



**Leibniz Institute of Freshwater Ecology and Inland Fisheries  
in the Forschungsverbund Berlin e.V.**

# **The model system**

# **MONERIS**

**Version 2.0**

**User's Manual**

by

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## Disclaimer

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## I. General model description

### I.1 Introduction

MONERIS is a multipurpose environmental model system for use by regional, state (e.g. Umweltbundesamt) and local agencies in performing watershed- and water-quality-based studies. It was developed at IGB to address three objectives:

- To identify source of nutrient emissions on a regional basis
- To analyze transport and retention of nutrients in river systems
- To provide a framework for examining management alternatives

Because many states and local agencies are moving toward a watershed-based approach within the Water Framework Directive of the European Union (WFD), the MONERIS system is configured to support environmental and ecological studies in a watershed context. The system is designed to be flexible and can support analysis at a variety of scales.

The Geographical Information System (GIS)-oriented Model MONERIS (Modelling Nutrient Emissions in River Systems) was developed to estimate nutrient inputs by point and various diffuse sources into rivers with catchments larger than 50 km<sup>2</sup>. MONERIS was also conceived as a system for identifying reduction needs to meet applicable water quality standards (target concentrations) by using different scenario options. The computation of target concentrations requires a watershed-based approach that integrates both point and diffuse sources. MONERIS can support this type of watershed-based point and diffuse source analysis for nutrients. Analysts can efficiently run a variety of different management options. With many of the necessary components together in one system, the analysis time is significantly reduced, a greater variety of questions can be answered, and data and management needs can be more efficiently identified. Users are encouraged to provide the MONERIS working group at IGB with comments and recommendations for further development.

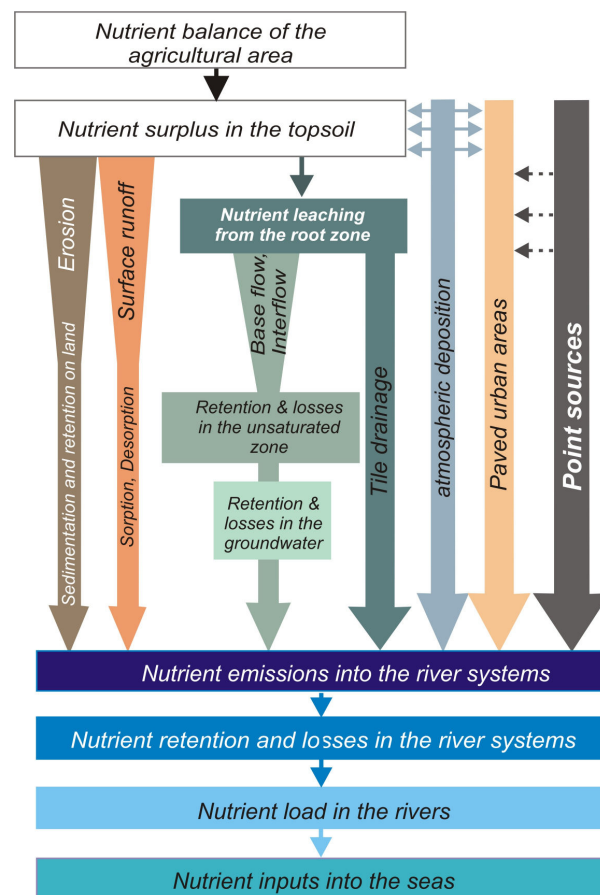
## I.2 System Overview

### I.2.1 Basic structure for model application

The model MONERIS (**MO**delling **N**utrient **E**missions in **R**iver **S**ystems) is an empiric conceptional model, which allows the quantification of nutrients emissions via various point and diffuse pathways into river basins (BEHRENDT et al., 2000; 2002a; 2002 b). It was developed in the research group of the Leibniz-Institute of Freshwater Ecology and Inland Fisheries (IGB Berlin). The basis for the model are data on runoff and water quality for the studied river catchments and a Geographical Information System (GIS) integrating digital maps as well as extensive statistical information for different administrative levels. The application of MONERIS allows a regionally differentiated quantification of nutrient emissions into river systems which can be shown in GIS generated maps.

Since 2007 MONERIS has a new model surface based on VBA – programming. Furthermore, a scenario manager was developed, which has the capability to calculate the effect of measures on the nutrient input into river systems for different pathways and for different spatial bases. During the last years MONERIS was applied for many European river systems (e.g. Axios, Elbe, Danube, Daugava, Po, Rhine and Vistula, Odra; see BEHRENDT et al., 1999; 2003a; 2003b; SCHREIBER et al., 2005; BEHRENDT & DANNOWSKI, 2005) and the total area of Germany (BEHRENDT et al., 2000) as well as currently in river catchments in Canada, Brazil and China.

While the point inputs from municipal waste water treatment plants and from industry are directly discharged into the rivers, diffuse emissions into surface waters are caused by the sum of different pathways, which are realised by separate flow components (see Figure I.2.1). The distinction of these individual components is necessary because both the concentrations of materials and the processes are at least clearly distinguished from one another. Consequently, seven pathways are considered



**Figure I.2.1:** Pathways and processes in MONERIS

within the MONERIS model:

- point sources (discharges from municipal waste water treatment plants and direct industrial discharges)
- inputs into surface waters via atmospheric deposition
- inputs into surface waters via groundwater
- inputs into surface waters via tile drainage
- inputs into surface waters via paved urban areas
- inputs into surface waters by erosion
- inputs into surface waters via surface runoff (only dissolved nutrients)

Furthermore, the retention in rivers, divided in main rivers and tributaries is calculated and enables a comparison of the input calculations with the observed river loads.

## **I.2.2 Temporal and spatial resolution**

Basis of the spatial resolution are analytical units (which are sub-catchments in a river basin). Originally the spatial discretization of catchment areas was designed for sub-catchments  $> 500 \text{ km}^2$ . Mathematically it is possible to run the model on a spatial resolution of  $1 \text{ km}^2$ , but due to the needs of calibration a minimum level of  $50 \text{ km}^2$  could be realized at present. The temporal discretization could be yearly or monthly, depending on the conceptual formulation of the problem. The integration of a monthly discretization is currently progressing.

## **I.2.3 Emission method of MONERIS**

Based on the analytical units (see Chapter I.4.1.1.1), the flow direction (flow tree, see chapter I.4.1.1.2) for every analytical unit is defined on the base of hydrological data and topology of the river system. Subsequently, the runoff from each analytical unit (chapter I.4.1.1.4) can be proceeded on the basis of further hydrological data (e.g. precipitation data) and observed runoff. On the base of these results the waterbalance for the different pathways of the analytical units can be calculated with the model MONERIS.

### **I.2.3.1 Point source emissions**

Point source emissions originate from municipal waste water treatment plants (WWTP) and direct discharges from industrial plants. For Germany, the regional based estimation of nutrient discharges from WWTP is based on the area-based GIS inventories for 1999. Since this inventory does not cover all treatment plants, the discharges from smaller treatment plants were determined on the basis of district based state information on outflow nutrients. For these, an almost equal division on the urban areas was employed and the specific inputs of the smaller treatment plants were multiplied by the area of the catchment. These values were then added to the treatment plant inventory. The advantage of this inventory is that the reference to the geographical position of the WWTPs is given.

The direct discharges from industrial plants for the period 1998 to 2000 were calculated on the basis of the results of the studies of ROSENWINKEL & HIPPEN (1997) for 1995. In addition, it was assumed that the discharges in individual catchments in 1999 changed in the same manner as those via municipal waste water treatment plants. Based on the data of the “DATEN-FORSCHUNGSZENTRUM” OF THE STATISTICAL STATE OFFICES (2007), where data of e.g. the nutrient inputs of all WWTPs are listed, these data could be obtained for all communities in Germany for 2004. So, the total amount of inputs of WWTPs is now possible to calculate. For other countries a database should be made available from the local authorities.

### I.2.3.2 Diffuse source emissions

The inputs via diffuse sources occur via five pathways:

- Atmospheric deposition on the water surface area: The basis for the estimation of direct inputs into freshwaters by atmospheric deposition is the knowledge of the water surface area of a basin which is connected to the river system (chapter I.4.1.2) and the annual deposition rates.
- Erosion runoff: The sediment and nutrient input via erosion is calculated only for these areas, which are relevant for the soil loss into rivers. The erosion module was validated with the suspended load and with the particular phosphorous load of the rivers.
- Surface runoff: The surface runoff is calculated on the base of the surface runoff (Chapter I.4.1.1), percentage of arable land, grassland and open areas with defined concentrations of nutrients in the surface runoff for these land uses.
- Paved urban areas: Inputs via paved urban areas are calculated under consideration of the regional differences in the sewage system as well as the degree of storage capacities of the mixed sewage systems.
- Tile drainages: The proportion of drained areas is determined on the base of digitalised drained areas for representative areas, soil type and soil water conditions. Nutrient inputs into rivers are calculated on the base of the values for summer and winter drainage discharge and the nutrient balance of the agricultural area.
- Base flow/Interflow: Nutrient inputs via base flow are calculated on the base of the nutrient balance of the agricultural area and the nitrogen concentration in the groundwater with aid of a retention function depending on hydrogeological conditions, seepage rate and the nutrient balance under consideration of the spacious retention times in the catchment area.

Additionally, a method is developed to quantify the nutrient retention in the surface water depending on the hydraulic load and the specific runoff of the river system (BEHRENDT et al., 2000) and modified by VENOHR 2006. Hence, a quantification of the nutrient load is possible on the basis of the nutrient inputs into rivers and consequently, a direct comparison with the calculated load of the discharge measurements and the nutrient concentration of the gauges.



## I.3 Requirements

### I.3.1 Personal requirements

For the optimal application of MONERIS the user should be aware of the considerable personal requirements. The valuation of the MONERIS results presumes a broad user's knowledge of the context and the interactions of physical, chemical and biological processes in river systems. In particular the user should have profound knowledge of standard software applications (e.g. Microsoft EXCEL 2003) and the ability to assess the input data due to their usability and reliability. Finally one should be able to formulate the objectives of a given problem in such a way that it fits with the functionality of the MONERIS model system. Each application needs a careful consideration, if the expectations of the obtained simulation results are appropriate with regard to the available input data and the particular features of the simulated river system. The reliability of the model results depends on the quality of input data as well as the methodic approaches which were chosen to acquire and describe the relevant processes in the specific river system.

MONERIS Version 2.0 is designed for different user levels. According to the individual objective and prerequisites it enables people to work with MONERIS as

- VIEWER (selection, combination and application of predefined scenarios as well as viewing and exporting the application results **without** the possibility of changing the formulas)
- MODELLER (access to all options of the VIEWER environment, possibility of loading new data, modification of scenario thresholds, modification of used parameters that will be indicated in the surface )
- MODIFIER (access to all options of the VIEWER and MODELLER environment, possibility to modify used equations, possibility to change and save modified values as standard)

The present version of the manual focuses on the VIEWER level mainly.

### I.3.2 Hardware and software requirements

During the conception and designing of MONERIS special attention was paid to the extensive application by using the widespread software of Microsoft-Office. Hence MONERIS has no software of its own but can be applied by using MS-EXCEL and can be operated on IBM-compatible personal computers (PCs) equipped with the software, random access memory (RAM), virtual memory, and hard disk space presented in Table I.3.1.

**Table I.3.1:** MONERIS Hardware and Software Requirements

Hardware / Software	Preferred Requirements
Processor	1.6 GHz
Virtual memory space	1 GB
Random access memory (RAM)	1024 MB RAM
Operating system	WINDOWS 2000, XP
ARC View	3.2
ARC GIS	9.0
Spreadsheet software	MS-Office EXCEL 2003 is an indispensable requirement since MONERIS 2.0 does not run with EXCEL 2000 or later versions

### I.3.3 Data requirements

This chapter provides a general overview of the required input data. A detailed description of the data requirements of MONERIS is given in chapter I.7, appendix C.

#### I.3.3.1 Spatial input data

For the application of MONERIS the following data are needed as geo-referenced datasets that could be integrated into a GIS. Since MONERIS is able to compute not only small sized (e.g. river Stör in North Germany, catchment size of 1,135 km<sup>2</sup>) but even large sized river basins (e.g. Danube river basin with a catchment size of 800,000 km<sup>2</sup>) the efforts of data searches depend on the chosen scale and the desired resolution. For GIS presentation of these data and the calculation results a uniform projection has to be chosen, e.g. in Central Europe the projection *Lambert Equal Area Azimuthal projection with the central meridian 20° E and the latitude of reference 55° N*.

- The **river network** is needed to calculate the water surface area (WSA). Maps like CORINE are not sufficient. The necessary information can be taken from various sources such as digitized topographical maps. For general overviews the *Environmental Research Systems Institute* (ESRI) “Digital Chart of the World” (1:1 Million, 1991/1992) is advisable.
- For the delineation of the investigation area with **catchment boundaries** and its subdivision into **sub-catchments** (= **analytical units** in MONERIS) it is necessary that the

runoff of all analytical units can be aggregated in the framework of a flow tree with a definite flow direction. The size of the analytical areas can be determined according to the objective of research and the data availability. If official catchment boundaries are not available the boundaries can be generated from the digital elevation model (e.g. SRTM-DEM data) by using "Arc Hydro Tools" from ARC GIS. The generation of the catchment boundaries can also be executed according to the position of the river monitoring stations. Therefore the geographical location of the monitoring stations in the river network as well as the location on the left or right river-bank are essential information.

- The **digital elevation model** (SRTM-DEM) from the *United States Geological Survey* (USGS) has a resolution of 3 arcsec (about 90 m × 90 m) and can be used for the delineation of the catchment borders and to give an overview of the relief in the river basin. The pathway of erosion requires input data with a spatial resolution of 100 m x 100 m, while for the estimation of the water surface area a grid of 1 km x 1km is necessary (chapter I.4.1.2).
- For **land use** classification, data from CORINE Land Cover (CLC) (*European Environment Agency* (EEA 1995) with a resolution of 100 m x 100 m can be used. The original classes of CORINE Land Cover (CLC) have to be aggregated for calculation to several classes as shown in chapter I.7, appendix C, Table C.3. If the information on land use for the investigation area is missing from CORINE, additional information on land cover can be taken from the USGS (*United States Geological Survey*, GLCC - Version 2, 1997) (Map2.5) and can be used to identify land use classes according to CORINE land cover. The spatial resolution of the USGS land cover map is 1000 m x 1000 m (based on 1-km AVHRR data spanning April 1992 through March 1993).
- **Physico-chemical soil parameters** can be derived from a digital **Soil Map** e.g. the soil map of the World (DSMW, FAO 1997) based on the FAO/UNESCO Soil Map of the World. The original scale of 1:5 000 000 can be used in terms of physico-chemical parameters such as soil texture (fen, bog, sand, silt, clay) drainage class as well as clay and nitrogen content in the upper soil layer. The data input for **erosion** can be provided by digital maps such as from the *National Institute of Public Health and the Environment* (RIVM) (1995) based on the Universal Soil Loss Equation (USLE) with a resolution of 1 km.
- A **hydrogeological map** is necessary for the differentiation of consolidated and unconsolidated rock regions as well as the depth of groundwater table (near and remote groundwater resources) within the river catchment area.
- The **hydrometeorological** input data can be obtained from interpolated distribution of precipitation data (monthly values of one arc/degree) available from the *Global Precipitation Climatology Centre* (GPCC). Maps of mean annual precipitation and mean an-

nual runoff as well as the data for summer and winter periods can be derived from these data.

- Data on **atmospheric deposition** of nitrogen oxides and ammonium with a resolution of 50 km for the years 1989-2004 can be received from the results of the *Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP)* coordinated by the *Chemical Coordinating Centre (CCC) (Norwegian Institute for Air Research, NILU)* and are needed for calculating the total nitrogen deposition in the investigated area.
- The digital maps of the **administrative areas** (districts, regions, and countries) in the river Basin are an essential information to derive population information and N-surplus.
- Concerning the **population data** absolute numbers are required for each analytical unit. In addition, a further map of population density can be created from the LandScan 2000 Global Population Database developed by *Oak Ridge National Laboratory (ORNL)*. The LandScan data set is a worldwide population database compiled on a 30" X 30" latitude/longitude grid. Census counts (at sub-national level) were apportioned to each grid cell based on likelihood coefficients which are based on proximity to roads, slope, land cover, night time lights, and other data sets. The LandScan files are available via the internet in ESRI (*Environmental Research Systems Institute*) grid format.

### I.3.3.2 Data for calculating point source emissions

For the emission from point sources the inventory of industrial discharges should include the most relevant types of industry: food-, chemical-, pulp and paper-, fertilizer-, mining-, iron and steel-, metal surface treatment-, textile-, leather industry and large agricultural plants. Further a digital map with the location of waste water treatment plants (**WWTP**) and **industrial dischargers** based on available inventories is needed. Also the portion of people connected to sewers and WWTP has to be implemented to the data base. Typical values included in the emission inventory of municipal discharges alongside the information regarding name of discharger, geographical location, river basin and main river are:

- raw water load (TPE)
- current treatment
- current capacity of WWTP (TPE)
- volume of wastewater discharge (m<sup>3</sup>/a)
- total load discharged into receiving waters (t/a)
- Plant capacity as inhabitant equivalents

### I.3.3.3 Monitoring data for surface water

The **water quality** database should comprise fortnightly and monthly values of concentration and daily or weekly discharge starting from the source of the river downstream to the outlet. Investigated nutrients for the calculations are Ammonia ( $\text{NH}_4$ ), Nitrite as Nitrogen ( $\text{NO}_2$ ), Nitrate as Nitrogen ( $\text{NO}_3$ ), Phosphates ( $\text{PO}_4$ ), Total Phosphorus (TP). Data on temperature is needed for nitrogen retention.

If the discharge was measured at another than a water quality station, some size proportional correction is necessary. To calculate the discharge at the water quality station the flow at the discharge monitoring station is multiplied with a conversion factor, which has to be determined from the relationship of the catchment areas of water quality monitoring and discharge monitoring stations (chapter I.4.1.1.2).

### I.3.3.4 Administrative and agricultural data

Administrative data have to be collected at the municipality or district level. Data on population, cultivation and livestock numbers for municipalities or districts should be available in tabular form. Administrative boundaries are needed to aggregate data on population and its proportions as follows:

- population connected to wastewater treatment plants (WWTP) and sewers
- population connected to sewers only
- population without connection to sewers.

Furthermore information on shares of combined and separate sewer systems is needed.

The derivation of the top soil **nutrient surplus** on agricultural areas at a district level is estimated according to the OECD methodology (OECD, 1997) and based on the statistical data. Information on **tile drainage** can be made available from different sources. For those regions where such information was missing, the percentage of tile drained areas can be estimated on the basis of the FAO soil map and figures given in this database on drainage capacity for the different soils. For more details see chapter I.4.2.2.5.

## I.4 Methodology and model description

### I.4.1 Water balance computation

#### I.4.1.1 Runoff within the catchment area

##### I.4.1.1.1 Hierarchical subdivision of modeling units

The subdivision of the river basin starts with the “**analytical unit (AU)**” as the smallest modelling unit of the MONERIS approach. The aggregation of all analytical units will finally lead to the river basin district (RBD) in the sense of the Water Framework Directive (WFD). As demanded by the Water Framework Directive 2000/60 EC (WFD, Art. 3.1; see EUROPEAN COMMISSION 2000) the Member States shall identify the individual river basins lying within their national territory and, for the purposes of the Directive, shall assign them to individual river basin districts. Therefore it is necessary to connect the MONERIS approach to the WFD requirements to build up a hierarchical system of the river network within a given river basin. This bottom-up structuring has to consider the definitions of sub-basin and river basin given by WFD articles as follows:

Analytical unit (AU): the smallest modelling unit within the MONERIS system

Catchment (CAT): sum of analytical units

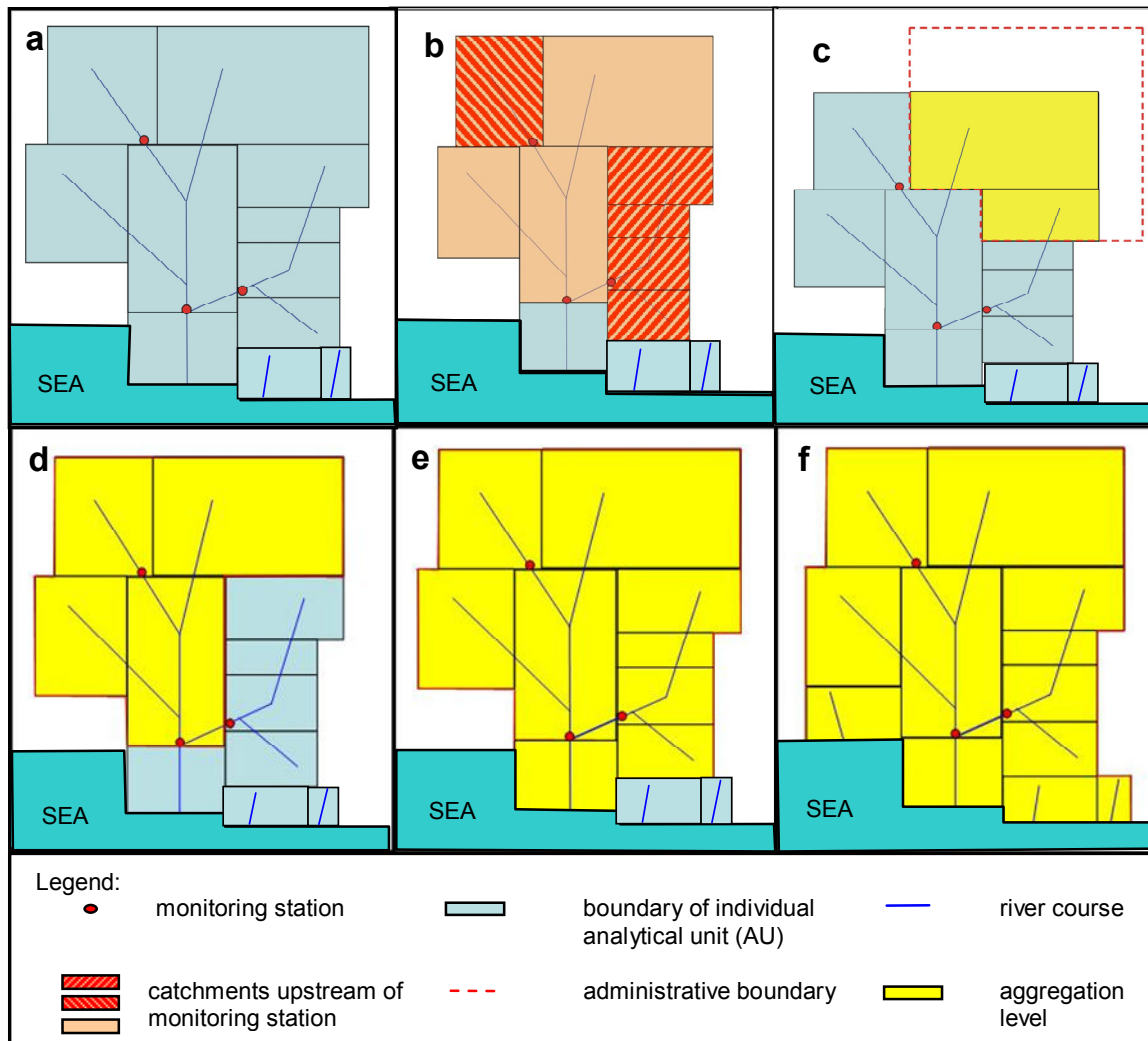
Sub-unit (SU): proportion of an administrative unit (e.g. country) in a given sub-basin

Sub-basin (SB): the area of land from which all surface runoff flows through a series of streams, rivers and, possibly, lakes to a particular point in a water course (normally a lake or a river confluence, WFD, Article 2, 1.4)

River basin (RB): the area of land from which all surface runoff flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth, estuary or delta. (WFD, Article 2, 1.3)

River basin district (RBD): the area of land and sea, made up of one or more neighbouring river basins together with their associated groundwaters and coastal waters, which is identified under Article 3 (1) as the main unit for management of river basins (WFD Article 2, 1.5)

Small river basins may be combined with larger river basins or joined with neighbouring sub-basins to form individual river basin districts where appropriate. Coastal waters shall be identified and assigned to the nearest or most appropriate river basin district. The presented structuring of the river basin is shown in Figure 4.1.



**Figure I.4.1:** Schematical subdivision of different modelling units.

**a** = Analytical Units (AU)

**b** = catchment of AU's

**c** = Sub-unit (SU)

**d** = Sub-basin (SB)

**e** = River basin (RB)

**f** = River basin district (RBD)

#### I.4.1.1.2 Flow tree

Basis of the emission and retention calculation are analytical units distinguished for an e.g. river systems or administrative borders. For these analytical units a flow tree has to be defined, which defines the flow direction for every analytical unit. So every catchment has to be allocated to the next downriver laying catchment.

The flow tree is designed on base of adequate Maps of the analytical units and the river system. To allocate the analytical units, new fields (From\_Id, To\_ID, Split\_ID, Comments) have to be added to the dbase-table of the analytical units dataset. Whereas the From\_ID field defines an ID for the analytical unit, the To\_ID refers to the downriver laying analytical unit, to which the defined analytical unit discharges. A lower From\_ID should always dewater to a higher To\_ID as the ID is also used as a sorting criteria (I.4.2). Thus the outflow of a certain

river basin is characterised by the highest ID of the basin. In general it is recommendable to start the allocation process in the furthestmost analytical unit with regard to the outflow of the river basin.

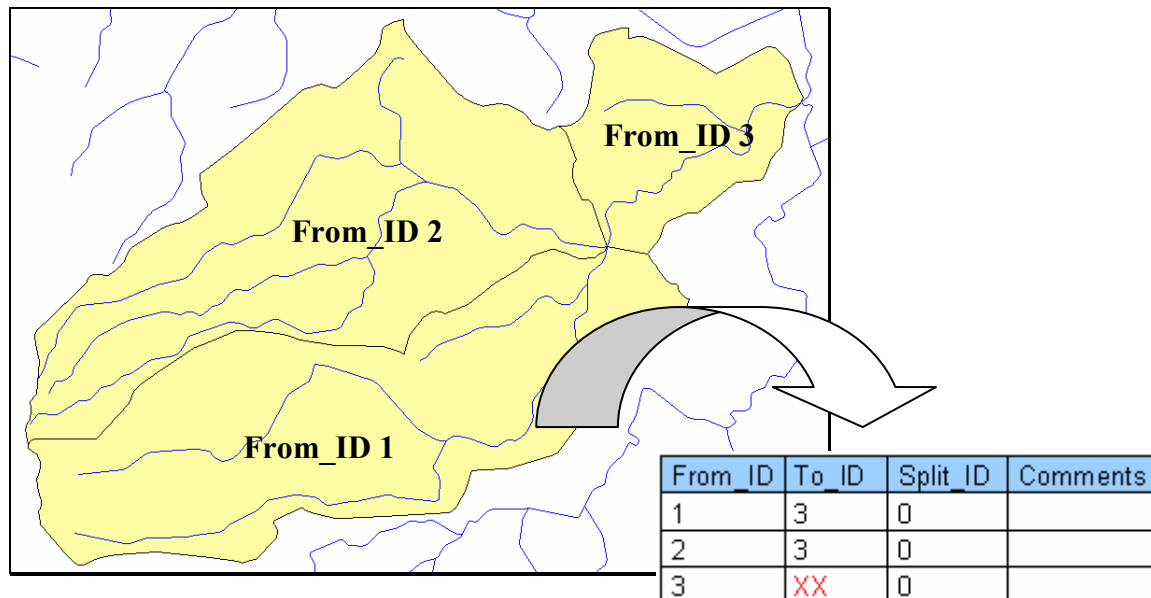


Figure I.4.2: GIS based FNE generation

If an analytical unit dewater into two different downriver laying analytical units (e.g. through a canal or a bifurcation) a Split\_ID has to be set (Figure I.4.3). In Figure I.4.3 for example, an analytical unit (yellow) dewater through a canal to another analytical unit (green) as well as to a downriver laying analytical unit. In this case, a Split\_ID has to be set:

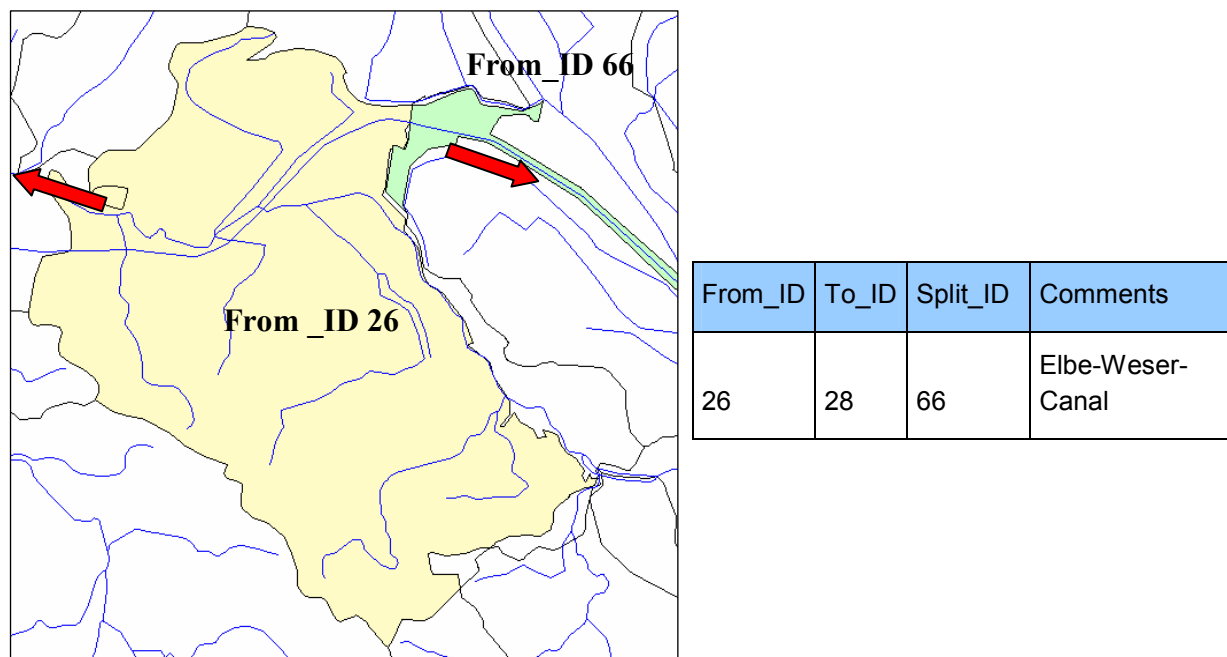


Figure I.4.3: Splitting of the River course



In some cases additional information are necessary to set the Split\_ID, concerning e.g. the flow direction of the canal.

If an Analytical unit dewater into the ocean an eye-catching ID (e.g. 99999) has to be set as To\_ID. It is recommendable to comment the ID by using the comments field of the table (e.g. “Coast Elbe”).

Special difficulties exist when the course of a river is identical (besides possible differences caused by digitising) with the course of the border between two different analytical units, e.g. because of country borders (Fig. I.4.4). In this case, the river has to be allocated to one of both areas completely.

It is relevant to use the same procedure for the FNE (Flow-Net-Equation) and WSA (water surface area) allocation.

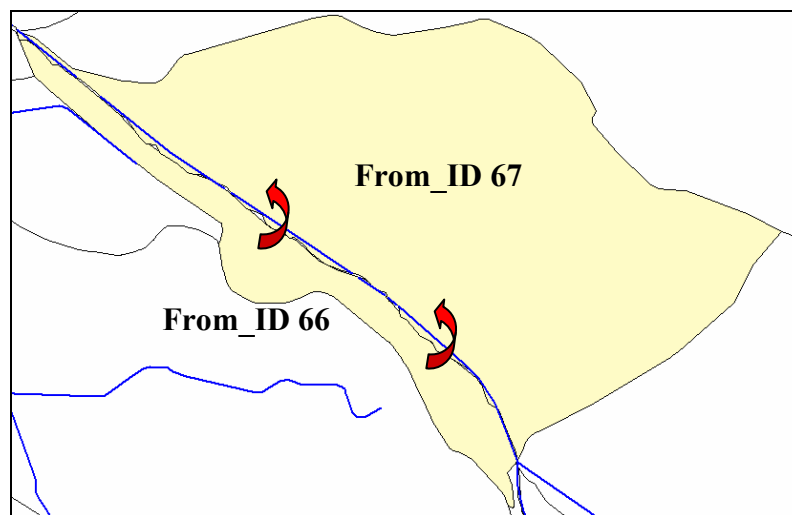


Figure I.4.4: Border Rivers

### I.4.1.1.3 Flow-Net-Equation

The **Flow-Net-Equation** (FNE) is the conversion of the flow tree information in formula for the usage in MONERIS. It describes the topology of the riversystem.

So for every analytical unit the following information are generated:

- ID of the respective analytical unit,
- the ID into which it dewater,
- the catchment area of the respective analytical unit and
- the catchment area of all analytical units, which contribute to the runoff of the respective analytical unit

A first evaluation of the results of the FNE can be carried out by using the BasicInfo worksheet. Therefore the catchment areas, which were specified with the data of the

monitoring stations have to be compared with the catchment areas (without splitting) of the monitoring stations generated by the FNE. In general a high degree of compliance between the specified and generated catchment areas of the monitoring stations is desirable. Although a deviation up to the factor “2” could be acceptable, for example if the gauge station captures only a part of the discharges of the catchment area (this could be the case if the station is located at one of the tributary river).

However, it is recommendable to control the FNE of the gauging stations with deviations  $>1.5$  to improve the performance of the runoff calibration process. Potential discrepancies can be caused due to an erroneous allocation of the analytical units in the course of the data preparation for the FNE or due to a faulty allocation of the monitoring stations.

#### I.4.1.1.4 Runoff calibration

To run MONERIS, (annual) values for the runoff for every analytical unit are indispensable. If no other model results for the runoff are available, a procedure for the runoff calibration developed at the IGB conducted by N/ETP runoff balance can be used.

To calibrate the runoff, beneath the FNE, information about annual precipitation, mean evapotranspiration and discharge at the gauge stations are necessary. Firstly, the mean runoff is calculated with averaged values (which is used e.g. for scenario calculations). To derive the annual runoff, annual values for precipitation and the discharge at the gauge stations were used. Because of mean values for evapotranspiration, factors were used to adopt the mean evapotranspiration to annual values.

#### I.4.1.2 Calculation of water surface area

The area of all surface waters within a catchment has to be quantified for the calculation of the nutrient retention in the rivers and lakes and for the calculation of the atmospheric deposition on the water surface.

The water surface area is generally available in the landuse data set in GIS. But there is one disadvantage, usually only the lake surface and rivers with high widths have aerial information, while smaller rivers are stored as linear elements, where only the river length can be obtained.

Therefore an approach was developed by VENOHR et al. (2005) for the estimation of the mean river width of main rivers and tributaries. The river width is calculated as dependent on the total catchment area, specific runoff and mean slope of the catchment (Equation I.4.1).

$$RW_{MR,TRIB} = k_{MR1,TRIB} \cdot A_{TAu,Au}^{k_{MR1,TRIB2}} \cdot q_{TAu,Au}^{k_{MR1,TRIB3}} \cdot sl_{Au}^{k_{MR1,TRIB4}} \quad (\text{Eq. I.4.1})$$

with	$RW_{MR, TRIB}$	= calculated mean river width (m)
	$A_{TAu, Au}$	= total catchment area (TAu) and analytical unit (Au) (km <sup>2</sup> )
	$Q_{TAu, Au}$	= specific runoff of the total catchment (TAu) and analytical unit (Au) (l/(s·km <sup>2</sup> ))
	$sl_{Au}$	= mean slope of the analytical unit (Au) (%)
	$k_{MR, TRIB}$	= modell coefficient (-)

For the calibration and validation approx. 500 river systems with different hydromorphological characteristics in Europe were taken. The calibration was performed on the base of river width measurements as well as on the river width given in detailed river maps.

The surface area of the rivers is added to the water surface of the lakes, differentiated for main and tributaries (Equation I.4.2). The river length of tributaries was determined for every analytical unit on base of the difference of all river lengths in the map and the lengths of the main river.

So the total area of the water surface of an analytical unit is:

$$WSA_{RW_{MR, TRIB}} = RW_{MR, TRIB} \cdot FL_{MR, TRIB} + A_{Lake} \quad (\text{Eq. I.4.2})$$

with	$WSA_{RW}$	= calculated area of the surface waters differentiated in main and tributary river (m <sup>2</sup> )
	$RW$	= river width of main rivers (MR) and tributary rivers (TRIB) (m)
	$FL$	= River length main rivers (MR) and tributary rivers (TRIB) (m)
	$ALake$	= surface area of lakes in main rivers (MR) and tributary rivers (TRIB) (m <sup>2</sup> )

The calculated total area of the surface waters was verified with statistical data of german counties.

For the calculation of the surface water area it is important to consider, that with an increasing scale of the maps the generalisation is increasing as well, so that small rivers and meanders are missing. Thus the real area of the surface water is underestimated. Therefore the river lengths in maps with different scales were compared and scale factors for main rivers ( $S_{MR}$ ) and tributary rivers ( $S_{TRIB}$ ) were deduced. For the comparison different maps in the scale of 1:25.000, 1:100.000, 1:250.000 and 1:1.000.000 is used. Data were available for 87 german catchment areas. It was assumed, that all rivers in the real lengths are given in the scale of 1:25.000.

With consideration to the scale factor the following equation for the calculation of the water surface area is conducted (Equation I.4.3)

$$WSA_{RW_{MR, TRIB}} = S_{MR, TRIB} \cdot RW_{MR, TRIB} \cdot FL_{MR, TRIB} + A_{SEE} \quad (\text{Eq. I.4.3})$$

**Table I.4.1:** Scale factor for different maps divided in main rivers (MR) and tributary rivers (TRIB)

map	Scale	Scale factor	
		$S_{\text{TRIB}}$	$S_{\text{MR}}$
DTK25	25000	1,00	1,00
UBA1000	100000	1,83	1,11
UBA-OSU1000	100000	2,10	1,11
DLM250	250000	3,23	1,11
DLM1000	1000000 (250000)	2,99	1,13
BART1000	1000000	8,40	1,18
DCW1000	1000000	6,28	1,17

## I.4.2 Quantification of nutrient emissions

### I.4.2.1 Nutrient emissions from point sources

#### I.4.2.1.1 Wastewater treatment plants

The basis for the estimation of the phosphorus and nitrogen inputs from municipal wastewater treatment plants (WWTPs) is the determination of the necessary entry parameters (see chapter I.7, annex C). The individual nutrient inputs from municipal wastewater treatment plants (WWTPs) are based on a GIS-supported inventory (e.g. list of individual WWTP with allocation to the analytical unit). It comprises the information as given in chapter I.5.3 (Table I.5.18 and I.5.19).

The annual quantity of treated runoff from WWTP is separated into industrial and commercial wastewater (QCOM), external water (QEX) and total wastewater (QTOT).

The population connected to a WWTP can be estimated depending on the size of the WWTP according to the sewage statistics for the rivers. The loads from wastewater treatment plants are calculated as the product of the mean nutrient concentration and the mean annual discharge.

$$EWW_N = 86.4 \cdot 365 \cdot Q_{WW} \cdot (CWW_N) \quad (\text{Eq. I.4.4})$$

with  $EWW_N$  = nitrogen emission from wastewater treatment plants (t/yr)  
 $Q_{WW}$  = water discharge of the wastewater treatment plant (m<sup>3</sup>/s)  
 $CWW_N$  = concentration of nitrogen in wastewater (mg/l)

$$EWW_P = 86.4 \cdot 365 \cdot Q_{WW} \cdot CWW_P \quad (\text{Eq. I.4.5})$$

with  $EWW_P$  = phosphorus emission from wastewater treatment plants (t/yr)  
 $CWW_{TP}$  = concentration of total phosphorus in wastewater (mg/l)

The N and P emissions of a WWTP can be estimated based on different methods for each plant depending on the data available. For all WWTPs the emissions can be estimated on the basis of inhabitant-specific nutrient emissions and the treatment efficiency for different types of wastewater treatment (see Table I.4.2).

**Table I.4.2:** N removal performance for various types of treatment plants

Plant type	N removal (%)
Wastewater pond (unaerated)	50
Wastewater pond (aerated)	30
Activated sludge plant	30
Mechanical treatment	10
Submerged trickling filter/Percolating filter	25
Treatment using plants	45
Nitrification	45
Denitrification	75

If detailed data for the emissions from municipal wastewater treatment plants are not available, then the emissions for the population connected to the unknown WWTPs have to be calculated.

$$EWW_N = 86.4 \cdot 365 \cdot IN_{CON} \cdot EIN_N \cdot RR_N \quad (\text{Eq. I.4.6})$$

with  $IN_{CON}$  = connected inhabitants  
 $EIN_N$  = inhabitant-specific nitrogen output (g N/(inh.·day))  
 $RR_N$  = nitrogen removal rate ( %)

$$EWW_P = 86.4 \cdot 365 \cdot IN_{CON} \cdot EIN_P \cdot RR_P \quad (\text{Eq. I.4.7})$$

with  $IN_{CON}$  = connected inhabitants  
 $EIN_P$  = inhabitant-specific phosphorus output (g N/(inh.·day))  
 $RR_P$  = phosphorus removal rate ( %)

#### I.4.2.1.2 Direct industrial discharges

Available data on direct industrial inputs have to be identified separately and will not be considered for scenario calculations.

### I.4.2.2 Nutrient emissions from diffuse sources

#### I.4.2.2.1 Nitrogen surplus and Phosphorus-Accumulation

The **soil surface balance** calculates the difference between the total quantity of nutrient inputs entering the soil and the quantity of nutrient outputs leaving the soil of the agricultural area annually. The calculation of the soil surface balance is a modified version of the so-called "*gross balance*" which provides information about the complete surplus (deficit) of nutrients into the soil, water and air from an agricultural system. Different approaches exist for the calculation of the nutrient balances on national and international level. The calculations are based on the agricultural statistics and nutrient equivalents for livestock and crops. The estimate of the annual total quantity of **nutrients inputs** for the soil surface nitrogen and phosphorus balances, includes the addition of statistical data (e.g. inorganic or chemical nitrogen and phosphorus fertilizer, livestock manure nutrient production etc.). The estimate of the annual total quantity of **nutrient outputs**, or nutrient uptake, for the soil surface nutrient balance additionally includes the quantity of harvested and forage crops.

Based upon these parameters and the coefficients of nitrogen fixation and specific N and P uptake the nutrient surplus in the agricultural area can be estimated by the following equations:

- **Nutrient Input** = Fertilisers + Net Input of Manure + Other Nutrient Inputs
- **Nutrient Output** = Total Harvested Crops + Total Forage
- **Nutrient Surplus** = Nutrient Outputs – Nutrient Inputs
- **Nutrient Surplus per Hectare Agricultural Land** = Nutrient Balance(tonnes of nutrient) divided by the Total Area of Agricultural Land (hectares)

Because these balances can be calculated only for reference years on base of the agricultural statistics, the results have to be transferred to a yearly result:

$$NS_{CY} = NS_D \cdot \frac{NS_{CCY}}{NS_{CRY}} \quad (\text{Eq. I.4.8})$$

- with  $NS_{CY}$  = calculated Nitrogen surplus per year per AU (kg/(ha·yr))
- $NS_D$  = detailed N-surplus for a reference year (kg/(ha·yr))
- $NS_C$  = longterm time series with N-surplus for countries (countries for Germany) (kg/(ha·yr))
- $NS_{CCY}$  = countrywide N\_surplus of the calculated year (kg/(ha·yr))
- $NS_{CRY}$  = countrywide N\_surplus of the reference year (kg/(ha·yr))

Nutrient balances of the agricultural area on a district level can be obtained from the OECD methodology (OECD, 1997) based on the statistical data (FAO, 2007). National calculations

are obtainable for example for Germany from the Federal Agricultural Research Centre (LANGE et al, 2006) or the University of Gießen (BACH et al., 2003).

#### **I.4.2.2.2 Nutrient emissions via atmospheric deposition**

Input data for the estimation of direct inputs into freshwaters by atmospheric deposition are:

- the area of all surface waters within a basin connected to the river system
- the P-deposition rate and N-deposition rate

The method to calculate the water surface area is described in chapter I.4.1.

For Europe, the deposition values for nitrogen, the results of the EMEP program, are available as grid maps with a cell size of 50 km as NO<sub>x</sub>-N and NH<sub>4</sub>-N deposition in kg N/(ha·yr). Other data, e.g. national data with a better resolution are also available, e.g. for Germany (GAUGER et al., 2006).

The deposition data have to be overlaid with the catchment boundaries for the estimation of the mean NO<sub>x</sub>-N and NH<sub>4</sub>-N deposition within the catchments.

Total P-deposition rate - depending on land use of the concerned area - may be between 0.3 and 3.0 kg P/(ha·yr). On the base of statistical data analysis (BEHRENDT et al., 2002) a mean value of 0.37 kg P/(ha·yr) is used for European catchments. For other countries the value can be changed on base of statistical data.

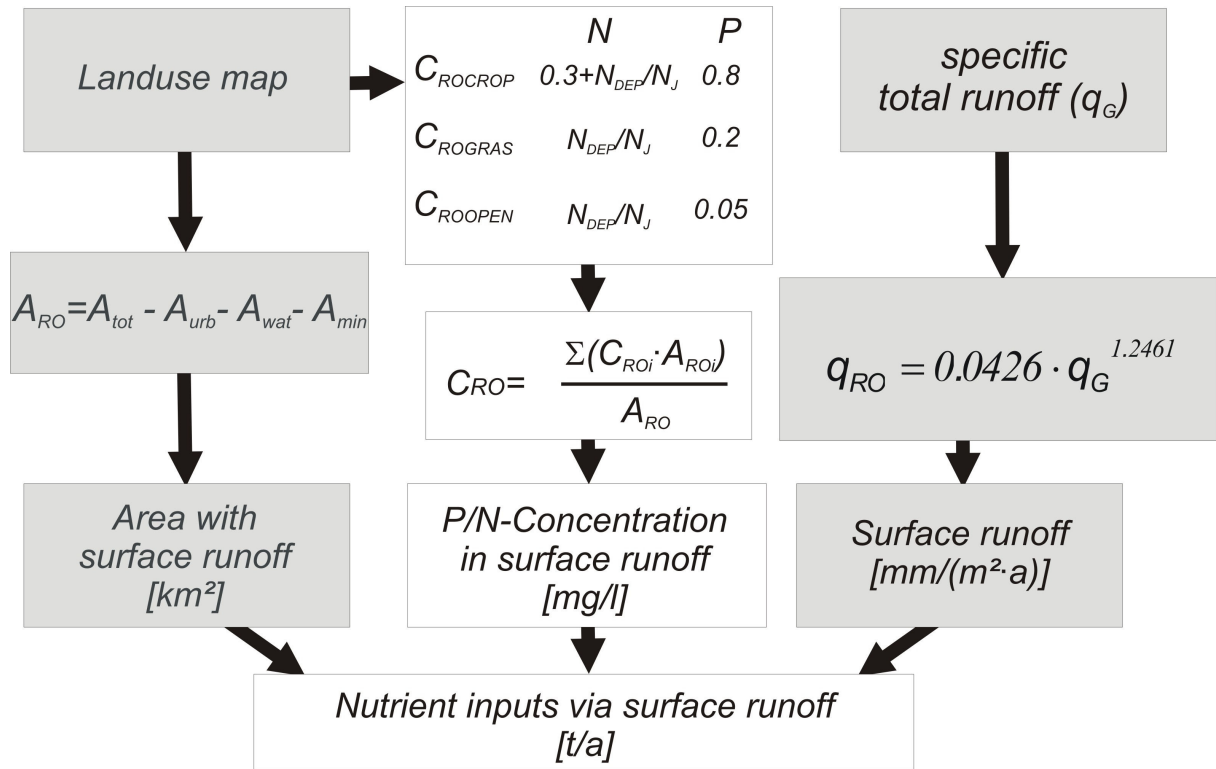
The nutrient inputs via atmospheric deposition are calculated from the product of the area-specific deposition and the mean area of surface waters in a catchment.

$$EAD_{N,P} = A_W \cdot DEP_{N,P} \quad (\text{Eq. I.4.9})$$

with  $EAD_{N,P}$  = nutrient emissions via atmospheric deposition (t/yr)  
 $DEP_{N,P}$  = area-specific deposition (t/(km<sup>2</sup>·yr))

#### **I.4.2.2.3 Nutrient emissions via surface runoff**

The inputs of dissolved nutrients by surface runoff were determined according to the scheme presented in Figure I.4.5.



**Figure I.4.5:** Nutrient emissions via surface runoff

The surface runoff is calculated with an approach developed by CARL & BEHRENDT (2003), which describes the surface runoff as function of the total runoff. The results of this conceptual time series model are comparable with the results of the hydrological models SWAT and DIFGA applied for the case study catchments within the daNUbs-project (ZESSNER et al., 2003).

The function is given in the following equation (I.4.10):

$$q_{RO} = 0.0426 \cdot q_G^{1.2461} \quad (\text{Eq. I.4.10})$$

with  $q_{RO}$  = specific surface runoff (l/(km<sup>2</sup>·s))  
 $q_G$  = average yearly specific runoff (l/(km<sup>2</sup>·s))

The average yearly specific runoff  $q_G$  is calculated for each analytical unit as the quotient between the measured runoff ( $Q$ ) and the area of the analytical unit. For the analytical units the surface runoff is calculated from specific long-term total runoff for the catchments by overlay of the catchment boundaries with the specific long term runoff. The total surface runoff within a catchment can be calculated from the product of the specific surface runoff with the total area. But it has to be considered that paved urban areas cause surface runoff, too. Therefore the surface runoff from natural areas within the catchment is:

$$Q_{RO} = 86.4 \cdot 365 \cdot q_{RO} \cdot A_{EZG} - Q_{URB} \quad (\text{Eq. I.4.11})$$



with  $Q_{RO}$  = surface runoff from non-paved areas (m<sup>3</sup>/s)  
 $A_{EZG}$  = catchment area (km<sup>2</sup>)  
 $Q_{URB}$  = surface runoff of urban areas (m<sup>3</sup>/s)

The estimation of nutrient inputs via surface runoff considers only the dissolved nutrient components transported with the surface runoff into river systems. The nutrient concentration in surface runoff of every analytical unit can be estimated as area-weighted mean of the concentrations in the surface runoff of the different land use categories and requires the division of the agricultural areas into arable land and grassland. For the area-weighted concentrations of nitrogen and phosphorus in surface runoff, the following is valid:

$$C_{RO_{N,P}} = \frac{C_{ROAR_{N,P}} \cdot A_{AR} + C_{ROGRAS_{N,P}} \cdot A_{GRAS} + C_{ROFOR_{N,P}} \cdot A_{FOR} + C_{ROOP_{N,P}} \cdot A_{OP}}{A_{AR} + A_{GRAS} + A_{FOR} + A_{OP}} \quad (\text{Eq. I.4.12})$$

with  $C_{RO_{N,P}}$  = nutrient concentration in surface runoff (mg/l)  
 $A_{AR}$  = area of arable land (km<sup>2</sup>)  
 $A_{GRAS}$  = grassland area (km<sup>2</sup>)  
 $A_{FOR}$  = area of forest (km<sup>2</sup>)  
 $A_{OP}$  = open area (km<sup>2</sup>)  
 $C_{ROAR_{N,P}}$  = nutrient concentration in surface runoff from arable land (mg/l)  
 $C_{ROGRAS_{N,P}}$  = nutrient concentration in surface runoff from grassland (mg/l)  
 $C_{ROFOR_{N,P}}$  = nutrient concentration in surface runoff from forest (mg/l)  
 $C_{ROOP_{N,P}}$  = nutrient concentration in surface runoff from open land (mg/l)

The nutrient input via surface runoff to the river system is therefore:

$$ERO_{N,P} = C_{RO_{N,P}} \cdot Q_{RO} \cdot 86.4 \cdot 365 \quad (\text{Eq. I.4.13})$$

with  $ERO_{N,P}$  = ..nutrient input via surface runoff (t/yr)

For the calculation of the emissions by surface runoff the nutrient concentrations given in Table I.4.3 are used for all analytical units (BEHRENDT et al., 2000).

**Table I.4.3:** Nutrient concentrations in surface runoff for arable land, grassland and open areas

Use	Nitrogen	Phosphorus
	[g/m <sup>3</sup> N]	[g/m <sup>3</sup> P]
Arable land	0.3+N <sub>DEP</sub> /N <sub>J</sub>	0.8
Grassland	N <sub>DEP</sub> /N <sub>J</sub>	0.2
Forest	N <sub>DEP</sub> /N <sub>J</sub>	0.035
Open land	N <sub>DEP</sub> /N <sub>J</sub>	0.035

#### I.4.2.2.4 Nutrient emissions via water erosion

The estimation of nutrient emissions from soil erosion is shown in Figure I.4.6 with consideration of sediment inputs and the nutrient enrichment ratio.

For the calculation of soil erosion different maps of potential soil losses can be used, depending on the availability of such maps. For larger river basins in Europe the potential soil loss map PESERA is available from JRC. But IGB has established also an own potential soil loss map based on the NASA-SRTM DEM, CORINE landcover and the European Soil map of the European Soil Bureau.

To be able to calculate long-term average on-site soil erosion according to USLE based on soil losses, the sediment delivery ratio (SDR) of a catchment must be determined (WALLING, 1983; 1996). For the modelling of sediment input potentials of running waters, a GIS based system was developed which allows the calculation of the area of a catchment to which running water sediment inputs contribute. For that, a high-resolution digital data-set (river-network, land-use, soil and elevation data) was used. Up to now, this is only possible for some catchments, so a modification was required so that the data could be applied to other catchments. For this, the relationship between the SDR and particular catchment characteristics or parameters from the available low-resolution digital database was sought. Using a non-linear multiple regression, beside slope the proportion of arable land is typically identified as the parameter which has the greatest influence on the sediment delivery ratio (SDR).

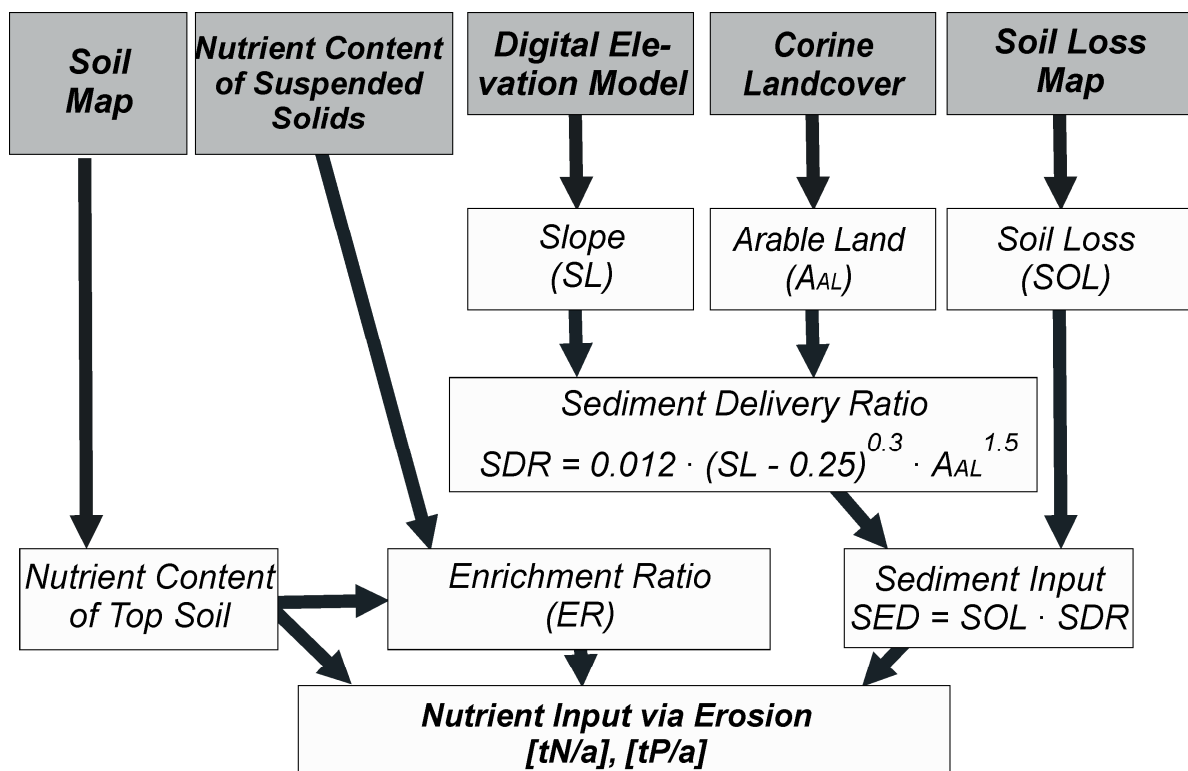


Figure I.4.6: Nutrient emissions via erosion

The sediment delivery ratio for the sub-catchments is determined according to Equation I.4.14 (BEHRENDT et al., 2000):

$$SDR = 0.012 \cdot (SL_{CA} - 0.25)^{0.3} \cdot A_{AR}^{1.5} \quad (\text{Eq. I.4.14})$$

with SDR = sediment delivery ratio (%)  
 SL<sub>CA</sub> = mean slope from USGS-DEM (%)  
 A<sub>AR</sub> = area of arable land from CLC (%)

The sediment input due to erosion for the river basins is then calculated according to Equation I.4.15:

$$SED = SOL \cdot SDR \quad (\text{Eq. I.4.15})$$

with SED = sediment input (t/a)  
 SOL = soil loss (t/a)

For the calibration of the SDR model for use over long time-periods, it is necessary to use a weighting factor for two periods in consideration of the great variability of transport of suspended particulates over time. This weighting factor is calculated from the relationship of the number of heavy rain event days (according to ROGLER & SCHWERDTMANN, 1981) in the two periods considered to the number in the total period.

The P-content of surface soils in the two study periods was calculated on the basis of annual P-surplus and its cumulative values for each German state for the period 1955 to 1996. The starting value for the surface-soil P-content in the mid fifties is based on the information of WERNER et al. (1991). The spatial differentiation of the starting value is based on the clay content of the various soil types of the general soil map. The particular P-content of arable soils for the two study periods is based on the previous P-accumulation in the individual states and the spatially differentiated background content. For the calculation of N-emissions via erosion, information on N-content of arable soils in the soil map is used.

The relationship of phosphorus content in particulates of rivers with high discharges to the estimated P-content of surface soils is the basis for the determination of the enrichment ratio (ER). With this it can be concluded that the ER is inversely proportional to the root of the specific sediment input of a catchment.

For the TP and TN content of the topsoil the values derived from the soil map and long-term accumulation of P in agricultural soils are used (see above).

The enrichment ratio is calculated according to the following equations from BEHRENDT et al. (2000):

$$ER_p = 18 \cdot \left( \frac{SOL}{A} \right)^{-0.47} \quad (\text{Eq. I.4.16})$$

with ER<sub>p</sub> = enrichment ratio for phosphorus

$$ER_N = 7.7 \cdot \left( \frac{SOL}{A} \right)^{-0.47} \quad (\text{Eq. I.4.17})$$

with  $ER_N$  = enrichment ratio for nitrogen

The nutrient inputs by erosion are finally calculated as the product of the nutrient content of soil, the enrichment ratio and the sediment input:

$$EER_P = 86.4 \cdot 365 \cdot P_{SOIL} \cdot ER_P \cdot SED \quad (\text{Eq. I.4.18})$$

$$EER_N = 86.4 \cdot 365 \cdot N_{SOIL} \cdot ER_N \cdot SED \quad (\text{Eq. I.4.19})$$

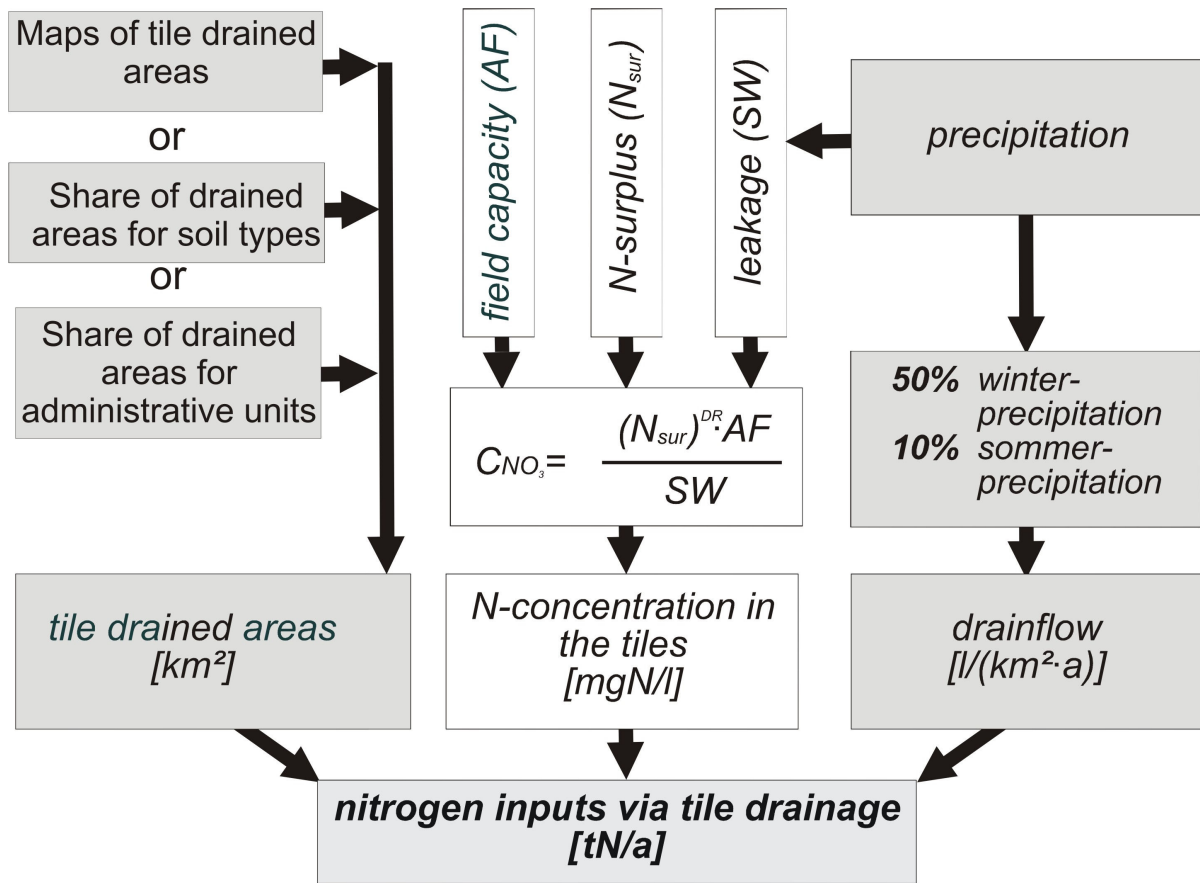
with  $EER_{N,P}$  = nutrient input via erosion (t/a)

#### I.4.2.2.5 Nutrient emissions via tile drainage

The quantification of nitrogen and phosphorus inputs through tile drainage is based on the size of the drained area, the amount of drainage water and the average nutrient concentrations in the drainage water (Figure I.4.7).

For the estimation of the size of drained areas within a basin three types of input data are possible:

- Maps of tile drained areas
- Share of drained areas for soil types transferred from representative areas with information about tile drained areas (BEHRENDT et al., 2000 or HIRT, 2005a,b)
- regional statistics for administrative areas, e.g. for municipalities



**Figure I.4.7:** Nutrient emissions via tile drainage runoff

The drainage water volume is calculated according to KRETZSCHMAR (1977) under the assumption that the drained water is the sum from 50 % of the winter and 10 % of the summer precipitation:

$$q_{DR} = 0.5 \cdot P_{WI} + 0.1 \cdot P_{SU} \quad (\text{Eq. I.4.20})$$

with  $q_{DR}$  = specific drain water flow (mm/(m<sup>2</sup>·a))  
 $P_{WI}$  = average precipitation in the winter half year (mm/(m<sup>2</sup>·a))  
 $P_{SU}$  = average precipitation in the summer half year (mm/(m<sup>2</sup>·a))

This approach takes into account the regional different distribution of rainfall and the volume of drainage water. On the basis of measurements, average P concentrations in the drainage water for various soil types were determined. The results are shown in Table I.4.4. The P concentration in the catchments was calculated as an area-weighted mean on the basis of the values in Table I.4.4 and the areas of sandy soils, loams, fen and bog soils according to the soil map:

$$C_{DRP} = \frac{C_{DRSp} \cdot A_{DRS} + C_{DRLp} \cdot A_{DRL} + C_{DRFp} \cdot A_{DRF} + C_{DRBp} \cdot A_{DRB}}{A_{DRS} + A_{DRL} + A_{DRF} + A_{DRB}} \quad (\text{Eq. I.4.21})$$

with  $C_{DRP}$  = drainage water phosphorus concentration (mg P/l)  
 $C_{DRSp}$  = drainage water phosphorus concentration for sandy soil (mg P/l)

- $C_{DRLP}$  = drainage water phosphorus concentration for loamy soil (mgP/l)  
 $C_{DRFP}$  =..drainage water phosphorus concentration for fen soil (mg P/l)  
 $C_{DRBP}$  =..drainage water phosphorus concentration for bog soil (mg P/l)  
 $A_{DRS}$  =..area of drained sandy soil (km<sup>2</sup>)  
 $A_{DRL}$  =..area of drained loams (km<sup>2</sup>)  
 $A_{DRF}$  = area of drained fen soil (km<sup>2</sup>)  
 $A_{DRB}$  = area of drained bog soil (km<sup>2</sup>)

**Table I.4.4:** P concentrations used for drainage water for different soil types

Soil type	$C_{DRP}$ (mg P/l)
Sandy soils	0.20
Loamy soils	0.06
Fen soils	0.30
Bog soils	10.00

The calculation of nitrogen concentrations follows the methods described in BEHRENDT et al. (2000) and is based on the regionally differentiated N surpluses. From the N surpluses, the leakage water quantity and the exchange factor, the potential nitrate concentration in the infiltrating water is calculated according to FREDE & DABBERT (1998). This potential nitrate concentration in the upper soil layer is reduced by a denitrification factor (DR) which was estimated to 0.85 (BEHRENDT et al., 2000). The following equation is used for the calculation of the nitrate concentration in drainage water:

$$C_{DRNO3-N} = 86.4 \cdot \frac{(N_{SUR})^{DR} \cdot 100}{LW} \quad (\text{Eq. I.4.22})$$

- with  $C_{DRNO3-N}$  = nitrate concentration in drainage water (g N/l)  
 $N_{SUR}$  = nitrogen surplus of agricultural areas (kg N/(ha·yr))  
 DR = exponent for denitrification (0.85)  
 LW = leakage water quantity (l/(m<sup>2</sup>·a))

The emission via tile drainage can then be calculated from the product of the drained area, the drain flow and the drain concentration:

$$EDR_{N,P} = 86.4 \cdot A_{DR} \cdot q_{DR} \cdot C_{DRN,P} \quad (\text{Eq. I.4.23})$$

- with  $EDR_{N,P}$  = nutrient emissions via tile drainage (t/yr)  
 $A_{DR}$  = drained area (km<sup>2</sup>)

#### I.4.2.2.6 Nutrient emissions via groundwater

The nutrient inputs by groundwater are calculated from the product of the groundwater outflow and the groundwater nutrient concentration and include the natural interflow and the base flow. Figure I.4.8 shows a scheme for the calculation of nitrogen emissions via groundwater.

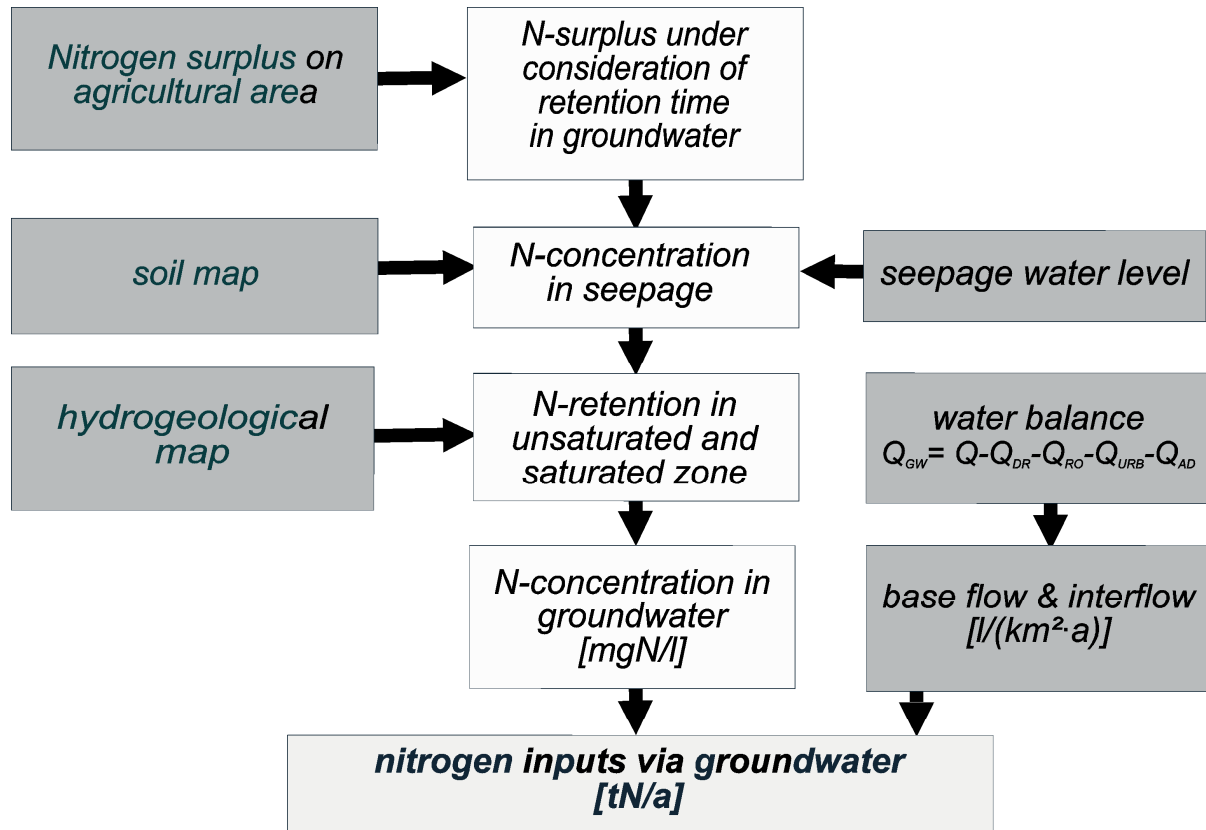


Figure I.4.8: Nitrogen emissions via groundwater

The groundwater flow was calculated for each analytical unit from the difference of the total runoff and the estimated sum of the other discharge components (tile drainage flow, surface runoff, storm water runoff from paved urban areas, and atmospheric input flow):

$$Q_{GW} = Q - Q_{DR} - Q_{RO} - Q_{URB} - Q_{AD} \quad (\text{Eq. I.4.24})$$

- with
- $Q_{GW}$  = base flow and natural interflow (m<sup>3</sup>/s)
  - $Q$  = average runoff (m<sup>3</sup>/s)
  - $Q_{DR}$  = tile drainage flow (m<sup>3</sup>/s)
  - $Q_{RO}$  = surface runoff from non-paved areas (m<sup>3</sup>/s)
  - $Q_{URB}$  = surface runoff from urban areas (m<sup>3</sup>/s)
  - $Q_{AD}$  = atmospheric input flow (m<sup>3</sup>/s)

### *P-concentration in the groundwater*

Groundwater concentrations of soluble reactive phosphorus (SRP) for the different soil types are taken from BEHRENDT et al. (2000) (Table I.4.5). Using these values, the P concentration in the analytical units is calculated on the basis of the concentrations and the areas of sandy soils, loamy soils, fen and bog soils as area-weighted average for the agricultural land according to Equation I.4.25:

$$C_{GWAG_{SRP}} = \frac{C_{GWS_{SRP}} \cdot A_S + C_{GWL_{SRP}} \cdot A_L + C_{GWF_{SRP}} \cdot A_F + C_{GWB_{SRP}} \cdot A_B}{A_S + A_L + A_F + A_B} \quad (\text{Eq. I.4.25})$$

with	$C_{GWAG_{SRP}}$	= groundwater SRP concentration for agricultural land (mg P/l)
	$C_{GWS_{SRP}}$	= groundwater SRP concentration for sandy soil (mg P/l)
	$C_{GWL_{SRP}}$	= groundwater SRP concentration for loamy soil (mg P/l)
	$C_{GWF_{SRP}}$	= groundwater SRP concentration for fen soil (mg P/l)
	$C_{GWB_{SRP}}$	= groundwater SRP concentration for bog soil (mg P/l)
	$A_S$	= area of sandy soil (km <sup>2</sup> )
	$A_L$	= area of loamy soil (km <sup>2</sup> )
	$A_F$	= area of fen soil (km <sup>2</sup> )
	$A_B$	= area of bog soil (km <sup>2</sup> )

**Table I.4.5:** SRP-concentrations in groundwater for various soil types

Soil type	Use	Expression	$C_{GW_p}$ (g P/m <sup>3</sup> )
Sandy soils	Agricultural land	$C_{GWS_p}$	0.1
Loam	Agricultural land	$C_{GWL_p}$	0.03
Fen soils	Agricultural land	$C_{GWNM_p}$	0.1
Bog soil	Agricultural land	$C_{GWHM_p}$	2.5
	Woodland/open areas	$C_{GWWAOF_p}$	0.02

In a second step, the average particular SRP concentrations in groundwater of the analytical units are calculated as an area-weighted average from the SRP concentrations of agricultural and non-agricultural areas:

$$C_{GW_{SRP}} = \frac{C_{GWAG_{SRP}} \cdot A_{AG} + C_{GWWOOP_{SRP}} \cdot A_{WOOP}}{A_{AG} + A_{WOOP}} \quad (\text{Eq. I.4.26})$$

with	$C_{GWS_{SRP}}$	= SRP concentration in groundwater (mg P/l)
	$C_{GWWOOP_{SRP}}$	= groundwater SRP conc. for woodland and open areas (mg P/l)
	$A_{WOOP}$	= woodland and open area (km <sup>2</sup> )

Further it should be taken into account that there are clear differences between the concentrations of soluble reactive phosphorus (SRP) and total phosphorus in anaerobic groundwater (DRIESCHER & GELBRECHT, 1993). The concentration of TP for aerobic groundwater is the same as the SRP-concentration, but for anaerobic groundwater it has to be



taken in account that a difference between TP and SRP exist. According to BEHRENDT (1996) and DRIESCHER & GELBRECHT (1993) it can be concluded that the total phosphorus concentrations are 2 to 5 times higher than SRP concentrations determined in the normal standard monitoring programmes. Since information on areas of anaerobic groundwater is not available, areas with a higher probability of anaerobic conditions are determined through a comparison of nitrate concentrations in groundwater and those in leakage water (see below). For the calculation of total phosphorus concentrations in groundwater it was therefore determined that in accordance with Equations I.4.27 and I.4.28, nitrogen concentrations in groundwater exceed a critical value ( $l_{gw}$ ) and the TP-concentrations in groundwater are 2.5 times greater than the SRP concentrations. Normally, the value of  $l_{gw}$  is in a range of 0.05 to 0.15.

$$C_{GW_{TP}} = 2.5 \cdot C_{GW_{SRP}} \quad \text{if } C_{GW_N} \leq l_{gw} \cdot C_{SW_N} \quad (\text{Eq. I.4.27})$$

$$C_{GW_{TP}} = C_{GW_{SRP}} \quad \text{if } C_{GW_N} > l_{gw} \cdot C_{SW_N} \quad (\text{Eq. I.4.28})$$

with  $C_{GW_N}$  = nitrogen concentration in groundwater ( $\text{g/m}^3$ )  
 $C_{SW_N}$  = nitrogen concentration in leakage water ( $\text{g/m}^3$ )  
 $C_{GW_{TP}}$  = TP concentration in groundwater ( $\text{g/m}^3$ )  
 $C_{GW_{SRP}}$  = SRP concentration in groundwater ( $\text{g/m}^3$ )

### ***N-concentration in the groundwater***

The N concentrations in the groundwater are derived from the potential nitrate concentration in the top soil. For the fact that the residence time of water and substances on their way from the root zone to the groundwater and in the groundwater itself is much larger than for tile drainage, this residence time has to be taken into account for the groundwater pathway. The reasons are on the one hand that the quantity of N-losses through denitrification can be dependent on time. On the other hand, the level of the nitrogen surplus of the agricultural area is changing over time and therefore the nitrogen in groundwater flowing recently into the surface waters is in relation to the N surpluses in the past.

A rough approximation of the water residence time in the unsaturated zone and in the aquifer can be given on the basis of long-term observations of nitrate concentrations in rivers and long-term estimates of nitrogen surplus. BEHRENDT et al. (2000), in a comparison of long-term changes of the nitrogen surplus averaged over different periods of previous years with the long-term behaviour of the observed nitrate concentrations in the river Elbe, found mean residence times of about 30 years. Based on application of the WEKU model (KUNKEL & WENDLAND, 1999; KUNKEL et al., 2007) found a median of 29 years for the residence time for groundwater in the unconsolidated rock region of the Elbe basin, which corresponds with the result of BEHRENDT et al. (2000).

For German areas the estimations for the water residence time of KUNKEL & WENDLAND (1999) were used. For areas where no information about the water residence time is available it is assumed that the water residence time account for

$$TT_{GW} = \frac{3000}{q_{gw}} \quad (\text{Eq. I.4.29})$$

with  $q_{gw}$  = specific groundwater flow (mm/(m<sup>2</sup>·a))  
 $TT_{GW}$  = Travelling time of the groundwater

$$q_{GW} = \frac{Q_{GW}}{A_{CA}} \cdot 86.4 \cdot 365 \quad (\text{Eq. I.4.30})$$

Based on these results, the nitrogen surpluses for the different analytical units were corrected according to the following formula:

$$N_{TTSUR} = \frac{1}{TT_{GW}} \sum_{t=t_0}^{t_0-TT_{GW}} N_{sur_t} \quad (\text{Eq. I.4.31})$$

with  $N_{TTSUR}$  = average nitrogen surplus within the period of travelling time (kg/ha)  
 $N_{sur_t}$  = nitrogen surplus of agricultural areas (kg/ha)

The N surplus values thus estimated are used for the calculation of the overall potential nitrate concentrations in leakage waters for the areas contributing to base flow. For this, the first steps of the approach of FREDE & DABBERT (1998) are used. A condition for this is that the net-mineralisation and immobilisation are negligible. Then, the following applies:

$$C_{LWPOT_{NO3-N}} = \frac{N_{TTSUR} \cdot 100}{q_{gw}} \quad (\text{Eq. I.4.32})$$

with  $C_{LWPOT_{NO3-N}}$  = potential nitrate concentration in leakage water for the total area with base flow (g N/m<sup>3</sup>)

The nitrogen retention (mainly denitrification) in the soil, the unsaturated zone and the groundwater is calculated from the comparison of the regionalized groundwater concentrations of nitrate and the potential nitrate concentration in leakage water. This comparison was carried out for the whole of Germany. It could be shown that the nitrogen retention is dependent on the level of infiltration water and the hydrogeological conditions according to Map II.8. The model coefficients are given in Table I.4.6.

$$C_{GW_{NO3-N}} = \left( \sum_{i=1}^4 \frac{1}{1 + k_{1i} \cdot LW^{k_{2i}}} \cdot \frac{A_{HRT_i}}{A_{CA}} \right) \cdot C_{LWPOT_{NO3-N}}^b \quad (\text{Eq. I.4.33})$$

with  $C_{GW_{NO3-N}}$  = nitrate concentration in groundwater (g N/m<sup>3</sup>)  
 $b$  = model coefficient for denitrification (0.641)  
 $k_1$  and  $k_2$  = model coefficients  
 $A_{HRT}$  = area of different hydrogeological rock types (km<sup>2</sup>)

**Table I.4.6:** Model coefficients for the determination of N retention in areas with different hydrological conditions

Hydrogeological rock type	K <sub>1</sub>	K <sub>2</sub>	B
Unconsolidated rock areas near groundwater	2.752	-1.54	0.627
Unconsolidated rock areas far groundwater	68.560	-1.96	0.627
Solid rock areas with good porosity	6.02	-0.90	0.627
Solid rock areas with poor porosity	0.0127	0.66	0.627

Finally, the nutrient emissions via groundwater are estimated from the product of the regionalized nutrient concentrations and the groundwater flow of the basins:

$$EGW_{N,P} = 86.4 \cdot 365 \cdot Q_{GW} \cdot C_{GW_{N,P}} \quad (\text{Eq. I.4.34})$$

with  $EGW_{N,P}$  = nutrient emissions via groundwater (t/yr)

The nutrient emissions via groundwater are calculated for each of the analytical units.

DON emissions are needed for the riverine nitrogen retention. For the calculations it is assumed that DON underlies no retention and it therefore has to be subtracted from the total nitrogen emissions. Only the concentration of long-chained DON molecules should be considered for this pathway.

DON emissions via groundwater are calculated by applying the groundwater recharge for forested areas and wetlands. DON concentrations can be set for forested areas and wetlands separately. DON concentrations typically vary widely between 0 and 6 mg/l. DON concentrations in forests are often lower than in wetlands and in warmer climates they can drop to 0 mg/l.

#### I.4.2.2.7 Nutrient emissions from paved urban areas

Within this pathway nutrient inputs stem from four different routes:

- inputs from impervious urban areas connected to separate sewer systems
- inputs from impervious urban areas by combined sewer overflows
- inputs from households and impervious urban areas connected to sewers without treatment
- inputs from households and impervious urban areas not connected to sewer systems

The total urban area can be taken from a landuse map, e.g. the CLC map. For the calculation of the impervious urban area, the population density is also taken into account according to the approach of HEANEY et al. (1976):

$$A_{IMP} = 9.6 \cdot (0.4047 \cdot POP_{DEN})^{0.573 - 0.0391 \cdot \log(0.4047 \cdot POP_{DEN})} \cdot A_{URB} \quad (\text{Eq. I.4.35})$$

with  $A_{IMP}$  = impervious urban area (km<sup>2</sup>)  
 $A_{URB}$  = total urban area (km<sup>2</sup>)  
 $POP_{DEN}$  = population density (inhabitants/ha)

The total paved urban area is split into the different sewer systems according to the percentage of the different sewer systems in the catchments. For Germany, the statistics of the German states is used for the length of combined, waste water and separate sewers.

The mean elevation of the analytical units is derived from a Digital Elevation Model (Map II.2) to separate combined and separated sewer. To calculate the total discharge from the different sewer systems, the calculation of surface runoff from impervious areas as the proportion of precipitation is necessary. These values can be calculated according to HEANEY et al. (1976) for every analytical unit from the level of impervious areas with Equation I.4.36:

$$a_{IMP} = 0.15 + 0.75 \cdot \frac{A_{IMP}}{A_{URB}} \quad (\text{Eq. I.4.36})$$

with  $a_{IMP}$  = share of precipitation realized as surface runoff from impervious urban areas

With the share of the precipitation realized as surface runoff from impervious urban areas and the yearly rainfall, the specific surface runoff which is discharged from impervious urban areas during storm water events can be estimated for all analytical units:

$$q_{IMP} = a_{IMP} \cdot P_Y \quad (\text{Eq. I.4.37})$$

with  $q_{IMP}$  = specific surface runoff from impervious urban areas (l/(m<sup>2</sup>·a))

The total surface runoff from impervious urban areas discharged by combined and separated sewers can be calculated by multiplication of the specific surface runoff with the impervious urban areas connected to the different types of sewer system.

A schematic overview of the applied method is given in Figure I.4.9.

### ***Nutrient emissions from separate sewer systems***

The nutrient emission via **separate sewer systems** is estimated by means of area-specific emissions. Referred to BROMBACH & MICHELBACH (1998) we use an area-specific P emission (of 2.5 kg P/(ha·yr). The area-specific N emissions is calculated from the sum of the atmospheric N deposition and a value for leaf-litter and excreta from animals (4 kg N/(ha·yr). The N and P inputs are calculated by multiplying the area-specific emissions with the paved urban area connected to separate sewer systems.

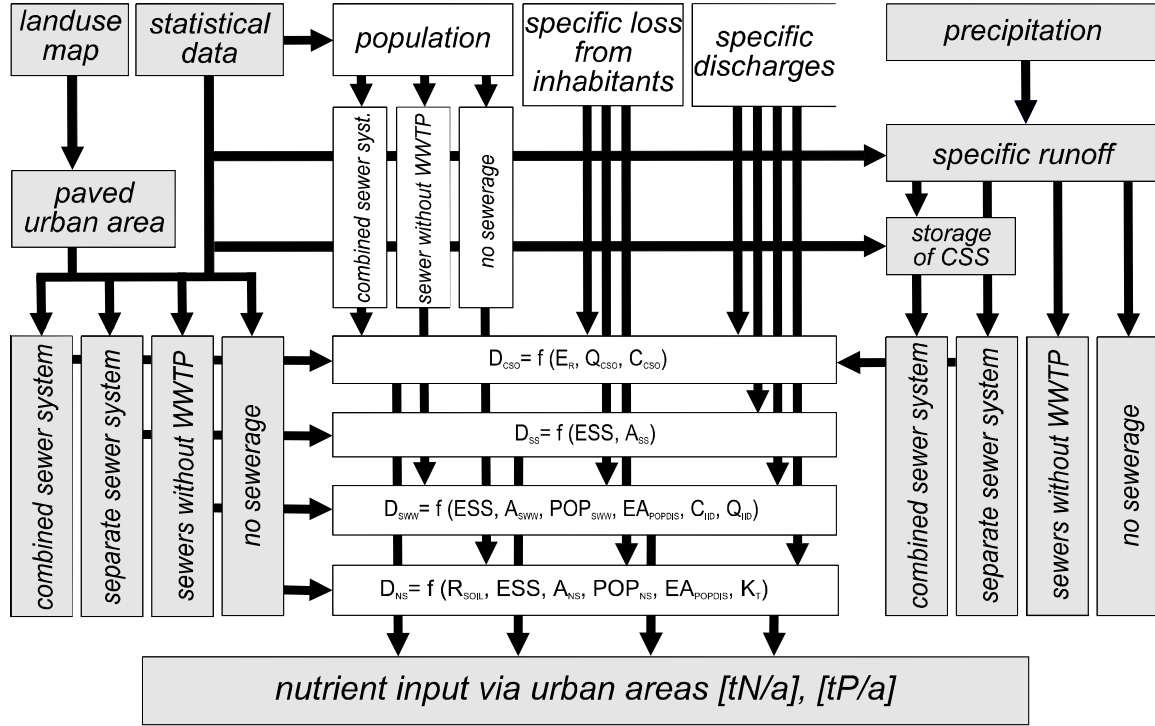


Figure I.4.9: Nutrient emissions from urban areas

$$EUS_{N,P} = ES_{IMP_{N,P}} \cdot A_{IMPS} \quad (\text{Eq. I.4.38})$$

with  $EUS_{N,P}$  = nutrient inputs via separate sewers (t/yr)  
 $ES_{IMP}$  = specific nutrient emissions from impervious urban areas (t/(km<sup>2</sup>·a))  
 $A_{IMPS}$  = impervious urban area connected to separated sewer system (km<sup>2</sup>)

### Nutrient emissions from combined sewer overflows

The estimation of the nutrient emissions is based on the approaches from MOHAUPT et al. (1998) and BROMBACH & MICHELBACH (1998).

The quantity of water discharged during storm water events from combined sewer overflows is dependent on the specific runoff from the paved urban areas, the number of people connected to combined sewers, the inhabitant-specific water discharge, the share of industrial areas in the total impervious urban area, the area specific runoff from these industrial areas and the number of the days with storm water events:

$$Q_{IMPC} = q_{imp} \cdot A_{IMPC} + Z_{NST} \cdot (IN_C \cdot q_{IN} + a_{COM} \cdot q_{COM} \cdot 100 \cdot 86.4 \cdot A_{URB}) \quad (\text{Eq. I.4.39})$$

with  $Q_{IMPC}$  = storm water runoff from combined sewer system (m<sup>3</sup>/yr)  
 $A_{IMPC}$  = impervious urban area connected to combined sewer system (km<sup>2</sup>)  
 $Z_{NST}$  = effective number of storm water days  
 $IN_C$  = number of inhabitants connected to combined sewer system  
 $q_{IN}$  = daily wastewater output per inhabitant (l/(E·d))  
 $a_{COM}$  = proportion of total urban area in commercial use  
 $q_{COM}$  = specific runoff from commercial areas (m<sup>3</sup>/(ha·d))

It is assumed that the effective number of storm water days ( $Z_{NST}$ ) is dependent on the level of precipitation. For German river systems it was found that

$$Z_{NST} = 0.0000013 \cdot P_Y^{2.55} \quad (\text{Eq. I.4.40})$$

The discharge rate of a combined sewer system was estimated according to a method developed by MEIBNER (1991) and is dependent on the annual precipitation as well as the storage volume of the combined sewer. The storage volume holds back a fraction of the waste water during the storm water event and retards the flow to the treatment plant. Data on the storage volume of the combined sewers in the German countries are taken from the sewage water statistics. The discharge rate was estimated according to Equation I.4.41:

$$RE = \frac{\frac{4000 + 25 \cdot q_R}{0.551 + q_R}}{V_S + \frac{36.8 + 13.5 \cdot q_R}{0.5 + q_R}} - 6 + \frac{P_Y - 800}{40} \quad (\text{Eq. I.4.41})$$

with    RE                      = discharge rate of combined sewer overflows (%)  
            $q_R$                       = rainfall runoff rate (l/(ha·s))  
            $V_S$                       = storage volume (m<sup>3</sup>)

The nutrient concentration in a combined sewer can be calculated from the area-specific emission rate of the impervious urban area, the inhabitant-specific nutrient emissions and the concentration of nutrients in direct industrial effluents:

$$C_{C_{N,P}} = \frac{((EIN_{N,P} \cdot IN_C + C_{COM_{N,P}} \cdot Q_{COMC}) \cdot Z_{NT} + ES_{IMP_{N,P}} \cdot A_{IMPC} \cdot 100) \cdot \frac{RE}{100}}{Q_{COMC}} \quad (\text{Eq. I.4.42})$$

with     $C_{C_{N,P}}$                       = nutrient concentration in combined sewers during overflow (g/m<sup>3</sup>)  
            $EIN_{N,P}$                       = inhabitant specific nutrient output (g/(E·d))  
            $IN_C$                         = number of inhabitants connected to combined sewer system  
            $C_{COM_{N,P}}$                       = nutrient concentration in commercial wastewater (g/m<sup>3</sup>)  
            $Q_{COMC}$                       = runoff from commercial areas connected to combined sewers (m<sup>3</sup>/d)

For the nutrient concentration in commercial wastewater values of 1 g N/m<sup>3</sup> and 0.1 g P/m<sup>3</sup> are used (BEHRENDT et al. 2000).

The nutrient emissions from combined sewer systems into each river system are then calculated from the product of the quantity of water discharged by the overflow and the mean nutrient concentration during such events:

$$EUC_{N,P} = C_{C_{N,P}} \cdot RE \cdot Q_{IMPC} \quad (\text{Eq. I.4.43})$$

with     $EUC_{N,P}$  = nutrient emissions via combined sewer overflows (t/yr)

### ***Nutrient inputs from the impervious areas and inhabitants connected to sewers but not to a WWTP***

Furthermore, the nutrient inputs from the **impervious areas and inhabitants connected to sewers but not to a WWTP** must be considered. The population connected to sewers but not to WWTPs can be taken from the statistics. It is assumed that the proportion of urban areas connected to a sewer but not to a waste water treatment plant corresponds only to the proportion of people connected to a sewer system. Regarding the inputs of materials, these areas can be considered in the same way as the areas connected to separate sewer systems (see above). The same is assumed for the specific values of the nutrient inputs from these areas.

It is supposed that the particulate fraction of the human nutrient output only from inhabitants connected to sewers is transported to waste water treatment plants. For the dissolved fraction, it is assumed that this proportion is fully supplied to the sewer system. The total nutrient input along this pathway will then be calculated according to Equation I.4.44:

$$EUSO_{N,P} = ES_{N,P} \cdot A_{IMPSO} \cdot 100 + IN_{SO} \cdot EIN_{D_{N,P}} \cdot 0.365 + C_{COM_{N,P}} \cdot Q_{COMSO} \quad (\text{Eq. I.4.44})$$

with	$EUSO_{N,P}$	= nutrient input from impervious urban areas and only from inhabitants connected to sewers (t/yr)
	$A_{IMPSO}$	= only urban area connected to sewers (km <sup>2</sup> )
	$IN_{SO}$	= only inhabitants connected to sewers
	$Q_{COMSO}$	= annual runoff only from commercial areas connected to sewers (m <sup>3</sup> /s)
	$EIN_{D_{N,P}}$	= inhabitant specific output of dissolved nutrients (g/(inh·d))

The specific human dissolved nitrogen output was assumed to be 9 g N/(inh·d). For phosphorus it must be assumed that the dissolved emissions are different for every country, because the use of phosphorus in detergents varies between the countries. Therefore, country-specific values for the phosphorus in detergents are derived and implemented in MONERIS.

### ***Nutrient inputs from people not connected to a sewer system***

In addition to the inputs from separate and combined sewer systems, the nutrient emission into the river systems from **impervious urban areas and people not connected to a sewer system** have to be considered. The following formula according to BEHRENDT et al. (2000) is used:

$$EUN_{N,P} = (100 - R_{S_{N,P}}) \cdot (ES_{IMP_{N,P}} \cdot A_{IMP_{N,P}} \cdot 100 + IN_N \cdot EIN_{D_{N,P}} \cdot 0.365 \cdot (100 - W_{TR})) \quad (\text{Eq. I.4.45})$$

with	$EUN_{N,P}$	= nutrient input from inhabitants and impervious urban areas (t/yr) connected neither to sewers nor to wastewater treatment plants (t/yr)
	$R_{S_{N,P}}$	= nutrient retention in the soil (80 % for nitrogen and 90 % for phosphorus)
	$A_{IMP_{N,P}}$	= impervious urban area connected neither to a sewer nor to a wastewater treatment plant (km <sup>2</sup> )
	$IN_N$	= inhabitants connected neither to sewers nor to wastewater treatment plants

$W_{TR}$  = proportion of dissolved human nutrient output transported to wastewater treatment plants (%)

It is assumed that 40 % of the dissolved human phosphorus and 20 % of the dissolved human nitrogen output is transported to a wastewater treatment plant with the particulate fraction generally transported to a WWTP.

#### I.4.2.2.8 River loads

For the calculation of nutrient loads the data sets for available monitoring cross-sections of the sub-catchments have to be used. As shown by KELLER et al. (1997) and ZWEYNERT et al. (2004) the application of different calculation procedures may lead to divergent results. Particularly with regard to small catchment areas under- or overestimations may arise. In terms of mean annual nutrient load this can be seen as estimated value rather than an ensured result (KELLER et al. 1997). Among all approaches the OSPAR method has led to the most trustable calculation of observed nutrient loads (LITTLEWOOD, 1995). Therefore, the computation of the mean annual nutrient load is calculated by using the OSPAR method (OSLO PARIS COMMISSION, 1996) (Eq. I.4.46).

$$Ly = \frac{Q_d}{Q_{Meas}} \cdot \left( \frac{1}{n} \sum_{i=1}^n C_i \cdot Q_i \cdot U_f \right) \quad (\text{Eq. I.4.46})$$

with	Ly	= annual load (t/yr)
	Qd	= arithmetic mean of daily flow (m <sup>3</sup> /s)
	Qmeas	= arithmetic mean of all daily flow data with measurement of concentration (m <sup>3</sup> /s)
	Ci	= concentration (mg/l)
	Qi	= measurement of daily flow (m <sup>3</sup> /s)
	Uf	= correction factor for the different location of flow and concentration measuring station within the same catchment (-)
	n	= number of data with measurements within the investigation period (-)

The consideration of hydrological years, calendar years or other calculation periods has to be applied as a uniform procedure for the entire investigation area.

#### I.4.2.2.9 Retention in surface waters

In surface waters, retention (sum of all loss and transfer processes) is an important element of the nitrogen balance. Decisive processes for nitrogen retention are influenced by numerous variables and occur in varying intensity in all surface waters. While small scale studies demand a detailed knowledge of characteristics of the river section, retention can be estimated by a small number of variables. Nitrogen retention can be modeled by the conceptual THL approach of VENOHR (2006) by using temperature and hydraulic load (runoff divided by



water surface area). For the estimation of the water surface area see chapter I.4.1.2. The calculation of the retention is based on the following assumptions:

dissolved organic nitrogen (DON) is not affected by retention  
 inputs of point sources can discharge to the main river directly  
 large water bodies (e.g. lakes) at the outlet of the river basin can be effective for the retention  
 for the nutrient loads of the upstream river catchment as well as for the loads of the analytical units from the tributaries

Thus the following equations are applied:

$$L_{TN\sum i} = [(E_i - E_{DONi} - E_{Di})R_{Ti} + (L_{i-1} - L_{DON\sum i-1})R_{MRi} + E_{Di}]R_{LOi} + L_{DON\sum i} \quad (\text{Eq. I.4.47})$$

$$L_{DIN\sum i} = [(E_i - E_{DONi} - E_{Di})R_{Ti} + (L_{i-1} - L_{DON\sum i-1})R_{MRi} + E_{Di}]R_{LOi} \quad (\text{Eq. I.4.48})$$

$$L_{TP\sum i} = [(E_i - E_{Di})R_{Ti} + L_{i-1} \cdot R_{MRi} + E_{Di}]R_{LOi} \quad (\text{Eq. I.4.49})$$

with  $L_{TPi}$  = calculated TP load for catchment of an analytical unit i (AUi)  
 $L_{TNi}$  = calculated TN load for catchment of AUi  
 $L_{DINi}$  = calculated DIN load for catchment of AUi  
 $E_i$  = total (P or N) emissions from AUi  
 $E_{DONi}$  = DON emissions from AUi  
 $E_{Di}$  = emissions from point sources discharging directly into the main river  
 $R_{Ti}$  = Retention tributaries  
 $R_{MRi}$  = Retention in main river without retention in waterbody at the outlet of the AU  
 $R_{LOi}$  = Retention waterbody at outlet of AU

### ***Retention of Nitrogen in tributaries and main rivers***

The retention of Total Nitrogen (TN) (Equation I.4.50) and Dissolved Inorganic Nitrogen (DIN) (Equation I.4.51) is calculated with the following computations without a distinction into tributaries and main rivers:

$$R_{THL_{TN}} = \frac{C_{TN_{in}} - C_{TN}}{C_{TN_{in}}} \approx 1 - \frac{1}{1 + 4.74 \cdot e^{0.067T} \cdot HL^{-1}} \quad (\text{Eq. I.4.50})$$

$$R_{THL_{DIN}} = \frac{C_{DIN_{in}} - C_{DIN}}{C_{DIN_{in}}} \approx 1 - \frac{1}{1 + 8.58 \cdot e^{0.067T} \cdot HL^{-1}} \quad (\text{Eq. I.4.51})$$

with  $T$  = water temperature in °C  
 $HL$  = Hydraulic Load in m/yr

### Retention of Phosphorus

The approach for the retention of Phosphorus distinguishes between tributaries and main rivers. The retention in **tributaries** is calculated as mean from the following approaches:

$$TP_{LOAD} = \frac{1}{1 + 26,6 \cdot q^{-1,71}} \cdot TP_{EMISSION} \quad (\text{Eq. I.4.52})$$

$$TP_{LOAD} = \frac{1}{1 + 13,3 \cdot HL^{-0,93}} \cdot TP_{EMISSION} \quad (\text{Eq. I.4.53})$$

The determination of the hydraulic load (HL) in m/yr follows the Equation I.4.54:

$$HL_{TRIB_i} = Q_i / WSA_i \quad (\text{Eq. I.4.54})$$

The retention of Phosphorus in the **main rivers** is calculated with the Hydraulic Load (HL) approach only.

$$HL_{MR_i} = Q_{\Sigma i} / (WSA_{MR_i} - WSA_{LOi}) \quad (\text{Eq. I.4.55})$$

$$HL_{MR_i} = Q_{\Sigma i} / WSA_{LOi} \quad (\text{Eq. I.4.56})$$

with	$Q_i$	= runoff from selected AU (m <sup>3</sup> /yr)
	$Q_{\Sigma i}$	= runoff from catchment of selected AU (m <sup>3</sup> /yr)
	$WSA_{MR_i}$	= water surface area of main river in selected AU (m <sup>2</sup> )
	$WSA_{TRIB_i}$	= water surface area of all tributaries in selected AU (m <sup>2</sup> )
	$WSA_{LOi}$	= water surface area of water body at outlet of selected AU (m <sup>2</sup> )

## I.5 MONERIS model structure

### I.5.1 The EXCEL Structure of MONERIS

**Table I.5.1:** The EXCEL Worksheet structure of MONERIS

Section	Worksheet	Description
<b>Input Data</b>	Basicinfo	General analytical unit (AU) data, Chapter I5.2
	Periodical Data	Collated annual data from periodical data, Chapter I.5.3
	Surplus	Country Data on N-Surplus, P accumulation, emissions, P from detergents, C-Factor, CSO storage volume, inhabitant specific
	WWTP	Individual and aggregated WWTP data
<b>Edited Input Data</b>	Intermediate	Aggregated, transformed or modified data from the Basicinfo and Periodical data for Scenarios
	Runoff Separation by CARL	Runoff Separation into surface flow, interflow, baseflow, subsurface flow
	WSA	Water surface areas, calculated as long term mean, has to be refreshed manually
<b>Pathways</b>	Atmospheric Deposition	
	Tile drainage	
	Groundwater	
	Surface Runoff	
	Erosion	
	Point Sources	
	Urban Systems	
	Retention	
<b>Results</b>	Background	Emissions under natural conditions
	Waterbalance	Collation of WB results
	Emissions net	Collation of results for analytical units
	Emissions total	Aggregation of results for analytical units, Catchment
	Scenario Results	Results for long term, dry year, wet year, fixed values
	Target concentrations	Target concentrations results, based on Scenario results

## I.5.2 Preparing the Basicinfo-Worksheet

The Basicinfo worksheet provides general analytical unit data which are assumed to be constant throughout the calculation period, like the area of analytical units, land use or soil classes. The spatiotemporal variable data in contrast are governed in the Periodical data worksheet (Chapter I.5.3).

### General structure of the Basicinfo-file

In general the header of the single columns of the Basicinfo consists of four lines. In these lines the contents of the columns are determined and explained.

**Table I.5.2:** The Basicinfo header

Rows	Contents	Example
1	Category	Landuse
2	Sub- Category	Arable land
3	Specification	< 1%
4	Units	km <sup>2</sup>

In the following a diversified overview about the Categories and its sub-units will be provided and shortly commented if necessary. Since most of the relevant data were described in the Data requirements chapter I.3.3 it was refrained from describing the data more closely in this part. Please consult the indicated chapters to achieve further information.

### Catchment Description

The catchment description category refers to the administrative classification of the catchment mainly. It is subdivided into the following sub- categories:

**Table I.5.3:** Catchment Description. (\* optional Sub-Categories)

Category	Sub- Category
CATCHMENT DESCRIPTION	ID
	<i>ID_GIS</i> *
	Country
	State
	<i>LAWA</i> *
CATCHMENT DESCRIPTION	<i>Adress</i> *
	<i>Description</i> *
	Analytical unit (AU)
	Sub-unit (SU)
	Sub-basin (SB)
	River basin (RB)
	River basin district (RBD)
	<i>Monitoring stationname</i> *

Whereas most of the subtopics are self-explanatory, it is important to point out that the ID should be a continuous ID, beginning in the first row and ending in the last. The fields ID\_GIS, LAWA, Address, Description and Monitoring station name are optional fields. The terms for describing the river basin structure are defined in chapter I.4.1.1.1. These terms are important for the aggregation of the results.

### *Catchment Area and Flow net equation (FNE)*

**Table I.5.4:** Catchment Area and FNE

Category	Sub- Category	Specification	Units
CATCHMENT AREA	Monitoring station		km <sup>2</sup>
	Net		km <sup>2</sup>
FLOW NET EQUATION	Without splitting		
	With splitting		
	Main river		

For further information about the Catchment area and FNE data consult Chapter 1.4.1

### *Atmospheric Deposition*

**Table I.5.5:** Atmospheric deposition

Category	Sub- Category	Specification	Units
ATMO DEP	NH4	Long term	mg/m <sup>2</sup>
	NOX	Long term	mg/m <sup>2</sup>

For further information about the Atmospheric Deposition data consult Chapter I.4.2.2.2.

### *Precipitation and Evapotranspiration*

**Table I.5.6:** Precipitation and Evapotranspiration

Category	Sub- Category	Specification	Units
PRECIPITATION	Long term	Annual	mm/yr
	Long term	Summer	mm/yr
EVAPOTRANS-PIRATION	Long term	Annual	mm/yr

For further information about the Precipitation and Evapotranspiration data consult Chapter I.3.3.1.

### Landuse and Tile Drainage

**Table I.5.7:** Landuse and Tile drainage

Category	Sub- Category	Specification	Units
LANDUSE	Urban area		km <sup>2</sup>
	Arable land	< 1 %	km <sup>2</sup>
	Arable land	1 - 2 %	km <sup>2</sup>
	Arable land	2 - 4 %	km <sup>2</sup>
	Arable land	4 - 8 %	km <sup>2</sup>
LANDUSE	Arable land	> 8 %	km <sup>2</sup>
	Grasland		km <sup>2</sup>
	Natural covered land (forest, grassland, shrubland)		km <sup>2</sup>
	Water surface		km <sup>2</sup>
	Open pit mine		km <sup>2</sup>
	Open area		km <sup>2</sup>
	Wetland		km <sup>2</sup>
	Remaining areas		km <sup>2</sup>
	Total area with	Erosion potential	km <sup>2</sup>
TILE DRAINAGE		Area	%

For further information about the Landuse and Tile Drainage data consult Chapter I.3.3.1, I.4.2.2.5.

### Elevation and Slope

**Table I.5.8:** Elevation and Slope

Category	Sub- Category	Specification	Units
ELEVATION		Derived from 1km GRID	m
SLOPE_1000	Net	Derived from 1km GRID	%
SLOPE_100	Net	Derived from 100m GRID	%

For further information about the Elevation and Slope data consult Chapter I.3.3.1.



**GIS often delivers slope data in degree. Please ensure that your Basicinfo input data are given as percentage**

## Soil

**Table I.5.9:** Soil

Category	Sub- Category	Specification	Units
SOIL	Sand		km <sup>2</sup>
	Clay		km <sup>2</sup>
	Loam		km <sup>2</sup>
	Fen		km <sup>2</sup>
	Bog		km <sup>2</sup>
	Silt		km <sup>2</sup>
	N content topsoil		%
	Clay content topsoil		%

For further information about the Soil data consult Chapter I.3.3.1.

## Soil loss

**Table I.5.10:** Soil loss

Category	Sub- Category	Specification	Units
SOIL LOSS	Arable land	MED_SL_1_	t/(ha·yr)
	Arable land	MED_SL_1_2	t/(ha·yr)
	Arable land	MED_SL_2_4	t/(ha·yr)
	Arable land	MED_SL_4_8	t/(ha·yr)
	Arable land	MED_SL_8_	t/(ha·yr)
	Arable land	MED_SL_GRA	t/(ha·yr)
	Arable land	MED_SL_NATCOV	t/(ha·yr)
	Mean total	Catchment	t/(ha·yr)

For further information about the Soil loss data consult Chapter I.3.3.1.

## C-Factor and Nitrogen surplus

**Table I.5.11:** C-Factor and Nitrogen surplus.

(\* Reference year has to be set by the Modeller/Modifier in the settings)

Category	Sub- Category	Specification	Units
C-FACTOR	current		-*
NITROGEN SURPLUS	current		kg/(ha·a)

For further information about the C-Factor and Nitrogen surplus data consult Chapter I.4.2.2.6.

## Hydrogeology

**Table I.5.12:** Hydrogeology

Category	Sub- Category	Specification	Units
HYDRO-GEOLOGY	Unconsolidated soil	Shallow groundwater	km <sup>2</sup>
	Unconsolidated soil	Deep groundwater	km <sup>2</sup>
	Consolidated	High porosity	km <sup>2</sup>
	Consolidated	Impermeable	km <sup>2</sup>

For further information about the Hydrogeology data consult Chapter I.3.3.1.

## Sewer systems

**Table I.5.13:** Sewer systems

Category	Sub- Category	Specification	Units
SEWER SYSTEMS	Sewer flow length		km
	Black and gray water		km

For further information about the Sewer system data consult Chapter I.4.2.2.7.

## River Flow length

**Table I.5.14:** Flow length

Category	Sub- Category	Specification	Units
RIVER FLOW LENGTH	MR		km
	TRIB		km

For further information about the Flow length data consult Chapter I.4.1.2

## Lake area

**Table I.5.15:** Lake area

Category	Sub- Category	Specification	Units
LAKE AREA	MR	Total area in AU	km <sup>2</sup>
	MR_AU outlet	Area of lakes at outlet to be considered separated for Retention	km <sup>2</sup>
	TRIB	Total area in AU	km <sup>2</sup>

For further information about the Lake area data consult Chapter I.4.1.2.



### I.5.3 Preparing the Periodical-Data-Workbook

The Periodical data file provides the spatiotemporal variable data for MONERIS. In contrast to the Basicinfo-worksheet, the Periodical data file consists of various worksheets governed in the Periodical data-workbook. Some of these worksheets can be allocated to certain main categories. To ensure a better clarity of the Periodical data structure this allocation will be carried out first. The main characteristics of each category will be outlined briefly.

In the Country data category country specific data for certain years for all considered countries are governed in the according worksheets. The considered time period is user-defined upgradeable, if the user is logged in as modeller or modifier (Chapter I.5.4.4.1). For all considered countries an unambiguous ID and Shortname has to be set. The default shortnames are based on the ISO 3166 standards. For further information about the input data of the worksheets consult Chapter I.5.2 or the model developers.



**The Shortname set in the Periodical data has to correspond to the data enlisted in the country field of the Basicinfo file. The AU has to be allocated to one country unambiguously.**

**Table I.5.16:** Country data

Main Category	Periodical Data Worksheet
Country data	CSO_storage
	C_Factor
	P_accumulation
	N_surplus
	TP_per_inhabitant
	TP_detergents_per_inhabitant

**Table I.5.17:** Analytical unit data

Main Category	Periodical Data Worksheet
Analytical unit data	Atmo. dep. NHx
	Atmo. dep. NOx
	Atmo. dep. TP
	Preci. Annual
	Preci. summer
	Splitting_factor
	Calc. runoff net
	Obs. runoff
	Obs. DIN load
	Obs. TN load
	Obs. TP load
	Water temp.
	Inhabitants total
	Connected Inhabitants
	Inhab. conn. to sewer + WWTP

In the analytical unit data category, specific data for certain years for all considered analytical units are governed in the according worksheets. In addition to the single year data, further data for the time scales 'long term', 'dry year' and 'wet year' are listed. The ID has to correspond with the continuous ID of the Basicinfo-worksheet. For further information about the input data of the worksheets consult Chapter I.5.2.

**Table I.5.18:** WWTP data

Main Category	Periodical Data Worksheet
WWTP data	WWTP

In contrast to the Country and analytical unit data categories the WWTP data worksheet possesses a particular table structure. The following table presents an overview about the WWTP worksheet structure.

**Table I.5.19:** The WWTP worksheet structure. (\*optional Categories)

Category	Sub- Category	Specification	Units
ID			
Total discharge from WWTP per catchment	TP		kg/yr
	TN		kg/yr
	Q-WWTP		m <sup>3</sup> /s
ID			
<i>WWTP NAME</i> *			
Country_ID			
<i>Type</i> *			
<i>Population equivalent</i> *	Original		-
Population equivalent	Completed		-
<i>Cities&gt;10000</i> *	Name		
<i>Cities&gt;10000</i> *	Pop		
Size class			-
TREATMENT STAGE	Primary		-
TREATMENT STAGE	Secondary		-
TREATMENT STAGE	Tertiary N		-
TREATMENT STAGE	Tertiary P		-
TREATMENT STAGE	N short		-
TREATMENT STAGE	P short		-
<i>N conc. at outlet</i> *	Original		mg/l
<i>P conc. at outlet</i> *	Original		mg/l
<i>Discharge</i> *	Current original		m <sup>3</sup> /yr
N load	Current		t/yr
P load	Current		t/yr
Discharge	Current completed		m <sup>3</sup> /yr
N conc. at outlet	Current		mg/l
P conc. at outlet	Current		mg/l

For further information about the input data of the WWTP data worksheet consult Chapter I.3.3.2.

## I.5.4 The MONERIS user interface

### I.5.4.1 Getting started

#### *Basic EXCEL settings to start MONERIS*

To work with macros in EXCEL the security settings in EXCEL have to be modified. Go to the “*Tools*” scroll-down menu, choose “*Options*”. Switch to the “*Security*” tab and click the “*Macro-Security*” button. Select the “*Medium*” security level of the “*Security Level*” tab. Switch to the “*Trusted Publishers*” tab and activate the “*Trust access to Visual Basic Project*” Option-Button.



**Version 1.2 needs the Crystal-report file**

#### *Starting MONERIS*

To Start MONERIS go to the “*MONERIS*” menu and select Start. The MONERIS User Interface opens.



**Figure I.5.1:** Starting MONERIS



When MONERIS was moved to a new folder/ hard drive you have to set the Periodical\_data.xls file. Basicinfo.xls has not necessarily to be set until you need to update input data.

### I.5.4.2 The MONERIS user interface

The MONERIS User interface consists of the following three main working environments.

#### *The MONERIS Navigation-Bar (Chapter I.5.4.3)*

In the Navigation-Bar the spatial and temporal reference of the modelling process can be defined. The chosen spatial and temporal settings are presented in the ‘Spatial Relation Info Box’ on the upper side band of the MONERIS User Interface to provide an overview about the current model settings in all of the working environments.



All Analytical Units are selected, long term

**Figure I.5.2:** The Spatial Relation Info Box

Additionally the Pathways Status dialog of the Navigation-Bar presents an overview about the modifications made by the user.

#### *The MONERIS Main Menu (Chapter I.5.4.4)*

The Main Menu consists of three tabs allowing you to define basic settings and scenarios and to view and export the results.

- The MONERIS **Model Setup** – To set the basic settings (Chapter I.5.4.1)
- The MONERIS **Scenario Manager** – To apply predefined and individually modified scenarios (Chapter I.5.4.4.2)
- The MONERIS **Results** – To view and export the results (Chapter I.5.4.4.3)



**The Scenario Manager is only applicable for calculating periods**

#### *MONERIS- Additional Options (Chapter I.5.4.5)*

In the Additional Options workspace further more detailed settings like ‘update input data’, ‘setup model system’ and ‘update equations’ can be defined. These options are not applicable for users logged in as viewers and are not needed once the model has been set up.

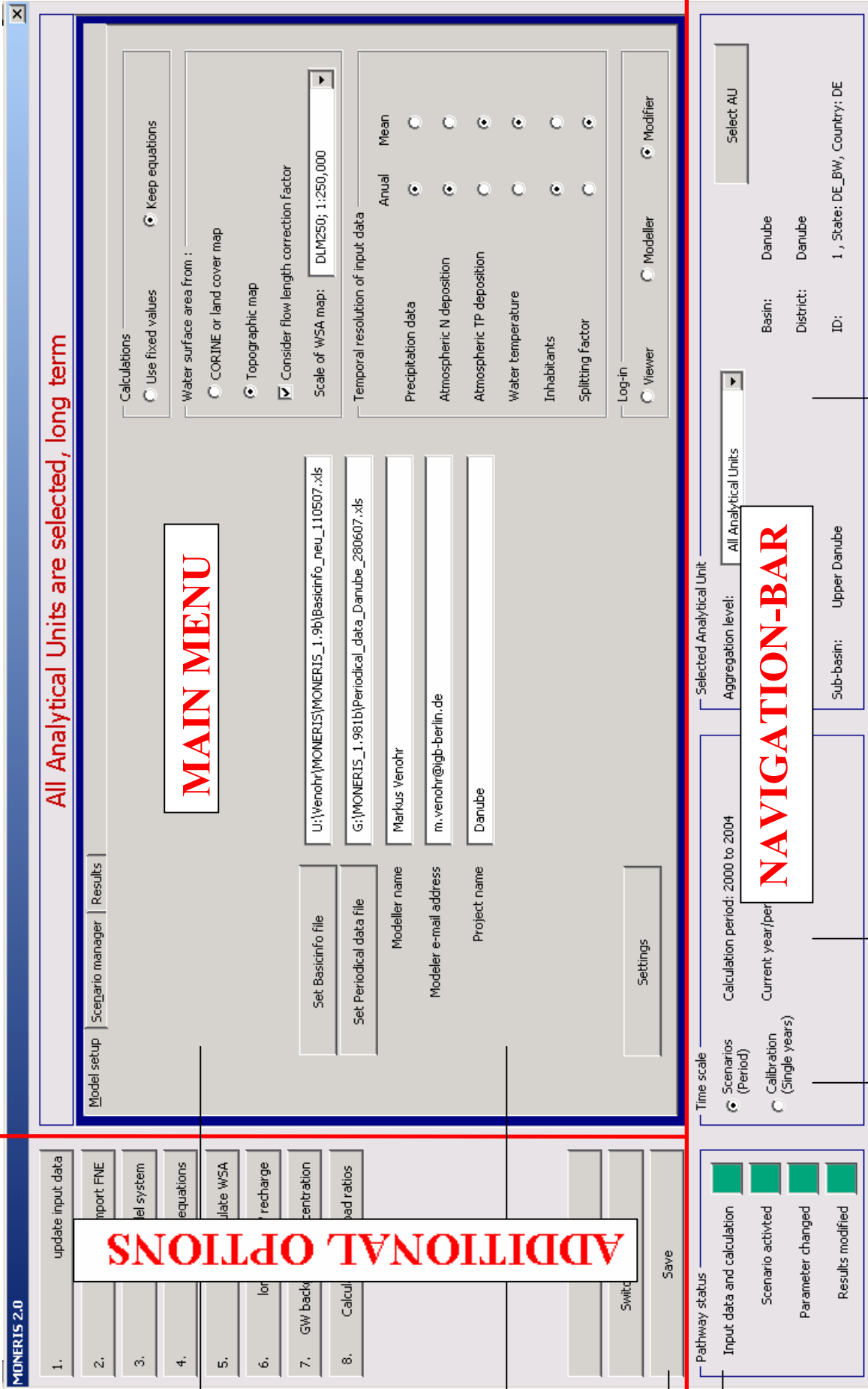


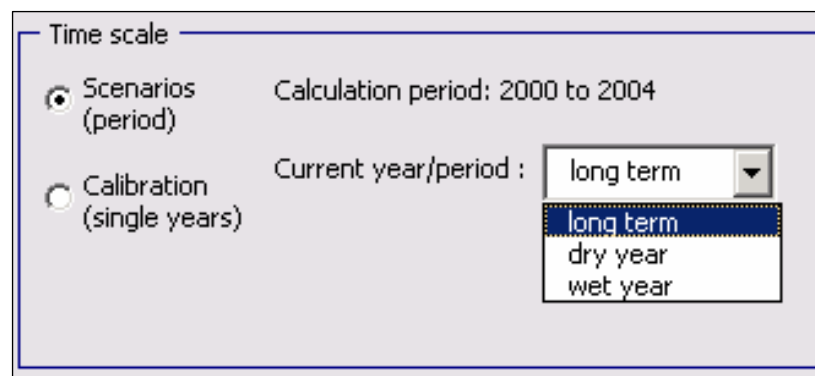
Figure I.5.3: The MONERIS User Interface structure

### I.5.4.3 The MONERIS Navigation-Bar

In the Navigation-Bar the spatial and temporal reference of the modelling process can be defined.

#### *Defining a Time Scale*

The model calculates emissions and loads for periods and single years. Since Viewers are not permitted to apply the ‘Calibration (single years)’ option of the ‘Time scale’ dialog, they can only choose between the different conditions ‘long term’, ‘wet year’ or ‘dry year’ in the “*Current year/period*” drop down list. Choosing one of these options determines the hydrologic data (Precipitation, Runoff and Evapotranspiration) that will be considered for the modelling run.



**Figure I.5.4:** Defining a Time Scale

In general the conditions ‘long term’, ‘wet year’ and ‘dry year’ describe the effects of hydrologic variability.

- **Long Term:** The ‘long term’ setting considers mean hydrologic and anthropogenic conditions of the calculation period.
- **Wet Year:** The ‘wet year’ setting considers mean anthropogenic and wet hydrologic conditions of the calculation period.
- **Dry Year:** The ‘dry year’ setting considers mean anthropogenic and dry hydrologic conditions of the calculation period.

#### *Using the ‘Selected Analytical unit’-dialog*

In the ‘Selected Analytical unit’-dialog basic settings to determine the spatial relation of the scenarios and the presented results can be selected. Whereas the model calculates on the basis of single analytical units, the analytical units can be grouped by certain criteria using the ‘aggregation level’- dialog in the forefront of calculating scenarios or viewing the results.

To select a certain spatial relation (e.g. Analytical unit, Country, Basin) you want to work with, you can use the “*Select AU*” button.

Selected Analytical Unit

Grouping criterium:

Analytical unit: 1002      Basin: Danube

Sub-unit: DE\_1      District: Danube

Sub-basin: Upper Danube      ID: 2 , Country: DE\_BW, State: DE

**Figure I.5.5:** The Selected Analytical unit dialog

After clicking this button a dialog with various search options appears. Select the section you want to search in and enter the search criterion. Click on the binoculars button afterwards.

Search sub-catchments

ID  sub-unit

Country  sub-basin

State  basin

analytical unit  river basin district

description  monitoring stationname

0 sub-catchments found

**Figure I.5.6:** Searching for analytical units

All relevant results will be presented in the yellow coloured list box. To select one of the presented entries just click on the according entry of the list box and the related analytical unit will be activated automatically in the 'Selected Analytical unit' dialog. It is just possible to select one of the presented entries.

MONERIS\_1.9b

## Country: RO

Search sub-catchments

ID: 303

Country: RO

State: RO

analytical unit: 10108

description: no comment

sub-unit: RO\_9

sub-basin: Tiza

basin: Danube

river basin district: Danube

monitoring stationname: Beclean

350 sub-catchments found

295	no comment	10112	RO_9	RO	Tiza
296	no comment	10111	RO_9	RO	Tiza
297	no comment	10110	RO_9	RO	Tiza
298	no comment	10113	RO_9	RO	Tiza
299	no comment	10115	RO_9	RO	Tiza
300	no comment	10114	RO_9	RO	Tiza
301	no comment	10116	RO_9	RO	Tiza
302	no comment	10109	RO_9	RO	Tiza
303	no comment	10108	RO_9	RO	Beclean
304	no comment	10101	RO_9	RO	Tiza
305	no comment	10102	RO_9	RO	Tiza
306	no comment	10103	RO_9	RO	Tiza
307	no comment	10106	RO_9	RO	Tiza

mg/l: 2, 1,6, 0,14, 0,15

concentration

Buttons: RUN, Switch to EXCEL, Save, Refresh, Exit

Pathway status

Input data and calculation

Scenario activated

Parameter changed

Results modified

Time scale

Scenarios (period): Calculation period: 2000 to 2004

Calibration (single years): Current year/period: long term

Selected Analytical Unit

Country: RO

Grouping criterion: RO\_9

Analytical unit: 10108

Sub-unit: Tiza

Sub-basin: 303 , Country: RO, State: RO

Basin: Danube

District: Danube

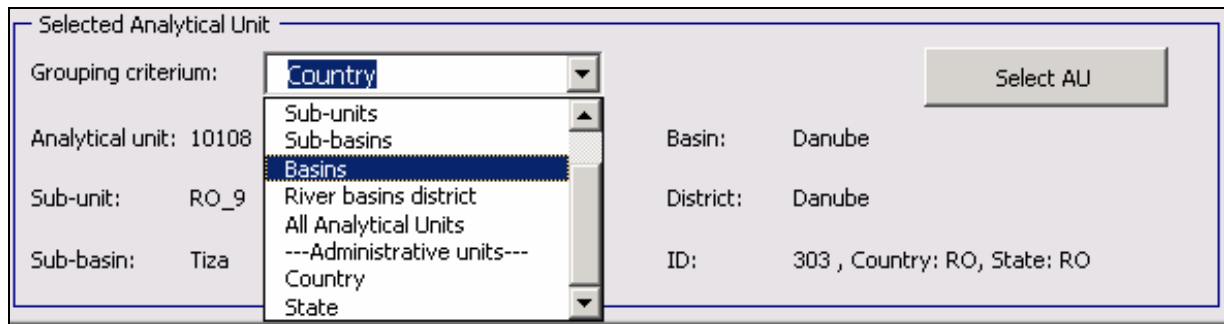
ID: 303 , Country: RO, State: RO

Figure I.5.7: Selecting an analytical unit



Once an analytical unit has been selected you can build groups of analytical units by choosing a aggregation level. If you want to apply scenarios e.g. for the spatial relation “Romania”, select an analytical unit laying in Romania by using the “*Select AU*” button and group the analytical units of Romania by selecting the aggregation level ‘country’.

Already set aggregation levels will be considered for a newly selected analytical unit.



**Figure I.5.8:** Grouping analytical units

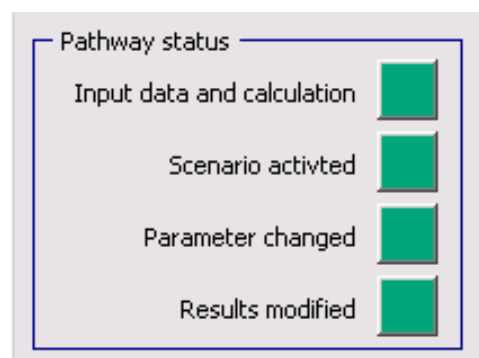
The selected analytical unit, aggregation level and period/year is highlighted in the ‘Spatial Relation Info Box’ on the upper side **band** of the MONERIS User Interface.



**Figure I.5.9:** The Spatial Relation Info Box

### Pathway status

In the ‘Pathway status’ dialog of the MONERIS User Interface you get an overview whether modifications have been made by the user. If no modifications were made, all fields remain in green colour. If modifications were made, these modifications will be indicated through a red colour of the according field. Since Viewers do have very limited possibilities to modify the default settings of MONERIS, the ‘Scenario activated’ field is the only relevant in Viewer modus.



**Figure I.5.10:** The Pathway status dialog

### I.5.4.4 The MONERIS Main Menu

As already outlined the MONERIS Main Menu consists of three tabs allowing you to define basic settings and scenarios and to view and export the results. These working environments will be discussed in detail in the following.

#### I.5.4.4.1 The MONERIS Model Setup

The MONERIS Model Setup consists of different dialogs to set the basic settings to run MONERIS. These dialogs will be described subsequently in detail.

The screenshot shows the 'Model setup' tab of the MONERIS Model Setup dialog. The 'Model setup' tab is highlighted with a red circle. The dialog contains the following fields and options:

- Set Basicinfo file:** U:\Venohr\MONERIS\MONERIS\_1.9b\Basicinfo\_neu\_110507.xls
- Set Periodical data file:** G:\MONERIS\_1.981b\Periodical\_data\_Danube\_280607.xls
- Modeller name:** Markus Venohr
- Modeller e-mail address:** m.venohr@igb-berlin.de
- Project name:** Danube
- Settings:** A button at the bottom left.
- Calculations:** Radio buttons for 'Use fixed values' and 'Keep equations' (selected).
- Water surface area from:** Radio buttons for 'CORINE or land cover map' and 'Topographic map' (selected). A checkbox for 'Consider flow length correction factor' is checked.
- Scale of WSA map:** A dropdown menu showing 'DLM250; 1:250,000'.
- Temporal resolution of input data:** A table with columns 'Annual' and 'Mean' for various input data types.
 

	Annual	Mean
Precipitation data	<input checked="" type="radio"/>	<input type="radio"/>
Atmospheric N deposition	<input checked="" type="radio"/>	<input type="radio"/>
Atmospheric TP deposition	<input type="radio"/>	<input checked="" type="radio"/>
Water temperature	<input type="radio"/>	<input checked="" type="radio"/>
Inhabitants	<input checked="" type="radio"/>	<input type="radio"/>
Splitting factor	<input type="radio"/>	<input checked="" type="radio"/>
- Log-in:** Radio buttons for 'Viewer', 'Modeller', and 'Modifier' (selected).

Figure I.5.11: The MONERIS Model Setup Menu

#### Project Initialization

To initialize a new MONERIS project you have to set the path for the prepared Periodical data file by clicking the “Set Periodical data file”.

The screenshot shows the 'Set Periodical data file' dialog. It contains a button labeled 'Set Periodical data file' and a text field displaying the file path: G:\MONERIS\_1.9b\Periodical\_data\_Danube\_140507.xls.

Figure I.5.12: Setting a Periodical data file

Select the Periodical Data workbook and press “OK”. The path for the Basicinfo file has only to be set, when you are logged in as Modeller or Modifier.

Information about the preparation of the Basicinfo and the Periodical Data worksheets can be found in Chapter I.5.2, I.5.3.



The Periodical Data file is password protected and will be opened in the ‘read only’ modus. If you are logged in as Viewer, data or the whole file can be copied or saved under a new name, but the modified file will not be accepted for the current calculations. Changes in the Periodical Data can only be made and saved when you are logged in as Modeller or Modifier.

### *The Log-in dialog*

Three different types of Log-ins are distinguished in MONERIS. These types lead to distinct options in the course of the modelling process.



**Figure I.5.13:** The MONERIS Log-in dialog

### *VIEWER (Default Login)*

- Enables you to select, combine and apply predefined Scenarios as well as to view and export the results

### *MODELLER*

- Includes all options available in the viewer environment
- Enables you to load new data
- Enables you to modify scenario thresholds
- Allows you to modify used parameters that will be indicated in the surface

### *MODIFIER*

- Includes all options available in the viewer and modeller environments
- Enables you to modify used equations
- Enables you to change and save modified values as standard



**The Modeller and Modifier Log-ins are password protected. If you type in the wrong password you will be logged in as Viewer automatically**



The dialogs ‘Temporal resolution of input data’ and ‘Water surface area from’ are only accessible for users logged in as Modellers or Modifiers. There is no access for users logged in as Viewers.

### Calculations

In the ‘Calculations’ dialog one can choose between the options ‘Use fixed values’ and ‘Keep equations’. Activating the use fixed values option leads to the substitution of the equations used in the EXCEL worksheets by fixed values. This leads to reduced memory requirements for the MONERIS file from up to 20MB.

#### I.5.4.4.2 The MONERIS Scenario Manager

As already indicated in Chapter I.2 the MONERIS Scenario Manager is only applicable for calculating periods. Once switched to the Scenario Manager tab you are able to define and apply certain **packages of measures** for the selected analytical units and to define and apply **scenarios** for all analytical units (Chapter I.5.4.3).

In the Scenario Manager you can decide if you want to work with the predefined packages of measures or if you want to define your own packages by using the tools offered in the Scenario Manager.

The screenshot shows the MONERIS Scenario Manager dialog box. The 'Scenario manager' tab is selected and circled in red. The dialog is divided into two main sections: 'Package of measures' on the left and 'Scenarios' on the right.

**Package of measures:**

- Package of measures: [Dropdown menu]
- Buttons: Save as new package, Delete package, Apply package
- Categories: Agriculture, Urban systems, WWTP P, WWTP N
- Measures:
  - Convert arable to grassland: Slope class < 1 %, 1 - 2 %, 2 - 4 %, 4 - 8 %, > 8 % (radio buttons for yes/no)
  - Conservation tillage for arable land: (radio buttons for yes/no)
  - Reduction of tile drained areas: [Input: 0] 0 - 30 %
  - Change of N-surplus: [Input: 0] -50 - 50 %
  - Connection of agriculture and surface waters: [Input: 0] 0 - 30 %

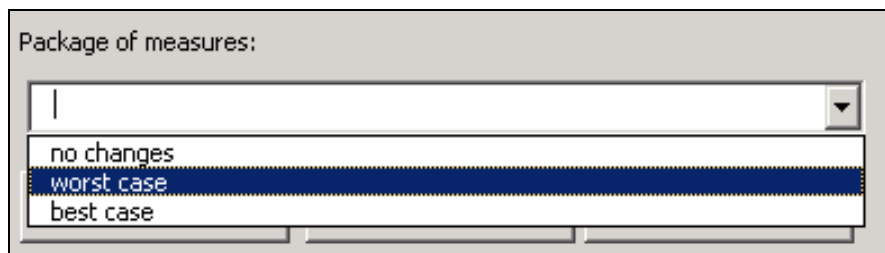
**Scenarios:**

- Scenarios: [Dropdown menu]
- Buttons: Save as new scenario, Delete scenario, Change border values
- Target concentration:
  - Max TN single concentration at AU outflow: [Input: 2] mg/l
  - Max TN concentration at river basin outlet: [Input: 2] mg/l
  - Max TP single concentration at AU outflow: [Input: 0,1] mg/l
  - Max TP concentration at river basin outlet: [Input: 0,1] mg/l
  - Apply target concentration button
- Set as reference button

Figure I.5.14: The MONERIS Scenario Manager

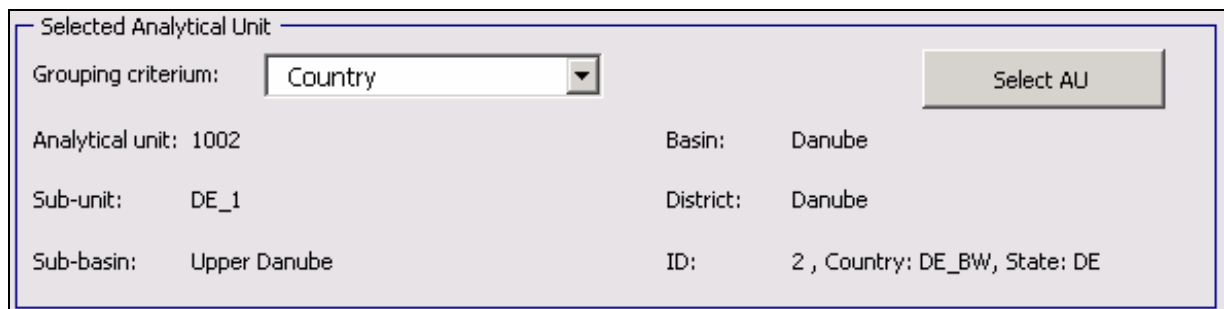
### Working with predefined packages of measures

To apply the predefined packages of measures use the scroll-down menu of the ‘Package of Measures’ dialog and select the package of measures you want to work with.



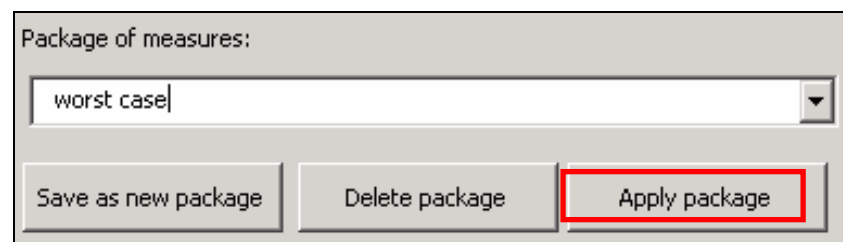
**Figure I.5.15:** Choosing Packages of Measures

Afterwards you can choose the spatial relation you want to apply the package of measures for by using the ‘Selecting Analytical unit’ dialog (Chapter I.5.4.3).



**Figure I.5.16:** The Selected Analytical unit dialog

Press the “Apply Package” button to enter the defined values for the chosen spatial relation into the EXCEL database and to start the calculation.



**Figure I.5.17:** Applying packages of measures

### Allocating predefined packages of measures to different spatial units

If you have chosen e.g. the worst case package for the aggregation level: ‘Country’ = “Germany” you might want to apply the best case scenario for another spatial unit e.g. “Romania”. Select the spatial relation “Romania”, choose the best case package and press the “Apply Scenario” button again.

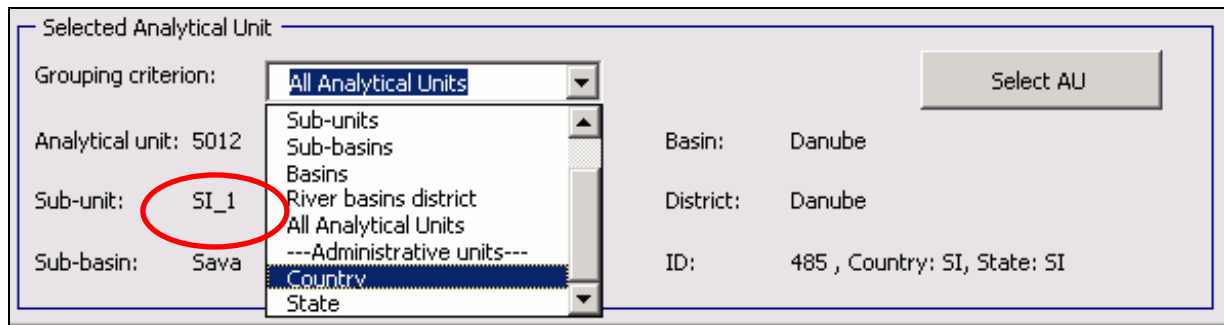


Figure I.5.18: Grouping analytical units

Now the best case data for the spatial relation “Romania” are added to the EXCEL database which contains the worst case data for “Germany” already. Thus the worst case data for Germany as well as the best case data for Romania were taken into account for the current modelling run.

### *Saving packages of measures*

If you want to keep the packages of measures for Germany and Romania, click the “Save as new scenario” button. Enter a name for the defined scenario in the dialog and press the “Save” button.

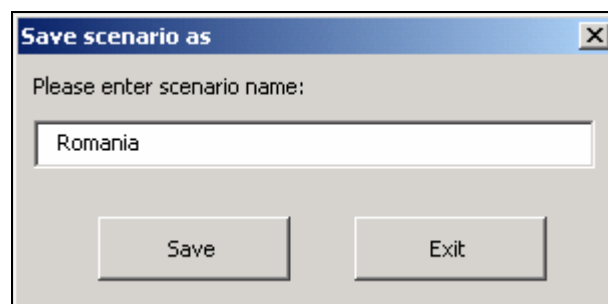


Figure I.5.19: Saving scenarios

The defined scenario is now added to the ‘Scenario settings’ scroll-down menu. If you want to rerun the new defined scenario, just select it in the scroll-down menu and the scenario will be applied again automatically.

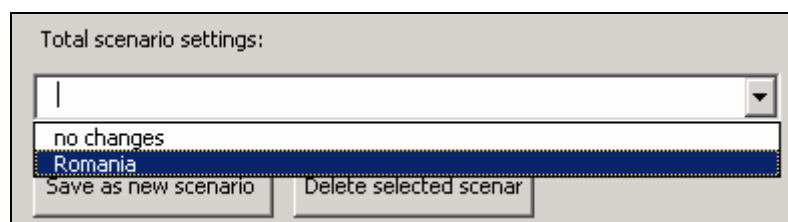


Figure I.5.20: Loading scenarios

### Defining packages of measures - Overview

In addition to the predefined scenarios the MONERIS Scenario Manager holds the potential to customize the packages of measures. Therefore you can modify the predefined settings in the Agriculture ①, Urban systems ②, WWTP P ③ and WWTP N ④ tabs. The tabs ③ and ④ are only applicable, if individual WWTP data are used. How to define new packages of measures will be described in chapters I.5.4.4.2 to I.5.4.5.

Figure I.5.21: Defining packages of measures

After having defined your package of measures you can save the new combination of measures by clicking the “Save as new package” button. Type in a name for the defined package in the dialog and press the “Save” button.

Figure I.5.22: Saving packages of measures

The defined package is now added to the ‘Package of measures’ scroll-down menu. To work with this new package of measures, select the spatial relation you want to apply the package for and press the “*Apply Package*” button.

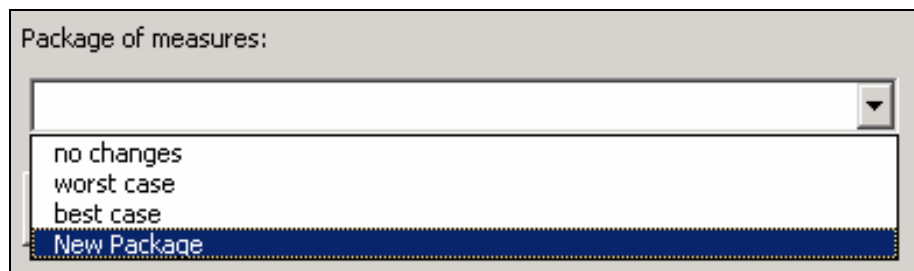


Figure I.5.23: Loading packages of measures

### Defining measures for Agriculture

In the ‘Agriculture’ tab one can choose which areas of a defined analytical unit with a certain slope will be converted from arable to grassland by using a ‘yes/no’ dialog. In addition it can be determined which areas of a certain slope class are cultivated with conservation tillage. While these measures primarily aim at the reduction of the simulated erosion, the other definable settings of the ‘Agriculture’ tab aim at further measures for simulating agricultural impacts on nutrient emissions.

Agriculture		Urban systems	WWTP P	WWTP N																									
<div style="display: flex; justify-content: space-around;"> <div> <p>Convert arable to grassland</p> <table border="0"> <tr> <td>Slope class &lt; 1 %</td> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td>Slope class 1 - 2 %</td> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td>Slope class 2 - 4 %</td> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td>Slope class 4 - 8 %</td> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td>Slope class &gt; 8 %</td> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> </table> </div> <div> <p>Arable land cultivated without plough</p> <table border="0"> <tr> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> <tr> <td><input type="radio"/> yes</td> <td><input checked="" type="radio"/> no</td> </tr> </table> </div> </div>					Slope class < 1 %	<input type="radio"/> yes	<input checked="" type="radio"/> no	Slope class 1 - 2 %	<input type="radio"/> yes	<input checked="" type="radio"/> no	Slope class 2 - 4 %	<input type="radio"/> yes	<input checked="" type="radio"/> no	Slope class 4 - 8 %	<input type="radio"/> yes	<input checked="" type="radio"/> no	Slope class > 8 %	<input type="radio"/> yes	<input checked="" type="radio"/> no	<input type="radio"/> yes	<input checked="" type="radio"/> no	<input type="radio"/> yes	<input checked="" type="radio"/> no	<input type="radio"/> yes	<input checked="" type="radio"/> no	<input type="radio"/> yes	<input checked="" type="radio"/> no	<input type="radio"/> yes	<input checked="" type="radio"/> no
Slope class < 1 %	<input type="radio"/> yes	<input checked="" type="radio"/> no																											
Slope class 1 - 2 %	<input type="radio"/> yes	<input checked="" type="radio"/> no																											
Slope class 2 - 4 %	<input type="radio"/> yes	<input checked="" type="radio"/> no																											
Slope class 4 - 8 %	<input type="radio"/> yes	<input checked="" type="radio"/> no																											
Slope class > 8 %	<input type="radio"/> yes	<input checked="" type="radio"/> no																											
<input type="radio"/> yes	<input checked="" type="radio"/> no																												
<input type="radio"/> yes	<input checked="" type="radio"/> no																												
<input type="radio"/> yes	<input checked="" type="radio"/> no																												
<input type="radio"/> yes	<input checked="" type="radio"/> no																												
<input type="radio"/> yes	<input checked="" type="radio"/> no																												
Reduction of tile drained areas	<input type="text" value="0"/>	0 - 30 %																											
Change of N_surplus	<input type="text" value="0"/>	-50 - 50 %																											
Connection of agriculture and surface waters	<input type="text" value="0"/>	0 - 30 %																											

Figure I.5.24: Defining measures for Agriculture



**Table I.5.20:** Description of measures for agriculture

Measure	Description
<b>Conversion of arable land to grassland</b>	With settings in 'Agriculture', arable land can be converted to grassland with consideration of different slope classes
<b>Conversion of conventional tillage to conservation tillage of arable land</b>	With settings in 'Agriculture', arable land with conventional tillage can be changed to arable land with conservation tillage with consideration of different slope classes
<b>Reduction of tile drained areas</b>	In the 'Reduction of tile drained areas' dialog the user gets the possibility to reduce the in the Basicinfo worksheet defined tile drained areas about a certain percentage. The eligible percentage ranges from 0 to 30%. These percentages refer to the current tile drained area.
<b>Change of N-surplus</b>	In the 'Change of N-surplus' dialog the user can vary the average N-surplus of the calculation period about a determinable percentage. The eligible percentage ranges from -50 to 50%.
<b>Connection of agriculture and surface waters</b>	The 'Connection of agriculture and surface waters' dialog refers to the simulation of erosion processes. In this dialog the percentage of agricultural land that transports eroded material directly to surface waters can be reduced. The eligible percentage ranges from 0 to 30%. These percentages refer to the percental area of agricultural land of the catchment area.

### Defining measures for Urban systems

In the 'Urban systems' tab one can modify various parameters that influence the emission of nutrients from urban systems.

The screenshot shows the 'Urban systems' tab selected in the MONERIS model interface. The interface includes a navigation bar with tabs for 'Agriculture', 'Urban systems', 'WWTP P', and 'WWTP N'. The 'Urban systems' tab is active, displaying a list of parameters for defining measures for urban systems. Each parameter has a corresponding input field (text box or radio buttons) and a range or status indicator.

Parameter	Input Field	Range/Status
Increase of storage for combined sewers	0	0 - 100 %
Storages for rainwater of separate sewers	0	0 - 50 %
Conversion of paved urban area to unpaved area	0	0 - 20 %
Proportion of solids in septic tanks to WWTPs	0	0 - 100 %
Portion of people connected to sewers and WWTP	0	0 - 100 %
Connected to sewers and WWTP	<input type="radio"/> yes <input checked="" type="radio"/> no	
P-free detergents	<input type="radio"/> yes <input checked="" type="radio"/> no	

**Figure I.5.25:** Defining measures for Urban systems

**Table I.5.21:** Description of measures for urban systems

<b>Measure</b>	<b>Description</b>
<b>Increase of storage for combined sewers</b>	The 'Increase of storage for combined sewers' simulates the enlargement of the storage facilities of combined sewer systems. A value of 100% represents a volume of 23.3 m <sup>3</sup> per hectare connected to paved urban area. The eligible percentage ranges from 0 to 100%.
<b>Storages for rainwater of separate sewers</b>	The 'Storage for rainwater of separate sewers' dialog functions analogously to the 'Increase of storage for combined sewers' dialog. The current estimated value for the degree of development is determined on the basis of country wide statistics. The eligible percentage ranges from 0 to 100%.
<b>Conversion of paved urban area to unpaved area</b>	In the 'Conversion of paved urban area to unpaved area' dialog one can reduce the calculated total paved urban area. This reduction is carried out independently from the calculation of the population density. The new unpaved area is not allocated to any other land use. The eligible percentage ranges from 0 to 20% of the currently paved urban area.
<b>Proportion of solids in septic tanks to WWTPs</b>	In the 'Proportion of solids in septic tanks to WWTPs' dialog one can reduce the proportion of the population connected to septic tanks. This modification is limited by the statistically detected share of population connected to sewers only. At least this share of population has to persist. The eligible percentage ranges from 0 to 100%.
<b>Portion of people connected to sewers and WWTP</b>	In this dialog only that portion of urban population usually connected to sewers is provided an additional access to WWTPs. The eligible percentage ranges from 0 to 100%.
<b>Connected to sewers and WWTP rural</b>	In this dialog only that portion of rural population usually connected to sewers is provided an additional access to WWTPs. The eligible percentage ranges from 0 to 5%.
<b>Connected to sewers and WWTP urban</b>	In the 'Connected to sewers and WWTP urban' dialog it can be assumed that all households connected to sewers are also connected to WWTPs. If you want to apply this setting select 'yes' in the belonging 'yes/no' dialog.
<b>P-free detergents</b>	In the 'P- free detergents' dialog you can reduce the person-specific Phosphorus releases by the amount of Phosphate that originates from detergents of urban systems and WWTPs. The current values are considered as country wide means. If you want to apply this setting select 'yes' in the belonging 'yes/no' dialog.

### Defining measures for WWTP P/ WWTP N

In the 'WWTP P' and 'WWTP N' tabs discharge concentrations for individual WWTPs of a certain size (connected inhabitants) can be defined (table I.5.26 (user surface currently departs from screenshot) and table I.5.27). In general these concentrations should be based on the target settings of the EC-Directive on Sewage (table I.5.22) but might be adjusted manually as well. On both tabs you can enter values for 5 different classes which are defined in table I.5.22. Since WWTP data for class 1 are not available, the Scenario Manager considers data beginning with class 2 only.

Label	Input	Range
P-concentration of WWTP Class 2	0	0 - 6 mg/l
P-concentration of WWTP Class 3	0	0 - 6 mg/l
P-concentration of WWTP Class 4	0	0 - 2 mg/l
P-concentration of WWTP Class 5	0	0 - 2 mg/l
P-concentration of WWTP Class 6	0	0 - 1 mg/l

**Figure I.5.26:** Defining measures for WWTP P

Label	Input	Range
N-concentration of WWTP Class 2	0	0 - 60 mg/l
N-concentration of WWTP Class 3	0	0 - 60 mg/l
N-concentration of WWTP Class 4	0	0 - 15 mg/l
N-concentration of WWTP Class 5	0	0 - 15 mg/l
N-concentration of WWTP Class 6	0	0 - 10 mg/l

**Figure I.5.27:** Defining measures for WWTP N

**Table I.5.22:** Concentrations for the Scenario Calculations

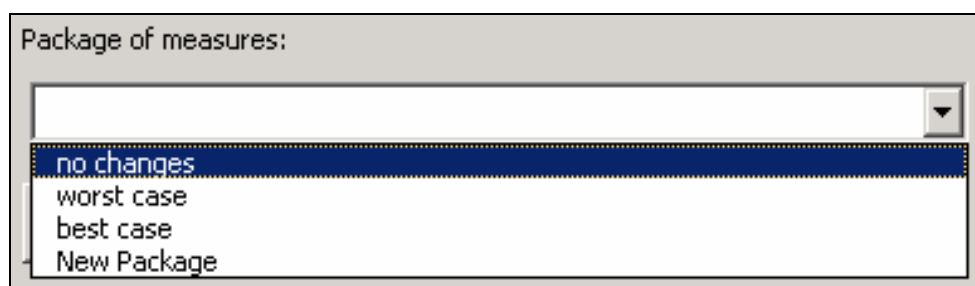
(\* definite concentrations for the scenario calculations will still have to be discussed)

Class	WWTP population equivalent	Phosphorus*	Nitrogen*
2	< 500	5,0	30,0
3	< 10000	4,0	30,0
4	< 50000	3,0	15,0
5	< 100000	1,0 - 2,0	15,0
6	> 100000	0,5 - 1,0	10,0

### Recovering default settings

To recover the default settings for the packages of measures select the ‘no changes’ entry of the scroll-down menu of the ‘Package of Measures’ dialog. Select ‘All Analytical Units’ in the ‘Selected Analytical unit’-dialog and press the “Apply Package” button.

Alternatively you can select the ‘no changes’ entry of the scroll-down menu of the ‘Scenario Settings’ dialog.

**Figure I.5.28:** Recovering default settings

### Working with target concentrations

In the ‘Target concentration’ dialog one can define target concentrations for riverine loads. Type in the concentrations you want to set as target concentrations and press the “Apply target concentration” button.

Two different procedures can be applied to derive the reduction need for Nitrogen and Phosphorus emissions to reach a certain target concentration.

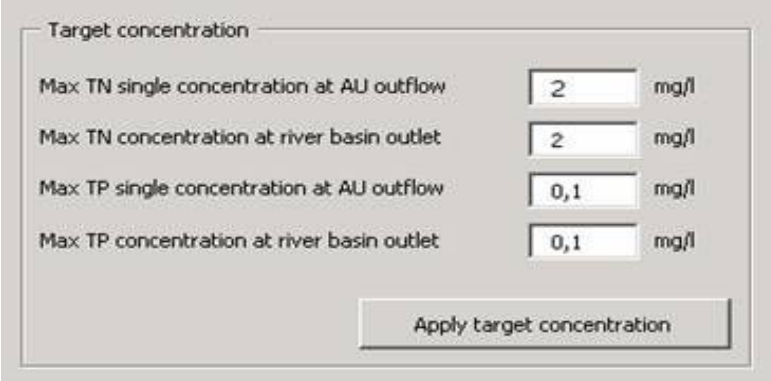
First a maximum concentration for the single loads of individual analytical units can be set. Here resulting outflow concentrations at the outlet of an Analytical unit will be reduced to the set maximum outflow concentration.

Like for the “Apply package” button the value for the concentrations set for the AU outlet are only applied to those Analytical units being selected by the grouping criterion.

Like this you can set individual out flow concentration for different Analytical units, countries or other groups of analytical units.

Second a maximum resulting concentration of riverine loads at the river basin outlet can be set. For this procedure the resulting concentration of the river load at the river basin outlet from all Analytical unit will be individually compared to the set target concentration. The

highest outflow concentrations are subsequently reduced until the target concentration has been reached.



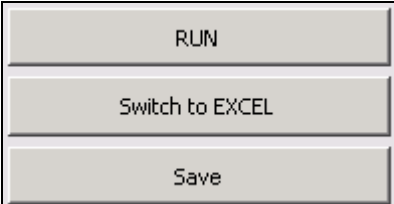
Target concentration	
Max TN single concentration at AU outflow	2 mg/l
Max TN concentration at river basin outlet	2 mg/l
Max TP single concentration at AU outflow	0,1 mg/l
Max TP concentration at river basin outlet	0,1 mg/l

Apply target concentration

**Figure I.5.29:** Setting Target concentrations

### *Calculating single loads*

If you want to calculate the single loads for the three predefined conditions ('long term', 'wet year', 'dry year' (Chapter I.5.3)), press the "Run" button of the MONERIS User Interface. Single loads are the loads calculated for a single analytical unit. The results refer to the basin outlet and the outlet of the river basin district of the selected analytical unit.



RUN
Switch to EXCEL
Save

**Figure I.5.30:** MONERIS Control buttons

### I 5.4.4.3 The MONERIS Results

The ‘results’ tab of the MONERIS User Interface opens up the possibility to view the results of the current calculation in form of figures and key values.

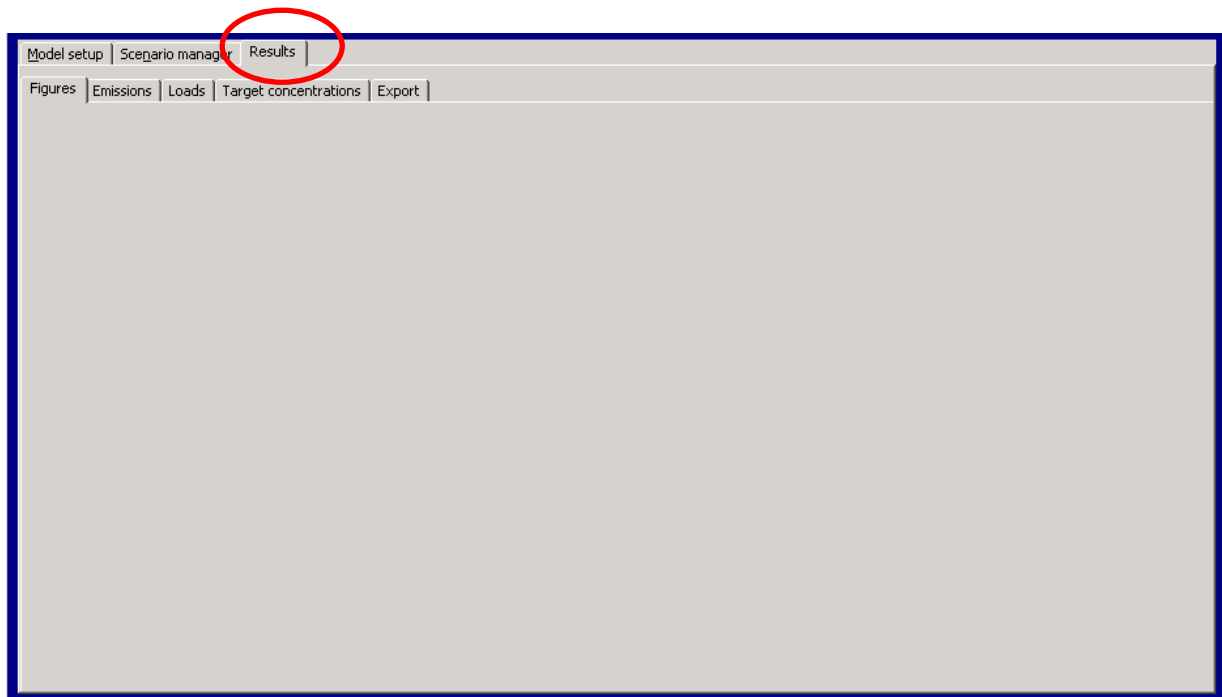


Figure I.5.31: The MONERIS Results

#### *Viewing results as figures*

To display the results as figures activate the ‘figures’ tab of the ‘results’ tab. Select the figures you want to display in the ‘Display figures’ dialog of the ‘Additional Options’ User Interface and press the “Refresh figures” button. The chosen figures will be displayed in the adjacent field.

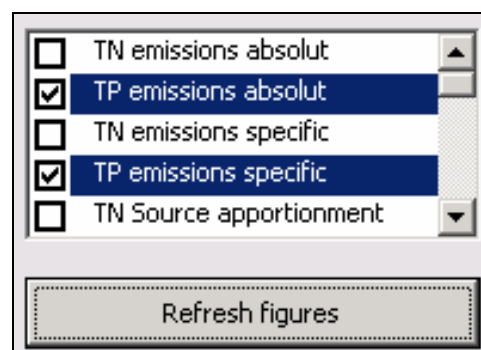
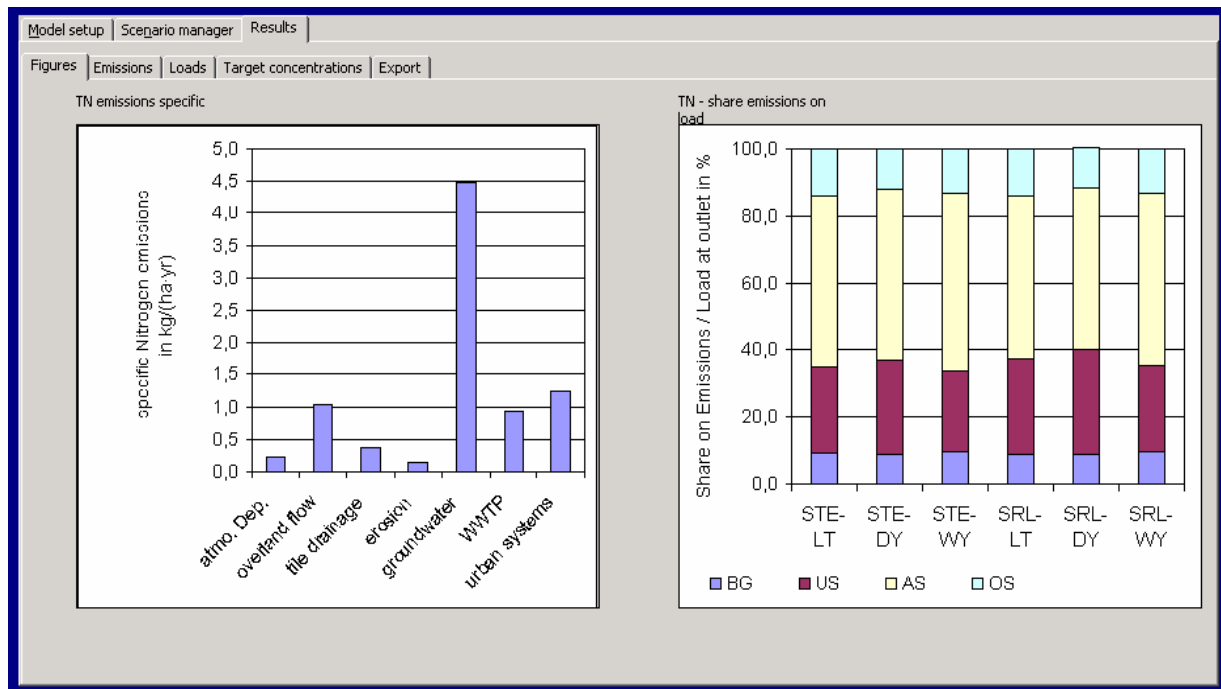


Figure I.5.32: Selecting figures

You can select and display up to six figures at the same time. If you run the model a second time, e.g. by applying different scenarios, you have to press the “*Refresh figures*” button again to update the presented figures.



**Figure I.5.33:** The MONERIS Results dialog-Figures

### Viewing results as values

In addition to viewing the results as figures the MONERIS Results option holds the possibility to analyse the results by presenting some key values. By switching from one tab to another you have the possibility to evaluate the data for Emissions, Loads and Target concentrations. All of these results are presented for the conditions Long term, Dry year and Wet year.

### Emissions

The ‘Results-Emissions’- dialog provides an overview about the ‘Emissions from selected analytical units in tons/yr’, the ‘Emissions from selected analytical units in kg/(ha\*yr)(TN) and kg/(km<sup>2</sup>\*yr)(TP)’ and the ‘Proportion on total emissions in percent’ for Total Nitrogen and Total Phosphorus.

**Figure I.5.34:** The MONERIS Results dialog-Emissions

The ‘Results-Loads’- dialog provides an overview about the ‘Resulting load in t/yr’ and the ‘Share on resulting load at RBD outlet in percent’ for Total Nitrogen and Total Phosphorus.

**Figure I.5.35:** The MONERIS Results dialog-Loads



- Calculated net load from analytical unit: Gives the resulting load at an Analytical units outlet after retention in the surface waters of this AU (emissions from all other AU's are neglected) (see figure I5.30: L\_AU)
- Calculated load from catchment of selected Analytical Unit: Gives the resulting load at an Analytical unit's outlet after retention in the surface waters in all belonging Analytical units
- Calculated net load from Analytical unit at RBD outlet: Gives the load at the river basin district outlet (mouth to the sea) which results if only the emissions from the selected AU are considered (see figure I5.30: L\_OL)
- Calculated load from catchment of Analytical unit at RBD outlet: Gives the load at the river basin district outlet which results from the emissions of the selected AU
- Calculated load from selected analytical units at RBD outlet: Gives the load at the river basin district outlet which results from the group of Analytical units selected by the grouping criterion
- Share on total resulting load at RBD outlet: Gives the percentage contribution of the emissions from the selected (group of ) AU on the total resulting load from all Analytical units
- Share of Background/ agricultural/ urban and other sources on the total resulting load at RBD outlet: Gives the percentage contribution of the various sources from the selected (group of) AU on the resulting load from all Analytical units.

### ***Target concentrations***

The 'Results- Target concentrations'- dialog provides an overview about the 'Resulting load in t/yr' for Total Nitrogen and Total Phosphorus. Apart from the 'Target concentration at outlet' info box, the necessary reductions for all emissions and the pathways agriculture and urban systems are listed. Furthermore information about the reduction to reach the maximal net concentration is provided.

Model setup   Scenario manager   Results									
Figures   Emissions   Loads   Target concentrations   Export									
Resulting load in t/yr									
Total Nitrogen					Total Phosphorus				
	Long term	dry years	wet years		Long term	dry years	wet years		
Calculated net load from Analytical unit	925	679	881		28,0	19,4	30,7		
Calculated load from catchment of Analytical unit	854	609	818		26,2	17,7	28,8		
Calculated net load from analytical unit at RBD outlet	579	383	591		12,9	6,95	15,9		
Calculated load from catchment of Analytical unit at RBD outlet	535	344	549		12,0	30,7	14,9		
Calculated load from selected analytical units at RBD outlet	397876	308357	443961		16663	13589	18994		
Share on resulting load at RBD outlet in percent									
Share on total resulting load at RBD outlet	100	100	100		100	100	100		
Share of background on total resulting load at RBD outlet	10,1	10,0	10,7		14,5	11,8	16,6		
Share of agricultural sources on total resulting load at RBD outlet	54,2	54,0	56,5		23,3	22,8	25,5		
Share of urban sources on total resulting load at RBD outlet	19,0	21,6	17,5		58,0	61,5	53,4		
Share of other sources on total resulting load at RBD outlet	16,1	13,9	14,9		0,687	0,794	0,773		

Figure I.5.36: The MONERIS Results dialog–Target concentrations

## Exporting data

### Simple Data Export

The Export tab of the MONERIS User Interface holds the possibility to export certain results to an EXCEL file. Select the data you want to export ('Basicinfo', 'Periodical Data', 'Scenario settings', 'Scenario results', 'Emissions aggregated results', 'Loads aggregated results', 'Target concentrations aggregated results') and click the "Export" button. The export data 'Emissions aggregated results', 'Loads aggregated results' and 'Target concentrations aggregated results' are the basis of the data presented in the 'Emissions', 'Loads' and 'Target concentrations' dialogs of the 'results' tab.

Model setup   Scenario manager   Results						
Figures   Emissions   Loads   Target concentrations   Export						
Resulting load in t/yr						
	Total Nitrogen			Total Phosphorus		
	Long term	dry years	wet years	Long term	dry years	wet years
Calculated net load from Analytical unit	925	679	881	28,0	19,4	30,7
Calculated load from catchment of Analytical unit	854	609	818	26,2	17,7	28,8
Calculated net load from analytical unit at RBD outlet	579	383	591	12,9	6,95	15,9
Calculated load from catchment of Analytical unit at RBD outlet	535	344	549	12,0	30,7	14,9
Calculated load from selected analytical units at RBD outlet	397876	308357	443961	16663	13589	18994
Share on resulting load at RBD outlet in percent						
Share on total resulting load at RBD outlet	100	100	100	100	100	100
Share of background on total resulting load at RBD outlet	10,1	10,0	10,7	14,5	11,8	16,6
Share of agricultural sources on total resulting load at RBD outlet	54,2	54,0	56,5	23,3	22,8	25,5
Share of urban sources on total resulting load at RBD outlet	19,0	21,6	17,5	58,0	61,5	53,4
Share of other sources on total resulting load at RBD outlet	16,1	13,9	14,9	0,687	0,794	0,773

Figure I.5.37: The MONERIS Export function

The Windows ‘Save As’ dialog opens. Navigate to the directory you want to save your results in and type in a name for your export file.

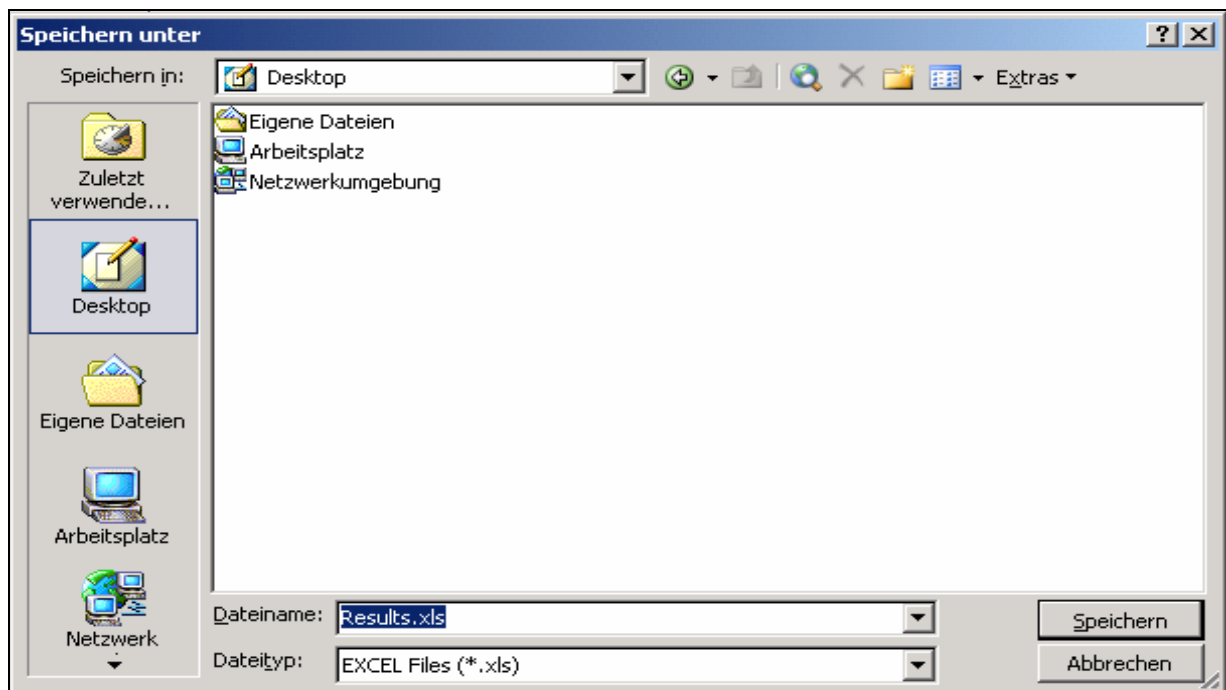
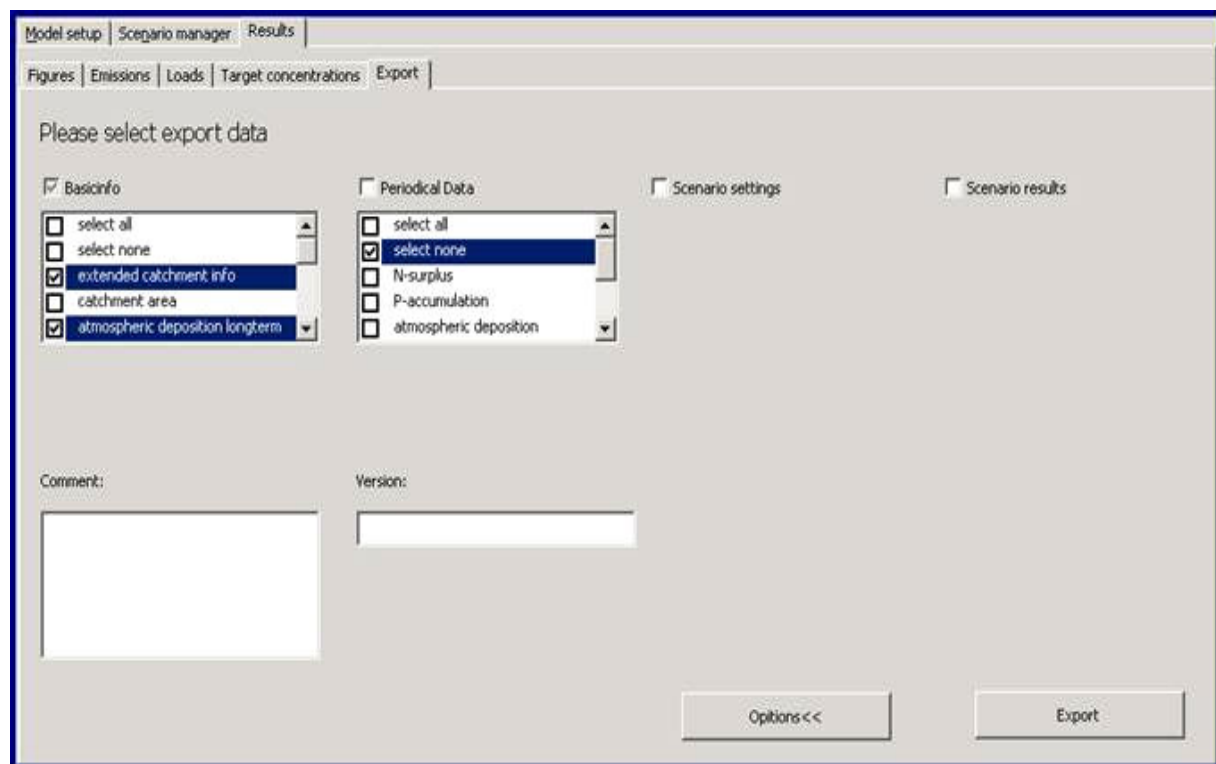


Figure I.5.38: Saving Export data to file

Click on the “Save” button and the data are exported.

### Customized Data Export

To customize the set of data for the Export function, click the “*Options*” button. Select the data of the ‘Basicinfo’ and ‘Periodical Data’ you want to export and click the “*Export*” button. Follow now the procedure for the simple data export and the selected data will be exported to the determined directory.



**Figure I.5.39:** Customized data export

### Viewing exported data

If you have chosen all exportable data of the ‘Export’ dialog the export-file contains the following worksheets:

**Table I.5.23:** Structure of the exported data file

Sheet name	Content
Wet_year:	Contains the Results for ‘Wet year’
Dry_year:	Contains the Results for ‘Dry year’
Long term:	Contains the Results for ‘Long term’
Periodical data:	Contains mean values for the defined period of the periodical data file
Basicinfo:	Contains the data of the Basicinfo file
Meta-data:	Contains Meta-data about the current modelling run

Since the structures of the Basicinfo (Chapter I.5.2) and Periodical data (Chapter I.5.3) were explained already, the structure of the export worksheets ‘long term’, ‘wet year’ and ‘dry year’ will be described in this chapter.

These worksheets have the following basic structure:

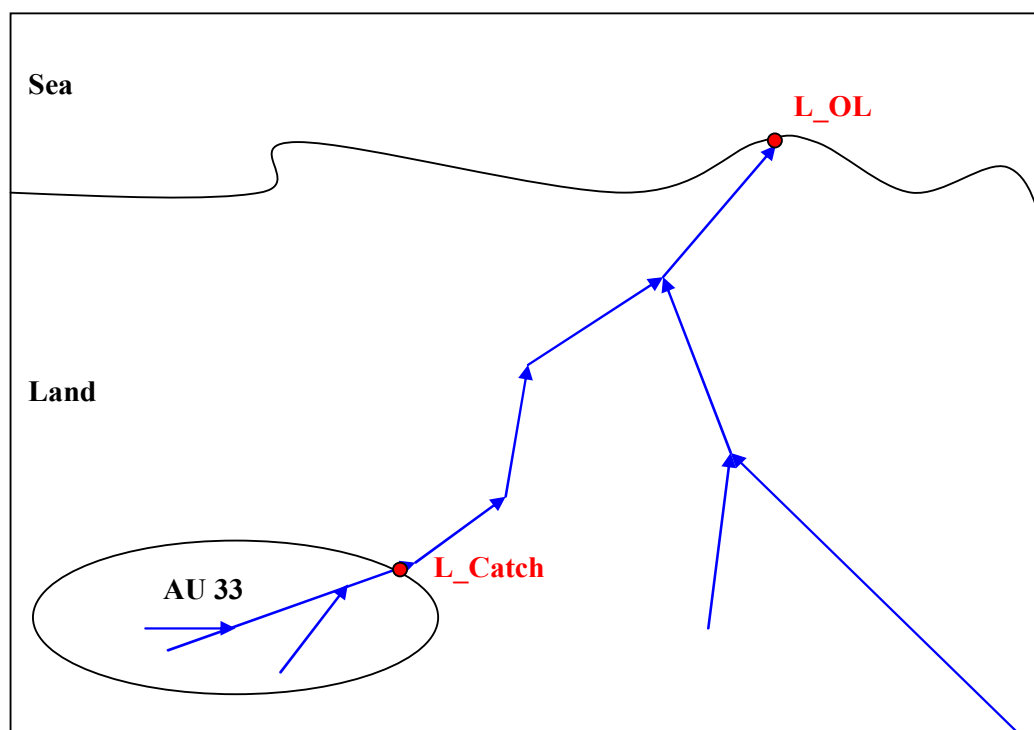
**Table I.5.24:** Worksheet structure of exported data. (\*l t = long term; d y = dry year; w y = wet year)

Category	Subdivision	Period*	Unit
RUNOFF	Net	l t/d y/w y	m <sup>3</sup> /s
NITROGEN	Tot	l t/d y/w y	m <sup>3</sup> /s
	Atmo. dep.	l t/d y/w y	t/yr
DIN_TOTAL EMISSIONS	Overland flow	l t/d y/w y	t/yr
	Tile drainage	l t/d y/w y	t/yr
	Erosion	l t/d y/w y	t/yr
	Groundwater	l t/d y/w y	t/yr
	WWTP	l t/d y/w y	t/yr
	Urban systems	l t/d y/w y	t/yr
	Total N	l t/d y/w y	t/yr
	Background	l t/d y/w y	t/yr
	Urban systems	l t/d y/w y	t/yr
	Agricultural sources	l t/d y/w y	t/yr
	Other sources	l t/d y/w y	t/yr
	L_AU/emi	l t/d y/w y	-
TN_TOTAL EMISSIONS	L_AU/emi	l t/d y/w y	-
DIN_TOTAL EMISSIONS	L_OL/emi	l t/d y/w y	-
TN_TOTAL EMISSIONS	L_OL/emi	l t/d y/w y	-
DIN_TOTAL EMISSIONS	L_OL/L_cath	l t/d y/w y	-
TN_TOTAL EMISSIONS	L_OL/L_cath	l t/d y/w y	-
DIN_AGRICULTURAL SOURCES	L_AU/emi	l t/d y/w y	-
TN_AGRICULTURAL SOURCES	L_AU/emi	l t/d y/w y	-
DIN_AGRICULTURAL SOURCES	L_OL/emi	l t/d y/w y	-
TN_AGRICULTURAL SOURCES	L_OL/emi	l t/d y/w y	-
DIN_AGRICULTURAL SOURCES	L_OL/L_cath	l t/d y/w y	-
TN_AGRICULTURAL SOURCES	L_OL/L_cath	l t/d y/w y	-
DIN_URBAN SOURCES	L_cath/emi	l t/d y/w y	-
TN_URBAN SOURCES	L_cath/emi	l t/d y/w y	-
DIN_URBAN SOURCES	L_OL/emi	l t/d y/w y	-
TN_URBAN SOURCES	L_OL/emi	l t/d y/w y	-
DIN_URBAN SOURCES	L_OL/L_cath	l t/d y/w y	-
TN_URBAN SOURCES	L_OL/L_cath	l t/d y/w y	-
CALC LOAD	TN	l t/d y/w y	t/yr

Category	Subdivision	Period*	Unit
SINGLE LOAD AT AU	TN	1 t/d y/w y	t/yr
SINGLE LOAD AT OL	TN	1 t/d y/w y	t/yr
SHARE ON TOTAL EMISSIONS	Total emissions	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Background	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Urban systems	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Agricultural sources	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Other sources	1 t/d y/w y	%
SHARE ON RESULTING LOAD	Total emissions	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Background	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Urban systems	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Agricultural sources	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Other sources	1 t/d y/w y	t/yr
PHOSPHORUS	Atmo. dep.	1 t/d y/w y	t/yr
TP_TOTAL EMISSIONS	Overland flow	1 t/d y/w y	t/yr
	Tile drainage	1 t/d y/w y	t/yr
	Erosion	1 t/d y/w y	t/yr
	Groundwater	1 t/d y/w y	t/yr
	WWTP	1 t/d y/w y	t/yr
	Urban systems	1 t/d y/w y	t/yr
	Total-P	1 t/d y/w y	t/yr
	Background	1 t/d y/w y	t/yr
	Urban systems	1 t/d y/w y	t/yr
	Agricultural sources	1 t/d y/w y	t/yr
	Other sources	1 t/d y/w y	t/yr
	L_AU/emi	1 t/d y/w y	-
TP_TOTAL EMISSIONS	L_OL/emi	1 t/d y/w y	-
TP_TOTAL EMISSIONS	L_OL/L_cath	1 t/d y/w y	-
TP_AGRICULTURAL SOURCES	L_AU/emi	1 t/d y/w y	-
TP_AGRICULTURAL SOURCES	L_OL/emi	1 t/d y/w y	-
TP_AGRICULTURAL SOURCES	L_OL/L_cath	1 t/d y/w y	-
TP_URBAN SOURCES	L_AU/emi	1 t/d y/w y	-
TP_URBAN SOURCES	L_OL/emi	1 t/d y/w y	-
TP_URBAN SOURCES	L_OL/L_cath	1 t/d y/w y	-
CALC LOAD	TP	1 t/d y/w y	t/yr
SINGLE LOAD AT AU	TP	1 t/d y/w y	t/yr
SINGLE LOAD AT OL	TP	1 t/d y/w y	t/yr

Category	Subdivision	Period*	Unit
SHARE ON TOTAL EMISSIONS	Total emissions	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Background	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Urban systems	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Agricultural sources	1 t/d y/w y	%
SHARE ON TOTAL EMISSIONS	Other sources	1 t/d y/w y	%
SHARE ON RESULTING LOAD	Total emissions	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Background	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Urban systems	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Agricultural sources	1 t/d y/w y	t/yr
SHARE ON RESULTING LOAD	Other sources	1 t/d y/w y	t/yr

### Explanations of the defined terms



**Figure I.5.40:** Schema for the analysis of the results

(**L\_Catch** = Load at the outlet of an Analytical Unit; **L\_OL** = Load at the River Basin District outlet)

**Table I.5.25:** Explanations of the defined terms

<b>Terms</b>	<b>Explanation</b>
<b>L_AU/emi</b>	The relation $L_{catch}/emi$ provides information about the total percentage of retention within a certain analytical unit.
<b>L_OL/emi</b>	The relation $L_{OL}/emi$ provides information about the complete retention of the emissions of a certain analytical unit at the river basin district outlet.
<b>L_OL/L_catch</b>	The relation $L_{OL}/L_{AU}$ provides information about the retention in the main river, beginning at the outlet of the catchment and ending at the river basin district outlet.
<b>Calculated load</b>	The ‘Calculated load’ is the load calculated for the catchment of an AU. The calculated load can be compared to the measured load.
<b>Single load at AU</b>	Single loads are the loads calculated for a single analytical unit. ‘The single loads at AU’ refer to the catchment outlet of the selected analytical unit.
<b>Single load at OL</b>	Single loads are the loads calculated for a single analytical unit. ‘The single loads at OL’ refer to the outlet of the river basin district after retention in the main river.
<b>Share on total emissions</b>	The ‘Share on total emissions’ provides information about the fraction of the emissions of a certain analytical unit that contribute to the total emissions of a river basin district.
<b>Share on resulting load</b>	The ‘Share on resulting load’ provides information about the fraction of the loads of selected analytical units to the resulting load at the river basin district outlet.



### I.5.4.5 Closing MONERIS

To close the MONERIS User interface click the “Switch to EXCEL” button and close EXCEL as normal.

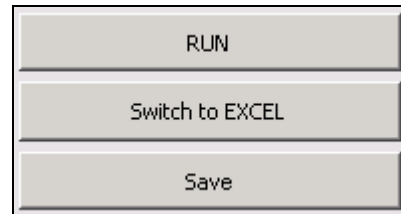


Figure I.5.41: Switch to EXCEL

Click “Yes” if you want to leave MONERIS without saving. Else save the project and close MONERIS afterwards.

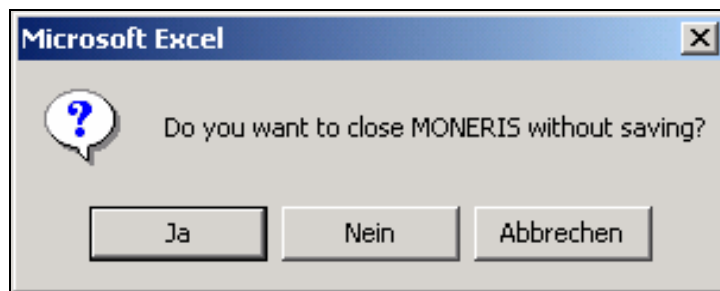


Figure I.5.42: Closing MONERIS

#### *Saving a Project*

You can save your MONERIS Project either in the MONERIS User Interface by clicking the “Save” button or as a normal EXECL file on EXCEL level. To save the project on EXCEL level click the “Switch to EXCEL” button and save the project like a usual EXCEL file.

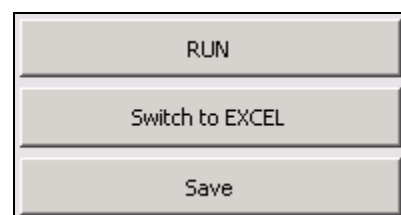


Figure I.5.43: Saving a project



**The ‘SAVE AS’ function in EXCEL does not work. Copies of MONERIS can only be done with programs like explorer or Norton commander**

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## Appendix C: Table of Data requirements

The calculation of nutrient inputs into surface waters with MONERIS (BEHRENDT, 2000) considerably bases on data available from standard monitoring programs and figures available in statistical reports. In this chapter the data requirements are subdivided as follows:

- Basicinfo data : input data for different pathway calculations in the EXCEL sheets of MONERIS 2.0 (Table C.1)
- Periodical data : data from monitoring programmes, statistical reports and coefficients (Table C.2)

### Maps

The most input data for the Basicinfo can be derived from following maps:

- catchment area of the gauge station (CAG): please add the ID for each catchment
- catchment area of the monitoring station (CAM): please add the ID for each catchment.
- river flow net (RIV)
- lakes (LAK)
- soil type map (ST)
- land use map (LU)
- digital elevation model (DEM)
- administrative boundaries (AB)
- hydrogeological map (HG): porosity, permeability
- location of climatic station (LC)
- atmospheric deposition (LD)
- location of river monitoring station (LRM)
- location of gauging station (LG)
- map of tile drained areas (TD)
- nitrogen surplus (NS)
- phosphorus accumulation (PS)
- location of WWTP and dischargers (WWTP)
- soil loss map (SL)

Tab. C.1: List of Basicinfo data

CATEGORY	SUB- CATEGORY	SPECIFICATION	UNIT
CATCHMENT DESCRIPTION	ID	-	-
	ID_GIS	-	-
	Country	-	-
	State	-	-
	LAWA	-	-
CATCHMENT DESCRIPTION	Adress	-	-
	Description	-	-
	Analytical unit (AU)	-	-
	Sub-unit (SU)	-	-
	Sub-basin (SB)	-	-
	River Basin (RB)	-	-
	River basin district (RBD)	-	-
	Monitoring stationname	-	-
CATCHMENT AREA	Monitoring station	-	km <sup>2</sup>
	Net	-	km <sup>2</sup>
ANALYTICAL UNIT AREA	Total	-	km <sup>2</sup>
	Net	-	km <sup>2</sup>
FLOW NET EQUATION	Without splitting	-	
	With splitting	-	
	Main river	-	
ATMO DEP.	NH4	Long term	mg/m <sup>2</sup>
	NOx	Long term	mg/m <sup>2</sup>
PRECIPITATION	Long term	Annual	mm
	Long term	Summer	mm
EVAPOTRANSPIRATION	Long term	Annual	mm/(m <sup>2</sup> /yr)
LANDUSE*	Urban area	-	km <sup>2</sup>
	Arable land	< 1 %	km <sup>2</sup>
	Arable land	1 – 2 %	km <sup>2</sup>
	Arable land	2 – 4 %	km <sup>2</sup>
	Arable land	4 – 8 %	km <sup>2</sup>
	Arable land	> 8 %	km <sup>2</sup>
	Grasland	-	km <sup>2</sup>
	Natural covered land (forest, grassland, shrubland)	-	km <sup>2</sup>
	Water surface	-	km <sup>2</sup>
	Open pit mine	-	km <sup>2</sup>
	Open area	-	km <sup>2</sup>
	Wetland	-	km <sup>2</sup>
	Remaining areas	-	km <sup>2</sup>
	Total area with	Erosion potential	km <sup>2</sup>
TILE DRAINAGE		Tile drained area	%
ELEVATION		Derived from 1km GRID	m
SLOPE_1000	Net	Derived from 1km GRID	%
SLOPE_100	Net	Derived from 100 m GRID	%

CATEGORY	SUB- CATEGORY	SPECIFICATION	UNIT
SOIL	Sand	-	km <sup>2</sup>
	Clay	-	km <sup>2</sup>
	Loam	-	km <sup>2</sup>
	Fen	-	km <sup>2</sup>
	Bog	-	km <sup>2</sup>
	Silt	-	km <sup>2</sup>
	N content topsoil	-	%
	Clay content topsoil	-	%
SOIL LOSS	Arable Land	MED_SL_1_	t/(ha·yr)
	Arable Land	MED_SL_1_2	t/(ha·yr)
	Arable Land	MED_SL_2_4	t/(ha·yr)
	Arable Land	MED_SL_4_8	t/(ha·yr)
	Arable Land	MED_SL_8_	t/(ha·yr)
	Arable Land	MED_SL_GRA	t/(ha·yr)
	Arable Land	MED_SL_NATCOV	t/(ha·yr)
	Mean total	Catchment	t/(ha·yr)
C-Factor	current		-
NITROGEN SURPLUS	current		kg/(ha·yr)
HYDROGEOLOGY	Unconsolidated soil	Shallow groundwater	km <sup>2</sup>
	Unconsolidated soil	Deep groundwater	km <sup>2</sup>
	Consolidated	High porosity	km <sup>2</sup>
	Consolidated	Impermeable	km <sup>2</sup>
SEWER SYSTEMS	Sewer flow length	-	km
	Black and gray water	-	km
RIVER FLOW LENGTH	Main river (MR)	-	km
	Tributary (TRIB)	-	km
LAKE AREA	MR	Total area in AU	km <sup>2</sup>
	MR_AU outlet	Area of lakes at outlet to be considered separated for Retention	km <sup>2</sup>
	TRIB	Total area in AU	km <sup>2</sup>

\* areas with erosion potential = total catchment area - urban areas - water surface areas - wetlands

Tab. C.2: List of periodical data for the level of country data and analytical units

MAIN CATEGORY : COUNTRY DATA			
CATEGORY	SUB- CATEGORY	SPECIFICATION	UNIT
CSO-STORAGE		-	
C-FACTOR		-	
P ACCUMULATION		-	kg/(ha·yr)
N SURPLUS		-	kg/(ha·yr)
TP per Inhabitant		-	
TP_detergents_per_inhabitant		-	
MAIN CATEGORY : ANALYTICAL UNIT			
CATEGORY	SUB- CATEGORY	SPECIFICATION	UNIT
ATMO DEP.	NHx	Study period	mg/m <sup>2</sup>
	NOx	Study period	mg/m <sup>2</sup>
	TP	Study period	mg/m <sup>2</sup>
PRECIPITATION	Prec_mean_annual	-	mm/(m <sup>2</sup> /yr)
	Summer	-	mm/(m <sup>2</sup> /yr)
SPLITTING FACTOR	Splitting factors	-	-
RUNOFF	Net catchment	calculated	m <sup>3</sup> /s
	Total catchment	observed	m <sup>3</sup> /s
OBSERVED LOAD	DIN	-	t/yr
	TN	-	t/yr
	TP	-	t/yr
WATER TEMPERATURE	T <sub>w</sub>	-	°C
INHABITANTS	Total	-	-
	Connected inhabitants	-	-
	Connected to WWTPs and sewers	-	-

Tab. C.3: List of periodical data for the level of WWTP

MAIN CATEGORY : WWTP			
CATEGORY	SUB- CATEGORY	SPECIFICATION	UNIT
ID			
Total discharge from WWTP per catchment	TP		kg/yr
	TN		kg/yr
	Q-WWTP		m <sup>3</sup> /s
WWTP NAME			
Country_ID			
Type			
Population equivalent	Original		
Population equivalent	Completed		
Cities>10000	Name		
Cities>10000	Population		
Size Class			
TREATMENT STAGE	Primary		
	Secondary		
	Tertiary N		
	Tertiary P		
	N short		
	P short		
N conc. at outlet	Original		mg/l
P conc. at outlet	Original		mg/l
Discharge	Current original		m <sup>3</sup> /s
N load			t/yr
P load			t/yr
Discharge			m <sup>3</sup> /yr
N concentration at outlet	Current		mg/l
P concentration at outlet	Current		mg/l

## Appendix D: Abbreviations and Acronyms

A <sub>AL</sub>	Arable Land
AU	analytical unit
AVHRR	Advanced Very High Resolution Radiometer
CCC	Chemical Coordinating Centre
CLC	CORINE Landcover
CORINE	Coordinated Information on the European Environment
C-Factor	crop factor of the USLE
CSO	combined sewer overflow
DIN	dissolved inorganic nitrogen
DSMW	digital Soil Map of the world
EEA	European Environmental Agency
EMEP	Co-operative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe
ER	Enrichment Ratio
ESRI	Environmental System Research Institute
FAO	Food and Agriculture Organization
FNE	Flow net equation
GIS	Geographic Information System
GPCC	Global Precipitation Climatology Centre
ICPDR	Inventory of International Commission of Protection of the Danube River
IGB	Leibniz-Institute of Freshwater Ecology and Inland Fisheries
ISO	International Organisation for Standardization
JRC	Joint research centre of the European Commission
Lawa	German Working Group on water issues of the Federal States and the Federal Government
MONERIS	MOdelling Nutrient Emissions in RIver Systems
MR	Main River
N	Nitrogen
NH <sub>4</sub> -N	ammonia-nitrogen
NH <sub>4</sub>	ammonia
NILU	Norwegian Institute for Air Research
NO <sub>2</sub>	Nitrit

NO <sub>3</sub>	Nitrat
NO <sub>x</sub> -N	nitric oxides-nitrogen
NO <sub>x</sub>	nitric oxides
OECD	Organization for Economic Co-operation and Development
ORNL	Oak Ridge National Laboratory
P	Phosphorus
PO <sub>4</sub>	Phosphat
PESERA	Pan-European soil erosion risk assessment
QD	domestic wastewater
QCOM	commercial wastewater
QEX	external wastewater
QU	urban wastewater
QST	storm wastewater
QTOT	total wastewater
RAM	Random Access Memory
RB	river basin
RBD	river basin district
SB	subbasin
SDR	sediment delivery ratio
SED	Sediment Input
SL	Slope
SOL	Soil Loss
SRP	soluble reactive phosphorus
SRTM	Shuttle Radar Topography Mission-Data
SRTM-DEM	Shuttle Radar Topography Mission-Digital Elevation Model
SU	subunit
TN	total nitrogen
TP	total phosphorus
TPE	treated population equivalents
TPE <sub>IN</sub>	treated population equivalents (inhabitants)
TPE <sub>IID</sub>	treated population equivalents (indirect industrial discharges)
TRIB	Tributaries
UBA	German Federal Environmental Agency
USGS	United States Geological Survey



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USLE	Universal Soil Loss Equation
VBA	Visual Basic Application
VSEU	Valuated Soil Ecological Unit
WFD	Water Framework Directive of the European Union
WSA	Water surface area
WWTP	wastewater treatment plant
WWTP N	discharge concentration of nitrogen for individual WWTP's
WWTP P	discharge concentration of phosphorus for individual WWTP's
Zn	Zinc

## Appendix E: Abbreviations used in MONERIS

a	unit conversion factor
A <sub>AR</sub>	area of arable land from CLC
A <sub>AG</sub>	agricultural area
A <sub>CA</sub>	catchment area
a <sub>COM</sub>	proportion of total urban area in commercial use
A <sub>DR</sub>	drained area
A <sub>DRB</sub>	area of drained bog soil
A <sub>DRL</sub>	area of drained loams
A <sub>DRF</sub>	area of drained fen soil
A <sub>DRS</sub>	area of drained sandy soil
A <sub>EZG</sub>	catchment area
A <sub>FOR</sub>	area of forest
A <sub>GRAS</sub>	grassland area
A <sub>b</sub>	area of bog soil
A <sub>HRT</sub>	area of different hydrogeological rock types
A <sub>IMP</sub>	impervious urban area
A <sub>IMPC</sub>	impervious urban area connected to combined sewer system
A <sub>IMPN</sub>	impervious urban area connected neither to a sewer nor to a wastewater treatment plant
A <sub>IMPS</sub>	impervious urban area connected to separated sewer system
a <sub>IMP</sub>	share of precipitation realized as surface runoff from impervious urban areas
A <sub>IMPSO</sub>	urban area connected only to sewers
A <sub>Lake</sub>	surface area of lakes in main rivers (MR) and tributary rivers (TRIB)
A <sub>L</sub>	area of loamy soil
A <sub>F</sub>	area of fen soil
A <sub>OP</sub>	open area
AS	specific metal input from impervious urban areas
A <sub>S</sub>	area of sandy soil
AS <sub>URB</sub>	specific heavy metal input from impervious urban areas
A <sub>TAu,Au</sub>	total catchment area (TAu) and analytical unit (Au)
A <sub>URB</sub>	total urban area

$A_{\text{WOOP}}$	woodland and open area
$B$	modul coefficient for denitrification (0.641)
$C$	cover-management factor – the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow
$C_{\text{COM}_{\text{N,P}}}$	nutrient concentration in commercial wastewater
$C_{\text{DR}_p}$	drainage water phosphorus concentration
$C_{\text{DRS}_p}$	drainage water phosphorus concentration for sandy soil
$C_{\text{DRL}_p}$	drainage water phosphorus concentration for loamy soil
$C_{\text{DRF}_p}$	drainage water phosphorus concentration for fen soil
$C_{\text{DRB}_p}$	drainage water phosphorus concentration for bog soil
$C_{\text{DRNO}_3\text{-N}}$	nitrate concentration in drainage water
$C_{\text{WN}_\text{N}}$	nitrogen concentration in groundwater
$C_{\text{GWAG}_{\text{SRP}}}$	groundwater SRP concentration for agricultural land
$C_{\text{GWB}_{\text{SRP}}}$	groundwater SRP concentration for bog soil
$C_{\text{GWF}_{\text{SRP}}}$	groundwater SRP concentration for fen soil
$C_{\text{GWL}_{\text{SRP}}}$	groundwater SRP concentration for loamy soil
$C_{\text{GWS}_{\text{SRP}}}$	groundwater SRP concentration for sandy soil
$C_{\text{GW}_{\text{TP}}}$	TP concentration in groundwater
$C_{\text{GWNO}_3\text{-N}}$	nitrate concentration in groundwater
$C_{\text{GW}_{\text{SRP}}}$	SRP concentration in groundwater
$C_{\text{GWWOOP}_{\text{SRP}}}$	groundwater SRP concentration for woodland and open areas
$c_i$	measured concentration
$C_{\text{LWPOTNO}_3\text{-N}}$	potential nitrate concentration in leakage water for the total area at base flow
$C_{\text{RO}}$	surface runoff from non paved areas
$C_{\text{ROAR}_{\text{N,P}}}$	nutrient concentration in surface runoff from arable land
$C_{\text{ROGRAS}_{\text{N,P}}}$	nutrient concentration in surface runoff from grassland
$C_{\text{RON}_{\text{P}}}$	nutrient concentration in surface runoff
$C_{\text{ROFOR}_{\text{N,P}}}$	nutrient concentration in surface runoff from forest
$C_{\text{ROOP}_{\text{N,P}}}$	nutrient concentration in surface runoff from open land
$C_{\text{SW}_\text{N}}$	nutrient concentration in leakage water

$CWW_{DIN}$	concentration of dissolved inorganic nitrogen in wastewater
$CWW_{NORG}$	concentration of organic nitrogen in wastewater
$CWW_P$	concentration of phosphorus in wastewater
$D$	atmospheric deposition rate of heavy metals
$DEP_{N,P}$	area-specific deposition
$DR$	exponent for denitrification
$EAD_{N,P}$	nutrient input via atmospheric deposition
$E_{Di}$	emissions from point sources discharging directly into the main river
$E_{DONi}$	DON emissions from AUi
$EDR_{N,P}$	nutrient emissions via tile drainage
$EER_{N,P}$	nutrient input via erosion
$ER_N$	enrichment ratio for nitrogen
$ER_P$	enrichment ratio for phosphorus
$EGW_{N,P}$	nutrient input via groundwater and natural interflow
$E_i$	total (P or N) emissions from AUi
$EIN_{D,N,P}$	inhabitant-specific output of dissolved nutrients
$EIN_N$	inhabitant-specific nitrogen output
$EIN_{N,P}$	inhabitant-specific nutrient output
$EIN_P$	inhabitant-specific phosphorus output
$ERO_{N,P}$	nutrient input via surface runoff
$ES_{IMP}$	specific nutrient emissions from impervious urban areas
$ETR_{MAX}$	maximum annual evapotranspiration
$EUC_{N,P}$	nutrient emission via combined sewer overflows
$EUN_{N,P}$	nutrient input from inhabitants and impervious urban areas connected neither to sewers nor to wastewater treatment plants
$EUS_{N,P}$	nutrient inputs via separate sewers
$EUSO_{N,P}$	nutrient input from impervious urban areas and inhabitants connected only to sewers
$EW_N$	nitrogen emission from wastewater treatment plants
$EW_P$	phosphorus emission from wastewater treatment plants
$FL$	River length main rivers (MR) and tributary rivers (TRIB)
$HL$	hydraulic load
$IN_C$	number of inhabitants connected to combined sewer systems
$IN_{CON}$	connected inhabitants

$IN_N$	number of inhabitants connected neither to sewers nor to wastewater treatment plants
$IN_{SO}$	number of inhabitants connected only to sewers
$K$	soil erodibility factor – the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 22.1 m length of uniform 9 % slope in continuous clean-tilled fallow
$k_{MR,TRIB}$	modell coefficient
$L$	slope length factor – the ratio of soil loss from the field slope length to soil loss from a 22.1 m length under identical conditions
$L_{DINi}$	calculated DIN load for catchment of $AU_i$
$L_{TPi}$	calculated TP load for catchment of an analytical unit $i$ ( $AU_i$ )
$L_{TNi}$	calculated TN load for catchment of $AU_i$
$LW$	leakage water quantity
$L_y$	annual load
$n$	number of data
$N_{SUR}$	nitrogen surplus of agricultural areas
$N_{surt}$	nitrogen surplus of agricultural areas
$N_{TTSUR}$	average nitrogen surplus within the period of travelling time
$Q_i$	runoff from selected $AU$
$Q_{\Sigma i}$	runoff from catchment of selected $AU$
$P$	support practice factor – the ratio of soil loss with a support practice like contouring, stripcropping, or terracing, to soil loss with straight-row farming up and down the slope
$p$	number of years with measuring data in the study period
$POP_{DEN}$	population density
$P_{SU}$	average precipitation in the summer half year
$P_{WI}$	average precipitation in the winter half year
$P_Y$	average annual precipitation
$Q$	average runoff
$q$	specific runoff
$Q_{AD}$	atmospheric input flow
$q_{COM}$	specific runoff from commercial areas
$Q_{COMC}$	runoff from commercial areas connected to combined sewers
$Q_{COMSO}$	annual runoff from commercial areas only connected to sewers
$Q_{DR}$	tile drainage flow

$Q_D$	arithmetic mean of daily flow
$q_{DR}$	specific drain water flow
$q_G$	average yearly specific runoff
$q_{GW}$	specific groundwater flow
$Q_{GW}$	base flow and natural interflow
$Q_{Meas}$	arithmetic mean of all daily flow data with measurement of concentration
$q_{IN}$	daily wastewater output per inhabitant
$q_{IMP}$	specific surface runoff from impervious urban areas
$Q_{IMPC}$	storm water runoff from combined sewer systems
$q_R$	rainfall runoff rate
$Q_{RO}$	surface runoff from non-paved areas
$q_{RO}$	specific surface runoff
$Q_{TAu,Au}$	specific runoff of the total catchment (TAu) and analytical unit (Au)
$Q_{URB}$	surface runoff from urban areas
$Q_{WW}$	water discharge from the wastewater treatment plants
$R$	rainfall-runoff erosivity factor – the rainfall erosion index plus a factor for any significant runoff from snowmelt
$RE$	discharge rate of combined sewer overflows
$R_{LOi}$	Retention waterbody at outlet of AU
$R_{MRi}$	Retention in main river without retention in waterbody at the outlet of the AU
$R_{Ti}$	Retention tributaries
$RR_N$	nitrogen removal rate
$RR_P$	phosphorus removal rate
$R_{SN,P}$	nutrient retention in soil (80 % for nitrogen and 90 % for phosphorus)
$RW_{MR, TRIB}$	river width of main rivers (MR) and tributary rivers (TRIB)
$S$	slope steepness factor – the ratio of soil loss from the field slope gradient to soil loss from a 9 % slope under otherwise identical conditions
$SDR$	sediment delivery ratio
$SED$	sediment input
$SOL$	soil loss
$SLCA$	mean slope from USGS-DEM
$sl_{Au}$	mean slope of the analytical unit (Au)
$TT_{GW}$	Travelling time of the groundwater

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$U_f$	correction factor for the different location of flow and concentration measuring station within the same catchment area
$V_s$	storage volume
$WSA_{LOi}$	water surface area of water body at outlet of selected AU
$WSA_{MRi}$	water surface area of main river in selected AU
$WSA_{TRIBi}$	water surface area of all tributaries in selected AU
$WSA_{RW}$	calculated area of the surface waters differentiated in main and tributary river
$W_{TR}$	proportion of dissolved human nutrient output transported to wastewater treatment plants
$Z_{NST}$	effective number of storm water days

## II. Application of MONERIS within the Danube river basin

### II.1 Characterization of catchment area

The Danube River Basin is a large sized river basin of more than 800000 km<sup>2</sup> that covers several countries in Central and South Eastern Europe (Map II.1). This chapter shortly presents the relevant input data for the application of MONERIS (see I.3.3). It follows the overall structure there.

#### II.1.1 Spatial input data

Large-scale national **river networks** of some countries<sup>1</sup> were merged with mid- to small-scale “Corine Land Cover” (in 2000 by EEA 2004) and “Digital Chart of the World” (ESRI 1993) datasets to elaborate a harmonized river network for the whole basin. Overlapping parts were removed and polygon segments were preferred to lines thus retaining area information. Although being projected uniformly, deviations were common and had to be manually considered for length and area statistics. In addition, a 3’’ SRTM digital **elevation** model (USGS 2007) was used for elevation (Map II.2) and slope classification (Map II.3).

Based on this network, the basin was further sub-divided according to elevation, administrative areas and hydrological districts in close cooperation with national partners. The results had to be verified and aligned along the countries’ boundaries. More than 900 **analytical units** (AU) could thus be separated. (Map II.4 and Chapter I.4.1.1.1)

**Land cover** classes were obtained by merging the “Corine Land Cover” (EEA 2004) and “Pan-European Land Use and Land Cover Monitoring” (PELCOM 2004) databases. The original classification was adapted to the MONERIS landuse classes (Map II.5, see also chapter I 5.2 and table I 5.7). Arable land was attached to slope classes.

The European **Soil Database** version 2 (EUROPEAN SOIL BUREAU NETWORK & THE EUROPEAN COMMISSION 2004) was suitable for discriminating soil properties. It already consisted of layers for several physico-chemical properties (see Map II.6 as an example). Furthermore, soil loss was estimated using slope, Corine Land Cover classes and agricultural statistics (Map II.7, see chapter I 4.2.2.4).

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<sup>1</sup> Germany, Austria, Hungary, Serbia, Bulgaria, Romania, Slovenia, Slovakia and Switzerland



REGIONALE ZUSAMMENARBEIT DER DONAULÄNDER (1986) provided an **hydrogeological map** that was used to discriminate rock types according to consolidation and groundwater level (Map II.8).

Monthly means for several decades of **precipitation** were calculated by interpolating<sup>2</sup> global (GPCC 2002) and some national station data<sup>3</sup>. The results were aggregated to annual, summer and winter means. Map II.9 shows the long-term annual mean. Long-term **runoff** was based upon “Mean Annual Runoff in the Danube Basin” map (REGIONALE ZUSAMMENARBEIT DER DONAULÄNDER 1986, Map II.10).

Long-term **atmospheric deposition** rates of nitrogen oxides and ammonium were taken from the CO-OPERATIVE PROGRAMME FOR MONITORING AND EVALUATION OF THE LONG-RANGE TRANSMISSION OF AIR POLLUTANTS IN EUROPE (2002). Total nitrogen deposition was defined as the sum of both input data (Map II.11).

Spatial data on **municipality** (GFK MACON GMBH 1999) and city population (HELDERS 2006) was used to calculate population density and to distinguish between urban and rural population (Map II.12).

## II.1.2 Data for calculating point source emissions

Point source emission data was taken from the INVENTORY OF INTERNATIONAL COMMISSION OF PROTECTION OF THE DANUBE RIVER (ICPDR 2000). As an example, the location of water treatment plants is shown in Map II.13.

## II.1.3 Monitoring data for surface water

Monitoring station data from the TRANSNATIONAL MONITORING NETWORK (TNMN 2006) and national data from most countries were combined to build monitoring database (Map II.14). This database described water temperature and discharge as well as chemical parameters on water quality although the number of measured parameters and the temporal coverage differed very much.

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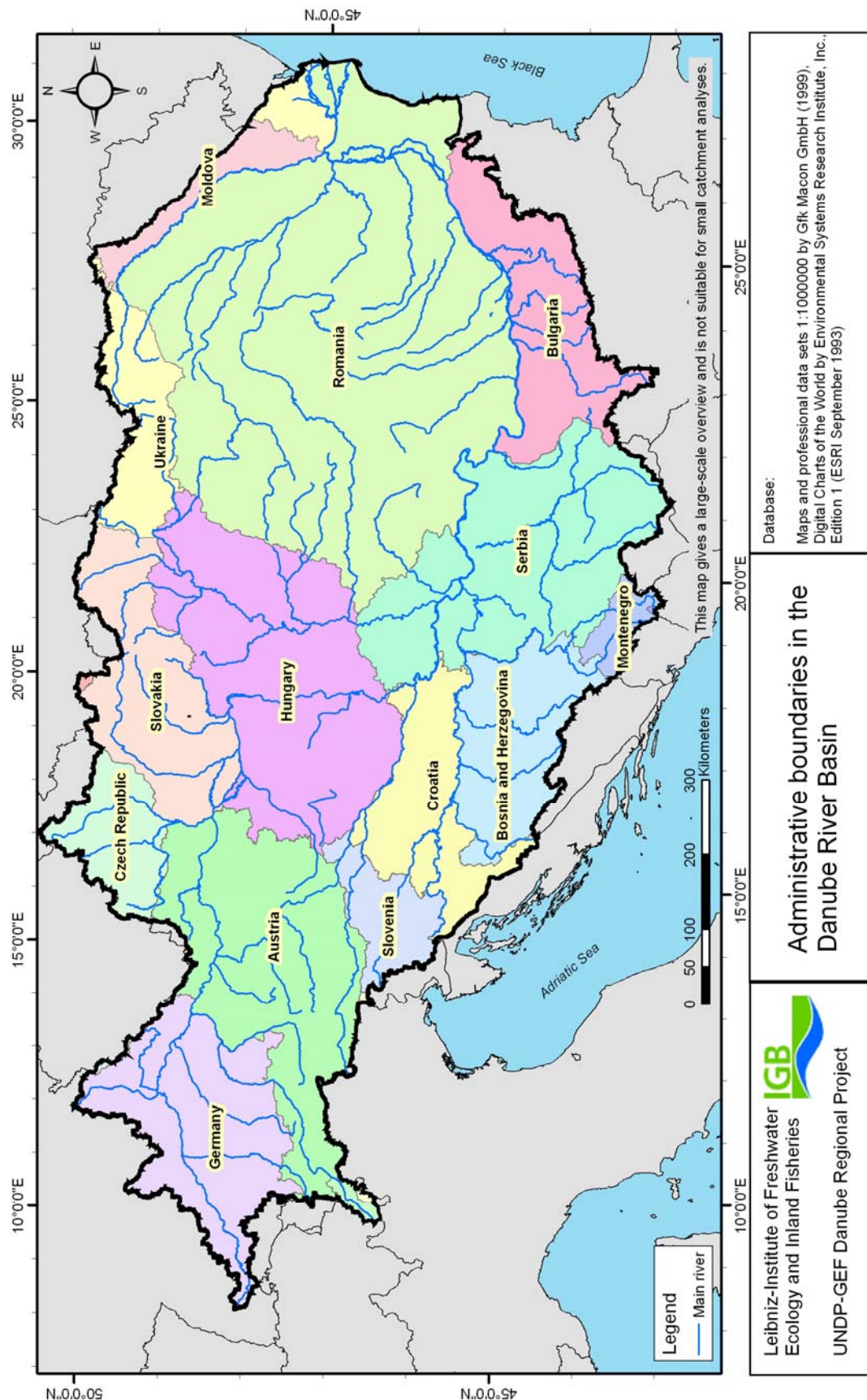
<sup>2</sup> using Inverse Distance Weighted (IDW) interpolator as implemented in the software ArcView 3.2 (ESRI 1999), parameters: neighbors = 8, power = 1

<sup>3</sup> Slovakia, Slovenia, Romania, Poland, Hungary, Germany and Austria

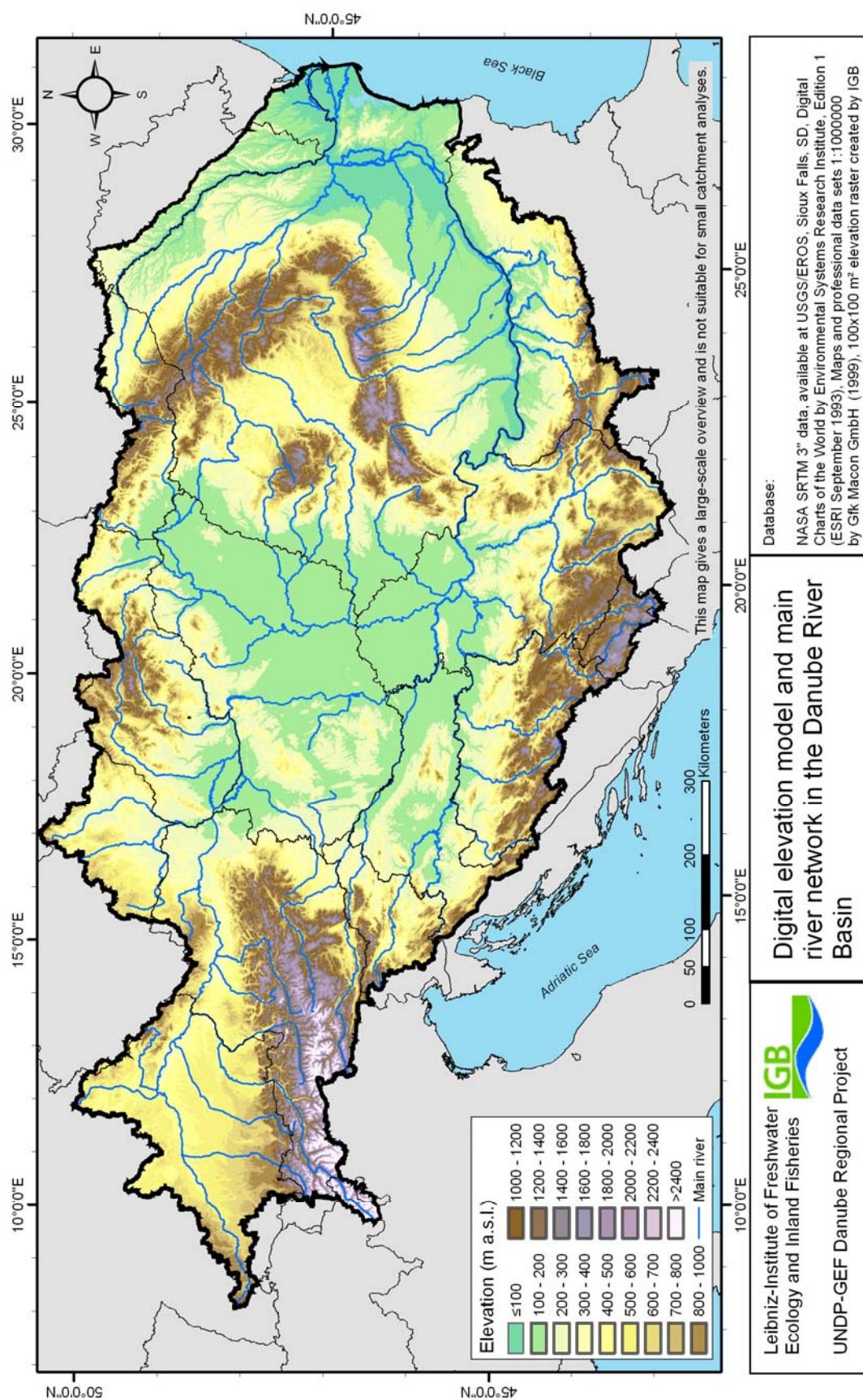
#### **II.1.4 Administrative and agricultural data**

FAOSTAT (FAO 2007) and national data was used for statistics of agriculture and land use over several decades. Pre-existing values for the former Soviet Union, Czechoslovakia and Yugoslavia had to be assigned to their succeeding countries by multiplying with the fraction in the first year of independence of the respective countries. Land use fractions were finally used to adjust the C factor of the soil loss equation.

#### **II.1.5 Maps**

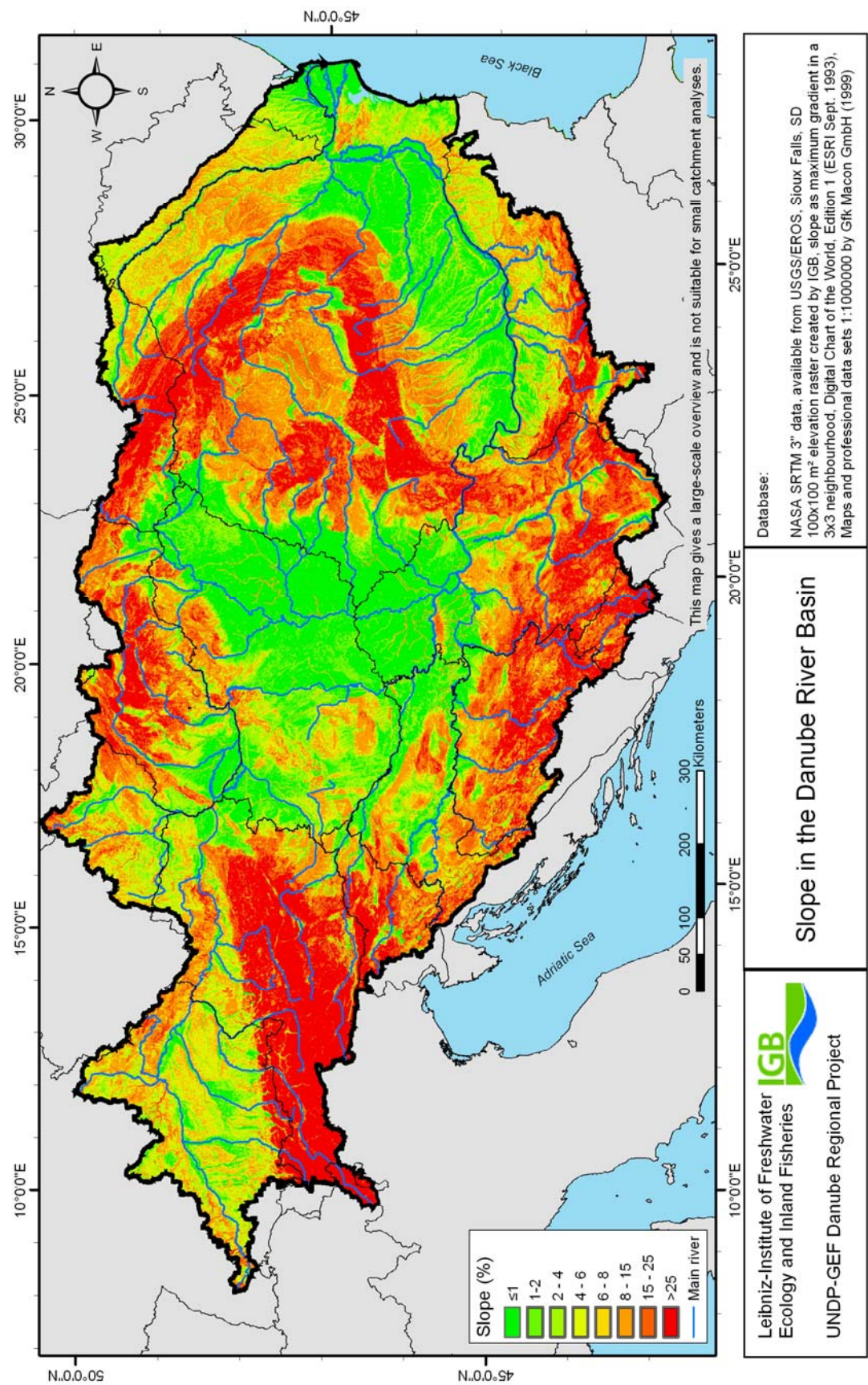


**Map II.1:** Administrative boundaries in the Danube River Basin



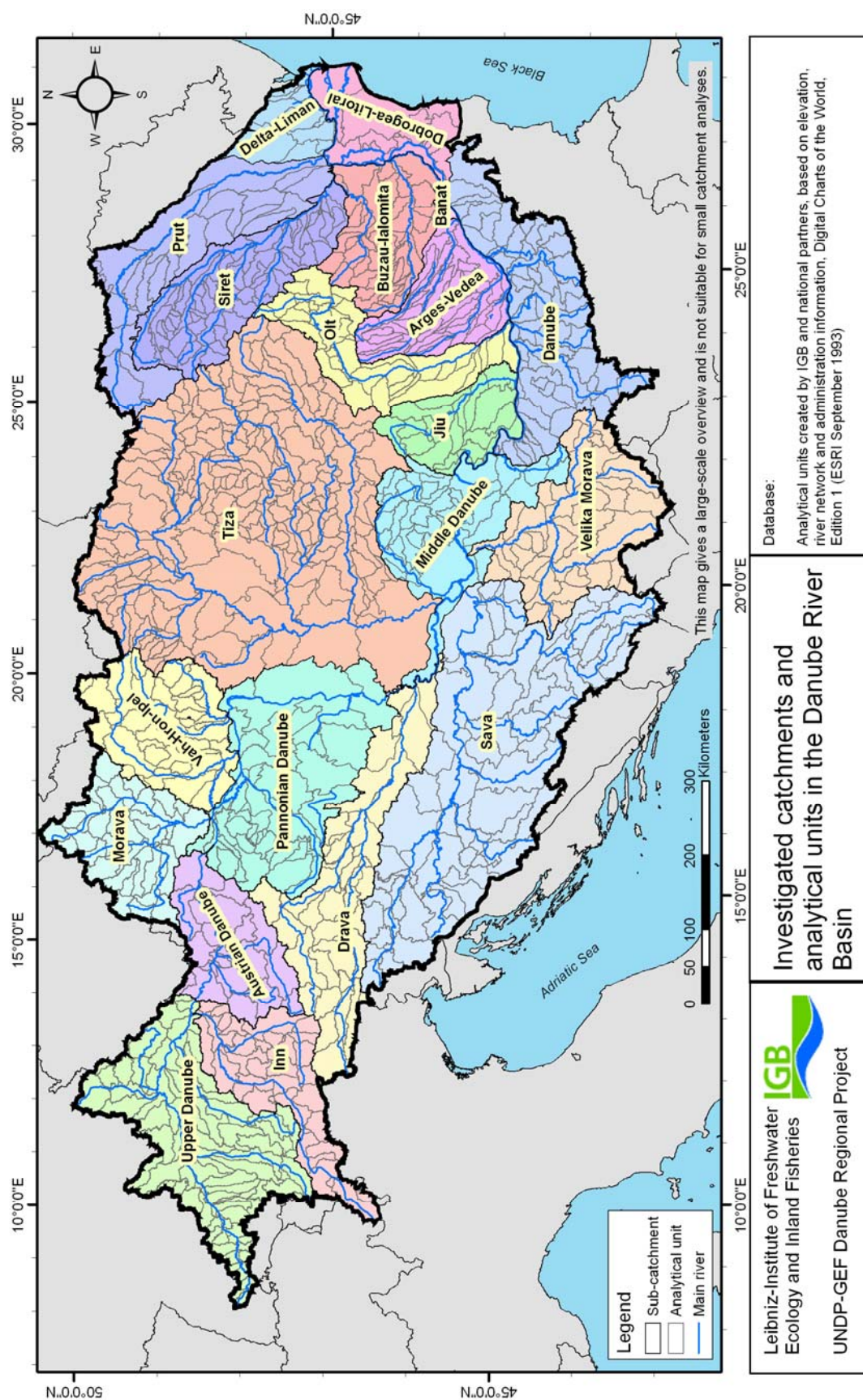
**Map II.2:** Elevation and main river network in the Danube River Basin





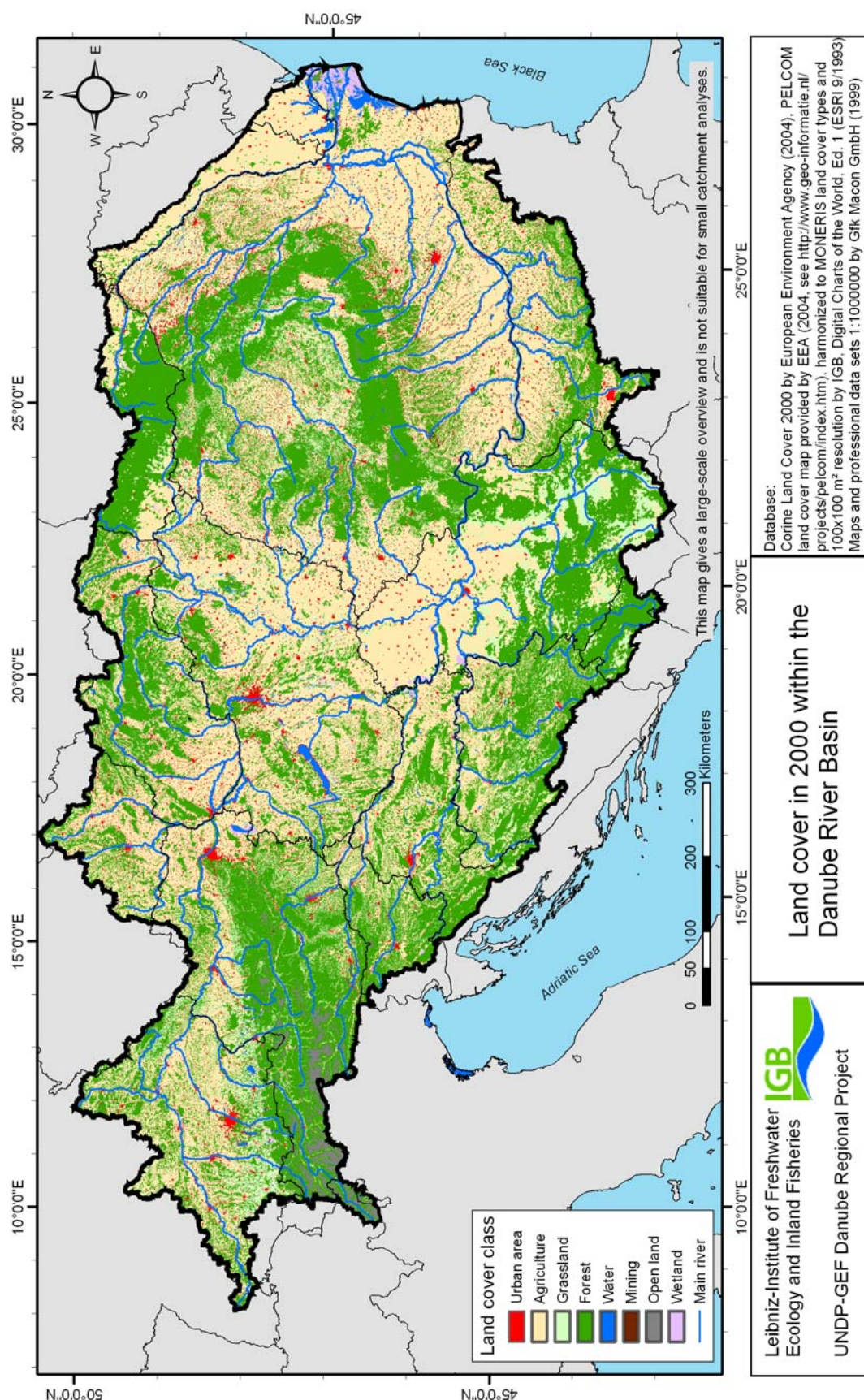
Map II.3: Slope in the Danube River Basin





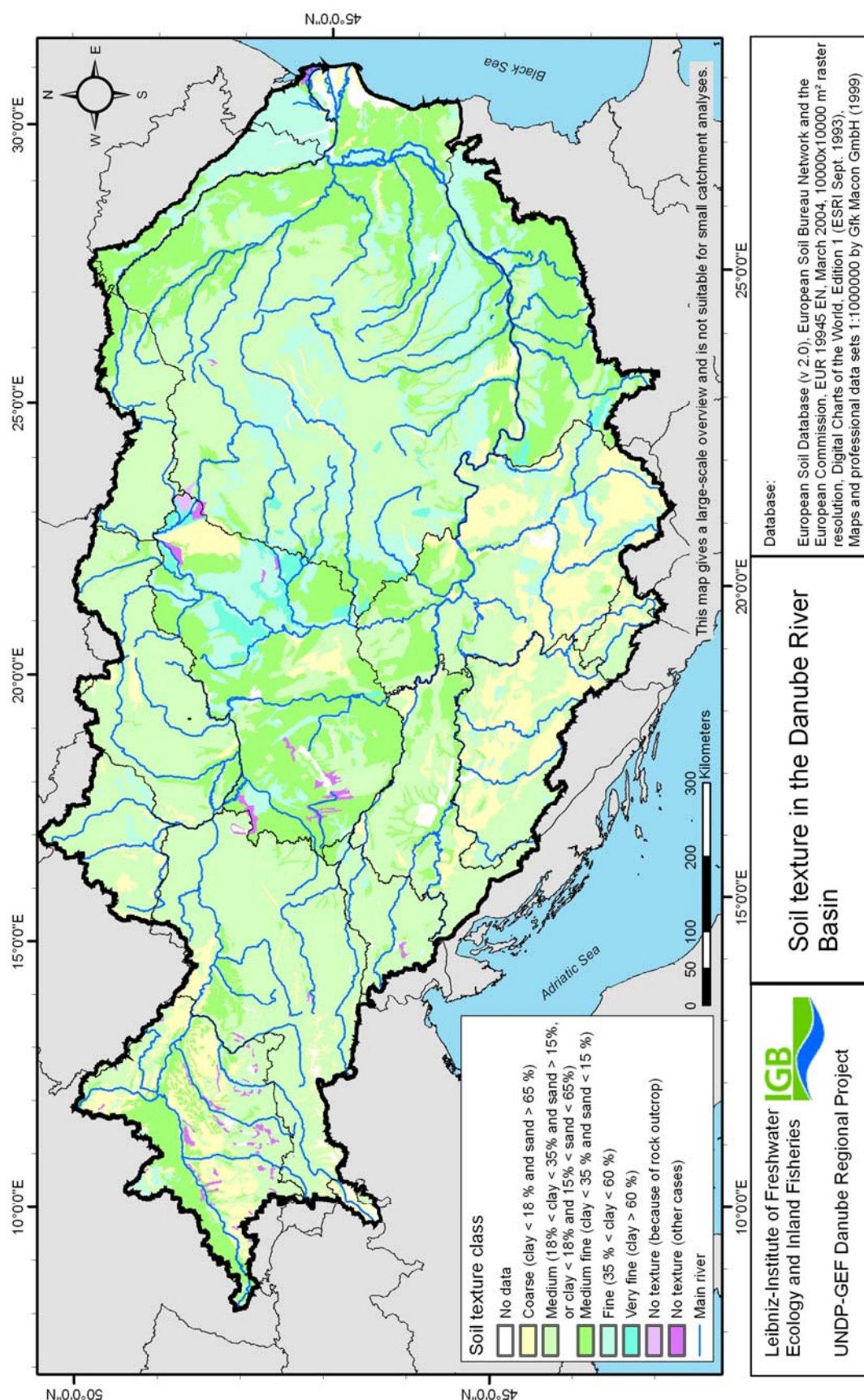
**Map II.4:** Catchments and analytical units in the Danube River Basin





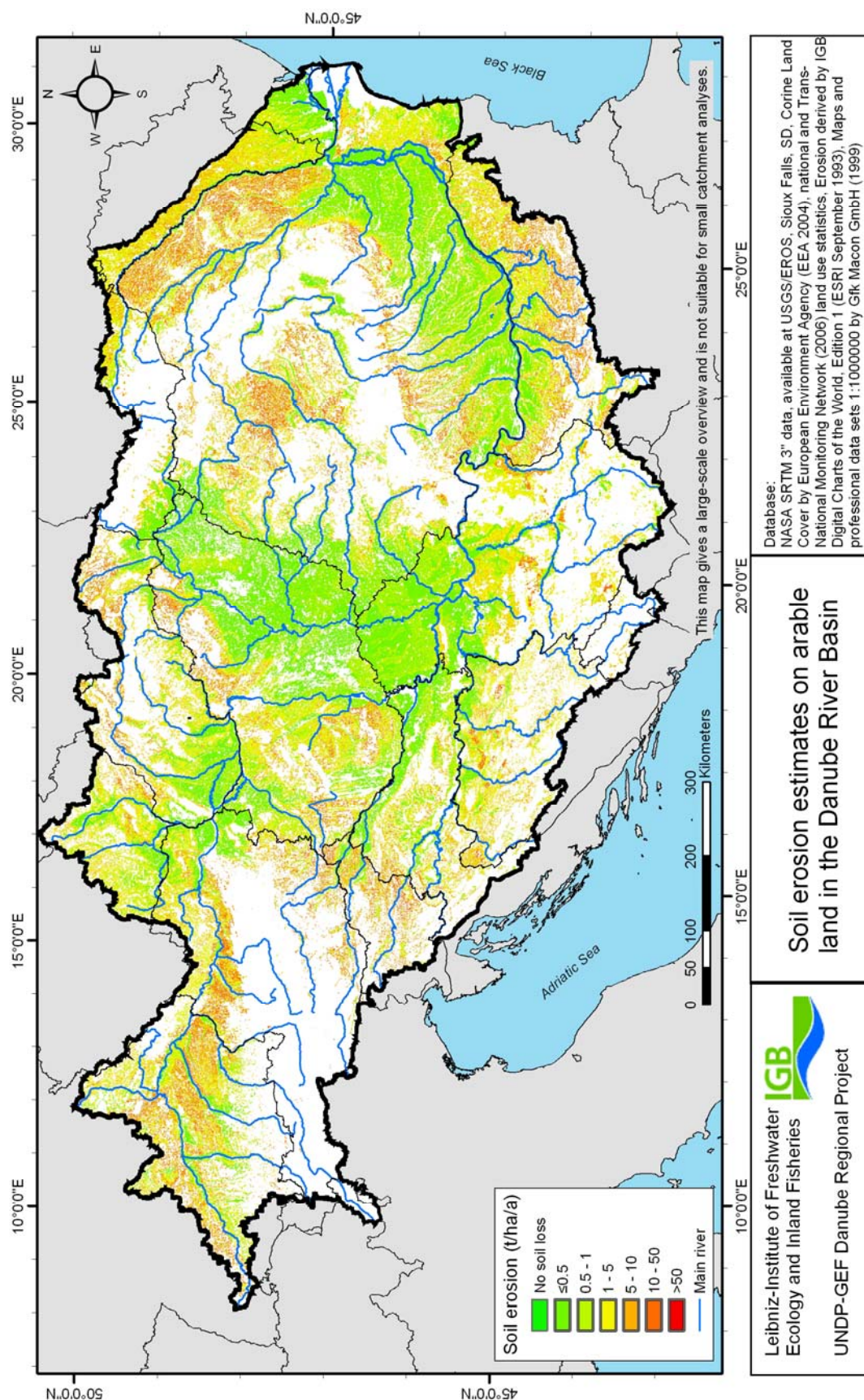
Map II.5: Land cover in 2000 within the Danube River Basin





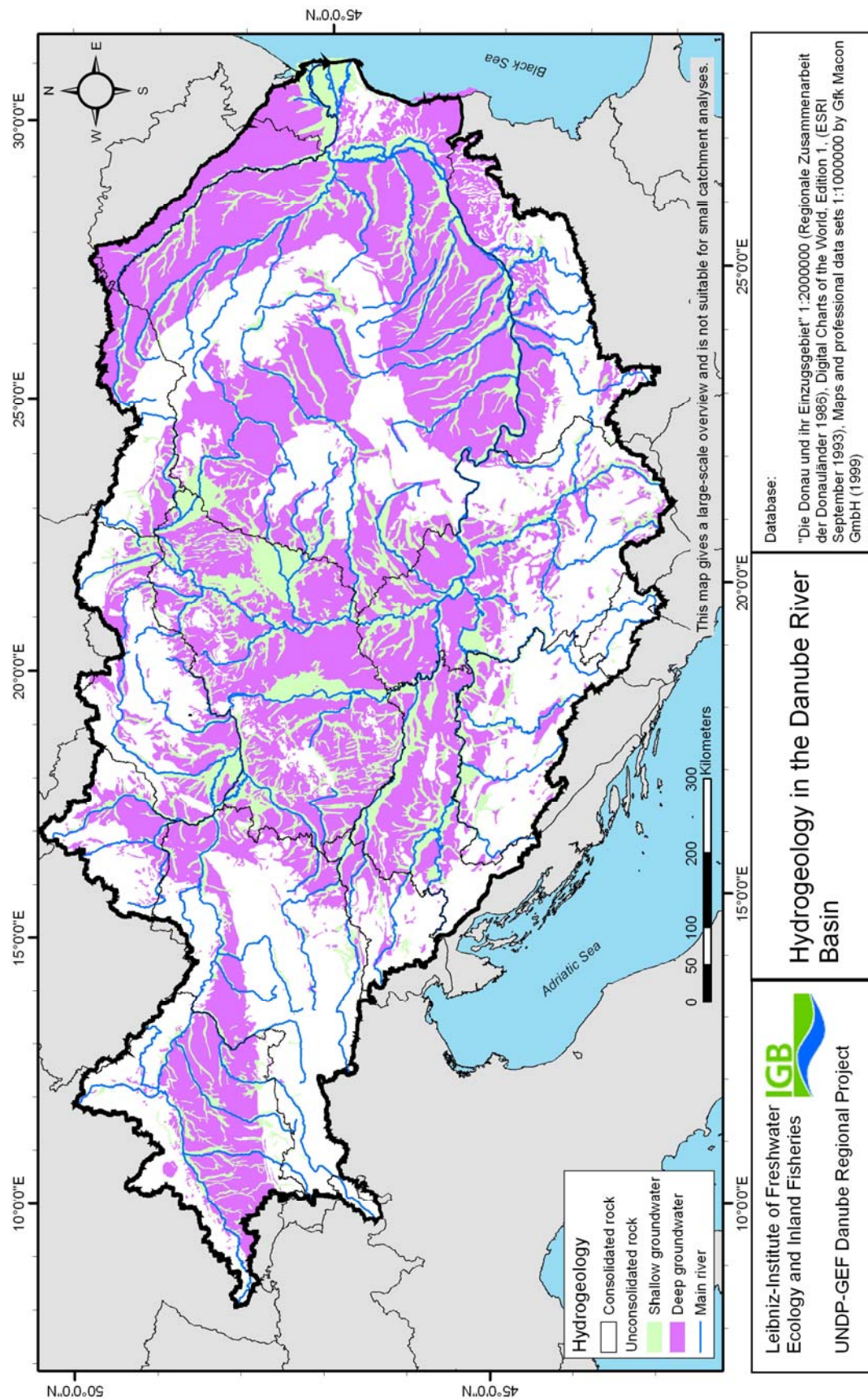
Map II.6: Soil texture in the Danube River Basin



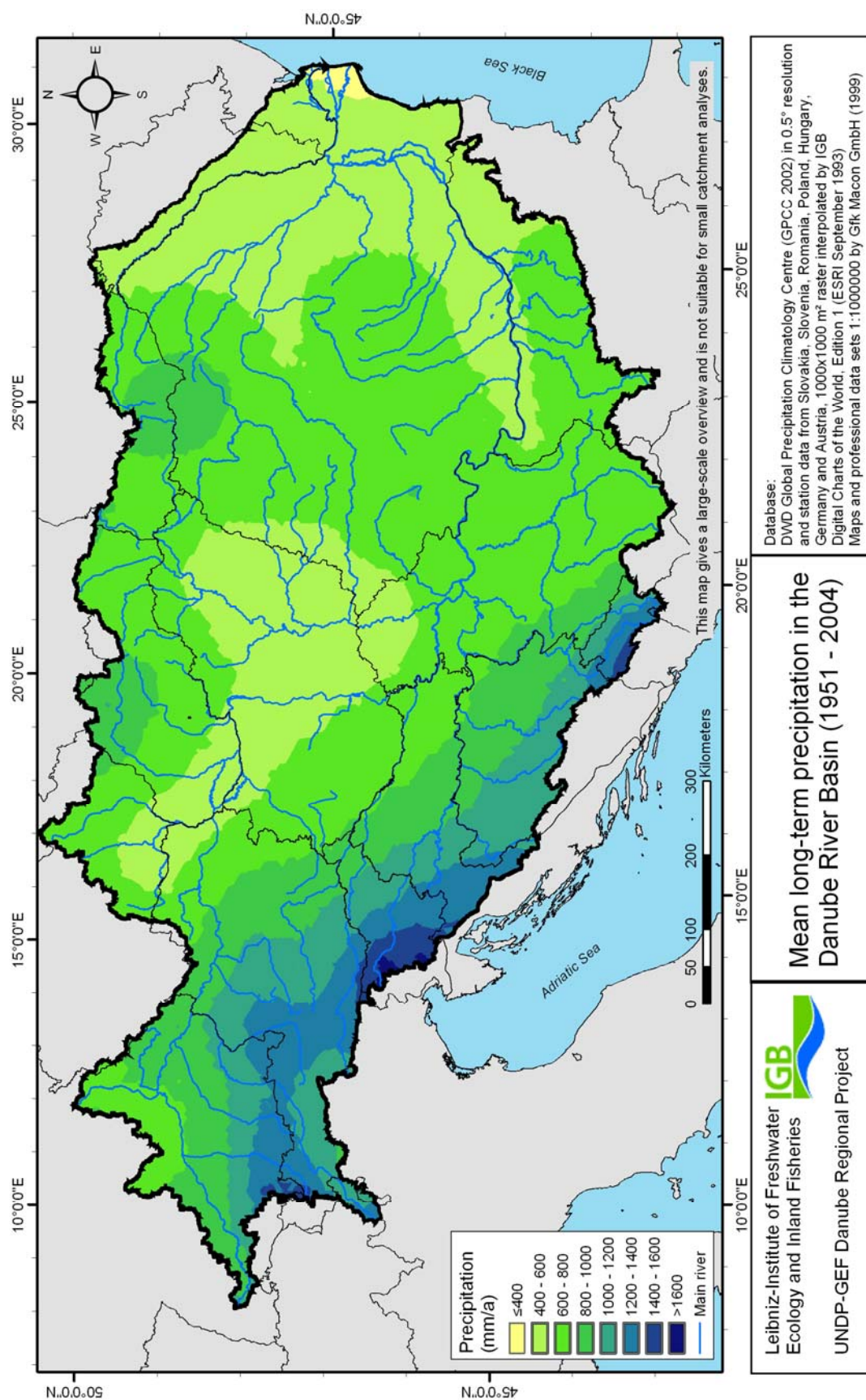


**Map II.7:** Soil erosion estimates on arable land in the Danube River Basin



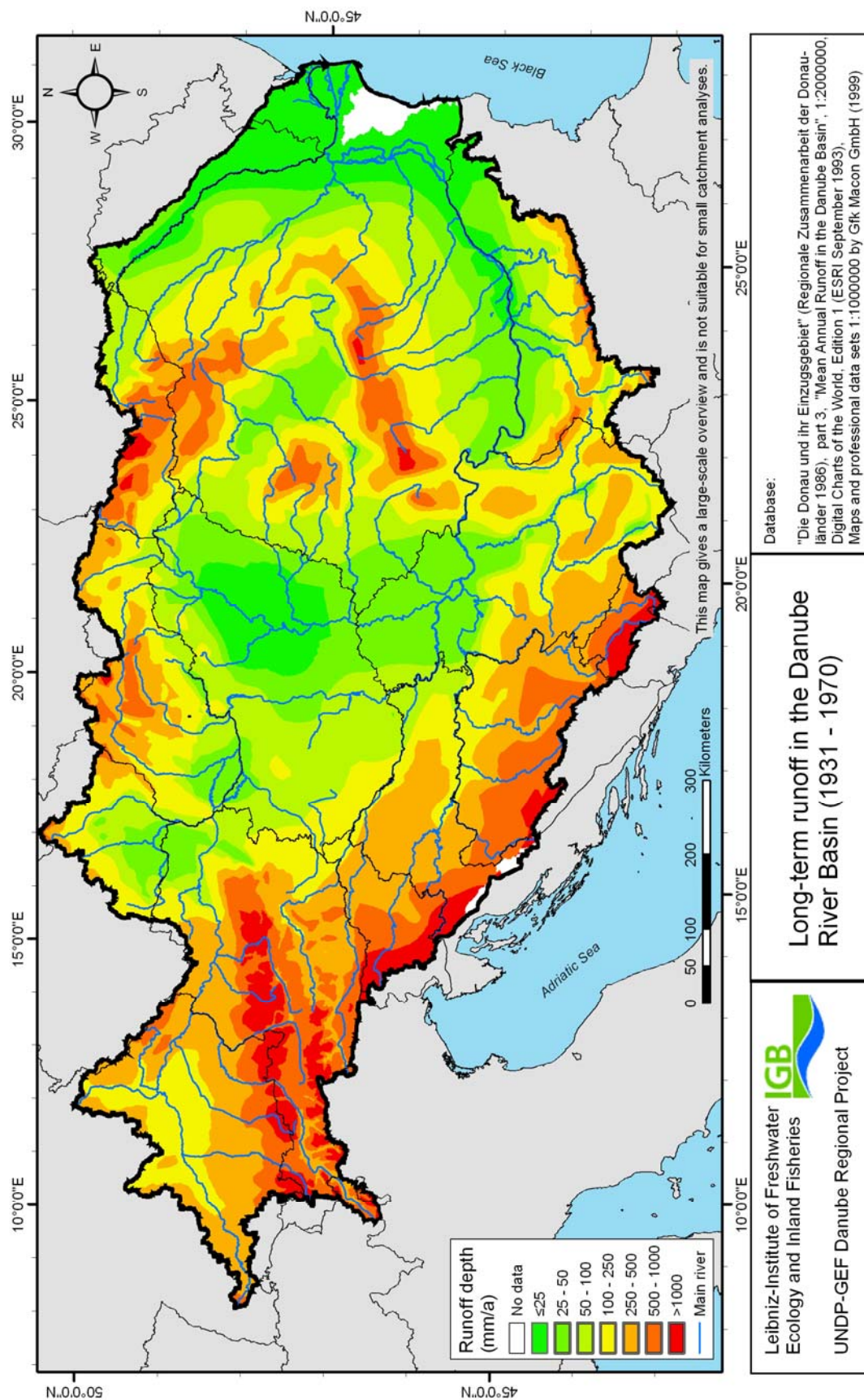


**Map II.8:** Hydrogeology in the Danube River Basin

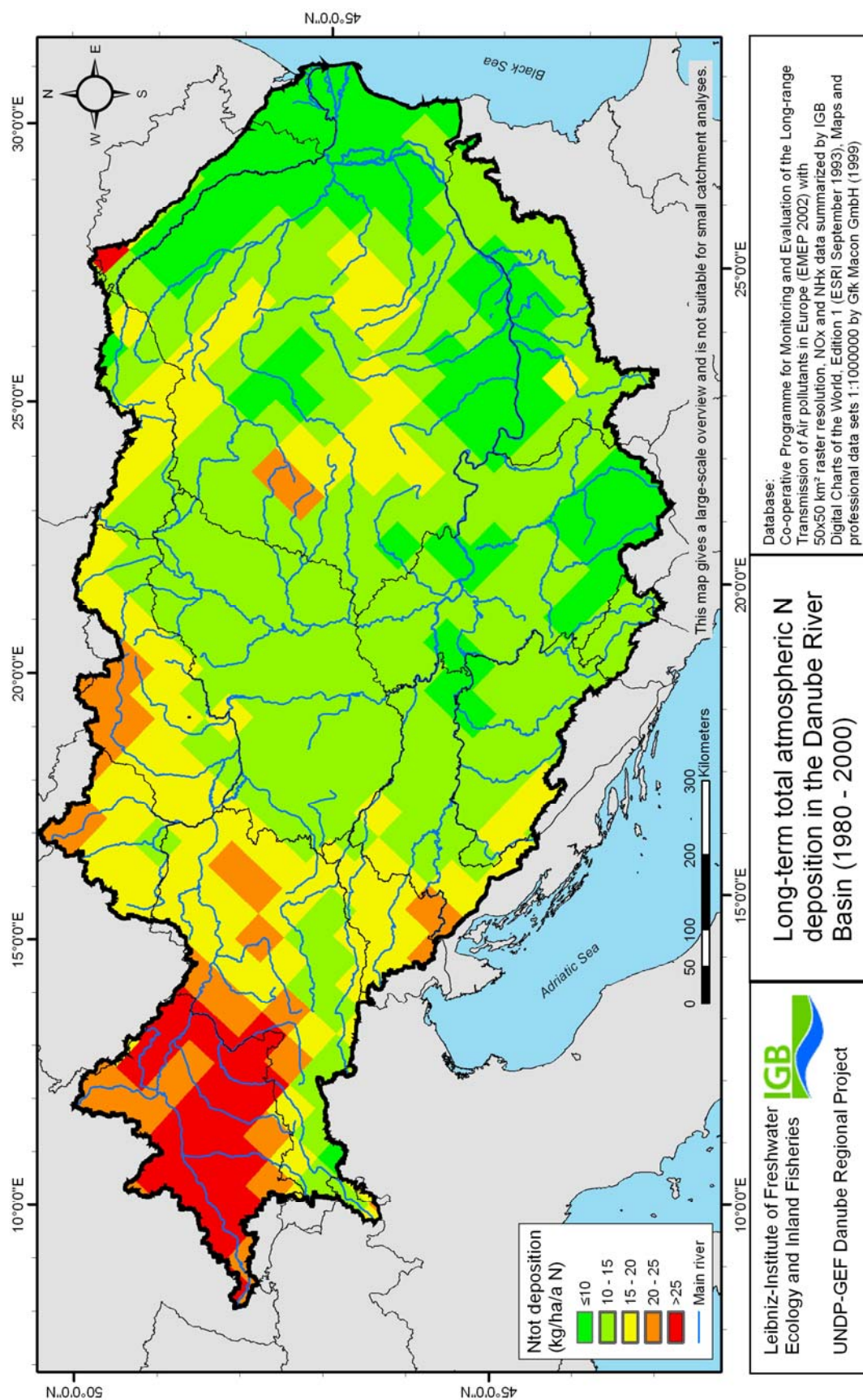


Map II.9: Long-term precipitation in the Danube River Basin (1951-2004)



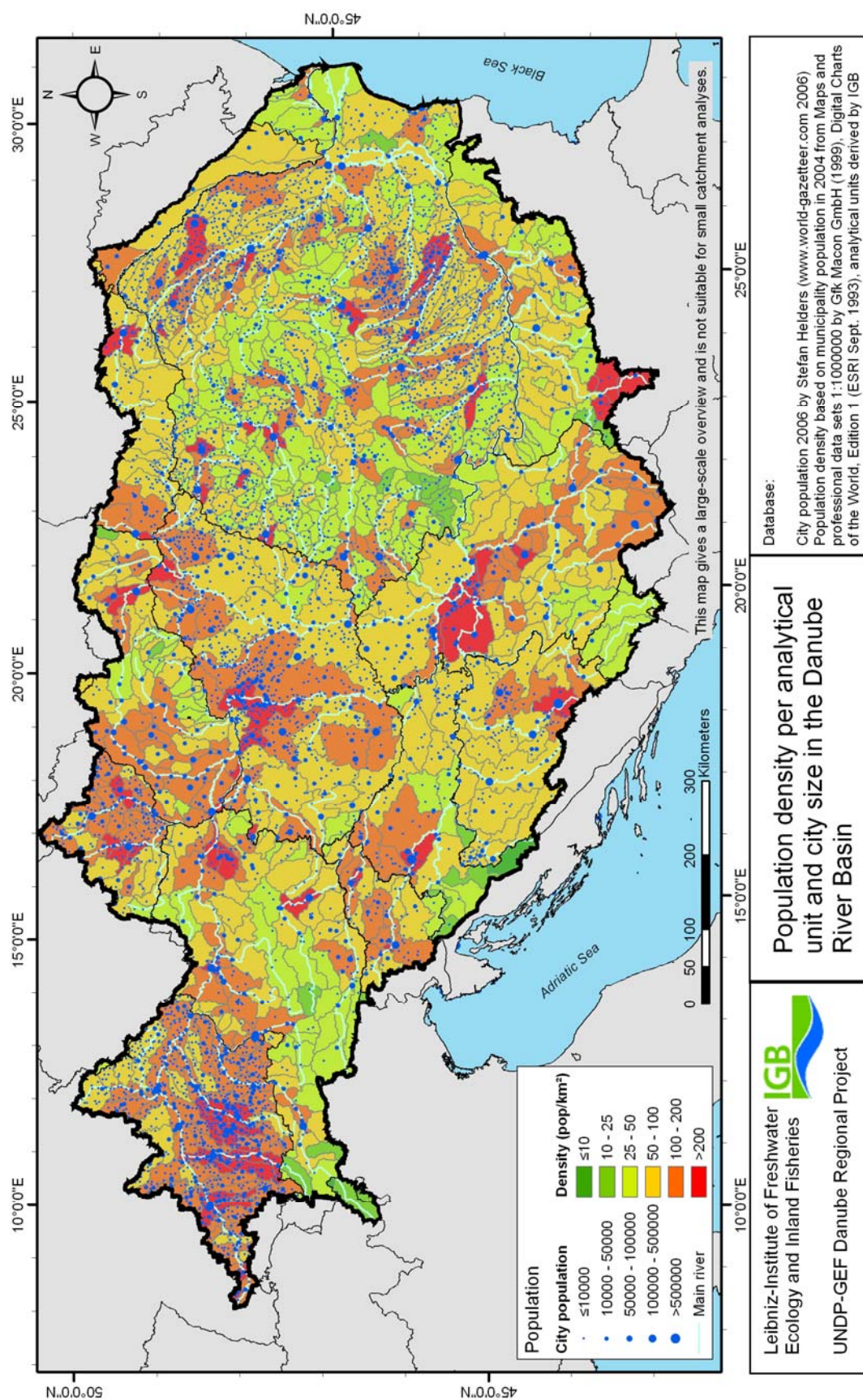


**Map II.10:** Long-term runoff in the Danube River Basin (1931-1970)

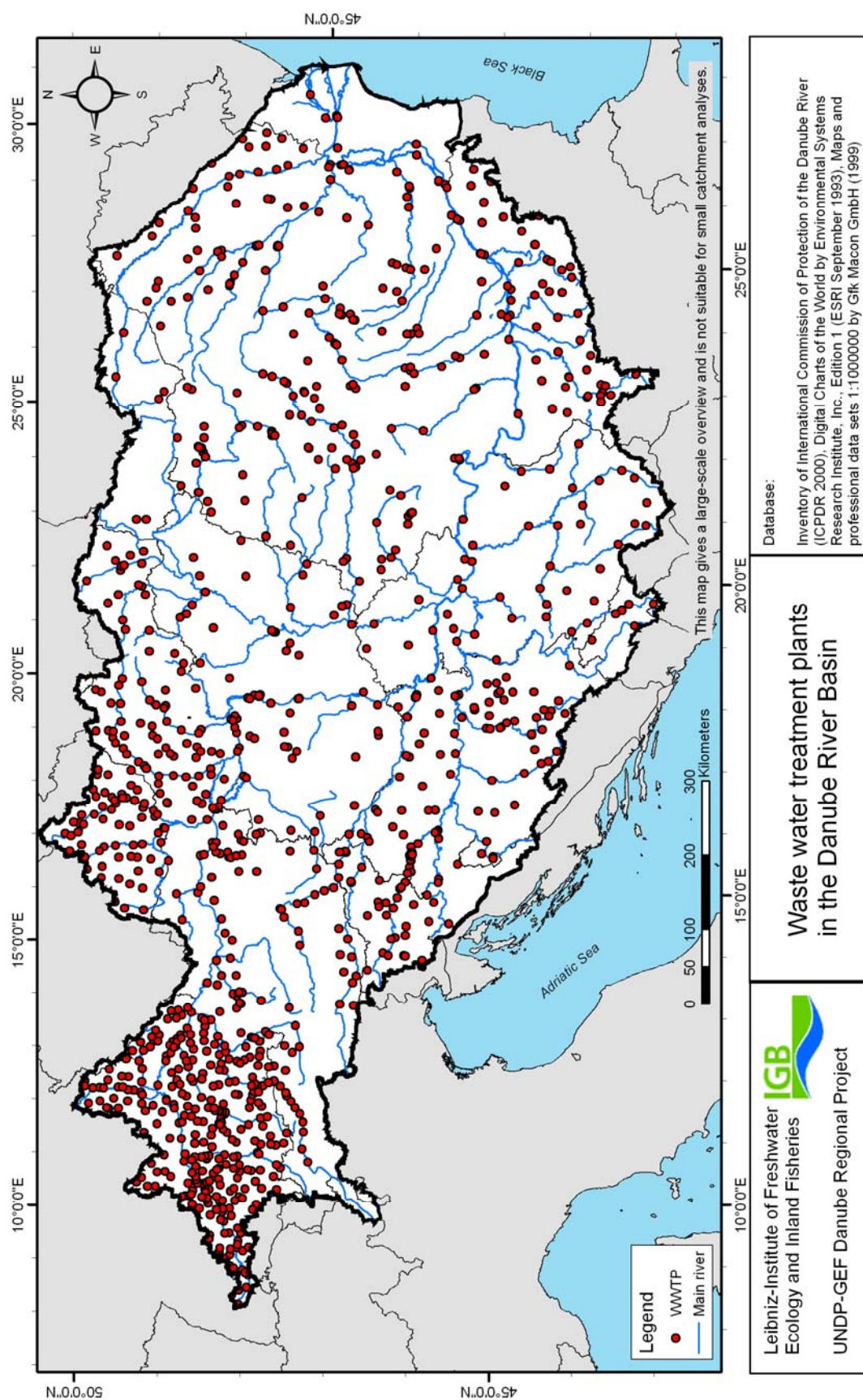


**Map II.11:** Long-term total atmospheric N deposition in the Danube River Basin (1980-2000)



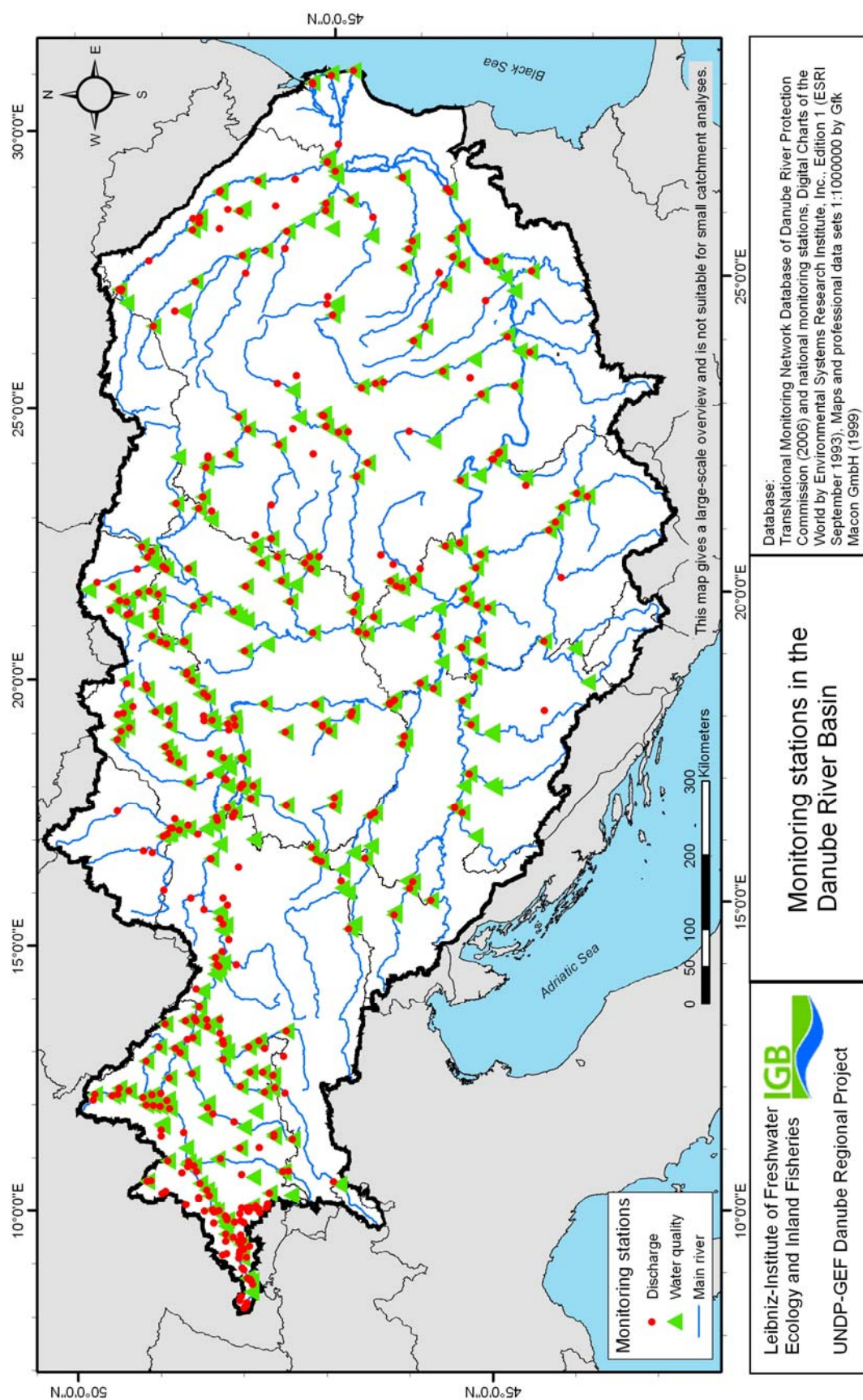


**Map II.12:** Population density and city size in the Danube River Basin



Map II.13: Waste water treatment plants in the Danube River Basin





**Map II.14:** Monitoring stations in the Danube River Basin



## II.2 References

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