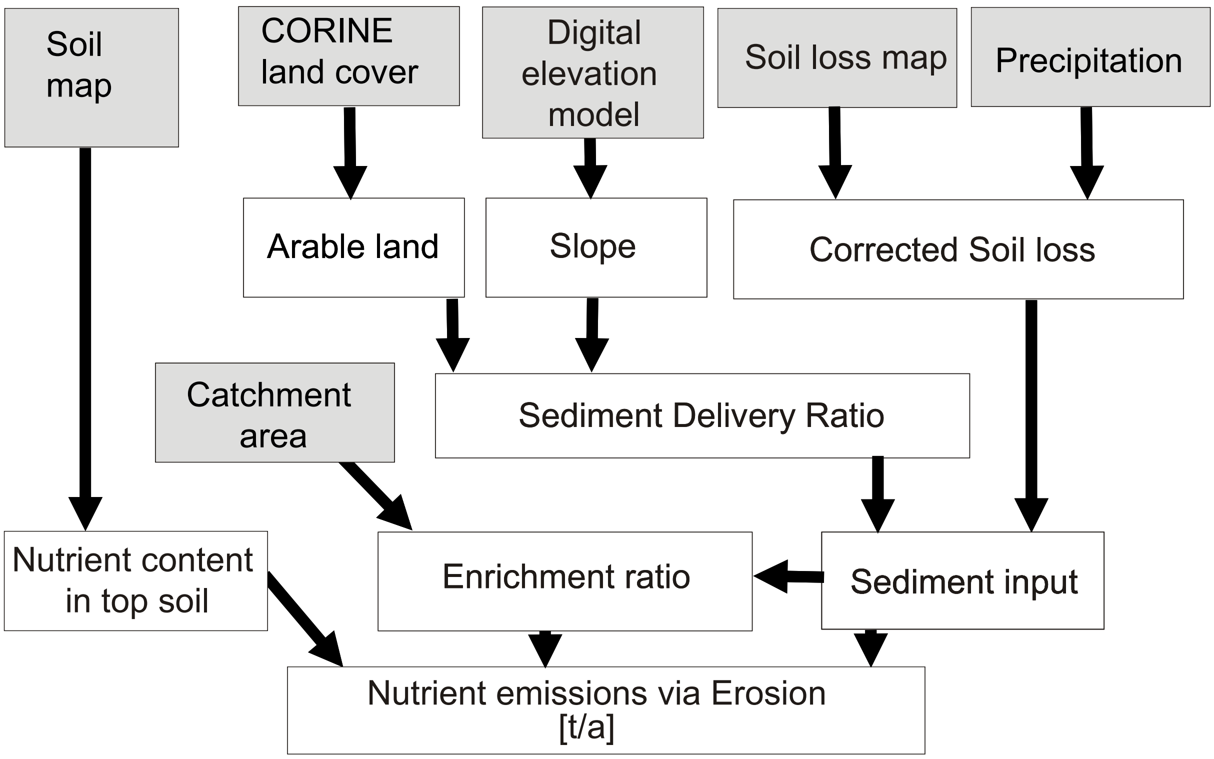


Fig. 9: Nutrient emissions via erosion.

MONERIS needs a soil loss map as emission data. If such a map is not available, this data has to be generated. There are several erosion models which can be used, the Universal Soil Loss Equation (USLE) and its derivatives probably being the most well-known. Precipitation, land use, soil and terrain are used to estimate long term annual means of soil loss.

The results have to be intersected with land use classes and arable land subdivided according to slope (<1%, 1-2%, 2-4%, 4-8%, >8%). This subdivision is relevant to consider protection measures against soil loss in MONERIS (Section 5.3.5.2)

As climatic conditions change from year to year, so does the sediment loads. Thus, the long term soil loss is multiplied by a weighting factor (Eq. 10) which is calculated as the ratio between the precipitation of the observed year and the long term average precipitation.

$$ER\_SL_{AL+GL} = \left(ER\_SL_{AL} + ER\_SL_{GL}\right)\frac{N}{\overline{N}} \qquad \text{Eq. 10}$$

ER_SL_{AL+GL}	= weighted soil loss of arable and grassland, in t/yr
ER_SL_{AL}	= total erosion of arable land, in t/yr
ER_SL_{GL}	= total erosion of grassland, in t/yr
N	= precipitation, in mm/yr
$\overline{N}$	= mean long term precipitation, in mm/yr

The soil loss from naturally covered areas is calculated by Eq. 11:

$$ER_{SL_{nat}} = CE12 \cdot IM_{snow_A} \cdot (BI_{SL_{nat\,cov}} \cdot BI_{nat\,cov} \cdot 100) \cdot 100 \cdot \frac{N}{\overline{N}} \qquad \text{Eq. 11}$$

$ER_{SL_{nat}}$	= total soil loss from naturally covered areas, in t/(ha·yr)
IM_{snow_A}	= snow or ice covered areas in the analytical unit, in km²
$BI_{SL_{nat\,cov}}$	= mean soil loss from naturally covered areas, in t/(km²·yr)
$BI_{nat\,cov}$	= naturally covered areas, in km²
N	= precipitation, in mm/yr
$\overline{N}$	= mean long term precipitation, in mm/yr
$CE12$	= model constant

Local soil loss can only be understood as a potential sediment emission. Due to deposition in the catchment, the observed sediment load is lower. The sediment delivery ratio (SDR) describes the ratio of sediment load to total soil loss. It depends on the conditions in the catchment (WALLING, 1983) and cannot be easily calculated for every catchment. For this reason, an empirical equation was developed, which combines simple catchment parameters with the sediment delivery ratio. The slope and the proportion of arable land were identified as the most important parameters by non-linear multiple regression analysis. Additionally, a proportion of areas that are potentially erosive is assumed (default value is 20 % see constant CE19) (Eq. 12). MONERIS assumes that slopes below 0.25 % do not account for sediment emission. The SDR is zero here.

$$ER_{SDR} = \mathrm{C}E1 \cdot (BI_{slope_{1000}} + CE4)^{CE2} \cdot \left(CE19 + A_{al\_portion}\right)^{CE3} \quad \text{Eq. 12}$$

ER_{SDR} = sediment delivery ratio, in %

$BI_{slope_{1000}}$ = mean slope (1000m) in the analytical unit, in %

$A_{al\_portion}$ = portion of arable land on the analytical unit area, in %

$\mathrm{C}E1-4;19$ = model constants

Thus, in MONERIS the sediment emission is (Eq. 13):

$$ER_{SEDin} = ER_{SLcorr} \cdot \frac{ER_{SDR}}{100} + ER_{SLnat} \quad \text{Eq. 13}$$

ER_{SEDin} = sediment emissions, in t/yr

ER_{SLcorr} = corrected soil loss by precipitation, in t/yr

ER_{SDR} = sediment delivery ratio (SDR), in %

ER_{SLnat} = natural soil loss, in t/yr

Based on the sediment emission, the enrichment ratio is calculated by Eq. 14:

$$ER_{ENR} = CE7 \cdot \left(\frac{ER_{SEDin}}{BI_{AU_A}}\right)^{CE9} \qquad for \left(\frac{ER_{SEDin}}{BI_{AU_A}}\right) > 1$$ Eq. 14

$$ER_{ENR} = CE11 \qquad for \left(\frac{ER_{SEDin}}{BI_{AU_A}}\right) \leq 1$$

ER_{ENR}	= enrichment ratio
ER_{SEDin}	= sediment emissions, in t/yr
BI_{AU_A}	= area of the analytical unit, in km²
$CE7;9;11$	= model constants

Thus, the total nutrient emission by erosion is the sum of (Eq. 15 respectively Eq. 16):

$$ER_{TP} = \frac{ER_{TS_{TPcont}}}{1000000} \cdot \left(ER_{SEDin} - ER_{SLnat}\right) \cdot ER_{ENR} + \frac{CE13}{1000000} \cdot ER_{SLnat}$$ Eq. 15

Respectively:

$$ER_{TN} = \frac{ER_{TS_{TNcont}}}{1000000} \cdot \left(ER_{SEDin} - ER_{SLnat}\right) \cdot ER_{ENR} \cdot \frac{CE8}{CE7} + \frac{CE14}{1000000} \cdot ER_{SLnat}$$ Eq. 16

ER_{TP}	= phosphorus emissions via erosion, in t/yr
ER_{TN}	= nitrogen emissions via erosion, in t/yr
$ER_{TS_{TPcont}}$	= phosphorus content in top soil, in mg/kg
$ER_{TS_{TNcont}}$	= nitrogen content in top soil, in mg/kg
ER_{SEDin}	= sediment emission, in t/yr
ER_{SLnat}	= natural soil loss, in t/yr
ER_{ENR}	= enrichment ratio, dimensionless
$CE7-8;13-14$	= model constants

The constants in the above mentioned equations correspond to the nutrient content in the topsoil of natural areas. The enrichment ratios of total nitrogen and total phosphorus are defined as constants in MONERIS.

4.2.2.5 Nutrient emissions via tile drainages

The quantification of nitrogen and phosphorus emissions via tile drainages into surface waters is calculated using three parameters: size of tile drained areas, tile drain discharge, and the mean nutrient concentration of tile drain discharge.

Fig. 10 gives a general description of the calculation steps for nitrogen emissions via tile drainages:

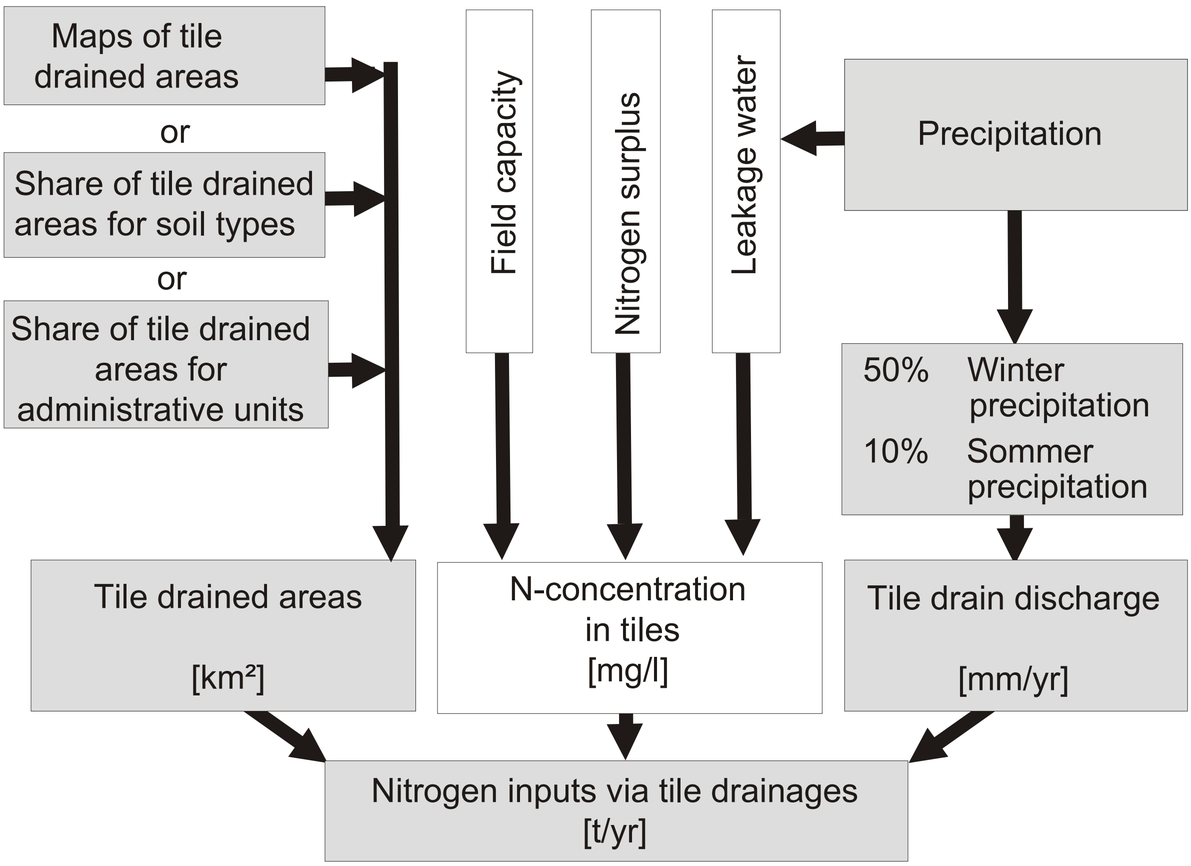


Fig. 10: Nitrogen emissions via tile drainages.

Size of tile drained areas

For the estimation of the size of tile drained areas in an analytical unit, three different kinds of input data are used:

- Maps of tile drained areas
- Estimation of the percentage of tile drained areas for different soil types derived from information about tile drained areas from representative areas (BEHRENDT ET AL., 2000 or HIRT, 2005a, b).
- Regional statistics for administrative areas

For Germany, the percentage of tile drained areas can be quantified for site types, based on the mesoscale soil mapping (MMK; available for the new federal states of Germany). The site type describes an aggregated level of the MMK, in which comparable regional site types (lowest level) are aggregated according to characteristic substrate and soil conditions. Tile drained areas were localized for some representative areas, and then this calculated percentage of tile drained areas was transferred to the total area of the new federal states. In MONERIS this indirect approach to estimate tile drained areas by their characteristic site types was applied, since site types express water conditions, and thus provide information about their degree of water logging and the necessity of tile drainage.

In many areas, especially in Western Europe, there is neither a duty to give notice nor any systematic registration of tile drainages. Thus there is little data available on location of tile drained areas. BACH ET AL. (1998) started an experts' inquiry within the agricultural authorities in order to estimate the percentage of tile drained areas for the old federal states.

Tile drain flow

The tile drainage runoff rate is calculated following KRETSCHMAR (1977), who stated that annual drain flow consists of 50 % of the winter precipitation and 10 % of the summer precipitation. This approach also acknowledges regional differences in the allocation of precipitation and amount of drain flow (Eq. 17):

$$TD_{q_{spec}} = CTD1 \cdot N_{WI} + CTD2 \cdot N_{SO} \qquad \text{Eq. 17}$$

$TD_{q_{spec}}$	= area specific drain flow, in mm/yr
N_{WI}	= precipitation in winter, in mm/yr
N_{SO}	= precipitation in summer, in mm/yr
$CTD1-2$	= model constants

Mean nutrient concentration in tile drain runoff

The mean phosphorus concentration in the analytical unit is calculated as an area weighted mean of the concentrations shown in Table 4.

Table 4: Phosphorus-concentrations in tile drain runoff in four different soil types.

Soil types	P-concentration in mg/l	Model constants
Sandy soil	0.20	CTD3
Loamy soil	0.06	CTD4
Fen	0.30	CTD5
Bog	10.00	CTD6

Thus the phosphorus emission is calculated (Eq. 18):

$$C_{DR_p} = \frac{CTD3 \cdot A_{DRS} + CTD4 \cdot A_{DRL} + CTD5 \cdot A_{DRNM} + CTD6 \cdot A_{DRHM}}{A_{DRS} + A_{DRL} + A_{DRNM} + A_{DRHM}}$$ Eq. 18

A_{DRS}	= area of tile drained sandy areas, in km²
A_{DRL}	= area of tile drained loamy areas, in km²
A_{DRNM}	= area of tile drained fens, in km²
A_{DRHM}	= area of tile drained bogs, in km²
$CTD3-6$	= model constants

The nitrogen concentration in drain outlets (Eq. 19), and the potential nitrate concentration in the leakage water is calculated, basing on the regionally differentiated nitrogen surplus (BACH ET AL., 1998) following the approach of FREDE & DABBERT (1998). The concentration of leakage water should accord with the concentration of the tile drainage water. The boundary condition is that net mineralisation and net immobilisation are both negligible.

$$TD_{TNC} = \frac{\left(IM_{Nsurp}\right)^{CTD7}}{TD_{q_{spec}}} \cdot 100$$ Eq. 19

TD_{TNC}	= nitrogen concentration in tile drain outlets, in mg/l
IM_{Nsurp}	= nitrogen surplus, in kg/(ha·yr)
$TD_{q_{spec}}$	= area specific tile drain discharge, in mm/yr
$CTD7$	= model constant

The potential nitrate concentration in the topsoil is reduced by a denitrification exponent (CTD7) estimated as 0.85 (BEHRENDT ET AL., 2000).

4.2.2.6 Nutrient emission via groundwater

For the calculation of the groundwater pathway, the following input data is required:

- land use
- hydrogeology (subdivided into consolidated rock with high porosity or impermeable and unconsolidated rock types with shallow and deep groundwater, e.g. as given by the hydro geological map of Europe from National Institute of Public Health and the Environment (RIVM)
- nitrogen surplus on agricultural areas
- hydrology
- meteorology
- atmospheric deposition
- soil information

The nutrient emission via the groundwater is calculated as a product of groundwater flow, and nutrient concentration in the groundwater. The groundwater flow consists of base flow and natural interflow. Fig. 11 shows the scheme for the calculation of the nutrient emission via groundwater.

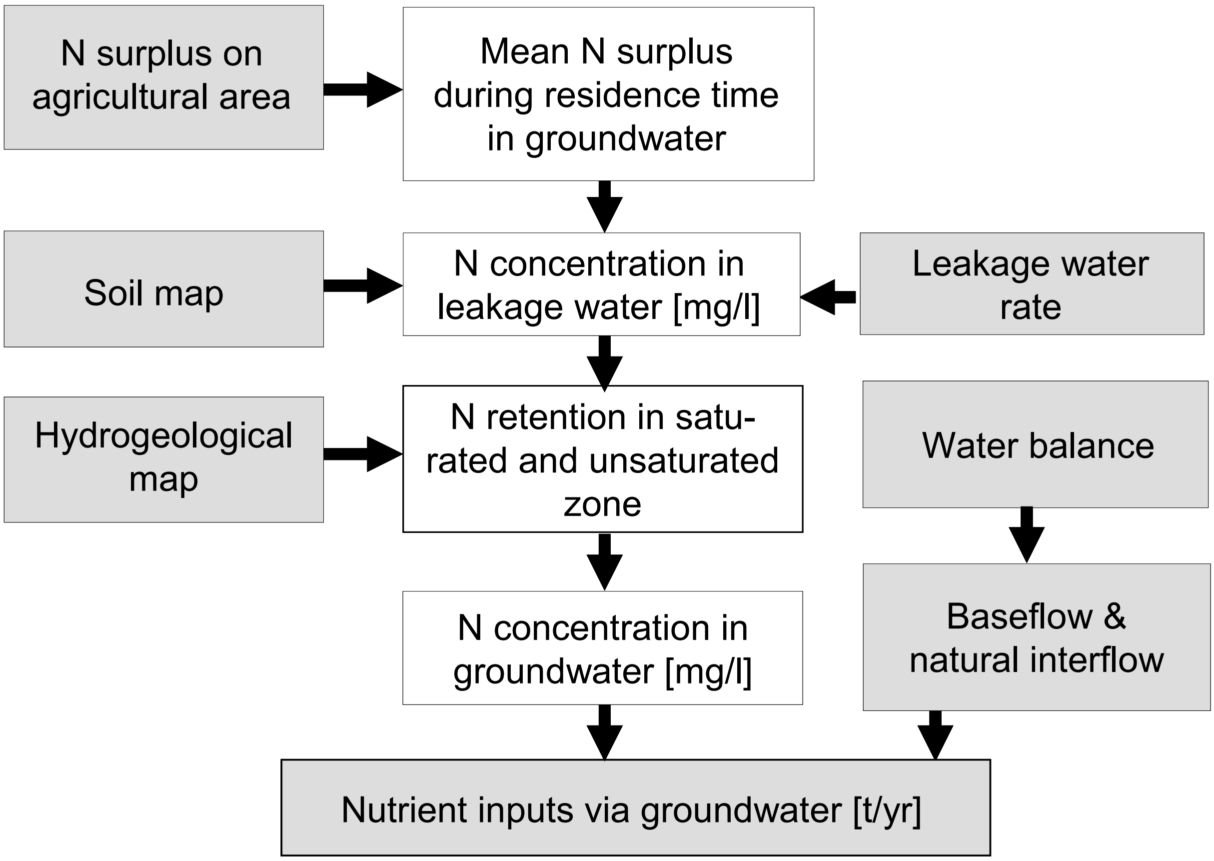


Fig. 11: Nitrogen emissions via groundwater

The groundwater flow is calculated for each analytical unit as the difference between total discharge and the calculated sum of the four discharge components (drain flow, surface runoff, precipitation on water surface areas, and runoff from connected, sealed urban areas).

The values for concentrations of soluble reactive phosphorus (SRP) in the groundwater of different soil types given by BEHRENDT ET AL. (2000) are presented here in Table 5. Using these values, the phosphorus concentration of the analytical unit is calculated as an area weighted mean, basing on concentrations and the size of areas of sandy and loamy soils, fens and bogs that are used for agriculture.

Table 5: SRP- concentrations in the groundwater for different soil types.

Soil type	**Land use**	**SRP- concentrations in mg/l**	**Model constants**
Sandy soils	agricultural areas	0.10	CGW4
Loamy soils	agricultural areas	0.03	CGW5
Fens	agricultural areas	0.10	CGW6
Bogs	agricultural areas	0.50	CGW7
-	forest/open area	0.02	CGW8

In the catchments, the phosphorus concentration is calculated as an area weighted mean, with the information given in Table 5 (concentrations) and in soil maps (such as BÜK) for soils such as sandy soils, loamy soils, fens and bogs used for agriculture using Eq. 20:

$$C_{GWLN_P} = \frac{CGW4 \cdot A_S + CGW5 \cdot A_L + CGW6 \cdot A_{NM} + CGW7 \cdot A_{HM}}{A_S + A_L + A_{NM} + A_{HM}} \qquad \text{Eq. 20}$$

C_{GWLN_P} = phosphorus concentration in groundwater under agricultural use, in mg/l

A_S = size of sandy soil areas, in km²

A_L = size of loamy soil area, in km²

A_{NM} = size of fens, in km²

A_{HM} = size of bogs, in km²

$CGW4-7$ = model constants

Finally, the mean phosphorus concentration in the groundwater of each analytical unit is calculated as an area weighted mean of the phosphorus concentrations for agricultural and non agricultural areas (especially forest and open areas) (Eq. 21). These calculated areas are relevant for the groundwater recharge rate.

$$C_{GW_P} = \frac{C_{GWLN_P} \cdot A_{LN} + CGW8 \cdot A_{WAOF}}{A_{LN} + A_{WAOF}} \qquad \text{Eq. 21}$$

C_{GW_P}	= mean phosphorus concentration in groundwater, in mg/l,
C_{GWWAOF_P}	= phosphorus concentration in groundwater for forest and open areas, in mg/l
C_{GWLN_P}	= phosphorus concentration in groundwater under agricultural use, in mg/l
A_{LN}	= size of agricultural areas, in km²
A_{WAOF}	= size of forest and open areas, in km²
$CGW8$	= model constants

In aerated groundwater, the concentration of total phosphor is the same as the concentration of SRP. However in anaerobic groundwater, the total phosphor concentration may be up to five times higher than the SRP concentration (BEHRENDT, 1996; DRIESCHER & GELBRECHT, 1993). If no data is available about anaerobic groundwater conditions, a comparison between the nitrate concentration in the groundwater and in the leakage water provides the phosphorus concentration. If the nitrogen concentration in the groundwater is less than 0.1 mg/l the total phosphor concentration in the groundwater is 2.5 (CGW2) times higher than the SRP concentration. Otherwise the total phosphor concentration does not change.

The nitrogen concentration in the groundwater derives from the potential nitrogen concentration in the topsoil. As the residence time of water and other substances travelling through the root layer into the groundwater, and in the groundwater itself, can vary over several years, the current nitrogen concentration of the topsoil has to be replaced by a mean value representing the concentration during the whole residence time. With this approach, the changing nitrogen surplus on agricultural areas during the groundwater residence time can be accounted for. For areas in Germany, the calculations of groundwater residence times from KUNKEL & WENDLAND (1999) can be applied. If no groundwater residence times are available, the values can be calculated using the simplified Eq. 22. Individual years are calculated, which are then aggregated into five year classes.

$$GW_{RT} = \frac{3000}{GW_{qltcorr}}$$ Eq. 22

GW_{RT} = groundwater residence time, in yr

$GW_{qltcorr}$ = long term mean of annual groundwater recharge, in mm/yr

For the residence time, a mean nitrogen surplus is calculated. As the nitrogen surplus is surveyed for several years only, years in between have to be interpolated. Therefore values are used which are published for bigger administrative units such as the national level.

For areas that are not fertilized or used for agriculture the atmospheric deposition is initially averaged for the length of groundwater the residence time and then firstly and finally area weightedly averaged for the analytical unit.

The mean nitrogen concentration in the leakage water is a result of the quotient of the area weighted nitrogen surpluses inclusive of atmospheric deposition, and the area weighted specific groundwater flow of all areas that contribute to the groundwater recharge.

Nitrogen retention, especially by denitrification in the soil, in the unsaturated zone, and in the groundwater, is assessed by comparing regional nitrate concentrations in groundwater and the potential nitrate concentration in leakage water. This comparison was conducted in Germany and showed that nitrogen retention depends on the amount of leakage water rate and on hydro geological conditions.

To estimate the retention of nitrogen in the unsaturated zone, four hydro geological conditions are distinguished:

- Unconsolidated rock, shallow groundwater
- Unconsolidated rock, deep groundwater
- Consolidated rock, high porosity
- Consolidated rock, impermeable

To calculate the nitrogen concentration in groundwater Eq. 23 is applied:

$$C_{GW_{NO3-N}} = \left(\sum_{i=1}^{4} \frac{1}{1 + k1 \cdot GW_{qltcorr}^{\ k2}} \cdot \frac{A_{HG\,i}}{A_{EZG}} \right) \cdot C_{SWPOT_{NO3-N}}^{CGW\,21} \qquad \text{Eq. 23}$$

$C_{GW_{NO3-N}}$	= nitrogen concentration in groundwater, in mg/l
$A_{HG\,i}$	= area of hydro geological rock types, in km²
$GW_{qltcorr}$	= long term mean of annual groundwater recharge, in mm/yr
A_{EZG}	= analytical unit area, in km²
$C_{SWPOT_{NO3-N}}$	= potential nitrogen concentration in leakage water, in mg/l
$CGW\,21$	= model constant
k_1 and k_2	= model constants

Constants k1 and k2 vary depending on the hydro geological rock types in the analytical unit (Table 6).

Table 6: Model constants used to estimate nitrogen retention in different hydro geological rock types.

Hydro geological rock types	$\mathbf{k_1}$	$\mathbf{k_2}$
unconsolidated rock, shallow groundwater	CGW13	CGW14
unconsolidated rock, deep groundwater	CGW15	CGW16
Consolidated rock, high porosity	CGW17	CGW18
Consolidated rock, impermeable	CGW19	CGW20

To examine the internal nitrogen retention in the river, the dissolved organic nitrogen (DON) emissions are needed. In MONERIS it is expected that especially long chain DON molecules are subject to only negligible retention. The DON emissions via groundwater are calculated using the groundwater recharge underneath forest and wetlands. These DON concentrations can be evaluated separately for forests and wetlands; in general DON concentrations vary between 0 and 6 mg/l, being lower in forested areas than in wetlands, and in warmer regions they can approach 0 mg/l (VENOHR, 2006).

4.2.2.7 Nutrient emissions from urban systems

Nutrient emissions from urban systems are those washed from sealed urban areas into sewer systems, where they are possibly retained until they finally reach surface waters, (nutrient emissions from unsealed urban areas are considered in the groundwater pathway, section 4.2.2.6). The nutrients passing from the combined sewer systems into WWTPs are accounted for in the description of point sources from municipal WWTP. During heavy rainfall events, the storage capacity of municipal WWTP connected to a combined sewer system can be exceeded, and leads to an overflow, allowing raw sewage from households, commercial use and streets to reach surface waters.

In MONERIS, the nutrient emissions from sealed urban areas are described in four separate pathways (Fig. 12):

- Nutrient emissions from sealed urban areas connected to separate sewer systems

  Via this pathway emissions are calculated which reaches the separate sewer systems with precipitation.

- Nutrient emissions from sealed urban areas and inhabitants (E) connected to combined sewer systems

  Emissions derive from heavy rainfall events leading to an overflow, and thus cause direct emissions into surface waters.

- Nutrient emissions from inhabitants and sealed urban areas, that are connected to a sewer system, but not to a municipal WWTP

  It is expected, that the certain amount of the sealed urban area, which is not connected to a municipal WWTP but to a sewer system accords to the certain number of inhabitants that is connected in the same way.

- Nutrient emissions from inhabitants and sealed urban areas that are not connected to sewer systems

  The inhabitants are either connected to small treatment plants which dewater directly into the groundwater, or collect their sewage in septic tanks.

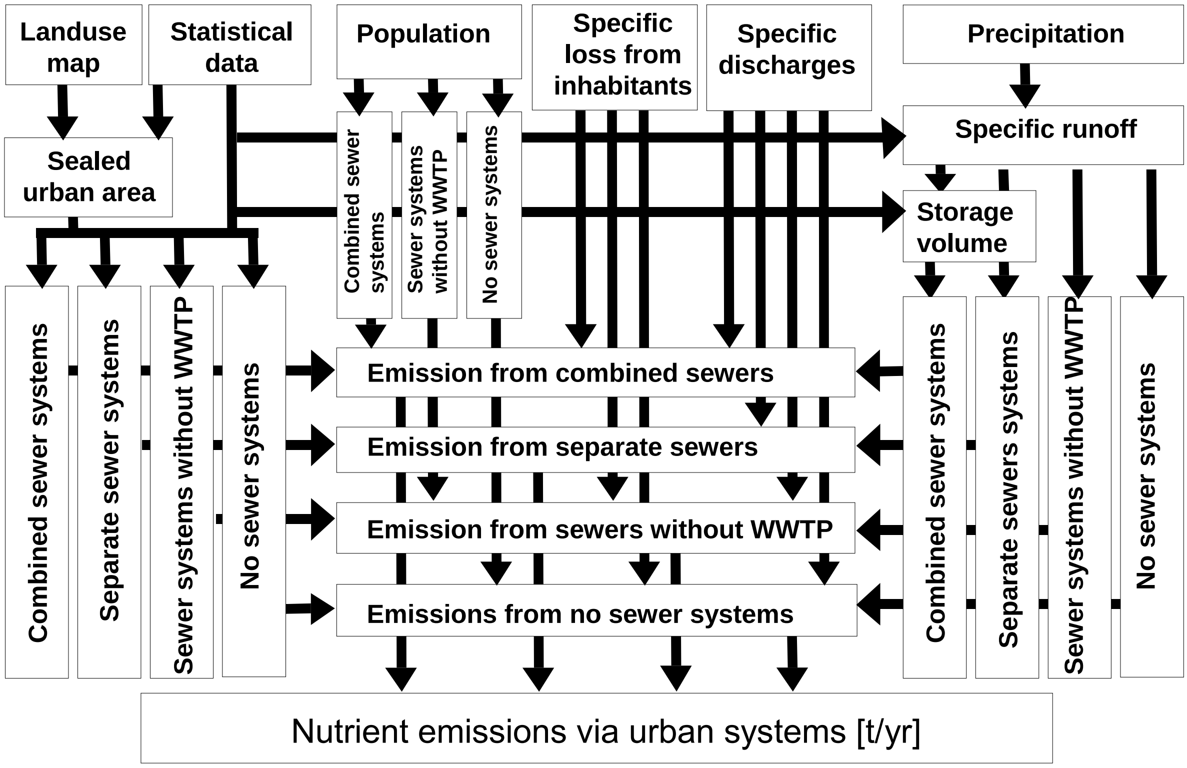


Fig. 12: Nutrient emissions via urban systems.

The total urban area can be deduced from a land use map. From this, the size (%) of the sealed urban area can be calculated using the approach of HEANEY ET AL. (1976) (see Eq. 24), which considers the population density.

$$US\_A_{imp\%} = CUS2\left(CUS1 \cdot US\_E_{DICHTE}\right)^{CUS3 - CUS4 \cdot \log\left(CUS1 \cdot US\_E_{DICHTE}\right)} \qquad \text{Eq. 24}$$

$US\_A_{imp\%}$ = size sealed urban area, in %

US_E_{DICHTE} = population density, in inhabitants/ha

$CUS1-4$ = model constants

With:

$$US\_E_{DICHTE} = \frac{US\_Inh_{tot}}{US\_A_{URB}} \cdot 0.01 \qquad \text{Eq. 25}$$

US_E_{DICHTE} = population density, in inhabitants/ha

US_Inh_{tot} = total inhabitants, in thousands

US_A_{URB} = total urban area, in km²

The total urban area is accordingly to the connection rate of inhabitants, and proportionally to the length of the sewer systems partitioned to the different sewer systems.

Inhabitants

The following data about the number of inhabitants are entered into the Periodical Data, and used to calculate the different connection rates of urban inhabitants:

- Inhabitants connected to any kind of sewer system
- Inhabitants connected to sewer systems and WWTP
- Total number of inhabitants
- Inhabitants not connected to WWTP
- Inhabitants connected to DCTP without public sewer system
- Inhabitants connected to septic tanks

In addition, we also calculate, on the basis of the portion of hydro geological rock types, how many inhabitants discharge, after passing the decentralized treatment plants, into surface waters directly via sewer systems or indirectly via soil- and groundwater passage (infiltration).

Areas

The percentage of the total sealed urban area (Eq. 24) and the sealed area of an analytical unit (from CORINE Land Cover (CLC) of the European Environmental Agency (EEA)) multiplied by the urban area of an analytical unit the sealed area of an analytical unit is calculated, a value which is needed for the further partitioning of sealed urban areas.

It is expected that the number of inhabitants connected to different sewer systems, as documented by water statistics bureaux, is proportional to the relationship of the variably connected areas.

With these pre-calculations, one can calculate all the areas that are connected to one of the four separately examined pathways (Eq. 26):

$$US\_A_{SS} = \frac{IM\_SSS\_pro\_TSS}{\left(IM\_CSS\_pro\_TSS + IM\_SSS\_pro\_TSS\right)} \cdot US\_IUA \cdot \frac{US\_INH_{connWandSS}}{US\_INH}$$ Eq. 26

US_A_{SS} = area connected to separate sewer systems, in km²

$IM\_SSS\_pro\_TSS$ = portion of separate sewer systems, dimensionless

$IM\_CSS\_pro\_TSS$ = portion of combined sewer systems, dimensionless

US_IUA = sealed area of the catchment, in km²

$US\_INH_{connWandSS}$ = inhabitants connected to WWTP and sewer systems, in thousands

US_INH = connected inhabitants, in thousands

Additionally, the sealed urban areas that are connected to sewer systems but not to WWTPs and that are either not connected to sewer systems or to WWTP are calculated (Eq. 27).

$$US\_A_{only\_SS} = \frac{US\_IUA \cdot US\_Inh_{connSS}}{US\_Inh}$$ Eq. 27

$US\_A_{only\_SS}$ = area, connected to sewer systems only, not to WWTPs, in km²

US_IUA = sealed urban area of the catchment, in km²

US_Inh_{connSS} = inhabitants connected to sewer systems, in thousands

US_INH = connected inhabitants, in thousands

Thus the total sealed area of the catchment is the sum of all above mentioned partial areas in km² (Eq. 28).

$$US\_A_{notconn} = US\_IUA - US\_A_{SS} - US\_A_{CS} - US\_A_{onlySS}$$ Eq. 28

$US\_A_{notconn}$ = not connected area, in km²

US_IUA = sealed urban area of the catchment, in km²

US_A_{SS} = area connected to separate sewer systems, in km²

US_A_{CS} = area connected to combined sewer systems, in km²

$US\_A_{only\_SS}$ = area connected to sewer systems only, in km²

Runoff

To calculate the runoff from sealed urban areas, the runoff coefficient according to HEANEY ET AL. (1976) is applied (Eq. 29). The more of the area that is sealed, the larger is the coefficient, and thus the part of the precipitation which reaches the sewer systems.

$$US\_impA_{Q\_ratio} = CUS5 + CUS6 \cdot \frac{US\_A_{imp\%}}{100} \qquad \text{Eq. 29}$$

$US\_impA_{Q\_ratio}$ = runoff coefficient, in %

$US\_A_{imp\%}$ = share of sealed urban area, in %

$CUS5-6$ = model constants

The area specific runoff from sealed urban areas can then be calculated, depending on the runoff coefficient, the annual precipitation, and the size of the sealed area. The area specific runoff reflects how much of the precipitation actually reaches the sewer systems, in relation to the share of sealed urban areas (Eq. 30).

$$US\_Q_{CS} = \frac{US\_impA_{Q\_ratio} \cdot N_{yr} \cdot \mathrm{US\_A_{CS}}}{1000} \qquad \text{Eq. 30}$$

US_Q_{CS} = runoff from sealed urban areas dewatering into combined sewer systems, in m³/yr

$US\_impA_{Q\_ratio}$ = runoff coefficient, in %

N_{yr} = annual precipitation, in mm/yr

US_A_{CS} = area connected to combined sewer systems, in km²

For sealed urban areas that dewater to the different sewer systems, the parameters and terms used are shown in Table 7.

Table 7: Terms for sealed urban areas that dewater to different sewer systems.

Terms for different types of sewage connections	**Area**	**Runoff**
Combined sewer systems	US_A_{CS}	US_Q_{CS}
Separate sewer systems	US_A_{SS}	US_Q_{SS}
Sewer systems without WWTP	US_A_{onlySS}	US_Q_{onlySS}
Not connected to sewer systems	$US\_A_{notconn}$	$US\_Q_{notconn}$

The discharge from all sealed urban areas is the sum of all runoffs from the different connection types (see Table 7), and is used for the water balance and other MONERIS pathways (the unit is converted from m³/yr to m³/s). This total discharge only considers the discharge that derives from precipitation, as the discharge, derived from households is accounted for in point sources. Thus the discharge from the combined sewer systems, calculated in the way mentioned below, does not describe the total discharge from combined sewer systems properly. To do so, heavy rainfall events that lead to a spillway (of also waste waters from households and commercial areas) in the combined sewer systems have to be accounted for. This is why the calculation of the discharge from combined sewer systems has to be extended by the following term (Eq. 31):

$$US\_CSO\_Q_{CS} = US\_CSO_{qCSO\_Inh} \cdot \frac{US\_CS_{Qr}}{100} \qquad \text{Eq. 31}$$

$US\_CSO\_Q_{CS}$ = discharge from combined sewer system during overflow events, in m³/s

$US\_CSO_{qCSO\_Inh}$ = realized runoff in combined sewer system on days with heavy rainfall, in m³/s

US_CS_{Qr} = portion of discharge by spillway, in %

Nutrient emission via combined sewer systems

In heavy rainfall events, the combined sewer systems cannot store the entire volume of water and direct it to the WWTPs; the excess water is transported directly, without treatment, into surface waters. This case is referred to as overflow, but to surface waters it often means a heavy impact. This situation is in contrast to “normal” rain events, when the combined sewer system can accommodate the volume of water. For combined sewer systems, the amount of discharge is calculated based on number of inhabitants and amount of precipitation.

For calculating the part of heavy rainfall events that reaches the sewer systems via the annual precipitation, the number of days with heavy rainfall events can be estimated (Eq. 32).

$$US\_SRT = N_{yr}^{CUS8} \cdot CUS7 \qquad \text{Eq. 32}$$

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

N_{yr} = annual precipitation, in mm/yr

$CUS7-8$ = model constants

Only some of the heavy rainfall events lead to a release, and the release may not be of an entire day's duration. During a heavy rainfall event, sewage from households that stayed in the sewer systems for several hours is available.

The deposition of nutrients inside the sewer systems has to be considered, leading to the assumption that not only the times the spillways are used have to be taken into account. This is why an "effective number of heavy rainfall days" is applied in MONERIS. The effective number of heavy rainfall days is the ratio of release rate with storage volume (under normal conditions) and without storage volume (overflow event) (Eq. 33):

$$US\_SRT_{eff} = US\_SRT \cdot \frac{US\_CS_{Qr}}{US\_Q_{CSO}} \qquad \text{Eq. 33}$$

US_SRT_{eff}	= effective number of days of heavy rainfall events, in d/yr
US_SRT	= number of heavy rainfall events, in d/yr
US_CS_{Qr}	= portion of discharge by spillway, in %
US_Q_{CSO}	= release rate of the combined sewer system in the case of overflow with no storage volume, in %

The release rate of a combined sewer system depends, in part, on its technical status and the resulting storage volume, which holds a part of the sewage on heavy rainfall days and transfers it delayed to the WWTP. According to MEIßNER (1991) Eq. 34 describes the release rate:

$$US\_CS_{Qr} = \left[\left(\frac{\frac{(4000 + 25 \cdot CUS24)}{(0.551 + CUS24)}}{(\frac{CD\_CSOV}{100} \cdot 23.3 + \frac{(36.8 + 13.5 \cdot CUS24)}{(0.5 + CUS24)}} \right) - 6 + \frac{(N_{yr-800})}{40} \right] \qquad \text{Eq. 34}$$

US_CS_{Qr}	= portion of discharge by spillway, in %
N_{yr}	= annual precipitation, in mm/yr
CD_CSOV	= storage volume of combined sewer systems, in %
$CUS24$	= model constant

MEIßNER (1991) and BROMBACH & MICHELBACH (1998) anticipate a storage volume of 23.3 m³/ha at a technical status of 100 %, and 0 m³/ha at a technical status of 10 %. To quantify the technical status, data from municipal waste water statistics are used.

Since the release rate depends, in part, upon precipitation, it has to be calculated separately for each analytical unit. However, the precipitation-runoff rate is assumed to be 1 l/(ha·s) for all analytical unit.

In case of an overflow event, the release rate of the combined sewer system for overflow conditions is calculated with the storage volume of combined sewer systems of 0 %.

For calculating the amount of waste water from commercial areas, MONERIS applies the approach of MOHAUPT ET AL. (1998). Commercial areas are assumed to be 0.8 % of the total urban area, and the commercial runoff rate is assumed to be 0.5 l/(ha·s) for 10 h/d, which equals 432 $m^3/(ha \cdot d)$.

The calculation of the discharge in combined sewer systems after heavy rainfall events is solved using following equation:

$$US\_QInh_{CSO} = term1 \cdot term2 \qquad \text{Eq. 35}$$

$$term1 = \left(US\_Inh_{connWandSS} \cdot \frac{CUS14}{1000} + CUS15 \cdot \frac{0.8}{100} \cdot US_{IUA\_tot} \cdot 100 \cdot \frac{\frac{86400}{1000}}{1000} \cdot \frac{CUS16}{24} \right)$$

$$term2 = US\_SRT_{eff} \cdot \frac{US\_A_{CS}}{US\_IUA_{tot}} + US\_Q_{CS}$$

US_QInh_{CSO}	= discharge on heavy rainfall day, in m³/yr
$US\_Inh_{connWandSS}$	= inhabitants connected to sewer systems and WWTP, in thousands
US_IUA_{tot}	= total sealed urban area of the analytical unit, in km²
US_SRT_{eff}	= effective number of days of heavy rainfall events, in d/yr
US_A_{CS}	= sealed urban area connected to combined sewer systems, in km²
US_Q_{CS}	= area specific runoff from sealed urban areas connected to combined sewer systems, in m³/yr
$CUS14-16$	= model constants

The inhabitant-specific daily waste water rate is assumed to be 130 l/(inhabitants·d). The amount of water derived from the effective overflow events is applied in the Eq. 36 considering the existing storage volume and the optimum storage volume, to calculate the volume which can be filled at total working load:

$$US\_Q_{CSOV} = US\_SRT_{eff} \cdot US\_A_{CS} \cdot \frac{CD\_CSOV}{100} \cdot \frac{23.3 \cdot 100}{1000}$$ Eq. 36

US_Q_{CSOV} = water volume at total working load, in m³/yr

US_SRT_{eff} = effective number of days of heavy rainfall events, in d/yr

US_A_{CS} = area connected to combined sewer systems, in km²

CD_CSOV = storage volume of the combined sewer system, in %

Thus the total discharge of overflow events entering surface waters can be calculated according to Eq. 37.

$$US\_\mathrm{Q}tot_{\mathrm{CSO}} = US\_QInh_{CSO} + US\_Q_{CSOV}$$ Eq. 37

$US\_\mathrm{Q}tot_{\mathrm{CSO}}$ = area specific discharge during overflow events, in m³/yr

US_QInh_{CSO} = realized discharge on heavy rainfall days, in m³/yr

US_Q_{CSOV} = water volume at total working load, in m³/yr

The above assumptions allow calculation of the nitrogen concentration in combined sewer system at overflow events according to Eq. 38:

$$US\_TNC_{CSO} = \frac{((term1 + term2) \cdot term3)}{US\_Qtot_{CSO}} \qquad \text{Eq. 38}$$

$$term1 = \frac{PD\_Inh_{tot}}{1000} \cdot \frac{US\_Inh_{connWandSS}}{US\_Inh} \cdot CUS11 \cdot US\_SRT_{eff}$$

$$term2 = CUS15 \cdot \frac{0.8}{100} \cdot US\_IAU_{tot} \cdot \frac{\frac{100}{365}}{1000} \cdot CUS11 \cdot \frac{US\_STR_{eff}}{365} \cdot \frac{CUS16}{24}$$

$$term3 = \frac{US\_A_{CS}}{US\_IUA_{tot}} + \frac{((PD\_NH_{yUS} + PD\_NO_{xUS}) \cdot US\_imp\_a_{Q\_ratio} + CUS13 \cdot 100) \cdot US\_A_{CS}}{365}$$

US_TNC_{CSO}	= nitrogen concentration at overflow conditions in combined sewer systems, in mg/l
PD_Inh_{tot}	= number of connected inhabitants
$US\_Inh_{connWandSS}$	= inhabitants connected to sewer systems and WWTP, in thousands
US_Inh	= connected inhabitants, in thousands
US_SRT_{eff}	= effective number of days of heavy rainfall events, in d/yr
US_IUA_{tot}	= total sealed area in the analytical unit, in km²
US_A_{CS}	= sealed urban area connected to combined sewer systems, in km²
PD_NH_{yUS}	= atmospheric NH_y deposition, in mg/m²
PD_NO_{xUS}	= atmospheric NO_x deposition, in mg/m²
US_Qtot_{CSO}	= discharge during overflow events, in m³/yr
$US\_imp\_a_{Q\_ratio}$	= runoff coefficient, in %
$CUS11;13;15-16$	= model constants

For the calculation of the phosphorus concentration in combined sewer systems at overflow events, phosphorus emissions from commercial waste waters are also considered (Eq. 39).

$$US\_TPC_{CSO} = \frac{((term1 + term2) \cdot term3)}{US\_Qtot_{CSO}} \qquad \text{Eq. 39}$$

$$term1 = US\_Inh_{connWandSS} \cdot CD\_P_{Inh} \cdot US\_SRT_{eff}$$

$$term2 = CUS15 \cdot \frac{0.8}{100} \cdot US\_IAU_{tot} \cdot \frac{100 \cdot 365 \cdot 86400}{1000000} \cdot CUS9 \cdot \frac{US\_STR_{eff}}{365} \cdot \frac{CUS16}{24}$$

$$term3 = \frac{US\_A_{CS}}{US\_IUA_{tot}} + (CUS10 \cdot US\_A_{CS} \cdot 100)$$

US_TPC_{CSO}	= phosphorus concentration at overflow conditions in combined sewer systems, in mg/l
$US\_Inh_{connWandSS}$	= inhabitants connected to sewer systems and WWTP, in thousands
US_Inh	= connected inhabitants, in thousands
CD_P_{Inh}	= inhabitant specific phosphorus emissions, in g/(inhabitants·d)
US_SRT_{eff}	= effective number of days of heavy rainfall events, in d/yr
US_IUA_{tot}	= total sealed urban area in the analytical unit, in km²
US_A_{CS}	= sealed urban area connected to combined sewer systems, in km²
$US\_\mathrm{Q}tot_{\mathrm{CSO}}$	= discharge during overflow events, in m³/yr
$CUS9-10;15-16$	= model constants

The influence of external water emissions into the system is excluded, as it is assumed that the sewer systems act as donator for water during heavy rainfall events. Data about nutrients are based on statistical data for administrative units.

Finally the nutrient emissions via combined sewer systems at overflow events can be calculated by (Eq. 40):

$$US\_N,P_{CS} = \frac{US\_TPC,TNC_{CSO} \cdot US\_Q_{CS}}{1000000} \quad \text{Eq. 40}$$

US_N,P_{CS} = nutrient emission via combined sewer systems in case of release, in t/yr

US_TPC,TNC_{CSO} = nutrient concentration in combined sewer systems at overflow events, in mg/l

US_Q_{CS} = area specific runoff from sealed urban areas connected to combined sewer systems, in m³/yr

Nutrient emissions via separate sewer systems

Nutrient emissions from process water and waste water are expected to be calculated in the pathway point sources by the WWTP inventory. Nutrient emissions via separate sewer systems are then calculated by area specific emissions. According to BROMBACH & MICHELBACH (1998), the area specific phosphorus emission from atmospheric deposition, litter and excrements amounts to 2.5 kg/(ha·yr). As the atmospheric deposition of nitrogen is so high (MALMQUIST, 1982) this value is calculated separately to the emission from litter and excrements for nitrogen as can be seen in the following equation. MONERIS uses an area specific nitrogen emission (litter and excrements) of 4 kg/(ha·yr) (Eq. 41).

$$US\_TNC_{SS} = term1 \cdot term2 \qquad \text{Eq. 41}$$

$$term1 = \left(\frac{\left(PD\_NH_{yUS} + \mathrm{PD\_NO_{xUS}}\right)}{N_{yr}} + \frac{\mathrm{CUS13} \cdot 100}{\left(N_{yr} \cdot US\_imp\_a_{Q\_ratio}\right)} \right)$$

$$term2 = \left(1 - CUS32 \cdot \frac{US\_RKB}{100}\right) \cdot \left(1 - CUS33 \cdot \frac{US\_RBF}{100}\right)$$

US_TNC_{SS}	= nitrogen concentration in separate sewer systems after retention, in mg/l
PD_NH_{yUS}	= atmospheric NH_y deposition, in mg/m²
PD_NO_{xUS}	= atmospheric NO_x deposition, in mg/m²
N_{yr}	= annual precipitation, in mm/yr
$US\_imp\_a_{Q\_ratio}$	= runoff coefficient, in %
US_RKB	= portion of retention clarifier basins on separate sewer system, in %
US_RBF	= portion of retention soil filter on separate sewer system, in %
$CUS13;32-33$	= model constants

The nutrient concentrations in separate sewer systems depend on the retention processes in the retention ponds and in retention soil filters. In MONERIS, there is an assumption of retention of 35 % for TP and 0 % for TN in retention clarifier basins, and of 35 % for TP and 45 % in retention soil filters.

Consequently, the nutrient emission via separate sewer systems is calculated by Eq. 42:

$$US\_N,P_{SS} = \frac{US\_TPC,TNC_{SS} \cdot US\_Q_{SS\_N}}{1000000} \qquad \text{Eq. 42}$$

US_N,P_{SS}	= nutrient emission via separate sewer systems by precipitation, in t/yr
US_TPC,TNC_{SS}	= nutrient concentration in separate sewer systems after retention, in mg/l
$US\_Q_{SS\_N}$	= discharge from precipitation in separate sewer systems, in m³/yr

Nutrient emission from sealed urban areas and inhabitants that are connected to sewer systems or decentralised water treatment plants (DCTP) with sewer systems, but not to municipal WWTP

Emissions from sealed urban areas, which are connected to sewer systems or DCTP with sewer systems, but not to municipal WWTPs, are calculated using the discharge from sealed urban areas and the nutrient concentrations in it, as well as the inhabitant specific emission per inhabitant and day (Eq. 43).

$$US\_TN_{onlySS\_impA} = PD\_NH_{yUS} + PD\_NO_{xUS} + CUS13 \cdot \frac{\frac{100}{US\_imp\_a_{Q\_ratio}}}{1000} \cdot US\_A_{onlySS} \qquad \text{Eq. 43}$$

$US\_TN_{onlySS\_impA}$	= nitrogen emission from areas not connected to WWTP, in t/yr
PD_NH_{yUS}	= atmospheric NH_y deposition, in mg/m²
PD_NO_{xUS}	= atmospheric NO_x deposition, in mg/m²
$US\_imp\_a_{Q\_ratio}$	= runoff coefficient, in %
US_A_{onlySS}	= sealed urban area connected to sewer systems only, in km²

The inhabitants connected to DCTP can either be connected to DCTP according to DIN1 or DIN2 or even to virtual WWTP. Depending on the technical status different amounts of nutrients can reach surface waters. Thus emissions from these inhabitants are calculated as the product of the number of inhabitants, the retention capacity and the inhabitant specific daily nutrient inputs.

Information on dissolved nitrogen emissions from inhabitants vary between 9 and 12 g/(Inhabitant·d) (LINDTNER & ZESSNER, 2003; WERNER ET AL., 1991; ATV 1997), and can be adapted via constants in MONERIS. Dissolved phosphorus emissions vary from country to country, since the usage of phosphates in dishwasher and detergents is different, thus a variety of country specific values for dissolved phosphorus emissions from humans and detergents are used in MONERIS.

Referring to the technical status of the DCTP following retention capacities are applied:

- 10 % for nitrogen and 7 % for phosphorus, following technical standards, quality specification and terms of supply (TGL) or Deutsches Institut für Normung DIN 4261-01 and DIN 4261-03 (in the following DIN 1)
- 15 % for nitrogen and 13 % for phosphorus (if DIN 4261-02 is applied)

According to DIN 1, DCTP are not equipped to aerate waste water, whereas according to DIN2, DCTP are equipped to aerate waste water.

For areas that are connected to sewer systems only but not to WWTP, the nutrient emissions are calculated as the sum of emissions from inhabitants and streets (Eq. 44):

$$US\_TN,TP_{onlySS} = US\_TN,TP_{onlySS\_impA} + US\_TN,TP_{vWWTP} + US\_TN,TP_{DCTPDIN1\_DIN2} \quad \text{Eq. 44}$$

US_TN,TP_{onlySS} = total emission of inhabitants and areas connected to sewer systems only, in t/yr

US_TN,TP_{onlySS_impA} = nutrient emissions from areas connected to sewer systems only, in t/yr

US_TN,TP_{vWWTP} = nutrient emissions of inhabitants connected to virtual WWTP, in t/yr

$US\_TN,TP_{DCTP\_DIN1\_DIN2}$ = nutrient emissions of inhabitants connected to different DCTPs , in t/yr

Nutrient emissions from inhabitants not connected to sewer systems

For the calculation of nutrient emissions from urban areas that are neither connected to WWTP nor to sewer systems, is assumed that a certain emission derives from streets and another from human faeces. These inhabitants can either be connected to DCTP, without connection to communal sewer systems or to septic tanks. In both cases it is assumed that particulate nutrients are retained, whereas dissolved nutrients reach the groundwater where certain retention takes place during the passage through the soil.

The following assumptions are made:

- Retention in the groundwater is calculated as for DCTP with sewer systems. For groundwater retention in the soil, values of 50 % for consolidated and 90 % for unconsolidated rock are assumed.
- 10 % of nutrient emissions via septic tanks reach surface waters, 90 % reach WWTPs.
- Nutrient emissions from industrial diffuse/indirect dischargers do not take place

Eq. 45 shows the calculation of the emissions from unconnected sealed urban areas for nitrogen. The atmospheric deposition is considered separately for nitrogen, as the values are estimated to be very high whereas for phosphorus one constant value is applied for the emission from the streets (2.5 kg/(ha·yr) for atmospheric deposition, litter and excrements).

$$US\_TN_{notconn} = \frac{\left(\frac{PD\_NH_{yUS} + PD\_NO_{xUS} + CUS13 \cdot 100}{US\_impA_{Q\_ratio}}\right) \cdot \frac{US\_A_{notconn}}{100}}{1000} \qquad \text{Eq. 45}$$

$US\_TN_{notconn}$	= nitrogen emissions via sealed urban areas from inhabitants not connected to public sewer systems , in t/yr
PD_NH_{yUS}	= atmospheric NH_y deposition, in mg/m²
PD_NO_{xUS}	= atmospheric NO_x deposition, in mg/m²
$US\_impA_{Q\_ratio}$	= runoff coefficient, in %
$US\_A_{notconn}$	= sealed urban area, connected to sewer systems only, in km²

4.2.2.8 Retention in surface waters

In surface waters, retention is an important element of the nutrient cycles. Retention is defined as the sum of all long term and short term losses.

The calculation is subject to following conditions:

- It is expected that nutrient emissions of the analytical unit reach the tributaries (TRIB) uniformly distributed, and are there subject to retention (the load of the tributaries).
- If the examined analytical unit lies within the total catchment (not a headwater region), the load coming from all upstream analytical units is subject to the retention in the main river.
- Nutrient emission from point sources that enter the main river directly, are not subject to retention in the examined analytical unit, neither in the tributaries, nor in the main river. These nutrient emissions are only considered for retention calculations for the main river downstream of the examined analytical unit.
- An additional water surface (such as a lake) at the outlet of an analytical unit leads to an additionally calculated retention for the load that reaches the analytical unit outlet, including also these nutrient emissions that derive from point sources discharging directly into the main river.

The nitrogen retention is calculated using the THL-approach according to VENOHR (2006), which considers temperature and hydraulic load (quotient of annual discharge and the water surface area). For the calculation of water surface areas, see section 4.1.4. Estimation of nitrogen retention is based on the assumption that for dissolved organic nitrogen (DON) only a negligible retention occurs.

The phosphorus retention is calculated using the approaches developed by BEHRENDT & OPITZ (2000) and BEHRENDT ET AL. (2000), which considers hydraulic load (HL) and the runoff rate (q). In tributaries, the phosphorus retention is calculated according to both approaches (HL and q), and finally the results are averaged. In main rivers, retention is calculated depending on the hydraulic load only, because the runoff rate is not suitable for the calculation (VENOHR, 2006).

4.2.3 Observed nutrient loads in rivers

For the validation of the model results, data on observed loads are needed for comparison. Thus these loads are necessary input data for the model.

For the calculation of nutrient loads, the data from the available observation periods of the analytical unit are necessary. KELLER ET AL. (1997) and ZWEYNERT ET AL. (2004) showed that different approaches led to different results. Especially for small catchments over- and underestimations occur. Monitoring intervals are of decisive importance: the uncertainties of calculated loads increase with decreasing monitoring frequency (for nitrogen monitored at a frequency less than 14 days there is an uncertainty of minimal 20-30%).

The OSPAR method (OSLO PARIS COMMISSION, 1996) lead to the most reliable results for observed nutrient loads (LITTLEWOOD, 1995), therefore this method is applied for the calculation of the mean annual nutrient load (Eq. 46).

$$Ly_{Lobs} = \frac{Q_d}{Q_{Meas}} \cdot \left(\frac{1}{n} \sum_{i=1}^{n} C_i \cdot Q_i \cdot U_f \right) \qquad \text{Eq. 46}$$

Ly_{Lobs}	= annual hydraulic load, in t/yr
Q_d	= arithmetic mean of the daily discharge, in m³/s
Q_{Meas}	= arithmetic mean of all daily discharges with measurements of concentration, in m³/s
C_i	= concentration, in mg/l
Q_i	= daily discharge, in m³/s
U_f	= correction factor for different locations of discharge and water quality monitoring locations within the same catchment, dimensionless
n	= number of data with measurement within the observation period, dimensionless

5 Model structure of MONERIS

MONERIS consists of following files and folders:

- MONERIS_2.14.1vba.xls

This file comprises the source code, the user surface, and pre-prepared sheets with which to visualize and evaluate the results of MONERIS.

- MONERIS_ DB_2.14.1.mdb

MONERIS_DB_2.14.1.mdb is a password protected database, in which input data, project meta-information, calculation setups and results are saved. The password is valid for the database, and can only be changed by the modeller or modifier using Excel. The password must be set in Excel before work with the database can begin.

- Constants.mdb

Constants.mdb is a password protected database, containing all model specific parameters and constants. The password differs from that for MONERIS_DB_2.14.1.mdb. The constants.mdb can only be opened and edited by the developers from IGB and by certain users after instruction by the IGB.

- MONERIS_Libraries

This folder contains the program-libraries needed for the application of MONERIS. The folder has to be deposited in the same directory as the Excel file MONERIS 2.14.1vba.

5.1 Structure of the MONERIS file

For work with MONERIS, some sheets are pre-prepared in Excel (Table 8). The red category contains information on settings and first results, and the blue category contains the modelling data.

Table 8: The Excel workspace structure of MONERIS.

Category	Sheet	Description
Introduction	Start	Basic instructions and visualisation of user surface
Setups	Pwd	Password of modeller and modifier status
	Settings	Model setups
	Temp	Sheet to save temporarily data, is overwritten by MONERIS
	Figures	Visualization of results
	Reference	Results of reference period
	Aggregated	Compilation of results for visualisation on user's surface
Modelled data	Data	General data for analytical units
	Retention	Calculation of water internal retention, especially accumulative retention
	Water balance	Compilation of MONERIS water balance-results
	Emissions net	Compilation of input results
	Emissions total	Summation of „emission net“ results, according to the topology of the area
	Target concentration	Target concentration, based on the scenario-results
	Scenario results	Results of scenario calculation for selected criteria, divided into different discharge conditions (long term, wet year and dry year)
	User specified	User defined compilation of results that are not overwritten by MONERIS. Compilation also possible in Viewer-Log-in.

5.2 Data structure of MONERIS

All input data and model results are administrated in an Access database. The database contains seven sheets:

- Basicinfo

The basic information table contains information on the analytical units that is taken as constant (for example catchment areas, land use, soil data).

- Periodical Data

The periodical data table contains time series with annual data for analytical units. These time series have to be prepared and introduced without gaps in the data.

If there is no inventory of individual WWTP available, total inputs by WWTP and direct industrial discharges can be used instead. This Remaining_WWTP table also offers the possibility to account for inputs by open pit mines and other types of land use.

- Monitoring_Data

The monitoring-data-table consists of annual means of measured discharges and temperatures as well as of observed loads (TN, DIN, and TP).

- Individual_WWTP

This table comprises the inventory of individual WWTP and direct industrial dischargers which are allocated to a certain analytical unit. The inventory should be assembled for one year, or at least a narrow period. Temporal changes of the discharge from WWTP can be considered by correction factors (WWTP_P_history, WWTP_N_history, Industry_P_history, Industry_N_history) in the table Periodical Data.

- Country Data

This table contains time series, based on country levels, such as technical status and storage volume of combined sewer systems, nitrogen surplus, phosphorus accumulation and inhabitant specific phosphorus output.

- Project-Meta-Information

This table stores all superordinated information of one project. One project summarizes all the input data belonging to one river system. Within one project, single years and variants of input data must be based on the same analytical units and area topology.

The standard version of input data has to be defined as the variant “standard”. Other variants of a project consist of different data sources, for example outlet discharges calculated with different models. Variants of input data can be stored as separate basic info and periodical data tables. If a certain variant is only available as basic info or periodical data, the “standard” variant in each of the other tables is used.

5.2.1 Contents of the basic info table

For presenting the contents of the "basic info table", in this section of the manual, the table is divided into sections that contain distinct types of information.

Description of the catchments

The category "description of catchments" comprises all descriptive and labelling data, and information for further aggregation of analytical units at different aggregation levels (Table 9).

Table 9: Description of the catchments.

Category	Sub-category	Description	Field name
Description catchment	ID	ID number of an analytical unit	ID
	ID_GIS *	Unique ID number given by GIS of an analytical unit	ID_GIS
	Country	Country	BI_Country
	State	Federal state	BI_State
	Coordination area	Superordinating area of the sub basin to which the analytical unit belongs	BI_WA
	Sea	Sea that the river basin district dewaters into	BI_Sea
	Description*	Allocation of the analytical unit to an EU- or No-EU-country	BI_des
	Analytical Unit (AU)	Smallest model unit	BI_AU
	Sub unit*	Share of an administrative unit (e.g. federal state) of a certain catchment	BI_SU
	Sub basin*	Summary of bigger sections of a river system or tributaries	BI_SB
	River basin *	Area, of which the total discharge enters at one single outlet into a sea	BI_RB
	River Basin District	River system with administratively appendant ground- and coastal waters.	BI_RBD
	Outlet	Outlet of a river system	BI_OL_ref

(* optional subcategories)

Six of the sub-categories, namely ID_GIS, BI_des, BI_SU, BI_SB, and BI_RB, are optional and not necessary for the calculation of MONERIS. However, they can be helpful in selection of certain analytical units (or aggregation levels) and visualization of the results.

BI_RBD and BI_OL_ref are necessary for calculation of the accumulative retention at the outlet of a river system. Additionally BI_OL_ref identifies an area as the outlet of a river system. The accumulative retention is determined by the topology of the area, and its formula is defined in section 4.1.1.

Catchment size and flow net equation (FNE)

The category ”catchment size and flow net equation” contains information on the area topology and gauging stations (Table 10).

Table 10: Catchment size and area topology.

Category	Description	Field name	Unit
Size of analytical unit	Size of analytical unit	BI_AU_A	km²
Quality gauging station *	Name of the monitoring station for quality parameters	BI_MS	-
	Official information on catchment size of the monitoring station for quality parameters	BI_MONIcatch_A	km²
Area topology	ID of the downstream analytical unit, into which the analytical unit dewaters	TO_ID	-
	ID of the analytical unit, into which the defined analytical unit dewaters via additional channels or connecting passages	Splitt_ID	-

(* optional information)

Atmospheric deposition

The category “atmospheric deposition” covers the long term mean concentrations (in mg/m^2) of NO_x and NH_y deposition (Table 11).

Table 11: Atmospheric deposition.

Category	Sub-category	Specification	Field name	Unit
Atmospheric deposition	Atmospheric deposition of NHy	Long term mean	BI_AD_nhxlt	mg/m²
	Atmospheric deposition of NOx	Long term mean	BI_AD_noylt	mg/m²

Further information about atmospheric deposition can be found in section 4.2.2.1.

Precipitation and evapotranspiration

The category “precipitation and evapotranspiration” includes long term mean values for precipitation and evapotranspiration (Table 12).

Table 12: Precipitation and evapotranspiration.

Category	Description	Specification	Field name	Unit
Precipitation	Sum of precipitation per year	Long term mean	BI_PREC_yrlt	mm/yr
	Sum of precipitation in summer	Long term mean	BI_PREC_slt	mm/yr
Evapotranspiration	Sum of precipitation in winter	Long term mean	BI_EVAPO_lt	mm/yr

Land use and tile drainages

The category “land use and tile drainages” contains information on the size of areas under different uses. Arable land is divided into classes with different slopes (Table 13).

Table 13: Land use and tile drainages.

Category	Description	Specification	Field name	unit
Land use classes	Urban area		BI_LU_urb	km²
	Arable land with a certain slope class of:	< 1 %	BI_AL_1	km²
		1 - 2 %	BI_AL_1_2	km²
		2 - 4 %	BI_AL_2_4	km²
		4 - 8 %	BI_AL_4_8	km²
		> 8 %	BI_AL_8	km²
	Grassland		BI_GL	km²
	Naturally covered area (forest, shrubs)		BI_NATCOV	km²
	Water surface area	According to land use map	BI_WSA	km²
	Open pit mine area		BI_OPM	km²
	Open areas		BI_OA	km²
	Wetlands		BI_WL	km²
	Remaining areas		BI_REM	km²
	Areas with erosion potential		BI_POTERO	km²
Tile drainages	Share of tile drained areas (based on arable and agricultural land)		BI_TD	%

Further information on land use and tile drainage data can be found in section 4.2.2.5.

Information on elevation and slopes

The category “elevation and slopes” comprises the mean elevation and mean slope of each analytical unit. Calculations done to date are based on 1 km GRIDs (Table 14).

Table 14: Elevation and slopes.

Category	Description	Specification	Field name	Unit
Elevation	Mean elevation of analytical unit	Based on 1km GRID*	BI_ELEVA	m
Slope	Mean slope of analytical unit	Based on 1km GRID*	BI_SLOPE_1000	%
		Based on 100m GRID*	BI_SLOPE_100	%

By default, GIS exports the slope in degree. Please make sure that basic info data is shown in percent.

Soil

The category “soil“ describes the areas of each analytical unit, divided into classes of soils by the dominated soil texture (Table 15).

Table 15: Soil.

Category	Description	Specification	Field name	Unit
Soil types	Sand dominated	Sand areas	BI_SO_S	km²
	Clay dominated	Clay areas	BI_SO_C	km²
	Loam dominated	Loam areas	BI_SO_L	km²
	Fen dominated	Fen areas	BI_SO_F	km²
	Bog dominated	Bog areas	BI_SO_B	km²
	Silt dominated	Silt areas	BI_SO_SI	km²
	nitrogen content in topsoil	Share of nitrogen in topsoil (amount)	BI_SO_Ncont	%
	Clay content in topsoil	Share of clay in topsoil (amount)	BI_SO_Ccont	%

Soil loss

The category “soil loss” contains information on the soil loss of each analytical unit, depending on land use and on slope classes for the arable land (Table 16).

Table 16: Soil loss.

Category	Sub-category	Description	Specification	Field name	Unit
Soil loss	Arable land	Soil loss of arable land with slope classes of:	< 1%	BI_SL_AL1	t/(ha·yr)
			1-2 %	BI_SL_AL1_2	t/(ha·yr)
			2-4 %	BI_SL_AL2_4	t/(ha·yr)
			4-8 %	BI_SL_AL4_8	t/(ha·yr)
			>8 %	BI_SL_AL8	t/(ha·yr)
	Grassland	Soil loss from grassland		BI_SL_GL	t/(ha·yr)
	Naturally covered areas	Soil loss from naturally covered areas		BI_SL_NATCOV	t/(ha·yr)
	Mean soil loss of all areas	Soil loss from all areas		BI_SL_mean	t/(ha·yr)

For further information on soil loss see section 4.2.2.4.

C-factor, phosphorus accumulation and nitrogen surplus

This category covers input data on the C-factor (cover and management factor from USLE), phosphorus accumulation and nitrogen surplus. The reference year can only be set by the modeller or modifier (Table 17).

Table 17: C-factor, phosphorus accumulation and nitrogen surplus.

Category	Description	Field name	Unit
C-factor*	C-factor for erosion calculation following USLE	BI_C	-
Phosphorus accumulation	Phosphorus accumulation in the soil of a reference year	BI_Pacc	kg/(ha·yr)
Nitrogen surplus*	Nitrogen surplus of a reference year	N_surpl	kg/(ha·yr)

Hydrogeology and groundwater

The category “hydrogeology and groundwater“ contains the area of each analytical unit divided into different hydro geological rock types, and the mean groundwater residence time (Table 18).

Table 18: Hydrogeology and groundwater.

Category	Description	Specification	Field name	Unit
Hydrogeology	Unconsolidated rock	Shallow groundwater	BI_HYG_uncs	km²
		Deep groundwater	BI_HYG_uncd	km²
	Consolidated rock	Permeable	BI_HYG_conhp	km²
		Impermeable	BI_HYG_conimp	km²
Groundwater	Mean residence time		BI_GW_rest	yr

For further information on hydrogeology see section 4.2.2.6.

River length and water surface area of lakes

This category comprises information on “river length and water surface areas of lakes” in each analytical unit, for the main rivers and tributaries (Table 19).

Table 19: River length and water surface area of lakes.

Category	Description	Specification	Field name	Unit
River length	Main river	Length of river sections defined as main river	BI_fl_mr	km
	Tributaries	Length of river sections defined as tributaries	BI_fl_trib	km
Water surface area of lakes	Main river	Water surface area of lakes for main rivers (also lakes at the outlet)	BI_Lakes_mrA	km²
	Tributaries	Water surface area of lakes for tributaries	BI_Lakes_tribA	km²
	Water surface area at analytical unit outlet (main river)	Water surface area of shallow lakes at the outlet of an analytical unit	BI_WSA_mrol_f	km²
		Water surface area of deep lakes at the outlet of an analytical unit	BI_WSA_mrol_t	km²
		Water surface area of reservoirs at the outlet of an analytical unit	BI_WSA_mrol_res	km²

5.2.2 Contents of the periodical data table

The “periodical data table” contains mean annual values for each analytical unit (Table 20), describing for example atmospheric deposition rates on different types of land, observed discharge and loads, and sewer systems. In addition to data for single years, data is also provided for long term means (‘long term’, year number 7777), as well as for dry and wet years (‘dry year’ year number 8888, ‘wet year’ year number 9999). The ID of the analytical unit has to be the same as the same from the basic info table.

Table 20: Data of the analytical unit.

Category	Sub-category	Description	Field name	Unit
Atmospheric deposition and precipitation	Atmospheric deposition of NHy	Agricultural areas	atmo_dep_NHy_AL	mg/m²
		Grassland	atmo_dep_NHy_GL	mg/m²
		Water surface areas	atmo_dep_NHy_WSA	mg/m²
		Naturally covered areas	atmo_dep_NHy_NC	mg/m²
		Urban areas	atmo_dep_NHy_US	mg/m²
		Open areas	atmo_dep_NHy_OA	mg/m²
	Atmospheric deposition of NOx	Agricultural areas	atmo_dep_NOx_AL	mg/m²
		Grassland	atmo_dep_NOx_GL	mg/m²
		Water surface areas	atmo_dep_NOx_WSA	mg/m²
		Naturally covered areas	atmo_dep_NOx_NC	mg/m²
		Urban areas	atmo_dep_NOx_US	mg/m²
		Open areas	atmo_dep_NOx_OA	mg/m²
		Atmospheric deposition of TP	atmo_dep_TP	mg/m²
		Annual precipitation	preci_annual	mm/a
		Summer precipitation	preci_summer	mm/a
	Calculated runoff of the analytical unit		calc_runoff_net	m³/s
Observed discharges and loads	Observed runoff		obs_runoff	m³/s
	Observed DIN-load		obs_DIN_load	t/yr
	Observed TN-load		obs_TN_load	t/yr
	Observed TP-load		obs_TP_load	t/yr
	Water temperature		water_temp	°C
	Splitting factor		splitting_factor	-
	Total number of inhabitants		inhabitants_total	-
	Number of connected inhabitants		connected_inhabitants	-
	Number of inhabitants connected to sewer systems and WWTP		inhab_conn_to_sewer_wwtp	-

Category	Sub-category	Description	Field name	Unit
Sewer systems and connected inhabitants	Number of inhabitants connected to septic tanks		inhab_septic_tanks	-
	Number of inhabitants connected to small WWTP but not to sewer systems		inhab_kka_no_sewer systems	-
	Storage of combined sewer systems		CSO_storage	%
	WWTP factor for phosphorus	Factor to calculate changes of WWTP phosphorus-discharges according to a reference year	WWTP_P_history	-
	WWTP factor for nitrogen	Factor to calculate changes of WWTP nitrogen-discharges according to a reference year	WWTP_N_history	-
	Nitrogen inputs from small WWTP	Nitrogen inputs from small WWTP, not defined as individual WWTP	WWTP_N_remain	t/yr
	Phosphorus inputs from small WWTP	Phosphorus inputs from small WWTP, not defined as individual WWTP	WWTP_P_remain	t/yr
	Phosphorus loads from industrial direct dischargers	Sum of phosphorus loads from industrial direct discharger	Industry_P_history	t/yr
	Nitrogen loads from industrial direct dischargers	Sum of nitrogen loads from industrial direct discharger	Industry_N_history	t/yr
	Proportion of combined sewer length	Proportion if combined sewer length regarding to the total sewer length	prop_com_sewer systems	%
	Proportion of conservation tillage	Proportion of arable land with conservation tillage	prop_cons_tillage	%

5.2.3 Contents of the individual WWTP table

Often statistical information is incomplete. Therefore the original value and the finally used value (which may have been completed or corrected) are stated in the "individual WWTP table" (Table 21).

Table 21: Structure of the individual WWTP table.

Category	Description	Field name	Unit
ID	ID of analytical unit, in which the WWTP discharges	Catch_ID	
Original effluent	Original effluent of the WWTP	discharge_org	m^3/yr
Used effluent	Completed effluent of the WWTP	discharge_cur_comp	m^3/yr
Name of WWTP*	Name of the WWTP/location	WWTP_name	
Country name	Country name of the respective sub-basin	country_name	
Type of WWTP *		Type	
Inhabitant equivalent *	Inhabitant equivalent – original data	pop_eq_org	-
Inhabitant equivalent	Inhabitant equivalent – completed data	pop_eq_comp	-
Technical status of WWTP	Size class of WWTP	size_class	-
Treatment stage	Treatment stage 1	TS_1	-
	Treatment stage 2	TS_2	-
	Treatment stage 3 (nitrogen)	TS_3N	-
	Treatment stage 3 (phosphorus)	TS_3P	-
	Nitrogen short	TS_shortN	-
	Phosphorus short	TS_shortP	-
Original nitrogen load	Nitrogen load at WWTP outlet – original data	N_load_org	kg/yr
Original phosphorus load	Phosphorus load at WWTP outlet – original data	P_load_org	kg/yr
Used nitrogen load	Nitrogen load at WWTP outlet – completed data	N_load_comp	t/yr
Used phosphorus load	Phosphorus load at WWTP outlet– completed data	P_load_comp	t/yr
Original nitrogen concentration *	Nitrogen concentration at WWTP outlet – original data	N_conc_org	mg/l
Original phosphorus concentration *	Phosphorus concentration at WWTP outlet – original data	P_conc_org	mg/l
Used nitrogen concentration	Nitrogen concentration at WWTP outlet – completed data	N_conc_comp	mg/l
Used phosphorus concentration	Phosphorus concentration at WWTP outlet – completed data	P_conc_comp	mg/l

(*optional categories)

For further information on input data of the WWTP inventory see Annex A.

5.2.4 Contents of the country data table

In the “country data table”, the country specific data of multiple years for all calculated years of the project are administrated (Table 22). At present, the time sequences range from 1910 to 2025. Thus mean nitrogen surpluses during groundwater retention time can be calculated. For calculation of scenarios, a calculation year can be selected from the country data table. For all countries in the country data table, unique IDs and short names have to be defined, and then transferred into the country meta-table. The given short names are based on ISO 3166 standard.

Table 22: Country specific data.

Category	Description	Field name	Unit
Country specific data	C-factor for erosion calculation according to USLE	C_factor	-
	Phosphorus accumulation in the soil	P_accumulation	kg/(ha·yr)
	Nitrogen surplus in the soil	N_surplus	kg/(ha·yr)
	TP input per inhabitant and day according to country Data	TP_per_inhabitant	g/(E·d)
	TP input by detergents per in-habitants and day according to country data	TP_detergents_per_inhabitant	g/(E·d)
	Retention soil filter storage	RBF	%
	Rain reservoir	RKB_storage	%
	Portion of small WWTP ac-cording to DIN 2	Portion_KKA	%

5.3 The MONERIS user surface

5.3.1 Getting started

Excel setup to start MONERIS

To start MONERIS, the macro-editor of Excel has to be activated. In case the security setups have to be changed, in the tab “tools“, open the tab “options”. Change to the tab “security“ and click the button “macro-security”. In the tab “security-level” choose „medium“. After that, change to the tab „trusted publishers“ and activate the field „trust access to Visual Basic Project“. Then end with „okay“ and reopen MONERIS.

Access setup to start MONERIS

To start MONERIS, not only Microsoft Excel, but also Microsoft Access has to be installed.

Libraries used by MONERIS

MONERIS needs several libraries for accurate workflow. These libraries can be found in the folder MONERIS_LIBRARIES, included in the model folder MONERIS. The library folder has to be copied into the directory where MONERIS_2.14.1vba.xls is saved, before MONERIS can be started.

Starting MONERIS

To start MONERIS, open the excel file. Click on “MONERIS“ from the Excel toolbar, and choose “Start“ (see Fig. 13). The MONERIS-user surface opens.

Fig. 13: Starting MONERIS.

5.3.2 Working with the MONERIS user surface

The MONERIS user surface consists of three main surfaces (Fig. 14):

- Control area
- Operation area
- Main menu

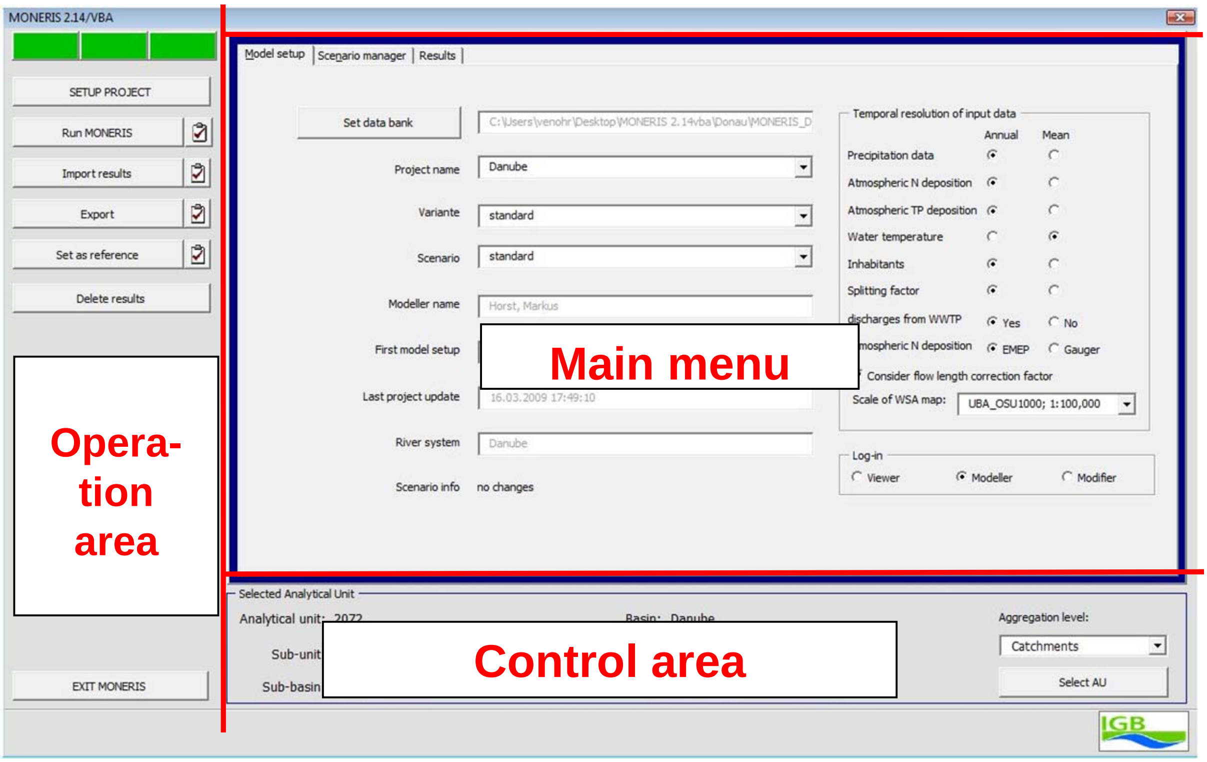


Fig. 14: Structure of the MONERIS user surface.

MONERIS operation area (Section 5.3.3)

The MONERIS model manages the setup of projects, calculation, import and export of results, and creation of a reference status.

MONERIS control area (Section 5.3.4)

Single analytical units or groups of analytical units can be selected by the control area. This selection applies to the allocation of measures of scenarios, and the presentation of results on the MONERIS user surface.

MONERIS main menu (Section 5.3.5)

The main menu consists of three tabs, dealing with basic setups for the model (model setup), options to change scenarios (scenario manager), and the records of the results (results).

- Model setup – to select the database, project, variant, and scenario, as well as the display of basic setups (Section 5.3.5.1)
- Scenario manager – to define packages of measures and create scenarios (Section 5.3.5.2)
- Results – to display the results that are imported from the database (Section 5.3.5.3)

5.3.3 MONERIS operation area

The operation area part of the main menu surface, allows adjustments for calculations and the presentation of results.

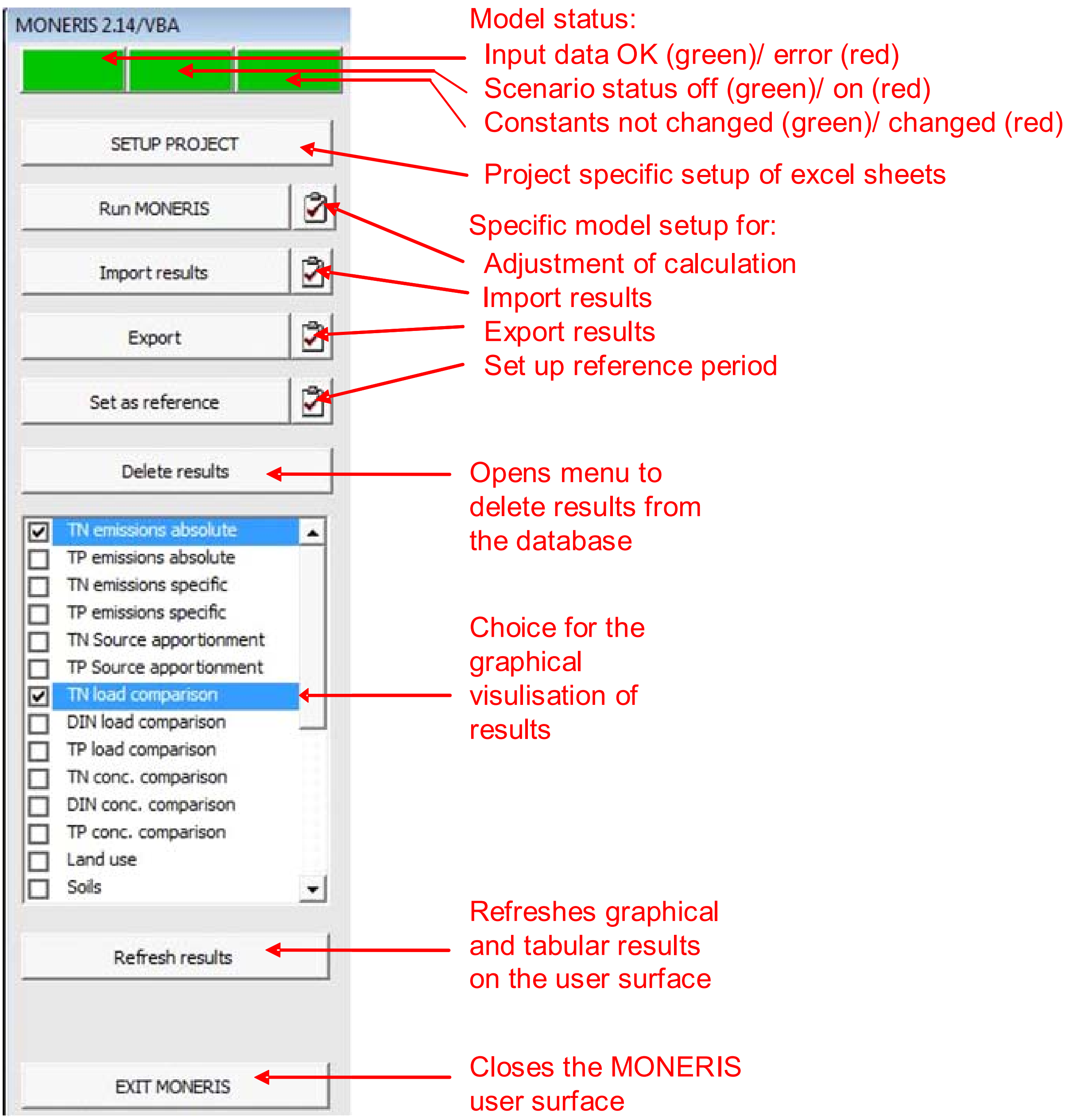


Fig. 15: Detailed “Operation area” part of the user surface.

At the top of the operation area surface, there are three coloured fields (Fig. 15). If they are green, there are no problems with input data (left field), scenarios are turned off (field in the middle), and no problems with constants or standard values in use (right field). If the fields are red, there are problems with the input data, scenarios are activated, or constants have been changed.

The functions of the different buttons are now presented:

SETUP PROJECT

By pressing “Setup Project”, Excel sheets for a new project are prepared in MONERIS_2.14.1vba. A project has to be established only once. In case of a change to another project it has to be established for the new project. Only modellers and modifiers can set up new projects.

RUN MONERIS

Pressing the “Run MONERIS” button initiates the process of reading data from the database undertaking the calculations, and writing results into the database (Fig. 16).

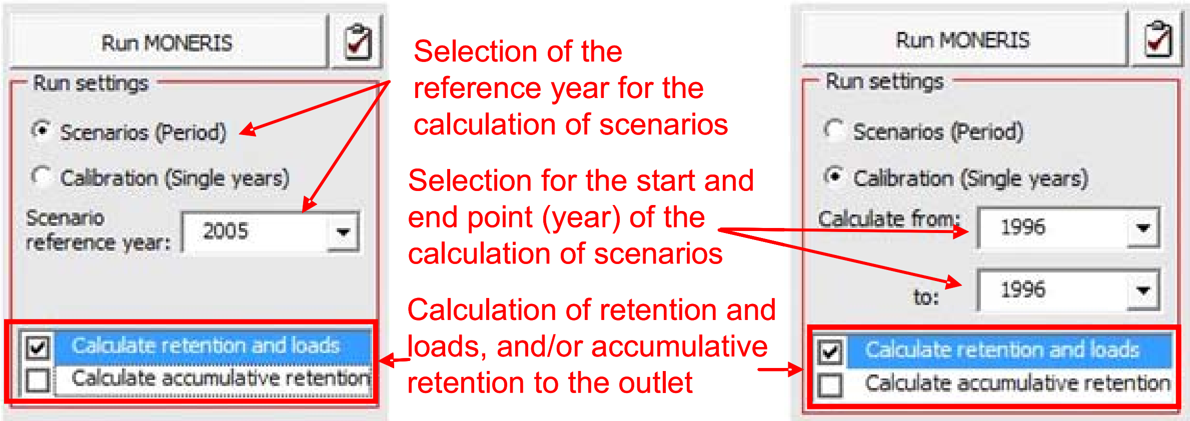


Fig. 16: Detailed information on the button “Run MONERIS”.

The menu allows the setup of the extent of calculations. The user can either choose between “Calibration” (Single years - (Fig. 16 right side)) or “Scenarios” (Period - (Fig. 16 left side)). The three scenarios (dry year - DY, long term – LT and wet year - WY) differ in the applied precipitation and discharge and thus represent different hydrologic conditions. Therefore, the periodical data table in the MONERIS database has to be filled by the user with the respective data. It is possible to simulate DY and WY, by choosing the driest and wettest years respectively from a time series. Alternatively, the complete values of a DY or WY chosen from a time series can be used. If the calculation runs for periods, all three types of hydrologic conditions are calculated automatically.

Regarding country wise input data, it is possible to choose via “Reference year” one year by which to investigate temporal changes of nutrient surpluses. This is necessary, when scenarios (period) are calculated. When 2015 is chosen as reference year, the development of the nitrogen surplus until 2015 is used for the calculation. This can be important for the calculation of the mean nitrogen surplus during the groundwater residence time. This “Reference year” which is set in the model setup is independent of the year which can be “Set as reference” (see detailed model setup user surface in Fig. 14) and is then applied for the comparison of model results for several years.

If single years are selected, start- and endpoint (years) of the calculation have to be determined. The list box only shows the years for which data is available in the MONERIS database. The calculation of single years does not consider any scenarios, although they might be selected in the user surface. Scenarios can only be calculated for hydrologic conditions (DY, LT, and WY).

Additionally, the retention and loads in surface waters, and the accumulative retention, can be calculated. With choosing each of these calculations, the time for processing increases. If information on inputs only, but not on retention and loads, are needed, these latter two fields should be deactivated.

In case there are already results in the database, corresponding to the selected setups, project, variant, scenario, year or period, these results will be deleted and new results are written into the database each time the program is run.

IMPORT RESULTS

This button starts the import of results from the database into MONERIS_2.14.1vba (Fig. 17), into the sheet “Import results”. If “Periods“ is chosen, there is the possibility to select out of three hydrologic conditions (LT, WY, DY). “Calibration” allows the import of data for single years.

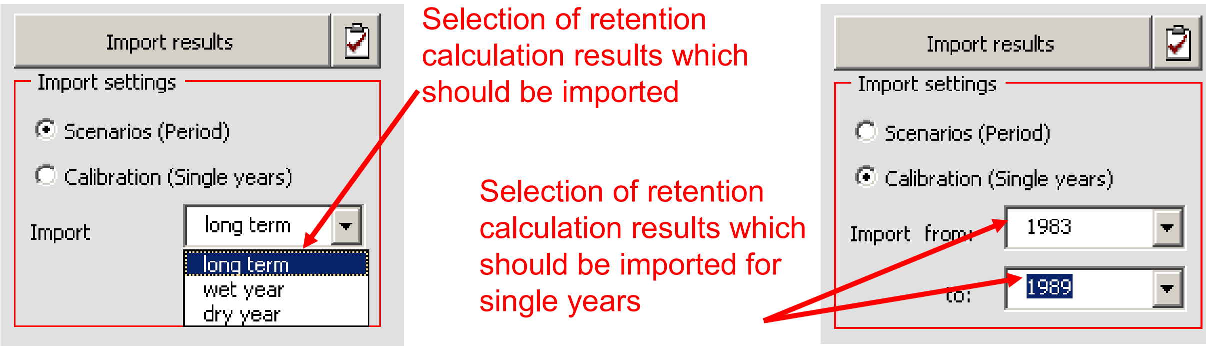


Fig. 17: Detailed information on the button “Import results”.

EXPORT RESULTS

The button “Export” results saves the results that were imported into another Excel file. Therefore you activate the results you want to export, and click “Export” (Fig. 18). Another window opens, and the directory and the name of the new Excel file can be chosen. Meta data is also exported along with the regular data.

Fig. 18: Detailed information on the button “Export” results.

“Input data” comprises a copy of the basic info table. Exporting “Scenario results” means the export of results (retention in main rivers and tributaries and loads - also share of loads at the outlet - divided into sources) under different hydrological conditions (DY, WY, LT). The structure of the three sheets is explained in the following table (Table 23).

Table 23: Structure of exported data for LT = long term; DY = dry year; WY = wet year; the components of the nutrient balance are specified in the column description, which is not part of the exported table.

Component of nutrient balance	Description	Field name	Time frame	Unit
NITROGEN-SOURCES	total nitrogen	total N	LT, DY, WY	t/a
	Via background conditions	Background	LT, DY, WY	t/a
	Via urban systems	urban systems	LT, DY, WY	t/a
	via total agriculture	N-Agricult total	LT, DY, WY	t/a
	via different fertilizers	N-Agricult_fertilizer + manure	LT, DY, WY	t/a
	via NHy on agricultural areas	NHy-Agriculture	LT, DY, WY	t/a
	via NOx on agricultural areas	NOx-Agriculture	LT, DY, WY	t/a
	via other sources total	other sources total	LT, DY, WY	t/a
	via NHy from other sources	NHy other sources	LT, DY, WY	t/a
	via NOx from other sources	NOx other sources	LT, DY, WY	t/a
	Organic nitrogen in groundwater	organic in GW	LT, DY, WY	t/a
	Via point sources and urban systems directly into the main river	PS+US in MR	LT, DY, WY	t/a
DIN RETENTION	In tributaries	TRIB	LT, DY, WY	-
	In main rivers	MR	LT, DY, WY	-
	In shallow lakes at main rivers at the outlet	MR_SL_OL	LT, DY, WY	-
	In deep lakes at main rivers at the outlet	MR_DL_OL	LT, DY, WY	-

	In reservoirs at main rivers at the outlet	MR_RES_OL	LT, DY, WY	-
	Accumulative retention in main rivers	MR_ACCU	LT, DY, WY	-
TN RETENTION	In tributaries	TRIB	LT, DY, WY	-
	In main rivers	MR	LT, DY, WY	-
	In shallow lakes at main rivers at the outlet	MR_SL_OL	LT, DY, WY	-
	In deep lakes at main rivers at the outlet	MR_DL_OL	LT, DY, WY	-
	In reservoirs at main rivers at the outlet	MR_RES_OL	LT, DY, WY	-
	Accumulative retention in main rivers	MR_ACCU	LT, DY, WY	-
PHOSPHORUS-SOURCES	Total phosphorus	total-P	LT, DY, WY	t/a
	Via background conditions	Background	LT, DY, WY	t/a
	Via urban systems	urban systems	LT, DY, WY	t/a
	via total agriculture	agricultural sources	LT, DY, WY	t/a
	Via other sources	other sources	LT, DY, WY	t/a
	Via point sources and urban systems directly into the main river	PS+US in MR	LT, DY, WY	t/a
TP RETENTION	Tributaries	TRIB	LT, DY, WY	-
	Main rivers	MR	LT, DY, WY	-
	In shallow lakes at main rivers at the outlet	MR_SL_OL	LT, DY, WY	-
	In deep lakes at main rivers at the outlet	MR_DL_OL	LT, DY, WY	-
	In reservoirs at main rivers at the outlet	MR_RES_OL	LT, DY, WY	-
	Accumulative in main rivers	MR_ACCU	LT, DY, WY	-
NITROGEN SHARE ON LOAD AT OBSERVED LOAD (OL)	Via background conditions	Background	LT, DY, WY	t/a
	Via urban systems	urban systems	LT, DY, WY	t/a
	Via different fertilizers	N-Agricult_fertilizer + manure	LT, DY, WY	t/a
	Via NHy on agricultural areas	NHy-Agriculture	LT, DY, WY	t/a
	Via NOx on agricultural areas	NOx-Agriculture	LT, DY, WY	t/a
	Via NHy from other sources	NHy other sources	LT, DY, WY	t/a
	Via NOx from other sources	NOx other sources	LT, DY, WY	t/a
	Total netto at outlet	total net at OL	LT, DY, WY	t/a
	Total sum at outlet	total sum at OL	LT, DY, WY	t/a

	Load of the analytical unit	load at AU	LT, DY, WY	t/a
PHOSPHORUS SHARE ON LOAD AT OL	Via Background conditions	Background	LT, DY, WY	t/a
	Via urban systems	urban systems	LT, DY, WY	t/a
	Via agricultural sources	agricultural sources	LT, DY, WY	t/a
	Via other sources	other sources	LT, DY, WY	t/a
	Total netto at outlet	total net at OL	LT, DY, WY	t/a
	Total sum at outlet	total sum at OL	LT, DY, WY	t/a
	Load of the analytical unit	load at AU	LT, DY, WY	t/a

"Emissions", "Retention and loads", "Aggregated results" and "User specified results" contain the results of the selected analytical unit (or an aggregation level) for previously selected years. Thereby "User specified results" contains the data that has already been saved in the MONERIS Excel sheet "User specified results".

SET AS REFERENCE

Applying the button "Set as reference" stores those results, that were previously imported into Excel, as a reference status in a further table. Thereafter they can be compared to different imported results. The menu "Reference status" describes the setup and time frame of the results saved as reference (Fig. 19).

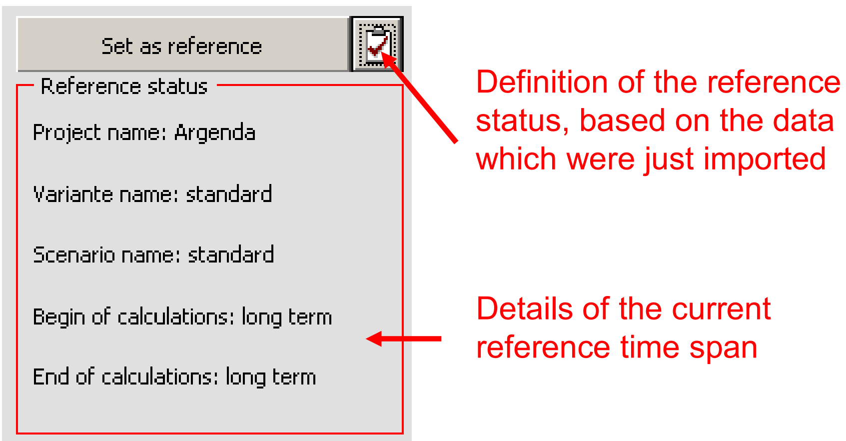


Fig. 19: Detailed information on the button "Set as reference".

DELETE RESULTS

This button opens the menu to delete results and their respective meta-information in a database. At each deletion, 1.5 million datasets can be deleted. If the number of datasets to be deleted exceeds this number, the deletion procedure is repeated.

EXIT MONERIS AND SAVE

The MONERIS user surface can only be closed by the command button “EXIT MONERIS”, and Excel is then opened (Fig. 20).

Fig. 20: Command button to exit MONERIS and open Excel.

In Excel, MONERIS can be closed via the cross in the right top of the toolbar (Fig. 21). However, Excel will ask whether the changes should be saved. If pressing “yes” (Ja), MONERIS automatically saves under the name with which the Excel file was opened. If pressing “no” (Nein), Excel is exited without saving. “Cancel” (Abbrechen) leads you back to Excel.

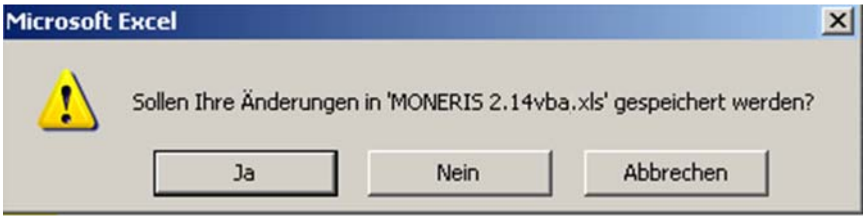


Fig. 21: Exit Excel and save.

Saving the current MONERIS_2.14.1vba version, is only possible in Excel. All the data and results in the Access database are not influenced, as this data is saved automatically in the course of the calculation. If data in the Access database is supposed to be deleted, this has to be done via the MONERIS user surface.

Saving the current MONERIS_2.14.1vba is possible in Excel only!

Single functions and the operation areas will be explained in further sections of the handbook, and in the processing steps.

5.3.4 The MONERIS Control field

The section “Selected Analytical Unit” (Fig. 22) allows the user to change the spatial relationship of the results and the spatial application frame of scenarios: single analytical units can be grouped according to different aggregation criteria (list field “Aggregation level”). Generally, MONERIS calculates on the base of all analytical units. The selected analytical unit is permanently shown.

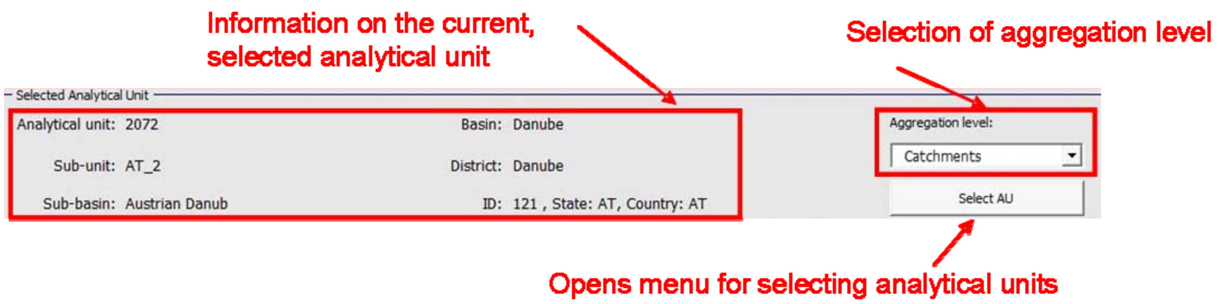


Fig. 22: Detailed information on the “Selected Analytical Unit” section.

The button “Select AU” opens the window in which the analytical unit can be selected.

The following criteria can be applied in the list field “search in” (Fig. 23):

ID	ID of the analytical unit
State	ISO short name of the country or state
Working area	name of the working area
Sea	name of coastal areas or seas
Description	individual description of analytical unit
Sub unit	name of the sub unit
Sub basin	name of the sub basin
Basin	name of the basin
Monitoring station name	name of the monitoring station

Insert the term you are looking for into the textbox “Search for“, choose the category in which you want to search, and press the button with the binoculars symbol to start the search (Fig. 23).

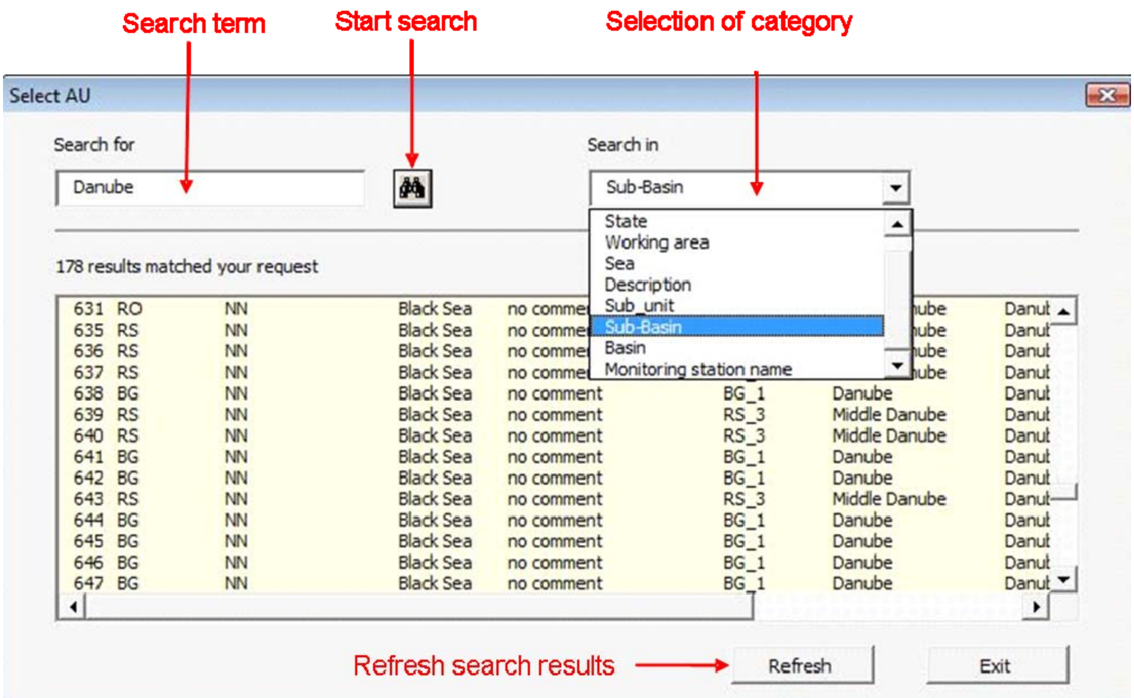


Fig. 23: Detailed information on the button "Select AU".

The list field shows all analytical units that partly or totally match the request in the selected category. To choose one of the shown analytical units, the respective list entry has to be double clicked. Only one analytical unit can be selected. The button "Exit" leaves the search mode, and the information belonging to the selected analytical unit is shown in the analytical unit section.

If the analytical unit is selected, the aggregation level acts as the tool to group other analytical units according to certain attributes. The following aggregation levels can be applied:

Analytical Unit	smallest calculation unit in MONERIS, corresponds to the previously selected area
Catchment	hydrological catchment of the selected analytical unit
Sub unit	sum of analytical units of an administrative unit (e.g. state)
Sub basin	definition according to WFD, Art. 2, Nr. 14
River basin	definition according to WFD Art. 2, Nr. 13
River basin district	definition according to WFD, Art. 2, Nr. 15
All analytical units	all analytical units of a project, eventually from several river basin districts
Country	sum of analytical units within a country
States	sum of analytical units within a federal state (for Germany)

The selected aggregation criterion is used for the next selection again until it is changed.

The selected analytical units, the aggregation level, and the temporal frame, are shown in the spatial relation information box in the results tab of the MONERIS user surface, after the model results have been imported from the database (see Fig. 24 and section 5.3.5.3).

Fig. 24: Example of contents of the “spatial relation information box” (e.g. all analytical units have been selected without an aggregation level for a long term period).

5.3.5 The MONERIS main menu

The MONERIS main menu comprises three tabs, which contain the basic model setups, the scenario manager, and the results. Each of these tabs is now described in detail.

5.3.5.1 Model setup

The MONERIS model setup contains different buttons and list boxes to define the basic settings: selection of database connection, project, variant, and scenario. According to the project setup, the modeller’s name, the first model setup, last project update, name of the river system that is worked on, and, if selected, information on the scenario (see Fig. 25) is recorded.

The right hand side of this tab shows meta-information on the temporal resolution of the input data, and settings of the water surface area calculation (Section 4.1.4). This section visualizes the settings; changes can only be done in the database directly.

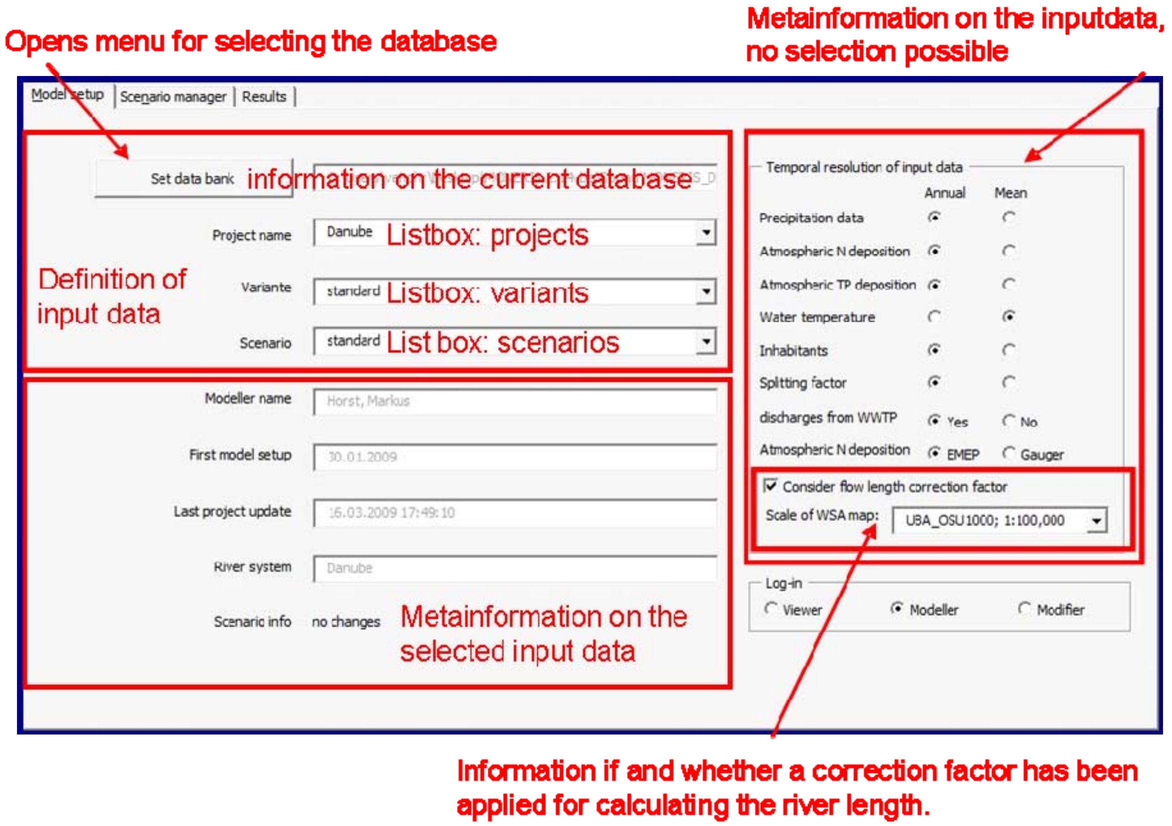


Fig. 25: MONERIS model setup menu.

Initialization of the project

To initialize a project you have to connect MONERIS_2.14.1vba.xls to the MONERIS_2.14.1vba.mdb. To connect click the command button “Set data bank” and confirm your selection in the now opening “Select database” dialog by pressing “enter” or double click (Fig. 26)

Fig. 26: Introducing the database.

If the previously applied database cannot be found by Excel, MONERIS asks you to reset the database. The selection of the database can be done by all users.

Although, there can be different variants applicable e.g. different input data on hydrology only one variant can be applied per calculation. Calculations with other variants have to be done afterwards. The same applies for scenarios which can be created by the user (see section 5.3.5.2).

The Constants-database has to be in the same folder as the currently used MONERIS_2.14.1vba. MONERIS accesses this database automatically, this is not influenced by decisions of the user, nor can the name of the Constants-database be changed.

The name of the MONERIS_DB_2.14.1 input database can be changed and the password is determined by the modeller. The constants database has to be in the same folder as MONERIS 2.14.1vba.xls. Its name and password must not be changed by the user!

Application of passwords

If the MONERIS_DB_2.14.1 database is password protected, its password is the same as that of the modeller. The modeller password can only be changed, if you are logged in as modeller or modifier.

Log-in

In MONERIS three different log-in types are available, viewer, modeller, and modifier. These types vary in their access to results, data, and set up for calculation processes (Fig. 27)

Fig. 27: MONERIS Log-in.

VIEWER

- Selection, combination and application of given scenarios, import, visualization and export of results are possible.
- Most Excel-sheets are not visible, and there is no access to the input database.
- A new definition of the reference status is not possible.

MODELLER

- All viewers' options are available.
- Set up a project is possible.
- Access to the input database.
- All Excel result sheets are visible, and individual result tables can be prepared in the sheet "User specified".

MODIFIER

- o All viewer's and modelers options are available.
- o Complete access to all Excel sheets.
- o Changing and saving of modified parameters and constants possible.

The MODELLER- and MODIFIER Log-ins are password protected. If you type the wrong password you are automatically logged-in as VIEWER. The current log-in type can be changed by clicking the log-in type you want. After that, you have to type in the password.

5.3.5.2 Scenario manager

As already stated in section 5.3.3 MONERIS only considers scenarios for periods (hydrologic conditions, DY, LT, WY). After you have changed to the tab “Scenario manager”, you can choose one or more measures and save them as package of measures (Fig. 28). Thus, the first step is defined.

To apply this package of measures to one or more analytical units, a spatial allocation has to be executed. The second step is the definition of a scenario. Within this scenario, only a single package of measures can be allocated to each analytical unit. If several measures will be applied on an analytical unit, the measures should previously be saved together as one package of measures. This package can then be applied to the analytical unit. Thereby all the measures, defined in the package, are calculated.

When MONERIS is setup, experienced users who are logged in as modellers or modifiers, can define best case and worst case standard scenarios. Instructions for this setup are given in MONERIS workshops.

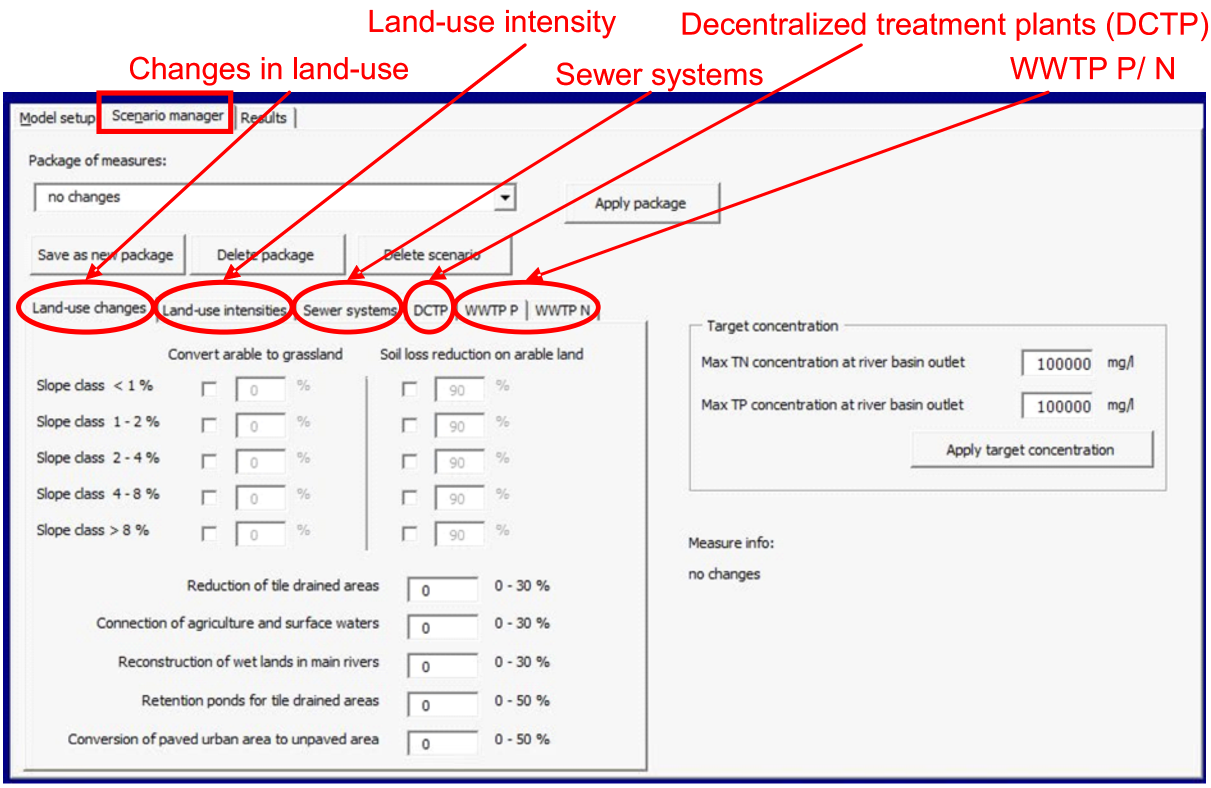


Fig. 28: MONERIS scenario manager.

Definition of packages of measures

In MONERIS, multiple options are implemented to estimate the potential of measures for reducing nutrient emissions. These measures reflect the effect of management options. Thus management options such as reduction of livestock, or increase of storage volume for liquid manure, result in the reduction of nutrient surplus. MONERIS does not consider the viability of these management options, but their effects on the nutrient surplus. Accordingly MONERIS can suggest a certain maximum nitrogen surplus value that must not be exceeded or the reduction of the surplus by a certain amount.

The offered measures are grouped according to following tabs on the user surface: ① land-use changes, ② land-use intensity, ③ sewer systems, ④ DCTP, and ⑤ WWTP P and ⑥ WWTP N (Fig. 29).

MONERIS does not check whether information on decentralized water treatment plants (DCTP) is available, and whether certain scenarios can be calculated. This means that certain measures do not have any effect on scenario calculations if the data is not available.

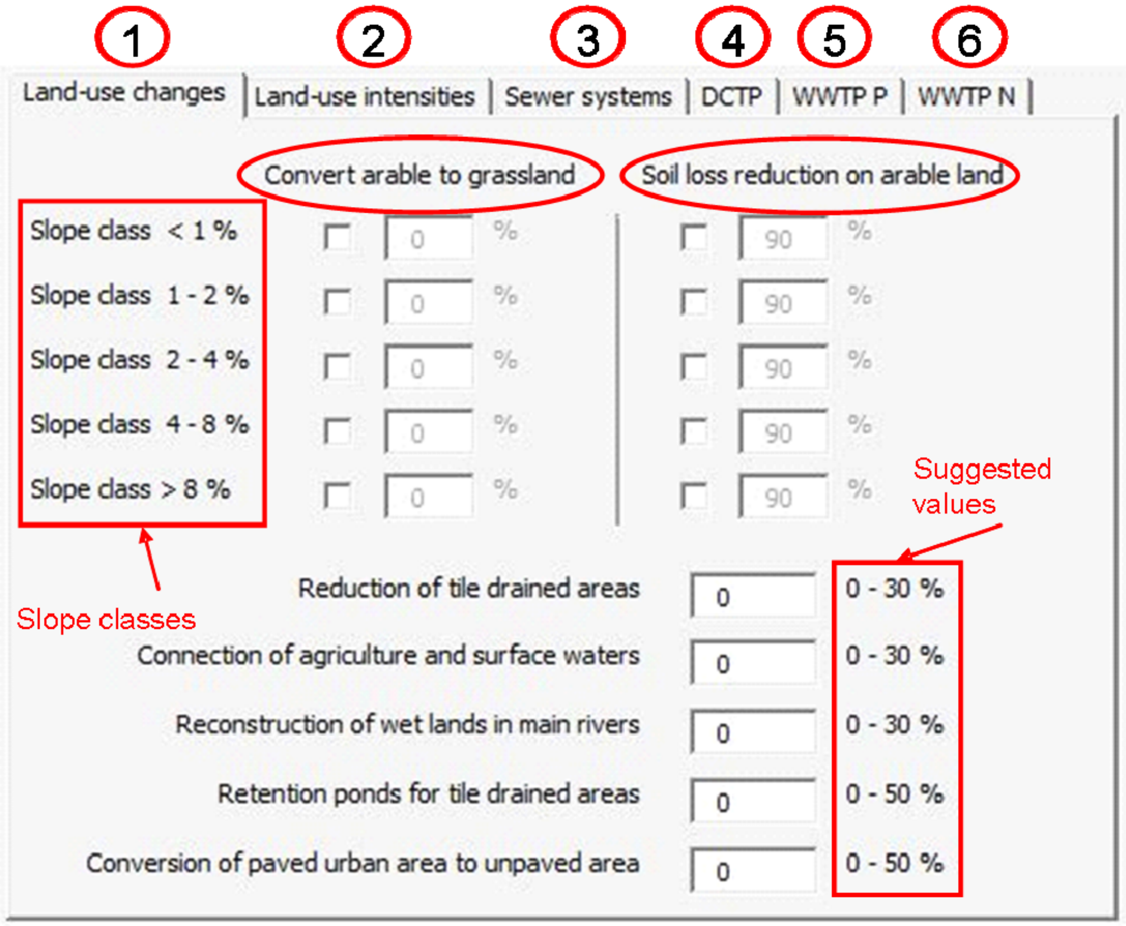


Fig. 29: Definition of measures in the section land-use changes.

Measures to land-use change

Measures from this tab influence the distribution of areas and certain characteristics of land-uses and land management such as tile drainages, and soil conserving ploughing (see Fig. 29 and Table 24).

Table 24: Description of measures for land-use changes.

Measure	Description
Convert arable land to grassland	Simulates the conversion of arable land to grassland. Influences the pathways of erosion, overland flow and tile drainages. For slope classes, the percentage of arable land to be converted can be determined. A conversion of grassland to arable land (negative area portions) is not possible and could lead to errors in the calculation.
Soil loss 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 %.
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 waters	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. Considering tile drainage discharges, the hydraulic load of retention ponds is calculated and used for the calculation of retention in retention ponds.
Conversion of paved urban area to unpaved area	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 20%.

Measures to change land-use intensities

Measures to change “Land-use intensities” (Fig. 30) contain scenario options regarding the change of nitrogen surplus, nitrogen deposition and phosphate free detergents described in Table 25.

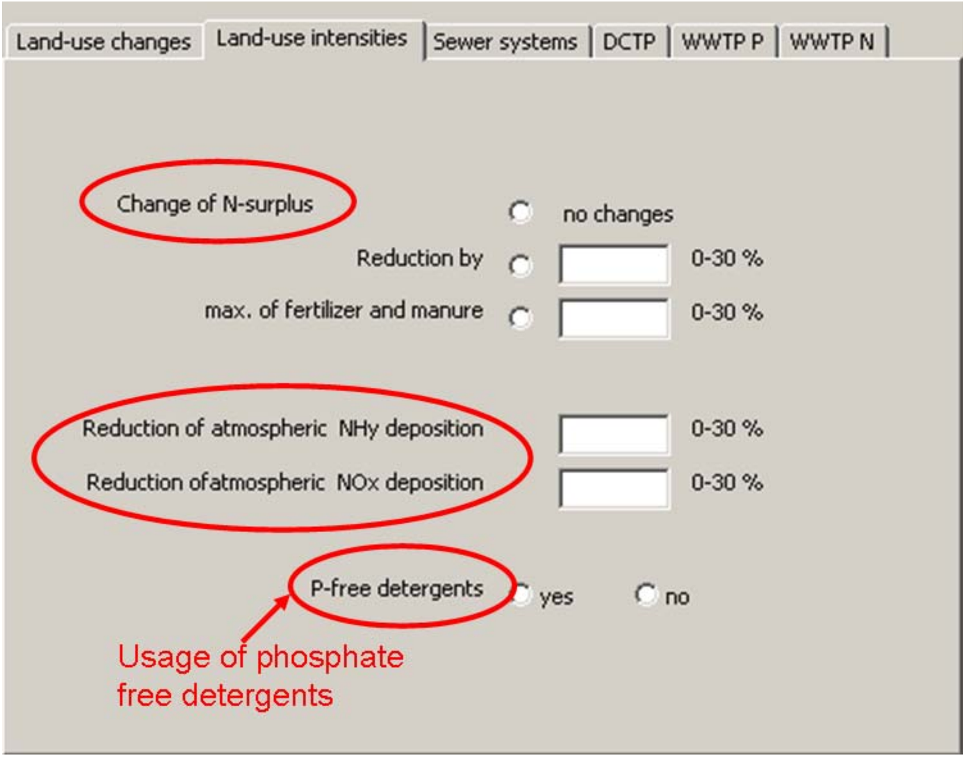


Fig. 30: Definition of measures in the section land-use intensities.

Table 25: Description of measures for land-use intensities.

Measures	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).
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.
phosphate-free detergents	With this measure the application of phosphate free detergents is calculated. This includes replacement of washing powder and detergents, depending on an inhabitant specific phosphorus emission, which is then estimated to equal 0. For DCTPs and WWTPs for up to 10,000 inhabitants, the effluent concentrations are reduced according to the share of detergents, including phosphate, on the total inhabitant specific emissions. For bigger WWTP, no changes of the effluent concentrations are expected.

Measures to change sewer systems

The tab “Sewer systems“ contains different parameters that influence the nutrient emission from urban systems via sewer systems (Fig. 31 and Table 26).

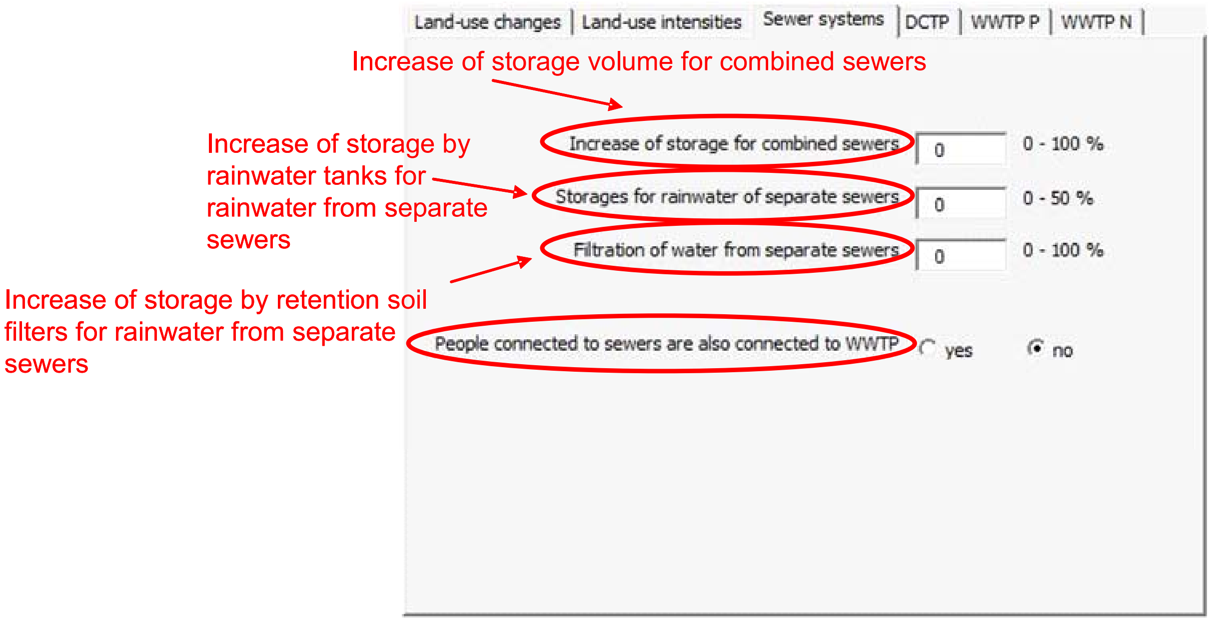


Fig. 31: Definition of measures in the section Sewer systems.

Table 26: Description of measures for Sewer systems.

Measures	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.
Storage for rainwater from separate sewer systems	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.
Filtration of water from separate sewer systems	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, a retention of 80% for nitrogen and 45% for phosphorus is estimated.
People connected to sewer systems are also connected to 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.

Definition of measures for decentralized treatment plants (DCTP)

The tab “DCTP“ contains measures to reduce the nutrient emissions via decentralized treatment plants (Fig. 32 and Table 27).

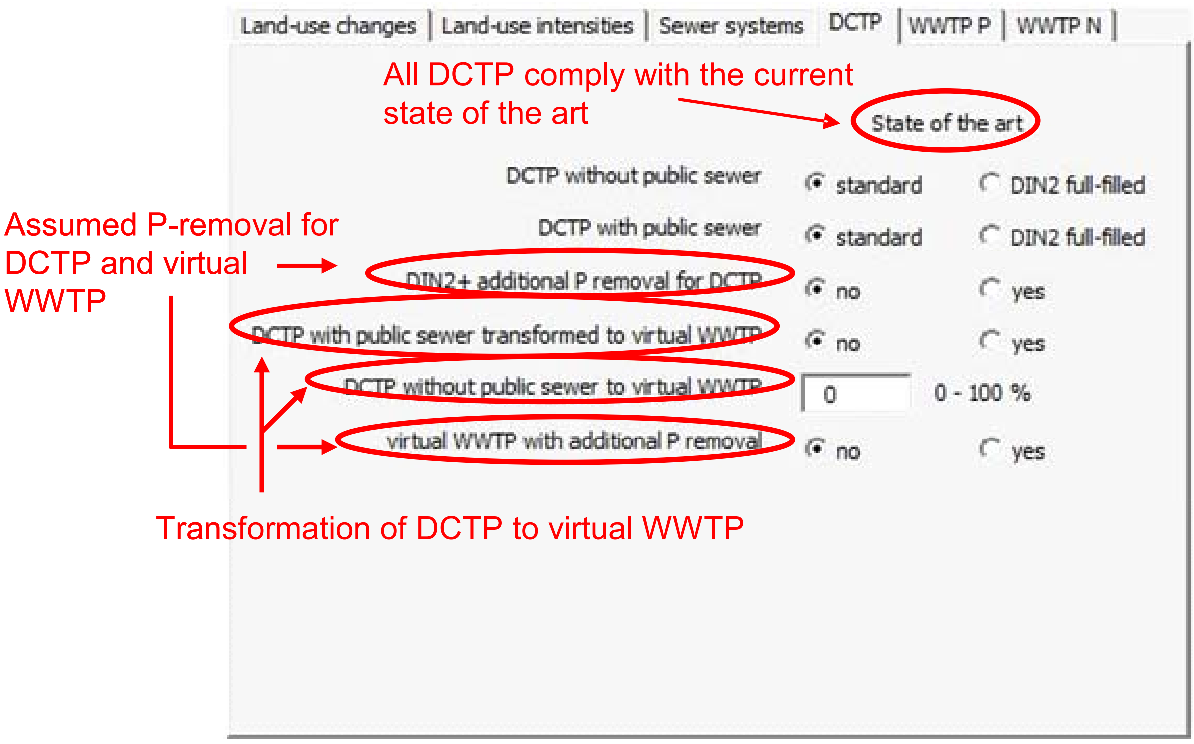


Fig. 32: Definition of measures in the section DCTP (decentralized treatment plants).

Table 27: Description of measures for DCTP (decentralized treatment plants).

Measures	Description
Technical status of the DCTP with or without public sewer systems	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. “DIN2-full-filled” 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 that virtual WWTPs exist, this measure implies phosphorus-removal for these WWTPs.

Definition of measures for phosphorus and nitrogen concentrations in WWTP

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 (Fig. 33 and Fig. 34). Generally, the concentrations should correspond to the target values of the EU directive for waste water (Table 28), although higher or lower values can be set. In both tabs, 5 different WWTP size classes are prepared, which are defined in Table 28. As WWTP data for size class 1 is not available, the scenario manager can only account for size class starting from size class 2.

If no individual WWTP inventory is available, the database can be filled instead with summary information on point sources. In this case a reduction of discharge from non-individualized inventory in percent is assumed.

Table 28: Concentrations for scenario calculations.

Size class	**Inhabitant equivalents**	**Phosphorus mg/l***	**Nitrogen mg/l***
2	2,000 – 5,000	4.0	30.0
3	5,000 – 10,000	4.0	30.0
4	10,000 -- 50,000	≤ 2.0	15.0
5	50,000 – 100,000	≤ 2.0	15.0
6	> 100,000	≤ 1.0	10.0

(* the effluent concentrations are suggestions, and can be changed by the user.)

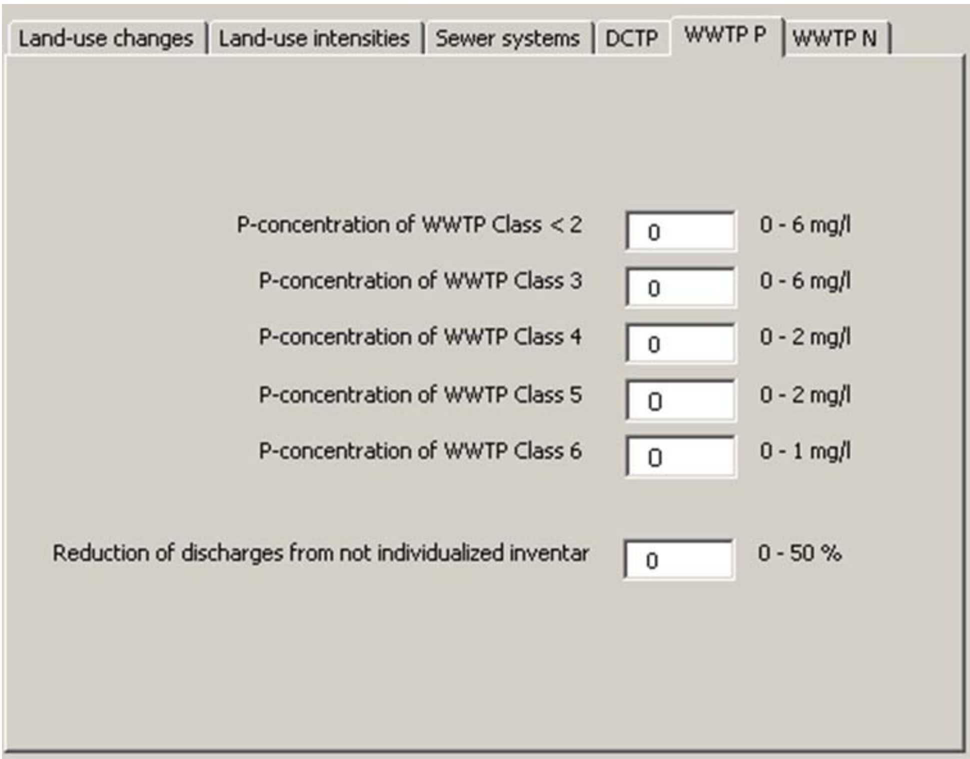


Fig. 33: Definition of measures in the section WWTP P.

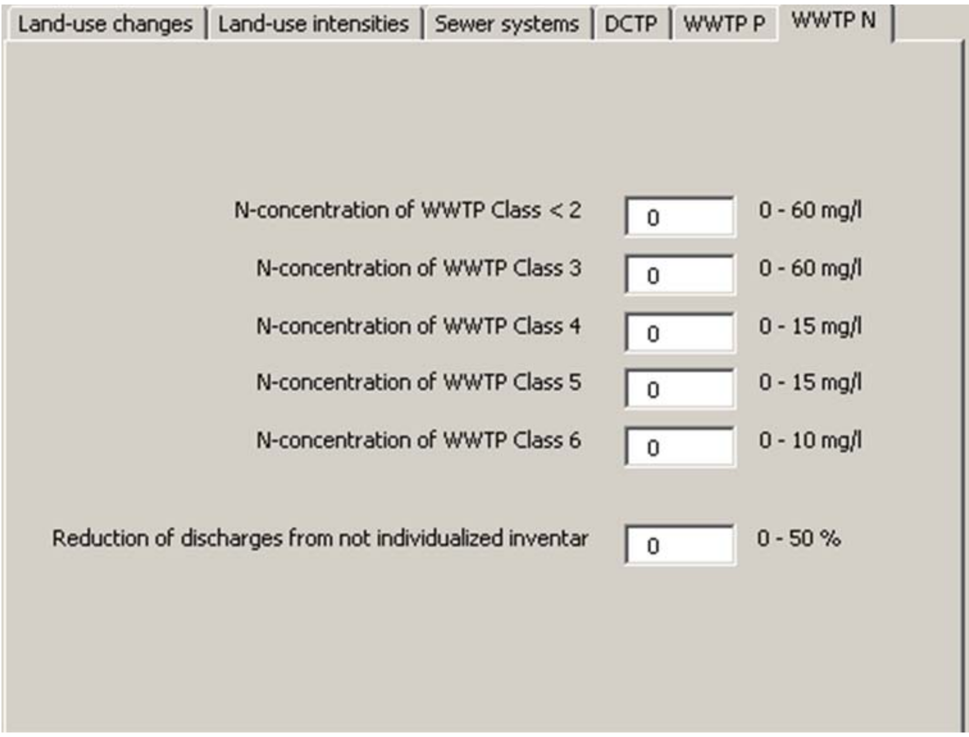


Fig. 34: Definition of measures in the section WWTP N.

After one or more measures have been selected, this combination of settings can be saved as a new package of measures. By pressing “Save as new package” (Fig. 35) a new form opens (Fig. 36).

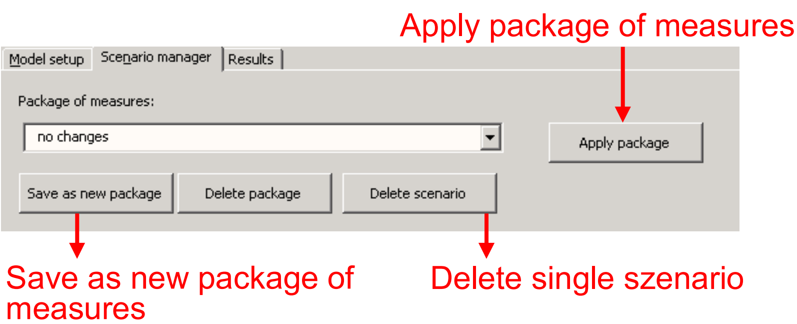


Fig. 35: Adding a new package of measures.

A name for the package can be written into the menu field, and a short description added into the “Measure info” field.

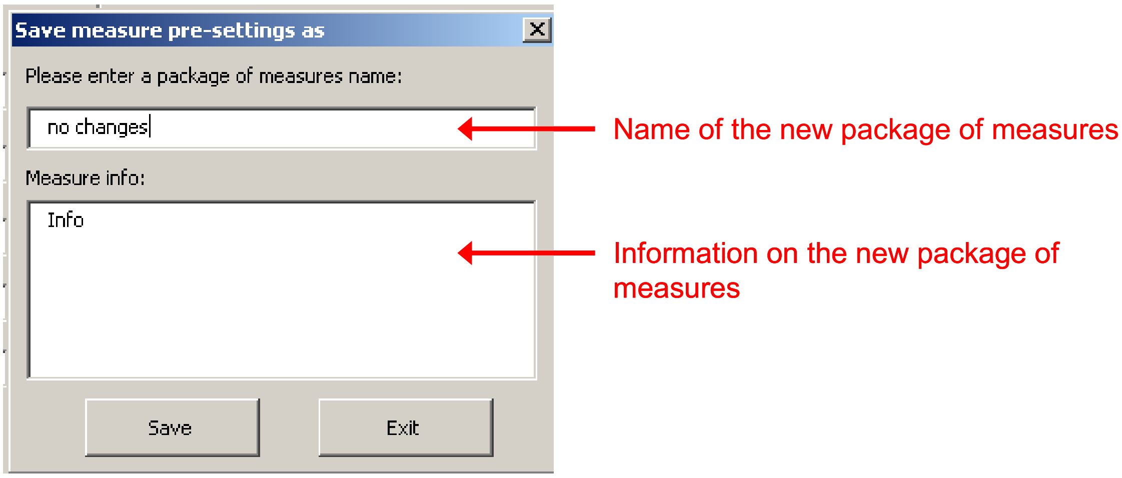


Fig. 36: Saving a package of measures.

Confirm the settings by pressing the command button “Save”. This newly defined package of measures is added to the package of measures in the scroll down menu (Fig. 14).

Allocation of a spatial unit to the package of measures

To proceed with the newly defined package of measures, the analytical unit to which the measures will be applied must be selected, (if necessary, return to the “Selected Analytical Unit” section and choose the correct analytical unit (or a certain aggregation level)). If the correct analytical unit displays in the “Selected Analytical Unit” section, press the command button “Apply package”, and a new form opens (Fig. 37). Thus a scenario, allocated to a certain analytical unit or to certain analytical units, can be defined by a new name, and information can be saved in the “Scenario info” box. This new scenario is added to the list box “Scenario” on the model setup menu, and can be selected via a scroll down menu (Fig. 14).

To consider a scenario for a calculation, it has to be selected from the list.

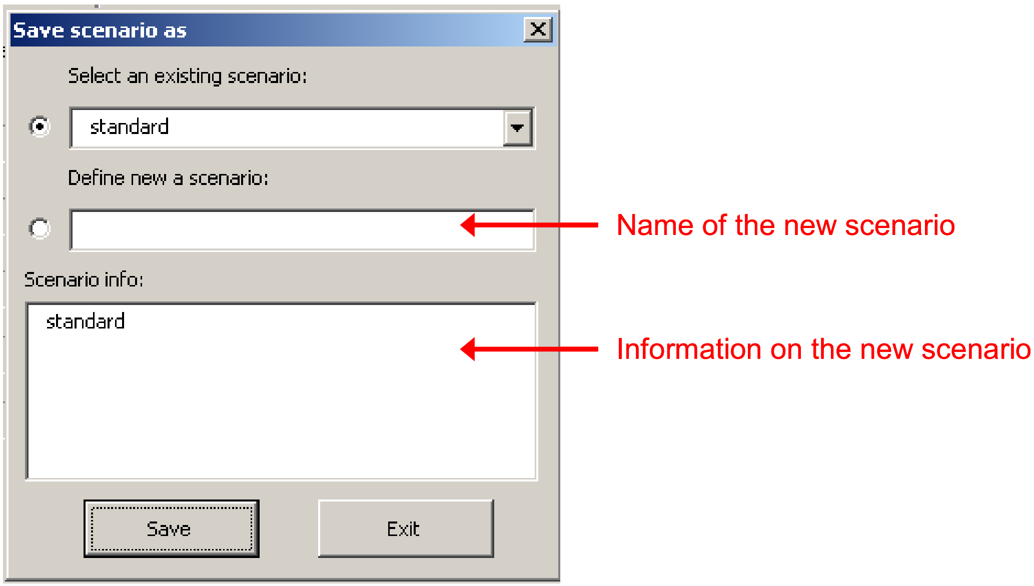


Fig. 37: Saving the spatially allocated package of measures as a scenario.

Combined application of several packages of measures

MONERIS allows the allocation of only one package of measures per analytical unit. Theoretically it is possible to create for each analytical unit its own package of measures and its allocation.

Therefore define a new package of measures, or choose an already existing package from the “Package of measures” scroll-down-menu, and then select the spatial unit for this package (see above). Press the command button “Apply package” and start with the next package of measures you want to allocate to the next analytical unit. This procedure is repeated until all desired packages have been allocated for all required analytical units.

Return to pre-settings

To delete the allocation of packages of measures, choose “no changes“ in the “Package of measures” scroll-down-menu. Then choose “All analytical units” in the selected analytical unit section, and press the command button “Apply package”. Alternatively you can choose the entry “no changes” in the “Scenario settings” scroll-down-menu.

Working with target concentrations

To reach a certain target concentration, the reduction of nitrogen and phosphorus emissions is necessary. The section “Target concentration” allows the definition of the maximum mean concentration of all emissions of an analytical unit. Enter the desired concentrations as target concentration into the textbox (see Fig. 38), and press the command “Apply target concentration”.

The concentrations at the outlet of an analytical unit, calculated by MONERIS, eventually have to be reduced to the target concentration. In a first step, the defined target concentration is considered for all analytical units. In a second step, the effect of the defined target concentration for emissions and the resulting loads is considered for a single analytical unit or a group of analytical units. The results can be seen in the tab “Target concentrations – long term”.

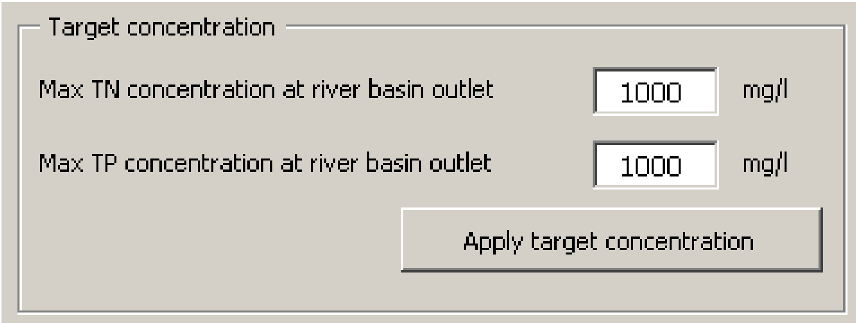


Fig. 38: Definition of target concentrations.

5.3.5.3 Results

Initially all calculation results are stored in a database. To be shown in Excel, and thus in MONERIS, they have to be imported. The only exceptions are the hydrologic conditions (DY, LT, WY), for which the results are stored in Excel and presented on the user surface automatically, to allow a direct comparison between the results.

The “Results” tab on the user surface always displays the temporal and spatial relationships, and the name of the activated scenario of the results (see Fig. 14).

5.3.5.3.1 Display of results as figures

In MONERIS, several figures are prepared that can be displayed on the user surface. To display these figures, open the tab “Figures” in the “Results” tab. Choose from the list of possible visualization options (Fig. 39), the results you want to display (maximum six), and press the command button “Refresh figures“. The selected results are displayed as figures, as can be seen in Fig. 39. To import new results or select new analytical units, refresh the figures by pressing the command button “Refresh figures“ again.

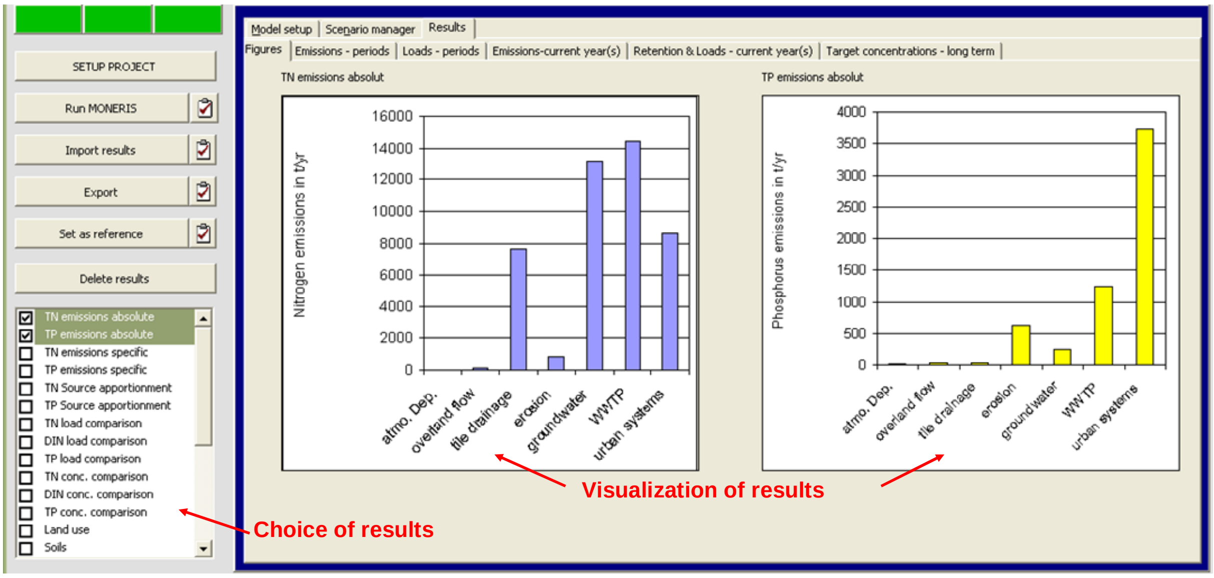
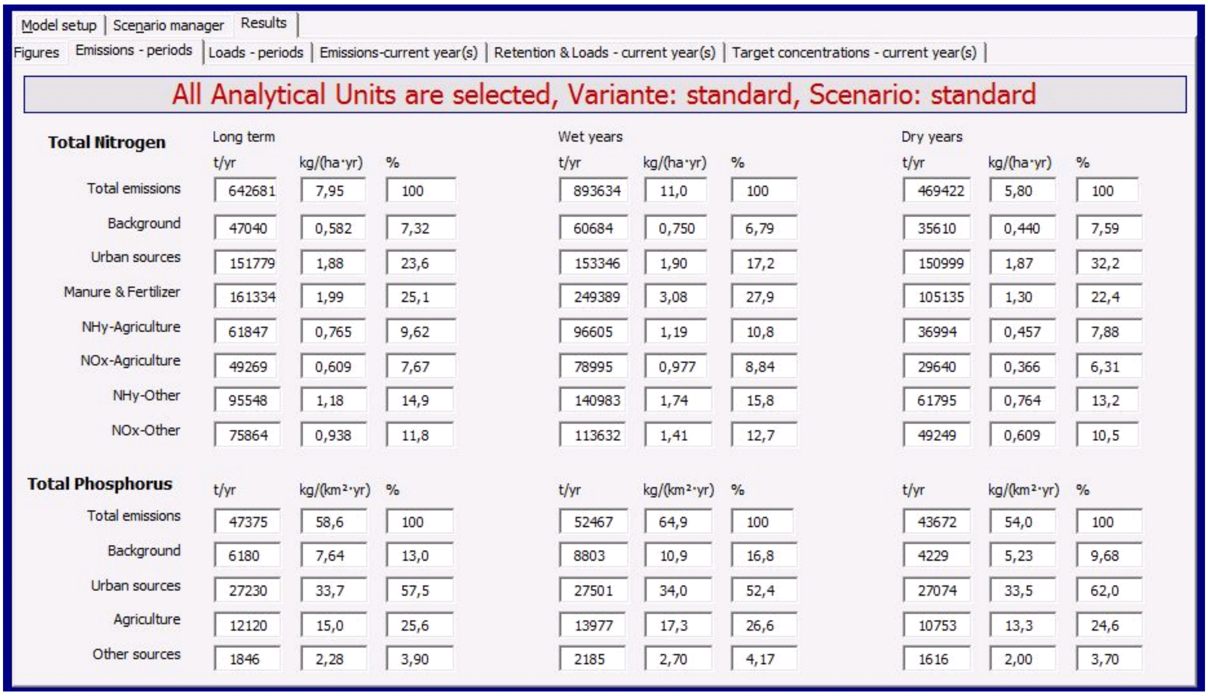


Fig. 39: Results displayed as figures in the result tab.

5.3.5.3.2 Display of results as values

In addition to the results displayed as figures, MONERIS also offers the option of displaying the results as aggregated values for emissions, retention, loads and target concentrations. These results display results partly from previously imported calculations (current year(s)), and partly as hydrological condition calculations (DY, LT, WY).

Emissions - periods



Total Nitrogen	Long term t/yr	kg/(ha·yr)	%	Wet years t/yr	kg/(ha·yr)	%	Dry years t/yr	kg/(ha·yr)	%
Total emissions	642681	7,95	100	893634	11,0	100	469422	5,80	100
Background	47040	0,582	7,32	60684	0,750	6,79	35610	0,440	7,59
Urban sources	151779	1,88	23,6	153346	1,90	17,2	150999	1,87	32,2
Manure & Fertilizer	161334	1,99	25,1	249389	3,08	27,9	105135	1,30	22,4
NHy-Agriculture	61847	0,765	9,62	96605	1,19	10,8	36994	0,457	7,88
NOx-Agriculture	49269	0,609	7,67	78995	0,977	8,84	29640	0,366	6,31
NHy-Other	95548	1,18	14,9	140983	1,74	15,8	61795	0,764	13,2
NOx-Other	75864	0,938	11,8	113632	1,41	12,7	49249	0,609	10,5
Total Phosphorus	t/yr	kg/(km²·yr)	%	t/yr	kg/(km²·yr)	%	t/yr	kg/(km²·yr)	%
Total emissions	47375	58,6	100	52467	64,9	100	43672	54,0	100
Background	6180	7,64	13,0	8803	10,9	16,8	4229	5,23	9,68
Urban sources	27230	33,7	57,5	27501	34,0	52,4	27074	33,5	62,0
Agriculture	12120	15,0	25,6	13977	17,3	26,6	10753	13,3	24,6
Other sources	1846	2,28	3,90	2185	2,70	4,17	1616	2,00	3,70

Fig. 40: Display of emission results as values for hydrological conditions (LT, WY, DY).

As can be seen in Fig. 40, the emission results for hydrological conditions are grouped into different sources. The nitrogen inputs that reach the surface water bodies effected by agriculture (sum of manure, mineral fertilizer, NH_y-Agriculture and NO_x-Agriculture deposition on agricultural land) must not accord to the nutrient inputs effected by agriculture (sum of manure, mineral fertilizer, NH_y-Agriculture and NO_x-Agriculture deposition on agricultural land and other areas). For phosphorus the emissions are shown for different sources.

Loads - periods

The result tab “Loads - periods” gives an overview of the resulting loads in t/yr (in the section “Retention and resulting load in t/yr“), and the share of resulting loads at the outlet of a catchment in percent (“Share of resulting load at RBD outlet in percent’), for total nitrogen and total phosphorus (Fig. 41 and Table 29).

The resulting loads are assigned to the emission pathways described in the previous section.

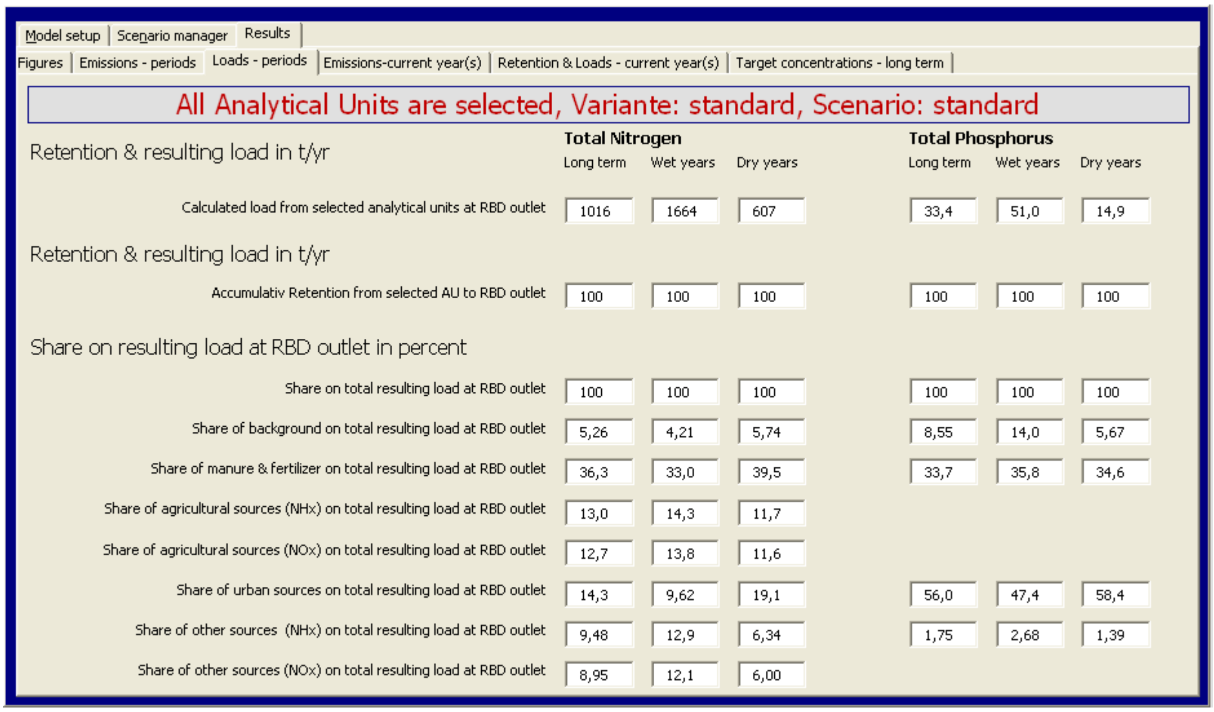


Fig. 41: Display of load results as values for hydrological conditions (LT, WY, DY).

Table 29: Explanation of displayed values in the section “Retention and Resulting load in t/yr“ and “Share on resulting load at RBD outlet in percent”.

Results	Description
Calculated net load from Analytical Unit	Displays the resulting load at the outlet of an analytical unit after retention in surface waters of this area. Emissions from surrounding analytical units are not considered.
Accumulative retention from selected Analytical Unit to RBD outlet	Shows the retention in t/yr from the outlet of an analyse unit up to the final outlet of the river basin district.
Share of total resulting load at RBD outlet	Displays the different pathways of the selected analytical units (or another aggregated form) as a percentage of the total load from all analytical units at the river basin district outlet.
Share of background/ agricultural/ urban and other sources of the total resulting load at RBD outlet	Displays the different sources of the selected analytical units (or another aggregated form) as a percentage of the total load from all analytical units at the river basin district outlet.

Emissions - current year(s)

The tab “emissions-current year(s)” shows the results of emissions for the current year(s) divided into pathways and sources for total nitrogen in t/yr and in kg/(ha·yr), whereas for total phosphorus in kg/(km²·yr). Additionally the percentage of the total emission of each pathway from each of these sources is displayed (Fig. 42).

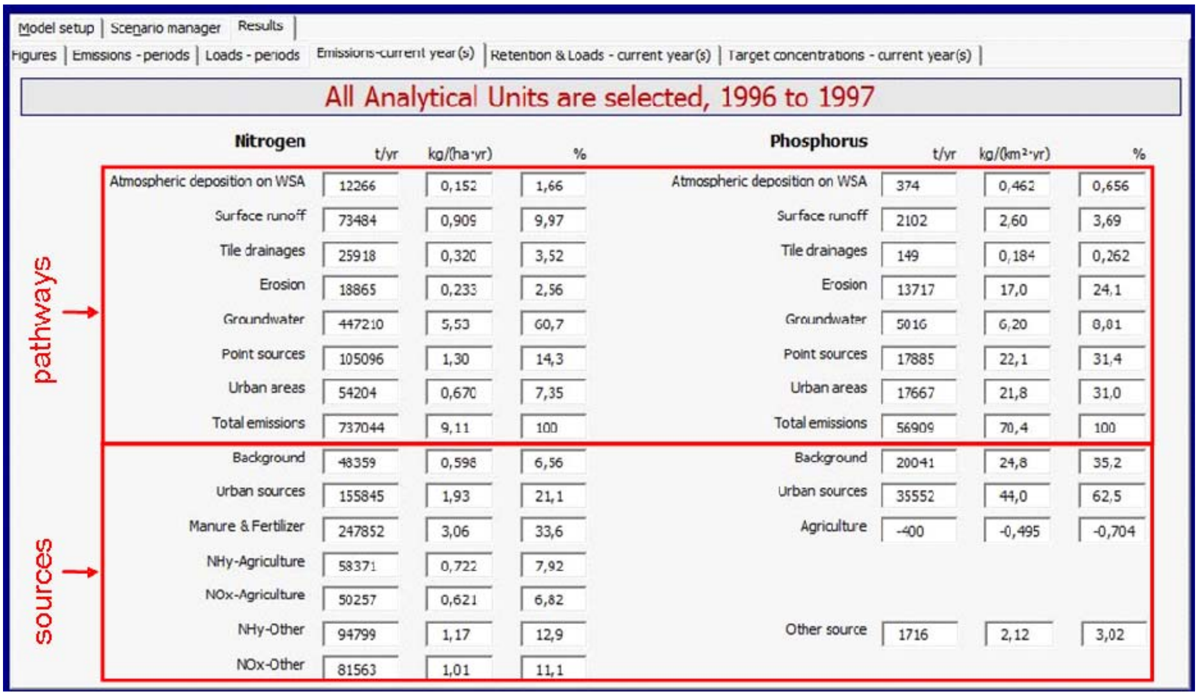


Fig. 42: Display of emission results for current year(s).

Retention and Loads – current year(s)

The tab “Retention and Loads –current year(s)” shows the retention for different nitrogen compartments and total phosphorus for tributaries and main rivers (Fig. 43). The resulting load is displayed either as observed load (OL) or calculated load (CL), depending which values are available. Some statistics are also presented: mean absolute deviation between calculated and observed loads, coefficient of determination (r²) and the Model Efficiency (EF).

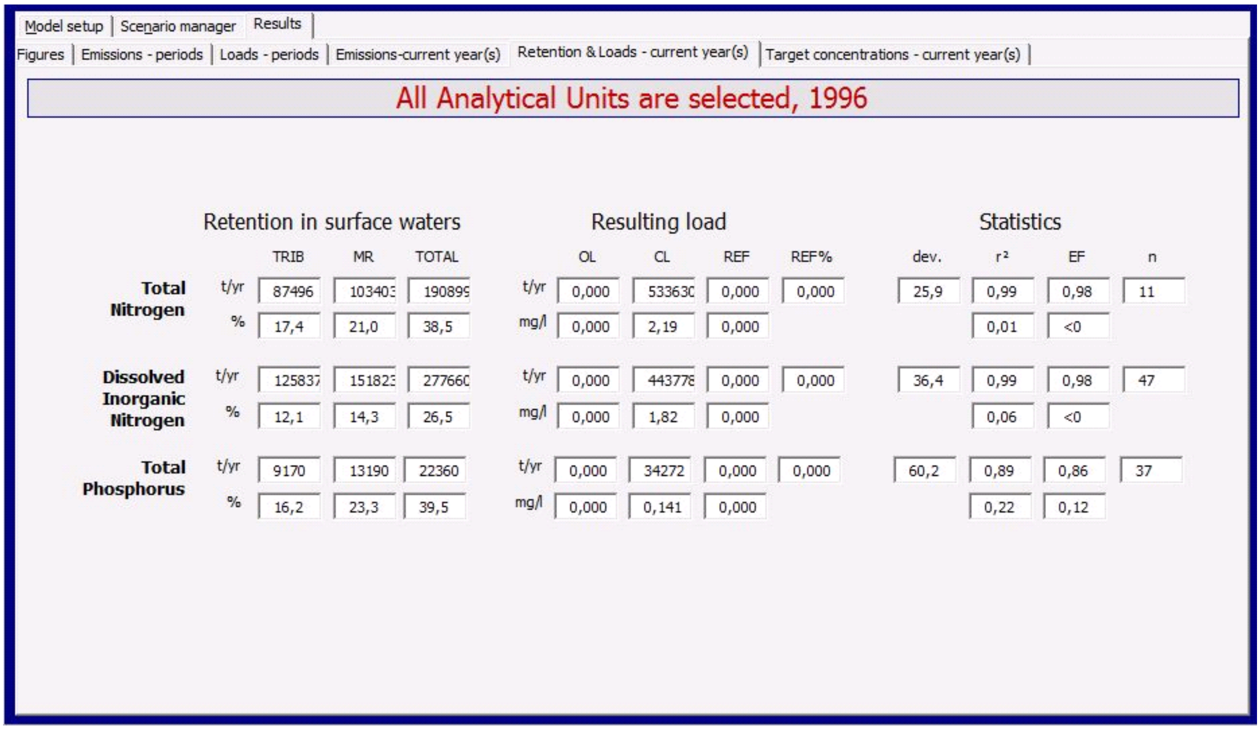
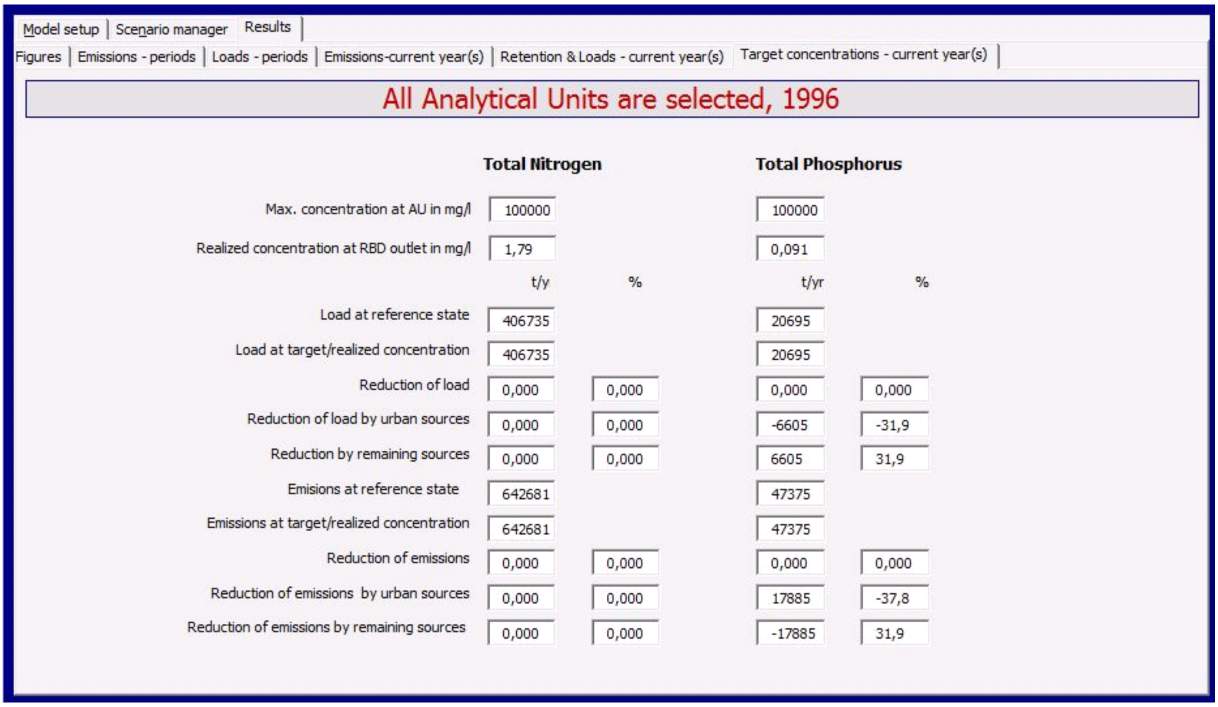


Fig. 43: Display of retention and load results as values for current year(s).

Target concentrations - current year(s)

The tab “Target concentrations – current years“ gives an overview of the resulting loads for total nitrogen and total phosphorus. The info-box “Target concentration at outlet“ shows the target concentrations determined in the scenario manager. The necessary reductions for emissions and loads, divided into sources, to reach the target concentration are listed. Additionally the reduction of nutrient inputs achieved by measures is shown (Fig. 44).



Model setup | Scenario manager | Results

Figures | Emissions - periods | Loads - periods | Emissions-current year(s) | Retention & Loads - current year(s) | Target concentrations - current year(s)

All Analytical Units are selected, 1996

	Total Nitrogen		Total Phosphorus	
Max. concentration at AU in mg/l	100000		100000	
Realized concentration at RBD outlet in mg/l	1,79		0,091	
	t/y	%	t/yr	%
Load at reference state	406735		20695	
Load at target/realized concentration	406735		20695	
Reduction of load	0,000	0,000	0,000	0,000
Reduction of load by urban sources	0,000	0,000	-6605	-31,9
Reduction by remaining sources	0,000	0,000	6605	31,9
Emisions at reference state	642681		47375	
Emissions at target/realized concentration	642681		47375	
Reduction of emissions	0,000	0,000	0,000	0,000
Reduction of emissions by urban sources	0,000	0,000	17885	-37,8
Reduction of emissions by remaining sources	0,000	0,000	-17885	31,9

Fig. 44: Display of target concentrations as values for current year(s).

6 Literature

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Annex A: List of necessary input data for MONERIS

required data	unit
Maps	
catchment boundaries	
river flow net and lakes	
map with land use data	
- urban area	
- area in agricultural use	
- arable land	
- grass land	
- water surface areas	
- open pit mine	
- open area	
- wetland	
- remaining areas	
- naturally covered areas (forests)	
Tile drainages	
- tile drained area (map, statistical data or percentages)	
digital elevation model (100 m Grid)	
- mean slope in catchment area	
soil map	
- sand dominated soils	
- clay dominated soils	
- loam dominated soils	
- fen dominated soils	
- bog dominated soils	
- silt dominated soils	
soil loss maps	(according to USLE)
hydro geological map	
- unconsolidated soil, shallow groundwater	
- unconsolidated soil, deep groundwater	
- consolidated high porosity	
- consolidated impermeable	
atmospheric deposition map (NHx and NOy) as Grid	
administrative boundaries	
location monitoring and gauge stations	
Data from statistical reports (belonging to administrative units)	
Inhabitants	[#]
arable land	[km²]
Nitrogen balance of the agricultural area	kg/(ha·yr)
Optional: Share of arable land with soil conserving practice	%
Hydro-chemical data (yearly data)	
measured runoff	[m³/s]
DIN-N	[mg/l]
TN	[mg/l]
TP	[mg/l]
Optional: Dissolved oxygen	[mg/l]

water temperature	[°C]
Soil information	
mean clay content	[%]
if soil loss map not available: mean soil loss from arable land	[t/(ha·yr)]
mean N content in soil	[mg/kg]
P accumulation in reference year	[kg/(ha·yr)]
soil loss information	
C-factor according to USLE	-
data on groundwater	
Optional: mean groundwater residence time	years
Climatic information	
annual / monthly precipitation	[mm/yr]
precipitation summer (months may to october)	[mm/yr]
long term average precipitation (20 – 30 years)	[mm/yr]
mean evaporation long term mean	[mm/yr]
Optional: Atmospheric deposition of TP for each year	[t/yr]
Urban systems	
total inhabitants per catchment	[#]
connected inhabitants to sewer systems	[#]
inhabitants connected to WWTPs and sewers	[#]
share of combined sewers on total sewers	[%]
separate sewer flow length	[km]
storage volume of combined sewer systems for each year	%
Optional: inhabitants connected to septic tanks for each year	[#]
Optional: inhabitants connected to decentralized treatment plants for each year	[#]
Inventory of industrial direct discharge	
discharge	m^3/yr
mean annual concentration or loads for TN and TP	mg/l
Waster Water treatment plant (WWTP) inventory	
Location (coordinates)	
WWTP capacity in population equivalents	[EW]
population equivalent treated in WWTP	[EW]
elimination rate	[%]
size class of WWTP	[#]
Treatment stages (short description)	[#]
total discharge from WWTP	[m^3/yr]
mean concentration TN	[t/yr]
mean concentration TP	[t/yr]
optional: Total discharge from WWTP TN	[t/yr]
optional: Total discharge from WWTP TP	[t/yr]
country specific data	
optional: TP and TN input per inhabitant and day	[g/(inhabitant·d)]
optional: TP input from detergents per inhabitant and day	[g/(inhabitant·d)]

Annex B: List of constants applied in MONERIS.

Shortname	Category	Description	Value	Unit
CBG6	Background	P background concentration groundwater	0.02	mg/l
CBG7	Background	P background concentration atmospheric deposition	0.1	mg/l
CBG8	Background	P background concentration surface runoff	0.035	mg/l
CBG9	Background	N background concentration atmospheric deposition	1	mg/l
CBG17	Background	natural erosion from snow covered areas	2	t/(ha·yr)
CBG18	Background	natural P content in soil	150	mg/kg
CBG19	Background	minimum leakage water rate	20	mm/yr
CBG20	Background	C-factor under background conditions	0.004	-
CBG22	Background	natural N content in soil	250	mg/kg
CE1	Erosion	SDR factor 1	0.006684	-
CE2	Erosion	SDR exponent for slope	0.3	-
CE3	Erosion	SDR exponent for relevant areas	1.5	-
CE4	Erosion	SDR factor to reduce slope	-0.25	%
CE5	Erosion	upper slope limit	0.25	%
CE6	Erosion	standard SDR if upper slope limit is exceeded	0	-
CE7	Erosion	enrichment ratio factor TP	18	-
CE8	Erosion	enrichment ratio factor TN	7.65957447	-
CE9	Erosion	enrichment ratio exponent	-0.47	-
CE10	Erosion	upper limit of relation sediment input/catchment area	1	-
CE11	Erosion	standard enrichment ratio if CE11 is exceeded	18	-
CE12	Erosion	natural soil loss	4	t/(ha·yr)
CE13	Erosion	background P content	150	mg/kg
CE14	Erosion	background P content	250	mg/kg
CE15	Erosion	correction factor for soil loss if diverging BA-map basis	1	8760kJ/m²
CE17	Erosion	empirical factor 1 for calculating r-factor	0.152	
CE18	Erosion	factor 2 for calculating r-factor	6.88	kJ/m² · mm/h

CE19	Erosion	factor to increase the portion of arable land with potential erosion underestimated by CLC	20	%
CGW1	Groundwater	general relation TP/SRP under aerobic conditions	1	-
CGW2	Groundwater	general relation of TP/SRP under anaerobic conditions	2.5	-
CGW3	Groundwater	P concentration under forest, current values	0.02	mg/l
CGW4	Groundwater	P concentration in sand, current values	0.1	mg/l
CGW5	Groundwater	P concentration in loam, current values	0.03	mg/l
CGW6	Groundwater	P concentration in fen, current values	0.1	mg/l
CGW7	Groundwater	P concentration in bog, current values	0.5	mg/l
CGW8	Groundwater	P concentration under forest, background conditions	0.02	mg/l
CGW13	Groundwater	unconsolidated rock, shallow groundwater factor 1	2752.221303	-
CGW14	Groundwater	unconsolidated rock, shallow groundwater exponent	-1.540040329	-
CGW15	Groundwater	unconsolidated rock, deep groundwater factor 1	68561.63114	-
CGW16	Groundwater	unconsolidated rock, deep groundwater factor 1	-1.958612958	-
CGW17	Groundwater	consolidated rock, high porosity factor 1	60.22649094	-
CGW18	Groundwater	consolidated rock, high porosity exponent	-0.903112691	-
CGW19	Groundwater	consolidated rock, impermeable factor 1	0.012733053	-
CGW20	Groundwater	consolidated rock, impermeable exponent	0.66151252	-
CGW21	Groundwater	exponent for calculating denitrification in the unsaturated zone	0.6367781	-
CGW22	Groundwater	factor for calculating long term changes of atmospheric deposition	1	-
CGW23	Groundwater	runoff separation: near surface flow, factor 1	1.099	-
CGW24	Groundwater	runoff separation: near surface flow, exponent	0.9497	-
CGW25	Groundwater	runoff separation: interflow, factor 1	0.1463	-
CGW26	Groundwater	runoff separation: interflow, exponent	1.1247	-
CGW27	Groundwater	runoff separation: base flow, factor 1	1.176	-
CGW28	Groundwater	runoff separation: base flow, exponent	0.8535	-
CGW29	Groundwater	runoff separation: surface flow, factor 1	0.0426	-
CGW30	Groundwater	runoff separation: surface flow, exponent	1.2461	-

CGW31	Groundwater	corrected P concentration by a redox factor	0.1	mg/l
CGW32	Groundwater	organic N concentration under forest	0	mg/l
CGW33	Groundwater	organic N concentration in wetlands	5	mg/l
CGW34	Groundwater	SiO2-concentration from unconsolidated rock	12	mg/l
CGW35	Groundwater	SiO2-concentration from consolidated rock	8	mg/l
CR1	Retention	q-approach, RT, factor 1 to calculate TP retention in tributaries after q	5.1	-
CR2	Retention	q-approach, RT, exponent to calculate TP retention in tributaries after q	-1	-
CR3	Retention	HL-approach, general factor to calculate TP retention	25.74	-
CR4	Retention	HL-approach, general exponent to calculate TP retention	-1	-
CR5	Retention	THL-approach, general factor to calculate DIN retention	8.58	-
CR6	Retention	THL-approach, general exponent to calculate DIN retention	0.067	-
CR7	Retention	THL-approach, general exponent to calculate DIN retention	-1	-
CR8	Retention	THL-approach, general factor 1 to calculate TN retention	4.74	-
CR9	Retention	THL-approach, general exponent to calculate TN retention	0.067	-
CR10	Retention	THL-approach, TN, exponent to calculate TN retention in tributaries	-1	-
CR11	Retention	THL-approach, factor 1 to calculate DIN retention in shallow lakes	8.58	-
CR12	Retention	THL-approach, exponent to calculate DIN retention in shallow lakes	0.067	-
CR13	Retention	THL-approach, exponent to calculate DIN retention in shallow lakes	-1	-
CR14	Retention	THL-approach, factor 1 to calculate DIN retention in deep lakes	8.58	-
CR15	Retention	THL-approach, exponent to calculate DIN retention in deep lakes	0.067	-
CR16	Retention	THL-approach, exponent to calculate DIN retention in deep lakes	-1	-
CR17	Retention	THL-approach, factor 1 to calculate DIN retention in reservoirs	8.58	-
CR18	Retention	THL-approach, exponent to calculate DIN retention reservoirs	0.067	-
CR19	Retention	THL-approach, exponent to calculate DIN retention in reservoirs	-1	-
CR20	Retention	THL-approach, factor 1 to calculate TN retention in shallow lakes	4.74	-
CR21	Retention	THL-approach, exponent to calculate TN retention in shallow lakes	0.067	-
CR22	Retention	THL-approach, exponent to calculate TN retention in shallow lakes	-1	-

CR23	Retention	THL-approach, factor1 to calculate TN retention in deep lakes	4.74	-
CR24	Retention	THL-approach, exponent to calculate TN retention in deep lakes	0.067	-
CR25	Retention	THL-approach, exponent to calculate TN retention in deep lakes	-1	-
CR26	Retention	THL-approach, factor 1 to calculate TN retention in reservoirs	4.74	-
CR27	Retention	THL-approach, exponent to calculate TN retention in reservoirs	0.067	-
CR28	Retention	THL-approach, exponent to calculate TN retention in reservoirs	-1	-
CR29	Retention	THL-approach, factor 1 to calculate TP retention in shallow lakes	25.74	-
CR30	Retention	HL-approach, exponent to calculate TP retention in shallow lakes	-1	-
CR31	Retention	HL-approach, factor 1 to calculate TP retention in deep lakes	25.74	-
CR32	Retention	HL-approach, exponent to calculate TP retention in deep lakes	-1	-
CR33	Retention	HL-approach, factor 1 to calculate TP retention in reservoirs	25.74	-
CR34	Retention	HL-approach, exponent to calculate TP retention in reservoirs	-1	-
CSP1	Tongehaltsmodell	clay-phosphorus-model, factor 1	10.2	-
CSP2	Tongehaltsmodell	clay-phosphorus-model, factor 2	150	-
CSR1	Surface Runoff	P concentration by fertilizer/under forest	0.035	mg/l
CSR2	Surface Runoff	P concentration by fertilizer/ under open land	0.035	mg/l
CSR3	Surface Runoff	N concentration by fertilizer/ under arable land	0,3	mg/l
CSR4	Surface Runoff	N concentration by fertilizer/ under grassland	0	mg/l
CSR5	Surface Runoff	N concentration by fertilizer/ under forest and open land	0	mg/l
CSR6	Surface Runoff	P saturation under arable land	90	mg/l
CSR7	Surface Runoff	P saturation grassland	80	mg/l
CSR8	Surface Runoff	P accumulation for Germany	1100	kg/(ha·yr)
CSR9	Surface Runoff	P solubility, factor 1	0.035	-
CSR10	Surface Runoff	P solubility, factor 2	0.000000618	-
CSR11	Surface Runoff	P solubility, factor 3	0.155	-
CSR12	Surface Runoff	P concentration in snow	0.005	mg/l
CSR13	Surface Runoff	N concentration in snow	0.1	mg/l
CSR14	Surface Runoff	upper limit of precipitation	800	mm/yr

CSR15	Surface Runoff	snow discharge, factor 1	4	-
CSR16	Surface Runoff	snow discharge, exponent	1	-
CSR17	Surface Runoff	correction factor if maximum discharge is exceeded by snowmelt	0.545637289	-
CSR18	Surface Runoff	coefficient surface runoff	0.0426	-
CSR19	Surface Runoff	exponent surface runoff	1.2461	-
CTD1	Tile Drainage	discharge coefficient winter	0.5	-
CTD2	Tile Drainage	discharge coefficient summer	0.1	-
CTD3	Tile Drainage	P concentration in sand	0.2	mg/l
CTD4	Tile Drainage	P concentration in loam	0.06	mg/l
CTD5	Tile Drainage	P concentration in fen	0.3	mg/l
CTD6	Tile Drainage	P concentration in bog	2	mg/l
CTD7	Tile Drainage	exponent describing the denitrification in the soil	0.85	-
CUS1	Urban Systems	factor 1 calculating the share of paved area of the total urban area	0.4047	-
CUS2	Urban Systems	factor 2 calculating the share of paved area of the total urban area	9.6	-
CUS3	Urban Systems	factor 3 calculating the share of paved area of the total urban area	0.573	-
CUS4	Urban Systems	factor 4 calculating the share of paved area of the total urban area	0.0391	-
CUS5	Urban Systems	factor 1, calculating the discharge ratio on impervious areas	0.15	-
CUS6	Urban Systems	factor 2, calculating the discharge ratio on impervious areas	0.75	-
CUS7	Urban Systems	factor 1, calculating the number of stormevents	0.0000012	d/yr
CUS8	Urban Systems	factor 2, calculating the number of stormevents	2.5	-
CUS9	Urban Systems	P concentration in commercial waste water	0.5	mg/l
CUS10	Urban Systems	specific P-input from streets	2.5	kg/(ha·yr)
CUS11	Urban Systems	inhabitant specific N-input	12	g/(E·d)
CUS12	Urban Systems	N concentration of commercial waste water	2	mg/l
CUS13	Urban Systems	specific N-input from streets	4	kg/(ha·yr)
CUS14	Urban Systems	inhabitant specific daily waste water	130	l/(E·d)
CUS15	Urban Systems	specific waste water from commercial areas	0.1	l/(ha·s)
CUS16	Urban Systems	duration of water flow after heavy rainfalls from commercial areas	10	h

CUS17	Urban Systems	N input of inhabitants only connected to sewers	9	mg/E
CUS18	Urban Systems	N input of inhabitants connected neither to sewers nor to WWTPs	9	mg/E
CUS19	Urban Systems	share of P-input of inhabitants connected neither to sewers nor to WWTPs	0.75	-
CUS20	Urban Systems	N retention in soil/ consolidated rock	50	%
CUS21	Urban Systems	N retention in soil/ unconsolidated rock	90	%
CUS22	Urban Systems	P retention in soil/ consolidated rock	50	%
CUS23	Urban Systems	P retention in soil/ unconsolidated rock	90	%
CUS24	Urban Systems	mean specific rainwaterflow	1	l/(ha·s)
CUS25	Urban Systems	factor 1 calculating the share of combined sewers of total sewers	0.01534	-
CUS26	Urban Systems	factor 2 calculating the share of combined sewers of total sewers	0.97541	-
CUS27	Urban Systems	exponent calculating the share of combined sewers of total sewers	196.66	-
CUS28	Urban Systems	share of solids transported from septic tanks to WWTPs	5	%
CUS29	Urban Systems	connection to separate sewers, factor 1	0.125	-
CUS30	Urban Systems	connection to separate sewers, factor 1	0.368	-
CUS31	Urban Systems	correction factor for point sources	0.7	-
CUS32	Urban Systems	TN retention of storm water sedimentation tank	0.35	-
CUS33	Urban Systems	TP retention of storm water sedimentation tank	0.35	-
CUS34	Urban Systems	TN retention of retention soil filter	0.8	-
CUS35	Urban Systems	TP retention of retention soil filter	0.45	-
CUS36	Urban Systems	P retention in septic tank	90	%
CUS37	Urban Systems	P retention in DCTP, surface waters DIN 1	7	%
CUS38	Urban Systems	P retention in DCTP, surface waters DIN 2	13	%
CUS39	Urban Systems	P-reduction by precipitation in DCTP DIN 2	80	%
CUS40	Urban Systems	P retention in virtual WWTP	35	%
CUS41	Urban Systems	P reduction by precipitation in virtual WWTP	80	%
CUS42	Urban Systems	N retention in septic tank	90	%
CUS43	Urban Systems	N retention in DCTP, surface waters DIN 1	10	%
CUS44	Urban Systems	N retention in DCTP, surface waters DIN 2	15	%

CUS45	Urban Systems	N retention in virtual WWTP	40	%
CW1	Point Sources	mean TN retention of sc-direct discharger to WWTP	0.7	-
CW2	Point Sources	mean TP retention of sc-direct discharger to WWTP	0.7	-
NAC1		reduction of NOx-deposition if non agricultural conditions (nac)	100	%
WSA1	Water Surface Area	factor 1, calculating river width of tributaries	0.152	-
WSA2	Water Surface Area	factor 2, calculating river width of tributaries	0.102	-
WSA3	Water Surface Area	factor 3 calculating river width of tributaries	1.018	-
WSA4	Water Surface Area	factor 4 calculating river width of tributaries	-0.25	-
WSA5	Water Surface Area	factor 1, calculating river width of main rivers	0.45	-
WSA6	Water Surface Area	factor 2, calculating river width of main rivers	0.515	-
WSA7	Water Surface Area	factor 3, calculating river width of main rivers	0.175	-
WSA8	Water Surface Area	factor 4, calculating river width of main rivers	-0.0276	-
WSA9_1	Water Surface Area	factor to correct the scale for tributaries, DTK25	1	-
WSA9_2	Water Surface Area	factor to correct the scale for tributaries, UBA1000	1.83	-
WSA9_3	Water Surface Area	factor to correct the scale for tributaries, UBA1000-OSU	2.1	-
WSA9_4	Water Surface Area	factor to correct the scale for tributaries, DLM250	3.23	-
WSA9_5	Water Surface Area	factor to correct the scale for tributaries, DLM1000	2.99	-
WSA9_6	Water Surface Area	factor to correct the scale for tributaries, Bart 1000	8.4	-
WSA9_7	Water Surface Area	factor to correct the scale for tributaries, DCW1000	6.28	-
WSA10_1	Water Surface Area	factor to correct the scale for main river, DTK25	1	-
WSA10_2	Water Surface Area	factor to correct the scale for main river, UBA1000	1.11	-
WSA10_3	Water Surface Area	factor to correct the scale for main river, UBA1000-OSU	1.11	-
WSA10_4	Water Surface Area	factor to correct the scale for main river, DLM250	1.11	-
WSA10_5	Water Surface Area	factor to correct the scale for main river, DLM1000	1.13	-
WSA10_6	Water Surface Area	factor to correct the scale for main river, Bart 1000	1.18	-
WSA10_7	Water Surface Area	factor to correct the scale for main river, DCW1000	1.17	-