Nutrient Management in the Danube Basin and its Impact on the Black Sea

DANUBS

Final Report

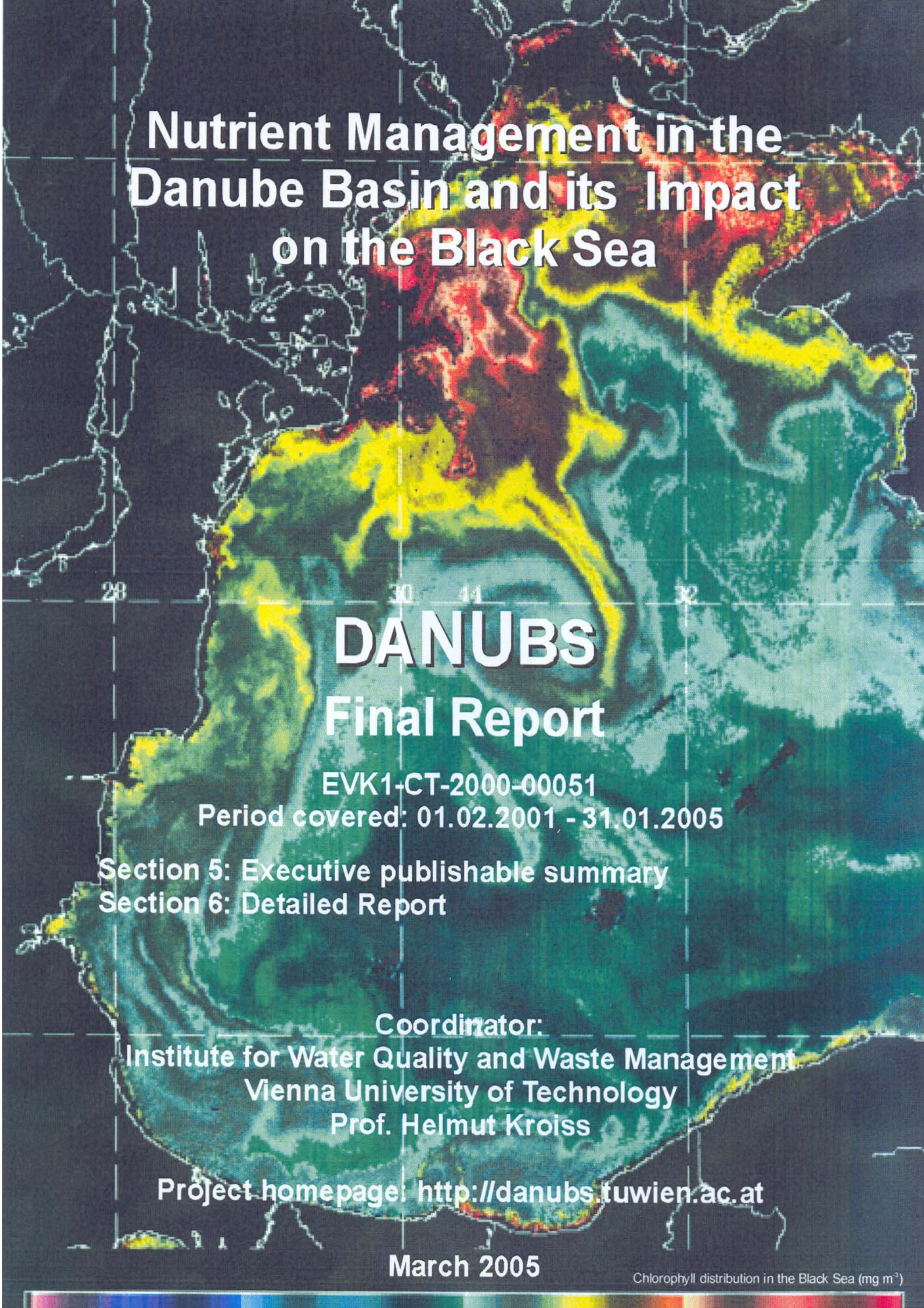
EVK1-CT-2000-00051
Period covered: 01.02.2001 - 31.01.2005

Section 5: Executive publishable summary
Section 6: Detailed Report

Coordinator:
Institute for Water Quality and Waste Management
Vienna University of Technology
Prof. Helmut Kroiss

Project homepage: http://danubs.tuwien.ac.at

March 2005



Chlorophyll distribution in the Black Sea (mg m^{-3})

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ICPDR has the status of a continuous observer

Project homepage: http://danubs.tuwien.ac.at

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PREFACE

The daNUbs Project within the 5th EU research framework has been performed by a team of researchers from many different disciplines and nationalities. Danube River Basin is unique in Europe and even in the world with regard to the variety of nations, languages, religions and historical background. Also the research institutions involved in daNUbs project are spread over Europe from East to West (Delft, NL to Constanta, RO) and from North to South (Kiel, D to Athens, GR). EU Water Framework Directive and the establishment of the International Commission for the Protection of Danube River (ICPDR), where EU is one of the commission members, have created a legal background enabling water quality management in the whole Danube Basin for the sake of the receiving Black Sea. In this respect nutrients (nitrogen, phosphorus and silica) play a dominant role for the quality of Western Black Sea Coastal waters, famous for beach tourism.

This report contains the scientific results of the 4 year daNUbs project and as coordinator we have to thank all those who have contributed to its success: all the researchers involved (more than 40 personalities), the representatives of ICPDR, our officers in EU administration (Hartmut Barth and Christos Fragakis), our mid term reviewers (Hartmut Kremer and Andy Garner) and all the staff members having contributed in one or the other way to the project. Special thanks have to be given to the organisers of the workshops and their teams in Delft (Jos van Gils), Athens (Villy Kourafalou) and Varna (Violeta Velikova) and the Vienna staff for the first and last workshop. During a project lasting 4 years more than 40 personalities will never reach consent in all respects and conflicts can not be avoided. It was a great success that the atmosphere of mutual understanding could be maintained until the final workshop in Vienna. During the 4 years we experienced many highlights, unforgettable the sunset at Cape Sounion in Greece but also difficult discussions on conflicts to be solved. Special thanks have to be expressed to Matthias Zessner who prepared the successful project proposal and to Christoph Lampert. These two had the difficult task to co-ordinate the complex scientific research program and our heterogeneous team and to perform the administrative work which is necessary for the success and for the flow of money we all rely on, but does not contribute to scientific recognition.

The project was well recognised in Brussels as a “success story”. Important progress in understanding the complex relationship between human activity in the Basin and the reaction of the natural water environment could be made. One of the most challenging aspects of this project was the close cooperation between the research team and the most important user of the results, the ICPDR. This feedback was of very high importance for both and resulted in an important contribution of the project to the Roof Report, the status report of Danube Basin prepared by ICPDR in accordance with the requirements of EU WFD. The documents elaborated for this project will not reflect the human effort of all the team members to make things happen, to introduce new ideas, to try to understand “other” personalities and subjects, to suffer from disappointments and to enjoy the atmosphere of a success of the team and the own contribution. This effort will have to be remembered by all of us and will hopefully lead to a continuation of cooperation for the sake of the European society the environment and the personal human relations in the future.

European Union has enabled this project and we all should be grateful for this and continue to strengthen the idea of peaceful cooperation for the sake of all of us.

Vienna, March 2005 Helmut Kroiss

EXECUTIVE SUMMARY

Contract Number: EVK1-CT-2000-00051 **Project Duration: 1.2.2001 – 31.1.2005**

Title: Nutrient Management in the Danube Basin and its Impact on the Black Sea (daNUbs)

Introduction

The Danube is about 2,900 km long, and the river catchment of just over 800,000 km^2 covers 33 % of the Black Sea basin. It is the second largest river basin on European territory. Its average discharge of approximately 6,500 m^3/s, contributes 55% to the freshwater discharge to the Black Sea. The catchment area has a population of 82 Million, which is 43 % of the total population within the Black Sea basin. The Danube Basin represents an extreme case of a transboundary water catchment, covering 18 different states. River basin management is very challenging due to big differences in socio-economic standards within the basin. International co-operation in water management issues dates back to the early 1990s. In 1998 the Danube River Protection Convention (DRPC) became the vehicle for joint river management, with the International Commission for the Protection of the Danube River (ICPDR) as the operational body. All Danube countries have adopted the European Water Framework Directive as the legislative framework for integral water management. The ICPDR is responsible for the international co-ordination.

Mismanagement of nutrients in the Danube Basin has led to severe ecological problems: the deterioration of groundwater resources and the eutrophication of rivers, lakes and especially the Black Sea. These problems are directly related to social and economic issues (e.g. drinking water supply, tourism and fishery as affected sectors; agriculture, nutrition, industry and waste water management as drivers). In order to recommend proper management for the protection of the water system in the Danube Basin and the Black Sea, an interdisciplinary analysis of the Danube catchment area, the Danube River system and the mixing zone of the Danube River in the North-Western Black Sea needs to be carried out.

Objectives:

The main objectives of the daNUbs project are:

- to improve the knowledge of the sources, pathways, stocks, losses and sinks of nutrients in a large river catchment,
- to improve the knowledge of the effects of nutrients (nitrogen, phosphorus and silica) on the receiving ecosystems with special emphasis on the coastal areas,
- to develop, improve and combine management tools for nutrients in the Danube Basin and
- to develop scenarios for nutrient management and the effect on water quality and the consequences on the socio-economic development in the Danubian countries.

This project links the emissions of nutrients from the sources (e.g. agriculture, waste water disposal, etc.) to the impact on groundwater, surface waters and the marine ecosystems. The project concentrates on the Danube as the main contributor to the nutrient pollution of the Western Black Sea shelf. The methodological approach is applicable to other rivers and coastal systems. Other environmental impacts like acidification, climate change, stratospheric ozone depletion and loss of biodiversity that might be the reason for further reducing nutrient emissions to the environment have not been evaluated and are not part of this project.

For the first time nutrient emission, transport and transformation models for river basins were successfully linked to physical and biological models for the Western Black Sea shelf area influenced by the Danube. The main problem solved is the strong variation between the models in the relevant time steps. While MONERIS (a nutrient emission model) works with 5 year averages, in the marine environment hours can be relevant for changes if wind speed and direction and hence the flow patterns of fresh water and Black Sea water in the shelf area are considered. daNUbs was successful to use the output of MONERIS model for diffuse sources (5 years mean) as input to the dynamic Danube Water Quality Model (DWQM) by using daily flow data and the bi-weekly concentration data of the river Danube in order to model the daily nutrient discharges to the Danube Delta. The Danube Delta Model (DDM) transforms these discharges to daily inputs to the Black Sea, which can be used by the Black Sea models.

Investigations in selected case study areas allow a much better understanding of the detailed processes influencing nutrient storage, transport and losses (denitrification). For this purpose models describing the distribution of runoff between surface runoff, intermediate and saturated zone (ground water) were compared and the outcome of these investigations were used for improving MONERIS model results. Slope, geological back ground, climate and especially precipitation play decisive roles in nitrogen (N) losses and N and phosphorus (P) storage. Detailed analytical approaches were applied for selected case study regions. The results indicate that from some areas N will never reach the surface waters due to denitrification.

The understanding of the natural loads discharged to the sea from diffuse and point sources and of the influence of nutrient management (short and long term) could be improved considerably. It could be shown that with regard to diffuse sources the change from natural systems to agricultural land use heavily increases nutrient emissions even if nutrient management is optimised for water protection. Changes in nutrient management show delayed effects in water quality for N and particulate P due to the long retention time in the groundwater (N) and in the soil (P). On contrary, the effects of a reduction of dissolved P emissions from point sources can be observed very fast. Dietary habits (nutrition) are in closely connected to animal and plant production and therefore to the resulting nutrient emissions to the hydrosphere, especially in closed agricultural markets.

Historic data on water quality were used to calibrate the models. With the help of the models, data gaps could be closed. A number of indicators were derived from marine ecological data which can be used for efficient monitoring of the Black Sea coastal area status. The combination of modelling and ecological assessment of Black Sea coastal waters influenced by the Danube (including cruise investigations and satellite imaging) allowed the definition of critical loads with a certain range of uncertainty. The strong variations of nutrient discharges over the last 40 years caused by severe political and economical changes were essential for this achievement which is of great importance for management decisions.

Socio economic relevance and policy implications

The socio economic relevance and policy implications of the daNUbs-project are very well documented. On various occasions results supported the work of ICPDR as relevant international organisation responsible for the co-ordination of water protection in the Danube Basin. Some of these occasions are listed below:

- Results of the basin-wide application of the MONERIS and the Danube Water Quality Model have already been used for the basin-wide roof report (status report) for the Danube Basin according to the requirements of the EU Water framework directive.
- Results were presented at the ICPDR-UNDP/GEF workshop "Nutrients as a Transboundary Pressure" in Sofia, January 2004 as well as at the ICPDR and BSC (Black Sea Commission) stocktaking meeting in Bucharest (Nov. 2004) to representatives of administrative bodies of all Danube and Black Sea countries.
- Results already affected the work of several ICPDR expert groups (e.g. EMIS, RBM, MLIM).
- Results will be used by ICPDR and national governments in order to develop the river basin management plan (WFD requirement) and its implementation.

Results

The situation in the North-Western Black Sea shallow waters has improved considerably since the early 90s due to reduced nutrient inputs, causing:

- reduced eutrophication, (reduced phytoplankton biomass, frequency of blooms and extension of high chlorophyll area),
- considerable increase in water transparency
- improvement of near bottom oxygen regime,
- regeneration of phytoplankton species (Diatoms) diversity,
- regeneration of phytobenthos,
- regeneration of macrozoobenthos (increase of species number and diversity).

Zooplankton community in the North-western and Western Black Sea is still controlled by the gelatinous macrozooplankton (Mnemiopsis, Aurelia, Pleurobrachia), with respective consequences on the recovery of the pelagic fish stocks. The limiting factor for phytoplankton growth in the eutrophic areas of the N-W-Black Sea is phosphorus (since 1997). In the off shore waters mainly nitrogen limits the primary productivity. As a consequence, the control of easily available P loads from Danube Basin directly control algae growth in N-W-Black Sea shallow waters.

The improvement of the coastal area is a result of decreasing nutrient discharges (especially phosphorus) to this part of the Black Sea. Current low discharges of N and P to the Black Sea by Danube river are the result of

- improved nutrient removal from waste water in Germany, Austria and the Czech Republic
- reduced phosphate discharges from detergents and
- the consequence of the economic crisis in central and eastern European countries which lead to:
  - closure of large animal farms (agricultural point sources),
  - dramatic decrease of the application of mineral fertilizers and
  - closure of nutrient discharging industries (e.g. fertilizer industry).

Conclusions

For a sustainable development of the Western Black Sea ecosystem the nutrient discharge from the Danube River should be further reduced but at least kept at its present level. Scenario calculations clearly show that the economic development in the Danube Basin may reverse the improving situation of the quality of the North-Western and Western Black Sea ecosystem, if nutrients are not managed properly. Policy measures have to be proactive and should focus on continuous and long term control of all anthropogenic point and diffuse sources of nutrients (waste water management, agriculture, combustion processes). Monitoring the effects of nutrient management in the river Danube and the Black Sea is important but it has to be taken into account that there is a time lag (up to > 20 years) between cognition of deficiencies, implementation of control measures and corresponding effects in the river Danube.

It is recommended to apply a strong precautionary principle regarding nutrient emission based on
- best available techniques for waste water treatment (point sources)
- and best available agricultural practice for reduction of nutrient losses from agricultural areas (diffuse sources)

as such a management policy meets both objectives:
- protection of ground and surface water quality in the catchment area and
- coastal eutrophication abatement in the North-Western and Western Black Sea shallow waters

This recommendation can be exemplarily specified as follows: consistent application of the EU IPPC directive for limitation of industrial point source emissions and "sensitive area requirements" according to the urban waste water directive with nutrient removal at municipal treatment plants in the Danube Basin with more than 10,000 p.e. should start immediately in order to avoid deterioration of the actual situation. Therefore the national governments should declare their total area in the Danube Basin as sensitive area. This would facilitate financial support of investments for waste water treatment with nutrient removal from international donor funds. Furthermore, a consistent implementation of measures to limit nutrient emissions from agriculture is necessary. These measures should include:
- application of best agricultural practice (NH_3-emission reduction, improved manure utilisation, precision in application of mineral fertiliser),
- integrated production and
- limitation of the intensity of agricultural production: the area specific production has to be optimised for economical and ecological sustainability of agriculture.

A production of animal protein oriented on animal protein consumption based on demands for healthy nutrition is effective for limitation of agricultural production. A limitation of agricultural production in addition to water protection could be relevant in respect to other environmental issues as well: acidification, climate change, stratospheric ozone depletion and loss of biodiversity. Future research will have to focus on these aspects as well.

Dissemination of results

Results have been presented at a specific daNUbs conference, at numerous other scientific conferences and will be presented on future conferences as well. Further applications of the methodology can be expected due to new achievements, especially in modelling, data quality assessment and in linking model results with applicable management tools for agriculture, waste water treatment, economical development and policy. Further dissemination of results to national and international bodies is going to be organized in cooperation with ICPDR. The project web-page (http://danubs.tuwien.ac.at) will be maintained for several years by the Institute for Water Quality, TU-Vienna and an electronic version of the daNUbs final report will be distributed via the homepage and e-mail.

Keywords: Danube, Black Sea, integrated river basin management, nutrients, nitrogen, phosphorus.

Content

1. Background

Mismanagement of nutrients (N and P) in the Danube Basin has led to severe ecological problems, among them the deterioration of groundwater and the eutrophication of rivers, lakes and especially the Western Black Sea. Nutrient discharges into the Black Sea have increased continuously since the early 1960s, specifically during the 1980s. The WBS has suffered chronic harmful algal blooms, permanent hypoxic situations, as well as mass mortalities of benthic and pelagic organisms including fish. These problems are directly related to social and economic issues (e.g. drinking water supply, tourism and fishery as affected sectors; agriculture, nutrition, industry and waste water management as responsible sectors). In order to recommend proper management for the protection of the water system in the Danube Basin and the Western Black Sea, the interdisciplinary analysis of the Danube catchment area, the Danube River system and the mixing zone of the Danube river in the Western Black Sea has to be further developed.

Recent publications indicate an improvement of the WBS environment due to the economic breakdown in the eastern countries and the consequent decrease of nutrient emissions. In all probability the economic situation in the transition countries will improve in the future. This will be linked to a higher nutrient turnover in agriculture as well as an increase of nutrient emissions via waste water if no adequate treatment is supplied. The challenge within the main part of the Danube Basin is to increase economic prosperity without endangering the ecological recovery of the Werstern Black Sea.

The total catchment area of the Black Sea is 2 400 000 km^2, entirely or partially covering 23 countries. The Danube is the main tributary to the Black Sea with an average discharge of about 194 km^3/a out of about 350 km^3/a total discharge of rivers. The population in the Black Sea Basin amounts to approximately 193 million people. The Black Sea itself has a surface area of 461 000 km^2, the average depth is about 1 240 m, the maximum depth 2 212 m. 90% of the water mass is anoxic. The only connection to the world's oceans is the Bosphorus Channel, with an average width of 1,6 km, depth of 36 m and a total length of 31 km. The Danube Basin covers about 803 000 km^2 and includes larger parts of 13 countries (Germany, Austria, Czech Republic, Slovak Republic, Hungary, Slovenia, Croatia, Bosnia-Herzegovina, Serbia-Montenegro, Romania, Bulgaria, Moldova and Ukraine). Small portions of other countries also belong to the watershed. The population in the Danube basin is approximately 82 million.

The motivation for starting the daNUbs project was that the nutrient balance of the Danube Basin was not completely understood and an integration of different management tools and models was missing. Another problem was that estimated nitrogen and phosphorus emissions in the Danube Basin did not fit to the measured loads in the river system. Emission estimations, especially for diffuse sources on large-scale river basins, are of high uncertainty; retention and losses of nutrients in groundwater and river systems are poorly understood and monitoring in river systems was not designed to calculate total transported loads, but to detect critical concentrations in the river. Therefore, much innovation was needed in order to develop effective tools that support strategic planning for improved nutrient and water quality management on a catchment scale (and especially in the case of large international rivers). The present project aims at providing these innovative tools.

2. Scientific/Technological and Socio-economic Objectives

General objectives are

- to improve the knowledge on the sources, pathways, stocks, losses and sinks of nutrients in a large river catchment,
- to improve the knowledge on the effects of nutrients (nitrogen, phosphorus and silica) on the receiving ecosystems with special emphasis on the coastal areas,
- to develop, improve and combine management tools for nutrients in the Danube Basin and
- to develop scenarios and prognoses for nutrient management and its effect on water quality and their consequences on the socio-economic development in the Danubian countries.

In order to fulfil these objectives, daNUbs was expected to deliver profound knowledge on the sources, pathways and sinks of nutrients in a large river catchment and on the demands of the Western Black Sea regarding an improvement of nutrient management in the Danube Basin. Quantitative models for calculating the fate of nutrients in large river basins and in the receiving sea were improved and combined concerning their application. Additionally results concerning the evaluation of scenarios for future nutrient management under consideration of socio-economic consequences were intended.

3. Applied Methodology and Scientific Achievements

3.1. Overall Approach of the Project

The project contains a combination of research elements of different nature (Figure 1):

(I.) One set of elements is mainly oriented towards research on an improved **process understanding** of the nutrient-driven natural processes in the Danube Basin and the Western Black Sea influenced by the Danube River. Here, information obtained from the literature and data reviews were supported by additional field work in regard to improve the data base. This research addresses (i) the nutrient balance in the catchment with main emphasis on diffuse pollution (e.g. agriculture, air pollution) and the transport, retention and losses of nutrients in the local groundwater and surface water systems (ii) the transport, retention and losses of nutrients and silica along the Danube River and (iii) the functioning of the Black Sea ecosystem with regard to the influence of riverine nutrient discharges.

(II.) Based on the results of these first elements, a second set of elements concentrates on combining, improving and applying **mathematical models** to assess nutrient fluxes quantitatively from the Danube Basin along the Danube and Danube Delta to the Western Black Sea and on the impact of these fluxes on the Western Black Sea. This part employs (i) the MONERIS-emission model based on GIS data base, (ii) the Danube Water Quality Model (DWQM) to describe the transport and transformation processes in the river system (iii) the Danube Delta Model (DDM) to quantify nutrient transport in the Danube Delta and (iv) the Black Sea Model to model the effect of the Danube load on the Western Black Sea. These models allow a holistic approach to the entire system, and scenarios have been developed as a basis for scenario evaluation.

(III.) Consequently, further elements of the project are oriented towards elaborating advise for future **strategic planning** on a catchment scale. This part includes (i) considerations on establishment of a comparable, periodic, basin-wide nutrient balances and (ii) the evaluation of different solutions for future nutrient management strategies in the Danube Basin considering socio-economic aspects and using cost-efficiency analysis.

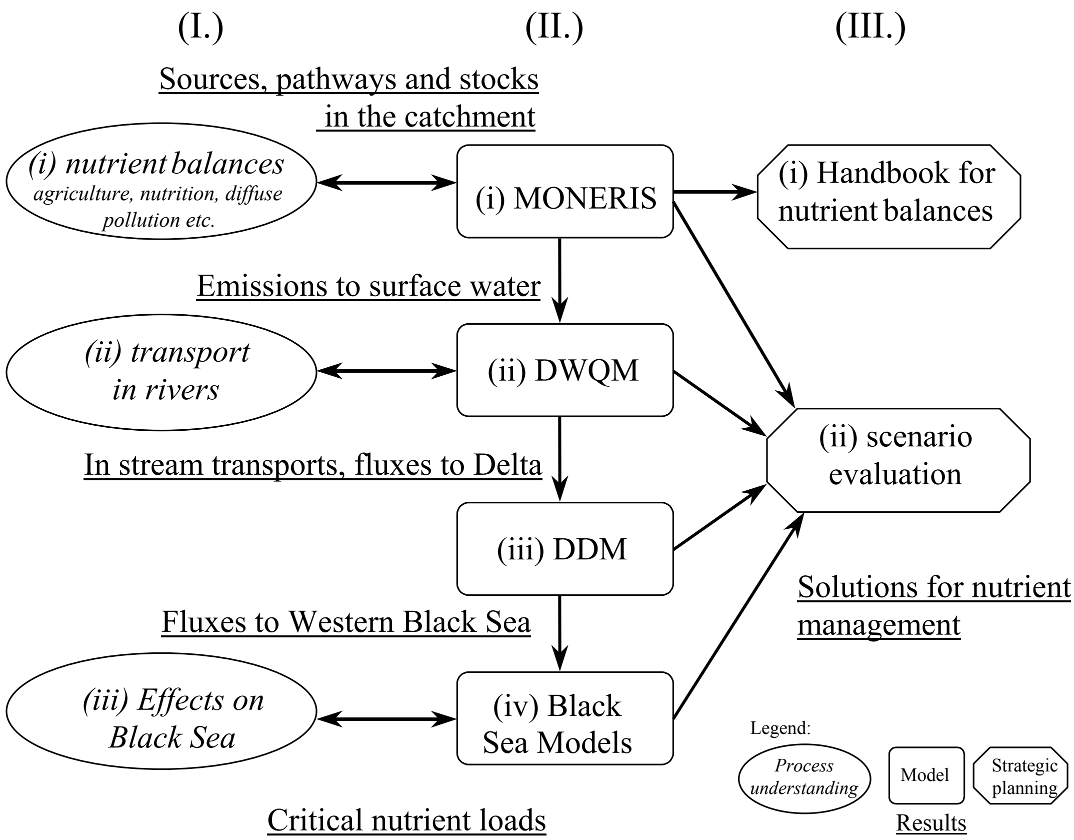


Figure 1: Graphical presentation of research elements of the project.

3.2. Description of Implemented and/or Revised Models

3.2.1. Overview of Modelling Framework

Figure 1 clearly shows the sequence of mathematical models to be used and their role in the overall project. MONERIS is supposed to calculate the nutrient emissions to the surface water on the basis of the development of human activities leading to such emissions, taking into account the pathways, losses and stocks in the terrestrial system and in the ground water. During the course of the project it became clear that MONERIS was also the most suited tool to account for losses and storage of nutrients in the small scale surface water network of the Danube Basin (see Section 3.3.2.2 for details). The inflow of nutrients to the Danube River and its main tributaries, as calculated by MONERIS is input to the Danube Water Quality

Model (DWQM). This model calculates the nutrient transport, losses and stocks in the Danube River and its main tributaries. At the upstream end of the Danube Delta, the river discharge and concentrations calculated by DWQM are transferred to the Danube Delta Model (DDM). This model calculates the nutrient transport, losses and stocks in the Danube Delta, as well as the resulting water and nutrient fluxes to the Black Sea, which are input to a set of Black Sea models. These latter models are used to calculate the fate of the Danube River nutrients in the marine environment and the subsequent ecological impact on the marine ecosystem.

The coupling between MONERIS and the DWQM is not trivial. Both models operate on different time scales: MONERIS considers averages over a number of years (typically 5), while DWQM operates on a daily basis. Furthermore, MONERIS does not distinguish different nitrogen and phosphorus species, while DWQM considers the full aquatic nutrient cycle. Details on the coupling between MONERIS and the DWQM can be found in Deliverable D5.1. The linkage between the DWQM, the DDM and the Black Sea models is done on the basis of time series for the water discharge and the concentrations.

3.2.2. MONERIS

The emission model MONERIS uses spatial and/or temporal varying input data regarding the natural system and the human activities in the Danube Basin. This comprises among other factors:

- Soil map.
- Meteorological data.
- Land use map.
- Population, degree of urbanisation, specific emissions of N and P.
- Connection to sewer systems and degree of waste water treatment.
- N surplus on agricultural soils, influenced by animal density, fertiliser use, efficiency of agriculture practice.
- P accumulation in soils.
- Erosion, optionally under influence of erosion abatement practices.
- Atmospheric deposition.

MONERIS uses this information to calculate the emissions of N and P to the surface water, by (semi-) empirical formulas. Seven different pathways are distinguished: (1) point sources (waste water treatment plants, industry, and agro-industry), (2) overland flow, (3) ground water flow, (4) tile drainage, (5) erosion, (6) diffuse emissions from urban systems and (7) atmospheric deposition. The emissions to the surface water stemming from the ground water pathway are calculated taking into account the relevant losses and retardation processes. It takes several years up to several decades for the infiltrated nutrients to travel through the ground water towards the surface waters. This implies that changes in the soils leading to changes in the infiltration of nutrients are not immediately reflected in the surface water. Furthermore, during the travel through the ground water a substantial amount of the infiltrated nitrogen is lost due to denitrification.

Typically, the load of nutrients leaving a catchment through the outflowing river water is significantly smaller than the emissions to the surface water. The surface water is able to remove and/or store a fraction of the emitted nutrients. The research carried out in the daNUbs project has demonstrated that this is indeed the case in the Danube River basin, and that most of the losses and storage of nutrients is taking place in the small surface waters (which are not explicitly included in the DWQM). These losses and storage processes of nutrients in the small surface waters are quantified by empirical formulas inside MONERIS.

In MONERIS, the Danube River basin is represented by a schematisation consisting of 388 sub-catchments of more or less homogeneous characteristics (Figure 2). The average size of these sub-catchments is about 2,000 km^3, with a substantial variation around this average.

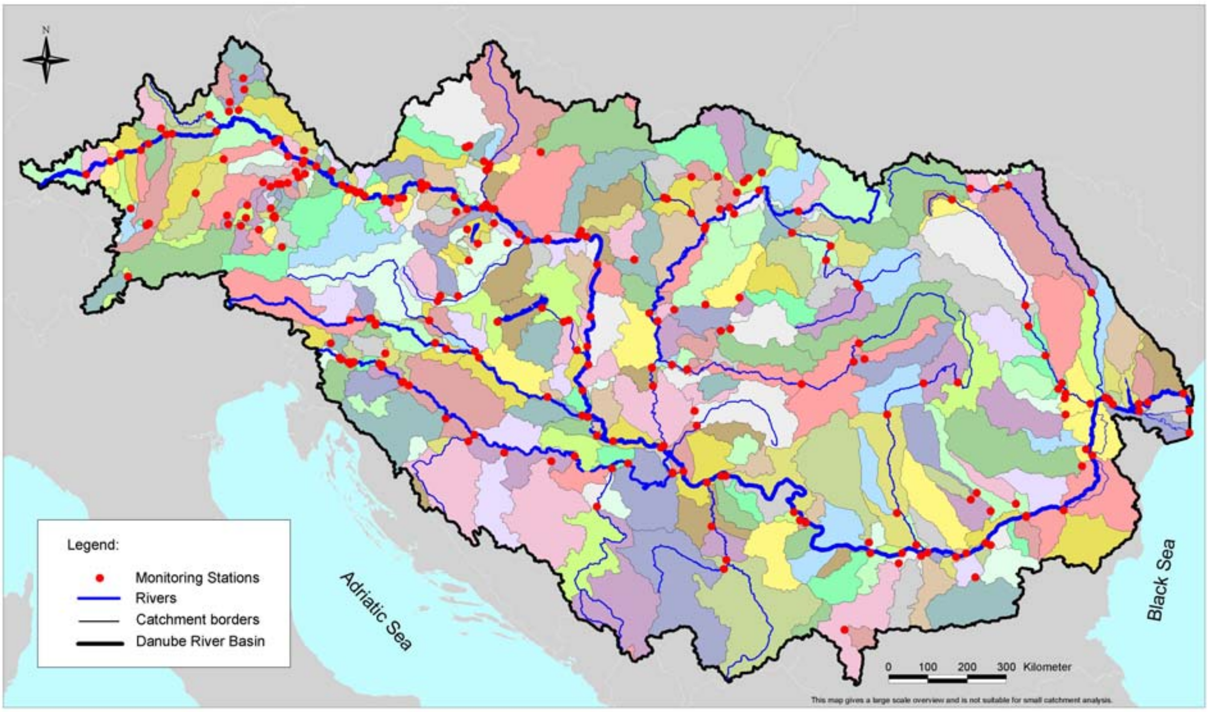


Figure 2: Overview of the schematisation of the Danube Basin in MONERIS.

Among the key achievements during the implementation of MONERIS to the Danube River Basin was the preparation of the model for the application of scenario calculations. Regarding the unified database the geological map for the Danube was revised in relation to the Danube Atlas at least for the holocen. Furthermore the complete point source inventory for Austria was included in the existing database. Regarding the model approaches itself the assumptions for the calculation of natural background as well as the identification of agricultural sources were revised. The submodel for surface runoff was changed to consider the relation between the change of the P storage of agricultural areas and the dissolved P concentration of surface runoff. A detailed data set on the longterm changes within the Danube countries was established for the application of the model regarding the reconstruction of the nutrient emissions and loads in the past. This was a precondition for the implementation of the scenario calculations.

3.2.3. Danube Water Quality Model and Danube Delta Model

The Danube Water Quality Model (DWQM, Figure 3, left) calculates the transport and retention of nutrients in the Danube River and its main tributaries on a daily basis, thus allowing a detailed impact assessment in the Danube Delta and the North-western Shelf of the Black Sea. Similarly, the Danube Delta Model (DDM, Figure 3, right) calculates the transport and retention of nutrients in the Danube Delta branches and the aquatic complexes in between these branches. Like the DWQM, the DDM uses a commercial one-dimensional open-channel dynamic numerical modelling system, capable of solving the equations that describe unsteady water flow and water quality.

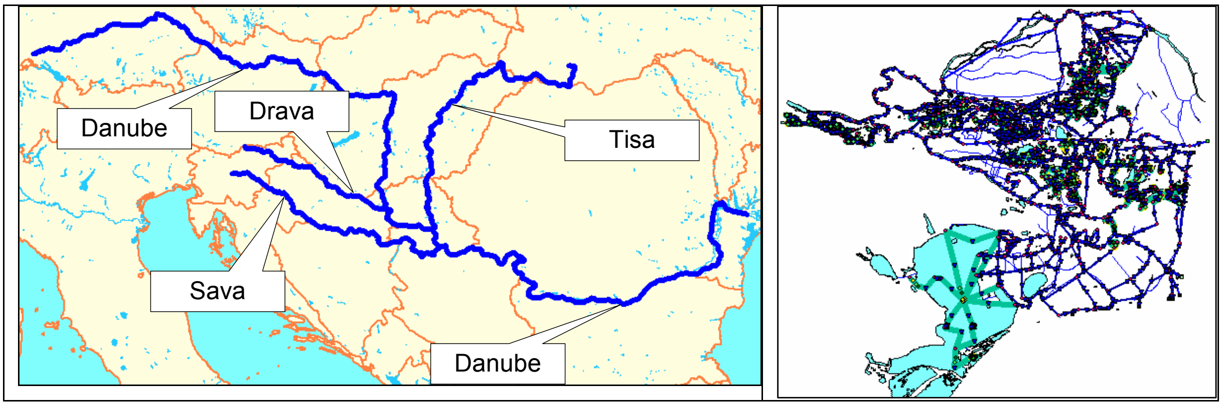


Figure 3: The schematisation of the Danube River and its main tributaries in the DWQM (left) and the schematisation of the Danube Delta in the DDM (right).

The water quality modelling programme used by the DWQM and the DDM is suitable to quantify the transformation, storage and loss processes of the nutrients N, P and Si. Both models distinguish the following state variables: dissolved oxygen, inorganic nutrients (NH_4, NO_3, Si, dissolved and particulate PO_4), dissolved organic N, inorganic suspended matter, algae and detritus (C, N, P, Si).

The revised DWQM as it was developed in daNUbs is based on an already existing DWQM which was developed in the EU funded Applied Research Programme for the Danube Basin (mid 1990s) and upgraded in the GEF/UNDP funded Danube River Basin Pollution Reduction Programme (van Gils, Bendow, 2000). In daNUbs, the DWQM was modified to disaggregate the 5-year average nutrient loads coming out of the small surface water network calculated by MONERIS to daily nutrient concentrations, on the basis of the day-to-day variation of the river hydrology. The DWQM also disaggregates the pools of total N and total P in a number of species which are related to its detailed representation of the nutrient cycling in the surface waters.

Specific aspects of the revised DWQM validation have been the seasonal variation of the concentration of nitrogen, the losses and storage processes in floodplains and reservoirs, and the behaviour of silica in the Danube and its main tributaries (Gils J. van, 2004). The work relied on the analysis of pre-existing data and data collected in daNUbs (Gils J. van, 2004a). It had to be concluded that the available data were far from complete (Si, organic nitrogen) and often inconsistent or even contradictory (suspended matter, phosphorus). Nevertheless, the revision was concluded to be successful in view of the objectives of daNUbs. The ability of the revised DWQM to reproduce the observed water quality during the Joint Danube Survey in 2001 illustrates this.

The DDM is specifically designed to predict the nutrient removal in the aquatic complexes and their transport from the catchments to the Western Black Sea. The most important nutrient loss process that has to be taken into account is the loss of N to the atmosphere by denitrification. “Removal” of phosphorus is mainly related to storage in the sediments by net sedimentation. To be able to make a distinction in biochemical processes in reed beds (standing and floating reed) and open water bodies these parts are separated in the hydrological model (Figure 4).

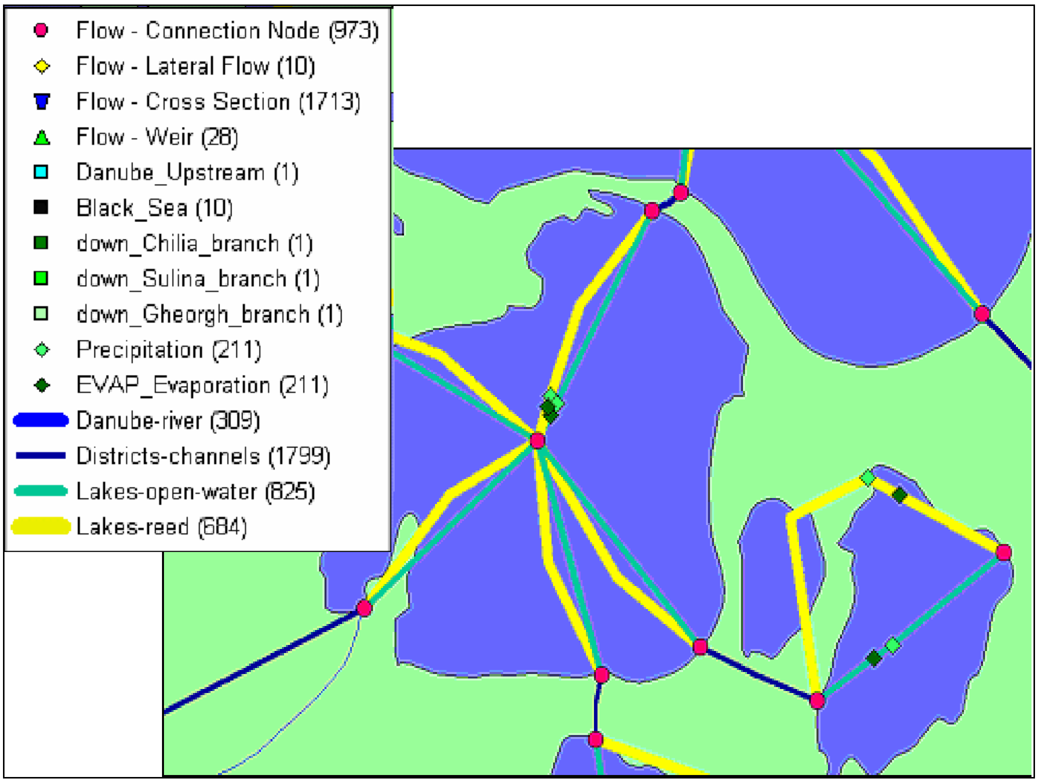


Figure 4: Modelling principle for reed beds versus open water and evaporation and precipitation.

The DDM has been calibrated using nutrient removal coefficients for each aquatic complex based upon weight factors between open water and reed beds of each of the complexes and depending on a function based upon the water level at Tulcea. Also the model includes the meteorological conditions as wind, precipitation and evaporation that play a significant role especially in the dry period and can not be ignored from a hydrological and water quality point of view (Constantinescu et al., 2003; Constantinescu & Bakkum, 2002).

3.2.4. Black Sea Models

A hierarchy of models that can be easily adjusted and applied for different scenario simulations was developed, as dictated by the project needs for management assessment. The model data flow and characteristics are shown in Figure 5.

The hydrodynamic model is based on the Princeton Ocean Model (POM) (Blumberg and Mellor, 1983) which is a 3-dimensional, sigma-coordinate, primitive equation and free-elevation model with a 2.5 turbulence closure submodel (Mellor and Yamada, 1982) which calculates vertical eddy viscosity / diffusivity taking account of the wind stirring and the stratification of the column. The model output includes the 3-D velocity field, temperature, salinity and free surface elevation. The model has been modified to include river plume dynamics, following the approach developed by Kourafalou et al. (1996a). This is a key model modification that allows the detailed description of the development and evolution of the Danube River plume.

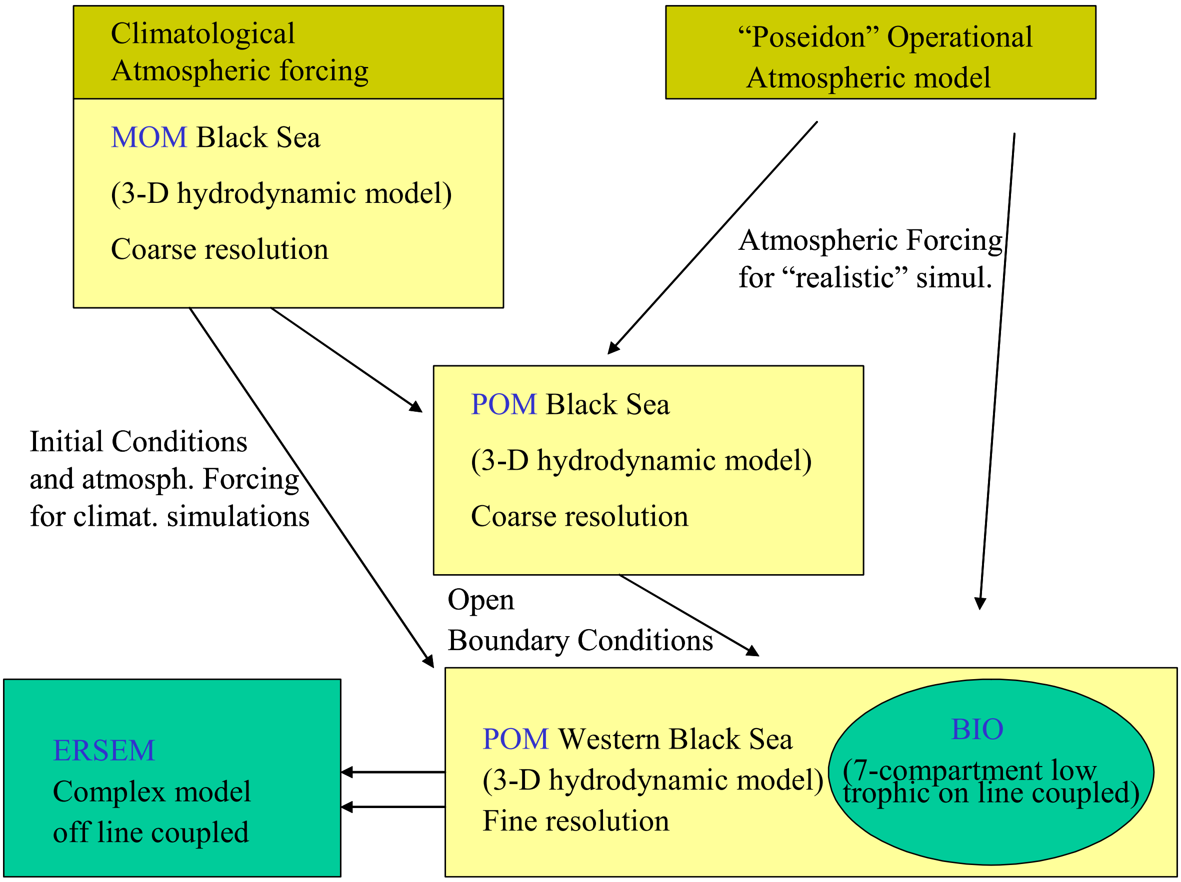


Figure 5: Schematic of model simulations connectivity and data flow.

The high resolution (~5Km) hydrodynamic shelf model is nested to a lower resolution (~10Km) basin scale model, which provides the necessary open boundary conditions. The initial density field and climatological atmospheric fluxes are provided by a long-term climatological run of a basin scale model which is based on the Modular Ocean Model (MOM) (Staneva and Stanev, 1997). Using the above climatological atmospheric fluxes and average Danube discharge rates (1994-2002) a 1-year long climatological type simulation was performed by the shelf model, providing initial conditions for a "realistic" simulation, where 6-hour atmospheric forcing and 1-day Danube discharge rates are employed for the period

2002-2003. This simulation is the base for our scenario simulations. The Danube discharge and nutrient input values are provided by the Danube Delta Model (DDM).

A low-trophic biological 5-compartment model (Phytoplankton, Zooplankton, detritus, NO_3, NH_4) which is based on the Fasham model (Fasham et al., 1990) is on-line coupled with the hydrodynamic shelf model, providing an overview of the 3-D seasonal phytoplankton variability over the Western Black Sea. The initial parameter set was taken by the study of Oguz et al. (1996) and Staneva et al. (1997, 1998) where the model was tuned to the open Black sea conditions. The most important innovation was the employment of a variable growth and uptake parameterisation for phytoplankton and zooplankton, that can take account of the large productivity gradient between the open sea and coastal areas. Furthermore, since the observed N/P ratios in the Danube area imply a P-limitation, the model was upgraded to include PO_4 and P-part of detritus as state variables. A simple model for sedimentation and resuspension depending on bottom stress was also employed. The model was calibrated using SeaWifs Chlf-α images from 2002-2003. Despite its simplicity, the coupled model can capture basic physical and biological processes affecting phytoplankton variability.

The European Regional Seas Ecosystem Model (ERSEM, Baretta et al., 1995) is a complex ecosystem model that simulates the biogeochemical cycling of carbon, nitrogen, phosphorus and silicon. It consists of five modules (conceptual units): Primary producer module; Microbial loop module; Mesozooplankton module; Benthic nutrients module and Benthic biology module. The dynamics of the biological functional groups are described by both physiological (ingestion, respiration, excretion and egestion) and population processes (growth, migration and mortality).

In the current application, ERSEM is implemented in the Danube influenced area. It is off-line coupled with POM hydrodynamic shelf model in a "box model" representation so that it captures the three-dimensional ecosystem variability. The location of the boxes which ranges from the Danube Delta to the Burgas bay, was chosen according to the specific circulation characteristics of the Northwestern Black Sea area, but also according to the availability of the data during 2002 in Bulgarian and Romanian waters. The thermal and haline stratification within the different boxes and lateral water fluxes are provided by the hydrodynamic shelf model, thus, incorporating the simulated river plume dynamics. For estimating the lateral fluxes the techniques described in Lehnard et al. (1995) were used. A mixed layer model is providing the vertical mixing coefficients while atmospheric fluxes are calculated using bulk parameterisation formulas. In addition to the horizontal and vertical advection-diffusion, the ecology is also forced by time series for radiation, temperature, suspended matter and riverine inputs. Thus, ERSEM is forced with water and nutrient inputs from the Danube River and computes distributions of ecosystem variables that are largely influenced by the variability of these inputs, in the context of the prevailing hydrodynamic and biological processes. In our application, all box regions are considered as 8 layered with 5m discretization, including a bottom box extending the 8-th model layer up to the sediments, having a benthic interface. Such box models have the advantage of being relatively inexpensive, allowing systematic sensitivity tests in complex biological models. The model tuning was done during the climatological simulation where a series of model runs and verifications took place using all the available climatological data provided by the work in work package 7 (deliverables 7.1 – 7.6) of the daNUbs project.

3.3. Results

3.3.1. Case Study Results

3.3.1.1. Description of Case Study Areas

Within the daNUbs project case study investigations were performed in order to improve the process understanding of relevant processes of water and nutrient balances on (sub)catchment scale and as test regions for methodologies applied on basin scale. For these investigations 5 case study areas (CSA) were selected covering various conditions of the Danube basin in respect to hydrology, morphology and land management practises. Additionally, the current state of the economic development of the Danubian countries is reflected in differences in the agricultural and urban waste water management sector. For performance of nutrient balances these 5 case study catchments were subdivided in altogether 26 subcatchments.

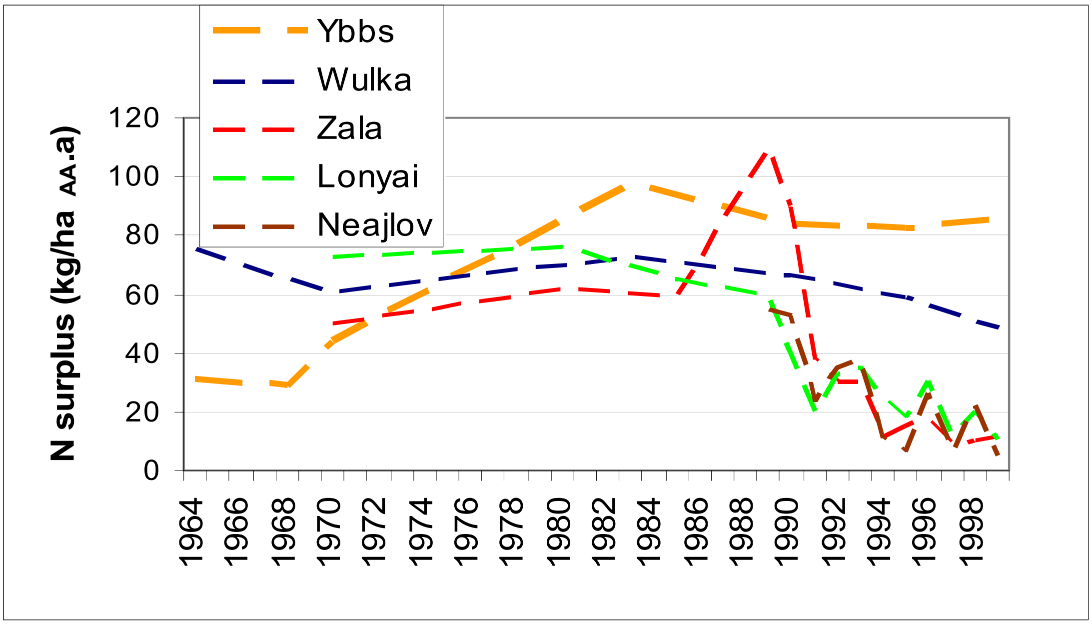


Figure 6: Long-term development of the nitrogen surplus on the agricultural soils (for Zala and Lonyai catchment with consideration of the net mineralization , see chapter 3.3.1.4)

In Table 1 a comparison of basic parameters of the 5 CSA is shown. The specific situations in the CSA and their subcatchments cover the variety of situations in the Danube Basin to a high extent (Zessner et al., 2004). Especially in the Hungarian (Zala and Lonyai) and Romanian (Neajlov) catchments there have been dramatic changes in the surpluses of nutrients on the agricultural areas during the last decades, with higher values in the 70ies and 80ies and a dramatic drop in the 90ies, due to breakdown of agricultural production (Figure 6) . In the table average values for the last 30 years are presented.

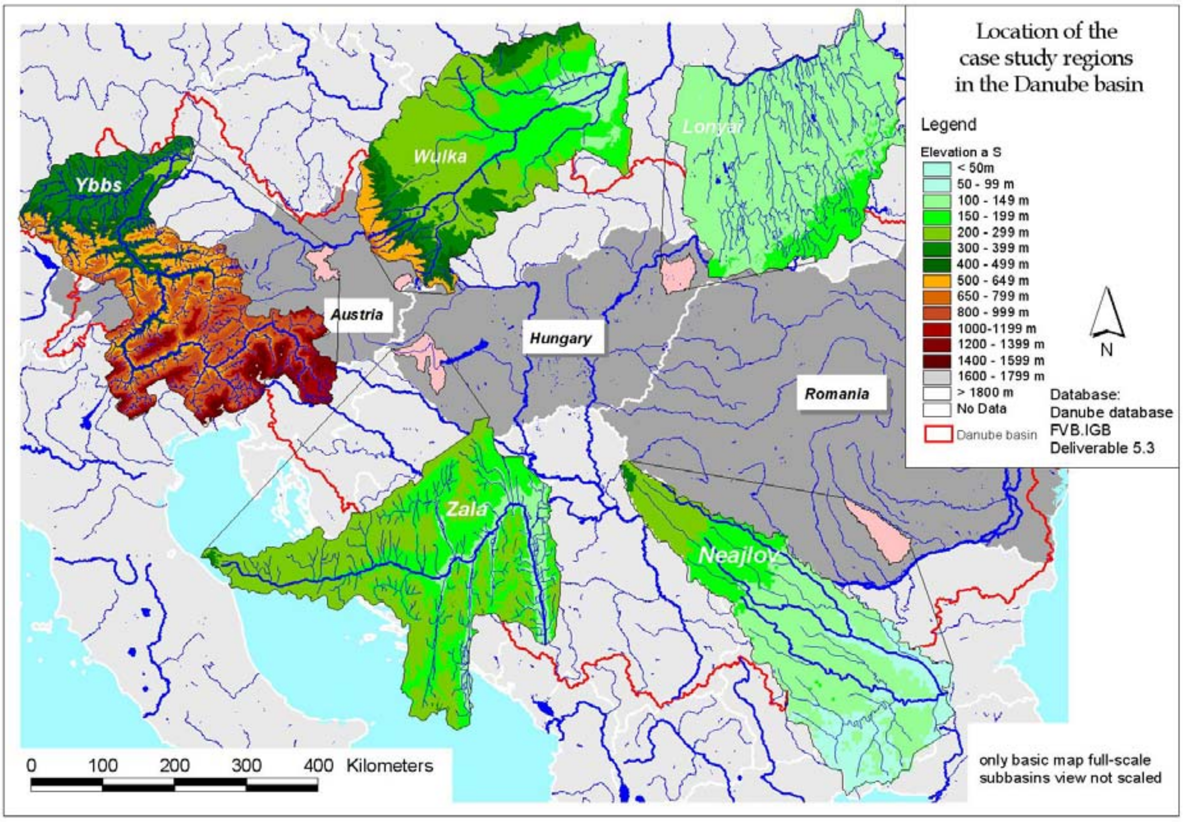


Figure 7: Location of the case study regions in the Danube basin

Table 1: Comparison of main characteristics of the case study regions (1996-2001)

Country		Austria		Hungary		Romania
Name of the river		**Ybbs**	**Wulka**	**Zala**	**Lonyai**	**Neajolov**
Total catchment area	km^2	1117	384	1529	2151	3720
share of arable land	%	12	54	54	76	78
share of agricultural grassland	%	27	12	8	4	4
share of forests	%	52	28	34	14	10
N-fertiliser application*	$kg/ha_{AA}/a$	150	100	47	25	69
P-fertiliser application*	$kg/ha_{AA}/a$	43	26	9	5	15
longterm N-surplus in agriculture***	$kg/ha_{AA}/a$	67	61	57	54	44
longterm P-surplus in agriculture***	$kg/ha_{AA}/a$	49	11	32	20	18
N-in agricultural soil	g/kg	3,6	1,5	1,2	0,9	1,6
P-in agricultural soil	g/kg	0,8	0,7	0,7	0,4	0,5
N-deposition	kg/ha/a	19	13,5	10	10	11
longterm N-surplus on total area***	kg/ha/a	38	45	39	45	38
longterm P-surplus on total area***	kg/ha/a	19	7	20	16	15
mean slope	%	30	8	6,3	0,9	0,22
average precipitation	mm/a	1390	665	651	629	500
average runoff**	mm/a	930	99	89	35	72
share of point source contribution	%	0,7	26	3,3	11,6	2,6
population density	inh/km^2	68	133	79	147	57
share connected to sewerage	%	74	95	50	41	6
share connected to wwtp	%	74	95	50	41	no data
predominant waste water treatment		C, N, (D), P	C, N, D, P	C, N(D), P	C, N	0, C

0…no treatment; C… carbon removal only; N…Nitrification; D…Nitrification/Denitrification; P...P-removal

* total application of fertilzer (incl. org., min., sewage sludge) related to agricultural area (ha_{AA})in use

**without contribution from point sources

*** 30 years

3.3.1.2. Water Balances

The objective of the water balance exercises was to increase the knowledge of the different key processes in terms of water pathways that lead to regional nutrient turnover. Furthermore, these calculations build the basis for evaluation of the results of the MONERIS model which is used for the whole Danube Basin in workpackage 5 of the daNUbs project. Therefore a detailed analysis of the water balances of the case study regions in different climatic and hydrologic conditions was developed. The following methods were used:

DIFGA 2000	is a baseflow separation technique
SWAT 2000	is a conceptual continuous model based on physical equations
MONERIS	is a GIS-based model based on empirical equations for large river basins using extensive statistical information

Table 2: Comparison of the model results

		Ybbs			Wulka		
catchment area	km²	1117			384		
average precipitation	mm/a	1377			709		
average terrain slope	%	31			8		
average discharge	m³/s	32,7			1,23		
average discharge	mm/a	904			99		
landuse characteristic	--	forest (52), pasture (32), arable land (12)			arable land (54), forest (28)		
soil characteristic	--	rendzina, luvisol			luvic chernoesem, orthic luvisol		
geological characteristic	--	consolidated rock, sediment			sediment		
Model results		SWAT	DIFGA	MONERIS	SWAT	DIFGA	MONERIS
period		1992 - 1997	1971 - 1997	1995 - 1997	1992 - 1997	1971 - 1997	1995 - 1997
evapotranspiration	mm	376		550	575		550
baseflow	%	45		93	40		58
lateral flow	%	35			11		
fast groundwater QG1	%		42			42	
slow groundwater QG2	%		29			16	
surface flow	%	19			5		
direct discharge (incl. tile drainage)			29			16	
surface runoff *)				6			5
modelled discharge	mm/a	930	852	851	107	93	99
point sources	%	1		1	26	26	29
tile drainage	%				19		8
		Zala			Neajlov		
catchment area	km²	1529			3720		
average precipitation	mm/a	656			496		
average terrain slope	%	3,15			0,55		
average discharge	m³/s	4,32			7,26		
average discharge	mm/a	87			60		
landuse characteristic	--	arable land (62), forest (34)			arable land (78), forest (10)		
soil characteristic	--	loam, sandy loam			luvisil, chernozem		
geological characteristic	--	loess, glacial sediment			--		
Model results		SWAT	DIFGA	MONERIS	SWAT	DIFGA	MONERIS
period		1997 - 2001	1997 - 2001	1997 - 2001	1995 - 2001	1995 - 2001	1995 - 2001
evapotranspiration	mm	426		567	409		419
baseflow	%	72,8		91,9	78		89
lateral flow	%	4,6			0		
fast groundwater QG1	%		34,5			45	
slow groundwater QG2	%		49,7			37	
surface flow	%	17,6			22		
direct discharge (incl. tile drainage)			15,8			18	
surface runoff *)				4,9			11
modelled discharge	mm/a	76	89	89	66	62	75
point sources	%	3		3,2			
tile drainage	%						
*) surface runoff from none paved areas + runoff from urban areas + direct flow							

At first a conceptual model based on physical equations was used (SWAT 2000). As input data average daily values of a 7 years time series were used, in detail the precipitation, the air temperature and the solar radiation, the relative humidity and wind speed. The application of the SWAT 2000 model showed already at the beginning the immense effort in regard to the spent time and the needed data as input for model parameter definition to achieve an acceptable model performance. Furthermore, it was noted that with the multitude of partly uncertain model parameters it is possible for the model to match the observed data with different, alike feasible model parameter sets. With the assistance of the hydrograph separation technique (DIFGA 2000), a complete other method for the estimation of the runoff components, it was tried to accommodate this problems. The feasibility of the estimated distribution of the runoff components was verified using other runoff separation methods and the literature, too. In addition the water balance for the case study regions was estimated using the MONERIS model. Detailed results are presented in Blaschke et al. (2002) of the daNUbs project.

The comparison of the different model results is difficult due to the different terms in the runoff components definitions of the model assumptions. The results of the water balance calculations using the different methods are summarised also in Table 2.

From the model applications and the model results the following statements can be deduced:

- The application of conceptual models based on physical equations requires a large demand on input data and the calibration effort of such models of a physical nature is rather time consuming.
- The runoff from drained areas in the MONERIS model is only a function of the hydro-morphology of the soils and does not consider actual land use.
- The base flow calculated with MONERIS was partly higher estimated in all case study regions than with the other methods.
- The detailed analysis showed that the runoff components vary obviously in amount and distribution depending on the seasonal conditions.

3.3.1.3. Erosion Estimates

Erosion estimates using a set of different models to calculate erosion and a set of different input data were performed for the case study catchments of the river Ybbs, Wulka and Zala. Based on the results obtained, sediment bound phosphorus and nitrogen loads were modelled. For Austria it was the first time, that soil erosion and nutrient load were modelled with a detailed data set at this scale. Also for the first time, models and data sets of a different degree of detail have been compared.

Transfer functions for input data

Usually the necessary input data for erosion modelling are not available in a way, that they can be used directly in the models. Therefore it was necessary to compile the required input parameters for soil erosion modelling and transform them into data that could be used in the different models. The difficulty of this task was increased due to the fact, that in different basic data and maps were available in Austria and Hungary. Therefore different algorithms had to be developed in order to transfer available data into required data.

Figure 8 gives one example for the development of these transfer functions, describing the relationship between silt contents of upper soil (data available) and susceptibility of soil to erosion (data necessary) which is one of the main parameters that affect soil erosion. In Figure 8 soil susceptibility is expressed as K-Factor which is the term that is needed by the erosion models USLE and MUSLE that had been applied for Austrian conditions. For Hungarian conditions other procedures had to be developed to link available soil information to soil physical input parameters. Main input data there was information on plastic limit of soil and content of organic carbon.

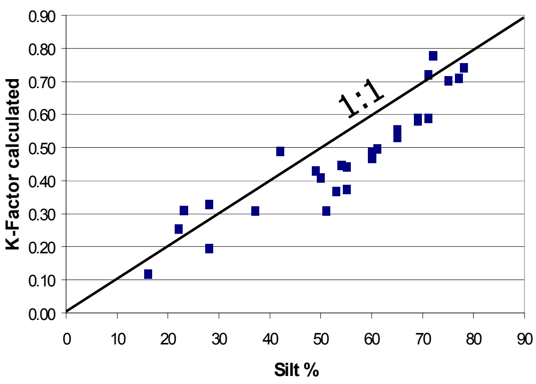


Figure 8: Relationship between upper soil silt content and susceptibility of soil to soil erosion (K-Factor) as required by the erosion models USLE and MUSLE according to Wischmeier and Smith (1978).

This was used together with information on the spatial distribution of soil types to calculate soil physical input data such as K-factor, field capacity, permanent wilting point, saturated hydraulic conductivity and others, which were needed for erosion modelling.

Application of erosion models

Two basic approaches have been used to model erosion in the selected case study areas, one approach based on the so called USLE and the second one based on a model called MMF (see Strauss et al. (2003) for references on both models). These models were selected because both may be used with relatively few input data. In addition to the general differences between the modelling theories, for each model different ways of model application have been tested. USLE for instance was applied in its original form to the catchments of the river Ybbs and Wulka and in a modified form (as part of the catchment management tool SWAT) to the catchments of the river Ybbs, Wulka and Zala. MMF also was applied in different versions to the catchments of the river Ybbs and Wulka. The versions mainly differed in the way to transform onsite erosion (erosion, that happens in agricultural fields or on other areas) into inriver sediment (the part of eroded material that finally reaches a stream and gets transported there). The models have also been tested with a set of different input data in order to estimate the effects of data with limited spatial resolution on soil erosion prediction. An example gives the annual average sediment load into the surface water of the river Zala as calculated using one modification of the USLE termed MUSLE (this is the erosion component which was implemented in the catchment management tool SWAT). Compared to measured sediment loads the calculated sediment input turned out to be at least half an order of magnitude higher (Table 3). Similar results have been obtained for the catchments of the rivers Ybbs and Wulka leading to the conclusion, that without

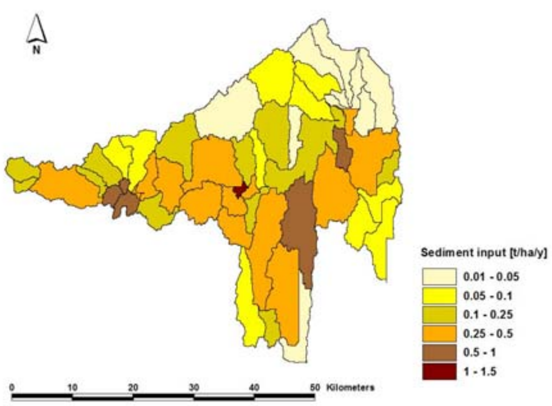


Figure 9: Yearly average sediment input into the surface water in the sub-basins of the Zala River (1997-2001)

implementation of regression relationships to balance out onsite erosion with inriver sediment (so called sediment delivery ratios) neither the USLE derived models nor the MMF based models were able to reflect measured data. Introduction of sediment delivery ratios on the other hand allowed to estimate sediment loads sufficiently well with both methodologies (Table 3). However, further testing has shown, that the computed sediment delivery ratios were sensitive to a change in the quality of input data. This means that for each combination of particular data set and erosion model a different calibration of sediment delivery ratios is required. This is especially important for transnational model applications, where different data sets may have been used to calculate soil erosion.

Table 3: Calculated sediment and phosphorus loads (using different models) and measured sediment and phosphorus loads at different subwatersheds of the river Ybbs (1992-2001), Wulka (1992-2001) and Zala (1997-2001)

	Sediment Yield (t/ha/a)				Phosphorus load (kg/ha/a)		
	MUSLE (as incorporated in SWAT)	USLE (using sediment delivery ratio)	MMF (using sediment delivery ratio)	Measured	Calculated (MMF)	Calculated (USLE)	Measured
Greimpersdorf	2.7	0.5	0.4	0.7	0.46	0.57	0.74
Krenstetten	6.2	0.6	0.6	0.4	0.77	0.67	0.47
Opponitz	0.5	0.4	0.5	0.4	0.44	0.31	0.29
Schuetzen	2.4	0.2	0.2	0.2	0.41	0.35	0.46
Walbersdorf	1.9	0.2	0.2	0.2	0.31	0.31	0.40
Wulkaprodersdorf	2.9	0.1	0.2	0.2	0.41	0.33	0.26
Trausdorf	2.8	0.2	0.1	0.2	0.24	0.27	0.34
Oslip	2.1	0.1	0.2	0.1	0.33	0.18	0.33
Nodbach	2.9	0.1	0.1	0.1	0.15	0.20	0.16
Zala	0.2	-	-	0.03	-	-	0.22

Estimation of phosphorus (P) loads due to erosion

For the estimation of P loads due to erosion different methodologies were tested. Finally, a concept similar to the calculation of sediment delivery ratios was employed for all erosion models (P load = P of soil *enrichment factor * sediment yield). The value of the enrichment factor of this equation varied with the different subcatchments. However, using a linear relationship between sediment yield and P content of sediment allowed to estimate the enrichment factor for each subcatchment. In addition to the uncertainties of erosion modelling, the estimation of P loads had to deal with very little information on the spatial distribution of soil P contents which forms one basis for the calculation of the P load. Compared to the variations in the value of the enrichment factor, the uncertainties in determination of the soil P content were much lower.

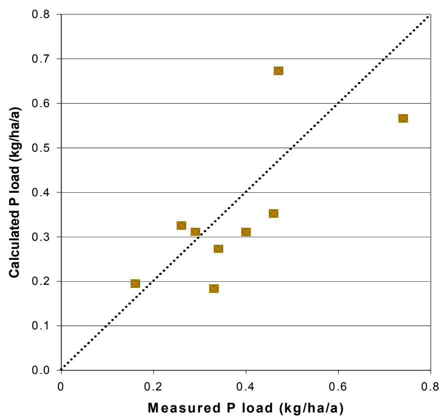


Figure 10: Relationship of calculated and measured P loads for different subcatchments of the river Ybbs and Wulka – USLE model

Data gaps

To simulate the effects of data with limited spatial resolution on erosion and phosphorus estimation various simplifications of the available data have been tested. Simplifications included elevation data, land use data and soil data. Various algorithms to account for limited spatial resolution data have been tested, however in some cases, additional information would be necessary. To use the CORINE data set (land use data available at European scale) it is for instance advisable to combine them with statistical information on actual land use (which for the Austrian case study areas was available at community level). Different grid resolutions of a digital elevation model were tested in the case study areas of the river Ybbs and Wulka. Slope as a main input parameter for soil erosion modelling differed greatly with grid resolution. Therefore ways to account for these changes were developed, leading to a set of regression equations to correct these errors. It was however found, that these equations can only solve part of the problem as they turned out to be regionally specific.

3.3.1.4. Nutrient Balances

Details on nutrient balance calculations on case study level are presented in the deliverables D1.3 and D1.4 of the daNUbs project (Zessner et al., 2004). The following gives an overview on the main outcomes of these investigations.

Table 4: Calculated N and P emissions as compared (MONERIS) to measured river loads for the case study regions

Nitrogen	Deposition	Overland flow	Tile drainage	Erosion	Ground-water	WWTP	Urban systems	total TN emission	TN river load
	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]
Wulka	0,06	0,01	1,29	0,42	2,59	1,11	0,16	5,6	3,7
Ybbs	0,11	0,61	1,43	0,35	16,93	0,68	0,33	20,4	18,7
Zala	0,04	0,20	0,00	0,46	1,78	0,75	0,14	3,4	2,8
Lonyai	0,07	0,08	0,00	0,16	0,16	2,71	0,19	3,4	1,1
Neajlov	0,19	0,00	0,05	0,38	1,05	0,34	0,71	2,7	2,6

Phosphorus	Deposition	Overland flow	Tile drainage	Erosion	Ground-water	WWTP	Urban systems	total TP emission	TP river load
	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]	[kg/ha*a]
Wulka	0,002	0,001	0,006	0,442	0,016	0,086	0,034	0,59	0,29
Ybbs	0,002	0,073	0,007	0,186	0,136	0,109	0,045	0,56	0,80
Zala	0,002	0,053	0,000	0,632	0,040	0,057	0,018	0,80	0,23
Lonyai	0,003	0,028	0,000	0,182	0,033	0,326	0,025	0,60	0,35
Neajlov	0,006	0,000	0,000	0,271	0,093	0,024	0,081	0,48	0,14

The MONERIS emission model was a useful tool for quantification of nutrient emissions in the case study catchments. All relevant emission pathways are considered. Most of the required data were available. Table 4 shows a comparison of the calculated emissions via different pathways for the different case study areas and the measured instream loads. In order to compare calculated loads with measured once instream retention has to be considered. For nitrogen a comparison between river loads calculated on the basis of

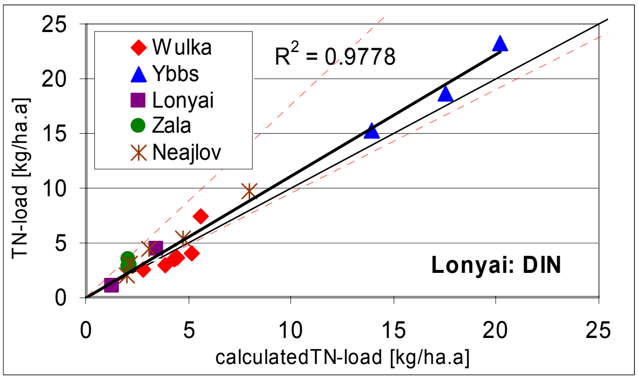


Figure 11: Comparison of calculated and measured nitrogen loads of different catchments with retention approach based on the hydraulic load

MONERIS approach and measured loads shows good agreements (Figure 11), if the instream retention (denitrification) is calculated based on a correlation to the hydraulic load (= river runoff divided by river surface area of a catchment). The average deviation between calculated measured N-loads in the different subcatchments of the case study areas was found to be 16 %.

For phosphorus the agreement between calculated and measured loads was not as good as for nitrogen. The average deviation for different subcatchments was about 50 %. This is significantly higher than it was found by Schreiber and Behrendt (2003) on the basin wide scale where this deviation was calculated to be 30 %. A reason for this could be the much higher dynamic of the phosphorus transport at high flow situations in smaller catchments (Figure 13) which hampers the quantification of erosion and instream retention on catchment scale as well as the monitoring of phosphorus loads.

The most important pathway for nitrogen emissions to surface waters is the groundwater. Quantitative assessment is based on the surplus on soils and on the denitrification in the soil and subsurface passage. Surplus on soils is derived based on an agricultural balance (field balance) and on deposition on non agricultural areas. The consideration of net-mineralisation in agricultural soils (release of nitrogen forms the organic nitrogen stock in soils) turned to be important in the cases of the Hungarian and Romanian case study areas, where the surplus suddenly dropped to close to zero at the beginning of the 90ies. The MONERIS approach does not explicitly consider net-mineralization but covers it to some extent by using long term averages for nitrogen surpluses in soils as basis for the calculation of nitrogen emissions via groundwater.

Even more important for assessment of nitrogen emissions via groundwater as the surplus in soils is the quantification of the retention (denitrification) of nitrogen in soils and groundwater. In respect to emissions to surface water in comparison between regions the denitrification in groundwater may overrule the influence of the surplus in soils. The MONERIS retention approach works well on subcatchment level, but it shows a high sensitivity on the categorisation of geological units (consolidated-impermeable to unconsolidated-deep groundwater). Appropriate information on geology and categorisation according the MONERIS definitions therefore is prerequisite for a successful application.

For more detailed assessment of areas mainly contributing to nitrogen emissions within a subcatchment the MONERIS model is not applicable. More detailed approaches based on flowtime of groundwater and time dependency of denitrification have to be used. Based on a first application of such an approach for two regions in the Austrian case study areas a differentiation of areas in areas which contribute to the nitrogen emissions to surface waters and such which do not was possible (Figure 12).

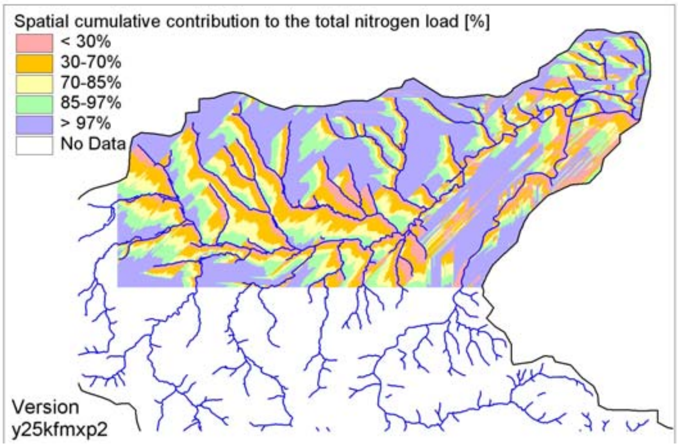


Figure 12: **Spatial distribution of the areas with their cumulative contribution to the total nitrogen emissions via groundwater**

Tile drainage and urban areas may have a significant relative contribution to nitrogen emissions depending on the local situation in a subcatchment (share of tile drained areas, share of population with on site disposal of waste water by septic tanks or pits). Quantification of these emission pathways often suffer from lack of adequate data on the tile drained areas and on the fate of the content of septic tanks and pits. Calculations mostly have to be based on rough estimation. For the accuracy of the overall balance the influence of these uncertainties usually is small. Point source emissions from municipal waste water have significant impact on nitrogen as well as phosphorus emissions in most of the subcatchments. Even if no specific data on these point sources exist, these emissions can be estimated with a relatively high accuracy based on population specific emissions and information on the waste water infrastructure.

Erosion is the main pathway for phosphorus emissions (details see chapter 3.3.1.3). In addition to the accurate estimation of soil erosion, for determination of the input into the surface water the determination of the sediment delivery ratio (ratio between eroded soil and soil particles transported into the river) is of decisive importance. A problem in this respect which is not completely solved yet is, how to distinguish between P-retention in the catchment and retention in the river system, or expressed in another way: which part of the sediment delivery ratio describes sedimentation before sediments reach the river system and which part describes retention after sediments have reached the river system (e.g. sedimentation in the river bed or in flooded areas). The MONERIS approach offers a practicable tool to determine the sediment delivery ratio till discharge to the river on the one hand and to estimate river retention based on an additional approach. Anyway, there is no way yet to check the plausibility of the differentiation between retention in the catchment and retention in the river. Further research is needed in this aspect.

It was clearly demonstrated, that high flow events significantly influence the P-load in river systems (Figure13). Most of the P-loads are transported within few days of a year. High flood events can transport P-loads in the order of magnitude of yearly average loads. Transported loads vary a lot between different years, depending on the discharge situation of the year. Using averages over some years (e.g. 5) reduces the influence of these fluctuations. Nevertheless, it is of high importance to include high flow events into load monitoring and calculation. The influence of high flow events on the phosphorus transport decreases with increasing catchment area and is of much higher importance in tributaries than in the Danube River.

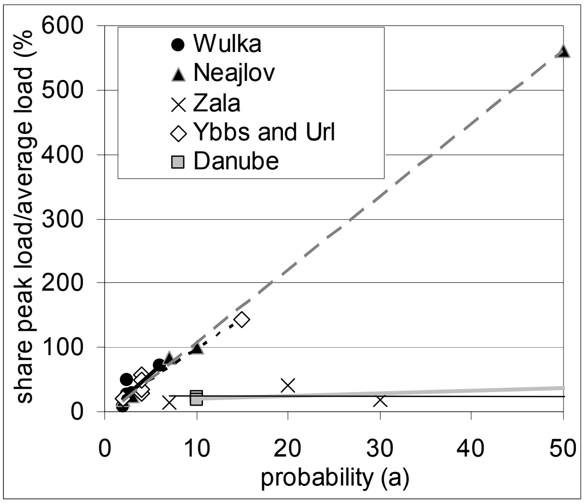


Figure 13: Relation between event probability and share of phosphorus loads transported during the event as compared to total average

For the Basin wide MONERIS application the case study investigations helped to develop an improved approach for water balance calculations and they showed the principle applicability of MONERIS for nutrient balance calculations under the circumstances in the Danube Basin. Further the advantage of the retention approach based on the hydraulic load for nitrogen and the principle problem to close the P-balance between emissions and instream loads for small catchments due to the high dynamic of the P-transport was shown. More in detail case study investigations showed the need for refinement of the approach for calculation of emissions from settlements not connected to sewer systems and developed an approach for estimation of point source pollution in case of missing or not reliable monitoring data.

3.3.2. Nutrient Fluxes in the Danube Basin and their Impact on Western Black Sea

3.3.2.1. Nutrient Emission in the Danube Basin

Nutrient emissions by point and diffuse sources were estimated for the Danube River Basin on the basis of a harmonised and integrated database at the sub-catchment level by application of the MONERIS model. At first the estimation of nutrient emissions was carried out for the time period 1998-2000 for 388 sub-catchments as well as the thirteen countries each responsible for more than 1 % of the total area of the Danube River Basin. Secondly, the model was applied for the reconstruction of the development of the nutrient loads in the Danube, to demonstrate that it is able to describe the changes of the relation between the intensities of human drivers and the reaction of the river system in the past. This step was necessary for the final step of the scenario calculations, because without the ability of the model to describe the changes in the past the application for scenario calculations would be questionable.

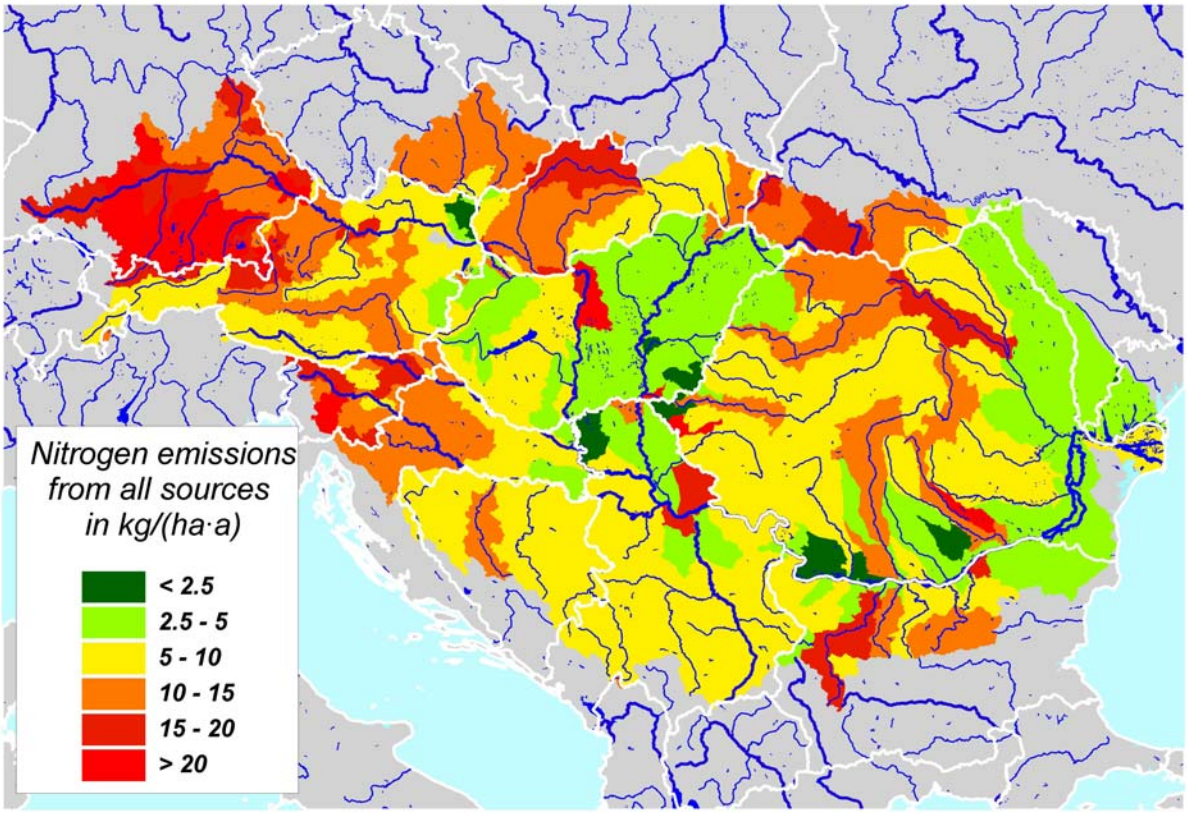


Figure 14: Nitrogen emissions from all sources (surface runoff, erosion, groundwater, tile drainage, atmospheric deposition, point discharges and urban areas) within the subcatchments of the Danube in the time period 1998-2000.

For the present state (period 1998-2000) the model result was that a total of 756 kt/y nitrogen (N) and 68 kt/y phosphorus (P) are emitted by the different pathways. 77 % of N-emissions and 53 % of P-emissions come from diffuse sources (Figure 15). The dominant pathway is groundwater for N-emissions and point source discharges for P-emissions with 43 % and 47 %, respectively. The regionalized analysis facilitates the identification of spatial hot spots for the individual emission pathways. Calculations performed for background conditions have shown that the nutrient emissions were approx. 6 kt/y P and 60 kt/y N. Consequently, the human impact is about 10 times higher than the background for P and 12 times higher for N. 32 % and 46 % of the total P and N-emissions were due to agricultural activities. Urban settlements are responsible for 54 % P and 29 % N (see Figure 17 and 18). An overview on the regional distribution of the nutrient emissions into the Danube river system is given for all N-sources in Figure 14.

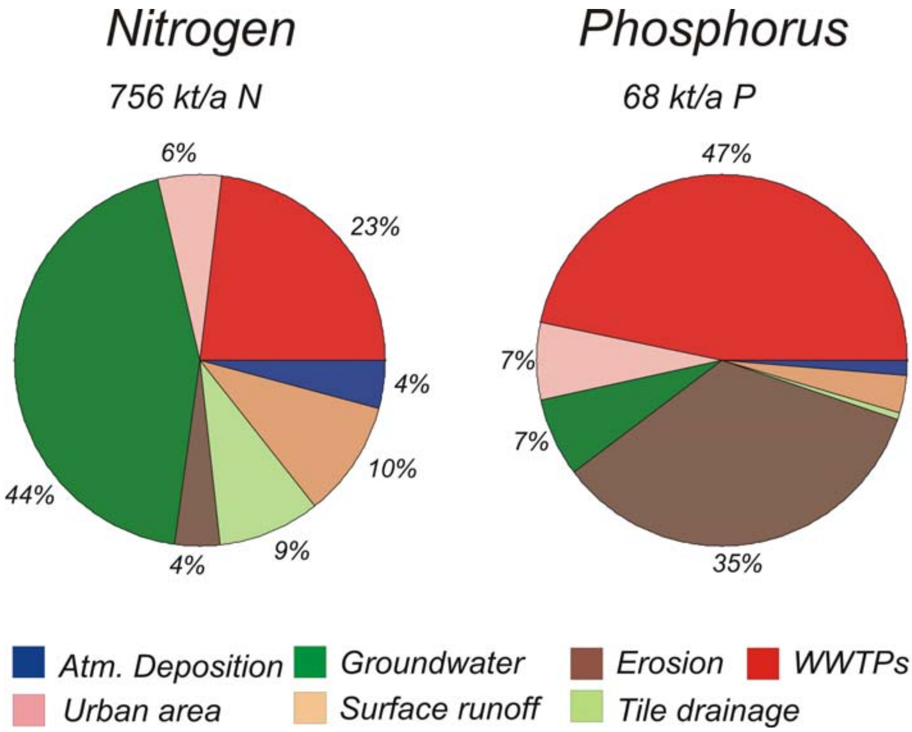


Figure 15: Nutrient emissions from different diffuse pathways and point sources for the total Danube in the time period 1998-2000.

As shown in Figure 3 the model calculates on the base of the investigated 388 subcatchments also the sum of the nutrient emissions for the individual Danube countries as well as aggregated results for the larger subbasins. The figure illustrates that the total nitrogen emissions into the subcatchments of the Danube vary in a very wide range depending on the intensities of landuse as well as the different hydrological and hydrogeological conditions. From the comparison of the portion of the human sources and background to the total nutrient emissions the major fields for possible further measures can be derived for the different levels of aggregation.

Figure 16 and Figure 17 demonstrate that the share of the different sources within the country parts of the Danube differ in a wide range. It is obviously that these differences result in different major task for possible reductions of the nutrient emissions in the countries. The high portion of the P-emissions from urban settlements for all countries with exception of Germany and Austria indicates that a further improvement of waste water treatment would bring further significant reduction of the total P-emissions into the Danube. For nitrogen it was found out (Figure 16) that agricultural emissions are the main source of emissions for all countries with exception of Hungary, Serbia and Montenegro and Bosnia and Herzegovina.

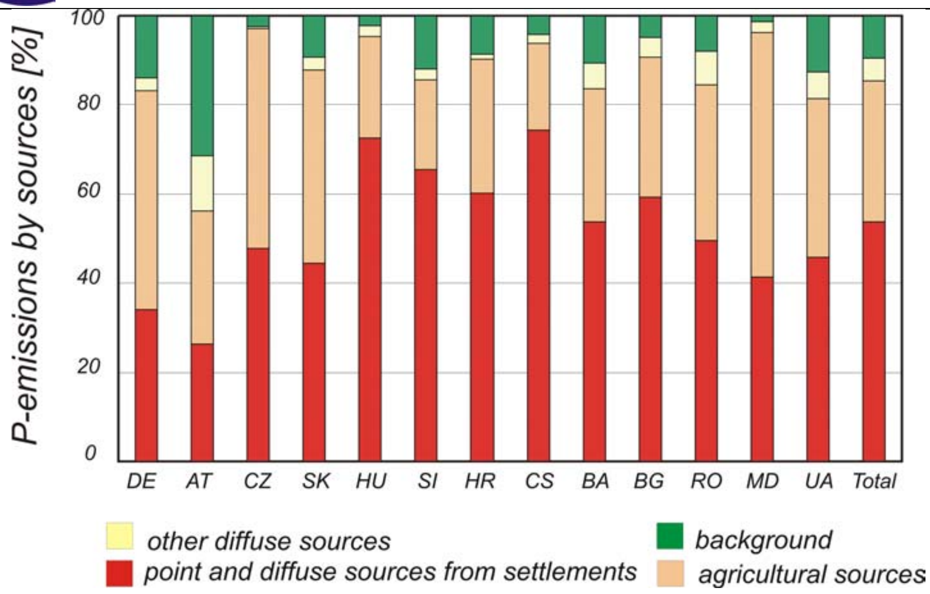


Figure 16: Phosphorus from human sources and natural background into the Danube area of the different countries in the time period 1998-2000.

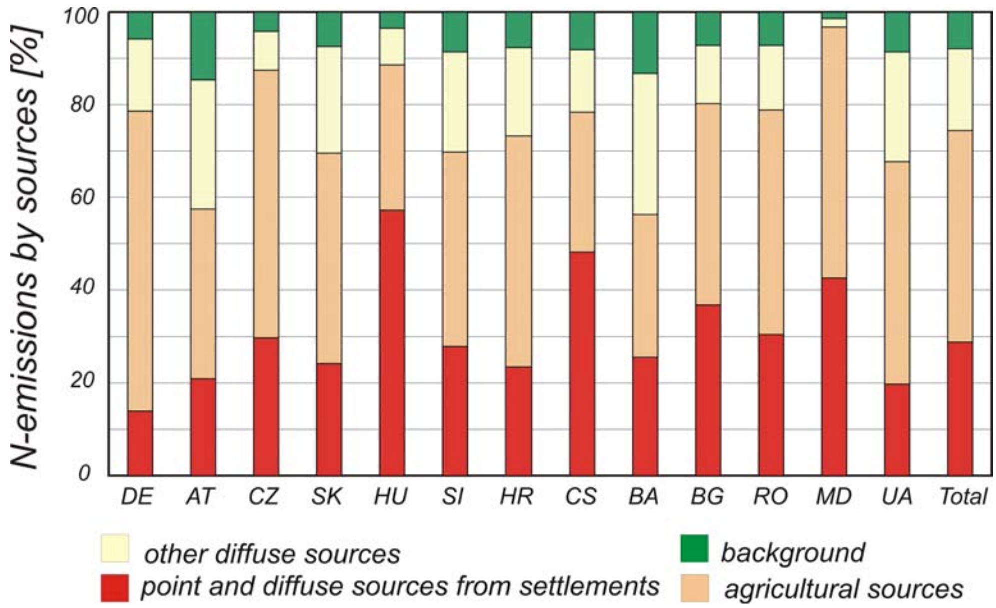


Figure 17: Nitrogen from human sources and natural background into the Danube area of the different countries in the time period 1998-2000.

A historical look at the development of the Danube nutrient emissions from point and diffuse sources over the last 50 years has been prepared based on the results of the present state situation, and a reconstruction by means of the model MONERIS (Schreiber et al., 2005; Behrendt et al. 2005). According to Figure 18 the diffuse source pollution of nitrogen has approximalty doubled in the period from the 1950s to the mid of 1980s. In the 1990s this pollution was reduced by about 15% mainly due to the reduction of the land use intensities as represented by the N-surplus on agricultural areas. The reduction of the nitrogen surplus is much larger, especially for the countries in the middle and lower part of the Danube Basin, than the reduction of the diffuse nitrogen sources. This is due to the differences in the residence time in the groundwater and the different retention rates for nitrogen in the unsaturated zone and in the groundwater. The large residence times in the groundwater are responsible for the fact that a further reduction of the diffuse nitrogen emissions can be assumed in the next years if the N-surplus will remain on the present level.

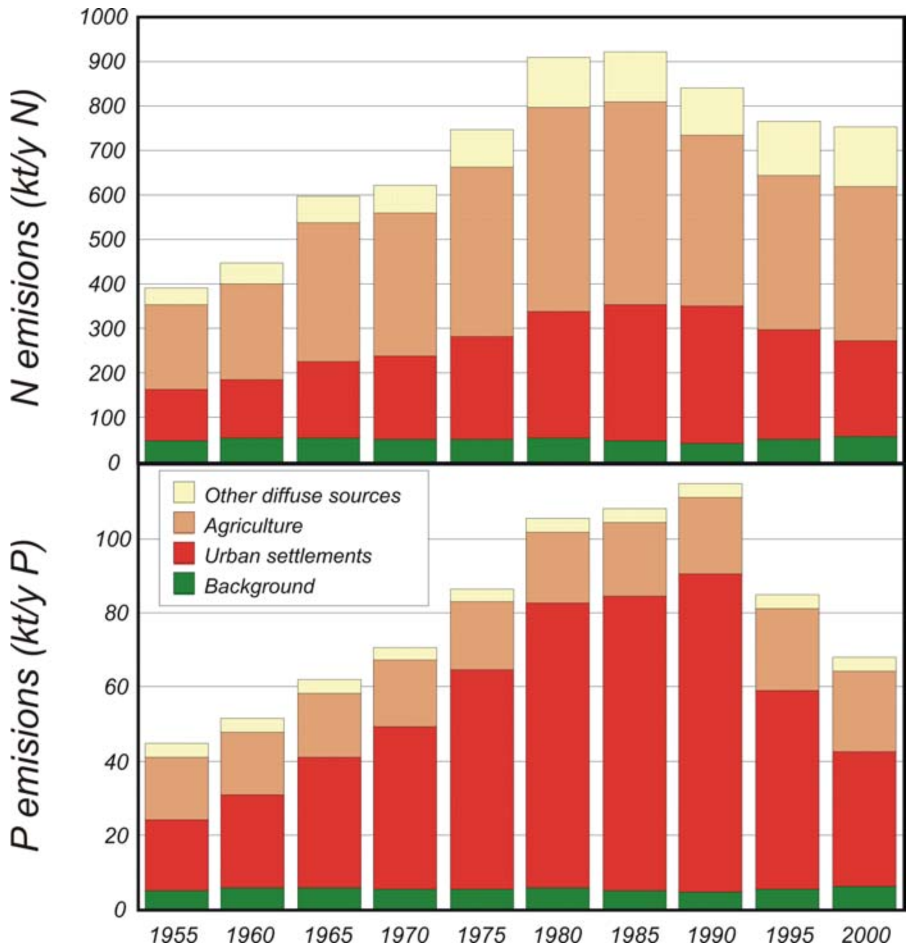


Figure 18: Changes of nitrogen and phosphorus emissions into the river system of the Danube from 1955 to 2000

The present level of the diffuse nitrogen emissions into the Danube river system is about 1.8 times higher than in the 1950s. Another reason for the change of the total nitrogen emissions is the change of the point source discharges and the discharges of people which are connected to sewerage but not to WWTP`s. The increase from the 1950s to the end of the 1980s is approximately a factor 4 and the decrease within the 1990s is about 30%. This is due to a decrease in the number of industrial discharges in the lower Danube countries after the political changes and substantial improvement of waste water treatment especially in Germany and Austria. For total N-emissions, it was found that the present state is a factor of 2.2 higher than in the 1950s but about 20 % lower than in the late 1980s.

For phosphorus the changes in the amount of diffuse source pollution are much lower than for nitrogen. This is because other pathways (erosion and surface runoff) are more important for the diffuse P-emissions into the river system. In addition, the main indicators for the diffuse P emissions as a portion of arable land were changed in the past to a lesser extent than the N-surplus. Further it should be noted that important parameters for changes of diffuse P-emissions by erosion over time, such as the change of the field size in the different regions of the Danube basin, are not available up to now. If these uncertainties in the database and for the modelling are taken into account, the present level of diffuse P emissions into the Danube river system is more than 10 % above the level of the 1950s.

For phosphorous it was found that changes in the amount of discharges from point sources and people connected to sewerage but not to WWTP`s are much higher than for the diffuse sources. An increase by a factor of 7.2 was indicated from the 1950s to 1990 for point sources. This development in the amounts of P from point sources is the result of two overlapping effects - increase of the use of P in detergents and an increase in connection of population to sewers and WWTPs. The decrease of the point P emissions is due to the replacement of P in detergents to a high proportion, the increase of P elimination in WWTPs and the closing of industrial and agricultural point sources in the lower part of the Danube Basin. The consequence is that the reduction of point P emissions is more than 60%. The present level in the upper Danube is in the range of the 1950s. The change of the total P emissions is larger than for nitrogen. A reduction of about 40% during the 1990s was estimated. In relation to the 1950s the present total P emissions are 2.4 times higher.

The reconstruction of the historical changes of the sources of nutrient pollution in the Danube shows that in the last decade a substantial reduction of nutrient pollution was reached in the Danube. Longterm data for the observed nutrient loads was available for 7 different stations in the Danube and its main tributaries. If the calculated and observed loads are compared to each other over all investigated time periods a mean deviation of 12 % for dissolved inorganic nitrogen and 22% for total phosphorus can be found. These deviations are smaller than the differences found for the period 1998 to 2000 for all 92 stations within the Danube river system. The reason is that all 7 stations with longterm load data represent larger catchments with a size between 40.000 and 800.000 km² for which the calculated as well as the observed loads have lower ranges of uncertainties than for smaller catchments.

The Figure 19 and Figure 20 shows the comparison of the measured and calculated nutrient loads for the stations at Jochenstein (German-Austrian border), upstream Sava (sum of the last Hungarian stations in the Danube, Drava and Tiza) and the station Reni the last monitoring station upstream of the Danube Delta. For the two upstream stations long term monitoring data were available back to the begin of 1970s (DIN) and 1980s (TP). The figures illustrate that the model is able to describe the load changes within the considered time period. Large deviations occur only for the DIN load at Jochenstein for the period around 1970 and for phosphorus in the last investigated time period for the station upstream Sava. For the station Reni data on observed load was available only for the last three time periods (van Gils et al., 2004) but also for the 1950's and 1960's Almazow (1961). For nitrogen the increase of the loads in the 1950's and 1960's and the changes since the early 1990's are calculated similar to the observation. A characteristic of the longterm nitrogen load is that it is influenced strongly by the discharges. Therefore lower N emissions together with the highest observed discharges in the last investigated time period lead to an increase of the DIN load in comparison to the period around 1990 for which the lowest discharges were measured.

If the emissions and the loads are compared for phosphorus it is obvious that the changes of the load are much lower than the changes of the emissions. This is due to the construction of the Iron Gate reservoir in the early 1970's, where about one third of the P load into this reservoir is retained (see also following chapter). From the reconstruction of the historical changes of nutrient emissions and loads it can be concluded that the model is able to calculate the influence of changed human activities on the nutrient emissions and loads in the Danube river system, therefore we can assume that the model is also able to implement scenario calculations where the measures are approximately in the same range than the variations of human activities in the past.

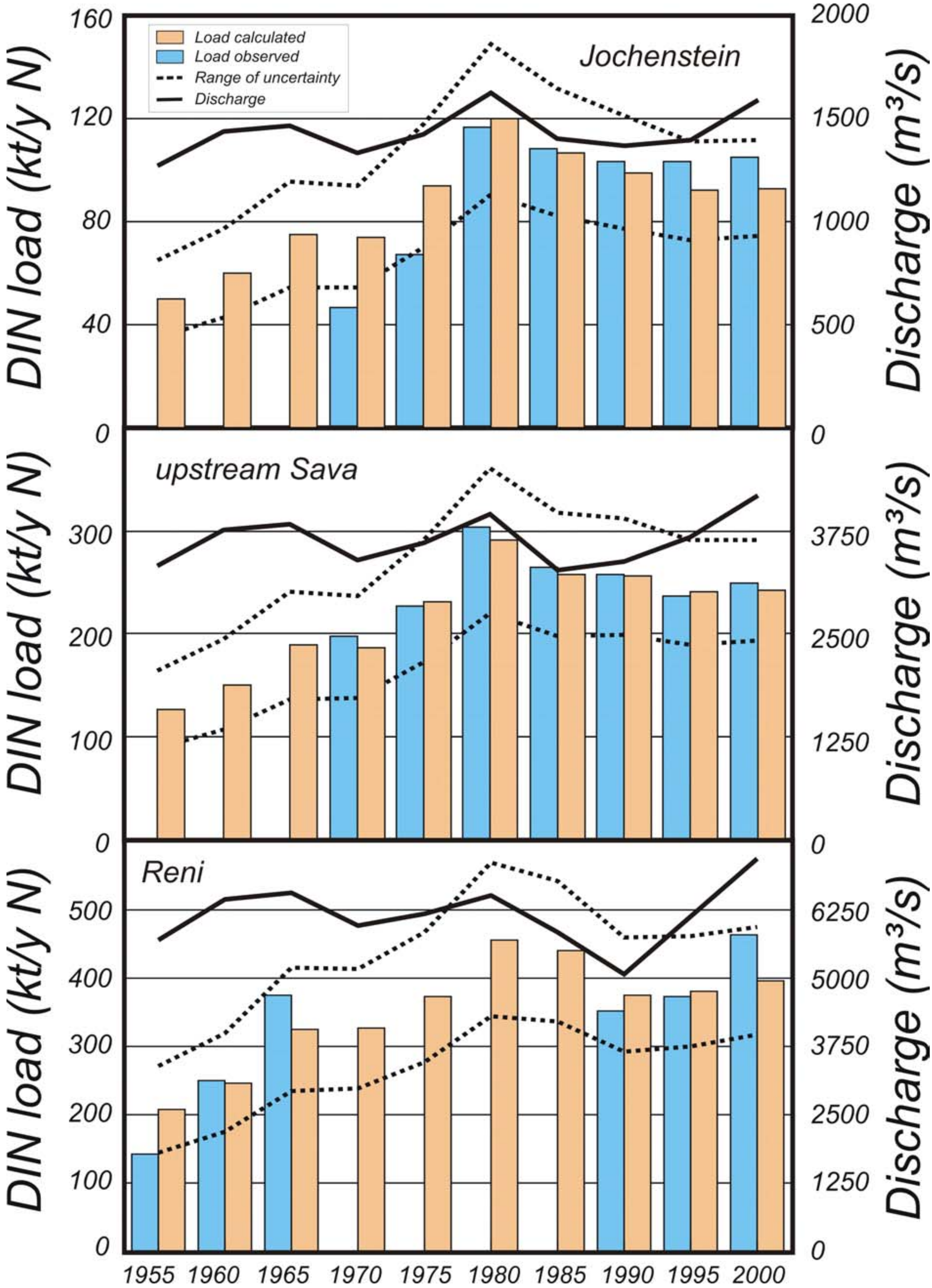


Figure 19: **Temporal changes of observed and calculated loads of dissolved inorganic nitrogen (DIN) in the Danube at the station Jochenstein upstream Sava and Reni.**

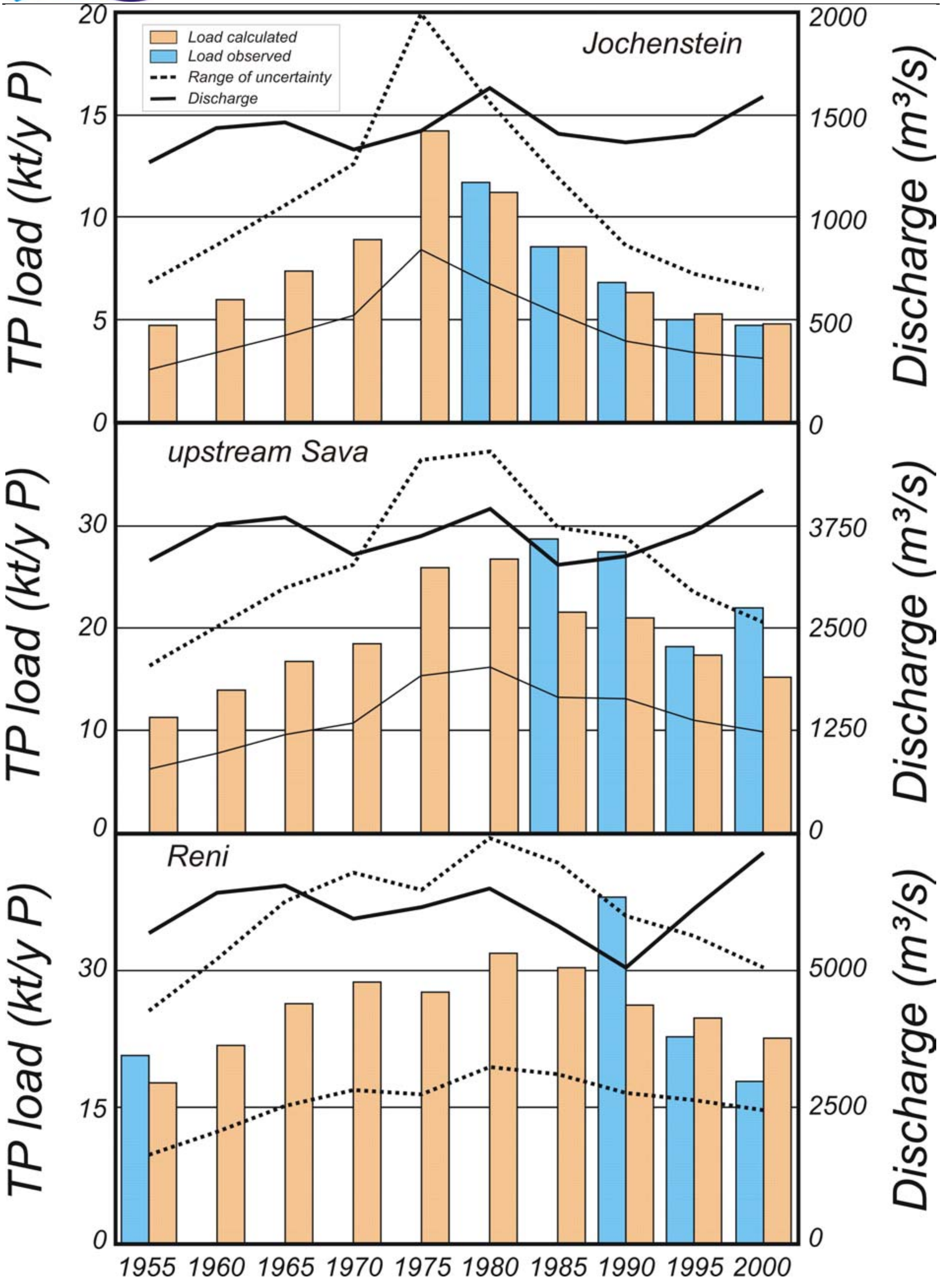


Figure 20: Temporal changes of observed and calculated loads of total phosphorus (TP) in the Danube at the station Jochenstein, upstream Sava and Reni.

3.3.2.2. Transport, Transformation and Retention in River Danube and its Main Tributaries

General

Once the emitted nutrients reach the surface waters, they are subject to transport, transformation and retention processes. There is a strong interaction between these processes. The retained fraction of nutrients is not transported downstream (and vice versa), while retention processes only act on certain forms (species) of nutrients, which are produced and/or consumed by different transformation processes. In this paragraph we will first discuss the different nutrient species and transformation processes, in relation to retention processes. Following that analysis, we will discuss the quantification of retention processes, and consequently the quantification of the downstream transport and the resulting river loads. It should be noted that *retention* is not an accurate term. Under retention we comprise: (a) *losses*: nutrients are permanently removed from the hydrosphere, and (b) *storage*: nutrients are (semi-)permanently immobilised, for example in river sediments. For practical reasons, the term retention is nevertheless used in the present section.

The results presented in this section are based on general knowledge of riverine systems, as much as possible supported and validated by field data from the Danube Basin. Due to the large spatial coverage, the Transnational Monitoring Network (TNMN) operated by 13 Danube countries under the umbrella of the ICPDR is the most important data set. At the end of the section we will evaluate the available data and formulate recommendations for future monitoring.

Unless it is mentioned otherwise, we discuss nitrogen, phosphorus and silica in terms of their total concentration, which is the sum of all nutrient species in both the dissolved and the particulate phase. Calculated or estimated nutrient fractions being transported or retained should be related to the total nutrient pools.

Fate of nitrogen, phosphorus and silica in the Danube Basin surface waters

There are three key driving forces for the fate of nitrogen (N), phosphorus (P) and silica (Si) in the Danube Basin surface waters: (i) the downstream transport of *dissolved* nutrient species, (ii) the dynamics of *fine particles*[1] in the river system, and (iii) the production of *phytoplankton*. The transport of dissolved species is controlled by the river hydrology, which shows a large variation especially in the smaller rivers, between periods of high flows and low residence time and periods of low flow and high residence time. The available data are sufficient to quantify these phenomena.

The *dynamics of fine particles* are also controlled by the river hydrology. During low flow periods, the suspended solids may settle to the bottom, where they may remain semi-permanently or may be washed out with the next flood. There is net sedimentation and permanent storage of particles in certain sections of the rivers, e.g. in the floodplains, in wetlands and in reservoirs. Unfortunately, the available data are not sufficient to quantify the dynamics of fine sediments on a basin-wide scale. The available data from different sources about the annual river load of suspended sediments are contradictory. This may well be caused by the fact that not all data sets sample frequently enough to capture high flow events. Due to the strongly elevated concentrations of suspended solids during high flow events, such events contribute more than proportionally to the annual river load.

[1] "Fine particles" are defined in line with the definition used in the TNMN as particles with a diameter smaller than 63 μm.

Dissolved inorganic nutrients are affected by the growth of *phytoplankton (algae)*. This creates live particulate organic matter containing nutrients, and forms the basis for the aquatic food chain. Excess dead organic matter from the food chain is recycled to the dissolved inorganic nutrient forms by biochemical processes. The uptake of nutrients by phytoplankton shows a seasonal variation governed by the availability of light and by the water temperature: the process is virtually absent in winter and proceeds at its maximum rate in the summer. The particulate organic forms created by phytoplankton growth behave to some extent like fine sediments and may be (semi-) permanently stored in the river sediments.

N, P and Si interact each in their own way with the drivers discussed above. For *nitrogen*, the dissolved species are dominating. On average and on a basin-wide scale, the interaction with fine sediments and the impact from phytoplankton growth are of limited importance. Exceptions are the transport of substantial amounts of particulate N during flood events, and the formation of high amounts of organic N during phytoplankton blooms. Unexpectedly, we found that Dissolved Organic Nitrogen (DON) forms a relevant part of the dissolved nitrogen in the River Danube. Many riverine data sets include only Dissolved Inorganic Nitrogen (DIN), which is supposed to be representative for total nitrogen. This could be misleading in the Danube case: the DIN mass balance probably presents a slightly biased image of the total nitrogen mass balance. Going in a downstream direction, an increasing part of the river load seems to be present in the form of DON. However, we have not been able to quantify the role of DON due to a lack of consistent data.

Retention of nitrogen is mainly the result of denitrification. The denitrification process is a loss process, which takes place in the ground water and in the river sediment. It is driven by the oxidation of organic carbon when dissolved oxygen is no longer available as an oxidiser and nitrates take over this role. As a result N_2 (and to some extent N_2O) escapes to the atmosphere.

For *phosphorus*, the dissolved species are relevant, but its fate is also strongly determined by particulate inorganic phosphorus (phosphates sorbed to particles or P-containing clay minerals). On average and on a basin-wide scale, the impact from phytoplankton growth is of limited importance. Exceptions are the formation of high amounts of organic P during phytoplankton blooms. The bio-availability of the different phosphorus species under the conditions typical for the Danube River is at present not known.

The fate of phosphorus is strongly linked with the fate of fine particles. Retention is mainly the result of storage of such particles in river sediments. This storage is permanent in areas of net sedimentation, in particular in the river floodplains, wetlands and reservoirs.

We have not discussed *silica* thus far. This is because anthropogenic sources contribute less than 10% to the emissions of dissolved silica to the surface water (Lampert, 2005). For this reason, silica was left out of the emission assessment in daNUbs. The "natural emissions" of silica are the result of leaching of Si from rocks and soils by hydrogeochemical processes. The only available older data regarding the Danube River silica load indicate that these natural emissions may have decreased substantially since the 1950s (typically by a factor of 2). Recent research in Scandinavian rivers, points at the role of damming of headwaters in reducing the leaching of silica, although the mechanisms are not yet fully understood.

With respect to the fate of silica in the surface waters, again the dissolved species are relevant. The role of inorganic silica in particles is unknown, but the available data do not suggest that in-stream dissolution of silica from clay particles is a relevant process. The impact from phytoplankton growth on dissolved silica is very strong. Diatom blooms are able to convert all available dissolved Si to organic forms ("biogenic silica") over a period of a few days only. In sedimentation areas, this may result in semi-permanent storage of silica in river sediments. The re-dissolution of biogenic Si is a relatively slow process, especially in the sediments. For this reason, there is a net removal of dissolved Si from the Danube Basin surface waters. The available data do not allow us to determine whether the removed silica is stored in the river sediments or transported downstream unnoticed in particulate form. We have been able to demonstrate that the removal of dissolved silica by algae blooms in the surface waters (reservoirs) is not responsible for a significant reduction of the riverine silica loads since the 1950s.

Modelling transport and retention

The daNUbs project has made a dedicated effort to model the transport, transformation and retention of nutrients on the scale of the Danube Basin. Figure 21 provides an overview of the assessment method, starting from the nutrient emissions to the surface waters up to the transport of nutrients towards the Black Sea.

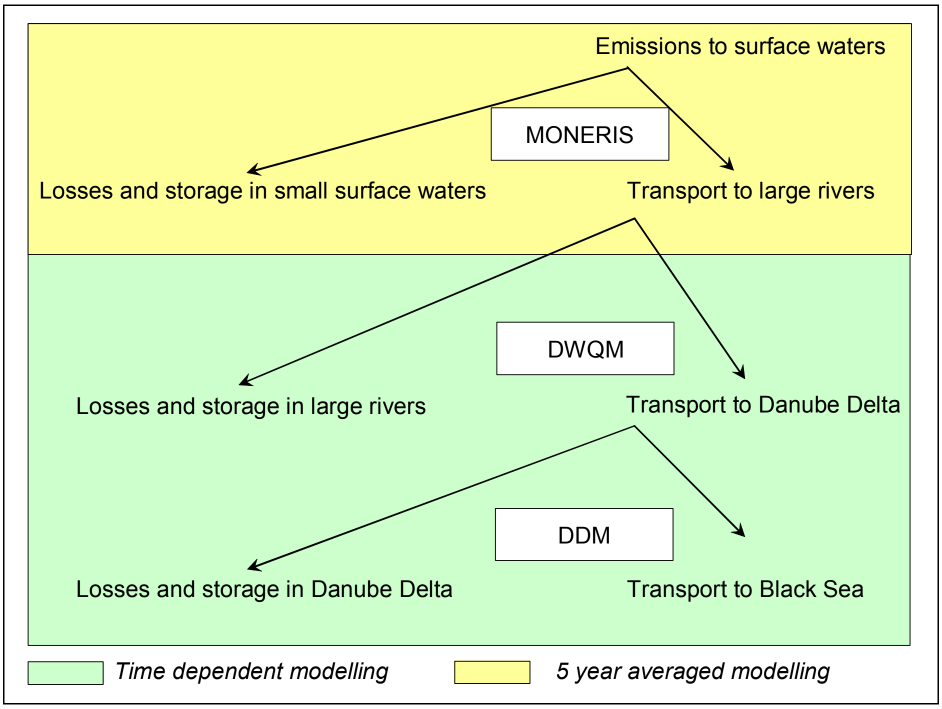


Figure 21: Overview of impact assessment on emissions and river loads.

The first step in the quantitative assessment is carried out by the model MONERIS. The model calculates the yearly averaged nutrient emissions to the surface waters, distributed over different pathways. Furthermore, MONERIS calculates the losses and storage of nutrients in the network of smaller rivers and lakes. The remaining nutrients are transported towards the large rivers. This assessment is again carried out on a yearly averaged basis. The Danube Water Quality Model (DWQM) calculates the in-stream nutrient loads and the storage and losses in the Danube River and its main tributaries. To do so, it disaggregates the yearly averaged fluxes calculated by MONERIS to daily concentrations, and it disaggregates the total nutrients to the different species in the aquatic nutrient cycles. Eventually, it calculates the nutrient fluxes towards the Danube Delta. The Danube Delta Model (DDM) has the specific objective to quantify storage and losses of nutrients in the Danube Delta as well as the resulting fluxes towards the Black Sea. Like the DWQM, the DDM calculates daily varying concentrations and considers the different nutrient species separately. Further details about the state variables and processes distinguished in the DWQM and the DDM are included in Section 3.2.

Retention in the ground water and smaller surface waters

While calculating the emissions of nutrients to the surface water, MONERIS already takes into account the loss of nitrogen in the soil and ground water mainly due to denitrification. The amount of the retention of nitrogen in the soil and groundwater is dependent on the level of the nitrogen surplus on agricultural land and the remaining catchment area, the hydrogeological characteristic of the catchment and the amount of leached water within the subcatchments. For the subcatchments of the Danube the retention in the soil and the groundwater varies between 62 (Sava) and 99 % (Delta Liman) (see figure 16). This retention is reduced if the agricultural land was drained artificially. Therefore the total retention in the pedosphere and lithosphere is lower for the subcatchment than the retention shown in figure 16 depending on the portion of artificial tile drained agricultural land.

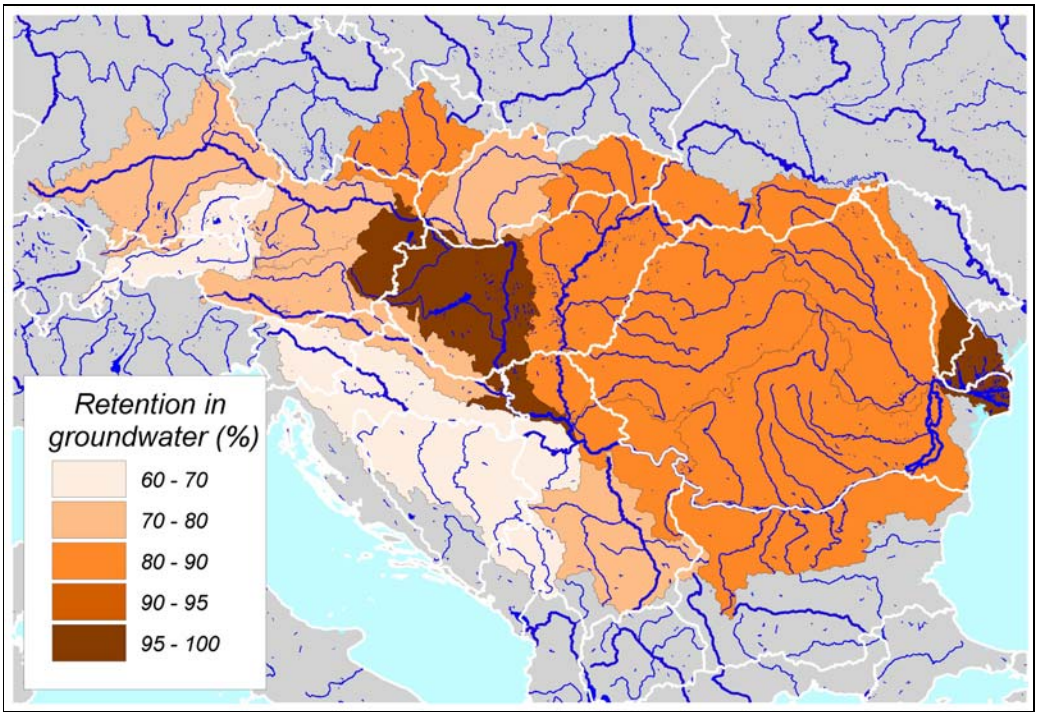


Figure 22: Typical distribution on sub-basin scale of the retention of nitrogen in the groundwater.

MONERIS also calculates the losses and storage of nutrients in the small rivers and lakes which are not explicitly included in the DWQM. This is done by empirical relations. For nitrogen, the “hydraulic load” is used as a factor to explain retention. The hydraulic load is defined as the runoff divided by the area of surface waters. This quantity reflects the nature of the major retention process denitrification: it represents the amount of water to be “purified” per square meter river sediment. For phosphorus, both the hydraulic load and the “specific runoff” are used as factors to explain retention. The specific runoff is defined as the runoff per unit of catchment area; it represents the degree of “flushing” of a certain area.

The calculated empirical retention factors for the 388 sub-catchments distinguished by MONERIS depend strongly on the abovementioned geohydrological parameters. The range of retention values is large. Figure 23 illustrates the range of variability of the nitrogen retention on the sub-basin scale.

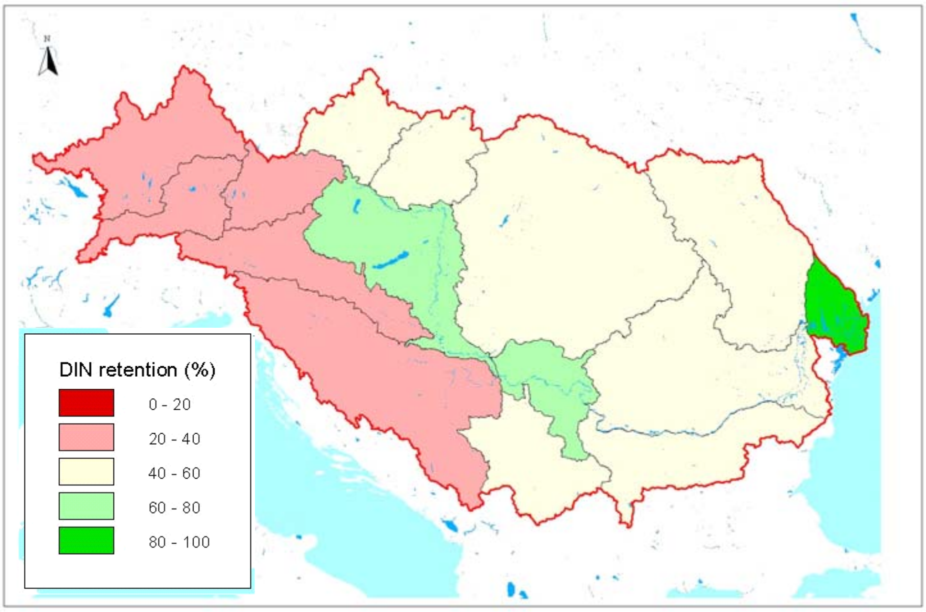


Figure 23: Typical distribution on sub-basin scale of the retention of nitrogen in the small scale surface water network.

The empirical retention formulas used do not include a dependency on the size of the catchment. Although this is theoretically incorrect, there is no practical problem. Apparently, the theoretical dependency of the retention on the catchment size is obscured by the much larger geographical variations.

Retention in the Danube River and its major tributaries

The retention mechanisms in the Danube River and its major tributaries are the same as those in the smaller surface waters. Due to the different hydraulic characteristics however, the relevance of the Danube River and its major tributaries is relatively small. The denitrification process is not as efficient as in the smaller surface waters, due to the large water depth and the high stream flow velocity of the major water courses. Its impact is too small to "see" it in view of the accuracy of the river load calculations. A similar argument holds for the storage of P in floodplains along the main rivers. For P there is an exception however: the backwater area of the Iron Gates I dam (downstream Beograd, km 1170 to km 935) forms an area of net sedimentation. The reservoir thus removes about 40% of the incoming river load of P. The dam was constructed in the late 1960s. The present net sedimentation can be considered part of the morphological adaptation of the system to its "new" man-made state. This process will last until the river cross-section has reached a new equilibrium with the flow conditions. This will not happen within the time frame considered in daNUbs (up to 2015). Eventually however, the Danube River loads of fine particles and P will increase due to reduced retention.

In the daNUbs project surveys were carried out in the autumn of 2002 which covered an extreme flood event in the Danube in Austria and Slovakia. Data were collected in Vienna during the whole event and downstream of Vienna in three places along the Gabcikovo reservoir (on the border between Slovakia and Hungary) during the first part of the event. The results of these surveys illustrated the great importance of flood events for the transport of fine sediments, phosphorus and organic nitrogen (see Figure 24). The total phosphorus load at Vienna during the survey period (8 August to 17 August) equalled 4.7 kt, while the average annual load at the TNMN station in Vienna-Nussdorf over the years 1997-2001 equals 8.5 kt. This clearly demonstrates that flood events contribute more than proportionally to the river load of phosphorus. A similar observation can be made for suspended solids.

The event also illustrated the role of floodplains as a sink for fine sediments and P. The estimated retention of fine sediments during the event in the floodplains of the old Danube bed parallel to the Gabcikovo PS Inlet Channel was 60%. Other surveys under normal flow conditions showed a retention in the order of 5%-15%. By means of data analysis including also data from other sources, we were able to demonstrate that this quite extreme event in the Upper Danube was rapidly “flattened out” further downstream. This suggests that the importance of such events on a basin-wide scale (in the larger rivers) is limited. This is supported by the fact that under the conditions covered in 1996-2001 by TNMN data, there is no significant point-by-point correlation between the river discharge and the concentration of suspended solids along the Danube River.

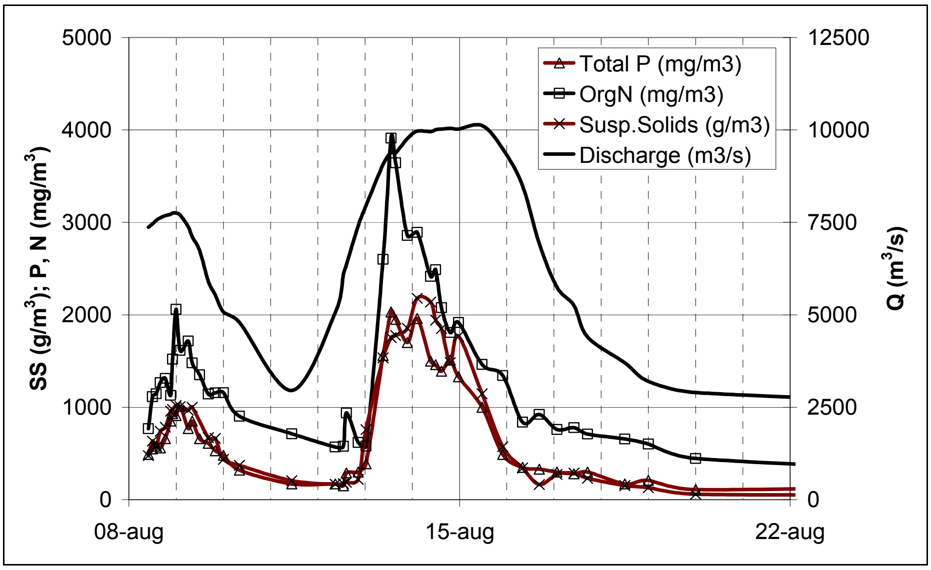


Figure 24 Observed river discharge and river concentrations of suspended solids, total P and organic N during the 2002 flood event at Vienna.

Retention in the Danube Delta

The impact of the Danube Delta on the Danube River loads is primarily determined by the hydrology of the Danube Delta. On average, more than 90% of the Danube waters cross the Danube Delta through the three main Danube branches Chilia, Sulina and Sf. Gheorghe (see Figure 25).

The water in the three major branches passes the Delta within 1 to 2 days, which means that in-stream processes can not cause significant losses and storage of nutrients. The water and nutrients entering the Delta aquatic complexes are strongly affected by loss and storage processes. According to simulations carried out with the Danube Delta Model, the annually averaged losses and storage amount to 3.1% of the incoming load of N and 2.4% of the incoming load of P. This implies that the Danube River loads are not significantly affected by the Danube Delta. Nevertheless, the nutrient losses and storage in the Danube Delta are taken into account in the calculation of nutrient transport towards the Black Sea. Even if the average impact of the Delta is small, there is considerable variation over the year: the momentaneous impact of the Delta various between 25% retention and 15% remobilisation.

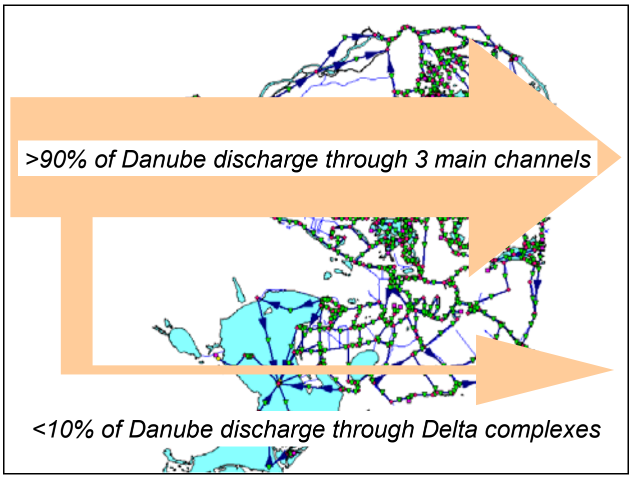


Figure 25: Water balance of the Danube Delta

Overall balances of N, P and Si

The results of the assessment of transport, transformation and retention in the Danube Basin surface waters, as calculated by MONERIS, the DWQM and the DDM are listed in Table 5.

Table 5: Overall balances of N, P and Si.

	N (kt/y)	N (%)	P (kt/y)	P (%)	Si (kt/y)	Si (%)
Emissions	687	100	67.8	100	≈ 515	100
Retention "small waters"	236	34	36.1	53	≈ 105	≈ 20
Inflow to DWQM	451	66	31.7	47	≈ 415	≈ 80
Retention in DWQM	16	2	7.6 (Iron Gates)	11	≈ 10	≈ 2
To delta	435	63	24.1	36	≈ 400	≈ 78
Retention in delta	13	2	0.6	1	≈ 5	≈ 1
To Black Sea	422	61	23.5	35	≈ 395	≈ 77

Table 5 clearly illustrates the important role of the smaller surface waters as compared to the major rivers and the Danube Delta. It is also clear that the total retention is quite different for the three nutrients: about 20% for Si, about 40% for N and more than 60% for P.

Data evaluation and recommendations for future water quality monitoring

From the data analysis we conclude that there is a lack of data or of understanding of the data for organic nitrogen, total phosphorus, the speciation of phosphorus, silica, chlorophyll-α, and the relation between the phosphorus and sediment dynamics. Furthermore, the consistency of data from different origins is in many cases problematic, which makes solid data analysis almost impossible. For this reason, model results had to be used for interpolation in time or space over sub-domains which were not covered by sufficient data or sufficiently accurate data.

On the basis of the research in daNUbs some recommendations were formulated towards future monitoring. The primary aim of these recommendations is support of the improvement Trans-National Monitoring Network (TNMN).

- Concerning the TNMN data sets, several water quality determinants, required by the monitoring program, pertaining to the nutrients are missing or partially available. To improve the reliability of future water quality characterization and load assessment it is important to collect all data required by the monitoring program at basin scale, together with those additional characteristics that are recommended below.
- The consistency of the TNMN data is managed by a Quality Assurance/Control programme. It is of the utmost importance that member states adhere to the agreed QC procedures, in order to maximise the consistency of the collected data.
- The results of the study on determination of the bio available phosphorus forms indicated that the particulate phosphorus and/or its particular fractions are an important part of phosphorus load. Therefore, analysis of the sediment (suspended solids) bounded phosphorus and/or its particular fractions (leachable with NH_4Cl, NaOH or HCl), should be included in the TNMN, or at least in related 'Special Surveys.'
- Nutrient retention (accumulation in the sediment and/or uptake by biota) could be studied in reservoirs in the frame of special studies to understand and describe accumulation, degradation and mobilisation processes. However, pollutant load calculations should be done in representative free-flow cross-sections along the river.
- The Danube transects (cross-sections) for load calculations should be selected on the basis of detailed preliminary surveys demonstrating cross-sectional variations in the concentration of the determinants as well as flow velocities, at low-, medium- and high-flow conditions. Based on this preliminary survey, the number and position of samplings should be defined. In general, three locations in the cross-section (left, middle, right), could be sufficient but one sample (from the middle of the river) of a well-mixed cross-section might be enough. The required number of samples may vary also according to the flow conditions (e.g. one sample could be appropriate at high flow but three samples in the cross-section would be needed at low water condition).
- As the load calculations on the basis of the TNMN data demonstrated significant uncertainty, it would be important to ensure the collection/analysis of a minimum of 24 samples per year, preferably 52, in the frame of the TNMN.
- The possibility to use systems for continuous observation of the water quality in order to arrive at accurate load estimates should be investigated.
- In addition to the recommendations above, pertaining to the upgrading of the TNMN, the implementation of "Special Surveys" should be encouraged.
    - Additional sampling during flood events would improve the load calculation of pollutants, e.g. nutrients (total-N and total-P), as the loads could be significantly different during flood periods,
- A survey type (once in four year) should combine sediment and pore water analysis in sedimentation zones of the Danube.

3.3.2.3. Tracing Danube Influence in the Western Black Sea

The Danube influence in the Western Black Sea is expressed both in variability of the abiotic environmental characteristics (specific hydrophysical and hydrochemical conditions) and qualitative/quantitative structure of a biota, which presents the most productive part of the living Black Sea. A methodology that consists of in-situ, satellite observations and numerical models has been developed in order to study the transport of the Danube induced by low salinity waters and the influence of the Danube nutrient load on the coastal ecosystem. The in-situ observations in 2001-2004 include daily measurements of nutrient loads at Sulina, weekly complex observations at Constanta, monthly or seasonal routine monitoring at 1 to 8 transects – 31 cruises (R/V NIMRD-Constanta, R/V IFA-Varna), R/V Aegeo in September 2002 and R/V Poseidon in September 2004 cruises. Daily satellite data for the period 1998-2003 were evaluated.

The Black Sea coupled hydrodynamic and ecosystem models are presented in section 3.2: the hydrodynamic Princeton Ocean Model (POM), modified to successfully simulate river plume dynamics; and the ecosystem models: (a) the low-trophic (POM-BIO) and (b) the complex European Regional Seas Ecosystem Model (ERSEM). The atmospheric inputs are of outmost importance on continental shelf dynamics and the Black Sea models have included all relevant air-sea interaction processes: changes due to wind, heat fluxes (solar radiation) and salt fluxes (evaporation, precipitation). Other important circulation forcing mechanisms that influence transport in the western Black Sea shelf and have been incorporated into the hydrodynamic model are: (a) buoyancy, due to the river discharge (Danube, but also remote inputs from the rivers Dniestr, Dniepr and Bug); (b) Topographic controls: delta shape, bottom friction, inner-shelf slope and (c) interaction with the basin-wide circulation and in particular the Rim Current.

The comprehensive ecosystem model is a particular application of the ERSEM (European Regional Seas Ecosystem Model) in the Western Black Sea. This is a unique development in the framework of the daNUbs project, as ERSEM is coupled with the above mentioned hydrodynamic and low-trophic ecosystem models, which include river plume dynamics. Thus, ERSEM has been forced with water and nutrient inputs from the Danube River and computes distributions of ecosystem components that are largely influenced by the variability of these inputs, in the context of the prevailing hydrodynamic and biochemical processes. Another innovation of the current study is the application of ERSEM in a “box-model” representation, so that it represents the three-dimensional ecosystem variables. For ERSEM the resultant circulation and tracer patterns have been applied to boxes covering the Western Black Sea, so that each box covers 10 grid cells of the hydrodynamic model shown above.

Two types of simulations have been completed on the transport and fate of Danube waters and associated nutrients on the Western Black Sea shelf: (a) climatological (multi-year), in order to study the seasonal variability of the circulation and the typical transport pathways and nutrient uptakes; (b) target period (2002-2003) in order to reproduce the observed patterns (wp7 shipboard surveys and SeaWIFS measurements) and validate the models against in-situ and satellite data. The climatological simulations have utilized a perpetual year record of wind and air-sea fluxes, where high frequency anomalies have been superimposed. The target period simulation has employed realistic, high-frequency (6-hourly) wind and fluxes obtained from the Poseidon operational atmospheric model (provided by HCMR, Greece). The model simulations have utilized Danube River water and nutrient inputs calculated by the DDM model (see section 3.2): daily values on a long-term averaged record (1994-2001) for the climatological simulation and realistic daily values for the target period.

Satellite data evaluation and climatological model simulations concentrated mainly on seasonal variability. A major finding was that the amount of Danube river discharge and the direction and magnitude of the wind stress were the main factors that determined the formation and evolution of the Danube River plume and therefore the transport pathways of the Danube inputs. The plume was further modified by the topographic features around the delta. In general, during winter (December-February) the water column is well-mixed and the prevailing winds are strong and mostly downwelling favorable (from the North, Northeast) in the Danube area. The Danube plume is deepened and constrained near the coast and directed to the south. During summer, winds are much weaker, the water column is stratified and occasional southern winds enable the offshore advection of the low-salinity waters toward the East, Northeast.

Observations and modelling suggest that the pathways of the Danube River influenced waters through the Western Black Sea shelf exhibit strong seasonal and inter-annual variability. Monitoring data show that in winter the end of the Danube induced frontal area could be found 15-20 miles offshore to the east, while in spring and summer it would be up to 120 miles offshore. The influence of wind is particularly evident in the model computed surface salinity and nutrient distributions as well as on satellite measured chlorophyll. The influence of atmospheric fluxes is also important, especially the heat flux induced summer stratification, that allows the horizontal advection of the Danube induced low salinity / high nutrient waters, even in the presence of light winds. This is due to the fact that the riverine waters occupy the upper part of the stratified water column and they are exposed to enhanced wind influence.

Northerly and easterly winds (downwelling-favourable) press the low-salinity, eutrophic surface waters towards the coast, in an elongated, narrow band. The river influenced area is deepened vertically. The opposite takes place with southerlies and westerlies (upwelling-favourable) winds: offshore advection of riverine waters far towards the central western Black Sea, expansion of the plume width, reduction of the southward transport and of the vertical width of the plume layers.

In cases of strong Danube discharge, the effect of the winds is substantially weakened. For instance, satellite data from April 2001, show that easterly winds do not stop the offshore advection of Danube waters to the east, as they did efficiently during a period of low Danube discharge in July 2001. The upwelling phenomenon in the Western Black Sea often takes place in early summer, when the thermocline is not well established and the requested energy can be provided by wind. Then in several hours the water temperature can decrease by up to 10º C and the salinity increases up to 19.0 PSU, as often observed in June in the coastal areas. The upwelling events are usually of local character, rather small in scale – spatially up to 20-30 miles off the coast and temporarily a few days depending on the duration of the westerly winds.

The realistic model simulations (high frequency wind forcing and daily Danube water and nutrient discharge) covered the target period 2002-2003 - two years with different conditions in both river and wind stress inputs. The differences are particularly evident in the two summer periods, which were employed for the scenario-based calculations (see section 3.3.3.2). Summer of 2002 had high discharge and downwelling-favorable winds, while summer 2003 had low discharge and upwelling-favorable winds.

Examples of the summer season for the 2002-2003 model simulation, 8-day satellite data composites and wind velocity averages for the same periods are shown in Figure 26 - Figure 29. The 6-10 September 2002 period (taken as late summer conditions) is the duration of the extended R/V Aegeo survey that provided valuable data for model validation. The winds, averaged from 6-hourly values (source: HCMR operational “Poseidon” atmospheric model) are shown in Figure 4. There is a remarkable agreement in the salinity patterns and the model simulated phytoplankton (conversion to Chl-a assumed C/Chl-a=50 and C/N=6.625 ratios) was also successfully validated against in-situ data and SeaWifs Chl-a images The Danube influenced area is clearly identified in the SeaWifs Chl-a images and the model simulated phytoplankton, especially during summer when nutrient limitation is stronger and the Danube provides the main nutrient supply.

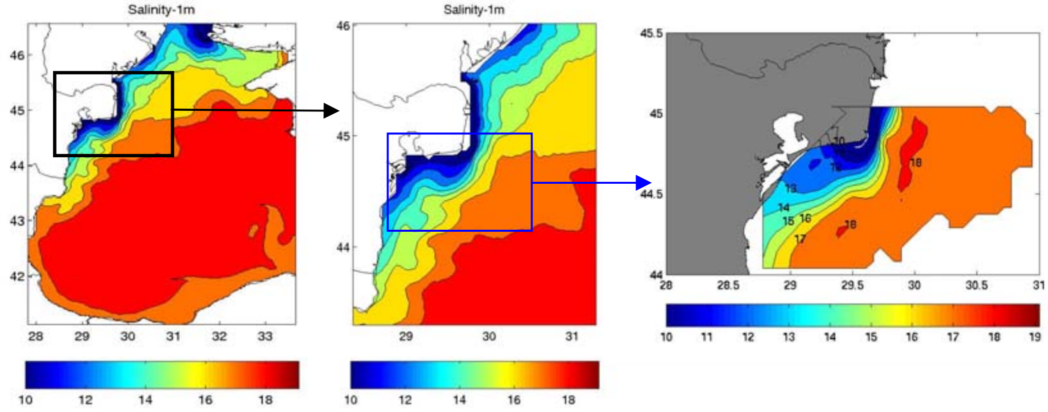


Figure 26: Model to data comparison (averaged over the cruise period of 6-10 September 2002). Left: model surface salinity for the western Black Sea. Middle: same, but zoomed in the data survey area. Right: the data survey surface salinity.

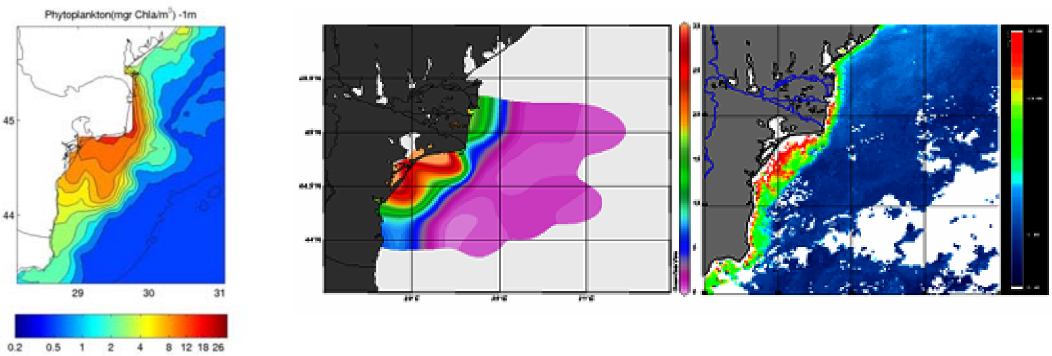


Figure 27: Model to data comparison (averaged over the cruise period of 6-10 September 2002). Left: model chlorophyll-a on the data survey area. Middle: data survey chlorophyll-a. Right: chlorophyll-a from satellite data.

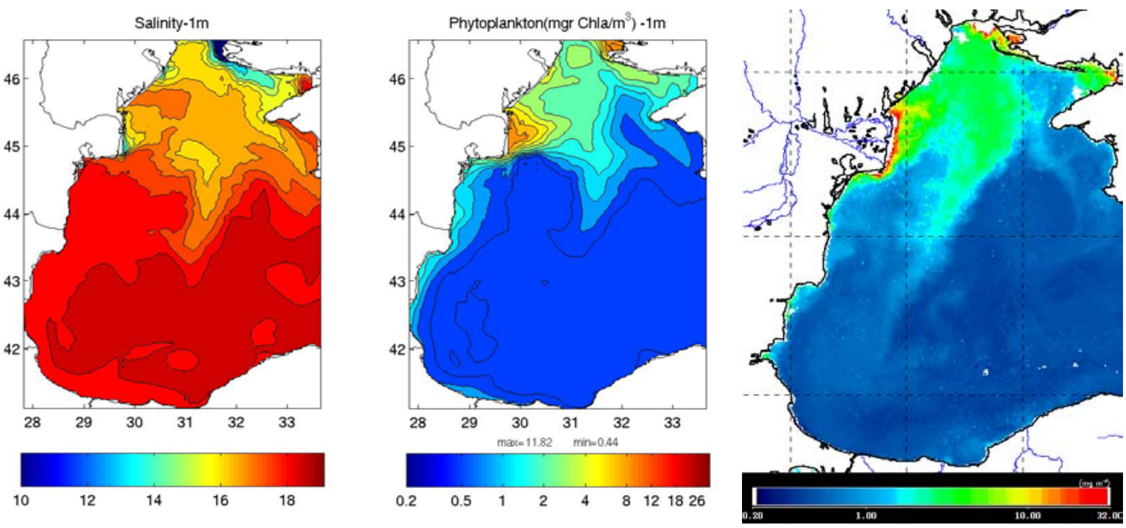


Figure 28: Model to data comparison (averaged over 8-12 July 2003). Left: model surface salinity for the western Black Sea. Middle: same, but for chlorophyll. Right: SEAWIFS chlorophyll.

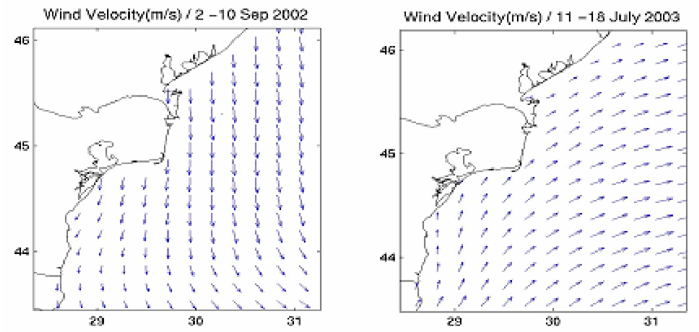


Figure 29: Wind velocity averaged over the periods 2-10 Sept. 2002 (northerlies) and 11-18 July 2003 (southwesterlies).

The sensitivity of the coupled model to changing Danube nutrient loads was demonstrated as well in the following simulations: the seasonal cycle of nutrients and biological variables in the Danube plume area (with salinity lower than 17 PSU) was predicted by the model for two periods (averages for 1980-1983 and 1990-1993), characterised by different level and seasonal dynamics of nutrient loads.

The response of the Western Black Sea to the Danube nutrient discharge during the target period (2002-2003) was also analyzed. Time evolution of key ecosystem variables in 2002 (Figure 30) was presented for the box off the Romanian coast and together with the related time series of the observational data, whenever available (2002 surveys); the data have been averaged in the model boxes for a more realistic comparison and the one-sigma (standard) deviations from the mean have also been plotted. Similar calculations were made for the coastal area off the Bulgarian coast.

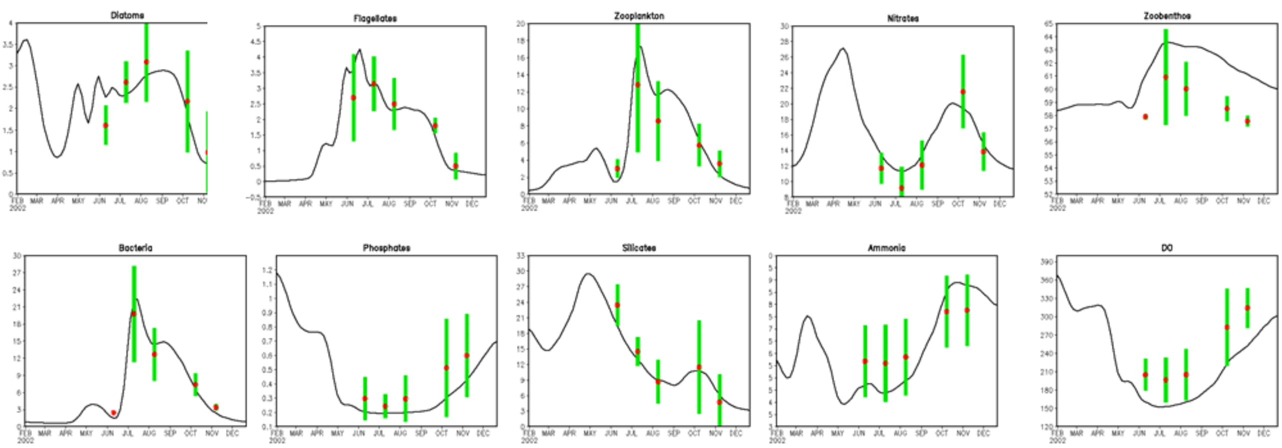


Figure 30: Time evolution of diatoms, flagellates (mgChla/m^3), total zooplankton(mg C/m^3), bacteria(mg C/m^{-3} x 10^{-3}), zoobenthos (mg C/m^3), and nitrates (mmol/m^3) for 2002. Full line- model simulations, for the box south of the Danube River plume (off the Romanian coastal area). Red symbols: data from observation, averaged for the corresponding box. Green lines standard deviation from the mean data value.

Model predictions clearly suggest that the unbalanced nutrient enrichment of the Black Sea in 2002 stimulates the diatom component of the phytoplankton community as long as phosphate is available. During periods of high N/P ratios, which was characteristic for 2003, mostly heterotrophic flagellates predominate over diatoms implying phosphorus limitation of the primary production in the Danube influenced waters.

Comparisons show a reasonable correlation between predictions and observations. Therefore, the ability to use realistic forcing and produce results that agree with data indicates that the applied models are suitable for simulating the response of the coastal ecosystem to changing nutrient loads.

Eutrophication-related effects under the Danube influence.

The Western Black Sea has a long history of change and decline associated with eutrophication influence. Since the early 1970s the eutrophication-related effects were many and diverse – harmful algal blooms, reduction of water transparency and oxyden diminution, decline in density of macroalgae and fouling of beaches with dead algae and foam, mass mortality of fish and shelfish, increase in density of species indicating that the Western Black Sea was replete with unutilized organic matter. At the end of the 1980-s we talked about decades needed for the Black Sea to recover, if at all possible. However, since the early 1990s the persistent reports about the irreversibly degrading Black Sea have started to disappear. Signs of relaxation in the evolution of the Sea were registered. Since 1995 decrease in nutrients concentrations, frequency and magnitude of phytoplanton blooms and decrease in number and duration of hypoxic or anoxic situations were found as a relatively stable tendency. The observed ecological status in 2001-2004 confirmed that the Western Black Sea was no longer a reference point for progressive water quality deterioration, though eutrophication-related effects were still present.

The Western Black Sea is highly heterogeneous, all parameters of sea waters vary not only in time but significantly also in space due to the different levels of Danube influence and local characteristics. Correspondingly, we observe different levels of eutrophication with decreasing tendency from the Danube Delta to the South (Table 6).

Table 6: Average values of nutrient concentrations (mg.m^{-3}) for the period 2001-2003 at Sulina (Danube waters), Constanta (Romanian nearshore waters) and in the Bay of Varna (Bulgarian waters nearby Cape Galata).

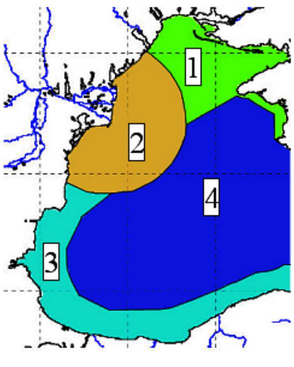
Area	Si-SiO4	P-PO4	N-NO2	N-NH4
Sulina	1795	56	63	146
Constanta	387	17	12	85
Bay of Varna	126	9	2.1	48

A first visible eutrophication-related effect in an aquatic ecosystem is the intense algal proliferation, causing misbalance with possible ultimate consequences - prolonged oxygen deficiency and mortality of macroalgae and benthic animals. The following regions of characteristic chlorophyll_a patterns (algal proliferation) related to Danube influence (especially to nutrient loads stemming to the Black Sea) were identified in the Western Black Sea (Figure 31):

1. Region 1 (26 000 km^2) north of latitude 45 N (R1), which covers the north-western shallow shelf area and which is influenced by the Danube at southerly winds and also by the rivers Dniester and Dnieper. In the northern part of R1, as a consequence of the input of nutrient rich river waters and due to the shallowness of the sea, high surface chlorophyll values can be observed throughout the year.
2. Region 2 (34 000 km^2) covers the area in front of the Danube delta (R2), which is directly affected by the river water and which is defined as an area within an orbit of 100 km radius around the Danube delta. Evidently, phytoplankton production processes in this region are strongly determined by the inflow of nutrient-rich river waters.

3. Region 3 (36 00 km^2) includes the coastal waters of the narrow shelf belt along the western, south-western and southern Black Sea coast (R3). The western shelf is influenced by Danube transformed waters, especially during high Danube inflow. The pathway of Danube transformed waters is mostly located in the area 3-20 miles offshore the Western coast of the Black Sea. The phytoplankton productivity in this region is also controlled by smaller inlets with respective nutrient sources and mixed by coastal winds and currents.
4. Region 4 (104 000 km^2) covers the central-offshore area of the western Black Sea including the Rim current and the Crimea-induced eddy street in the northern and north-western part (R4). The central part of the western Black Sea exhibits generally low surface chlorophyll, except eddy street, which is partly affected by pigment-rich waters from region 1 and 2 and partly by vertical nutrient transport as a consequence of fronts and eddies formation.

Due to strong advection in the western Black Sea, an overlapping of the borders of these regions must be considered.



1) R1 - North-western Shelf ;
2) R2 - Area of direct Danube river-water influence;
3) R3 - Western and southern Shelf ;
4) R4 - Central Western Black Sea.

Figure 31: Regions of characteristic chlorophyll a patterns and different level of Danube influence.

The levels of eutrophication in R1 and R2 are comparable, whereas R3 and R4 are characterized by lower values of nutrients and correlated phytoplankton standing stock.
Enhanced phytoplankton production in the Danube river plume (R2), mainly in the range of salinity 10-17.0 PSU, takes place during the whole year and shows a good correlation with the Danube river water and nutrient discharges. The Danube waters themselves do not transfer large amounts of living phytoplankton biomass into the Black Sea, where most of the freshwater algae do not survive (Bodeanu et all, 1998; Mihnea, 1997; Moncheva et al, 1999; Velikova et al, 1999).

For the period 2001-2003 a comparison between the directly Danube river influenced Romanian waters (RW) and indirectly influenced Bulgarian waters (BW) showed the following results:

- The Danube input as a main source of nitrate nitrogen and silica for the Western Black Sea is well demonstrated in the horizontal distribution of these parameters, showing much higher values in the vicinity of the river mouth in North Romanian waters and gradual decrease to the south parts of Bulgarian waters. The horizontal gradients of ammonia and phosphates are less expressed, however a similar decrease from North to South is observed.
- In 2001-2003 2-3-fold decrease in PO_4-P concentrations was observed both in Romanian and Bulgarian Black Sea waters in comparison with those of 1990s due to diminished riverine and land-based input of phosphorus. No significant change in silica loads

transferred with Danube waters into the Black Sea and concentrations of silica in RW and BW was found. In RW the level of nitrite and nitrate nitrogen was realitively stable since the early 1990s. Slight increase in ammonium nitrogen was recorded during the last years due to 20-40 % higher values of NH_4–N in April-December in comparison with the 1980s. In BW significant decrease in nitrate nitrogen was found in 2001-2003 in comparison with those of the 1990s and the total nitrogen predominantly consisted of ammonium and organic nitrogen. Evidencies for secondary eutrophication, related to mobilization of nutrients deposited in sediments, are being persistently discussed during the last years. Different authors suggest an increase in organic forms of nutrients in the Western Black Sea, however, the data is far from reliable yet and no results could be provided about temporal and spatial variability of organic nitrogen and phosphorus. However, some biological indicators support this idea – as increase in density of heterotrophic algal species and *Noctiluca scintillans*.

- The subaqueous part of the Danube delta is an important sink for riverine dissolved and biogenic particulate silica with an estimated long term biogenic silica storage of $9.1*10^9$ mole y^{-1} (55% of the total riverine dissolved Si + freshwater biogenic Si). The nearshore areas of high sediment accumulation store ~90% of the total buried biogenic Si in the Danube subaqueous delta.
- Approximately 47% of biogenic Silica buried in the the nearshore-high sedimentation rate areas of the Danube subaqueous delta is affected by transformation reactions after burial (i.e. precipitation of authigenic aluminosilicate coatings). In the case of the low sedimentation rate areas, 28% of the buried biogenic silica ha been transformed.
- Romanian waters are more affected by oxygen deficiency than Bulgarian waters. In both areas the oxygen regime improved considerably as compared to the 1970s and 1980s.
- In general, the concentrations of suspended matter and its inorganic part, decrease from Romanian to Bulgarian waters, whereas the share of organic matter increases with the distance from the Danube delta.
- The average values for transparency are about 1m higher along the Bulgarian coast than in the central and southern parts of Romanian waters.
- Overall, the density and biomass of bacterioplankton in Romanian waters are 3-fold higher than in Bulgarian waters. Since the early 1990s the bacterioplankton community in the Western Black Sea is in a relatively steady state.
- The phytoplankton biomass in Romanian waters is 2-3 fold higher than in Bulgarian waters, and the species composition is more diverse due to proliferation of fresh, brackish and marine water species, while in Bulgaria fresh water species are rare. In the whole Western Black Sea the annual average of algal biomass significantly has decreased since 1995 in comparison with the period of progressive eutrophication (1980s). In 2001-2003 the biomasses of algae in Bulgarian waters were in average 2-fold lower than in 1995-2000.
- The density and biomass of mesozooplankton in Romanian and Bulgarian waters are comparable, showing still a depression in the community. In both areas in 2001-2003 mass development of non-trophic species were observed. The similar level of zooplankton development, but different levels of primary production, indicates, that the excessive algal biomass in Romanian waters is much higher than in Bulgarian waters, correspondingly the level of eutrophication is higher, which is confirmed by the observed concentrations of nutrients and organic matter.
- In the benthic community the biomass is about the same in Romanian and Bulgarian waters, due to the recovery of *Mollusca* species (mussels) in both areas. However, the densities of *Polychaeta* species (eutrophication indicators) are much higher (up to 5-times) in Romanian waters. The recovery of the community in the Western Black Sea is mainly qualitative at present.

In order to estimate the impact of the Danube river on the Western Black Sea in terms of phytoplankton standing stock SeaWiFS satellite data from 1998 to 2003 were evaluated for the amount of chlorophyll in a region extending as a semi-circle (Figure 31, region 2) in front of the Danube delta. For this region the size of the eutrophic area was calculated (with annual mean chlorophyll > 1.4 mg m^{-3}, a threshold value calculated from the Central Western Black Sea (region R4) mean chlorophyll concentration and the standard deviation for the whole 5 years period (~95 % of the background values)). For the eutrophic conditions all pixels with values higher than the threshold and lower than 62 mg.m^{-3} (higher values exceed the algorithm's sensitivity) were used. The size of the eutrophic area was related to the Danube water discharge and the Danube River load of dissolved P This approach shows that Danube phosphate discharge is well correlated with the phytoplankton standing stock and indicates a considerable decrease over the last 6 years which was certainly also related to the decreasing water discharge rates. Except for 2001, when satellite-derived chlorophyll values were extraordinarily high for the entire Black Sea, the size of the high chlorophyll area within the river water-influenced region has also decreased (Figure 32).

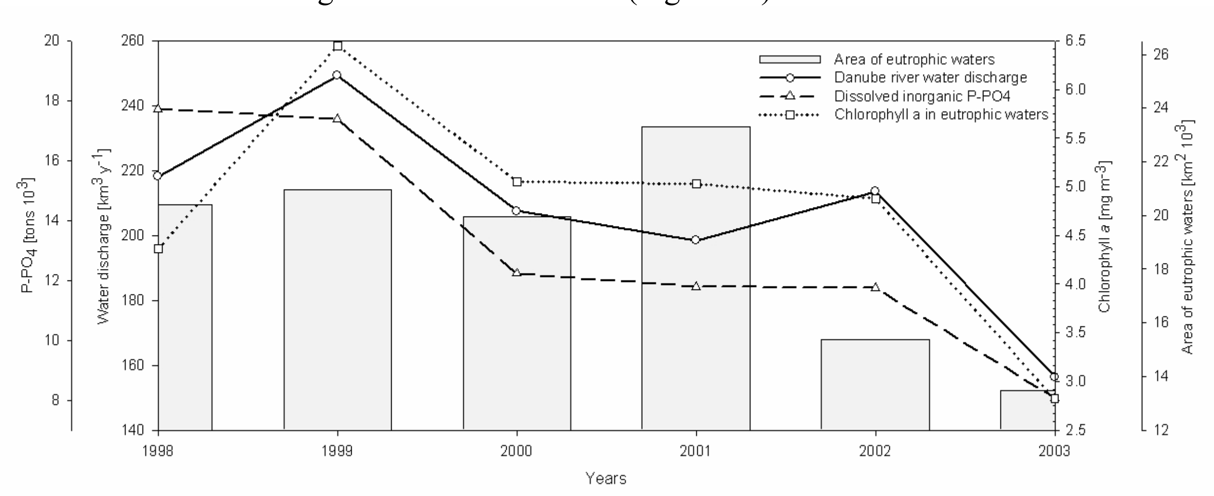


Figure 32: Correlation of satellite-derived chlorophyll data and areas of eutrophic waters (Chl_a >1.4 mg m^{-3}) off the Danube delta with Danube water and phosphorus discharge from 1998 to 2003.

In the region off the Danube delta the N/P ratios exceed 16 (Redfield ratio) at very low phosphate values throughout the year, when dissolved nitrogen species are still present. The latter supports the idea that phosphorus is the limiting factor for primary productivity in the region of direct Danube influence. In region 3 and Central Black Sea phosphate is often still present in the surface water when nitrogen values are extremely low or completely absent, which implies a nitrogen limitation for phytoplankton growth in this part.

3.3.2.4. Determination of Critical Loads for Danube Discharges to Western Black Sea

The determination of the amount of river borne nutrients, which can be disposed to a marine ecosystem without harm, requires a solid background knowledge about the system questioned. This includes the original state of the ecosystem before anthropogenic pollution, the kind of pollution in the river and its impact on the marine environment; the kind and extent of damage to the ecosystem under pollution stress, which in turn requires a definition of " harm to the ecosystem" as well as the size and location of the ecosystem.

In the Danube - Black Sea system some of these background informations exist due to the fact that there has been a strong increase in pollution since the early 1960s and a decrease in nutrient loads since the early 1990s, a period from which valuable data series and descriptions of the Black Sea ecosystem exist. In addition in the frame of the EU-daNUbs project, considerable knowledge of the source, kind and amount of riverine nutrients and of the status quo of the North-Western Black Sea shallow waters (here considered as the most sensitive part of the ecosystem) has been obtained.

With this information we can consider the Danube nutrient loads in the early 1960s as tolerable, because there was no reported damage to the N-W Black Sea shallow water ecosystem. However, we observed a considerable improvement in the N-W Black Sea shallow waters after the late 1990s (reduced dissolved nutrients off the Danube Delta, reduced phytoplankton blooms, strongly improved near bottom oxygen regime, considerable increase in benthic macro fauna). Finally in 2002 and 2004 we observed an extended recovery of epibenthic flora and fauna in the N-W Black Sea shallow waters which is a proof of the absence of long lasting anoxic conditions in this region. On the basis of the results in can be concluded that with the present nutrient loads the N-W Black Sea ecosystem is capable to recover.

When considering hypoxia and its consequences as the main hazard to the marine environment of the N-W Black Sea, phytoplankton biomass production is the determining factor. Phytoplankton primary productivity in the river water influenced eutrophic area off the Danube Delta since the late 1990s appears to be phosphorous limited. Consequently the phosphorous loads determine the "environmental quality" of this region. Therefore the present Danube phosphorous loads, which are of a similar magnitude as those of the late 1960s, may be considered as "tolerable loads" to be disposed for a sustainable N-W Black Sea environment.

However, there are several limitations as to this "statement": The Black Sea environment is subject to continuous alterations as abiotic and biotic factors are concerned. This includes e.g. global warming and atmospheric changes, introduction of foreign species or over fishing. These factors and their influence on the ecosystem and consequently on nutrient depending production processes can be hardly predicted.

3.3.3. Evaluation of Scenarios for Future Management

3.3.3.1. Introduction of Scenarios and Conditions

Recommendations for future management in the daNUbs project are based on the evaluation scenarios for future development. The basic concept of scenario evaluation is shown in Figure 33. Different scenarios were elaborated as bundle of (technical) measures. On the one hand these scenarios define the input of calculations of nutrient emissions, nutrient discharges to the Black Sea and effects of these nutrient discharges on the Western Black Sea ecosystem. These calculations were performed with a combination of the MONERIS-emission model, the Danube Water Quality Model (DWQM), the Danube Delta Model (DDM) and the Black Sea Models (chapter 3.3.3.2). On the other hand socio-economic evaluations of scenarios were also performed (chapter 3.3.3.3).

The term "scenario" within the daNUbs project is used for considered future developments in nutrient management practices. That means, scenarios consider changes consciously implemented by society. Effects of these measures are depended on different natural factors as well (e.g. catchment hydrology, wind conditions in the Black Sea). Different possible future situations for these natural factors have been also considered within the model calculations. To differentiate between "scenarios" for natural factors and "scenarios" as future measures, different assumptions for natural factors in the following will be called "conditions".

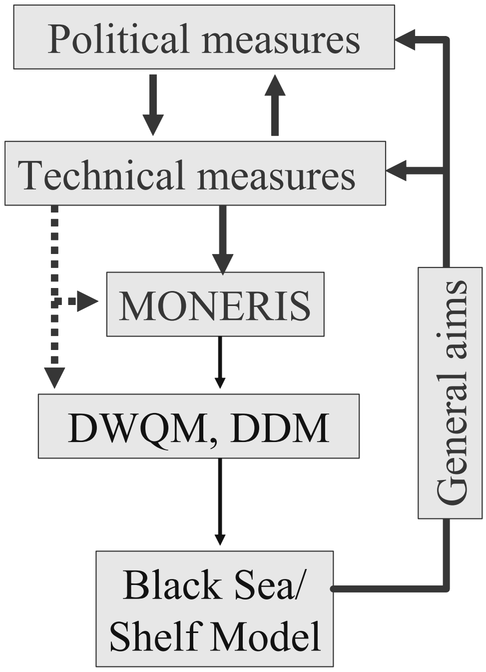


Figure 33: Basic concept of scenario evaluation

Five different scenarios have been developed. The time horizon for the implementation of the measures for these scenarios is the year 2015. The basic intentions of the scenarios are summarised in the following. Scenario 1 is the continuation of the present situation in waste water management and agricultural production (BAU, "Business as usual scenario"). Changes are only due to an expected change of population in the Danube Basin and long term effects of N retardation in soils and groundwater, which delay the effects of changes in agricultural practice on the emissions to surface waters. Scenario 2 describes a situation with a high agricultural productivity as it was the case in the 80ies in the whole Basin and a development in waste water management according to requirements of the EU-urban waste water directive (UWWD) for "normal areas" ("high production scenario"). Scenario 3 describes the same situation with application of best available practice in agriculture and requirements for "sensitive areas" in waste water treatment (BAT, "best available technique scenario"). Scenario 4 describes a situation where reduction measures especially in agriculture are further extended including restriction of animal production based on a minimum requirement to supply the local population with healthy nutrition (0,1 AU/(inh.a)) and to achieve an enhanced erosion abatement ("green scenario"). Scenario 5 describes a situation with an expected development in agriculture and a determination of treatment requirements in waste water treatment based on appropriate ambient water quality protection ("policy scenario").

In order to quantify effects of different scenarios on the emissions to surface waters and the discharge via Danube river to the Black Sea it is necessary to translate the assumptions into numerical parameters as input for emission modelling. The main input parameters for the MONERIS emission model and for calculation of the nitrogen surplus in agriculture as input parameter into MONERIS, that were varied between the different scenarios are presented in Table 7 as basin wide average. The following describes how different values for parameters in different scenarios were derived.

<u>Scenario assumptions population</u>

FOA statistics were used to demonstrate the actual situation (2000) of population and the distinction between urban and rural population (FAOSTAT data, 2004; http://faostat.fao.org/faostat/ collections?subset=agriculture). The values for scenarios 1-5 are forecasts for 2015 from the same reference. For countries which are only partly within the Danube Basin, it was assumed that the relations between urban and rural population and trends in population development in the Danube Basin are the same as for the whole country.

Table 7: Variation of input parameters for scenario calcualition

		2000	Sc1	Sc2	Sc3	Sc4	Sc5
Population total	10^6 inh.	82,1	77,2	77,2	77,2	77,2	77,2
Population urban	10^6 inh.	57,6	54,2	54,2	54,2	54,2	54,2
Population rural	10^6 inh.	24,5	23,0	23,0	23,0	23,0	23,0
Specific P-emissions	gP/(inh.d)	3,6	3,6	4,7	3,00	2,50	3,00
Connections to sewers	% of total inh	62	62	80	80	78	80
Connections to wwtp	% of total inh	47	47	80	80	78	80
Mechanical wwtp	% of total inh.	6	6	0	0	0	0
Biol. wwtp with C-removal	% of total inh.	21	21	56	17	16	39
Biol. wwtp with N,P removal	% of total inh	20	20	24	63	62	41
N-efficiency of treatment	% of inflow to wwtp	50	50	45	69	70	56
P-efficiency of treatment	% of inflow to wwtp	57	58	51	77	77	62
Animal density	AU/ha_{AA}	0,49	0,49	0,73	0,73	0,20	0,56
Animal density	AU/inh	0,24	0,24	0,38	0,38	0,10	0,28
Use of mineral fertilizer	$kgN/(ha_{AA}.a)$	33	33	65	48	25	44
N-efficiency of plant prod.*	%*	155	155	175	160	150	165
Surplus on agricultural area	kgN/(ha.a)	29	29	58	47	22	40
Reduction of tile drainage	% of drained area	0	0	0	20	20	10
NH3-N deposition reduction	% of Sc0	100	100	119	100	78	104
Erosion abatement**	% of arable land	0	0	0	50	100	0

* N input (fertiliser, deposition, N-fixation) in relation to N-in harvested crops
** Minimum tillage, mulch techniques, i.e. mulch seeding ; intercropping

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Scenario assumptions waste water management

The specific P-emissions to the sewers consist of one part from population (1,65 g P/(inh.d)) and an other part from industry (1,0 g P/(inh.d)) which have been assumed to be constant for all scenarios except scenario 4, where reduction of specific emissions from these sources by source abatement (industrial production, urine separation) has been taken into account. In addition a part of specific P-emissions results from the use of detergents. For scenario 1 the assumed amount of P in detergents has been kept constant as compared to the actual situation. For scenario 2 the amount of P in detergents in Austria and Germany remains unchanged, but in the rest of the Danubian countries a situation like in the 80ies has been assumed. For scenarios 3 to 5 a reduction of P in detergents to about 0,35 g P/(inh.d) as it is the situation in Austria and Germany has been assumed for all countries. The specific N emissions were not considered as variable.

The connections to sewers were assumed to stay constant in scenario 1. In scenarios 2, 3 and 5, as approximation to the requirements from urban waste water directive, it was assumed that the total urban population and 30 % of the rural population are connected to sewer systems unless this percentage is already higher now. No additional connections to waste water treatment plants were calculated for scenario 1. In all the other scenarios the waste water collected in sewer systems is treated biologically as required in the EU urban waste water directive. In scenario 2 only carbon removal (including 30 % N and 35 % P removal) is applied unless the treatment level is already higher now. Scenarios 3 and 4 assumed N (80 %) and P (87 %) removal in all towns with more than 10,000 inhabitants. In scenario 5 based on results from EU/AR102A/91 (1997) on the dilution capacity of receiving waters in different Danubian countries nutrient removal was taken into account for treatment plants discharging to receiving waters with a dilution capacity at low flow of less than 2 $m^3/(pe.d)$ (pe: population equivalent). For other treatment plants only carbon removal was assumed.

Scenario assumptions agriculture

In general for all scenarios it was assumed, that the agricultural area remains unchanged. Production reductions result in reduced intensity of production per area but not in a reduction area used for agricultural production. As for waste water management scenario 1 is a prolongation of the actual situation. For scenario 2 the same productivity (animal and plant production) and N-efficiency of plant production (N input (fertiliser, deposition, N-fixation) in relation to N in harvested crops) was assumed for Austria and Germany as in 2000 and for the other countries in the Danube Catchment area as at the end of the 80ies. Scenario 3 has the same agricultural production but an increased N-efficiency in plant production based on application of best practice by 10 % in Austria and Germany and 20 % in the other countries as compared to scenario 2. In scenario 4 the animal production is reduced to 0,1 AU/(inh.a). Crop production is assumed according to the needs for food for the population and fodder for the animal stock. The N-efficiency was calculated with 150 %, assuming a best available practice on a relative low level of the intensity of production. For scenario 5 predicted agricultural production for the year 2015 according to FAOSTAT (2004) was taken into account. For the N-efficiency the value was set to 167 % an average value for EU15. The values for mineral fertiliser application and N-surplus were calculated based on these assumptions.

Changes in NH_3 emissions to the air can be achieved by better storage and spreading. Further reductions in life stock lead to reductions in NH_3 emissions and consequently NH_3 deposition. Assumptions of changes of Ammonium deposition have been made based on a correlation between life stock and Ammonia deposition derived for different countries based on data from different periods.

For phosphorus it was assumed that the surplus on soil in future will not be that high leading to significant changes in the P-content in top soil and thus will not have significant influence on the emissions to surface waters. P-emissions to surface waters from agriculture will mainly be influenced by the level of erosion abatement (use of minimum tillage, mulch techniques, i.e. mulch seeding ; intercropping). In scenarios 3 and 4 two different levels of application of erosion abatement in the basin have been applied.

Assumed conditions for natural factors

Considering the transported nutrient loads from the Danube Basin to the Black Sea, the main influencing natural factor is the hydrologic situation in the Basin. For calculation of the input data for the Black Sea Models, the river discharge of the Danube for the years 2002 and 2003 has been used, which covers low flow as well as high flow periods. To demonstrate the influence of hydrology on nutrient discharges to the Black Sea on a broader range, in addition, nutrient discharges of River Danube have been calculated using the long term average water discharge as well as maximum and minimum values for a period of 5 years.

The physical factors that influence the transport of the Danube River waters and associated nutrients through the North-Western Black Sea shelf are those associated with plume dynamics and air-sea interaction. These are natural factors that, although subject to intense seasonal and inter-annual variability, they are generally not influenced by human activities. Although the rate of Danube discharge and the nutrient loads are subject to man-made changes, there is a strong component of natural changes, associated with weather (short-term events) and climate (long term effects). Moreover, the circulation within the areas most affected by plume dynamics and the interaction with currents associated with basin-wide circulations (mainly the Rim Current), largely control the formation and evolution of the Danube River plume and the related coastal flows that determine the nutrient pathways. Topographic and bathymetric factors impose further natural controls on the nutrient transport.

For the scenario calculations, all hydrodynamic variables and air-sea interaction processes were kept constant. A simulation target period was defined, namely 2002-2003, so that the Danube water discharge and the atmospheric conditions would represent realistic magnitude and spatial and temporal variability. The particular target period was chosen because it covered two years of vastly different conditions, both typical of Black Sea hydrodynamic variability and within the full spectrum of conditions that control the Danube River plume formation and the nutrient transport pathways. The scenario calculations focused on summer conditions, as these are the periods of higher ecosystem variability. Summer 2002 had high Danube discharge and downwelling-favorable winds (mainly from the North, Northeast), while summer 2003 had low discharge and upwelling-favorable winds (mainly from the South, Southwest). Furthermore, the target period was rich in observational data that were used for model validation (see section 3.3.2.3).

3.3.3.2. Measures and their Impact on Nutrient Discharges and Western Black Sea Ecological Status

The impact of the measures formulated in the scenarios 1 to 5 as described in Section 3.3.3.1, has been analysed by means of the mathematical models described in Section 3.3.2. The current section presents the results of this assessment, in terms of the emissions, the river loads, the river concentrations and the consequences for the ecological status of the Western Black Sea coastal area.

Nutrient emissions

The Figure 34 illustrates the total emissions of N and P for the scenarios 1 to 5, calculated for the year 2015. The total emissions are subdivided over the pathways on one hand and over the sectors on the other hand.

The emissions in scenario 2, which includes implementation of the Urban Waste Water Directive for normal areas, are substantially higher than those in scenario 1, especially for P. For P this is the result of the increased emissions from the urban sector only, while for N the agriculture sector and the urban sector are both responsible. Scenario 3 shows a decrease in the emissions from the urban sector, due to the implementation of the Urban Waste Water Directive for sensitive areas. For N, this decrease is still compensated by increasing agriculture emissions despite the implementation of best available practice, while for P the agriculture emissions show a decrease as well, due to erosion abatement measures. Scenario 4 is a more extreme variant of scenario 3, including a drastic reduction of agriculture production corresponding to a reduced animal protein intake of the local population (healthy nutrition). Contrary to scenario 3, scenario 4 is sufficient to reduce the N emissions from agriculture to a level below that of scenario 1. Scenario 5 has similar emission levels as scenario 1. For P, the division over the sectors is similar in both scenarios, while for N an increase in the emissions from agriculture is compensated by a decrease in the urban sector.

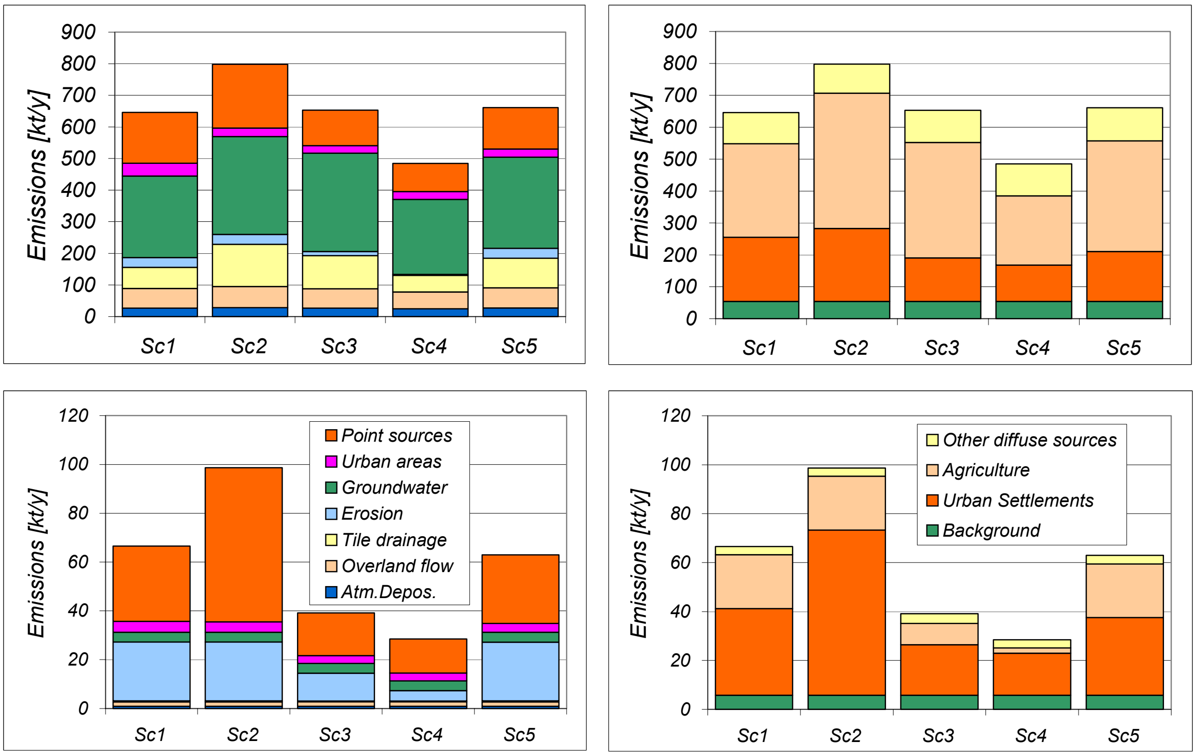


Figure 34: Calculated emissions of nitrogen (top) and phosphorus (bottom) for the scenarios 1 to 5, distributed over pathways (left) and over sectors (right).

Scenario 2 demonstrates that the emissions of N and P may increase in the period up to 2015 to a level that resembles the emissions in the 1980s, if the expected economic development in the middle and lower Danubian countries proceeds without proper environmental control measures. Scenario 5 for phosphorus and scenarios 3 and 5 for nitrogen demonstrate that such control measures can only be realised by proper domestic waste water management.

River loads towards the Danube Delta and the Black Sea

The calculated Danube River nutrient loads upstream of the Danube Delta for the scenarios 1 to 5 are shown by Figure 35. The loads clearly reflect the variation of the emissions between the different scenarios. Comparing the emissions (Figure 34) to the river loads (Figure 35), effect of losses and storage can be seen: about 40% of the emitted N and about 70% of the emitted P do not reach the Danube Delta. The nature of relevant losses and storage processes for N and P are discussed in Section 3.3.2.2.

The scenario 2 is clearly the worst case scenario, with a load of P 45% higher than in 2000 and a load of N 14% higher than in 2000 (Sc0). This situation strongly resembles the situation before the economic changes in the middle and eastern part of the basin in the 1980s. The other scenarios show similar or smaller loads than those of today.

Figure 35 also shows the Danube River loads under different hydrologic conditions as they have been observed in the recent past. A period of relatively low discharges, observed in 1989-1992, causes lower diffuse emissions and a higher retention capacity of the surface water system. A period of relatively high discharges, observed in 1998-2000, causes higher diffuse emissions and a lower retention capacity of the surface water system. As a result, the estimated river loads may vary considerably due to these hydrological variations. For N, the hydrology induced variation of the loads is of the same order of magnitude as the differences between the scenarios. This implies that the year to year loads depend as much on hydrology as on the development of the emissions. For P, the hydrology induced variability of the loads is a little lower than the differences between the scenarios. For both nutrients we can conclude that the effect on the river loads due to changes of human activities leading to nutrient emissions into the hydrosphere can to a large extent be counterbalanced by hydrological variations.

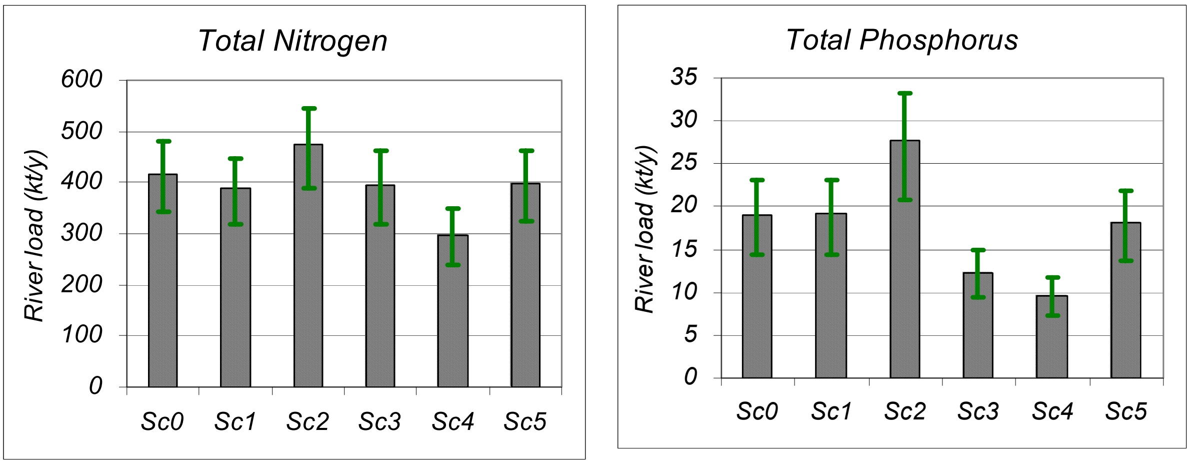


Figure 35: Calculated Danube River loads towards the Danube Delta, for the scenarios 1 to 5. The error bars show the variability of the loads, induced by differences in the river hydrology.

For nitrogen, the effect on the river loads of changes in the nitrogen surplus on agriculture soils is influenced by another factor. Drainage via ground water is the most important pathway for nitrogen emissions to reach the surface water. The transport process through ground water takes several years to several decades. Consequently, there is a significant time delay before changes in the nitrogen surplus on agriculture soils become visible in the river loads. This effect is illustrated by the difference between scenario 0 and scenario 1 in Figure 35. In terms of human activities leading to nutrient emissions to the hydrosphere, scenario 1 is almost the same as scenario 0 (which reflects the year 2000). Nevertheless, the emissions of N are 7% lower in scenario 1, due to the delayed impact of the reduced nitrogen surplus on agriculture soils in the 1990s.

The impact of the Danube Delta on the Danube River loads is very small (see Section 3.3.2.2). This implies, that the results presented in Figure 35 are not significantly affected by the Danube Delta. Nevertheless, the nutrient losses and storage in the Danube Delta are taken into account in the calculation of nutrient transport towards the Black Sea.

Disaggregation over time and over nutrient species

The DWQM and the DDM express the nutrient transport in terms of daily varying water discharges and nutrient concentrations. The distribution of the nutrient concentration over time is influenced by the river hydrology. Figure 36 provides examples for the concentration of total nitrogen and total phosphorus. This figure shows the concentration calculated by the DWQM for scenario 5, upstream of the Danube Delta for three hydrological periods: a low flow period (1989-1992, average discharge about 5370 m^3/s), a period with intermediate flows (2000-2003, 6150 m^3/s) and a high flow period (1997-2000, 7060 m^3/s).

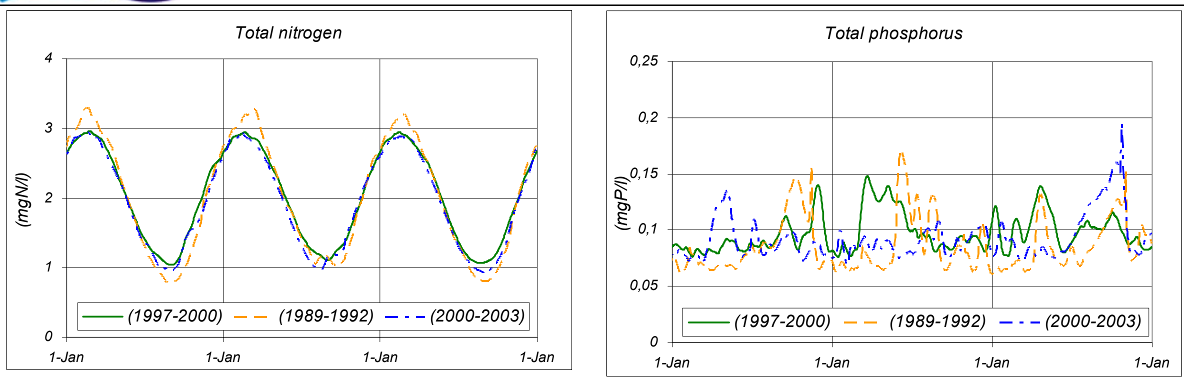


Figure 36: Disaggregation over time of the concentration of total N and total P for scenario 5, for a period with low river discharges (1989-1992), a period with intermediate discharges (2000-2003) and a period with high river discharges (1997-2000).

The results in all three periods are very similar for total nitrogen. This is because the dominating factor for the river concentration is the seasonal varying impact of nitrogen losses from the hydrosphere under the influence of biochemical processes (denitrification). Even though the concentrations are quite similar, the nitrogen loads differ strongly between the three periods, due to the differences in the river discharge. The results in the considered periods for phosphorus are very different. This is because the key pathways for the phosphorus emissions are strongly linked to the discharge fluctuations: the dilution of point sources and the erosion induced by high runoff events. Consequently, even if human activities leading to nutrient emissions are the same, the phosphorus concentrations in the surface waters experience very strong fluctuations induced by runoff variations. For nitrogen, the concentrations are much less affected by those variations.

The transport of nutrients in the Danube River, its main tributaries and the Danube Delta has been calculated for the different nitrogen and phosphorus compounds separately (see section 3.3.2.2).

Consequences for the ecological status of the Western Black Sea Coastal Area

Indicators are important for assessing ecosystem status and detecting trends, identifying vulnerability level and setting priorities in recovery measures. Monitoring can rise to a large number of possible indicators, as all the physical, chemical and biological parameters reveal different aspects of the ecosystem and therefore indicate a certain status. The concentrations of nutrients and oxygen, chlorophyll-a, abundance and biomass of different living organisms, species composition, suspended matter, turbidity, etc. are basic indicators of water quality and as a whole of the balance or misbalance in an ecosystem. However, multiple averaging in order to reduce the high amount of records to a few reported numbers might bring a misleading impression about the targeted ecosystem and even wrong understanding. Therefore, other kind of "aggregated data" are also needed. The existing integrated indices (e.g. nutrient cycling, trophic structure, biocumulative index, etc.) can be used to simplify the complex "picture" and present more credible interpretation of the results achieved. This task was accomplished by setting certain indicators that were suitable to evaluate the ecosystem status. The indicators were computed on both data and modelling, following the scenario based inputs from MONERIS, DWQM and DDM. Certain common criteria and considerations were taken into account, which determined that suitable indicators should: (i) be sensitive to potential impacts; (ii) encompass major components of the ecosystem; (iii) characterise the capacity of the Western Black Sea ecosystem, as it is a major point of departure for the development of concepts for the Danube river management plans. Among all available indicators provided by the daNUbs project monitoring program for the Black Sea the following were selected::

- N/P molar ratio (inorganic forms of nitrogen and phosphorus);
- Phyt/Zoo ratio (phytoplankton and zooplankton biomass ratio);
- Oxygen saturation of bottom layers;
- Biomass of macrozoobenthic communities.

Table 8: Ranges of indicators

Indicators ranges	N/P	P/Z	O2	Benthic biomass
Bad state	<10 and > 25	> 100	50 - 75%	1.5 - 200 g.m-^{2}
Good state	10-14 and 18-25	100 – 10	75 - 90%	200 - 850 g.m-^{2}
Very good state	15 – 17	< 10	> 90%	850 - 6500g.m-^{2}

These indicators are sensitive towards the evaluated impact which is connected with nutrient loads stemming from the Danube River to the Black Sea. The ranges (Table 8) for bad, good and very good status of an aquatic ecosystem are commonly accepted. They encompass major environmental components, especially vulnerable to eutrophication. Furthermore, the bottom oxygen saturation and biomass of macrozoobenthic organisms indicate the ecosystems potential for healthy assimilation of nutrient loads, as they become depleted (ultimate effects) due to the overloaded carrying capacity (when the system is replete with nutrients and organic matter, lacking balanced turnover of substances).

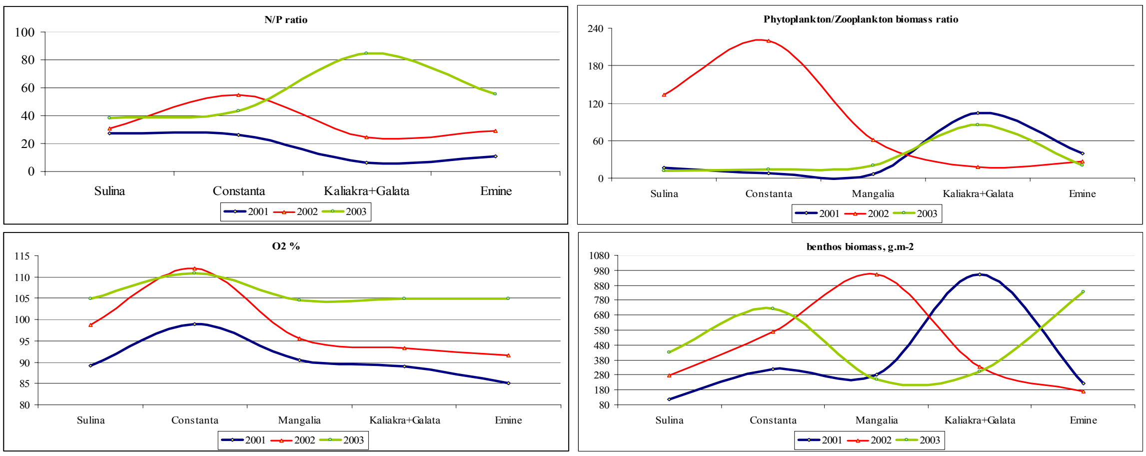


Figure 37: Data-derived annually averaged indicators at Sulina, Constanta, Kaliakra plus Galata and Emine in 2001-2003

The indicators in the Western Black Sea vary in time but also significantly in space due to the heterogeneous nature of habitats due to divers influences and local characteristics. The indicators also represent a variability from bad, through good to very good ecosystem state in the Western Black Sea. The ecosystem shift from a bad to a very good state is associated with a decrease in N/P and P/Z ratios, while bottom oxygen and benthic biomass increase. Important characteristic of a “bad” state is the greater variability of indicators in space, which implies certain misbalance in the ecosystem. Whereas reduced variability of the indicators is mostly related to an improved status. In general, the years 2002-2003 were “good” years for the Western Black Sea, though the level of benthic biomass even in the best situations was mostly not in the range 850-6500 g.m^{-2}. However, all other indicators, especially bottom oxygen, supported the idea of the improved shape of the ecosystem in comparison with the 1990s.

The same indicators were calculated based on ecosystem model scenarios. The objective is to determine future impacts based on scenario runs, by comparing model predictions with the current ecosystem status.

The scenario based ecosystem model simulations exhibited substantial variability of the indicators described above. This suggests that differences of the nutrient loads can lead to measurable changes in key ecosystem parameters, which are included in the chosen indicators. The model simulations show (Figure 38) that there is a correlation between input and response, as all indicators vary between bad, good and very good shape in the north-western Black sea ecosystem, following the scenario definitions that determine the characteristics of the river loads. For scenario 2, the indicators reveal a clear worse case for the state of the shelf ecosystem. The opposite end of the spectrum is seen in Scenario 4, where the ecosystem shifts to its best state. The changes in ecosystem status in Scenarios 1 and 5 are not so dramatically different, producing average levels for the indicators that lie between Scenario 2 (high production) and scenario 4 (green). The "base line" calculation for 2001-2003 (presented by scenario 0 representing the current status) is close to a very good condition of the ecosystem.

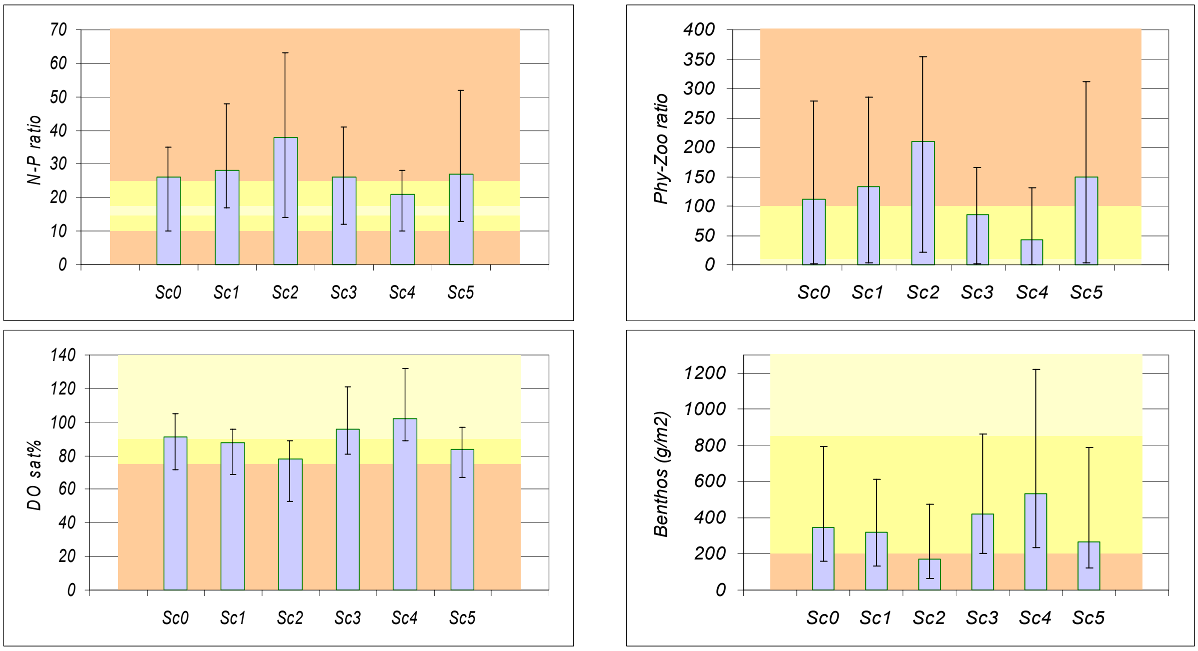


Figure 38: Mean (2001-2003) indicators for the western Black Sea for the scenarios 1 to 5. The min and max values are shown as well. The shadings corresponds to the bad (orange), good (yellow) and very good (beige) state of the sea.

The shift from a bad (Sc.2) to a very good state (Sc.4) of the ecosystem is characterised by a decrease of the N/P ratio. It varies from 38.1 (Sc.2) to 21.0 (Sc. 4). The Scenario 1 and 5 are close to the current situation of the ecosystem (Scenario 0) and the indicators of scenarios 3 lie between Scenario 5 and 2. The difference between the ecosystem responding to nutrient loads, is better pronounced in the Phytoplankton/Zooplankton ratio. As for N/P ratio, it follows the same trend from bade (Sc. 2) to good and very good cases (Sc. 4 and Sc. 3), associated with a decrease of the P/Z ratio. The bottom oxygen saturation and the benthic biomass indicate the ecosystem potential for a healthy assimilation of nutrients; they were depleted due to the overloaded capacity. That means that for a healthy ecosystem both indicators would be higher than for a bad one. The bottom oxygen saturation is varying between 102 % for Scenario 4 (that reveals a very good state of the ecosystem) and 78 % for

Scenario 2. For these indicators, scenario 3 also belongs to the very good state of the system, while scenario 1 and 5 represent the average status. As for the bottom oxygen, the shift of the ecosystem from a bad to a very good state is defined by the increase of the benthic biomass. The mean of benthic biomass varies from 170 (for Scenario 2) to 535 g/m-3 (for scenario 4). The indicator for the remainder of the scenarios is close to the present day situation and in the range of the benthos biomass that ranges from a good (Scenario 1 and 5) to a very good (Scenario 3) situation for the aquatic ecosystem.

Pronounced temporal and regional variability is observed in all indicators. However the basic trend of the north western Black Sea ecosystem state for shifting from bad (Scenario 2) to very good (Scenario 4) is kept by all regions. The differences of the indicators between the scenario simulations are highest in the areas most affected by the Danube River plume (see section 3.3.2.3 for region characteristics).

3.3.3.3.Economic analysis of scenarios

In this section the following questions had to be answered:
(a) How can the different scenarios of applying bundles of measures in agricultural production and wastewater management be characterised economically?
(b) What are the annual absolute costs of those bundles of, and of the constituting single measures, accruing to agricultural and wastewater firms (‘internal costs’) per country?
(c) Those costs have to be calculated relative to their effects, by dividing costs by effects, expressing either (1) cost-effectiveness ratios (CER) of the bundles of measures, being the decision criterion for the choice between scenarios at large (!) as preferable to another one, or (2) CERs of single measures (or even of selected process components of single measures), using these CERs to rank the latter. In case (1) the CERs express the conjoint costs of reducing 1 unit of nutrient load flowing into the Black Sea by implementing the whole bundle of measures at large in a scenario. In case (2) the CERs express the separated costs of reducing 1 unit of nutrient load by carrying out a single measure (or a single process component).
(d) Which relevant ‘external effects’ of the bundles of measures can be expected?
(e) Which circumstances determine the economic feasibility of measures, and instruments to induce them? The political feasibility of controversial measures is also considered.
(f) Which strategies to implement measures can, or should be, recommended?
For details see deliverable 9.2/9.3 of the daNUbs project (Schönbäck et al., 2005).

Cost-effectiveness of bundles of measures at large in nutrient management scenarios: The five scenarios are: (1) Business as usual (BAU), (2) High production (HP), (3) Best available techniques (BAT), (4) Green and (5) EU policy, all created as forecast for the year 2015. Measures already implemented in a reference scenario remain out of consideration in a further scenario to be assessed. The analysis of costs is based on the price level 2002/03. In addition it is assumed that the real price level in CEE countries increases by 2 % annually up to 2015 relatively to Austria and Germany.

A. Considering agriculture there are scenarios characterised by certain amounts of agricultural production, not considering any measure to change nutrient emissions (BAU and HP), and scenarios defined by specific measures to be carried out in order to reduce nutrient emissions (‘endogenously’), without a change in the level of agricultural production (BAT and Green). Figure 1 shows the basic structure of the scenarios: Starting point is BAU. Scenario HP shows the effects of high levels of additional agricultural production in CEE countries. The level of production in BAT is the same as the one in HP (carrying nutrient loads to the Black Sea from agricultural sources: 252,100 tN a^{-1}; 6,100 tP a^{-1}), the latter being used as the reference case for the former. Scenario BAU (nutrient load to the Black Sea from agricultural sources: 177,900 tN a^{-1}; 6,100 tP a^{-1}) is used as the reference case for Green. Going back to scenario BAU permits to consider also scenario EU policy: It is characterised by agricultural production higher than in BAU for most of the countries. Additionally, measures to reduce the nutrient emissions according to the EU environmental and Common Agricultural Policy are also assumed to be carried out at the same time. Thus it shows the final results of two kinds of driving forces put into effect simultaneously without showing separately the effects of the bundle of measures implemented. Based on the broadly specified bundles of measures in the scenarios BAT, Green and EU policy in work package 3, single measures had to be identified in detail, in order to calculate their costs. The effects of these bundles of measures in terms of decreased nutrient loads flowing into the Black Sea are a result of applying the respective retention and transport factors to nutrient emissions into the surface waters originating from MONERIS calculations.

In scenario BAT the bundle of measures is assumed to consist basically of (1) precision application of fertiliser on field level, (2) reduced ammonia emissions from manure to the atmosphere, (3) phase feeding in pig breeding, (4) partial substitution of mineral fertilisers for alternatives like compost and sewage sludge, (5) increased productivity in plant production through irrigation, (6) better pest management etc. and (7) reduced erosion and nitrogen leaking through alternative tilling methods. (8) Nutrient soil surface balances as well as nutrient farm gate balances are further measures effectuated by the public instrument of a legal commandment for most of the agricultural firms. In addition, (9) high nutrient surpluses on farm level will be penalised by a tax and low surpluses rewarded by a subsidy from the revenue of this tax. The bundle of measures in BAT causes, in the total of the 9 countries examined, internal costs of 1.5 bn€ a^{-1} reducing the nitrogen load flowing into the Black Sea by 14% and the phosphorus load by 61% of the total arising from agriculture.

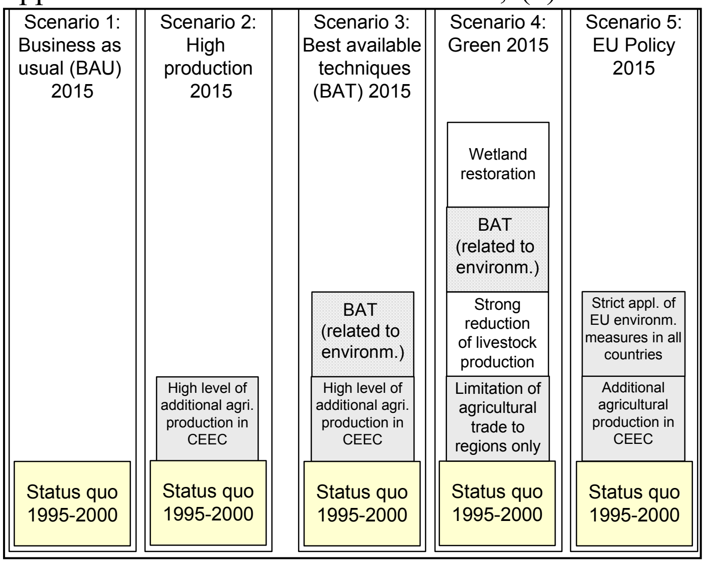
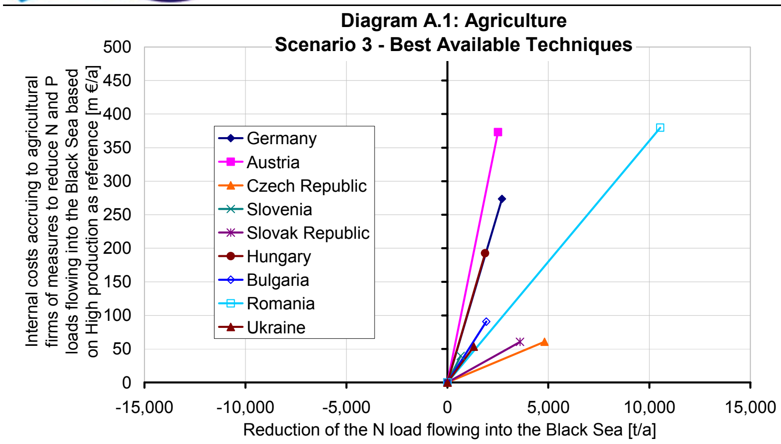
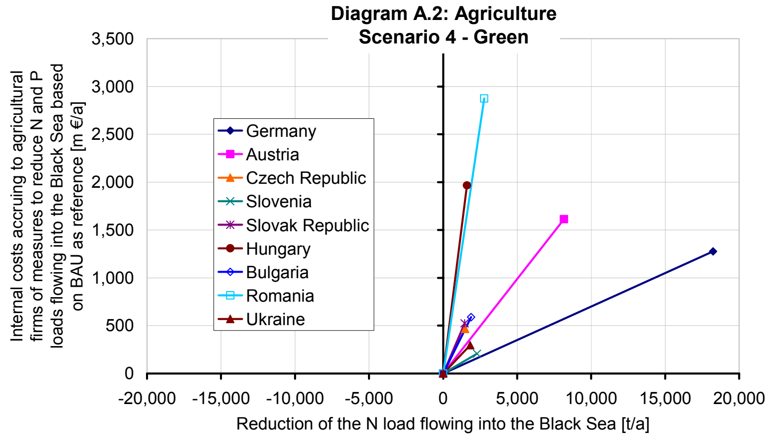
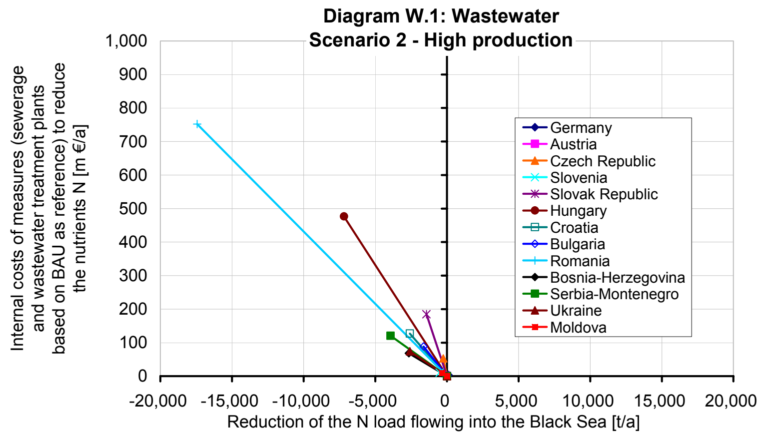


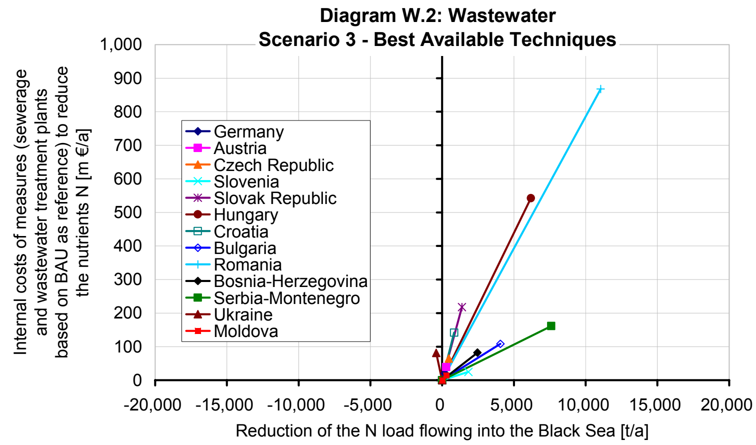
Figure 39: Comparison of scenarios

In scenario Green the bundle of measures contains (1) a drastic reduction of livestock production as a consequence of applying a tax on meat consumption high enough to attain such a low level of meat consumption (on average 25 kg $a^{-1}cap^{-1}$) that human health will be improved substantially; additionally, all losses of income of agricultural firms are assumed to be compensated out of the revenue of this tax. (2) All measures carried out in BAT are also put into effect here. (3) Wetlands are partly restored. The bundle of measures causes internal costs in the 9 countries examined of 9.6 bn€ a^{-1}, reducing the nitrogen load flowing into the Black Sea by 26% and the phosphorus load by 89% again of the total arising from agriculture.









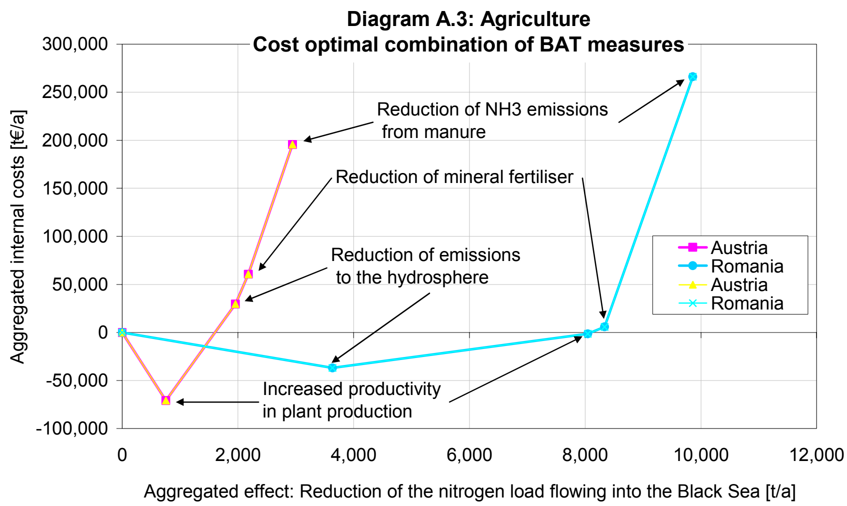
In scenario EU policy the bundle of measures is assumed to consist of (1) conversion of conventional to organic farming, (2) set aside of arable land, (3) partly restoration of wetlands, (4) reduction of erosion and nitrogen leaking through alternative tilling methods and reduced ammonia emissions to the atmosphere from manure. In this scenario the total nitrogen load flowing into the Black Sea is higher than in BAU in most of the countries (except Germany and Slovenia) by 17%. The effect of the increased agricultural production outbalances by far the effect on nutrient load caused by the measures. The phosphorus load will be decreased by 1 %. The internal costs of the bundle of measures amount to 0.6 bn€ a^{-1}.

The diagrams A.1 and A.2 exemplarily show, for the two rigorous measure scenarios, BAT and Green, the total reduction of nitrogen load flowing into the Black Sea, and the conjoint internal costs of the bundles of all measures in different countries. The costs consist of the change of all direct and indirect costs of production as well as changes in output (gains or losses) accruing to agricultural firms (‘internal costs’ of measures, i.e. governmental costs are excluded). The slope of the straight lines equals the cost-effectiveness ratios of the bundles of measures, related to nitrogen. In scenario BAT generally the cost-effectiveness ratios are high in the old EU member countries (Austria and Germany) because of the high cost level, while it is much lower in the CEE countries. An interesting exception is Hungary which has the highest cost-effectiveness ratio because of high retention of nutrients in soil and surface waters. In scenario Green the internal costs of the bundles of measures are generally much higher than in BAT because of the high losses of output caused by the drastic livestock reduction. The internal costs of livestock reduction range from 74 % (RO) to 87 % (CZ) of the internal costs of the bundle of measures. Comparing the CERs of the two scenarios referred to nitrogen reveals that in all countries scenario BAT is by far superior to Green, except in Germany where it is inferior.

B. Considering wastewater management, the scenarios differ from the ones defined for agriculture in as much as (a) all changes in nutrient emissions are explained by measures shown explicitly and (b) all four measure scenarios can be and are compared with the same reference scenario (BAU). The main difference between the countries consists in the number of population connected to wastewater treatment and the type of technique used to treat wastewater. The diagrams W.1 and W.2 show exemplarily the effects of the bundles of all measures in single countries, again in terms of reduced nitrogen loads flowing into the Black Sea, as well as their internal costs in the scenarios. A positive value of an effect indicates a decrease of nitrogen load, and a negative one the reverse. Diagram W.1 (HP) displays the situation that the whole DRB is considered as "normal area", and W2 (BAT) the one that the whole DRB is considered as "sensitive area", according to the EU-Urban Waste Water Directive. The explanation for the negative effects for nitrogen, shown in scenario HP (W.1), is that increased sewerage combined with wastewater treatment with carbon removal directly discharges nitrogen into the water bodies, whereas otherwise nitrogen would be eliminated by denitrification in the soil. Thus the difference in costs for all 13 countries (BAT minus HP) amounting to 400 m€ a^{-1} causes a decrease in nutrient loads flowing of 76,600 tN a^{-1} and 17,500 tP a^{-1} in BAT compared to HP.

In wastewater management the internal costs of the bundles of measures in different scenarios are in the range between 0.001 to 0.4 % of the countries' GDPs. In agriculture the corresponding internal costs range between 0.09 and 1.5 % of the countries' GDPs.

C. Optimisation based on cost-effectiveness of single measures: In case the bundles of measures are not regarded as fixed, a cost optimal choice of the measures in a single country as well as in the whole DRB based on separated costs and effects of single measures is possible. This is shown in Figure A.3 for measures of BAT in agriculture regarding nitrogen in AT and RO: A new bundle of measures can be assembled by selecting measures according to their CERs, which achieves a required effect at minimal costs not violating a previously specified budget constraint.



Comment: Reductions of emissions to the hydrosphere are: (1) intercropping, (2) mulch seeding, (3) zero tillage and (4) grubbing (because of less erosion the need for mineral fertiliser is lower)

External effects: To implement fully all measures in scenario BAT may increase the direct and indirect annual contribution of the seaside tourist industry in Bulgaria and Romania to their GDPs in 2015 by an amount approximately equal to as much as up to 5 to 7 % of the total annual costs of all those measures in the whole river basin (amounting to 3.9 bn€ a^{-1}, neglecting the costs of the measures in agriculture of four countries being not available). To lower meat consumption strongly would improve health substantially but lack of acceptance may prevent an increase of total welfare. Economic modernisation of sectors providing intermediate and investment goods (1) to agriculture is encouraged most by BAT and (2) to wastewater management is encouraged by scenario BAT and Green similarly.

Economic feasibility of the measures comprised in the scenarios BAT and Green: Measures causing costs to be incurred by firms or individuals will not be implemented by them voluntarily. Feasible public instruments to induce firms and/or individuals to comply with measures may be: (a) to command carrying out measures, (b) to tax behaviour generating high nutrient loads if the burdens (financially or regarding to a demanded renunciation of certain activities), and (c) to subsidise carrying out measures (being otherwise so costly that they wouldn't be performed by firms or individuals), provided minimal own capital is raised by investors and/or public co-finance is provided (e. g. for construction of wastewater facilities). Effective instruments can be applied also by NGOs or even individuals. To tax meat consumption to lower it drastically is economically feasible but not politically.

4. Conclusions and Recommendations

Methodology

- One main methodological success of the project is the linkage of the MONERIS emission model, the Danube Water Quality Model, the Danube Delta Model and the Black Sea Models (physical and biological), which could be combined despite of different time scales (5 years means – daily discharges).
- Different scenarios for the future development of waste water management, agriculture and life style were set up to analyse nutrient emissions to the rivers, the corresponding discharges to the Black Sea and the effects in the North-Western Black Sea shallow waters. These calculations were based on the assessment of all relevant sources and pathways of nitrogen and phosphorus emissions and the transport and retention in the surface waters including the Danube Delta.
- For the assessment of emission pathways according to MONERIS as macro-scale emission model the spatial resolution is the subbasin level (388 subbasins with an average size of 2000 km^2). This was found to be suitable for a Basin wide application. The accuracy of emission estimates declines with decreasing size of the considered subcatchments. Higher spatial and temporal resolutions of estimations of emissions need higher resolution of input data and the support by further models and approaches (see case study investigations).
- Case study investigations supported the basin wide MONERIS and Danube Water Quality Model application and improved the understanding of the relationship between human activities and the emissions of nutrients to surface waters. The results can be used to (substantially) improve subbasin nutrient management and assessment.
- A methodology consisting of in-situ data acquisition, satellite observations and numerical models has been developed to study the advection pattern of the Danube induced low salinity/high nutrient waters and the possible impact of river born eutrophication on the different parts of the North Western Black Sea ecosystem.

Data Quality and Assessment

- Existing data were sufficient to generate a general assessment of nutrient fluxes on a subbasin level. Efforts are needed for harmonisation of input data (e.g. resolution of digital elevation model, soil map, nutrient concentrations in soils, resolution of application of mineral fertilizers, amount of tile drained areas) and the completeness and quality of data.
- Load calculations based on the monitoring of the nutrient concentration in the river and the river discharge are necessary for calibration and validation of emission and transport models. The Transnational Monitoring Network (TNMN) of the International Commission for Protection of the Danube River (ICPDR), covering the whole Danube river and the main tributaries, is an important source of information. However improvements in the completeness and accuracy of monitoring data are needed (e.g. TP, TN).
- Historical data sets on Danube nutrient discharges show considerable diversities especially in the most downstream part of the Danube (before and at the Delta). This hampers the assessment of a historical development of loads discharged to the Black Sea based on monitoring data. Model results had to be used to close these gaps of information to demonstrate a possible development up till now. Dealing with these model results certain ranges of uncertainty have to be considered.

- Information on loads always has to be evaluated in combination with river discharge data as nutrient loads are highly influenced by the discharge. This influence may exceed the effects of changes in management practices from year to year or even a period of several years.
- Satellite remote sensing data substantially supported the evaluation of the status of the Black Sea ecosystem.

Development of Danube Loads

- Phosphorus loads discharged by the Danube according the MONERIS model results have decreased by about 30 - 50 % compared with loads in the 1980s . Dissolved phosphorus, easily available for the algae growth has been decreased to an even higher extent. The P-loads now are similar to those in the 60ies, which is, to some extent, caused by significant storage of phosphorus at the Iron Gate I (probably limited for the next decades).

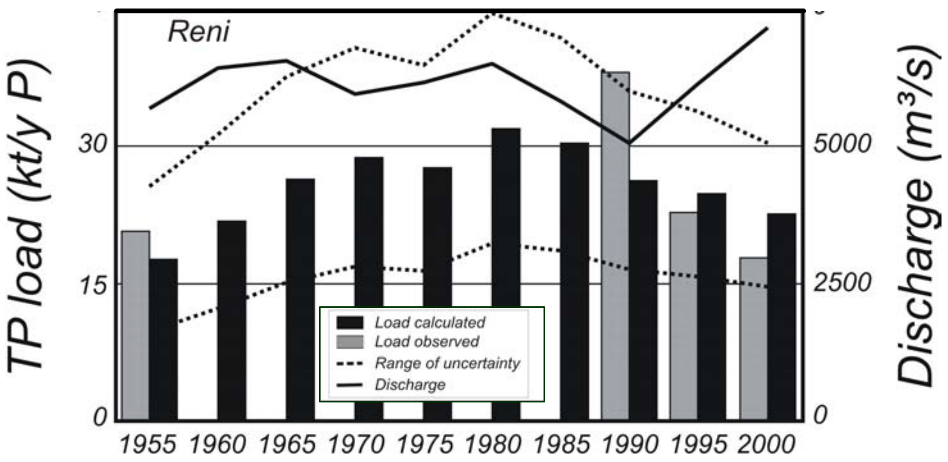


Figure 40: Temporal changes of observed and calculated loads of total phosphorus (TP) and discharges in the Danube at Reni station.

- Nitrogen emissions to surface waters of the Danube Basin have as well decreased considerably. Model results indicate that the effects of these reductions on the nitrogen loads to the Black Sea are to some extend hidden by a situation of relatively high Danube water flows during the period 1996-2002.
- Current low discharges of N and P to the Black Sea are the result of
  - improved nutrient removal from waste water in D, A and CZ
  - reduced phosphate discharges from detergents in other countries

  and the consequence of the economic crisis in central and eastern European countries which lead to:
  - closure of large animal farms (agricultural point sources),
  - dramatic decrease of the application of mineral fertilizers and
  - closure of nutrient discharging industries (e.g. fertilizer industry).

Role of Regional Influences

- The characteristics of nutrient emissions (total amount, relative share of pathways and sources) vary to a high extent across the Danube Basin.
- Retention (storage) of emitted P in and close to the river system (flooded areas) as well as denitrification in ground and surface waters strongly depend on the local/regional situation (hydrology, geology, morphology) and may have a strong influence on river loads under specific conditions.

- Elevated concentrations (phosphate, nitrate, ammonia etc.) due to nutrient emissions affect the ground and surface water quality is low mainly in regions with low groundwater recharge rates and low river discharge (small rivers) as the dilution capacity. At the same time the retention of P and the removal of N by denitrification are high. These regions contribute only little to the total nutrient discharge to the Black Sea. In these areas emission reduction (at waste water treatment plants or best agricultural practice) is effective mainly for the protection of the local/regional water quality. In such regions the influence of agricultural practice on nitrogen discharges via groundwater, differs completely depending on the distance (expressed in groundwater residence time) of an agricultural field related to surface waters.
- In regions with high groundwater recharge and high river discharge nutrient concentrations can be low, while the loads transported in the rivers are comparatively high (nutrient retention and losses during transport are low). Emission reduction in these regions effectively influences water quality of the Danube, the Delta and the Black Sea.
- The Danube river and its main tributaries play a minor role for N removal by denitrification. In respect to P, the Iron Gate I is still a major point sink.
- The Danube Delta does not play a dominant role in nutrient retention as > 90% of the nutrient load of the Danube passes the three main channels directly to the Black Sea.

<u>The advection pattern of the Danube river plume and eutrophic waters in the North -Western Black Sea.</u>

- The advection patterns of the Danube induced low salinity/high nutrients waters and associated river-borne nutrients over the North-Western Black Sea shelf are controlled by:
  (a) the amount of discharged water and its nutrient load;
  (b) the magnitude and direction of the prevailing winds; and currents, including front eddies, con- and divergences
  (c) the topography, inner-shelf slope and interaction with the basin-wide circulation and in particular the Rim Current.
- Most of the above mechanisms are subject to strong seasonal and inter-annual variability. The winter season is characterized by well-mixed shelf waters with relatively high values of surface chlorophyll a. The summer season is characterized by stratified shelf waters, and reduced Danube discharge. The inter-annual variability mainly due to changes in water discharge and nutrient loads plus the wind regime, has been demonstrated from observation and modelling in the Northwestern Black Sea shelf.

<u>The ecological status of the Western Black Sea shallow waters</u>

- The situation in the North-Western Black Sea shallow waters has improved considerably since the early 90s due to reduced nutrient inputs, causing:
  - reduced eutrophication, (reduced phytoplankton biomass, frequency of blooms and extension of high chlorophyll area.),
  - considerable increase in water transparency
  - improvement of near bottom oxygen regime,
  - regeneration of phytoplankton species (Diatoms) diversity,
  - regeneration of phytobenthos,
  - regeneration of macrozoobenthos (increase of species number and diversity).
- Zooplankton community in the N-W-Black Sea is still controlled by the gelatinous macrozooplankton (Mnemiopsis, Aurelia, Pleurobrachia), with respective consequences on the recovery of the pelagic fish stocks
- Limiting factor for phytoplankton growth in the eutrophic areas of the N-W-Black Sea is phosphorus (after 1997). While in the off shore waters mainly nitrogen limits primary productivity.

- As a consequence, the control of easily available P, directly influences algae growth in N-W-Black Sea shallow waters.

Consequences for Decision Making

- For a sustainable development of the Western Black Sea ecosystem the nutrient discharge from the Danube River should be diminished / at least kept on the present level. Emissions via different pathways can consequently change an increase of one emission pathway (e.g. due to recovery of the economy and agriculture in the middle and downstream part of the Danube Basin) should be compensated by the reduction in another country or of another pathway. In respect to compensation between different pathways it should be considered that in addition to enhancing eutrophication some of them have other detrimental affects on the environment (e.g. nitrate leaching – see below).
- Scenario calculations clearly show that the economic development in the Danube Basin may reverse the improving situation of the quality of the Western Black Sea ecosystem, if nutrients are not managed properly.
- Furthermore it has to be considered that the storage capacity of Iron Gate I is limited to several decades. After an equilibrium between sedimentation and resuspension P-discharges will increase.
- Policy measures have to be proactive and should focus on continuous and long term control of all anthropogenic point and diffuse sources of nutrients (waste water management, agriculture, combustion processes). Monitoring the effects of nutrient management in the river Danube and the Black Sea is important but it should be considered that there is a time lag (up to > 20 years) between cognition of deficiencies, implementation of control measures and corresponding effects in river Danube.
- It is recommended to apply a precautionary principle regarding nutrient emission based on
  - best available techniques for waste water treatment (point sources)
  - and best available agricultural practice for the reduction of nutrient losses from agricultural areas (diffuse sources)

  as such a management policy meets both objectives:
  - protection of ground and surface water quality in the catchment area and
  - coastal eutrophication abatement in the Western Black Sea shallow waters
- Based on the results of the scenario calculations this recommendation can be specified as follows:
  - The implementation of EU urban waste water directive (UWWD) with sewer development for all settlements with more than 2000 inhabitants and requirements for waste water treatment for “normal areas” (C-removal only) would lead to a significant increase of nutrient discharges to the Western Black Sea and should be avoided.
  - Consequent application of “sensitive area requirements” with nutrient removal in treatment plants in the Danube Basin with more than 10,000 p.e. is recommended to start immediately in order to avoid deterioration of the actual situation.
  - For the Black Sea protection sewer development (see above) should be handled as lower priority unless required by local ground water protection and hygienic aspects.
  - Industrial discharges of nutrients from individual point sources should be controlled based on a strong precautionary principle (IPPC-directive).
  - Erosion abatement based on minimum tillage and mulch techniques (i.e. mulch seeding, intercropping) is recommended to reduce particulate P emissions.
  - P surpluses in agricultural soils should be lowered to zero, where plant available P contents of the soils are already optimal. If P contents in soils are higher than the optimum, a zero P input policy is recommended.
  - The possible effect of nitrogen removal at point sources on the reduction of total nitrogen emissions is less significant than for phosphorus. Nevertheless it has to be

recommended because it is of decisive importance for the stabilisation of nitrogen loads discharged to the Black Sea because the recovery of agricultural production with increased fertilizer application in the middle and downstream part of the Danube Basin will increase the nitrogen emissions from agriculture even if best agricultural practice is applied.

- Consequent implementation of measures to limit N-emissions from agriculture is necessary.

  These measures should include:
  - application of best agricultural practice (NH_3-emission reduction, improved manure utilisation, precision in application of mineral fertiliser),
  - integrated production and
  - limitation of the intensity of agricultural production: the area specific production has to be optimised for economical and ecological sustainability of agriculture).

  This limitation should be in a range of
  - maximal animal density 0.4 – 0.7 AU/(ha_{AA}.a).
  - maximal average N-surplus 25 – 45 kgN/(ha_{AA}.a)
- Additional N-emission reduction can be achieved by a reduction of animal protein production to 0.1 animal units per inhabitant. This reduced production can contribute to fulfil the requirements for healthy nutrition of the population in the Danube Basin.

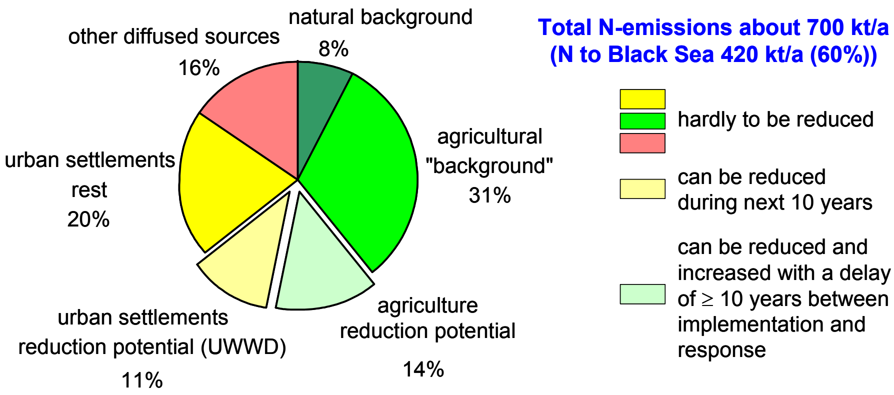


Figure 41: Reduction potential of nitrogen emissions (model results)

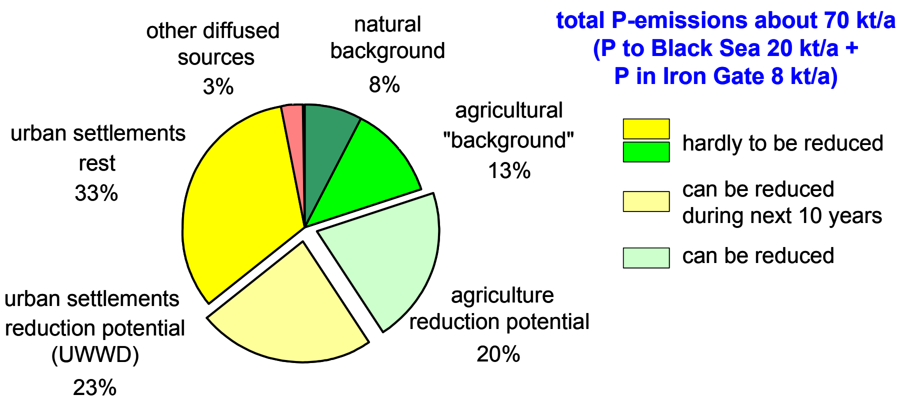


Figure 42: Reduction potential of phosphorus emissions (model results)

- N emissions by erosion/surface runoff and drainage into surface waters have impacts on eutrophication of (marine) surface waters. N emissions into groundwater by nitrate leaching however, have additional detrimental effects in respect to acidification (leaching of C, Mg), SO_4^- leaching (Pyrite ➔ SO_4), climate change and stratospheric ozone depletion (NO, N_2O emissions), the reduction of fossil DOC resources in the drainage zone and aquifer. Therefore, reducing such emissions should be a key objective.

- A sustainable nutrient management in agriculture should optimise C, N, P, S surpluses based on optimum nutrient contents of the soils, irrespective of the forms and directions of corresponding C, N, P, S emissions, because of positive effect on soil, water and climate.

Recommendations for Monitoring Strategy

- The implementation of an emission inventory based on harmonised input data and evaluation procedures has to be developed further. This is of high importance for the monitoring of sources and emissions. The collection of statistical data (animal stock and production, harvest, mineral fertilizer application etc.) with high spatial resolution is an indispensable prerequisite for an emission inventory.
- The existing monitoring in river systems and in the North-Western and Western Black Sea shallow waters needs to be continued and improved. Data quality assessment should be improved and all monitoring activities should be included into one quality control system for the river and also for the North-Western Black Sea coastal area which should include Bulgaria, Romania and the Ukraine.
- For the river monitoring in the Danube Basin and especially the Transnational Monitoring Network (TNMN) of ICPDR the following recommendations are proposed:
  - The monitoring frequency should be generally increased for most of the main Danube stations from monthly to biweekly measurements. Completeness and correctness of data sets are of highest priority. The number of intercalibration between the results of all laboratories has to be increased. Both measures are necessary to get better information on the observed loads in the Danube and to avoid inconsistency of data.
  - The consistency of the TNMN data is managed by a Quality Assurance/Control programme. It is of utmost importance that member states adhere to the agreed QC procedures, in order to maximise the consistency of the collected data.
  - Data sets/original data of the different stations should be available right after the measurement and not with a delay of several month or more than a year.
  - Additional stations should be added to the TNMN program, especially for the Danube upstream of the Drava, Sava and Velika Morava confluence, and stations in the Sava and Velika Morava in Serbia Montenegro.
  - In order to monitor the Danube river loads to the Black Sea a cross-section near Isaccea or Reni, just upstream the Delta should be monitored with more details, e.g., carrying out cross-sectional sampling and analysis of nutrients and other substances with appropriate frequencies at floods. These will ensure better information on the real load of substances to the Black Sea. The possibilities of continuous monitoring (measurement of NH_4, NO_3 and others with sensitive sensors) should be used.
- Monitoring as was done during the period of the daNUbs project in the Bulgarian and Rumanian coastal waters should be continued and not be subject to occasional project financing.
- Monitoring should also be done in the Ukrainian waters of the North Western Black Sea.
- Transboundary monitoring and frequent calibrations should be done among the 3 countries bordering the N-W Black Sea shallow waters.
- Monitoring should also be undertaken during the winter month in order to get a better understanding on the origin and the fate of the high winter phytoplankton standing stock.
- Sediment trapping and benthic nutrient release should be monitored to get better information on new and regenerated primary productivity in the shelf area.
- Satellite remote sensing should become an obligatory method to monitor the variability and heterogenity of temperature and water-colour of the surface water. It is important for

the sampling strategy to get this information before and during the monitoring cruises into the area.

- Intercalibration of river nutrient and Black Sea nutrients analysis is urgently required.
- Monitoring of mesozooplankton and especially macrozooplankton including fish larvae should be done with adequate plankton nets (Hensen net or similar large size nets). Samples for gelatinous zooplankton should be analyzed right after the catch possibly before preservation; calibration as to macro zooplankton analysis is needed within the whole Black Sea area.
- Monitoring of, and research in fish population dynamics are urgently needed in the Western Black Sea in order to understand the relevance of different factors (degree of eutrophication, gelatinous zooplankton, mesozooplankton) for the recovery of benthic and pelagic fish stocks.
- Monitoring of the benthos is urgently needed for all countries bordering the North Western Black Sea
- Underwater video recordings should be applied especially for the monitoring of the epibenthos.

Methodological Restrictions

- Focal point of recommendations concerning nutrient management in the daNUbs project is the protection of the North-Western and Western Black Sea shallow waters from hypertrophic conditions. In addition protection of local groundwater and surface waters of the Danube river and its catchment area is considered. There are related problems that will benefit of further reductions of nutrient emissions to the environment like acidification, climate change, stratospheric ozone depletion and loss of biodiversity. This impact has not been evaluated since it is not in the objectives of this project. Nevertheless for a future integrated approach of sustainable nutrient management these aspects should also be considered.
- The resolution of the input parameters for scenario evaluation is restricted mainly to country level. That means the evaluation of effectiveness of measures is only possible on country level up to now. The approach developed in daNUbs has the potential for more detailed evaluation in future applications.
- For future applications the combination of the MONERIS emission model with an agricultural farm gate balance would improve the possibilities for the development of strategies for nutrient management based on scenarios for nutrition and agriculture.
- The Ukrainian rivers Dniepr and Dniestr were not explicitly addressed in this study, but have an impact especially on the northern part of the North-Western Black Sea shallow waters. The information on the Ukrainian coastal waters of the North-Western Black Sea was restricted to mainly satellite remote sensing data and one research cruise in September 2004. Future investigations should focus much more on these regions.
- Natural ecosystems can react suddenly and unexpectedly even to small changes in loadings, climatic conditions or other environmental factors (e.g. stagnation periods, introduction of foreign species). Such events cannot reliably be predicted neither from monitoring results nor from existing simulations.
- Interpretation of the present relatively good status of the North-Western Black Sea shallow water is based on the actual state of scientific knowledge and sound observations. Nevertheless the occurrence of random deteriorations in the North-Western Black Sea shallow waters cannot be excluded even when recommendations are implemented and the nutrient loads remain unchanged or will further decrease.

5. Dissemination and Exploitation of Results

- Results of the Basin wide application of the MONERIS and the Danube Water Quality Model have already been used for the Basin wide roof report for the Danube Basin according to the requirements of the EU Water framework directive.
- Results were presented at the ICPDR-UNDP/GEF workshop "Nutrients as a Transboundary Pressure" in Sofia, January 2004 as well as at the ICPDR and BSC (Black Sea Commission) stocktaking meeting in Bucharest, Nov. 2004
- IWA organised a scientific conference which was held in Vienna on the 16.12.2004 where daNUbs results were presented to a broad audience.
- The scientific exploitation of the daNUbs concepts and results through conference papers and scientific journals in the fields of surface water protection, wastewater management, environmental engineering, agriculture, hydrobiology and marine biology will be continued.
- Further dissemination of results to national and international bodies is going to be organized in cooperation with ICPDR
- The project web-page (http://danubs.tuwien.ac.at) will be maintained by the Institute for Water Quality of the Vienna University of Technology for several years.
- The daNUbs - Final Report will be distributed after the approval by the EC to the International Commission for Protection of the Danube River (ICPDR), all relevant national organisations (national authorities, NGOs) and international organisations (e.g. the International Commission for Protection of the Black Sea or the International Commissions for protection of the River Rhine, Elbe and Oder). Additionally, the final report will be distributed to organisations in the USA (e.g. to the US Environment Protection Agency – EPA and the US Science Foundation), where the results will support management solutions concerning similar river basins like the Mississippi catchment.

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