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INTEGRATION OF THE NUTRIENT REDUCTION FUNCTION IN RIVERINE WETLAND MANAGEMENT

TECHNICAL GUIDANCE DOCUMENT

PROJECT COMPONENT 4.3

MONITORING AND ASSESSMENT OF NUTRIENT RETENTION CAPACITIES OF RIVERINE

WORKING FOR THE DANUBE AND ITS PEOPLE

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PREFACE

This document provides the technical basis for the guidance document on the integration of the nutrient reduction function in riverine wetland management (http://www.undp-drp.org/drp/themes_wetlands.html).

This technical guidance document reviews in chapter one the scientific and project-based literature on riverine wetlands and reduction of nutrient pollution. The chapter starts with a definition of what "riverine wetlands" means within the context of this report. It then summarizes the main mechanisms involved in nutrient dynamics between the main channel and riverine wetlands, and within riverine wetlands, with particular reference to transport, transformation and storage, removal and release.

Within the second chapter a case study in the DRB shows estimations on the nutrient retention capacity at three different wetland types.

Chapter three identifies the potential / importance of nutrient removal functions in riverine wetlands by evaluating recent, running and near-future projects (including the results from the questionnaire, experience from the demo projects)

Chapter four shows real world examples where nutrient removal is implemented in wetland management projects.

The last chapter explains the methodology for the guideline and recommendations in the guidance document.

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ABBREVIATIONS

DIN	Dissolved inorganic nitrogen
DRB	Danube River Basin
DRP	Danube Regional Project
EC	European Commission
EG	Expert Group
EU	European Union
EU WFD	EU Water Framework Directive
GEF	Global Environment Facility
HQ	High discharge (floods of different probability)
ICPDR	International Commission for the Protection of the Danube River
N	nitrogen
NO_3-N	Nitrate - nitrogen
P	phosphorus
TP	Total phosphorus
UNDP	United Nations Development Programme
WB	World Bank
WWTP	Waste water treatment plant

1. CURRENT KNOWLEDGE ON NUTRIENT DYNAMICS IN RIVERINE WETLANDS

1.1. Basic processes of nutrient dynamics in wetlands

Within river corridors, riverine wetlands have been recognized globally for their value in nutrient removal (Ambus, 1990; Cooper, 1990; Hill, 1990; Knauer & Mander, 1989; Lowrance et al., 1985; Pinay & Labroue, 1986). Wetlands have been investigated as buffer zones and retention areas which control fluxes of matter between terrestrial and aquatic interfaces (van der Peijl & Verhoeven, 2000). Surface water and groundwater fed natural wetlands have been found to affect the nutrient transport along rivers as well as nutrient input into lakes and estuaries (Thompson & Finlayson, 2001).

1.1.1. Nutrient related processes between the main channel and riverine wetlands

There are four basic processes affecting the nutrient content of the rivers:

- transport,
- transformation & storage,
- removal
- and release.

1.1.1.1. Transport

Nutrient removal in wetland systems is limited by the amount of nutrients transported into the wetland. In order to study the efficiency with which wetlands remove nutrients, it is necessary to consider the amount transported into the wetlands compared to the nutrient load transported in the river itself.

Nutrients are transported in river systems in dissolved and/or particulate forms. In upstream parts of river systems, the dissolved form of nitrogen is most prevalent. Phosphorus is mainly transported in particulate forms. In downstream portions of big rivers, such as the Danube, the particulate forms of nitrogen may increase. In addition to water-related nitrogen fluxes at different hydrological conditions (low to mean flow conditions, high flow and flood conditions or via groundwater and infiltrating river water) there is both atmospheric deposition and biotic N-fixation that have to be considered as inputs into the wetlands systems.

<u>Transport at low flow and average flow conditions</u>

Generally during low and average flow conditions in a river, the sum of dissolved fractions of nutrients transported in river systems predominates over particulate forms. Nevertheless, in downstream stretches of the Danube, organic particulate forms of nutrients may play an important role during low flows. Concentrations of the dissolved fractions of nutrients usually do not change very much in relation to the discharge (Zessner, 1999). Transport into a wetland system during low and average flow happens only where there remains a hydrological connection to the main channel. The potential nutrient retention (removal or storage) of wetlands is therefore limited by discharge (e.g. parapotamon regions sensu Amoros, 1987) in these channels.

Transport at high flow and flood conditions

Transport of suspended solids, and therefore of particulate bond nutrients, is highly dependent on the flow regime of the river. Concentrations of suspended solids usually rise as flows increase. For a single event, the increase in suspended solid concentration with rising flow and the declining in concentration with decreasing flow usually follow a pattern of hysteresis. This means that the suspended solid concentration at a certain discharge on the rising limb of a hydrograph will be greater than the concentration at the same discharge on the falling limb.

The effect of a high flow event on transported loads also varies with season. Typically, the transportation of suspended solids rises at a proportionally faster rate with increasing discharge. Therefore, the transport of suspended solids happens primarily at high flow and flood conditions. During flood events, large suspended solid loads can be transported considerable distances downstream within a relatively short period (a few days). However, the magnitude of the increase in suspended solid load depends on the discharge dynamics (e.g. the relation between discharge at low, average and high flow situations). In general, the increase in the amount of total phosphorous in suspension at high flow conditions is higher in upstream reaches than in downstream reaches. For example, data from the Danube in Vienna (a mid- to up-stream location) illustrate the effect of this dynamics (Zessner, 1999). The increase in phosphorus in suspension downstream was not significant.

Transport by groundwater or infiltrating water

In addition to the input by surface water, nutrients may be transported into wetlands by groundwater (from the catchment) or by bank filtration (from the main channel or other channels). Nitrate is primarily transported this way over longer distances.

Transport of ammonia and phosphate might be more prevalent under anaerobic conditions. Under aerobic conditions ammonia and phosphate are absorbed, precipitated or metabolized in the ground within short distances.

Atmospheric deposition and N-fixation

Deposition is defined as nutrient input from the atmosphere. Average values for atmospheric deposition in Austria are about 20 kg N ha^{-1} $year^{-1}$ which is more than the average removal by a forest ecosystem.

N-fixation is performed by bacteria living in symbiosis with leguminous plants or specific trees. For example, alder (*Alnus glutinosa*) is a tree species which host these symbiotic bacteria. The amounts fixed depend on the presence of these plants. Free-living bacteria are able to fix up to 30 kg N ha^{-1} $year^{-1}$. Generally, N-fixation is higher when nitrogen is limited.

1.1.1.2. Transformation and storage

Transformation of nutrients is a conversion from one nutrient compound into another. Storage can either take the form of temporary or long-term retention in a riverine wetland. Most nutrient transformation and/or storage in riverine wetlands are only of temporary nature. However, the retention of nutrients in riverine wetlands and the timing of subsequent nutrient releases to the main channel may affect water quality in the whole riverine landscape.

The main transformation and storage mechanisms and processes are sedimentation, precipitation, adsorption to and filtration through sediments, algal uptake, uptake by terrestrial plants and heterotrophic growth.

Sedimentation

The transport of suspended solids depends on flow velocity. In zones with reduced flow velocity sedimentation takes place. This may happen in the channels (e.g. parapotamons) of riverine wetlands or in flooded areas. Only particle-bound nutrients, mainly phosphorus are affected. These nutrients may be further transformed through mineralization, remobilization/solution, re-suspension, etc.

Precipitation

Phosphate may be precipitated mainly as strengit ($FePO_4$), variscit ($AlPO_4$), struvit ($MgNH_4PO_4$) or apatit ($CA_{10}(PO_4)_6(OH)_2$). In waters that are rich with lime apatit precipitation induced by macrophytes may play an important role with respect to the phosphorus cycle. The growth of 1g of algae biomass may induce a precipitation of calcite using up to 2.3g of phosphorus if enough phosphate is available. This significantly increases the phosphorus uptake by algae (Kreuzinger, 2000).

Iron or aluminum precipitation occurs when water infiltrates the soil and groundwater, underground and into groundwater. Together with ferric or aluminum ions phosphate may be precipitated. Aerobic conditions are necessary, as is the availability of ferric or aluminum ions, which are prevalent in the soil and sediment subsurface. In general this process is only significant when water infiltrates into the bed layer and or subsurface layers (groundwater).

Adsorption and filtration

Polyphosphates, organic phosphorus compounds and ammonia can be adsorbed at the surface of sediments (e.g. as clay particles, extra cellular polymeric substances (EPS)). This has important ramifications with respect to infiltration into groundwater. Suspended substances and particulate organic matter (POM) containing nutrients may be retained by filtration when infiltration occurs from wetlands channels into groundwater.

Algal uptake

For algae growth equivalent to 1g of dry substance biomass (DS) an average of about 8mg of P and 60mg of N are taken up. The phosphorus uptake by macrophytes might be much smaller (e.g. 2.3 mg P g^{-1} DS; Humpesch ed., 1998). The nutrients incorporated by algae are stored as algal biomass for short periods, related to the algal turn over of biomass. In addition to nutrient availability, other important factors controlling this process include temperature and light. Thus the intensity of algal biomass production is highly dependent upon seasonal changes and by suspended solid concentrations which might limit the availability of light for algal growth (Hein et al. 2005).

Plant uptake

If transported to the terrestrial part of a riverine wetland (e.g. through transport and sedimentation during a flood, transport by groundwater, or direct uptake from surface waters), nutrients can be taken up by terrestrial plants. The nutrient uptake from plants in forest ecosystems has been estimated to be approximately 100 to 150 kg N ha^{-1} $year^{-1}$ and 3 – 10 kg P ha^{-1} $year^{-1}$. Fertilized agricultural systems have uptake rates between 130 and 200 N ha^{-1} $year^{-1}$ and about 15 – 20 P kg ha^{-1} $year^{-1}$.

Plant residuals (e.g. leaves) and other organic matter undergo processes of degradation, humidification, mineralization and release and are often temporarily stored in soils. However, the direct input of falling leaves into water can be considerable. Again seasonal variation is important because the uptake by plants takes place in the growing season and leaf deposition at the end of the growing season.

In contrast to algae, terrestrial plants capture more stable particulate organic matter (POM) for storage. In addition the presence of trees in wetlands areas may influence the storage of nutrients in wetlands through the formation of debris dams and consequent changes in hydraulic and hydrological conditions.

Heterotrophic growth

Recent studies have pointed to the importance of the hyporheic[1] zone for nutrient cycling and organic matter processing in small streams with constrained mixing zones. For example, the hyporheic zone of a piedmont stream with a limited depth of a few centimetres contributed about 40% of the total ecosystem respiration (Battin et al. 2003). The degree to which the hyporheic zone affects stream ecosystem function has been ascribed to physical variables, biogeochemical processing rates, temperature, nutrient and oxygen supply, and the proportion of the total discharge flowing through the hyporheic zone. For large rivers and riverine wetlands, the exchange with the hyporheic zone also increases nutrient retention (Fischer et al., 2005). Of major importance for matter processing and nutrient uptake are the auto- and heterotrophic biofilm communities on the riverbed and at the interface of the hyporheic zone. Biological processing like macrozoobenthos grazing on biofilm and microbial degradation of coarse particulate organic matter (C-POM) to fine particulate organic matter (F-POM) increase nutrient transport to deeper areas of the hyporheic zone and thus, increase the substrate supply there.

1.1.1.3. Removal

Removal is the final elimination of nutrients from a river into a riverine wetland ecosystem in such a way that no future removal from the wetland back to the river will occur. In this sense only de-nitrification and harvest can be considered as removal. Storage of nutrients over long periods of time (e.g. decades) may also be considered as removal, depending on the time horizons under consideration in management plans.

Denitrification

Denitrification in general is the reduction of nitrate to N_2O and N_2. Several processes are known. The most important process in case of nitrogen removal in riverine wetlands is denitrification by heterotrophic micro-organisms. Where dissolved oxygen is absent, nitrate is reduced to gaseous N_2. Depending on conditions of denitrification N_2O may also be produced. From stochiometric considerations it can be seen that for the denitrification of 1g of NO_3 to N about 1g total organic carbon (TOC) is consumed by bacteria (Nowak & Svardal, 1989). The availability of organic carbon and temperature are important factors with respect to the intensity of this transformation. Another process of nitrogen removal is the Anammox reaction, the importance in wetlands is not known yet.

In riverine wetlands, the carbon source from denitrification may consist of organic substances transported into the system from the river. Another important process is the local production in wetlands. Up to 60mg of N are incorporated for the production of 1g algal biomass. This algal growth leads to an accumulation of about 330mg TOC in the water. Degraded under anaerobic conditions this may lead to a denitrification of up to 330 mg NO_3-N, which is significantly more than the nitrogen consumed for algae growth. In addition to the availability of TOC, scarcity of oxygen is also a controlling factor in this process. Even if soluble oxygen is measured in the water phase, denitrification might take place in locations where the transport of oxygen is restricted. Bottom sediments and their characteristics over depth are important in this respect.

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[1] Hyporheic zone - Defined as a subsurface volume of sediment and porous space adjacent to a stream through which stream water readily exchanges. Although the hyporheic zone physically is defined by the hydrology of a stream and its surrounding environment, it has a strong influence on stream ecology, stream biogeochemical cycling, and stream-water temperatures. Thus, the hyporheic zone is an important component of stream ecosystems.

In addition to heterotrophic denitrification, autotrophic denitrification may be of importance in sediment and subsurface zones in the presence of pyrite in oxygen-depleted circumstances. For each gram of NO_3-N removed about 0.7g of pyrite is needed (Kunkel et al., 1999).

Harvest

Harvest is the removal of plants or their products from the riverine wetland ecosystem. This type of removal occurs if plants are mowed, eaten by grazing animals or harvested for wood production or consumption. The removal of nutrients by grassland harvest can be remove 30 – 50kg N ha^{-1} $year^{-1}$ and 7 – 9kg P ha^{-1} $year^{-1}$ for each cut. By comparison, average values for timber production in forests are 5kg N ha^{-1} $year^{-1}$ and 0.5kg P ha^{-1} $year^{-1}$. Despite these estimations, harvesting is a topic of ongoing scientific debate.

Long term storage

Sediments (in the form of suspended solids, plant/algae residuals and precipitates) and adsorbed nutrients can be stored in wetlands systems over long periods of time. Succession and burial of plant material can lead to such long term storage of nitrogen (Adair et al., 2004). If this process is continuously processing within the time horizon of management planning, this storage mechanism effectively can be considered as removal. In this case sediments are retained in the wetland through siltation and/or the nutrient concentrations in sediments increase. Regarding the long term perspective, siltation may eventually lead to the loss of aquatic habitats in wetlands.

1.1.1.4. Release

Nutrients stored in wetlands are usually released over time. One of the principle means of release is through erosion of the sediment/soil layer and subsequent transport downstream by surface runoff and channel flow, especially during heavy precipitation events. In addition, re-suspension can take place, involving the release of bottom sediments in a riverine wetland channel. Re-suspension increases with higher flow velocities. Stored nutrients may also be transformed into dissolved forms by mineralization, solution and desorption. Transport of dissolved forms from riverine wetlands occurs either via surface waters or groundwater.

1.1.2. Nutrient dynamics within natural riverine wetlands on the example of Nitrogen and Phosphorus

1.1.2.1. Nitrogen dynamics

Nitrogen transformation and removal in wetlands is mainly caused by denitrification and vegetation uptake (e.g. Brettar et al., 2002; Haycock et al., 1993; Johnston et al., 1997). These two primary storage, transformation and/or removal processes provide an effective buffer that protects aquatic habitats from excessive nutrient uptake. Jansson et al. (1994) in contrary showed that in an artificially intermittent flooded meadow in South Sweden only a small amount of nitrogen removal was due to plant uptake and the major part of nitrogen losses was accounted for denitrification processes in the soil.

The process of denitrification requires zones of fluctuating oxygen and a supply of organic matter. The process is controlled by groundwater and surface water exchange conditions (Dahm et al., 1998; Pinay et al., 1994). Of special significance is the link between hydrological dynamics and the biogeochemical processes which occur in the soil layers among varying saturated and unsaturated zones. Denitrification can occur in the groundwater/surface water layer and in deeper depths with groundwater discharge when there are high concentrations of organic matter (Hill et al., 2000). This suggests that denitrification is frequently carbon-limited.

Denitrification efficiently removes nitrate only when there is a frequent supply of organic matter and low oxygen content, as is often found in riparian zones, floodplains and riverine wetlands.

Vegetation growth is of great significance in terms of N removal. Consequently, in constructed wetlands, the establishment of suitable abiotic soil conditions and the creation of micro-zones suitable for organic matter release has been shown to increase the capacity to remove N from the system (Meshram et al., 1994; Reddy & D'Angelo, 1994). The N removal capacity of riverine wetlands can reduce instream transport and buffer local N input from the surroundings and thereby affect N cycling in rivers (Dahm et al., 1998).

Nutrient removal within riverine wetlands is limited when saturation of the soil may not last long enough to provide the anaerobic environment necessary for denitrification process to influence nitrate loads; and/or when organic carbon availability provided by root exudates and leaf litter is not sufficient to sustain microbial respiration (and therefore denitrification) on a long-term basis. The uptake of nutrients by vegetation within riverine wetlands is variable in space and time. Vegetation uptake in riverine wetlands reaches a maximum during the summer – normally the driest, lightest and warmest period of the year in temperature latitudes. Microbial denitrification in riverine wetlands in this period may be at minimum (Pinay et al. 1994) because soil moisture levels are low and soils are well-aerated. During autumn and winter, when soil moisture stimulates anaerobic processes, denitrification is the principle process maintaining the buffering capacity of riverine wetlands. Soil temperature is sufficient in many cases (>4ºC) to sustain denitrification (Bremner & Shaw 1958), especially deep in the soil profile (mean ≈ 10ºC).

Large rivers with relatively complex morphological structures and hydrological exchange patterns have the potential for an intense turnover of organic matter and inorganic solutes due to high algal and microbial activity (Fischer et al. 2005). McClain et al. (2003) give several examples for biogeochemical hot spots within wetlands and riparian zones along rivers where denitrification processes are fostered because nitrate rich subsurface water reached areas of organic deposits. "*Such hot spot may occupy a relatively small portion of the riparian zone because these hot spots do not owe their existence to the riparian zone, per se, but to the movement of nitrate rich ground water into an organic, reducing substrate.*" Analysis of biogeochemical budgets indicates that river networks can remove 37–76% of the total N-input mainly via denitrification, with a high contribution by high-order river sections (Seitzinger et al. 2002). Large rivers are therefore important for the biogeochemical budgets of catchments (Behrendt and Opitz 1999; Seitzinger et al. 2002), even if the water depth-related retention in river channels decreases along a river continuum (Allan 1995; Alexander et al. 2000).

1.1.2.2. Phosphorus dynamics

Many riverine wetland ecosystems are less effective as P sinks than other ecosystem types (Vymazal, 1999). Phosphorus in wetlands is mainly (>95%) stored in the soil and leaf litter components of the subsurface layer so understanding the role of wetlands in P storage and/or removal requires assessing the interaction between soil and water.

Microbial and vegetative uptake along with sorption and precipitation regulate long-term P retention in wetlands. Mineral sediment deposition of particle-bound P leads to long-term storage and is dependent on surface water input and nutrient inputs. Unlike N and C, neither the organic nor the inorganic form of P can be lost in exchange with the atmosphere. Instead, an accumulation of P is frequently found in wetlands soils. The tendency towards release or storage of P depends on the overlying water column and associated biogeochemical processes (Reddy & D'Angelo, 1994). These processes include adsorption/desorption reactions, precipitation, mineralization of organic P, and diffusion of P from the soil to the water and vice versa (e.g. Noe et al. 2003).

The P storage capacity of a riverine wetland is determined by the physical and chemical soil characteristics and the amount of inorganic P entering the wetland. In natural wetlands, the sorption potential of a predominantly mineral soil appears to be higher than that of an organic-rich freshwater swamp soil (Masscheleyn et al., 1992). Where the sorption capacity of an organic-rich freshwater soil is limited, a higher transformation rate from inorganic to organic P is found. At low P loadings, wetlands have been found to release rather than to retain P. This emphasizes the buffering capacity of wetlands. A mass-loading model for North American wetlands used for wastewater treatment identified a proportional relationship for P storage and loadings entering the wetlands until a threshold loading mass are reached (Richardson et al., 1997). Higher loadings resulted in an increase of released P concentrations, with an estimated threshold loading in the range of 1g m^{-2} yr^{-1}. However natural wetlands may exhibit different threshold capacities for P retention (Turner, 1999).

Soil conditions affect the mechanisms of P retention. For example, in acidic soils P retention is controlled by aluminum and ferric phosphates if the activities of these cations are high. In alkaline soils P fixation is governed by the availability of calcium and magnesium compounds. The availability of P is highest in soils with slightly acidic to neutral pH and depends on the redox potential (Reddy & D'Angelo, 1994). Decreasing the potential for redox conditions leads to a decline in the P retention capacity of the soil surface.

In constructed wetlands, P storage can be estimated by hydrologic transport models in short-term experiments (e.g. Ho & Notodarmojo, 1995). Removal capacities for P in constructed wetlands are found to decrease with the age of the wetlands (Vymazal, 1999). One reason for this is the decline in available adsorption sites in the soil during constant flow conditions. In experimental settings of constructed wetlands, P removal was stimulated by pulsing the hydrologic loading and during frequent changes of soil conditions (Busnardo et al., 1992). Phosphorus removal by harvesting usually accounts for less than 10% of the total P removal in constructed wetlands (Vymazal, 1999).

1.2. The role of wetlands and their nutrient retention capacity within river networks

Although much of the scientific literature regarding natural wetlands notes the positive influence that wetlands have on water quality – particularly in removing nutrient pollution – there exists only limited quantitative data on the mechanisms behind this function (Tockner et al., 2002). Fischer & Acreman (2004) reviewed experimental data from 57 wetlands around the world. The majority revealed significant nutrient reduction for N and P. Few studies found wetlands to increase loadings of soluble N and P mainly during high flow events. Swamps and Marshes were found to be slightly more effective than riparian zones.

Much of the literature relates to constructed wetlands that are smaller in scale, specifically built to act as natural filtration pools and not directly comparable to natural wetlands (Vymazal, 1999). Many of the following data and conclusions therefore are derived from the investigations of riparian buffer strips (BS).

1.2.1. The longitudinal context

Within this chapter the recent standard of knowledge about wetlands with respect to different river sizes and characteristics is summarized. Within smaller rivers (low order rivers) vegetated buffer strips along the surface waters are predominant, whereas in large rivers (higher order rivers) principally broadened floodplain areas are found (e.g. Alexander et al., 2000; Setzinger et al., 2002).

1.2.1.1. Nitrogen removal

The nitrogen removal potential is shown by the fact that nitrogen retention generally increases with increased nitrogen loading, and the saturation level of nitrogen removal in wetlands is not reached (Jansson et al, 1995). The entire potential of nitrate removal is not fully realised in much "nitrate limited" systems (nitrate loads are not very high in this systems) (Fennesey & Cronk, 1997). Richardson et al. (2004) showed that denitrification in the upper Mississippi River is nitrate limited throughout the growing season and that the delivery of nitrate is strongly controlled by river discharge and hydrologic connectivity across the floodplain. The authors estimated that denitrification removes 6939 t Nyr^{-1} or 6.9% of the total annual nitrate input to the investigated reach.

VBS: Many studies reveal significant *removal of nitrogen* through riparian buffer strips (see review from Fennesey & Cronk, 1997). Peterjohn & Cornell (1984) find reductions of Nitrate (79%), PON (86%), Ammonium (73%) and organic N (62%) in surface agricultural runoff into a stream. Subsurface flow reduction has found to be even significantly greater where 90% of nitrate was reduced over the year. The authors calculated 33% of this reduction was due to plant uptake and the remaining two thirds was assumed to denitrification derived losses.

Vellidis et al. (2003) determined the water quality effect of a restored forested riparian wetland adjacent to a manure application area and a heavily fertilized pasture in the Georgia Coastal Plain. Water and nutrient mass balance showed that retention and removal rates for nitrogen species ranged from a high of 78% for nitrate to a low of 52% for ammonium. Most of the N removal was accounted for by denitrification.

Lowrance et al. (1984) find nutrient losses in a riparian forest receiving subsurface water also from agricultural drainage of 68% nitrate 30% phosphorus, 39% calcium and 23% magnesium. Nitrate losses due to denitrification were not quantified but plant uptake and the transformation into organic Nitrogen was also responsible for the total nitrate reductions.

Cooke & Cooper (1988) find 100% removal of nitrate in saturated soils (subsurface water fed, New Zealand), but after storm events the soils released reduced nitrogen which the authors contribute to local livestock grazing. Haycock & Burt (1992) revealed 97% and 82 % reduction of nitrate from subsurface water in forested and grass-dominated buffer strips, respectively. Forested buffers are presumed to have higher denitrification rates because the root system of the trees produces more carbon at greater depth in the soil profile (Fennesey & Cronk, 1997). Osborne & Kovacic (1992) also found vegetated buffer strips in smaller rivers to be effective in N reduction (up to 90%) in shallow GW. Over a year's period the forested buffer was more efficient than the grass VBS. Denitrification was found to be an important process during winter, though throughout the whole year (Haycock & Pinay 1992; Pinay et al., 1993; Osborne & Kovacic, 1993). In an earlier review from Petersen et al. (1992) 68-100% of N was found to be reduced in GW and 78-98% of N was lost in surface water from forested buffer strips (depending on initial nutrient concentrations, buffer width and soil type). Osborne & Kovacic (1992) report also from a literature review 40-100% of N losses in subsurface flows in forested VBS and 10-60% N reductions through grass VBS. Jansson et al. (1995) on the contrary found forest wetlands less efficient nitrogen traps than other wetland types citing forested wetlands in southern Sweden where the annual nitrogen retention was found to be close to zero.

Table 1 Relative nitrate removal of forested vs. herbaceous buffer strips

Relativ removal of N (%)			
Forested buffer strip	Herbaceous buffer strip	**Reference**	**In (source)**
100	84	Haycock & Pinay (1993)	Fennessy & Cronk (1997)
	N:P ratio 11 times lower	Correll (1991)	Fennessy & Cronk (1997)
76 (subsurface)	50 (surface)	Vought et al. (1991)	Fennessy & Cronk (1997)
	higher than forested	Lowrance et al. (1995)	Fennessy & Cronk (1997)
68-100 (subsurface)		reviewd from Petersen et al. (1992)	Osborne & Kovacic (1993)
78-98 (surface)		reviewd from Petersen et al. (1992)	Osborne & Kovacic (1993)
40-100 (subsurface)	10-60 (subsurface)	reviewed from Osborne & Kovacic (1993)	Osborne & Kovacic (1993)
78 (subsurface)		Vellidis et al (2003)	

The ideal *buffer width* for efficient nitrate removal has been found to be 20-30m, after that removal does not increase substantially (Vought et al., 1994).

The role of *vegetation* in nutrient retention of riparian buffer strips has been a case of debate in science (see Fennessy & Cronk, 1997). The authors conclude that plant uptake is not responsible for large amounts of nutrient removal but vegetation in riparian buffers is vital as it determines important conditions for denitrification and nutrient removal in general (e.g. promotes sedimentation and prevents erosion, requires soil aeration through oxidised rhizospheres, improves soil texture with leads to higher infiltration capacity, provides litter and root exudates as carbon source). Roots and root exudates of riparian trees put organic carbon deep into the soil profile (Sedell et al. 1991) and if the subsurface water connection is intact the availability of lots of DOC enhances denitrification (Schipper et al., 1991). Via plant uptake and assimilation nutrients are converted from inorganic to organic forms, which are less bioavailable. Therefore even if there is little net retention this conversion benefits water quality (Johnston, 1991). There is a strong annual and diurnal pattern of N uptake by plants, but it acts as a de-synchronization for nutrient peak flows during the growing season. If nutrients are abundant also plants can be effective nutrient sinks (Fennessy & Cronk, 1997).

<u>Floodplains</u>

Lowland floodplains in a review of Danish restoration projects have been shown to be important in storing sediment, organic matter, organic nitrogen and phosphorus. As proportional most of these materials are transported during flood events, even small inundated lowland floodplains are helpful in restricting downstream export (Kronvang, 2003).

A simulation by Babtist et al. find that a water detention area along the Sava (Croatia) contributes to the removal of up to 30% of the sediment and adsorbed phosphorus transported in the wetland from the river during high flow events. Van der Lee et al. (2004) found annual nitrogen reduction in the Rhine is less than 3% and phosphorus retention between 5 and 18% where floodplain sedimentation was identified as the most important retention mechanism for both N and P.

In a recent study Forshay & Stanley (2005) demonstrated the floodplain capacity of the Wisconsin River to decrease the dominant fraction of river borne N within days of inundation acting as an active N sink often driven by denitrification, and that enhancing connections between rivers and their floodplains may also enhance overall retention and reduce N exports from large basins. Along with the conclusions of Fennesey & Cronk (1996) for VBS of rivers the authors´ experiments (natural flooding, amendment experiments and in situ amendment in the field) showed, that also in floodplains of higher order rivers denitrification is nitrate limited and therefore the potential N reduction is driven by hydrologic transport into the wetland.

Some denitrification rates are summarised after the review from Fennesey & Cronk (1997) and other current papers in Table 2.

Table 2 Denitrification rates from selected literature, numbers in brackets indicate laboratory experiments.

Reference	Source	Site description	Rate of denitrification in g Nm-2a-1 if not otherwise denoted	Convertetd into g Nm-2a-1	Amendment
Ambus & Lowrance (1995)	Fennessy & Cronk (1997)	restored reparian forest	6.9	6.9	enriched with liquid manure
Forshay & Stanley (2005)		floodplain soil	0-483 µg Nm-2h-1	0 - 4.2	no or C enriched
Forshay & Stanley (2005)		floodplain soil	>10,000	10,000	N enriched
Groffman (1994)	Fennessy & Cronk (1997)	forested area	0.01	0.01	no
Groffman (1994)	Fennessy & Cronk (1997)	forested area	3.4	3.4	enriched
Groffman et al. (1991)	Fennessy & Cronk (1997)	forested buffer strips	0.22	0.22	nitrate + glucose
Groffman et al. (1991)	Fennessy & Cronk (1997)	grass buffer strips	1.58 g Nm-2d-1	576.7	nitrate + glucose
Hanson et al. (1994)	Fennessy & Cronk (1997)		0.5 - 1.6	0.5 - 1.6	no
Hanson et al. (1994)	Fennessy & Cronk (1997)		0.7 - 3.8	0.7 - 3.8	nitrate
Jansson et. al (1994)		river sediment	0.01-0.02 g Nm-2d-1	3.7 - 7.3	no
Jansson et. al (1994)		pond	300	300	no
Johnston (2001)	Fennessy & Cronk (1997)		59.7 (28.8 g Nm-2d-1)	59.7 (10,512)	nitrate
Johnston (2001)	Fennessy & Cronk (1997)		0.2 (6.1)	0.2 (6.1)	no
Lowrance et al. (1995)	Fennessy & Cronk (1997)	grass buffer strips	6.9	6.9	
Lowrance et al. (1995)	Fennessy & Cronk (1997)	young hardwood	4.3	4.3	
Lowrance et al. (1995)	Fennessy & Cronk (1997)	young pine	3.0	3	
Pattinson et al. (1998)	Richardson et al. (2004)	Wiske–Swale–Ouse River upstream reach	2.5 µg Ncm–2h–1	219	no
Pattinson et al. (1998)	Richardson et al. (2004)	Wiske–Swale–Ouse River downstream reach	91.7 µg Ncm–2h–1	8,033	no
PHARE project (1997)		floodplain forrest (Morawa/Dyje)	0.224 tha-1a-1	22,4	no
Richardson et al. (2004)		Upper Mississippi River (UMR)	105 µg Ncm–2·h–1	9,198	no
Richardson et al. (2004)		UMR, backwater	1.97 µg Ncm–2h–1	173	no
Richardson et al. (2004)		UMR, mainchannel	0.14 µg Ncm–2cmh–1	12,3	no
Seitzinger (1988)	Richardson et al. (2004)	river sediment	0.48 µg Ncm–2h–1	42.1	no
Seitzinger (1988)	Richardson et al. (2004)	oligo/mesotrophic lakes	0.007 to 0.08 µg	0.6 - 7.0	no
Seitzinger (1988)	Richardson et al. (2004)	eutrophic lakes	0.06 to 0.24 µg	5.3 - 21.0	no
Sjodin et al. (1997)	Richardson et al. (2004)	river sediment	0.18–10.2 µg	15.8 - 893	no
Various references reviewed	Jansson et al. (1998)	Bogs and fens (drainage basin Baltic Sea)	0.420-31 tha-1a-1	42 - 3,100	no
Venterink, Hummelink & van den Hoorn (2003)		floodplain soil (grass or reed)	0,015 gNm-2d-1	5.5	no

<u>River</u>

Denitrification takes also place in the sediments of the river itself (Fischer et al. 2005), e.g. 6% of annual TN export (15% nitrate loss by makrophyte uptake) in a Canadian river basin (Hill, 1979) or 7-35% nitrogen load decrease by denitrification (in a review from Seitzinger, 1988). Richardson et al. (2004) recently found the river sediments to have significantly lower denitrification activity than backwaters of the Upper Mississippi River (Table 1). Haycock & Burt (1992) found nitrate reductions in the river ranging from 5% to 60% in the summer when mean nitrate concentrations were lower. In an English river with exclusively agricultural catchment 15 % of the nitrate was found to be denitrified in the sediment at baseflow conditions, and even more under high-flow conditions in winter (Cooke & White, 1987).

In a first order river Mulholland et al. (2004) found that denitrification represented about 16% of the total nitrate removal rate from stream water under ambient conditions with low nitrate concentration. Total nitrate uptake rates were 0.32 mg N m^{-2} s^{-1} and denitrification rate was 0.0046 m^{-1}.

Experimental work at the Elbe (Fischer et al., 2005) revealed that in the central bed of the river, bacterial production and extracellular enzyme activity remained high down to the deepest sediment layers investigated leading the authors to the conclusion that carbon and nitrogen cycling in the river is controlled by the live sediments of the central river channel representing a ‘‘liver function’’ in the river’s metabolism.

1.2.1.2. Sediment trapping

VBS

Vegetation in riparian buffer zones controls patterns of sedimentation and erosion where re-suspension is seen as a process that may occur due to fluvial activity, but sedimentation is seen to be a relatively irreversible mechanism (Fennessy & Cronk, 1997). Novitzki (1979) showed that sediment load was 90% lower if the watershed area was covered with 40% of wetlands and lakes. However, only 5% of the wetlands were responsible for 70% of the sediment trapping. Strategic position of wetland within a watershed can maximize sediment retention and has been found more important than the absolute extent of wetland area (Johnston et al., 1990). Fairy narrow VBS can reduce sediment input to surface waters (reviewed by Karr & Schlosser, 1977), but the long-term effectiveness (Dillaha et al., 1986) is not fully known (Osborne & Kovacic, 1993).

Floodplains

The results of Danish restoration activities (numerous projects where the evaluation of success has been done only in a few cases) of wetlands “indicate that 254-3,002 g sediment m^{-2}, 70-360 g organic matter m^{-2} and 1.18-6.5 g phosphorus m^{-2} can be deposited on the floodplain during flooding events lasting 1 to 3 weeks (Kronvang, 2003).

The daNUbs Project (2005) clearly “illustrated the role of floodplains as a sink for fine sediments and P. The estimated retention of fine sediments during the flood event in August 2002 in the floodplains of the old Danube bed parallel to the Gabcikovo PS Inlet Channel was 60%. Other surveys under normal flow conditions showed retention in the order of 5%-15%. By means of data analysis including also data from other sources, it was demonstrated that this quite extreme hydrological event in the Upper Danube was rapidly “flattened out” further downstream. This suggests that the importance of such events in the upper part of the catchment is of minor impact on a basin-wide scale in large rivers.”

1.2.1.3. Phosphorus retention

VBS

Phosphorus retention appears to be maximized when buffer strips are composed of dense herbaceous and woody vegetation where stem density and related sediment deposition explains this P retention efficiency best (Fennesey & Cronk, 1997). Vellidis et al. (2003) determined the water quality effect of a restored forested riparian wetland adjacent to a manure application area and a heavily fertilized pasture in the Georgia Coastal Plain. Retention rates for both DRP and total P were 66%. Vought et al. (1994) find a bush/grass buffer most effective compared to a grassed or forested one. Osborne & Kovacic (1993) find a forested buffer strip less effective in reducing both total and dissolved P than were grass strips. Both wetland released P to the groundwater during the dormant season leading the authors to the recommendation of periodic harvesting intervention. Omernik et al. (1981) also suggested that forested BS become saturated with nutrients on an annual basis and therefore become inefficient filters. Although P retention in riparian ecosystems is not permanent the temporal delay in release can have water quality benefit downstream (Fennesey & Cronk, 1997).

Floodplains

Phosphorus retention during flood events is strongly related to sediment trapping efficiency and Venterink et al. (2004) conclude from their results in the Rhine delta that smaller flood events are the most effective phosphorus traps. The proportional P retention (% of P load) is highest in shallow rivers with a maximum contact between water and soil surface of channels or floodplains providing favorable conditions for sedimentation and as a consequence also for phosphorus retention.

In the French river Adour nearly 99% of the particulate phosphorus is transported during flood events. Dissolved phosphorus is mobilized during autumn and winter whereas it is retained during the vegetative period (Brunet & Brian Astin, 2000).

River

The river cannel itself also plays a role in the Phosphorus dynamics. Venterink at al. (2004) report retention rates of 0.23 g P s^{-1} km^{-1} in the main channel of the Dutch Rhine Tributaries. Zessner et al. (2005) - besides long term retention in floodplains - point out parts of the riverbed itself where the tractive forces are reduced as a location of sedimentation and phosphorus storage. Under anaerobic conditions the phosphorus in the sediment will partly be transformed into Orthophosphate continuously will contribute to the soluble phosphorus transport to downstream areas. At high flow events other parts of the river sediment will get mobilised again by re-suspension. These alternation processes decrease the share of the total phosphorus transport of larger catchments compared to small ones. High flow events contribute between 7 and 20 % to the total phosphorus transport in smaller catchments, whereas in big catchments much smaller contributions of flood events on the total P-transport can be expected as average over many years (Zessner et al., 2005).

1.2.2. The lateral extension

This part of the literature summary highlights the aspects of nutrient related processes within wetlands with respect to hydrologic exchange. The source of water (river water, seepage or groundwater) plays a distinct role in nutrient supply. The timing of floods and low waters, the characteristics of the connection to the main channel and the proportion of surface and subsurface flow determine the conditions in the related wetlands. River alteration may strongly alter this natural interaction between the catchment, the river and accompanying wetland elements.

VBS

Nitrate removal is maximized if water flow is subsurface, particularly in winter month when soils are saturated (Davidson & Swank, 1986). Surface flow leads primarily to the retention of sediment and absorbed pollutants via deposition. Residence time is probably the single most important variable for water quality improvement (Knight et al., 1987; Mitsch & Gosselink, 1993). The relative proportion of water flow above and below (which is difficult to measure) ground influences the effectiveness of any buffer strip. Flooded buffer strips have reduced residence time and therefore nitrate may run off quickly into adjacent streams.

Floodplains

Amoros & Bornette (2002) review amongst other things the role of connectivity of riverine floodplains on the suspended sediment and nutrient content summarizing essential processes for water quality aspects. With increasing connectivity the sediment load and the relative inorganic content decreases (Heiler et al., 1995; Martinet et al., 1993). In disconnected water bodies, turbidity depends mainly on phytoplankton, which is controlled by nutrient content in the water (Hein et al., 1999; Tockner et al. 1999). Dissolved nutrient content increases with connectivity to the river providing nutrient rich water and sediment (Heiler et al., 1995; Schiemer et al., 1999). In disconnected water-bodies the nutrient content also depends on the surrounding land use and the successional state (Bornette et al., 1998).

In the sense of a gradient of connectivity, a comparison with the results of Jansson et al. (1994) may be useful. They define denitrification as the main mechanism of nitrogen removal in wetlands whereas in lakes also sedimentation via algal biomass plays a large role. The water retention time as the most important crucial factor determines the amount of nitrogen removal. Thus lakes remove more nitrogen but nitrogen retention is higher in small wetlands (N retention per m2). This study recommends ponds as a means of reduction of nitrogen.

Forshay & Stanley (2005) state that "…only a handful of studies (e.g., Brunet et al., 1994; Knowlton & Jones, 1997; Tockner et al., 1999) have even documented changes in surface water chemistry over the course of flooding in this type of river system…". Concerning the connectivity related nutrient depletion the authors discuss: "The basic pattern of increasing N during flooding followed by decreasing concentrations as hydrologic connectivity between the river and floodplain is lost has also been observed in the Rhine and Danube floodplains of Europe, and the Missouri River floodplain in the U.S. (Van den Brink et al., 1994; Knowlton & Jones, 1997; Tockner et al., 1999). The Wisconsin River floodplain attenuated nitrate concentration to below-detectable limits in less than 6 days following isolation from the main channel. In contrast, a month was required for nitrate concentration to fall to pre-flood levels in the Danube River (Hein et al., 1999) and in experimental nitrate additions of inundated floodplain soils in a bottomland hardwood wetland in the southeastern U.S. (DeLaune et al., 1996). Several factors can influence the speed with which N concentrations decline during flood recession or intentional N additions, including water depth, sediment organic matter content (DeLaune et al., 1996; Brettar et al., 2002), initial nitrate concentration (Garcı´a-Ruiz et al., 1998) and time of year (Brunet & Astin, 2000). With a limited number of sites available for comparison, it is not clear what physical factors foster the rapid versus slow N removal among rivers, suggesting an important question for future research."

Venterink, Hummelink & van den Hoorn (2003) find similar and comparatively low denitrification rates in the Rhine Delta with simulated flooded agricultural grasslands and reedbeds which leads the authors to the conclusion that floodplain rehabilitation from grasslands into reedbeds may not increase N-retention through higher denitrification rates in the floodwater. They also point out that rehabilitation of floodplain wetlands may also serve as buffer strips reducing the amount of nitrate entering the river from polluted groundwater, and hence increasing N-retention in another way (e.g., Osborne & Kovacic, 1993; Vought et al., 1994; Fennessy & Cronk, 1997).

In another recent study Venterink et al. (2003) evaluated the importance of floodplains for nutrient retention in two distributaries of the River Rhine with different fraction of floodwater discharging through the floodplains by monitoring N and P retention in a body of water during downstream transport. Total nitrogen (TN) did not decrease significantly during downstream transport in both rivers, whereas 20 to 45 % of total phosphorus (TP) disappeared during transport in the river with a larger proportion of floodplain discharge. The authors suggest that sediment trapping efficiency was the driving force of this P retention pattern. These findings were confirmed by Van der Lee et al. (2004) who estimated nutrient losses in the same Rhine distributaries on an annual basis. Total retention of N was less than 3% of the annual load whereas the total retention of P was 5 to 18% of the annual P load, which is considered significant. Floodplain sedimentation was the most important retention mechanism for both N and P. Compared to estimates of total nutrient retention in the river network, floodplain P retention is therefore an important mechanism for the river IJssel with its natural floodplain, but not for the engineered river Waal. This goes along with recent findings from the Danube where phosphorus retention was shown to be highly dependent on the floodplain's hydrologic connectivity, as the retention capacity rises exponentially with rising discharge of the main channel (Hein et al., 2005).

<u>Alteration in river hydro morphology and their consequences for nutrient retention</u>

Nutrient cycling is influenced by: water velocity, timing and duration of inundation, connectivity of subsystems and residence time. Flood control measures influence the morphology, lower the river bed, decrease the saturated soil zone and may permanently lower the water table below the root zone. This alters the floodplain functions such as storage or release and the directing of water flows (Gordon et al., 1992). Cooper (1993) found three times higher nitrate concentration in canalized rivers with little or no buffer zones than in rivers with intact riparian wetlands.

The origin of the water supply (river, river infiltration and seepage, hill slope aquifer) depends on the water-body's location and its surface and subsurface hydrological connectivity. The water's origin determines the water temperature, turbidity and nutrient content, which greatly influence habitat heterogeneity, plant and animal recruitment, and ecosystem productivity. Pulsing connectivity controls nutrient inputs and the alternation of production and transport phases (Amoros & Bornette, 2002).

Adair et al. (2004) find high rates of N turnover, N mineralization, nitrification, and available N in chronofrequences of soils from a regulated semi-arid river (Colorado) contrasted by low availability and turnover rates in similar sites along an unregulated river. Puchalski (2003) focuses on the role of sediments from sites with different hydrological dynamics (oxbows in and behind dike) in nutrient uptake with respect to nutrient load in the water. Groundwater fed oxbow behind a dike releases more phosphate and ammonia at low nutrient concentrations in the water. The uptake of ammonia is minimal at high nutrient concentration in the water column and the production nitrite and DOM is high in comparison to the flooded areas.

The results of Comin et al. (2003) in a Spanish floodplain also indicate that natural floodplains with a mosaic of habitat and high landscape diversity have a higher potential for water and nutrient retention than floodplains with leveled terrain and a homogeneous agricultural surrounding. Floodplains with extensive natural vegetation can play a role as filters of suspended solids and nutrients during flood pulses (Spink et al., 1998). Floodplains which are intensively used by humans may behave either as a source or as a sink depending on type of organic matter and chemical compound considered (Tockener et al., 1999; Gergel et al., 2002)

1.3. Risks for wetlands related to nutrient retention functions

1.3.1. Retention of toxic substances – (bio-) accumulation

The (bio-) accumulation of toxic compounds in wetlands is a complex topic involving e.g. diverse chemical processes, biological hierarchies and food web constellations. Exemplarily a review from Matagi et al. (1998) finds that wetlands whether they are natural or artificial are capable to purify water containing heavy metals (Matagi, 1993; Tam and Wong, 1994; Mbeiza, 1993; Denny et al., 1995). The removal processes may occur in all compartments within a wetland. "The *water compartment* contains heterogeneous polyligands, i.e. fulvic, humic and tannic acids, amorphous metaloxyhydroxides of Mn, Fe, Al, clay, bacterial surfaces and associated exocopolymers, suspended particles and macro-molecules e.g. polysaccharides, proteins, etc (Greenland and Hayes, 1978; Tessier et al 1979; Luoma and Bryan, 1981). These substances demobilise the dissolved metal fraction of the incoming wastewater through various mechanisms. The water is effectively scavenged of heavy metals by precipitation of high molecular weight humic substances and hydrous oxides of manganese and iron, resulting in transfer of much of the dissolved heavy metals to the *sediments* due to adsorption processes which bind inorganic pollutants with varying strength to the surfaces by sediment colloids. In the *biota*, biological conversion occurs through assimilation and metabolism of micro-organisms living on and around the macrophyte and plant uptake and metabolism. In permanently anoxic water conditions in wetlands, decomposition of organic matter is by reduction and organic matter accumulates on the sediment surface. The resulting organic sediment surface is responsible for scavenging heavy metals from influent wastewater."

The same authors report high metal removal rates of close to 100% by wetlands but at the same time point out that there is requirement of long term investigation with special emphasis on heavy metal removal mechanisms. The use of wetlands to control pollution by means of heavy metal retention is considered to accumulate problems for the future because they can only be stored and not depleted. The destruction or harvesting of wetland biomass is considered to release the stored heavy metals into the environment again. In this sense wetlands seem not be a long-lasting solution for heavy metal contamination.

First analytical results from soils at the Meuse River confirm that soil may widely be contaminated by heavy metals in large concentration, not only for zinc and cadmium but also for lead, arsenic and mercury. Microbial life in this zone is lower than in less contaminated areas, probably because of such toxic environmental conditions (Aquaterra, Deliverable No.: BGC3.2)

Kadlec & Knight (1996) summarize the key interactions of (treatment) wetlands with heavy metals by three mechanisms: (i) binding to soil, sediments, and soluble organics, (ii) precipitation as insoluble salts, principally sulfides and oxyhydroxides and (iii) uptake by plants, including algae, and by bacteria. The authors underline the current incomplete knowledge on wetland performance in removing heavy metals.

1.4. Wetland management

1.4.1. Recognition of wetlands for catchments scale processes

Because most of the water in a watershed originates in the headwaters most efficient water quality control will target this part of the landscape (Fennessy & Cronk, 1997).

Mitch (1992) presented several alternatives for restoration strategies: buffer strips or as an alternative also wetland basins may be used to intercept waters from small tributaries, surface or tile drains to reveal better water quality. Van der Valk & Jolly (1992) suggested different scales of restoration within a watershed: wetlands at the base of the watershed, or small wetlands distributed in the upper reaches. Although Johnston et al. (1990) find riparian wetlands in larger rivers more effective in improving water quality, Fennessy & Cronk (1997) counter that most of the water will pass these wetlands through the river channel and would not be affected by riparian ecotone processes.

In the Mississippi basin Alexander et al. (2000) showed a rapid decline in the average first-order rate of nitrogen loss (which is nitrogen loss per unit travel time) with channel size (which is depth)—from 0.45 day-1 in small streams to 0.005 day-1, concluding that the proximity of sources to large streams and rivers is an important determinant of nitrogen delivery to the estuary area.

In a regression model applied to 16 drainage networks (wetlands are not integrated) in the eastern U.S. Seitzinger et al. (2002) predict N removed from streams and reservoirs (where reservoirs even with optimal spatial position and morphologic features revealed to contribute little to the N-removal) as an inverse function of the water displacement time of the water body (which is the ratio of water body depth to water time of travel). 37% to 76% of N input to these rivers is removed during transport through the river networks. Approximately half of that is removed in 1st through 4th order streams which account for 90% of the total stream length. The other half is removed in 5th order and higher rivers which account for only about 10% of the total stream length. This suggests a crucial contribution of larger rivers and streams to N removal within a river network.

McClain et al. (2003) found the use of metrics derived at one particular scale to evaluate the denitrification rates at broader or finer scales is typically unsuccessful, despite the fact that denitrification hot spots occur at multiple scales. "*For instance, at the 100–1000-m scale, riparian zones have been identified as important sites for the removal of upland-derived nitrate fluxes via denitrification (Peterjohn and Correll 1984; see Haycock and others 1997 for a review). Attempts to scale up this result by relating the presence of riparian wetlands to nitrate elimination via denitrification at the scale of 10–100-km2 catchments have been largely unsuccessful (Burt and others 1988; Osborne and Wiley 1988; Tufford and others 1998). At this scale, the arrangement of the wetlands relative to the flowpaths is the most critical metric (Basnyat and others 1999; Creed and Band 1998; Johnston and others 1990); it is not captured by total amount of riparian wetland present, but rather is best characterized by length of contact between upland and wetland. For the same reason, attempts to scale down the inverse relationship between percentage of wetland in larger catchments (100 km 2 and above) to nitrate fluxes at the outlet of smaller catchments have also failed*." For the nutrient management on the catchments scale the authors point out that certain riparian zones or wetlands may be more important due to their position and hydrologic connectivity in the basin, than others.

Kroiss et al. (2004) summarize driving forces for nutrient transport and losses in the Danube River basin. According to other studies (e.g. Alexander et al, 2002; Fennessy & Cronk, 1997) the authors see most of the denitrification potential mainly from the source to medium-size rivers with strong emphasis on processes in soil and groundwater (residence time) and the interaction between ground and river water (riparian zones), leading to the conclusion that large rivers (including wetlands along these rivers and the delta) have little influence on N transport and loss.

The daNUbs (2005) project also emphasis in this context the important role of the smaller surface waters as compared to the major rivers and the Danube Delta: "Elevated concentrations (phosphate, nitrate, ammonia etc.) due to nutrient emissions affect the ground and surface water quality mainly in regions with low groundwater recharge rates and low river discharge as the dilution capacity is low. At the same time the retention of P by sedimentation and the removal of N by denitrification are high. These regions contribute only little to the total nutrient discharge to the Black Sea. 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."

1.4.2. Implications for wetland management

This subchapter lists important statements and recommendations for wetland management purposes by topic.

- **Morphological & hydrological conditions:** Subsurface flow is the only clear site of nitrate loss (Jacobs & Gilliam, 1985; Haycock & Pinay, 1993). In surface flows this relation is not clear, eg. Hill (1988) find decreasing nitrate removal with increasing surface flow - management action should take account for this (Fennessy & Cronk, 1997). They therefore recommend large portions of water flux through the soil for optimal nitrate removal. With adequate retention times and carbon sources for denitrification 100% removal is possible. Management efforts often concentrate on hydrological measures. Temperate wetlands are adapted to the changes in the yearly hydroperiod. Management should take this into account by re-establishing natural like hydrological conditions (Fennessy & Cronk, 1997). Restoration projects therefore have to establish suitable hydrologic conditions in advance. Forshay & Stanley (2005) demonstrate the capacity to deplete repeated inputs of NO3-N in addition experiments, they propose pulsed flooding as an effective means of managing water releases, if N removal is the management goal. The seasonal pattern of inundation acts as a pulse leading to higher rates of productivity and creating higher nutrient uptake potential (Lugo et al., 1988 in Fennessy & Cronk, 1997).

> **Vegetation:** Correll (1991) suggested a design to promote retention of nitrate, sediment and phosphorus consisting of a forested buffer strip with waterlogged soils to create optimal conditions for denitrification. An herbaceous strip should maximise sediment associated phosphorus interception from an adjacent crop land. Osborne & Kovacic (1993) suggest designs of alternating grass and forested buffers to maximise N and P retention.

> **Harvest:** Harvesting to permanently remove biomass bond nutrients is also considered, but there are controversial opinions on this topic (periodic harvesting may maximise nutrient uptake ant prevent nutrient release, but natural systems can also provide prolonged removal periods without invasive management) (Fennessy & Cronk, 1997). There seem to be high variation in harvesting efficiency with different local premises: For example Puchalski (2003) showed a spatial zonation of nutrient metabolism of flood-sorted reed debris in early spring (lake litoral). Reed leaves are an effective P and NO3 trap. NH4 in contrast is released by the decaying leaves whereas the culm prisms retain ammonia. Removing old reeds was therefore not recommended in this case.

> **Evaluations:** A number of riparian restoration projects have begun in the last years but in many cases poorly defined project objectives and a lack of long term monitoring have hindered evaluations of their success or failures (Fennessy & Cronk, 1997).

> **Costs:** The economic value of floodplain rehabilitation due to nutrient removal has been assessed at 8.7 million € annually (in Denhardt, 2002). The average costs for restoration of floodplains along the River Elbe at 530 € ha^{-1} (Scholten et al., 2005.

2. CASE STUDY DANUBE BETWEEN VIENNA AND MEDVE

The case study area is situated between Vienna (rkm 1941) and Medve (rkm 1806) downstream Szigetköz. In between the 135 km river stretch of the Danube three floodplains different in origin and characteristics are under investigation:

> Lobau (Austria),
> Regelsbrunn (Austria) and
> Szigetköz (Hungary).

On base of monitoring data from the Trans National Monitoring Network (=TNMN) available at www.icpdr.org completed by measurements from the Vienna University of Technology (flood events of 2002), University of Vienna (Lobau, Regelsbrunn) and MAFI (Szigetköz) a rough approach is introduced to calculate nutrient transport and retention at different scales:

> nutrient transport behaviour at the river scale
> nutrient transport and retention/removal behaviour at individual floodplain scale.

In a synthesis, the nutrients retained/removed in the three floodplains are compared to the loads transported by the Danube considering different hydrological conditions. Consequently, the years 2002 (wet year, characterised by extremely high Danube discharges, with two flood events with a once in ten years probability (=HQ[2]$_{10}$) and one flood event with a once in a hundred years probability (=HQ_{100})) and 2003 (dry year, characterised by low discharges) are investigated to point out

> how discharge and hydrological exchange affects nutrient dynamics
> how these patterns differ between different nutrient species (TP, DIN) and
> if altered (Lobau), restored (Regelsbrunn) as well as mainly "artificial" (Szigetköz) floodplains differ in nutrient retention/removal capacity.

Results from this approach express the broad variability of nutrient retention/removal capacity of riverine wetlands with respect to hydrological variance. Results are helpful to understand and critically highlight load as well as retention/removal calculations from single years or events and to give an overview concerning the dimension of nutrient retention/ losses possibly caused by riverine wetlands on a short term perspective.

In a further step reasons for different nutrient retention/removal behavior in individual floodplains can be outlined with respect to list criteria remarkable in case of restoring riverine wetlands.

2.1. Case study area

2.1.1. Danube River

The river reach under investigation arranges the Upper Danube section with the Middle Danube section beginning below the inflow of the Morava River. With respect to its geo-morphological units the river reach is characterized by a significant decrease of riverbed slope downstream the Gabcikovo reservoir from a mean slope of 0.43‰ between Passau and Gabcikovo to a mean slope of only 0.17-0.07‰ between Gabcikovo and Budapest. Thus, it can be expected that a natural flow velocity reduction will occur downstream the Gabcikovo in addition to the backwater initiated by the Hydroelectric Power Station itself.

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[2] HQ 10 and HQ100 define the one in 10 years and one in 100 years flood event for this Danube stretch.

The Danube River reach between Vienna and Bratislava is characterised by alluvial forests on both sides. The main tributaries are the Schwechat and the Leitha (dexter) and the Morawa (sinistral) which are not considered in our estimates. Between Bratislava and Gabcikovo the Danube River shows typical features of a damned river. Flow velocities are reduced due to a broadened width profile and cause an accumulation of fine sediments.

In general within reservoirs the abiotic and biotic characteristics change from running waters to stagnant lake systems (JDS, 2002).

Downstream the Gabcikovo reservoir the Danube starts to develop from an alpine to a lowland river. The horizontal profile widens the slope and flow velocity decreases. (JDS, 2002)

The discharges of the Danube River reach with respect to the years 2002 and 2003 are discussed below.

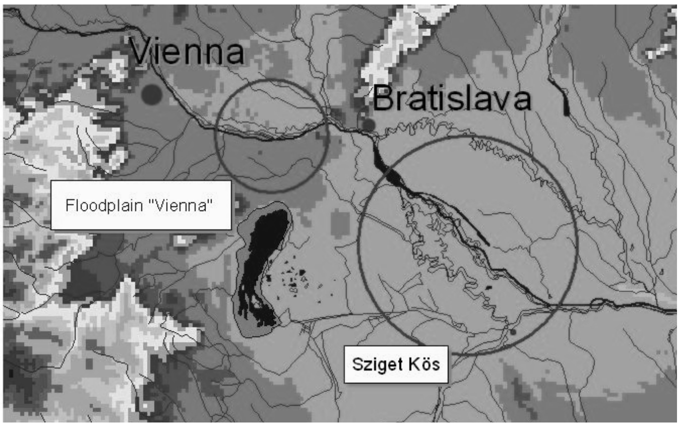

Figure 1 Case study region

2.1.2. Regelsbrunn

One example of re-activated hydrological connectivity is the floodplain segment of Regelsbrunn. It is dominated by a former river channel with a total length of 10km. The connectivity with the Danube was enhanced by lowering the embankments and by artificial dike openings in different inflow areas providing surface connection at water levels 0.5m below mean water (Schiemer et al., 1999; Hein et al., 2004). The weirs within the former side channel of the Danube have been lowered and broadened to produce more pristine conditions (Hein et al., 2005).

At low water level the water inflow to the sidearm system is reduced to seepage and groundwater of the river and amounts about 0.1 % of the river discharge. The conditions in the side-arm systems are lentic. At mean water level about 0.8 % of the main channel discharge is flowing through the side-arm (Austrian River Authority, unpublished report).

At flooding situations the river embankment is overflown and the whole floodplain gets inundated. Approximately 12 % of the main channel water enters the side-arm at a discharge of 5.000m^3s^{-1}. Regelsbrunn is used in this study as an example for a hydrological connected floodplain.

2.1.3. Lobau

Like the floodplain segment in Regelsbrunn before restoration, also the Lobau area is dominated by a former river channel that was severed upstream from the main channel after the main regulation of the Danube in the 19th century. Weirs, although partly already lowered and broadened, divide the side-arm into several basins with different connection pattern to the Danube main channel. Seepage and groundwater supply into the basins play a dominating role in large parts of the area. Above mean water level (~1900m^3/s) the floodplain fragment is connected to the main channel only at its downstream end. The Lobau is used in this study as an example for a hydrological altered (isolated) floodplain.

2.1.4. Szigetköz

The Szigetköz wetland is located between Győr and Mosonmagyaróvár at the Hungarian-Slovakian border with some 63km length and 8-14km width along River Danube. It is delineated by the Csallóköz Wetland and the Little Hungarian Plain to the north and south, respectively. Geomorphologically the area has two parts. The lower floodplain with an elevation of 1-2m above the average Danube water level is characterized by an intricate network of meanders of side channels, depressions and wetlands in oxbow lakes. The higher floodplain with an elevation of 4-5m above the average Danube water level forms a wide plain with some oxbow lakes over the fine grained sandy-gravely sediments. Since the initiation of massive constructions for river regulations, large amounts of water have been diverted from Szigetköz leading to significant drop of water levels in the channel system. As a consequence, channel morphology has been stabilised in the lack of essential flood events, wetland areas and habitats have been reduced due to drying, and sedimentation of channels has become the dominant processes. According to monitoring results, this has led in turn to accumulation of fine organic rich mud causing permanent reducing conditions in some areas of the wetland. In this way, Szigetköz is a contrary example for wetland rehabilitation. The Szigetköz Environmental Protection Area was established in 1987 on 9157ha with 1325ha of highly protected area. The protected area consists of the Danube floodplain, on one hand, and of the forested area of the Moson Danube, on the other hand. Szigetköz belongs to the Fertő-Hanság National Park Directorate on the Hungarian side. The Szigetköz wetland is used in this study as an example for a hydrological altered floodplain situated in the backwater of a large Hydro Power Station.

2.2. River Scale

2.2.1. Long term nutrient trends in the Danube River

2.2.1.1. TP loads

Considering nutrient transport in the Danube over a time series of 20 years (1978-1998, gauge at Vienna, Figure 2) it is obvious that TP loads in the Danube were effectively reduced since the 80^{th}. This reduction, mainly achieved by point source emission reduction (reduction of P containing laundry detergents in the end of the 80^{th} and initiation of P removal at WWTPs beginning in the 90^{th}) led to a decrease of average yearly phosphorus loads from ~ 11000 t/a, during the 70^{th} and 80^{th} down to ~ 7000 t/a since the 90^{th}.

However, phosphorus loads underlie significant fluctuation caused by the variability of hydrological conditions. High flow situations lead to a mobilization of suspended solids by soil erosion and sediment suspension which highly influence the concentration of TP.

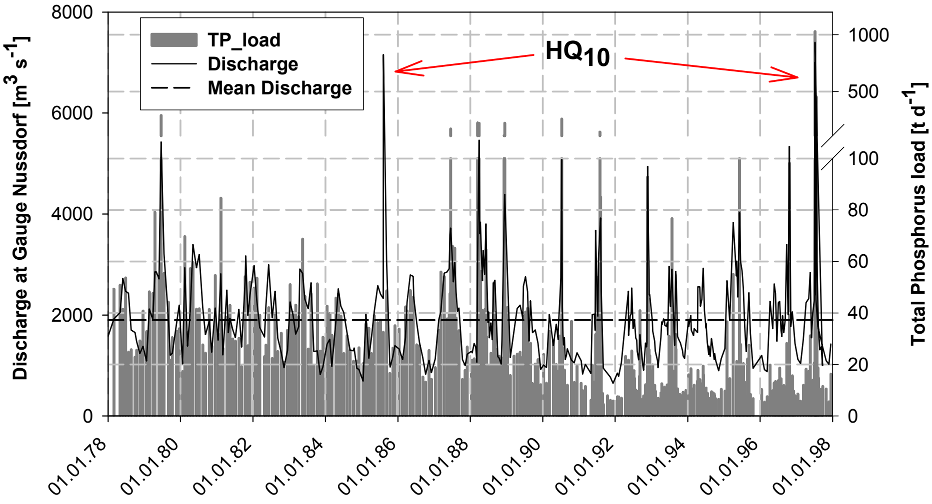

Figure 2 Long term trends of daily TP loads (1978-1998).

Thus, annual TP-loads are highly influenced by TP transport at high flow and strongly depend on number and intensity of high flow events. To derive serious information concerning the phosphorus loads transported during flood events it is necessary to monitor the whole flood period as was done in the frame of the "daNUbs project" in 2002 with one HQ_{10} followed by a HQ_{100}. Both flood events were intensively probed at Vienna (rkm 1941), Bratislava (rkm 1880) and Medve (rkm 1806). In a period between 6.08.2002 and 18.08.2002 at Vienna where data base is best, 40 samples were taken in total, considering increasing water levels as well as decreasing water levels which is essential for more precise load calculations of flood events due to the temporal variability of concentration of suspended solids and phosphorus (significant higher concentrations during increasing water levels with respect to decreasing water levels). At Bratislava and Medve daily samples were taken between 9th of August and 15th of August and thus the central periods of both flood events are covered.

2.2.1.2. NO_3-N loads

Figure 3 shows that the nitrate loads considering a 20 year period from 1978-1998 do not follow the clear downward trend which can be stated for the phosphorus loads in the Danube River at Vienna. As results from the EC-daNUbs project underline, agriculture is the dominant source for nitrate transported mainly by groundwater with a serious time delay until it is emitted to the surface water. Thus, measures reducing NO_3-N loads like the reduction of mineral fertilizer practiced from the beginning of the 90th will be reflected in decreasing surface water NO_3-N loads only after a time period which strongly depends on the flow velocity and the denitrification capacity in the groundwater and the unsaturated zone.

On the other hand reduction of NO_3-N loads from point loads (Waste Water Treatment Plants), by a forced implementation of a denitrification operation step during the 90th does not, compared to the load reduction of TP, show a similar reduction because the share of the total load from point sources in the case of NO_3-N is much smaller.

In general, due to denitrification processes NO_3-N concentrations in surface water show a distinct seasonality with higher concentration in winter and decreasing concentration during summer. Peak NO_3-N loads are mainly related to high flow events and especially high flow events during wintertime.

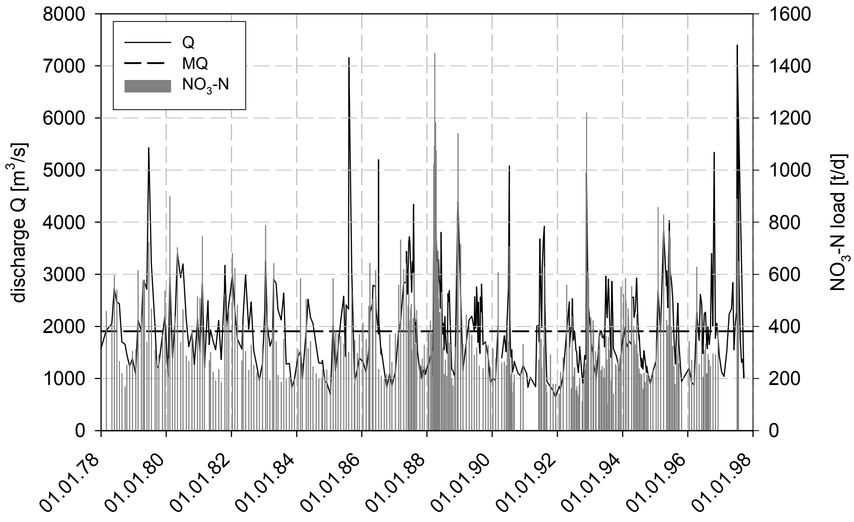

Figure 3 Long term trends of daily NO3-N loads (1978-1998)

2.2.2. Load calculation

On base of data from a period of 1997-2004 (considering effective TP load reduction during the 80th and 90th described above) using different sources like the TNMN, but even data provided by the Vienna University of Technology (2002 flood events) and the University Vienna, exponential regression curves relations for discharge:TP concentration and discharge:TP loads were calculated for gauge Nussdorf (Figure 4).

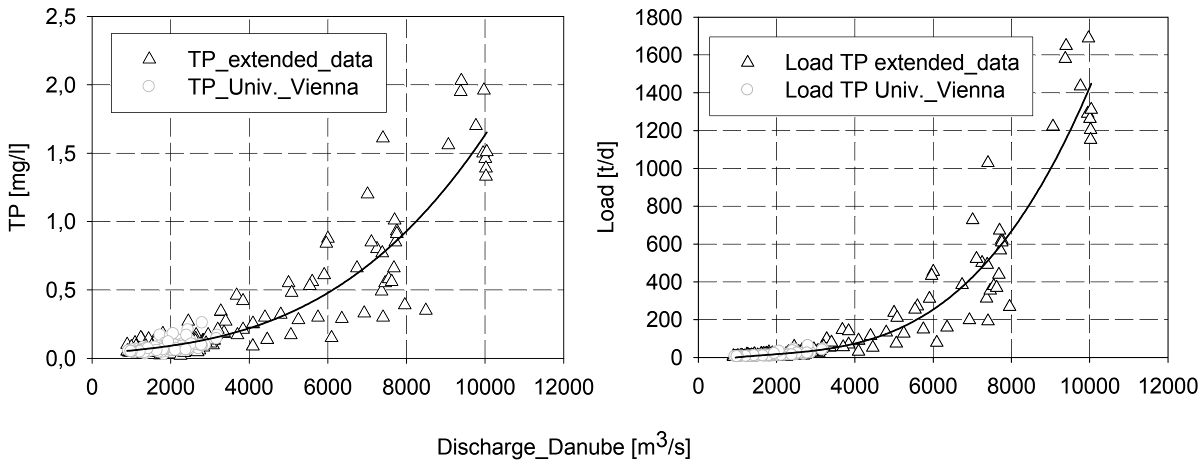

Figure 4 Regression analyses (Q:TP concentration; Q:TP load) on base of data from the TNMN (1997-2004), University Vienna and the Vienna University of Technology.

Higher discharges lead to higher TP concentrations and as a consequence to an even steeper exponential curve describing the TP loads transported by the Danube. It is obvious that the availability of data decrease with increasing discharges. The same tendency can be stated for the standard deviation of analyzed concentration, increasing with increasing discharge - a result of growing uncertainties with respect to probing, heterogeneities, but also as described above, a question of the moment when sampling was conducted during a flood event.

The exponential regression curves are used to calculate daily Danube river TP loads. All formulas and statistical patterns used for load calculation are shown in Table 3. With respect to the seasonal NO_3-N concentration pattern caused by denitrification in the river system the regression analyses for NO_3-N was bipartite into a summer half year (May-October) and a winter half year (November-

April). For Nussdorf the TP load regressions are bipartite with respect to discharge, considering a comparison of results from the Regelsbrunn model valid up to discharges of 3200m^3/s.

Table 3 Regression Models of the investigated sites between Vienna and Medve (TNMN data from 2003-2003, Nussdorf from 1997-2004, added by data from the 2002 flood event, source TU-Vienna and VITUKI).

TP	Formula F(x) load (t/d) / X=discharge (m^3/s)	r^2	n
Nussdorf	*f(x)= 1,28839+(-0,0111*X)+5,673E-6*X^2* *f(x)= 13,901e^{0,0005*X}*	Q< 3200 m^3/s: 0,55 Q> 3200 m^3/s: 0,85	58 148
Wolfsthal	*f(x)= 2,4576e0,0006X*	0,6	45
Bratislava	*f(x)=-2,7795+0,0049*X+2,1185E-6*X^2*	0,95	57
Medve	*f(x)= 17,3808+(-0,0145*X)+(7,4971E-006*X^2)*	0,94	60
NO_3-N			
Nussdorf	*f(x)= 403,83Ln(X)-2571,7* *f(x)= 0,1125X+70,171*	WH: 0,92 SH: 0,95	12 54
Wolfsthal	*f(x)= 457,82Ln(X)-2971,9* *f(x)= 0,1679X-48,897*	WH: 0,86 SH: 0,9	24 24
Bratislava	*f(x)= 0,2521X-32,325* *f(x)= 0,1215X+34,998*	WH: 0,84 SH: 0,95	24 33
Medve	*f(x)=0,1944X+61,919* *f(x)=0,133X+2,5186*	WH: 0,7 SH: 0,93	22 33

Regressions from Wolfsthal are presented here but will not be used for load calculation because of lack of data from the 2002 flood event.

2.2.3. Hydrology

The comparison of the discharges of the years 2002 and 2003 is based on daily discharge measurements at the gauging stations Nussdorf (Vienna, rkm 1935), Wolfsthal (rkm 1874, downstream Lobau and Regelsbrunn including the tributaries Schwechat, Leitha and Morava rkm 1880), Bratislava (rkm 1869) and Medve (downstream the Gabcikovo and the Sziget Kös, rkm 1806). With respect to the project frame this approach does not consider discharges of the tributaries listed up above nor does it include waste water discharges from Vienna and Bratislava. Thus, results presented here are rough estimates underlying a number of uncertainties in addition to uncertainty of the discharge measurements itself.

Furthermore, at high flow situations gauge Nussdorf does not represent the total Danube discharge (Neue Donau in use for flood protection), so that discharges for this periods are generated from gauge Greifenstein upstream. Unfortunately, gauge Greifenstein could not be used for load calculations because in the author's opinion estimates should base on one harmonized data source which is available for the whole Danube River Basin represented by the TNMN.

Figure 5 shows daily discharges for the year 2002 and 2003 for the gauges described above.

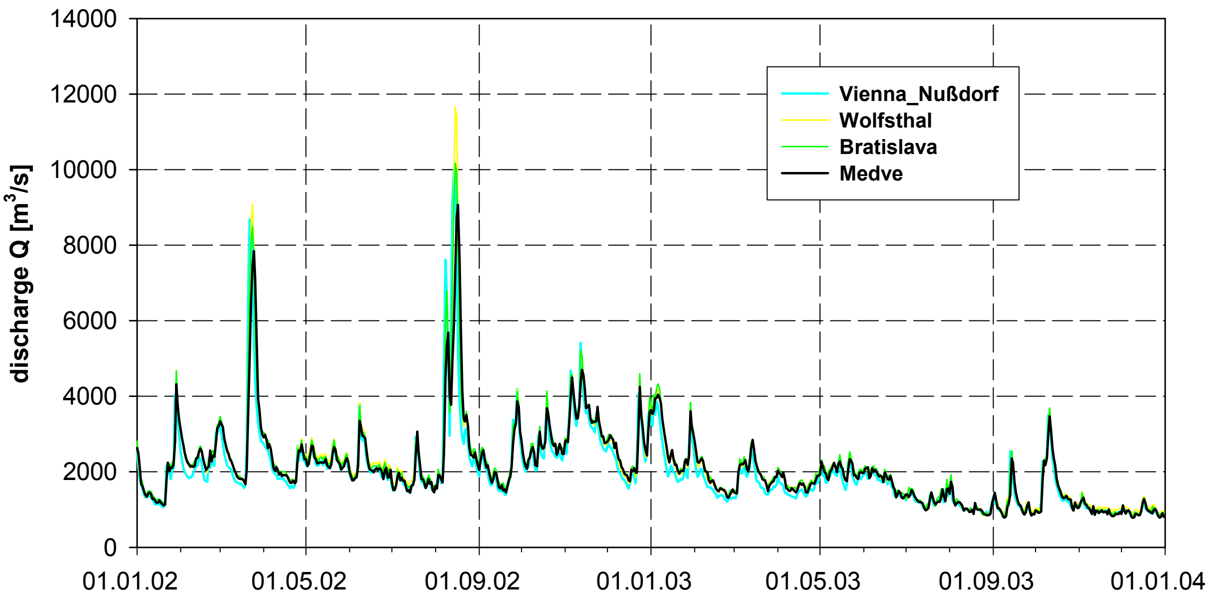

Figure 5 Danube Discharges at 4 TMNN gauging stations for 2002 - 2003

While the year 2002 is characterized by high discharges with a HQ_{10} (defined with 7300 m^3/s) between March and April and a HQ_{10} followed by an HQ_{100} (defined by 10400 m^3/s) in August 2002 (compared to a mean yearly high flow event HQ_1 with 5808 m^3/s), discharges in 2003 show conspicuously lower values with discharges significantly below the yearly mean water discharge (=MQ) of 1900 m^3/s during more than six months. In a period of two months Danube River discharges even were only slightly higher than mean yearly low water situations (=MNQ) defined with 840 m^3/s (statistical Danube discharge data represent mean values from 1951-1993).

The total yearly discharges of 2002 and 2003 compared to average values are shown in Table 4.

Table 4 Total yearly discharge at gauge Nussdorf (year 2002, 2003, mean and average value).

Year	Discharge Q [m^3/a]
2002	911373
2003	584541
Mean 2002-2003	747957
average value	693500

In a second step by simple subtraction of the discharges at the different gauging stations the water surplus or (temporally) retention can be estimated. As mentioned before, uncertainties are mainly related to the river reach between Vienna and Bratislava. While the discharge of treated wastewater from Vienna can be estimated with ~ 5m^3/s mean discharges from the Schwechat the Leitha and the Morava have to be considered with 8,2 m^3/s, 10,3m^3/s and 106m^3/s in case of extreme high flow events with 330 m^3/s, 97m^3/s and 940m^3/s (Hydrographisches Jahrbuch, 1999).

Consequently, positive values of the calculated discharge differences (representing a surplus of water from the tributaries) shown in Figure 6 are distinct between gauge Nussdorf and gauge Wolfsthal. The peak differences of -2000m^3/s at HQ_{10} and HQ_{100} at the beginning of the flood events are weakened by the discharge coming from the tributaries within this river reach, while the surpluses of 2000 m^3/s (during HQ_{10}) and 4000 m^3/s (during HQ_{100}) already includes this tributary caused influence. However, the discharge surpluses exceed the possible tributary caused discharge by far and represent periods of time delayed discharge from formerly flooded areas. The overall surplus of discharge which can be observed at this reach at no high flow conditions results from the discharge of the tributaries (listed above).

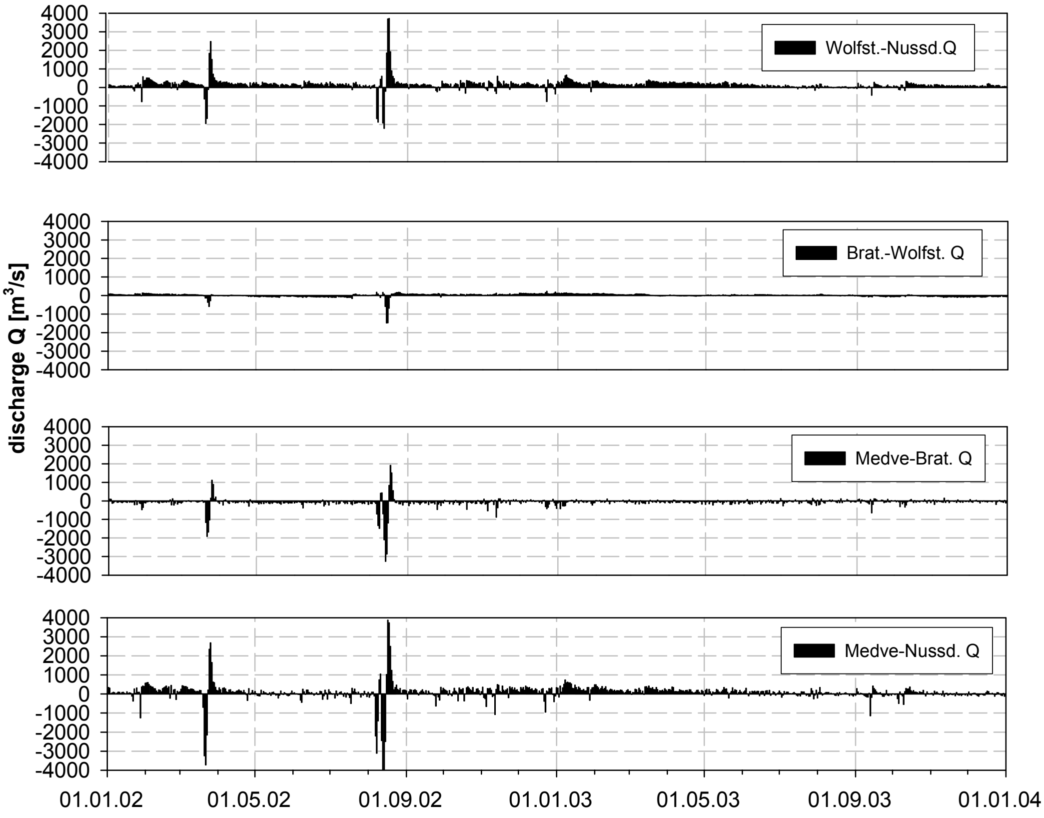

Figure 6 Differences of discharges between different TNMN gauging stations in the year 2002-2003.

The differences in discharges, representing water storage (negative values) or water surplus (positive values), show only little differences between gauges Wolfsthal and gauge Bratislava. This is mainly caused by the short distance of only 5 km and the restricted possible inundation area in between these gauging stations. The change of a general weak water surplus during winter and spring to a general weak water loss especially during summer indicates catchment induced variability.

Between Bratislava and Medve the retention of Danube water during the investigated early high flow events seems to be most distinct reaching discharge differences of 2000m^3/s during HQ_{10} and 3000m^3/s during HQ_{100}. Similar to the river stretch Nussdorf-Bratislava the period after the flood peak has passed is characterized by a discharge surplus caused by runoff of inundation water from the flooded areas. However, amounts of runoff at this river reach is significantly lower compared to the preceding retention underlining a general retention (groundwater recharge, pedding of depressions) or loss (evapotranspiration) of inundation water. A weak tendency of water losses can be stated for this river reach even at no high flow conditions, obviously due to losses from evaporation initiated by the extreme extended surface water area in the backwater of the Gabcikovo reservoir.

On the whole river reach between Nussdorf and Medve (129 km) discharges of rather 3000m^3/s seem to be retained by a HQ_{10} flood event during the first days while more than 4000m^3/s seem to be temporally retained during the HQ_{100}. After the discharge peaks have passed these areas, the discharge of the inundation water leads to time delayed discharge surpluses at the downstream gauging stations. However, these discharges are lower compared to the preceding retention which is mainly due to water losses on the river reach between Bratislava and Medve described above.

2.2.4. Comparison of loads in the river reach Nussdorf-Medve (2002-2003)

To underline the importance of hydrological conditions with respect to nutrient transport as well as for riverine wetlands acting as nutrient sinks or sources the years 2002 (extreme wet year with two HQ_{10} and a HQ_{100}) and the dry year 2003 are compared. On base of regression analysis (Table 3) daily TP and NO_3-N loads were calculated for Nussdorf, Bratislava and Medve and compared with each other. It has to be considered that this comparison made by subtraction of loads from the sampling point downstream with the loads of the sampling point upstream and in the end a subtraction of loads at Medve with loads calculated for Nussdorf give only a rough overview. Because of uncertainties from measurements, residence times (not considered), but especially from regression curves it is not possible to compare each discharge situation. Nevertheless, this rough model gives an overview of the transport and retention or removal character for two extreme years, which allows drawing general conclusions with respect to the investigated riverine wetland in between this river reach.

2.2.4.1. TP loads

Daily TP load calculations are based on the regression analyses summarized in Table 3. Figure 7 illustrates the huge variability of daily loads being transported by the Danube with respect to its discharge. While at mean discharges (1900 m^3/s) loads in a range of 10-30 t are transported per day, at high flow events this values can increase 50fold. Consequently, a huge share of an annual TP load can be transported within only a few days, depending on annual frequency and intensity of flood events.

However, the comparison of different gauging stations represents a rough approach only which can, due to regression analyses, underlie uncertainties at different discharge values, it is obvious that the calculated loads at the different stations range in the same order of magnitude.

Considering TP loads from the single years 2002 and 2003 underline the dominant role of the hydrological situation. While in the extreme wet year 2002 18.4 kt TP were transported by the Danube at gauge Nussdorf in the dry year 2003 only ¼ (4.3 kt) of TP was transported.

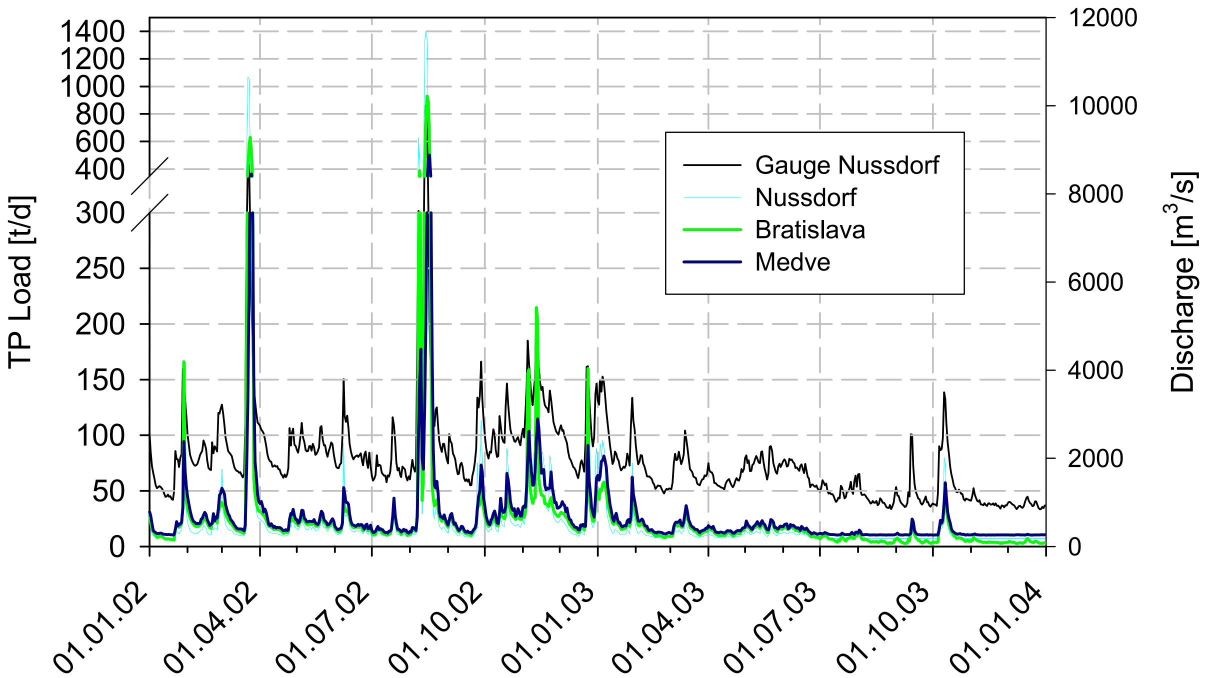

Figure 7 Danube TP loads at 3 TNMN gauging stations for 2002-2003 as well as discharges from gauge Nussdorf.

Figure 8 shows the surplus or retention of TP loads for different river reaches. The columns representing retention (negative values) or surplus (positive values) argue for a strong retention of TP between Vienna and Medve especially during the 2002 high flow events while at mean or low flow conditions a reasonable surplus of ~ 5 t TP/d from the tributaries and point sources can be found. Results of the HQ_{10} in March and the HQ_{100} in August give strong evidence that during high flow events TP is effectively retained and thus coincide with investigations made by Zessner et. al., 2005. As graphs underline only a minor share of the retained TP loads is transported at the end of the flood event, when water levels fall and inundation water runoff increases discharges downstream (Figure 6). Thus TP load results underline the importance of sedimentation processes during flood events caused by a reduction of the flow velocity in the impounded riverine area where TP effectively retained with suspended solids (see extreme flood event 2002).

However, it has to be taken into account that this retention process is partly reversible. Other flood events can remobilize solids from the riverine area again. Another process counteracting the benefits of TP retention on a long term perspective is aggradations of the riverine area.

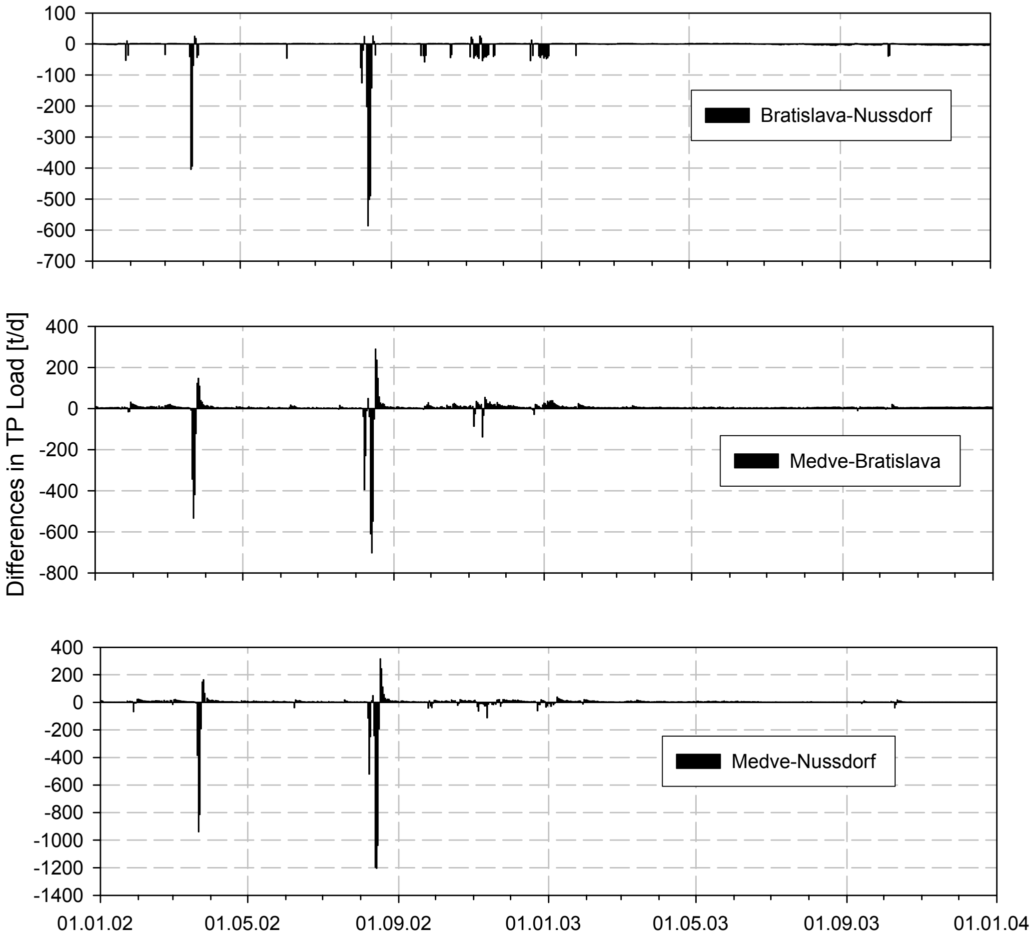

Figure 8 Differences of TP loads between different TNMN gauging stations in the year 2002-2003 (different scales).

2.2.4.2. NO_3-N loads

Figure 9 illustrates that daily NO_3-N load in the year 2002-2003 show significant variations mainly caused by hydrological conditions. Highest loads (>2000 t/d) are found at high flow conditions during spring with low water temperatures and a low denitrification potential in the surface waters. Especially during high discharges of the Danube River the highest NO_3-N loads can be found at sampling point Bratislava, while at sampling station Medve the loads seem to decrease again.

However, the increased NO_3-N load at Bratislava is not caused by the NO_3-N emissions from the tributaries and the capital cities but illustrates the limitations of the regression analyses based approach caused by data availability. Regression used for Bratislava in the winter half year does only cover discharge situations up to 4000m^3/s. Discharges > 4000 m^3/s during the winter half year are overestimated and thus can not be interpreted.

For 2002 the yearly NO_3-N loads at gauge Nussdorf are calculated with 165 kt and thus exceed loads calculated for the year 2003 with 109 kt by far, expressing the influence of hydrological conditions on yearly variability of NO_3-N loads transported by the Danube. It is obvious, that the differences of the annual NO_3-N loads are much lower than was found for the TP-loads.

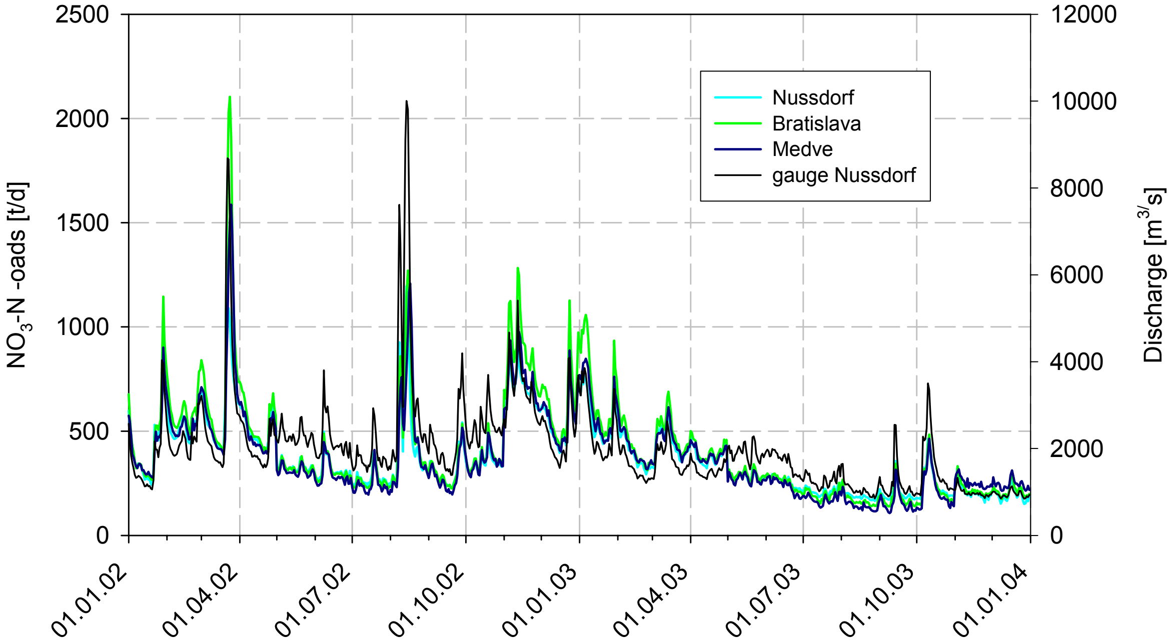

Figure 9 Danube NO3-N loads (t/d) at 3 TNMN gauging stations for 2002-2003.

The alteration of NO_3-N loads between Vienna and Medve is shown in Figure 10. Between Vienna and Bratislava in general a noticeable increase of the NO_3-N loads can be observed which is to a large extend related to the overestimation of loads for Bratislava during the winter half year described above. In the summer half year the data calculated for Bratislava show reasonable values. According to the hydrological situation (Figure 6) with flooding of the riverine area the flood event in August 2002 is characterized by a delay of NO_3-N loads transported downstream the Danube River. NO_3-N loads retained at the beginning of the flood event seem to be transported in the same order of magnitude downstream after the flood had passed (see extreme flood events 2002).

Between Nussdorf and Medve the same tendency is apparent during the flood events. During summer periods characterized by low flow conditions a continuously loss of NO_3-N loads can be stated which can be observed on lower values also at the river stretch between Nussdorf and Bratislava. At the river reach Nussdorf-Bratislava, this loss is obviously addressed to denitrification processes in the river itself at low flow conditions but also to a forced denitrification in the riverine wetlands Lobau and Regelsbrunn, as far as they are connected to the main stream. It is obvious that the removal in this river reach should be even higher than shown in Figure 10, because the surplus of the tributaries as well as the point loads are not included in this approach.

Between Bratislava and Medve in this time periods especially the reduced flow velocities in addition to the heating in the backwaters of the Gabcikovo will increase denitrification activity (increasing temperature) and effectiveness (increasing residence time). Furthermore the water enhancement of the large plain gravel aquifer of the Szigetköz can lead to a further loss of NO_3-N from the river system.

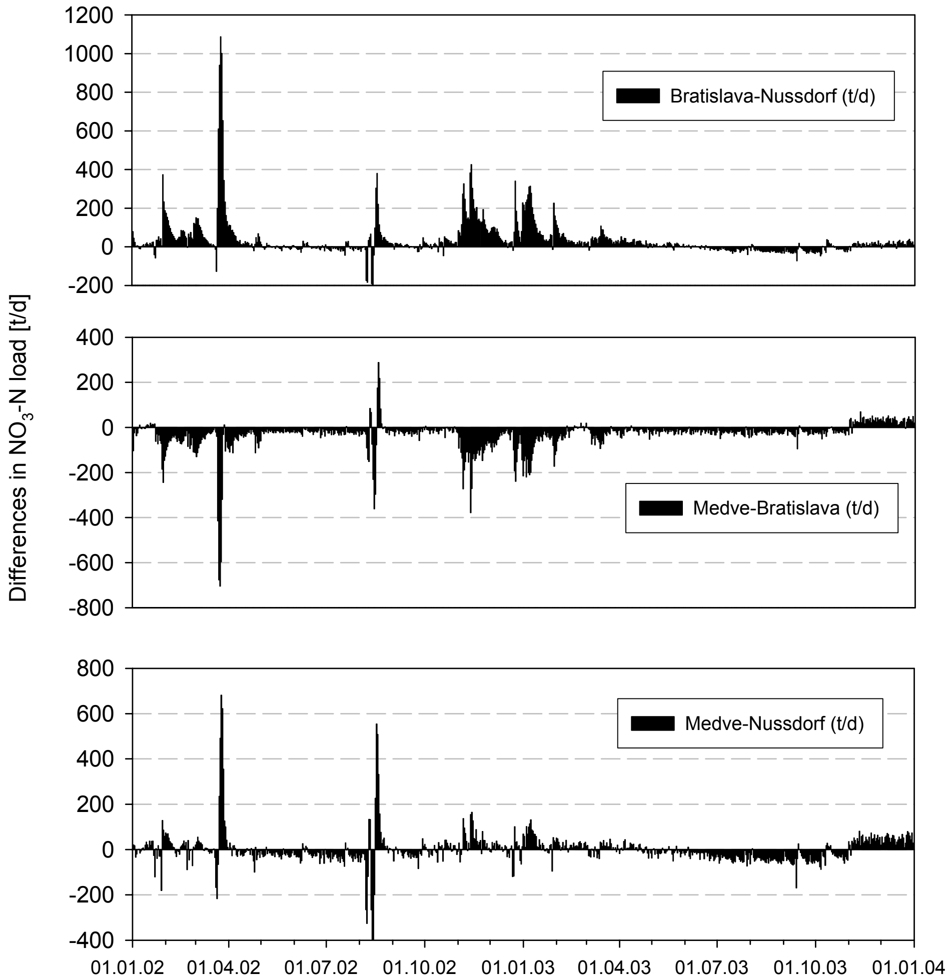

Figure 10 Differences of NO3-N loads between 3 different TNMN gauging stations between Vienna and Medve in the year 2002-2003 (different scales).

2.2.5. The extreme flood event 2002

For a closer insight concerning the nutrient loads being transported and retained by the Danube on the river reach from Vienna to Medve data of the HQ_{10} and the HQ_{100} flood event from August 2002 are presented.

Discharge curves from daily data (Figure 5 and 11) underline that the temporal occurrence of the flood was similar at Vienna, Bratislava and Medve but time delayed due to flooding of large retention areas.

From Figure 6 it was estimated which amounts of surface water were retained or lost at the different river reaches under investigation for the time period from 6th of August to the 23th of August including the HQ_{10} and the HQ_{100}. During this period at the river reach between Nussdorf and Wolfsthal a water surplus of 0,6 km^3 was calculated obviously caused by the discharge of the tributaries. At all other river reaches a water deficit was calculated which reached its maximum between Bratislava and Medve with a water loss of 0.7 km^3 during the period of 18 days. At the river reach Nussdorf to Medve the loss of water was calculated to be 0.4 km^3. By taking into account the surplus between Nussdorf and Wolfsthal, the total retention or loss of water within the investigated 18 days between Nussdorf and Medve amounts to 1.0 km^3. In total this would be an area of 1000km^2 covered by a water column of 1,0 m height, which becomes plausible taking into account the Szigetkös with an total area of 375 km^2 between the main Danube stream and the Mosonyi Danube (IAD, 2004). ❑

2.2.5.1. TP loads

Assuming a mean TP concentration of 1.5 mg/l during this period (see Figure 4) the retention of TP on the river reach between Nussdorf and Medve caused by water losses would amount to 1500 t TP. Calculating TP losses for the investigated period by using load calculations presented in Figure 8 a total of 3900 t TP were retained between Nussdorf and Medve while 6800 t TP were transported during this time period. This would amount to retention of rather 60 % of the transported TP loads.

Data calculated by Zessner et al., 2005 are in the same range with a general lower estimate of TP loads transported as well as retained during the 2002 flood event.

From load calculations Zessner et al., 2005 conclude that 70 % (~ 4800 t TP) of an average annual TP load was transported during the flood at Vienna. At Bratislava the TP load transported was in the same order of magnitude while a significant decrease was estimated for Medve (transport of ~ 3000 t TP = retention of rather 40 % of TP) but also downstream at Bazias (rkm 1072) and Gruia (rkm 857) where discharge peaks are flattened and flood water is transported over a longer period.

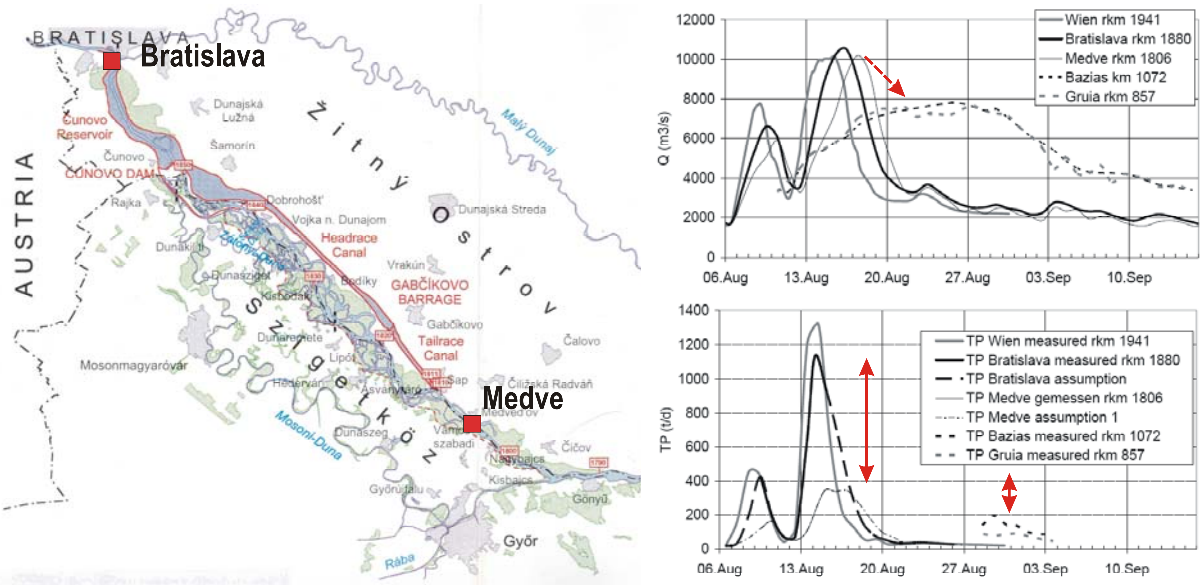

Figure 11 Discharge and TP loads transported by the Danube between Vienna and Gruia at two flood events HQ_{10} and HQ_{100} (Zessner et al., 2005).

Both estimates presented here give strong evidence that during flood conditions significant amounts of water and TP are transported but also retained in the inundation area. Furthermore results imply that flood events in the Danube river basin are restricted to certain river stretches and thus must not have direct impact on the loads transported to the Black Sea. However, this strongly depends on the meteorological conditions as the flood event from 2005 in the lower Danube reach expresses, when large areas of the Rumanian parts of the Danube floodplains as well as the Danube Delta were affected.

2.2.5.2. NO_3-N loads

Figure 12 shows the temporal development of NO_3-N loads transported during the HQ_{10} and HQ_{100} flood events of August 2002 at the investigated river reach between Vienna and Medve. Due to increasing discharges the loads rise from 200 to ~ 900 t NO_3-N/d at HQ_{10} and 1200 t NO_3-N/d at

HQ_{100}. The graphs show a similar trend with a time delay between Nussdorf and Medve of 2 (HQ_{10}) respective 3 days (HQ_{100}) due to a time delayed runoff from the flooded areas.

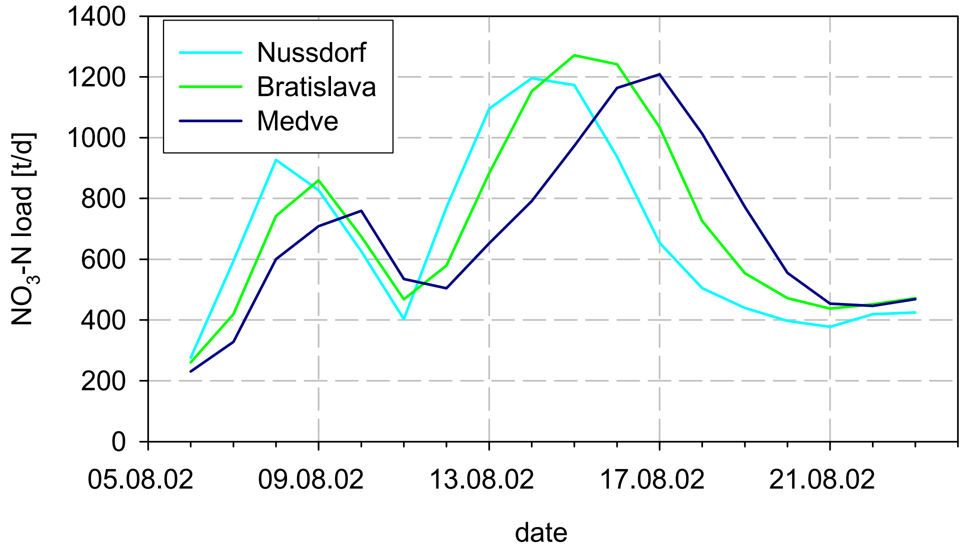

Figure 12 TN loads transported by the Danube between Vienna and Medve at to flood events HQ10 and HQ100 in August 2002.

Aggregation of data to the different river reaches in general reflect "retention" of NO_3-N at the beginning of the inundation period and a "mobilization" after the flood peak has passed. Different tendencies on the river reaches are related to the specific conditions with increasing loads between Nussdorf and Bratislava (650 t NO_3-N over 18 days) due to the tributaries and a loss of NO_3-N between Bratislava and Medve (530 t NO_3-N) (Figure 13) due to significant water losses especially related to the Szigetköz.

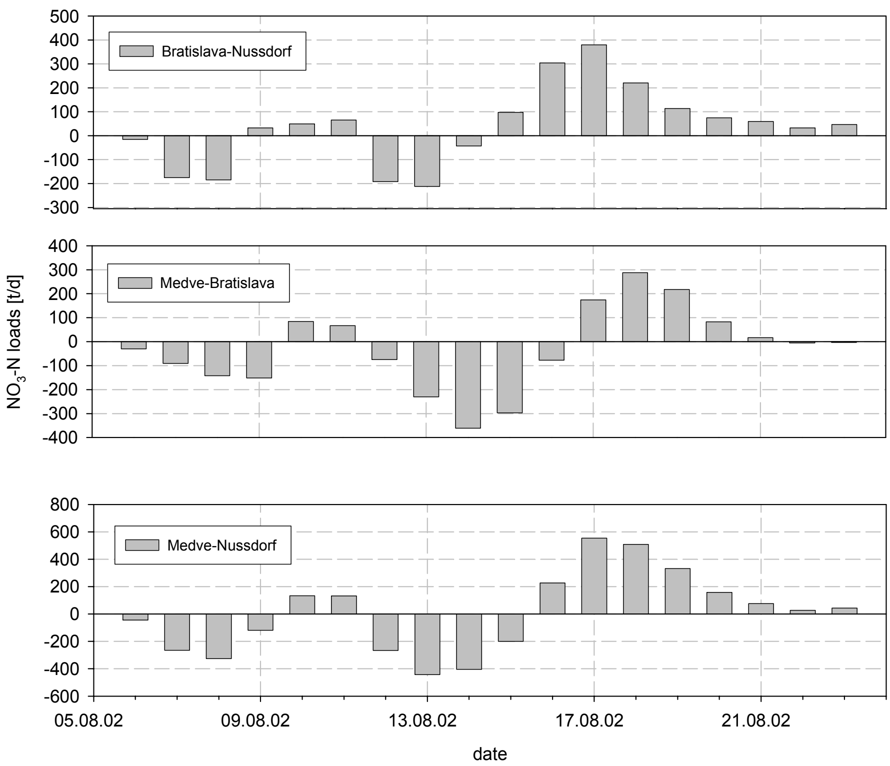

Figure 13 Differences of NO3-N loads between 3 different TNMN gauging stations between Vienna and Medve during the flood event of August 2002.

However, considering water losses of 1.0 km^3 the loss of 530 t NO_3-N between Bratislava and Medve seems to be underestimated (average concentration of NO_3-N being 1.5 mg/l would result in a loss of 1500 t NO_3-N). Thus, compared to 12000 t NO_3-N transported by the Danube during the high flow event the share of removed NO_3-N loads would probably range between > 4% to > 12.5%.

In a further step it will be evaluated in detail to which extent the three individual floodplains Regelsbrunn, Lobau and Szigetköz in between the described river stretch can contribute to phosphorus retention or nitrate removal. While presented results at discharges < 3200 m^3/s (Regelsbrunn) and < 4000 m^3/s (Lobau) base on input output measurements within the riverine systems retention or losses at exceeding discharges are estimated by combining the wetland models with results from the river scale.

2.3. Floodplain scale

2.3.1. Austrian wetlands Lobau and Regelsbrunn

The importance of the Danube stretch downstream of Vienna has been described in numerous papers (e.g. Tockner et al., 1998; Schiemer et al., 1999). In some parts of today's National Park Donauauen key functions within floodplains such as hydrological dynamics, flood pulses and bed load transport are still operative.

2.3.1.1. Methods

The long term data set used in this case study was provided by the Department of Freshwater Ecology (University of Vienna) and origin from several scientific programmes in the last decade. Regressions for in- and output in dependence to the Danube discharge were calculated from this available data base (Tab. 5) revealing significant relationships for nitrate, total phosphorus and suspended solids. Due to lower data density at high discharges, the relationships are valid for discharges in the Danube below 3100m3/s for Regelsbrunn and below 4000m3/s for the Lobau. Calculations have been done only within these ranges excluding high flow events.

The hydrological model for the retention calculations in Regelsbrunn was published by Reckendorfer & Steel (2004).

Table 5 Regression models of the investigated parameters for the two case study sites (x= discharge).

IN/OUT	Nutrient	Regression	Model	Parameter	R2	P
			Lobau			
IN	Nitrate (log)	sigmoid	f(x)=a/(1+e^(x-x0)/b))	a=3.3003; b=478.3342; y0=1691.1332	0.99	<0.02
OUT	Nitrate (log)	linear	f(x)=y0+ax	a=0.0005; y0=1.1428	0.98	<0.02
IN	Phosphorus, total	exp. growth	f(x)=ae^bx	a=9.6992; b=0.0007	0.96	<0.009
OUT	Phosphorus, total	exp. growth	f(x)=e^ax	a=0.0012	0.6	<0.0001
IN	Suspended solids	exp. growth	f(x)=e^ax	a=0.0010925	0.96	<0.0001
OUT	Suspended solids	exp. growth	f(x)=e^ax	a=0.0010743	0.59	<0.0001
			Regelsbrunn			
IN/OUT	Nitrate (retention)	sigmoid	f(x)=a/(1+e^(x-x0)/b))	a=1633.1531; b=-182.8796; y0=1970.4578	0.82	<0.0005
IN	Phosphorus, total	exp. growth	f(x)=ae^bx	a=26.197053112; b=0.0005441059015	0.87	<0.0001
OUT	Phosphorus, total	exp. growth	f(x)=ae^bx	a=25.176385807; b=0.0004295796838	0.79	<0.0005
IN	Suspended solids	exp. growth	f(x)=e^ax	a=0.001483	0.54	<0.0001
OUT	Suspended solids	exp. growth	f(x)=e^ax	a=0.001288	0.65	<0.0001

2.3.1.2. Comparison of the two different wetland types Lobau and regelsbrunn

In contrast to the Lobau, Regelsbrunn as the hydrological connected study site show retention of nitrate, phosphorus as well as suspended solids in a noteworthy amount. In the year 2002 about 300 t of nitrate, 21 t of phosphorus and 13,000 t of sediment has been retained, without taking the large high flood events into account. Recent estimations from Hein et al. (2005) which include the high water periods resulted in phosphorus retention in Regelsbrunn of about 175 t for the year 2002. The calculations for the year 2003, where the discharges in the Danube were much lower throughout the year (see fig. 14), only revealed retentions of 110 t of nitrate, 4 t of phosphorus and 2,400 t suspended solids (Tab. 6). Hein et al. (2005) present retention budgets of 11 to 43 t/a for the years 1997 to 2001. As the two case study years 2002 and 2003 cover the very ends of the hydrological spectrum with historical flood events on the one hand and an extensive period of low water condition on the other hand, these calculations seem realistic.

The Lobau showed losses of nitrate (10 t/a) and phosphorus (1 t/a) in the year 2002 but seemed to retain a slight amount of nutrients in the dryer year 2003. The sediment balance shows net inputs in both years, about 1,400 t in 2002 and scarcely 60 t in 2003.

Based on the total floodplain area this results in maximal nitrate retention rates of 0.73 t/ha*yr in Regelsbrunn and 0.04 t/ha*yr in the Lobau (Tab. 6). In a ranking of published denitrification rates of very different wetland systems, the Lobau is found in the rather ineffective group of wetlands whereas Regelsbrunn lies in the effective (sometimes amended) group of floodplains, bogs and fens or ponds (Tab. 7). Of course this comparisons are only restricted because the results of the most studies cited are nitrate losses due to denitrification and we can not quantify the different pathways of nitrate loss in our study nevertheless it gives a good impression of the capacity of our different sites.

Table 6 Mass balance in the two case study sites Regelsbrunn and Lobau for the years 2002 and 2003.

	Regelsbrunn						Lobau					
Year	**2002**			**2003**			**2002**			**2003**		
Compound	**in**	**out**	***total***	**in**	**out**	***total***	**in**	**out**	***total***	**in**	**out**	***total***
N			324			357	132	214	355	144	215	365
	41 days discharge > 3100m3/s			8 days discharge > 3100m3/s			9 days = 0; 14 days discharge >4000m3/s			9 days = 0		
	Mass balance total floodplain area (t/yr)											
Nitrate			*308.32*			*111.03*	49.88	-59.79	*-9.92*	13.04	-5.67	*7.37*
Phosphorus (total)	74.25	-53.33	*20.92*	16.58	-12.23	*4.35*	3.19	-4.16	*-0.97*	0.78	-0.4	*0.38*
Suspended solids	32,455	-19,423	*13,032*	6,193	-3,795	*2,397*	3,900	-2,469	*1,431*	313	-254	*59*
	Mass balance total floodplain area (t/ha*yr)											
Floodplain area	*473 ha*						*183 ha*					
Nitrate			*0.73*			*0.24*			*-0.06*			*0.04*
Phosphorus (total)			*0.05*			*0.01*			*-0.01*			*0.00*
Suspended solids			*31*			*5*			*8*			*0.3*
	Mass balance moistended area (t/ha*yr)											
Moistened area at mean water level	*69 ha*						*98ha*					
Nitrate			*5.03*			*1.65*			*-0.10*			*0.08*
Phosphorus (total)			*0.34*			*0.06*			*-0.01*			*0.00*
Suspended solids			*213*			*36*			*15*			*0.6*

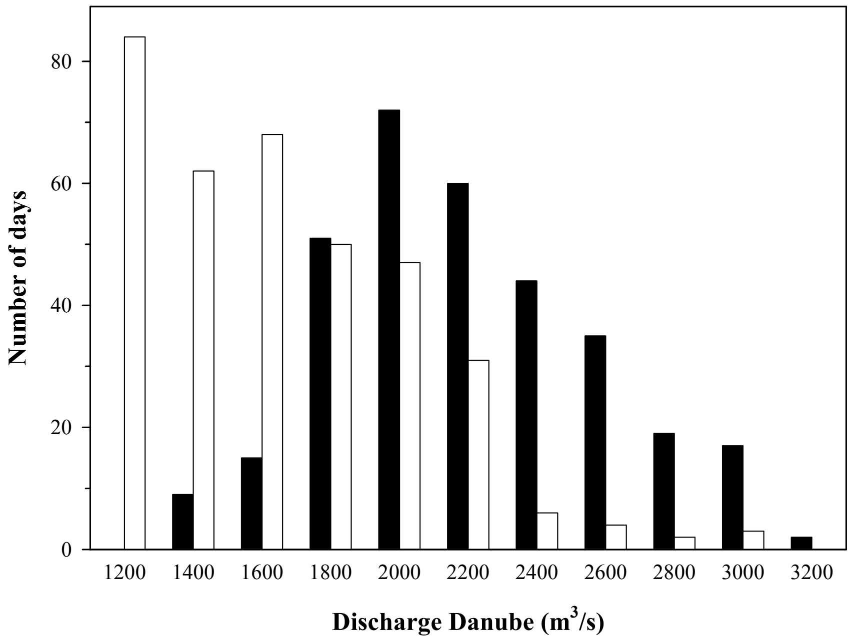

Figure 14 Distribution of discharges up to 3,100 m^3/s in the Danube (in classes, 200 m^3/s each) in the two study years. Black bars: year 2002, white bars: year 2003.

Table 7 Ranking of nitrate retention of literature values and the case study sites (Regelsbrunn and Lobau). * the literature values are denitrification rates.

Site description	Maximal nitrate retention (t/ha*a)*	Amendment	Reference
floodplain soil	100	N enriched	Forshay & Stanley (2005)
floodplain soil	42	no or C enriched	Forshay & Stanley (2005)
Bogs and fens (drainage basin Baltic Sea)	31	no	Jansson et al. (1998)
grass buffer strips	5,8	nitrate + glucose	Groffman et al. (1991)
pond	3	no	Jansson et. al (1994)
connected floodplain	0.73	no	Case study, Regelsbrunn
	0.597	nitrate	Johnston (2001)
floodplain forrest (Morawa/Dyje)	0.224	no	PHARE project (1997)
river sediment	0.073	no	Jansson et. al (1994)
grass buffer strips	0.069		Lowrance et al. (1995)
restored reparian forest	0.069	enriched with liquid manure	Ambus & Lowrance (1995)
floodplain soil (grass or reed)	0.0548	no	Venterink et al. (2003)
young hardwood	0.043		Lowrance et al. (1995)
degraded floodplain	0.04	no	Case study, Lobau
	0.038	nitrate	Hanson et al. (1994)
forested area	0.034	enriched	Groffman (1994)
young pine	0.03		Lowrance et al. (1995)
	0.016	no	Hanson et al. (1994)
forested buffer strips	0.0022	nitrate + glucose	Groffman et al. (1991)
	0.002	no	Johnston (2001)
forested area	0.0001	no	Groffman (1994)

The retention pattern of the case study sites depend on the hydrological situation. The highest nitrate retention in the hydrological connected site is found at lower discharges, whereas in the Lobau there is found a peak retention around 3500m3/s followed by a nitrate loss situation.

As expected, pattern for suspended solids and phosphorus retention show similar characteristics. In the restored site both retention capacities for sediment and for phosphorus rise with discharge. For the phosphorus retention the slope of the regression curve fits to the results in Hein et al. (2005) leading to the conclusion that our results could be extrapolated at least until a Danube discharge of 8000 m3/s. The deficiently connected site at the Lobau does not show large retention capacities neither for suspended solids nor for phosphorus.

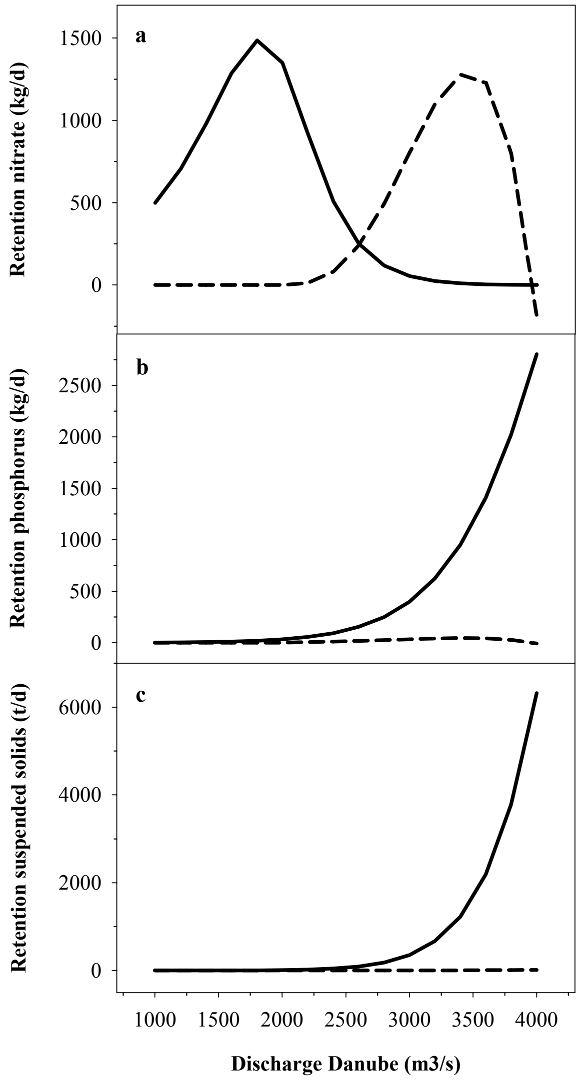

Figure 15 Relationship of the discharge in the Danube and the retention capacity for nitrate (a), phosphors (b) and suspended solids (c) in Regelsbrunn (solide line) and the Lobau (dashed line).

A similar pattern is found in relation to the size of area covered with water (Fig. 16) and the size of area covered with shallow water (< 0.5 m) or the length of shoreline. Within the discharge range covered by our models the investigated parameter rise with rising discharge. Differences may be found in the upper discharge section.

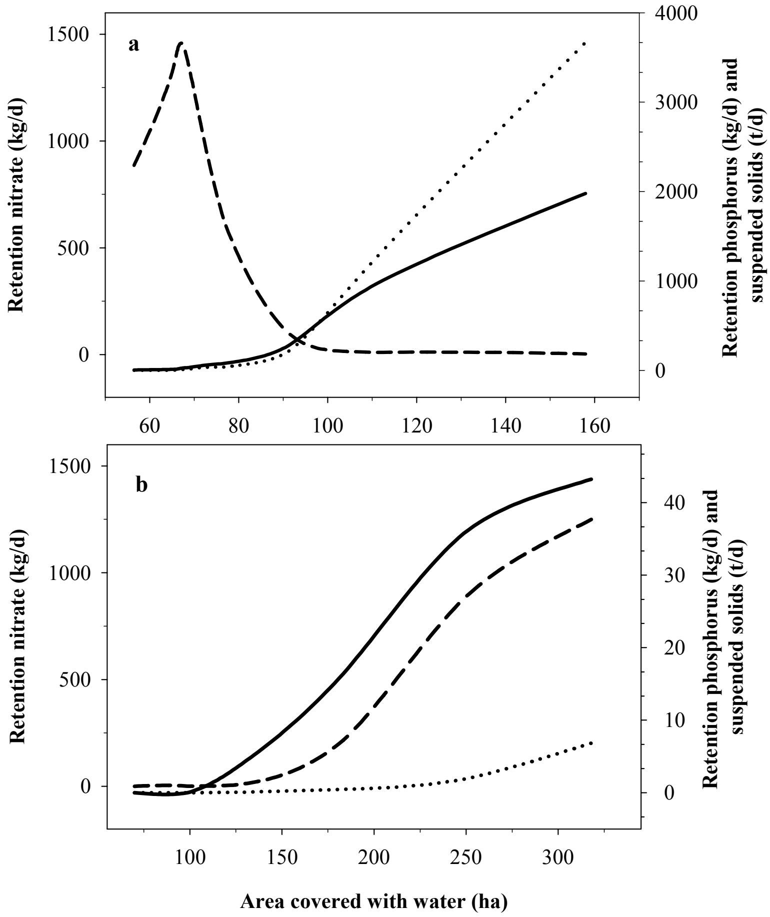

Figure 16 Relationship of the size of the water area in the floodplain and the retention capacity for nitrate (dashed line), phosphors (solid line) and suspended solids (dotted line). a: Regelsbrunn, b: Lobau.

2.3.1.3. Regelsbrunn and Lobau load estimates with high flow conditions included

Significant shares of annual loads of TP but also NO_3-N can be transported within a few days during high flow events (Figure 7 and 9). Concerning the question to which extent floodplains can act as matter and especially as nutrient sinks, it is crucial to study floodplain retention (TP) and removal (NO_3-N) behavior with respect to different hydrological conditions ranging from low and disconnected to completely integrated situations (flooding) as well as to extreme events (e.g. HQ_{10}, HQ_{100}). Unfortunately data representing extreme events are very scarce.

Data based on input-output measurements describe matter retention behavior (TP, SS) and losses of NO_3 in the riverine wetlands Regelsbrunn and Lobau related to discharges of the Danube < 3200 m^3/s and < 4000 m^3/s. To extent this data and to estimate

- loads transported to the floodplain and
- a reasonable retention or removal capacity

of the floodplains under investigation at high flow conditions, Danube nutrient loads at Vienna were related to the modeled discharges of the riverine wetlands, with:

$L_{(Wetland)} = L_{(DANUBE)} * Q_{(Wetland)}/Q_{(DANUBE)}$

L = load [t/d]

Q= discharge [m^3/s].

However, the altered wetland system Lobau is connected only at water levels which correspond to a discharge of >2100 m^3/s. Furthermore, at the input point flow direction can be reversed with respect to water level dynamics (increasing water levels of the Danube lead to a water enhancement of the system, decreasing water levels lead to discharges from the system to the Danube).

TP-loads

To test the validity of this simplified approach estimated TP loads were compared to TP model results used for discharges < 3200m^3/s presented in chapter 2.3.1. Considering the years 2002 and 2003 (taken into account only days with discharges < 3200m^3/s) both approaches show a good correspondence with discrepancies of only 17.5% in 2002 and 12.5% in 2003.

The calculations underline that significant TP loads are transported to the floodplain during high flow events. This is expressed by results from the extreme wet year 2002, when 1719 t TP (96% of the total load discharged to Regelsbrunn) were transported into or through the floodplain at discharges > 3200 m^3/s while over the whole year 1780 t TP are transported to the floodplain. However, even during the extreme dry year 2003 with mean discharges at Vienna of only 1500m^3/s and a maximum daily discharge of 3860m^3/s, within 10 days (with discharges > 3200 m^3/s) rather 70% (44 t TP) of the annual TP load (58 t TP) was transported to the floodplain.

Discrepancies between the calculated TP loads of the two approaches at the altered riverine wetland Lobau are significantly higher compared to the riverine wetland Regelsbrunn. While the input-out based model calculates a transport to the Lobau at discharges < 4000 m^3/s of 3,2 t TP (2002) and 0,8 t TP (2003) the Danube load based approach calculates a transport of 13 t TP (2002) and 1 t TP (2003) considering the same range of discharges. However, this difference is due to different flow related assumptions (input-output approach related assumption: discharge to Lobau at three days increasing water levels; Danube load related approach: discharge at one day of rising water levels).

Including discharges >4000 m^3/s result in a 2002 total transport of 150 t TP into the altered wetland, while at 2003 transport is 1 t TP in total (no discharges >4000 m^3/s). Similar to results concerning the riverine wetland Regelsbrunn in 2002 91% of TP loads are transported to the altered wetland Lobau during high flow events (here defined as discharges > 4000m^3/s).

Results imply that the annual TP loads transported to the floodplain can vary over a broad range. The high share of loads transported to the floodplain even at the dry year 2003 underlines the necessity to consider high flow events with respect to calculate serious nutrient and matter balances in riverine floodplains.

NO_3-N loads

NO_3-N loads discharged to the riverine wetland Regelsbrunn were estimated to be 4866 t in the year 2002 and 763 t in the year 2003. At discharge < 3200 m^3/s in the year 2002 1329 t NO_3-N were transported compared to 3537 t NO_3-N (72%) transported at discharges > 3200 m^3/s. In the year 2002 390 t NO_3-N were transported at discharges < 3200 m^3/s and 373 t NO_3-N (49%) at discharges > 3200 m^3/s.

Results imply that annual NO_3-N loads transported to the riverine wetland vary by a factor 6. Even the load transported to the wetland at discharges < 3200 can vary significantly with respect to the annual discharge distribution. Furthermore, in the case of NO_3-N seasonal variations have to be taken into account, with general low NO_3–N concentrations during the warm summer period and increasing concentrations during wintertime. While the shares of NO_3-N loads transported to the riverine wetland at high flow events are not as dominant as for TP, significant shares are transported even at dry years within only a few days of higher discharges (2003: rather 50 % in 10 days).

NO_3-N loads discharged to the altered wetland Lobau at discharges <4000 m^3/s in the year 2002 correspond to the calculated loads from the input-output based approach (deviation of 11 %) when using the same border conditions (assumed flow only at three days of rising Danube water levels). However, considering daily discharges to the Lobau altered wetland systems inputs increase up to 131 t NO_3-N at discharges < 4000 m^3/s and up to 330 t NO_3-N in total (considering Danube River discharges > 4000 m^3/s). For the year 2003 with no discharges > 4000 m^3/s the calculated loads are much smaller with 22 t NO_3-N.

In the year 2002 60% of the NO_3-N loads are transported during 25 days with discharges >4000m^3/s.

Table 8 TP and NO3-N loads transported to the riverine wetland systems Regelsbrunn and Lobau (altered system) for the years 2002 and 2003 considering high flow events.

Load estimates [t/a]								
TP					**NO_3-N**			
	2002		***2003***		***2002***		***2003***	
	total	*(high flow*)*	*total*	*(high flow*)*	*total*	*(high flow*)*	*total*	*(high flow*)*
Regelsbrunn	1780	1719	58	44	4866	3537	763	373
Lobau	150	137	1	-	330	199	22	-

- high flow Regelsbrunn: > 3200 m^3/s; Lobau > 4000 m^3/s.

2.3.1.4. Regelsbrunn and Lobau retention and loss estimates with high flow conditions included

To estimate a reasonable retention capacity of the floodplain for TP at high flow conditions it was assumed that the mean annual retention calculated by input-output measurements at discharges < 3200 m^3/s (Regelsbrunn) and > 4000m^3/s (Lobau) is valid even at high flow conditions.

This simplification will lead to a proper underestimation of TP retention which in general increases with the amount of water being transported to the riverine wetland and an overestimation of NO_3-N being retained only at low water velocities with lower discharges (however, water storage and losses at high flow events may be significant!).

TP retention

Estimates of the mean TP retention concerning loads transported to the Regelsbrunn wetland system at discharges <3200 m^3/s amounts to 28% considering the years 2002 and 2003. Thus, including discharges >3200 m^3/s leads to a possible retention of ~ 480 t in the year 2002 and ~ 15 t TP in the year 2003 (assuming the 28% retention of TP is valid even at discharges >3200 m^3/s).

This would result in a ~ 1.0 t TP/ha input to the floodplain in 2002 and ~ 0.03 t TP/ha in 2003. With respect to the annual TP loads transported by the River Danube at Vienna the estimated retention in Regelsbrunn in 2002 would come up to 2.3% of the yearly Danube TP load or more illustrative, more than two times the annual TP load emitted to the Danube by Vienna`s treated wastewater. In 2003 the TP retention would amount to only 0.2% of the annual load transported by the Danube at Vienna or 1/12 of the yearly TP load from Vienna`s main WWTP..

In the altered wetland system Lobau TP retention estimates are more complicated because the TP balances in the year 2002 at water discharges <4000 m^3/s result in a phosphorus mobilization of

30 % (input-output based approach). For the year 2003 TP retention of rather 50 % was balanced while input was low in general (0.8 t TP). On base of this broad range an estimate of TP loads retained in the Lobau seems to be impossible.

NO_3-N removal

At Regelsbrunn at discharges < 3200 m^3/s 308 t NO_3-N were removed in the year 2002 while 111 t NO_3-N were removed in the year 2003 (Table 6). Compared to a load of 1329 t NO_3-N transported to the wetland system in 2002 and 390 t NO_3-N transported at the year 2002 this would result in a 23 % (2002) and 28,5 % (2003) removal of NO_3-N. Considering results from figure 15 at discharges > 3200 m^3/s no further removal of NO_3-N can be expected. Thus, related to the total loads transported to the system which amounts to 4866 t NO_3-N (2002) and 763 t NO_3-N (2003) it can be assumed that removal of NO_3-N would amount to 6 % (2002) and 14.5 % (2003) of the input load reflecting hydrological and meteorological conditions at the two years.

However, with respect of the yearly NO_3-N loads transported by the Danube River the removal would amount to 0.2% in 2002 and 0.1% in 2003, only.

For the Lobau at the moment no removal rates for discharges >4000 m^3/s are calculated because of the high uncertainties stated above.

It has to be stated that removal and retention estimates at high flow conditions are based on several assumptions and reflect only the potential retention capacity. However, results imply a strong need for retention calculations, especially at high flow conditions to prove these estimates.

2.3.2. The Hungarian wetlands Szigetköz

2.3.2.1. Nutrient Monitoring and Results

The Szigetköz Monitoring System has been operational since 1995, including (1) geological, (2) surface water hydrology and chemistry, (3) groundwater hydrology and chemistry, and (4) biological monitoring. Nutrients are monitored as part of the two water monitoring systems.

Actual Geological Monitoring

Simultaneously with collecting water samples in sounding sites regular observations of the character of sedimentation versus erosion in specific channel reaches of actual geological observation sites also take place together with collecting samples and analysing their sedimentary features by the Geological Institute of Hungary (MÁFI). The state of channels involved in water recharge continually deteriorates. Downstream the cross-dykes channel erosion and the constant movement of coarse debris are prominent. The channel reach downstream the cross-dyke B11 has spectacularly been rearranged since 1993. Silting is predominant along other reaches slowed down by artificial inundation. The lower reach of the side-branch system in the active floodplain not involved in water recharge, namely the Ásványi-Danube and the Bagoméri-branch-system can also be attributed to the reach influenced by the backwater effect of the Bős tailrace canal. Their water regime and flow pattern are identical with the reach of the main channel between 1820 and 1811 RiverKM. This dynamic landscape re-structuring affects nutrient control by re-vegetation of formerly active channel parts, and by altering the transport and deposition pathways of sediment-bound nutrients.

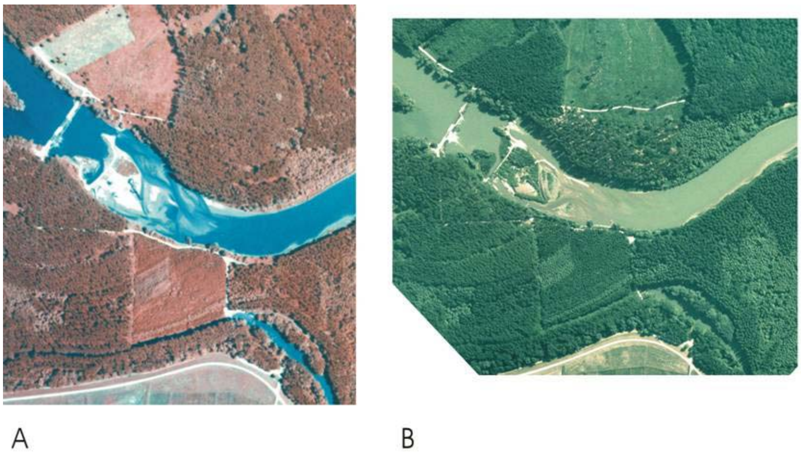

Figure 17 Air photos of cross-dyke B11 in 1993 (A - infrared) and in 2000 (B- ortophoto).

<u>Groundwater – Surface Water Integrated Monitoring</u>

The objective of this monitoring activity is to study hydrochemistry of groundwater, including nutrients, in interaction with surface waters. Therefore, MÁFI has been collecting quarterly (4 samples per year) pairs of surface- and groundwater (recovered in soundings) samples at 16 sites since 1988. Significant phenomena can be studied by the special sounding along the channels and characterise the relationship between the quality of surface and groundwater. This sounding method along the channel allows essentially studying short-distance (1-2 m) and short-term (some days) changes in water quality. Simultaneously, it can indicate some later occurring changes in water quality along flow direction taking place in more remote and deeper aquifers.

Additional samples were collected from observed natural springs and new observation wells established in 1995 for tracing the effect of the underwater weir constructed in the same year. In addition, between 1982 and 1987, 364 shallow, maximum 10-m-deep boreholes were completed in a network with average spacing of 1000-1500 m. They were supplemented by 24 boreholes of minor depth (≤50 m) and one borehole of intermediate depth (400 m). One part of the mentioned 24 boreholes was converted to groundwater observation wells serving as the basis for the groundwater level observation network of MÁFI established in Szigetköz.

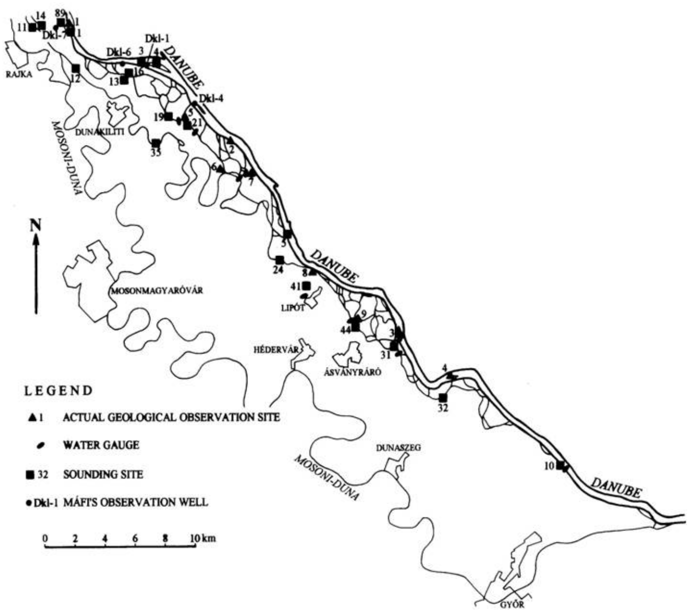

Figure 18 Observation sites of the Geological Monitoring (MÁFI)

In the Monitoring System the following hydrochemical parameters are measured:

> In-situ field analyses: measurement of hydrostatic groundwater level, water and air temperature, alkalinity, pH, electric conductivity and dissolved oxygen content.

> Laboratory analyses: routine and ICP-MS measurements were performed for the next components and elements:

> Main components: pH, alkalinity, specific conductivity, temperature, total hardness, carbonate hardness, Na+, K+, Ca2+, Mg2+, Fe2+, Mn2+, NH_4, Cl-, HCO3-, SO42-, NO3-, NO2-, PO42- and H2SiO3 content,

> Trace elements: Li, Be, B, Al, V, Cr, Mn, Co, Ni, Cu, Zn, As, As_H, Rb, Sr, Mn, Ag, Cd, Sb, Cs, Ba, La, Tl, Pb, Bi, Th, U content.

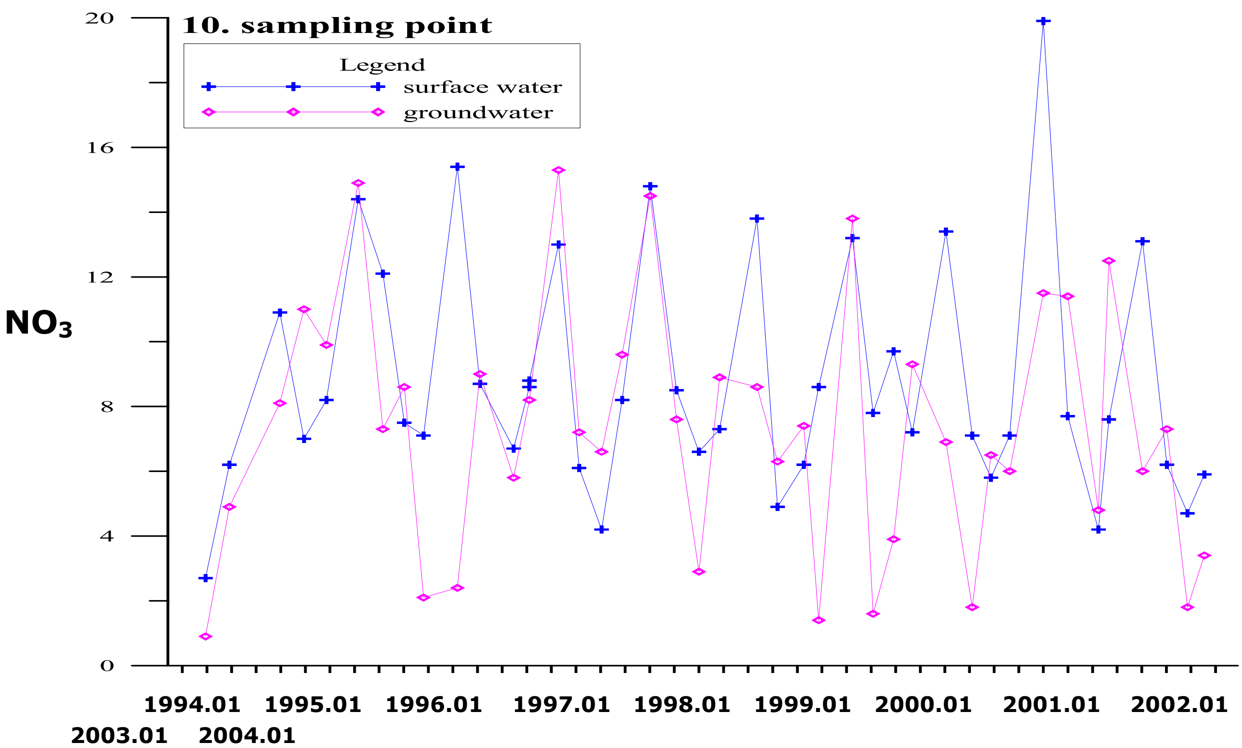

Figure 19 Examples for the long-term nutrient monitoring in groundwater and related surface water in the Szigetköz. Quarterly nitrate contents recorded in observation site 10 between 1994-2004 (in Nagybajcs) (data from the Geological Institute of Hungary, MÁFI).

Results of long-term monitoring show, that the water quality data do not, however, provide information on the amount of infiltration under deteriorating or improving conditions. In-situ recorded water temperature indicates the strength of relationship with infiltrating surface water. Accordingly, with regard to subsurface water flow in the Szigetköz, some three years should pass after infiltration for smoothing the original infiltration temperatures in order to reach the average temperature in compliance with the given depth. It has been stated that the water formed in this period in Szigetköz was substantially more reduced than before river diversion in 1995. However, the effect of this change on the former water-sediment interaction processes during filtration to deeper horizons cannot be estimated i.e. it is quite difficult to assess the quality of resulting subsurface confined aquifer.

Water quality in deep wells shows that changes in nitrate content are the most sensitive indicator of infiltration (cross filtration) conditions. It reacts even to the tiniest changes in the state of the channel (e.g. contamination). Formation of reducing conditions as well as the intensity of denitrification is indicated by falling nitrate content. During the studied period, nitrate content of Danube water decreased by some 1 mg/l. Since 1995 it constantly decreased at a rate higher than in Danube water, whereas it has approached the latter again recently. This suggests that formerly increasing contamination of the channel presumably ceased (as a result of multiple, intense floods?). In well Dkl-4 nitrate content is invariably high, nearly as high as in Danube. It manifests favorable infiltration conditions, reducing processes are weak or absent. However, minimum values recorded during the last two years suggest that infiltration conditions around the well deteriorate. Changes in nitrate content recorded in well Dkl-6 reflect a peculiar process. Seasonal change in amplitude shows diminishing trend and it is lower than that of the Danube. The change in amplitude can be the result of mixing with nitrate-bearing water. There is no sign of denitrification. Nitrate content had increasing trend in well Dkl-7, though its absolute value remained under Danube water. This increasing trend ceased recently becoming stagnant.

Water quality data in soundings represented by sample pairs taken from the probe and surface water since 1995 enable the assessment of long-term trends. Results show that some locations are characterised by stagnant water quality, while other locations have tendency of increasing nitrate content due to reduction of percolating waters together with constantly unfavourable rates of denitrification.

The monitoring activities so far have concluded that (1) the *in-situ* study of river reaches ensuring overbank screening can be arranged by reasonably implemented sounding sites and shallow boreholes, (3) a key role should further be given to the observation of sounding sites and especially shallow wells in the monitoring system set up for tracing changes in groundwater of the Szigetköz area, and (3) in the zone around the channel the quality of the water filtrating across this zone is governed by the joined effect of water-sediment-biological interaction processes.

Surface Water Monitoring

The objective of this monitoring activity is to study water quantities and qualities, including nutrients in the Szigetköz section of River Danube. In the Monitoring System the following hydrochemical parameters are measured:

- DOC, BOD, COD-Mn, COD-Cr, TOC,
- Temperature, EC, suspended sediments, **NH_4-N**, **NO_3-N**, **NO_2-N**, **Total N**, **Total P**, **Ortho-phosphate-P**, pH, Chlorophyll-a,
- Cl-, $SO_4$2-, TDS, and dissolved Hg, Pb, Cd, As, Cr, Cu, Ni, and Zn.

Results of long-term monitoring show, that the prevailing form of mineral N is NO_3-N with minor NH_4-N and NO_2-N content. Seasonal changes of various N forms are related to biological activity depending on water temperature. Accordingly, NO_3 content is higher in the cold winter season than in the warmer summer period. Phosphorus concentrations also reach minimum in the warmer summer season at all sampling locations. Nutrient available for the algae is sufficient for the eutrophic conditions. Detailed evaluation of long-term trends in nutrient parameters still need to be developed.

2.4. Nutrient storage in wetland soils

An important compartment in the nutrient cycle is the storage in wetland soils and sediments. Therefore soil profiles following a “chronosequence” schema (see Fig. 20) were selected and sampled in the Danube floodplain in autumn 2004, and various chemical, physical and biological soil properties (e.g., pH, particle size distribution, clay mineralogy, organic carbon content, microbial biomass) were characterised. Soil properties are reported in Lair et al. (2007). Most of the soil profiles classify as Fluvisols (WRB) and develop into Chernozems with soil age (see Table 9).

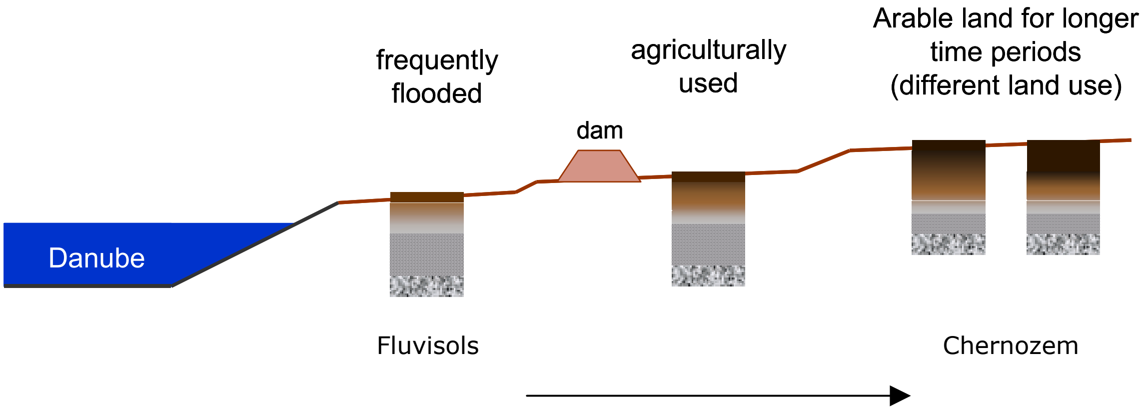

Figure 20 Chronosequence of soils in the Danube floodplain (Gerzabek et al., 2007).

2.4.1. Study area and sites of investigation

The area is located between 142 m above sea level (asl) in the east ("Brückelwiese", sites 6 and 7) and 150 m asl (meter above sea level) in the west ("large meadow", site 4). The parent floodplain has been formed by massive sedimentation of up to 7 m of quaternary coarse gravel over tertiary fine sediments. The coarse gravel keeps the groundwater, which can be found at depths of 1 to 5 m in the study area. These sediments are covered by alluvial fine sediments (mostly silt and fine sands), which flatten the formerly pronounced relief, so that the recent surface is only slightly structured. The thickness of the alluvial silt layer at the surface can reach more than 2 m. The layer of the coarse gravel can be missing in the area close to the Danube due to erosion processes of the river.

For the present analyses, 8 sites in the National Park "Donau-Auen" were selected, as listed in Table 9. Soil samples were collected and analysed to depths of 60 cm (island sites) and 20 cm (floodplain sites), respectively.

Table 9 Overview and description of sampling sites. Soil age was estimated using geological and historical maps: (*) <100 years, (**) 100 to 600 years, (***) 2000 to >10,000 years. Coordinates (°, min, sec.) according to WGS84.

Site	Soil age	Coordinates		Soil Classification (WRB)	Site description, land use
		East	North		
DA1	*	16°41'12''	48°07'14''	Calcari-Gleyic Fluvisol	Island, wood
DA3	*	16°52'49''	48°07'59''	Calcari-Gleyic Fluvisol	Island, wood
DA4	**	16°39'39''	48°08'05''	Humi-Gleyic Fluvisol (calcaric)	Inside the dam, acre
DA5	**	16°39'47''	48°08'03''	Humi-Gleyic Fluvisol (calcaric)	Inside the dam, forest
DA6	**	16°52'39''	48°08'36''	Mollihumi-Gleyic Fluvisol (calcaric)	Inside the dam, grassland
DA7	**	16°52'35''	48°08'38''	Mollihumi-Gleyic Fluvisol (calcaric)	Outside the dam, grassland
DA9	**	16°41'43''	48°08'42''	Mollihumi-Gleyic Fluvisol (calcaric)	Outside the dam, forest
DA10	**,***	16°41'10''	48°08'20''	Siltic Chernozem	Outside the dam, grassland

2.4.2. Phosphorus content in wetland soils

The inorganic phosphorus content varies between 288.4 ± 12.3 and 691.0 ± 54.2 mg pro kg sediment, whereas the lowest concentration was measured inside the dam at one grassland section and the highest content was measured in the river channel itself.

The organic phosphorus amount shows a clear distribution. The lowest level was measured at the island – wood sides (27.7 ± 14.1 mg pro kg sediment) and the highest outside the dam (grassland) with 401.1 ± 85.2 mg pro kg sediment. Figure 21 shows that the organic phosphorus content increases from the Danube and Danube islands to the sites inside the dam and finally the highest concentrations is found out side the dam. This is an indication that periodical flooding avoids the accumulation of organic phosphorus which is also related to heavy metal accumulation (Lair et al. 2007).

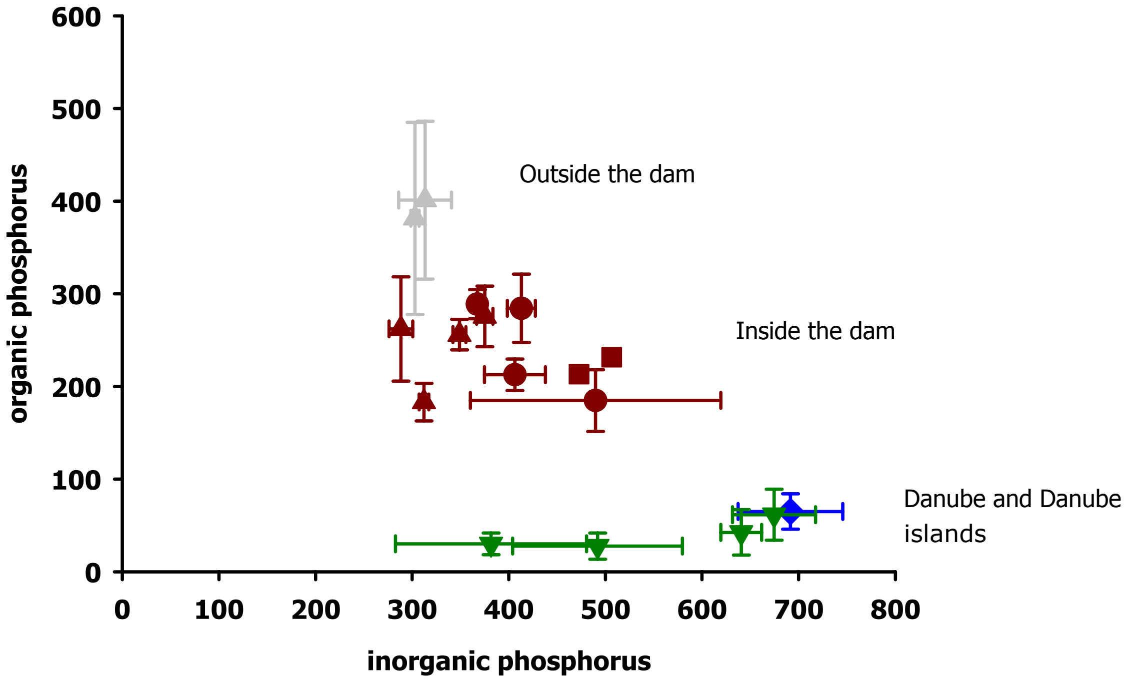

Figure 21 Mean inorganic and organic phosphorus and standard deviation from all sampling points in mg phosphorus per kg sediment

3. INVENTORY OF NUTRIENT REMOVAL CAPACITIES OF RIVERINE WETLANDS WITHIN THE DRB

3.1. Objectives

The objective of the inventory of nutrient removal capacities of riverine wetlands was the development and demonstration of an inventory methodology to support the harmonised assessment and monitoring of nutrient removal in the Danube River Basin. Implementation of complete inventory and creation of a full database was not the objective but rather to keep the approach simple for demonstration purposes. The collected information is to enable the assessment of wetland nutrient removal capacity and to enable the comparison of wetlands in terms of nutrient removal efficiency.

Specific objectives of inventory were the following:

> identification of screening-level key parameters (indicators) of nutrient removal capacities of riverine wetlands,

> developing a solid basis for harmonised long-term monitoring of wetlands based on the key parameters,

> establishment of a harmonised data collection methodology by means of standard questionnaire for future river basin-wide database development and operation,

> demonstrating a preliminary step towards future detailed nutrient dynamics modelling in wetlands in the river basin,

> providing a demonstration exercise for the screening-level inventory of wetlands in order to test ways of identifying information gaps and needs for future data collection and reporting improvement,

> increasing awareness of common interests in nutrient control among wetland managers in the Danube River Basin.

Questions to be answered by the inventory questionnaire are "Are there gaps in space, time and character in essential information, including monitoring activities?", "Is the wetland under restoration or are there planned activities that influence significantly nutrient removal capacities?", "Are there management or land use changes on-going or expected that would impact nutrient control?" or "Is nutrient removal among the main functions of the managed wetland?".

3.2. Scope of inventory

The first point to consider is the legacy of past, i.e. historical river regulation by dam construction and wetland draining for flood control and navigation promotion that defines and characterise the present situation in the Danube River Basin. Floodplain wetland reconstruction and management is very recent development in the Danube River Basin, mostly a task for the future. As a consequence, there is very limited experience about wetland reconstruction, especially in relation to nutrient control. Another limiting factor is the fact, that even on-going or planned wetland restorations aim at flood control and ecological habitat reconstruction and there is little attention paid for nutrient control as a function of the wetland. As a result, there is very limited data and experience on nutrient control available in the Danube River Basin. Based on previous studies and preliminary investigations, it can be said that even existing nutrient monitoring data is sporadic both in space and time, and characterised by lack of standard methods with respect to sample collection location, frequency and protocols and sample analysis methods. This makes the comparison of available data almost impossible. Thus, nutrient control is characterised by gaps in data and lack of harmonisation.

Secondly, not only data and experience is limited, but our knowledge on the impacts of wetland restoration, especially with respect to nutrient control, has also some gaps. Although nutrient control is an area of intensive research, studies are often isolated focusing on particular aspects of nutrients, while wetland management has to consider the wetland as a single entity. Numerical models are becoming increasingly available providing a field of intensive development. A further obstacle to knowledge development is the very nature of the wetland system: its overwhelming complexity. Thus, nutrient control is characterised by limited but fast developing scientific knowledge.

Thirdly, floodplains and associated wetlands are extremely dynamic systems that change fast, often in response to catastrophic flood events, affecting hydrological and ecological conditions, and sediment and nutrient dynamics. While this dynamics is one of the most attractive features of riverine wetlands, it makes data collection and long-term monitoring design very hard. In relation to natural dynamics and historic river regulation and floodplain exploitation, wetlands are indeed very varied in the Danube River Basin. This calls for site specific assessment and monitoring.

Against this background, development of harmonised wetland nutrient control inventory appears to be a real challenge. Considering the above constrains, the developed inventory methodology focused on screening-level data acquisition and did not attempt to provide ways of data collection for detailed site-specific studies and modelling. Instead, due to the novelty of the subject and complexity of the problem, the list of inventoried parameters was developed to keep a balance between relevance and simplicity. For example, despite of its importance, detailed information on ecological conditions such as vegetation types and ecosystem composition was not considered. Also, detailed data on hydrological, ecological and nutrient dynamics were not addressed in this attempt.

Since the objective of the project was to support wetland managers, only managed wetlands are considered and non-managed wetlands are out of the scope of the inventory.

3.3. Methodology development

Structure and functioning of wetlands determine nutrient removal capacity, therefore data acquisition was structured accordingly. Wetland structure is addressed by several points such as wetland area, RAMSAR and land use types, and links to other nearby wetlands. Functioning of wetland is investigated basically in the whole inventory including dedicated sections to wetland status and management, and nutrient and material fluxes.

Since assessment of ´nutrient removal´ is the main objective, wetlands as receptors were studied along the source-pathway-receptor chain. Therefore, the parameters in the inventory questionnaire describe the wetland as a receptor through questions such as wetland and land use types, if the wetland is a protected area, or if the wetland has known significant nutrient control function. Existence of point and non-point nutrient sources at the wetland is addressed at on point. Pathway routes are not detailed, however data on nutrient is inquired for the surface- and groundwater, soils and sediment and biota pathways. Also, relevant hydrological, sediment, hydrochemical and nutrient material fluxes are addressed in a separate section.

The collected information has to be able to support assessment and modelling of wetland nutrient removal. Two types of models were considered in the inventory: process-oriented dynamic models and material balance-based box models. Due to the fact that, on one hand, dynamic nutrient modelling is currently a field of intensive research and, on the other hand, high data input requirements of these models cannot be satisfied in most cases in the Danube River Basin, the inventory was designed to support the simpler material balance-based box models. Accordingly, the wetland is approached as a single compartment with nutrient input and output, and data is inquired at the river inlet and outlet, in addition to the within-wetland river section. As important indicators of nutrient control, material fluxes in relation to nutrients such as water discharge and sediment load are inquired. This data also provides ancillary data for nutrient removal estimation. Dissolved and sediment-bound nutrient input and output ratios are fundamental indicators of nutrient removal efficiency for wetland managers. Since riverine wetlands form in fact a chain of ecosystems along the river, parameters on the spatial context such as existence of close up- and downstream wetlands should promote linking of single wetland material-balance models.

One of the most important goals of the inventory was to lay the grounds for harmonised monitoring of wetland nutrient removal. Besides the fundamental monitoring of input and output material fluxes along various aquatic and terrestrial pathways, the inventory methodology enables the monitoring of wetland management activities, as well. For example, if currently planned restorations realise in the future or monitoring of essential parameters is installed.

Finally, the inventory was designed to support wetland management by providing a structured approach that yield useful information to the wetland managers. Dedicated sections on the status and management of wetland give insight into the main functions of the wetland (flood control, ecological, nutrient, recreation, etc.), legislative conditions, and wetland restoration activities, as examples. Since wetland management is a fast improving area, not only the on-going but future and planned management activities are inquired as well. The inventory was designed to improve the wetland managers´ appreciation for the Danube River Basin as a whole and for the fact that riverine wetlands are linked along the river course. This aspect is made explicit by questions such as ´existence of close riverine wetlands´ or ´professional links to other wetland managers´. Thinking in terms of nutrient input and output (what the wetland receives from upstream and what leaves the wetland downstream) should also promote managers´ spatial consciousness and their collaboration motivation. In order to support wetland managers at the local scale and managers at the regional and international scales being active with other important aspects of wetland management, the inventory was designed to provide clear link to other efforts such as flood control and land use planning (e.g. recreation, habitat protection, etc.). This is achieved by collecting data on these wetland management aspects and key functions.

3.4. The Questionnaire

The questionnaire developed for the inventory methodology has six sections and 27 points of questions. Section I "Wetland Identification and Location" is intended to enable linking of the inventoried data to spatial information systems and databases at the national and international levels. Section II "Status of Wetland" and Section III "Wetland Management" are concerned about the wetland management that influences nutrient removal. Special emphasis is put on the dynamics of wetland management, including on-going restoration activities, expected land use changes and future plans. Section IV "Nutrients" and Section V "Hydrology, Material Flux, Water Chemistry" are concerned about the media (surface- and groundwater, soils and sediments, and biota) and location (upstream of, downstream of or within the wetland) of measured parameters. Special emphasis is put on regular measurements in order to serve the purpose of nutrient monitoring. Note measured data is assumed to be readily available, therefore no actual datasets and values are requested but only metadata, i.e. the existence, actuality and character of data on measured parameters. Section VI "Notes, Comments, References" facilitate collection expert comments and ancillary information. With the introduction of this section hard data collected in the previous sections can be separated from soft data made available in this section.

The questionnaire is designed in a way that it is easy to transform into an internet web application where data can be collected from wetland managers on a regular (monitoring) basis in the future. Such an application may facilitate the online information distribution on wetland nutrient and environmental conditions. The questionnaire also provides a solid basis for the design of future monitoring aiming at the long-term and sustainable observation of wetland nutrient control. Since the inventory is a management-oriented effort, the questionnaire also enables the monitoring the management practices. This is important, since nutrient removal efficiency is fundamentally determined by wetland management practices.

Essential spatial data such as wetland drainage area, shape and connectedness, topographic conditions and spatial pattern of land use were not inventoried by the questionnaire. Firstly, asking for spatial GIS data would have made the questionnaire very long and difficult to fill-in, also possibly introducing lot of errors and inconsistencies, especially by using local data formats and standards. Secondly, most of the necessary data is readily available from harmonised digital GIS databases. For example, land use pattern can is available from the CORINE land cover database, terrain information can be obtained from the SRTM database, watershed information and drainage pattern can be easily recovered from the Catchment Characterisation and Modelling (CCM) River and Catchment Database.

The questionnaire design allows a feasible implementation of an inventory by keeping the questions to the possible minimum question and simplicity without compromising on relevance and value of information. Thus, the few questions clearly structured in six sections on 3.5 pages facilitate the wetland managers' response without difficulties. Many points were designed as yes-or-no questions making filling-in the questionnaire easy.

The structure of the questionnaire makes possible the easy evaluation of the obtained data and ranking of wetland sites in terms of nutrient control data availability, management efforts and needs. In this way, identification of follow-up test sites for further project activities is made easily possible.

Finally, the inventory methodology together with questionnaire has been reviewed by the involved national exerts in order to obtain supra-national harmonisation. Most importantly, the questionnaire has been tested on several case studies of wetlands benefiting from the excellent collaboration of the concerned local wetland managers. Completed questionnaires are found in this volume, together with the evaluation of the obtained data.

3.5. Results

3.5.1. Wetland Identification and Location

The questionnaire was sent to 44 wetland restoration projects or wetland areas within the DRB and 17 were received again.

The achieved project areas are distributed in 8 different Danube sub-river basins and are mainly Danube related wetlands (Tab. 10).

Table 10 Wetland sites from the replied questionnaires

Nr.	name	country	sDRB	river	area [km²]
1	Wachau	Austria	3	Danube	16
2	Nature Reserve Zitavsky Luh	Slovakia	5	Zitava river	1.24
3	Danube National Park	Austria	6	Danube	115
4	Nyaros Island	Hungary	6	Danube	5
5	Duna-Drava National Park	Hungary	6	Danube, Sio, Drava	180
6	Dunajske Luhy floodplain	Slovakia	6	Danube	150
7	Protected Landscape Körös	Serbia	9	Danube, Tisa, Körös	13
8	Geraiului Swamp, Oltului, Saiului Mouths National Reserve	Romania	12	Danube, Jiu, Calmatui, Vedea	70
9	Persina Nature Park	Bulgaria	12	Danube, Osam	21
10	Danube Delta	Romania	13	Danube	5050
11	Danube Delta Biosphere Reserve	Romania	13	Danube	5800
12	Upper Yalpugh	Moldova	14	Yalpugh	2.1
13	Middle Yalpugh (upper Congaz)	Moldova	14	Yalpugh	1.6
14	Middle Yalpugh (lower Congaz)	Moldova	14	Yalpugh	1.25
15	Lower Yalpugh	Moldova	14	Yalpugh	1.3
16	Lower Cahul	Moldova	14	Cahul	0.9
17	Katlabuh Lake	Ukraine	15	Danube, Enika, Big Katlabuh, Tashbunar	100

3.5.2. Status of the Wetland

The main part (65%) of the wetlands are protected by legislation, most of them are NATURA 2000 sites (29%) or protected by local and national laws (29%). The unprotected wetlands present only a minor percentage and are situated in Moldova and Ukraine.

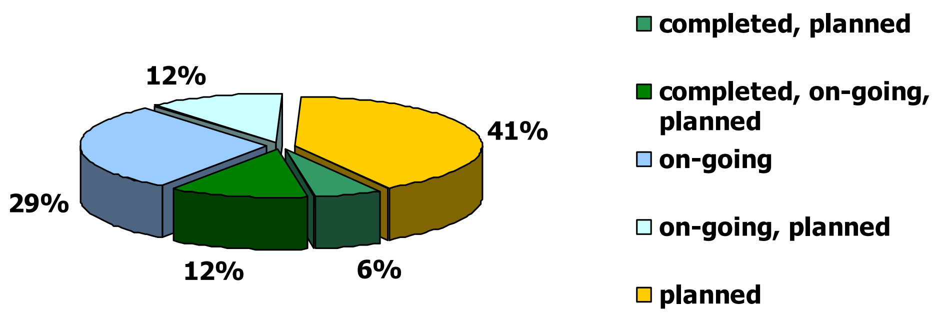

Figure 22 Percentage distribution of the status of wetland restoration projects in the DRB

In more than a half wetlands (53%) ongoing restoration activities take place (Fig. 22). The topics of this restoration measures are habitat restoration or reconnection of former side arms to the river. In 41% of the cases no completed or on-going restoration measures are established, but they are plans for the future. This future projects are dealing with side arm restoration by reconnection with the Danube or general habitat restoration.

To compare the restoration costs between the wetlands with their different areas, we calculated the expended US Dollar per square kilometre.

For these restoration projects whether they are completed, ongoing or planned the mean costs are 160,670 US $ per km². Minimum are 26 and maximum 1,184,927 US $ per km².

From these total budgets in the mean 10% are used for nutrient control measurements.

3.5.3. Wetland Management

As mentioned above the scopes of the inventory are managed wetlands, but it is interesting only two wetlands (Persina Nature Park and Katlabuh Lake) are area-wide managed.

In 6 cases respectively wetland areas are managed by environment/water management ministry or national park/biosphere reserve directory. 3 wetlands are under supervision of the republic and 2 by NGO´s.

The three main land uses in these wetlands are fishery, forestry and agriculture and in 11 cases future land use changes are planned.

The perceived wetland functions by the management are in 25% of cases flood control and in 23% habitat provision. The recreational function for the population is in 20% of cases argued.

3.5.4. Nutrients

The inventory of available nutrient data in the DRB shows that nutrient data older than 5 years are only in surface water and biota in a percentage more than 20% existing (Fig. 23). A rather good database within the last 5 years is on surface waters, soils and sediment and biota. A lack on information unfortunately exists in groundwater nutrient data.

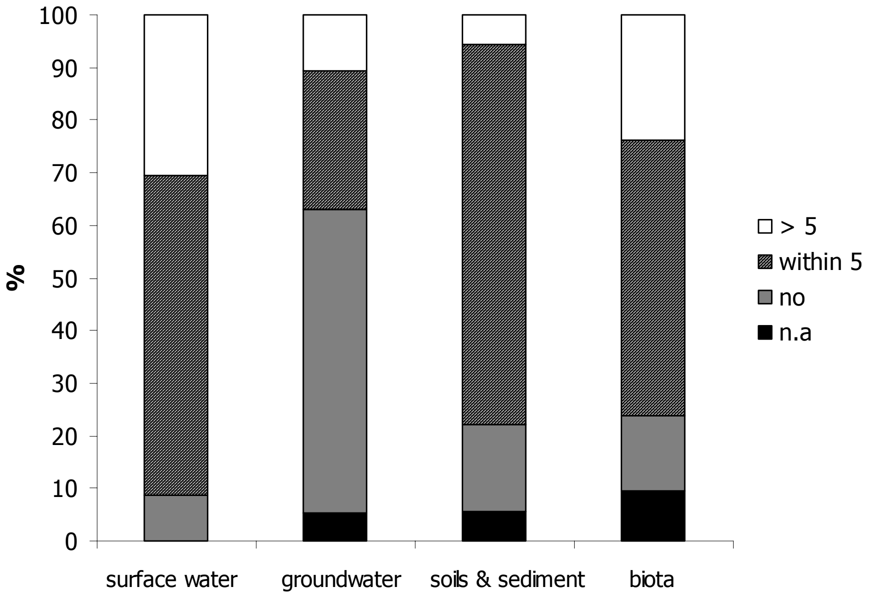

Figure 23 Percentage of available data for wetlands in different compartments

The motivation for monitoring nutrient dynamics in the wetlands is habitat protection, drinking water quality and general wetland functioning. In 41% of cases the wetland has known significant nutrient control function. However in comparison with other wetland function only a minor percentage (9%) found wetlands beneficial for nutrient pollution control.

82 % of the wetland managers recognized a nutrient source up-stream the wetlands, but only 18% within the wetland.

3.5.5. Hydrology, Material Flux, Water Chemistry

Between 30 and 41 % of cases a regular water discharge and nutrient data monitoring is established in the river inlet, outlet and within the wetland. In more than 50% of cases an area-wide water-quality monitoring is implemented.

A lack on information is on sediment load data, because in only 17 to 29% of the wetlands these parameters are measured.

4. REAL WORLD EXAMPLES OF NUTRIENT REDUCTION MEASURES IN WETLAND MANAGEMENT IN THE DRB

The previous chapters explained the theoretical background of the implementation of nutrient retention in wetland restoration and management. This chapter deals with real world examples in the DRB. In the following the 4 projects explain their motivation for monitoring nutrient retention and the methodology they used. Each project has a different background and therefore a different approach. The experience of these projects is also included in the recommendations for measuring nutrient retention in wetland management.

4.1. Hungary: Nutrient reduction and ecological revitalization on the wetlands of the Danube-Drava National Park

4.1.1. Introduction

In May 2002 the World Bank (WB) and the Hungarian Government jointly launched the project 'Reduction of Nutrient Discharges' within the frame of the WB-GEF Strategic Partnership for Nutrient Reduction in the Danube River and Black Sea. The overall objective of the project is *'to decrease nutrient discharges into the Danube river and loads to the Black Sea, by improving the reduction of nutrients in effluent from wastewater treatment plants at Budapest, and increasing the nutrient retention capacity at the wetlands of the Danube-Dráva National Park (DDNP)'* [WB, 2001]. The Budapest component of the project prescribes the extension and upgrading of the South-Pest and North-Budapest Wastewater Treatment Plants, while the DDNP component, which is the subject of this study, envisages different nutrient retention measures in the Gemenc and Béda-Karapancsa landscape units of the DDNP [WB, 2001] (Fig. Figure 2424).

The project is also aimed at serving as reference for similar nutrient reduction initiatives in Hungary and in the Danube basin [WB, 2001].

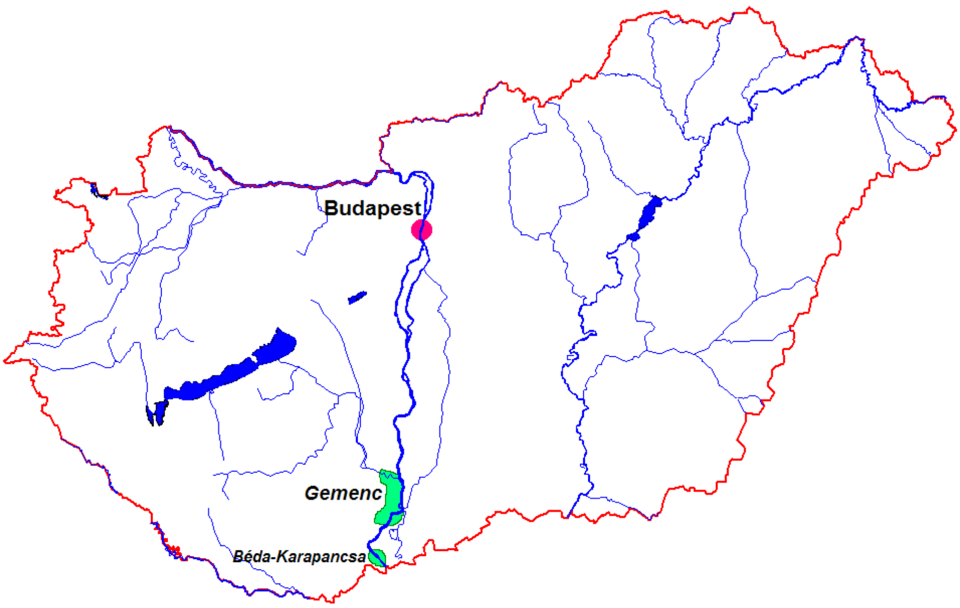

Figure 24 Location of the Gemenc and Béda-Karapancsa wetlands in Hungary

The first phase of the DDNP component was the preparation of a feasibility study [DHV, 2005] and a preliminary impact assessment study [VITUKI & VTK Innosystem, 2005]. This took place in March 2005. Results and conclusions are summarized below.

4.1.2. Description of the case study wetlands

The Gemenc and Béda-Karapancsa are characteristic floodplains of the Danube. Their wide areas are covered mainly by alluvial forests, which are fragmented by different water bodies. The types of these water bodies cover the full range of functional sets: eupotamon, parapotamon, plesiopotamon and paleopotamon [Amoros *et al.*, 1987] water bodies are all present in these floodplains. The ecological value of these floodplains is very high as they host habitats for several endangered species. The most important land use is forestry, even though hunting, fisheries and different forms of recreation are also present.

For more details about these floopdlains the reader is referred to Zsuffa [2001] and also to www.gemencrt.hu/english.htm.

4.1.3. Objectives and constraints

The primary objective of the DDNP component of the GEF project is thus nutrient reduction on the Gemenc and Béda-Karapancsa wetlands with the aim of reducing the nutrient load to the River Danube. The secondary - although equally important - objective is ecological restoration. Restoration of habitats for endangered fish, amphibian and wader species is envisaged. These habitats have been degraded significantly mainly due to negative hydrological changes (e.g. desiccation) but also to human disturbances. Finally, the project also aims at introducing nature sound management practices where economical and societal land uses are in harmony with nutrient reduction and ecological functions of these floodplains.

The above objectives are however constrained by several factors that need to be taken into consideration. It is of outmost importance not to reduce flood control safety and also not to degrade navigation and ice discharge conditions in the main channel. For this purpose the present morphological and hydrological conditions of the main channel should not be modified negatively. The flood control dike system may not be weakened either, and measures that would increase considerably the hydraulic resistance on the floodplain are also not allowed.

4.1.4. Planned measures and related expectations

11 planning units have been identified, 10 within the Gemenc and one is the Béda-Karapancsa itself. Nutrient reduction and ecological restoration measures have been formulated for these units. The type of proposed measures depends on the type of the unit. For standing water bodies water regime control measures, such as installation of weirs/sluices and dredging supply channels, are envisaged (Fig. 25). The aim is to divert water into the water body and also to increase the volume and residence time of water storage. It is expected to halt and reverse the desiccation process for the benefit of characteristic wetland ecosystems, and also to increase the rate of nutrient retention and removal.

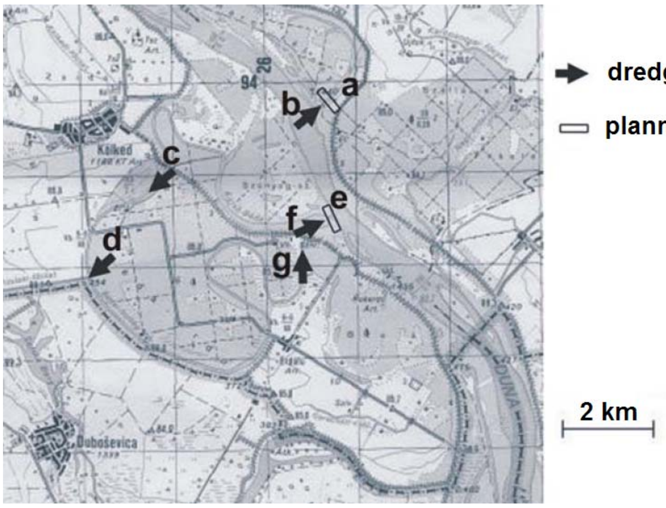

Figure 25 Planned measures in the Béda-Karapancsa wetland [DHV, 2005]

Water bodies envisaged as Eupotamon systems are proposed to be revitalized as flowing side channels of the Danube. Large scale dredging works are envisaged in order to open the silted and closed sections of the channel beds (Fig. 26). Restoration of habitats for rheophilic fish and invertebrate species is expected. Nutrient reduction is not taken into consideration in these cases.

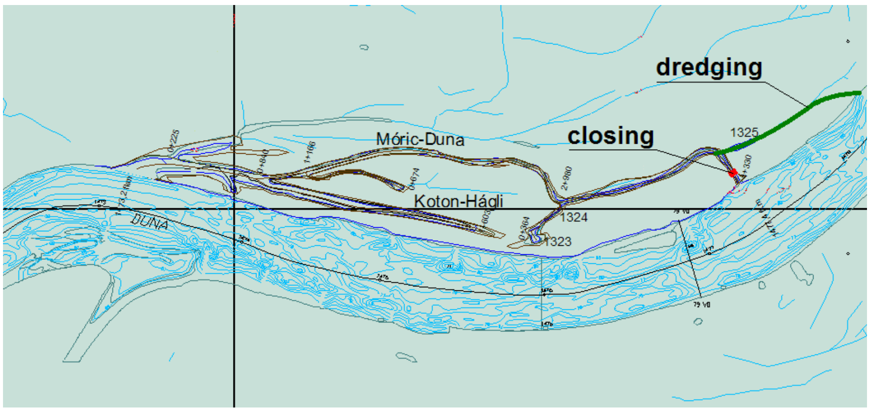

Figure 26 Restoration of the Móric Duna side channel in the Gemenc floodplain [VITUKI & VTK Innosystem, 2005]

Based on preliminary expert judgements, the following predictions have been made in respect of nutrient reduction:

> Efficient nutrient removal from the water of the main channel is practically not possible. The amounts of water that can be diverted to the floodplain are very small comparing to the amounts, which remain in, and are discharged by the main channel. In addition, this diversion can be realized quite seldom, during the short flood periods. Most of the time the water stays completely in the main channel and water quality processes are influenced only by in-channel processes.

> As far as tributaries flowing into the Danube through the floodplain are concerned, the perspectives for nutrient reduction are promising. It is possible to divert the entire flow of these tributaries into the floodplain where these waters could be spread and stored for nutrient removal purposes.

There are however several potential conflicts, which need to be taken into consideration. First of all nutrient reduction may endanger the needs of ecological restoration. The eutrophic and anoxic conditions accompanying efficient nutrient reduction processes might easily deteriorate the habitats of desired species. Thus the challenge is to find compromise solutions which are mutually beneficial for nutrient reduction and for ecological restoration.

4.1.5. The role of monitoring

The purpose of monitoring is to assess quantitatively nutrient reduction in the planning units. Thus nutrient flux in each surface hydrological link of the water body needs to be measured. This concerns not just those floodplain channels that connect the water body to the main channel or to other water bodies, but also tributary rivers and canals flowing into the water body from outside. The temporal resolution of measurements must be in accord with the intensity of surface flow processes. In case of floods, when the rate of water exchange between the main channel and the water body changes quickly, the frequency of monitoring must be in the scale of hours. In low flow, stagnant periods however daily, weekly or even monthly sampling frequency might be sufficient for assessing the nutrient budget of the water body.

Monitoring nutrient fluxes between the water body and the subsurface water system would be also important, although it cannot be implemented in practice. Nevertheless, these fluxes do not play significant role in the nutrient budget of water bodies of the Gemenc and Béda-Karapancsa floodplains, thanks to the thick clay layers that isolates the floodplain surface from the subsurface water system [Zsuffa, 2001].

Assessment of a complete nutrient budget requires monitoring of fluxes of all nutrient forms. Accordingly fluxes of all organic and inorganic nitrogen and phosphorous forms, as well as that of phytoplankton biomasses must be monitored at each link of the water body.

It is strongly recommended to support monitoring with modelling tools. For this purpose water quality models are envisaged for the planning units of the Gemenc and Béda-Karapancsa wetlands. According to Højberg *et. al.* [2007] models do have the potential to support monitoring in the following fields:

> quality assurance of monitoring data
> interpolation and extrapolation in time and space
> improvement of conceptual understanding
> improvement of monitoring programme.

Modelling however is likely to require auxiliary data [Zsuffa, 2001], which are not targeted by the monitoring programme. WQ models need first of all hydrological data, which could be generated either be monitoring or by hydrological modelling. Hydrological models require morphological, hydrological and meteorological boundary data, which again need to be monitored. In addition, WQ models require nutrient concentration data from the water body itself for calibration and validation purposes, furthermore other auxiliary data such as temperature, solar radiation, pH etc. might also be needed depending on the complexity of the model. Involving models will thus surely increase the scope of monitoring, yet models do have the potential to improve the quality and efficiency of monitoring and even to reduce its overall costs.

It is important to note that models are envisaged not only for supporting monitoring but also and first of all for supporting planning and impact assessment. This means that applying WQ and hydrological models on the water bodies of the Gemenc and Béda-Karapancsa floodplains (thus providing support for monitoring as well) will be essential parts of the project even if monitoring in itself would not justify it.

Finally, the planned monitoring activities need to be harmonized with the monitoring programme prescribed by the Water Framework Directive (WFD) [EC, 2000] in order to save costs. Firstly, data that will be generated by the first *surveillance* monitoring programme [EC, 2000] could be utilized since,

> it will coincide in time with the planning and implementation of the nutrient reduction project
> its wide scope covers most of the WQ, hydrological and morphological parameters needed for setting up models and for assessing nutrient reduction.

On the other hand, the frequencies of measurements, envisaged by the WFD for a surveillance monitoring programme, are insufficient for the needs of the project (3 months for nutrients and for other WQ parameters, 6 months for phytoplankton [EC, 2000]). The surveillance monitoring programme thus needs to be supplemented with the more intensive *operational* and *investigative* monitoring programmes [EC, 2000] of the WFD, even if it turns out that no such monitoring activities are needed according to the regulations of the Directive (e.g. the water body doesn't prove to be at risk). For the continuous monitoring of nutrient budget and retention in the water bodies operational monitoring is envisaged, while conceptualization and model building will likely require short term, intensive investigative monitoring programmes.

4.1.6. Forthcoming steps of the project

The major planning and assessment steps will take place in Phase II of the project, which will be launched by the spring of 2007. The following activities are planned to be carried out according to the TOR [WB, 2007]:

> detailed design of the monitoring system
> Preparation of the final design (in sufficient detail for licensing and construction)
> Preparation of a detailed environmental impact assessment (suitable for licensing)
> Development of the methodology that will be used to examine and evaluate operations and efficiency
> Development of the operational manual and special area management plan of the artefacts

The actual implementation of the plans is the last phase of the project. This will be started in 2009 at the earliest.

4.2. Bulgaria: Wetland restoration and pollution reduction project

4.2.1. Background

Environmental degradation in the Black Sea Basin has caused significant losses to riparian countries in reduced revenues from tourism and fisheries, loss of biodiversity, and increased water-borne diseases. Pollution is likely to increase as the regional economy recovers. The Danube/Black Sea Basin Partnership Strategy Report outlines the most urgent actions needed to be adopted by the countries of the region to fulfill their international legal obligations under the Danube and Black Sea Conventions. It proposes measures to reduce excessive nutrient loads, mostly nitrogen and phosphorus, in the rivers discharging into the Black Sea, particularly into the Danube. Indeed, this is the focus of the Bulgaria Wetlands Restoration and Pollution Reduction Project (herein the Project).

The proposed 5-year Project, which is part of the Danube/Black Sea Basin Strategic Partnership on Nutrient Reduction (Phase I), will assist the Government of Bulgaria in meeting its national and international commitments to reduce transboundary nutrient loads and to conserve biodiversity in the Danube and Black Sea Basins through improved management and sustainable use of natural resources and restoration of wetlands. In support of this objective, the Project will assist the Government of Bulgaria to: (i) restore critical priority wetlands in the Danube river basin and make use of the wetlands in riparian zones as nutrient traps; and (ii) promote protected areas management and sustainable use of natural resources, including protected areas management planning, water quality and ecosystems monitoring, and public awareness and environmental education. Although the Project focuses on directly addressing the restoration of a few priority wetlands in Bulgaria, the implementation of the Project will play a critical demonstration role within the region and help to promote nutrient reduction investments in other parts of Bulgaria and neighboring countries. The identified components of the Project are as follows:

A. Wetlands Restoration

1. Engineering Design and Supervision
2. Restoration Work Belene Island and Kalimok/Brushlen Marshes Additional Restoration Sites

B. Establishment of Protected Areas Management

1. Protected Areas Management Planning
2. Protected Areas and Landscape Management Implementation
3. Monitoring Program
4. Public Awareness and Education Program
5. Institutional Strengthening
6. Nutrient Reduction Strategy Guidelines

C. Project Coordination, Management and Monitoring

1. Project Coordination and Management
2. Project Monitoring and Evaluation

In January 2001, the Government of Bulgaria received a US$350,000 grant from the Global Environmental Facility (GEF) to advance Project preparation. A Project Preparation Unit has been established within the Ministry of Environment and Water to coordinate Project preparation activities. The World Bank pre-appraised the Project in September-October, the appraised it in December, 2001, and negotiated it in the beginning of April, 2002. More details are available on the World Bank website www-wds.worldbank.org

Funding of the Project is in place since October 30 2002. The total cost of the Project has been estimated at US$13.28 million. The GEF/World Bank Partnership Investment Fund for Nutrient Reduction finances US$7.5 million. The Government of Bulgaria finances taxes and some incremental expenses for up to US$2.9 million. Additional funds to co-finance this Project are granted by the Austrian Government about US$0.38 million and European Union through PHARE National Environment US$ 2.21 million. A brief description of each one of the Project components, for which funding is needed is attached. For additional information about this Project, please feel free to contact the Project Coordination Unit at the address shown below.

4.2.2. Wetland restoration

4.2.2.1. Objective:

To restore critical wetlands and the riverine landscape in the Danube/Black Sea basin.

4.2.2.2. Description:

Marshes on Belene Island within the Persina Nature Park (21,000 ha) and the Kalimok / Brushlen Marshes within the Kalimok-Brushlen Protected Site (6,000 ha) have been selected for restoration during the first phase of Project implementation on the basis of their potential for nutrient trapping and removal and value as biodiversity habitat.

One identified site sits within the Persina Nature Park , which is located along the Svishtov – Belene lowlands. Within Persina Nature Park, the Project will support the wetland restoration on eastern Belene Island, a 15 km long island. This eastern portion of the island is already a managed Nature Reserve under the jurisdiction of the Ministry of Environment and Water; the western portion is currently under the jurisdiction of the Ministry of Justice, which operates a prison there. The other identified site, within the Kalimok/ Brushlen Protected Site, is located 60 kilometers east of Ruse. Up until the 1950's, the marsh complex was a key part of the region's valuable fish resources. In the 1950's, a dyke was constructed between Ruse and Tutrakan for agricultural purposes, but it cut off fish from their historical spawning grounds. Fish ponds (encircling 560 ha of state-owned land) were constructed, but they were declared bankrupt and abandoned after the collapse of the state farming system. Most of the original marshlands are state-owned, and have reverted to reed beds. Adjacent areas are privately and municipality-owned and used for agriculture of varying productivity levels. This component expects to restore 3,000 ha (1,500 ha in Persina Nature Park and 1,500 ha in Kalimok-Brushlen Protected Site). The restoration only involved state or municipal land. No private land is expected to be flooded. Existing dykes will be raised or new dykes will be built to protect private property. The Project supported the civil works design and construction at identified sites.

Sub-Component: Restoration of wetlands in Belene Island and Kalimok/Brushlen Marshes

> Engineering Design and Supervision. The Project provided consultant services for engineering design and supervision of civil work construction in Belene Island and Kalimok/Burshlen Marshes, to allow for controlled flooding that optimizes nutrient trapping, biodiversity restoration, and fish production as well as to ensure sustainability of the wetland ecosystems. (Years 2002-04).

> Restoration of wetlands in Belene Island. The Project financed civil works for the construction and rehabilitation of small infrastructure needed for the restoration of wetlands in Belene Island, including sluices, canals, protective dykes, and access roads. (Years 2006-07).

> Restoration of Kalimok/Brushlen Wetlands. The Project will finance civil works for the construction and rehabilitation of small infrastructure needed for the restoration of only wetland Kalimok including sluices, canals, protective dykes, and access roads. (Years 2007-08).

4.2.3. Establishment of protected areas management

4.2.3.1. Objective:

To ensure sustainable development within the landscapes of Persina Nature Park and Kalimok/Brushlen Protected Site.

4.2.3.2. Description:

The wetlands restoration and management regime of both sites will incorporate the objectives of the local communities as well as the biodiversity objectives of the Nature Park and protected site, respectively. This component supported preparation of protected areas management plans as well as implementation of priority actions within the framework of protected areas management regimes. This component included the following activities: (i) development of protected areas management plans in each protected area; (ii) implementation of priority protected areas management actions, including management, operation and maintenance of restored wetlands and associated protected areas, establishment of a farmer transition support program, provision of technical support for development of "green" business; (iii) strengthening monitoring programs within the restored wetlands systems; (iv) public awareness and education program, which includes a small grant scheme for activities that promote biodiversity conservation and environmental education program; (v) institutional strengthening program for entities responsible for land/water management to ensure sustainable management and use of the restored sites

Sub-Components:

> Protected Areas Management Planning. The Project financed consultant services to support the administrations of Persina Nature Park and Kalimok/Brushlen Protected Site in the 2-3 year development of participatory management plans, which regulated all activities within the designated areas, including the demarcation of management zones for multiple resources use and economic development. The first year was dedicated to

fact-finding and establishment of consensus-building process, which help guided the identification of zones and management protocols. (Years 2004-06).

> Protected Areas Management Implementation. Under this sub-component, the Project financed:
  - Supply of Equipment for operation and maintenance of restored wetlands (Years 2003-05).
  - A Farmer Transition Support Fund to support economic activities that promote nutrient reduction and conservation objectives, helping farmers offset the one-time cost to farmers of adopting environmental friendly agriculture practices. The Fund supported measures to improve crop and soil management (through manure management), landscape and habitant management (through creating pastures), organic farming, reed management etc. (Years 2005-07).
  - A Eco-Business Development Facility, which will help local communities to develop marketable "eco-friendly" business proposal to access SAPARD or related funds for sustainable rural development and support implementation of a number of pilot schemes. (Years 2002-07).

> Monitoring program. Under this sub-component, the Project helped to establish a comprehensive program to monitor surface and groundwater, soil and sedimentation, biodiversity, crop and yields, meteorological parameters associated with the restored wetlands and related protected habitats. The Project financed: equipment for the monitoring of surface water quality and quantity, groundwater, meteorology, soils and sedimentation, and biodiversity; consultant services to provide training to ensure sampling and analytical procedures comply with modern Analytical Quality Control Procedures (e.g., with the EU environmental quality monitoring system) and to assist in the design, operation and maintenance of the monitoring system; and study tours. (Years 2004-07).

> Public Awareness and Environmental Education. The Project supported the establishment of a small grant scheme for biodiversity conservation targeted to local groups, and financed consultant services to develop an environmental education program targeted to schools, teachers, fisherman, hunters, etc. and to foster regional protected areas management cooperation with Romania. (Years 2003-07).

> Institutional Strengthening. The Project supported strengthening of local and regional institutions responsible for natural resources management, including protected areas management. The Project financed civil works for refurbishing of premises of Park Administrations, building new Visitor Center of Persina Nature Park in Belene, training and study tours within Bulgaria and abroad, equipment and incremental operating and maintenance expenses associated with the monitoring system, administration of the two protected areas and management of infrastructure to regulate flood regimes in the restored wetlands. (Years 2002-07).

4.2.4. Project management, coordination and monitoring

4.2.4.1. Objective:

To support the Project Coordinated Unit, which coordinated, managed and monitored Project activities.

4.2.4.2. Description:

This component financed activities of local, national, and international coordination required for the implementation and monitoring of Project activities. Most likely, this component supported a Project Coordination Unit (PCU) – modeled after the PPU but with physical presence on the restoration sites, to coordinate Project implementation by the different implementing agencies. The Project financed the operating costs of the Project Coordinated Unit located in the Ministry of Environment and Water. The PCU is responsible for all procurement, financial management, disbursement and overall monitoring and evaluation matters. The Project also financed consultant services for the implementation of the monitoring and evaluation program. (Years 2004-08).

4.3. Ukraine: Restoration of Katlabuh lake

4.3.1. Description of the study area

The Katlabuh lake is situated in Ukrainian Danube Delta and its one of the largest lakes in on Ukrainian side of the delta with the total area of 68 square km.

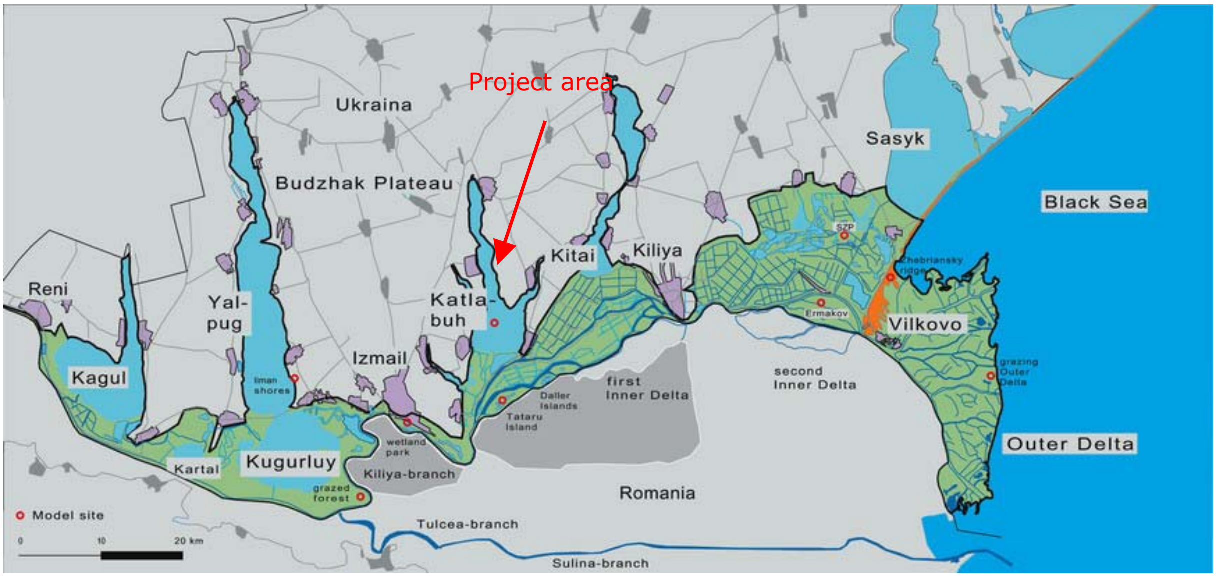

Figure 27 Ukrainian study side

In the 60's the dyke was built between the Katlabuh lake and the Danube River as well as the sluices at the canals connecting the lake to the Danube river. Thus, the lake was converted into a water reservoir, which resulted in a significant change of the water regime of the lake.

The embankment had dramatic consequences to the lake:

> Accumulation of salt and growth of mineralization and pollution of the water due to limited water exchange;

> Reedbeds filtering capacity for the lake was lost;

> Decline of the natural fish stock and a need for artificial stocking.

The main modern economic activities in the area are fishery and agriculture.

There are several villages around the lake and population of these villages uses the water from Katlabuh lake for drinking water supply and irrigation.

4.3.2. Main problems

Water-salt balance calculations for Katlabuh indicate that in order to maintain mineralization at the natural level water exchange rate should be doubled.

Nutrient pollutions is the second problem after mineralization for most of the Danube lakes that are artificially managed.

Under natural conditions Katlabuh lake played an important role in processing of nutrient loads form the catchments as well as in removal of nutrients from the Danube water. This important process was stopped as a result of embankment of the almost entire floodplain on Ukrainian section of the Danube, which has contributed to pollution of the Danube river, and thus the Black Sea.

4.3.3. Restoration outline and objectives

Katlabuh restoration model project is an important step towards a large-scale wetland restoration in Ukrainian part of the Danube delta.

The ongoing restoration works include reopening of the old channel between the Katlabuh lake and the Danube. The restoration activities were started in spring 2006. The first phase of restoration – reopening of the old channel and connection of the lake to the Danube River – should be finalized in spring 2007.

After reopening of the lake the first visible results will be available with the first flooding in spring – autumn 2007.

4.3.4. Nutrient monitoring scheme

The water quality monitoring data will be used firstly to investigate the impact of wetland restoration on nutrient loads and secondly to further advocate wetland restoration in Ukraine and in the Danube basin.

Regular observations of water quality in the lake prior and after the restoration efforts form an essential component of the project.

Analyses of the historical data still cannot fully demonstrate mutual influence of the Danube and the Katlabuh lake in terms of nutrient transport and utilization because sampling in the past was made only at a few points and does not demonstrate the spatial variation of nutrient loads in the Katlabuh lake.

Therefore, it was suggested to make additional sampling at 13 points around the lake in order to get a full understanding of spatial and temporal distribution of nutrients in the Katlabuh lake.

Monitoring of the water quality in the lake was done on the basis of the Ukrainian State Monitoring Programme state standard of Ukraine (SSU) ISO 5667-4:2003) for surface waters on monthly basis for various indexes including the nutrients. The samples were taken at 13 points around the lake as well as at the main inflows and outflows in November and December at peak and after the autumn flooding on the Danube.

4.3.5. Monitoring results

Biological Oxygen Consumption (BOC)

According to [1,2] Ukrainian water quality indexes for various uses, limits should not exceed 5 mgO_2/dm^3, while the limits for fishery waters should not exceed 3 mgO_2/dm^3.

In the samples taken at Katlabuh lake BOC_5 varied from 2,26 to 7,93, at the average oxygen concentration of 8,9 mgO_2/dm^3, which is on average 3 times of the limits for fishery wetlands varying from 1 to 4.

BOC_5 index for the Katlabuh lake is influenced by the small rivers discharging into the lake, which should be taken into account in further monitoring works.

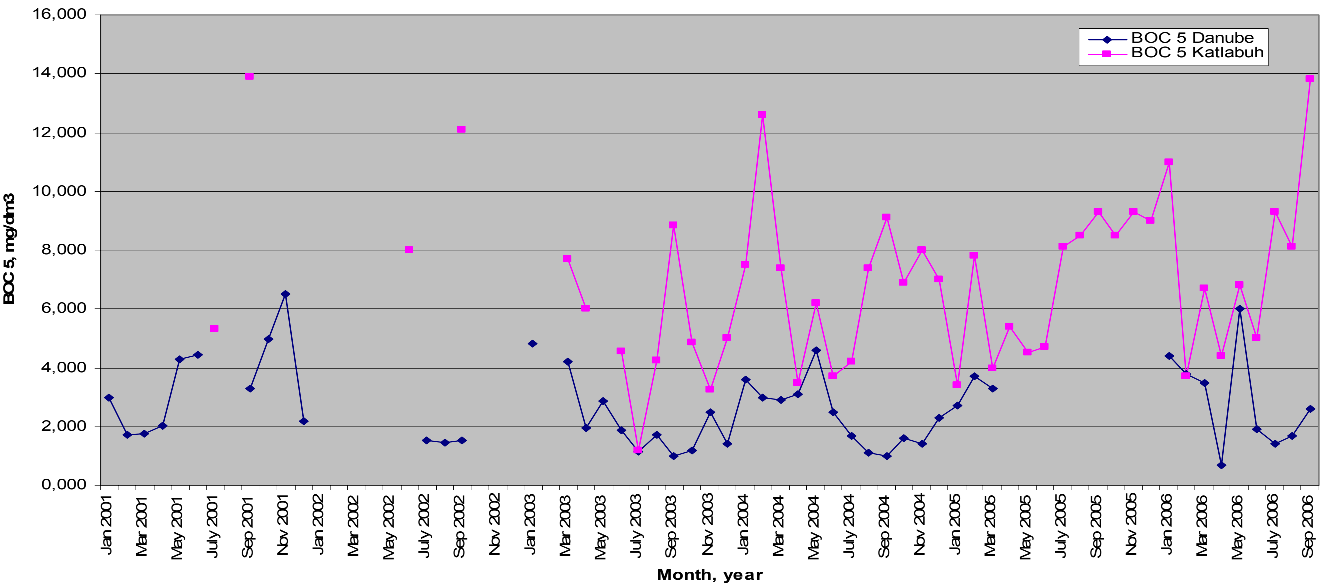

Figure 28 Long-term changes of BOC in Katlabuh lake and the Danube river.

Chemical Oxygen Consumption (COC)

According to UA standards, COC should not exceed 25mgO/dm ^{3}.

In the Katlabuh lake COC varied from 34 to 326 mgO/dm^3 with the average of 140-187 mgO/dm^3. Maximum values were stably registered near Pershotravneve village exceeding the limit 13 times with average values 5,6 -7,5 times of the limit.

Minimum values were registered at inflow canal form the Danube, while the maximum was registered at mouth of Enika river.

Nitrogen

In the natural wetlands inorganic nitrogen occurs is ammonium ions (NH_4^+), nitrites (NO_2^-) and nitrates (NO_3^-). These chemicals have common origin and easily transform from one to another.

Official limits in UA for fishery wetlands for ammonium (NH_4^+), nitrites (NO_2^-) and nitrates (NO_3^-) should not exceed 0,5, 0,02 and 45 mg/dm^3 respectively.

In Katlabuh lake concentrations of ammonium varied from 0,24-1,00, with the average of 0,53 mg/dm^3, which is slightly over the limit.

Content of nitrites (NO_2^-) varied from 0,00 to 0,90, with the average of 0,058 mg/dm^3, which is 2,9 times of the limit varying from 3,5 to 4,5 times of the limit.

At the inflow canal content of nitrites was stably high from 0,150 to 0,174 mg/dm^3, which is 7,5-8,7 times of the limit.

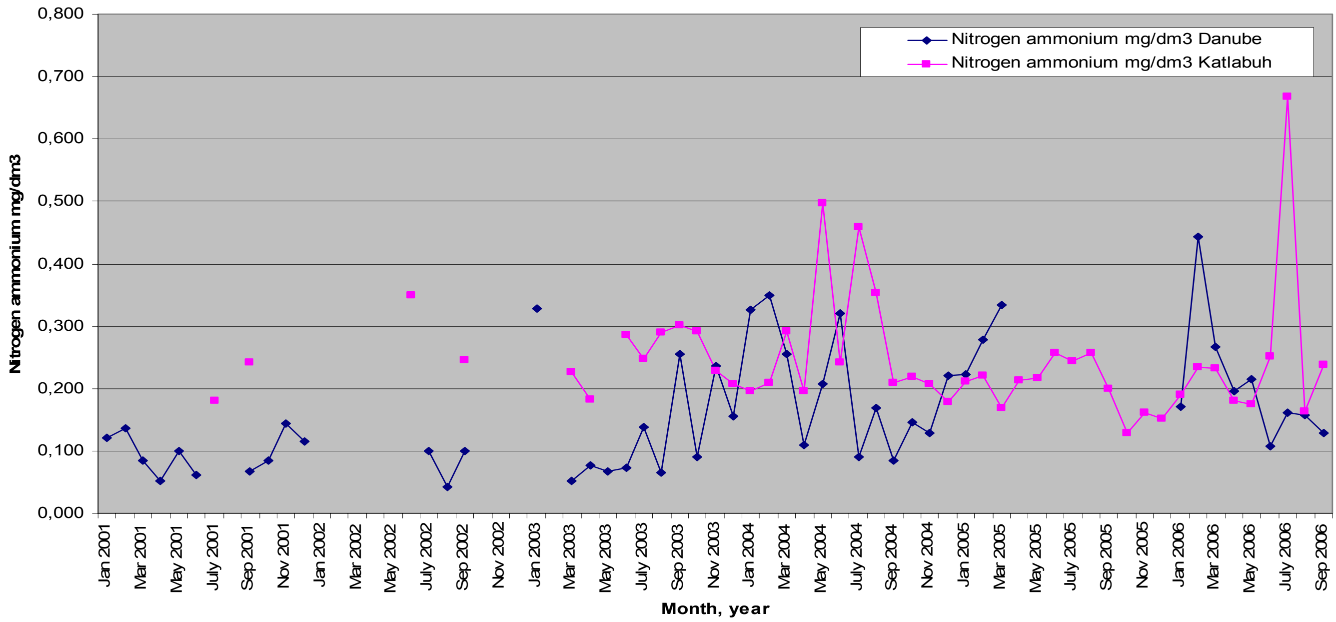

Figure 29 Long-term changes of ammonium in Katlabuh lake and the Danube river.

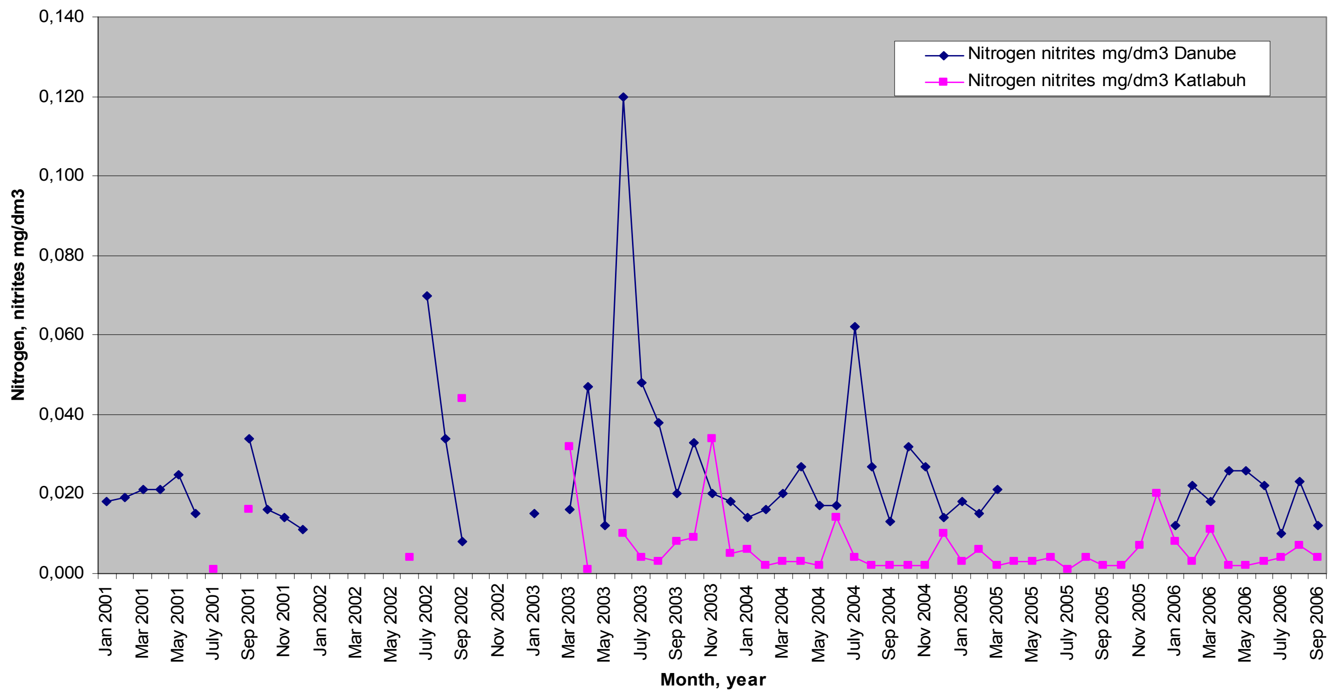

Figure 30 Long-term changes of nitrites in Katlabuh lake and the Danube river. Content of nitrates (NO_3^-) varied from 0 to 17 mg/dm^3, which is much lower than official limits.

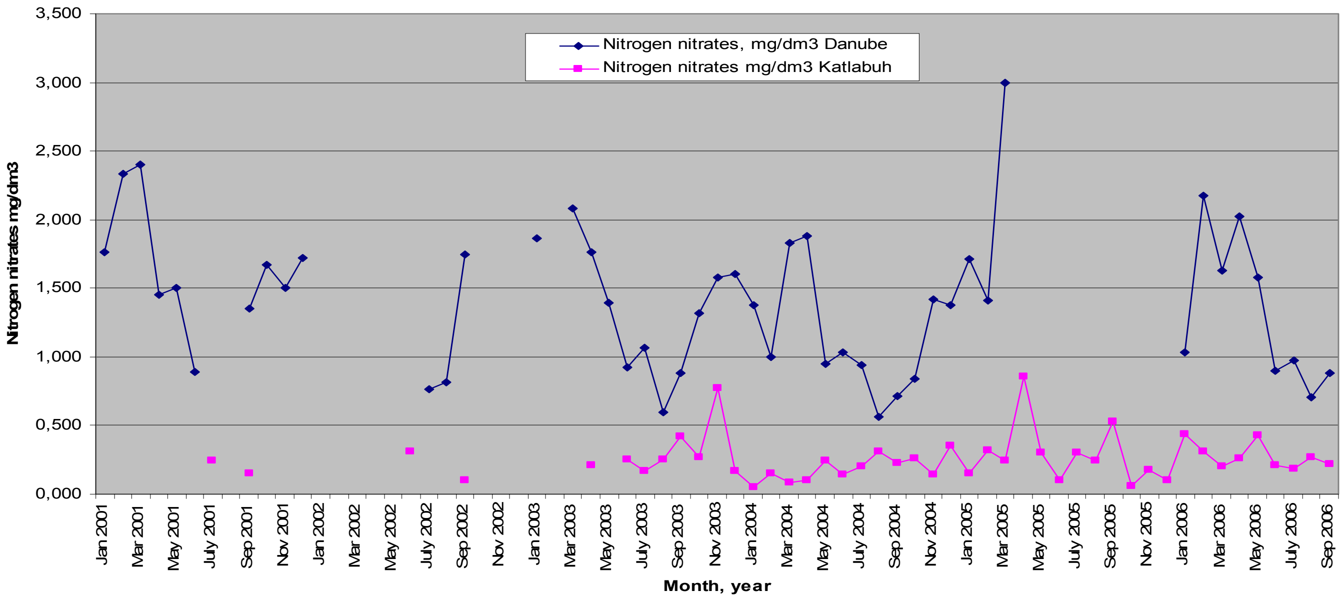

Figure 31 Long-term changes of nitrates in Katlabuh lake and the Danube river.

Chlorides and sulfates

According to Ukrainian regulations, the sources of drinking water supply and domestic supply should have not more than 350 mg/dm^3 of chlorides and 500 mg/dm^3 of sulfates.

Content of chlorides and sulfates in Katlabuh lake varied from 230 to 798 mg/dm^3 and 104-2340 mg/dm^3 respectively. Average values were 450 and 779 mg/dm^3 varying from 439 to 461 mg/dm^3 for chlorides and from 762 to 805 mg/dm^3 for sulfates. Similar concentrations were registered during the last 3 years.

Content of chlorides and sulfates at inflows from the catchment (mouth of Enika river) was over the limit and qualified the water as a chloride-sulfate type. Long-term observations showed the same situations. Thus Katlabuh lake receives considerable loads of chlorides and sulfates with the discharge of small rivers.

Mineral phosphorus (phosphates)

Official Ukrainian limits for phosphates is 0,2 mg/dm^3 and 0,5 mg/dm^3 for total phosphorus.

In the samples taken at Katlabuh, only the total phosphorus was measured. Its content varied form 0,047 to 0,390 mg/dm^3 with the average of 0,087 - 0,112 mg/dm^3.

At inflow canals and small rivers content of phosphorus varied from 0,056 to 1,780 mg/dm^3 with the average monthly values of 0,250 - 0,502 mg/dm^3.

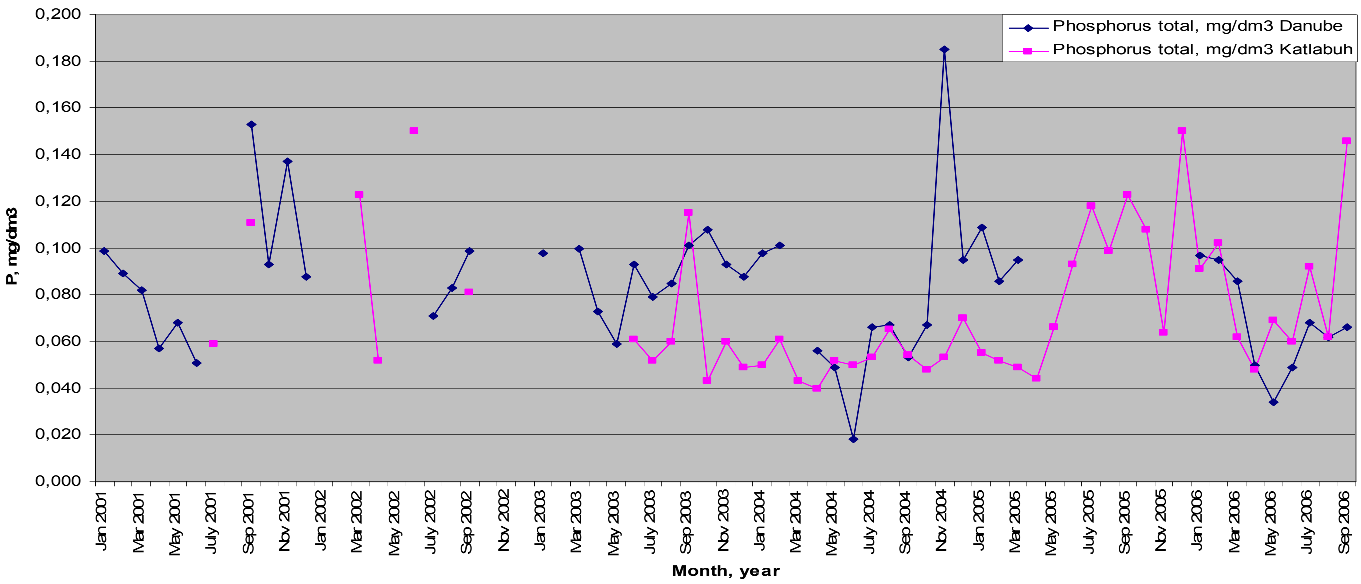

Figure 32 Long-term changes of phosphorus in Katlabuh lake and the Danube river.

Total salt

Mineralization is important for the sources of drinking and domestic water supply and should not exceed 1000 mg/dm^3. Monitoring results showed all the samples at all points have high mineralization varying from 1,11 to 4,97 g/dm^3 with average values 2,22 – 2,27 g/dm^3.

At the inflows form the Danube mineralization was within the limits, while in the inflows form the catchment it was stably high from 2,75 to 2,81 g/dm^3. Similar values for this point are indicated in the long-term database.

4.3.6. Conclusions

Influence of the catchment and small rivers

Growing content of pollutants in the lake is caused by inflow from the Danube and small rivers such as Big Katlabuh, Tashbunar, Enika. Analyses of the long-term data shows seasonal dynamics, i.e. water quality improves in spring and summer with flooding and worsens in autumn winter with the minimum water levels in the lake. Apart form embankment of Katlabuh lake itself, the small rivers were seriously modified as well: increase of arable lands and deforestation, dredging and regulation of their drainage caused decrease of water discharges, increase of evaporation from the water surface and thus deterioration of water quality in small rivers. Their surface water is naturally hyper-mineralized from 2.2 to 7.5 g/l.

Influence of the Danube

Water in the Katlabuh lake showed serious exceeding of the limits for a number of indexes (BOC5, COC, NO2-, Cl-. SO42-,PO4- etc.).

However, water quality in the Danube is different to Katlabuh lake according to several indexes.

General water mineralization in the Danube is significantly lower then in the lake and does not exceed 0,5 mg/dm3 varying form 0,27 to 0,44 mg/dm3.

Content of sulfates and chlorides in the Danube is 10 times less than in the lake with the average of 39,6 and 28,8 mg/dm3.

The situation with nitrites and nitrates and BOC is similar.

Removal capacities of the Katlabuh lake for the phosphorus are still not clear and the historical data do not show yet any trends or mutual dependence of the Katlabuh lake and the Danube. Although at some small rivers discharging into the lake, content of phosphorus is higher than official limit, but by and large it hardly affects the general phosphorus concentration in the Katlabuh water.

Therefore, it's clear that in order to improve water quality in Katlabuh lake, a natural extend of water exchange with the Danube River needs to be restored.

Expected changes after restoration

Restoration of natural water exchange in expected to lead to a significant decline in salt contents of the lake to the levels close to the Danube water. As historical data on water quality show, Katlabuh lake should still play a significant role in reducing nitrites and nitrates for the Danube. However, on the short term after the opening of the lake some negative effects are possible for both the Katlabuh lake and the Danube river. These effects relate first of all to washing out bottom deposits and return of chemical substances, especially such as nutrients to the Katlabuh lake and thus the Danube river and the Black Sea.

On the long term though, the effect of restoration on nitrogen transport needs to be further investigated as after reopening of the lake, positive changes are expected in the ecosystem of the lake related to development of aquatic vegetation and thus increase of removal capacity of the lake for the nutrients.

Moreover, the next phase of restoration works after reopening of the lake to the Danube, implies re-connection of extensive reedbeds in the downstream part of the lake. These reedbeds played an important role in filtering the Danube water flowing into the lake as well as Katlabuh water flowing into the Danube.

Therefore in order to fully assess the mutual influence of Katlabuh lake and the Danube river, it's necessary to continue monitoring works after reopening of the lake and especially on reconnection of the reedbeds to the Katlabuh lake.

4.4. Moldova: Problems and Solutions in Yalpugh and Cahul river basins

4.4.1. Background

Wetland location and identification

Local name. Comrat valley

Local ID: None

International name. Upper Yalpugh

Geographic co-ordinates: of centre point along the river:

latitude:46°16'03,00'' longitude: 28°39'38,92'"

Country: Republic of Moldova

County (or federal states): Gagauz Eri

EU region(s): South - Eastern Europe

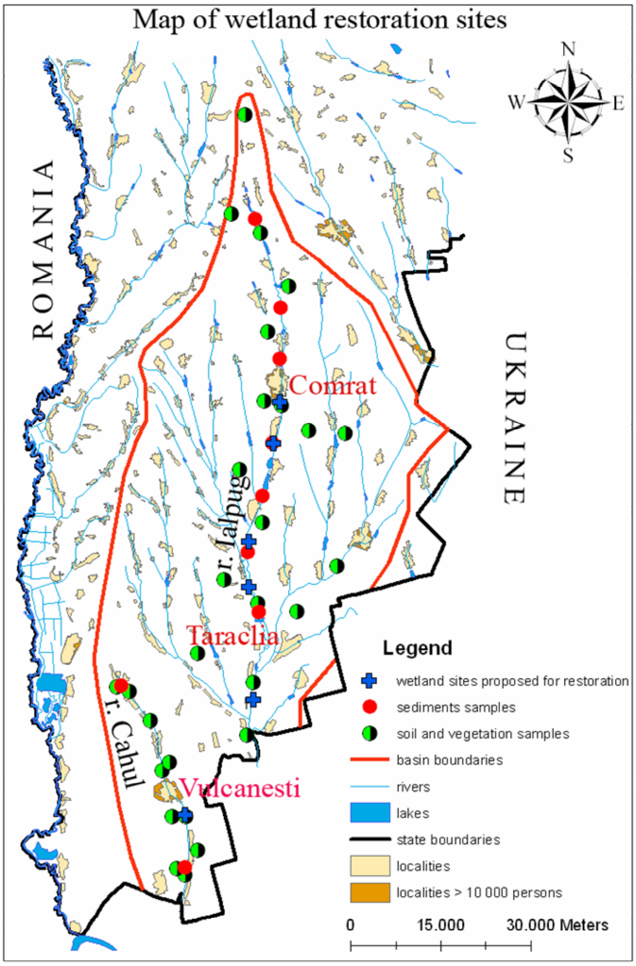

Figure 33 Map of demonstration wetland sites

4.4.2. Physiography of wetland

> wetland type (Ramsar definition): None

> climate – moderate continental. Average air temperature for July – 22,7 degrees for January – minus 3,5. average precipitation 370 mm. 70% of precipitation fall in spring autumn period and 30% during winter period

> hydrology (surface and ground water) total basin area of the Yalpugh basin is 3300 km2, average flow 4 mln m3/year for Cahul river – 900 km2, average flow – 3,3 mln m3. Due to a hot summer rivers dry up for 3-4 months every 4-5 years. Main water bodies: Taraclia water body – Yalpugh river, constructed in 1982, volume 62,5 mln. m3, surface 11 km2, Congaz – Yalpugh river – constructed in1961, volume – 5,07, surface – 3,08 km2, Comrat – Yalpugh river, constructed in 1957, volume 2,60 mln.m3, surface 1,52 km2

> biota (vegetation habitat etc): wetland vegetation is presented by meadow and steppe species. Average biomass for dry lands in non grazed areas is around 50 g/m2 of dried biomass. There are no protected areas in the basins of the Yalpugh and Cahul rivers. The most typical species Winter flowered stembergia (Steambergia coichicicfora), Scuat skullcap (scutellaria supine), Versicolored meadow saffron (bulbocodium versicolor), Cold beard grass (chrysopogon gryllus), etc

- anthropogenic (settlements, land use, structures, etc) There are around 90 localities in the region. They cover around 8% of the basin territory. Total population is about 270000 people. Rural population predominates more than 70%. Urban population is concentrated in there main towns Comrat, Taraclia and Vulcanesti. Style of life of urban population is close to those of rural one. Average percentage of population connected to sewer system is less than 10%, while to drinking water supply around 25%. Drinking water quality is assured manly from groundwater resources.
- Area of wetland: total area of wetland in the Yalpugh and Cahul river basins is around 71 km^2

4.4.3. Short history of wetland

4.4.3.1. Original status, main changes and uses in the past

Soviet authorities did not give any status to the wetland areas. Studied wetland areas used to be waterlogged till the beginning of mass desiccation activities started at the beginning of 70th. Till that time wetlands were used in traditional trades like reed harvesting for construction needs, fishing and hunting. Irrigation activities and desiccation led to appearing of the salts on the surface of alluvial soils and rising of the salinity of waters. Thus, mass irrigation stopped in 2-3 years after desiccation. At the same time constructed channels, power stations, water pipes and other infrastructure remained and is being destroyed.

In the middle of 80th industrial fishing performed was in Congaz and Taraclia water bodies (till 30 tonnes per year of fish from both reservoirs, Republic of Moldova in figures, Chisinau, 1986)). Actually 90% of wetland areas are used for agricultural purposes. Main crops are located in the lower part of the basins of two rivers (around 20% of total area). Rest of the wetlands can not be used in agriculture due to high TDS content in alluvial soils and water.

Actually there is a good opportunity for restoration activities, because due to financial constrains wetlands are not used in agriculture. Main problem with the nature restoration is overgrazing in the area.

4.4.3.2. Problems, efforts and plans

Main problem associated with the wetland management in the region are: lack of any legislative base for wetlands, programs and plans for wetland restoration in the region

Proposed wetlands present an importance because Yalpugh and Cahul rivers discharge to the lower Danubian lakes Yalpugh and Cahul. Studies organized within project: TACIS "Selected actions in Ukraine and Moldova, 1998-1999)" showed high nutrient contents in these lakes.

These wetlands also serve as a habitat for the species nested in the Yalpugh and Cahul lakes, which form the Danube Delta biodiversity. In particular, wetland host such mammals as: Neomys fodiens Penn, included in the " Red Book" prepared for edition in 1997 as a species is threatened to be extinct, Mustela lutreola L. (reedbelts of the Yalpugh river fens and waterbodies; in the " Red Book" edited in 1978 was nominated as a species or threatened to be extinct), Lutra lutra I.

(in the " Red Book" edited in 1978 and was nominated as a species threatened to be exist), Ondatra zibethica L. (reedbelts of the Yalpugh river; included in the "Red book" in 1978), Arvicola terrestris L. (Lower Danube lakes, Lower Prut and downstream of Yalpugh); Myopatamus coypus Moll. (specific for Lower Yalpugh fens).

Wetland areas also serve as a habitat for around 100 species of birds Branta bernicla (L) B. ruficollis Pall, Tadorna ferrufinea Pall, Nyroca ferina (L), Oidemia nigra (L), Somateria mollissima (L), Oxyura leucocephala Scop, Mergus serrator (L); reptilian Emys orbicularis (L) included in the "Red Book" in 1978, Suborder Ophidia, Natrix natrix, Nutrix tesselata (Laur.) and amphibian: Triturus cristatus dobrogicus Kirichescu, T. vulgaris (L), Bombina bombina (L) included in the "Red book" in 1997, Pelobatis fuscus fuscus Laurentus, Bufo bufo L., flood-lands, widely spread, Bufo virdis (Laur.), Hyla arborea, Rana ridibunda Pall., Rana esculent, Rana temporaria.

Flood control is actually organized by deepening of the Yalpugh river bed in its upper part on the distance around 20 km. the depth of the channel is around 1 – 1.2 m. They also play an important role in sediment control, but this function is affected by deepening of the river bed and siltation of the water bodies.

Research activities: research activities in the region were held at the beginning of 70^{th} with the objective of feasibility study for wetlands desiccation. After that there were no research. Evaluation of the biodiversity was organized in 1998 in the frame of the development of the map on biodiversity. No special research activities on nutrient reduction by wetland areas were not organized in the region.

There are no any plans aimed at wetland restoration. At the same time there is a commitment of local authorities to develop such plans and on their base organize wetland restoration activities to enhance ecological value and nutrient removal capacities of the wetland areas of the Yalpugh and Cahul rivers.

Priority of nutrient control derives from: reduction of nutrient loads on lower Danubian lakes, promotion of the development of the network of protected areas, biodiversity conservation, evaluation of the climate changes in the region due to wetland restoration activities, etc

Figure 34 Upper part of the Cangaz water reservoir

Figure 35 Upper part of the Moldovan part of the Cahul Lake

4.4.4. Status of the wetland

- *Is the wetland area protected by legislation.* Wetlands in the Yalpugh and Cahul river basin are not protected by legislation. There are no plans to develop any documents in this domain in the region. At the same time local authorities expressed their commitment in creation of the network of protected areas in the basins, which will also include wetlands. Forthcoming Danube river integrated management plan for Moldovian part of the Danube basin will include development of the nature protected areas network in the region for achieving of good ecological status by 2015.
- *Wetland restoration activities.* Such activities are held in the frame of the national Day on trees planting. Mainly such actions are organized by local authorities near main localities in the region. Average planting density is 1 tree per 10 m2. Only 20-25% of planted tress reach 3 years old.
- There are no special projects aimed at wetland restoration in the region

4.4.5. Wetland management

- Which management unit the wetland belongs to. Normally local environmental authorities are responsible for the management of natural resources of wetland areas. In case of the Yalpugh and Cahul rivers Environmental Inspectorate (subdivision of the Ministry of Ecology and Natural Resources) has a responsibility for wetlands in this region.
- Who manages wetlands now. Natural resources of wetlands are managed by local Environmental inspectorate
- Which are the main supervising/responsible authorities for wetland area. Local Environmental Inspectorate
- Are there other wetlands. Floodplain of the rivers present mainly wetland areas. Artificially around 90% of wetland areas are dried up and actually deepening of the 25 km of the upstream of Yalpugh river bed is continuing.
- Main land uses. Main land use is agriculture > 80%. At the same time arable lands cover around 40% of the wetland area in theirs lower part.
- Are expected changes of land use. Actually due to a financial constrains one could suppose abandoning of agricultural lands from agricultural activities and it could be expected that around 20% of the wetland areas could be involved in restoration activities.
- Main functions. In the middle of 70th wetland areas were presumed for agriculture. Actually the value of wetlands due to unproper management is very low and their fuctions are not relevant. In future one could expect rising of their functions such as nutrient pollution control, recreational, habitat /ecological.

4.4.6. Project description

4.4.6.1. Objectives of the project were the following

- Selection of potential sites for wetland restoration in the Yalpugh and Cahul river basins
- Estimation of nutrient removal capacities of wetland areas and nutrient budgets in the basins of the Yalpugh and Cahul rivers
- Development of measures for wetland restoration for Moldavian part of the Danube river basin (Yalpugh and Cahul rivers)
- Data on the state of environment in the wetland areas

Development of the Integrated River basin management plan for Moldavian part of the Danube river basin is recognized as a priority for environmental authorities in Moldova. In addition to it this part of the Danube basin was included according to the Odessa conference in February 2006 as a part of the Danube Delta. That is why actual project will contribute to the promotion of wetland restoration activities in this part of the Danube basin and thus certain wetland functions like sediment and nutrient pollution control will play more important role in the nearest 5 years.

4.4.6.2. Developed design

For the development of the project next activities have been undertaken:

- sampling of water, soils, sediments, vegetation (see map 1.). sampling was carried out in order to cover gaps in information on nutrient contents in the components of environment. It included main water bodies (Taraclia and Congaz), river bottom sediments. Soil sampling was performed for wetland areas first time for last 17 years. It allowed estimate real contents of nutrients in alluvial soils. Non agricultural vegetation has never been sampled in the region. Actually it covers around 50% of wetlands. Presented network of sampling sites and frequency (in May-June and in September) allowed obtaining of reliable data, which helped in calculation of the budgets together with data obtained form statistical and literature sources. Total 24 sampling stations were selected. They covered practically all main functional zones of the wetland areas in the basins.
- evaluation of the results of sampling campaign and statistical data
- calculation of nutrient budget based on data obtained from study
- consultation meetings with local authorities, NGOs and other stakeholders

4.4.6.3. Methods

There were used standard methods ISO for analysis of collected samples.

Sampled parameters

Mineral forms of nitrogen and phosphorus, total forms of nitrogen and phosphorus were measured. Calculation of the nutrient contents of nutrients in soils were made based on soil density for the strata of 30 cm. Sediments were sampled on strata of 5-7 cm in upper, middle and lower parts of the water body. Sediments column was sampled from the Taraclia water body till the depth of 60 cm, which allowed estimate nutrient stock in the sediments. Vegetation was measured for biomass and nutrient content. It allowed estimate stock of nutrients in the vegetation and calculation of nutrient budget.

4.4.7. Conclusions

According to the results of the project based on the sampling campaign, analysis of literature data, etc one could estimate that nutrient control measures trough wetland restoration could remove around 15-20% of nutrients reaching water ecosystems. The results showed that background flow from agricultural activities is main pollution source with nutrients of water ecosystems. Wetland restoration could lead to the sediment control and thus reduce amounts of nutrients reaching water ecosystems.

Reduction of nutrient loads on water ecosystems should be organized in order to introduce best agricultural practices on the watersheds and wetlands. Deterioration of wetlands could be limited trough stopping of deepening of the river bed, limitations on grazing, rising of public awareness, etc.

Local authorities expressed strong commitment for the wetland restoration activities. Wetland restoration issues have to be included in the developing IRBMP and nutrient reduction could reach the target of around 10% of all nutrient loads on water ecosystems coming from the watershed. Introduction of green carcasses on watersheds and in wetlands could increase the amount of nutrients stocked in vegetation, regulate sediment transport in the rivers floodplains and thus improve water quality in regard to nutrients of artificial lakes created on the Yalpugh river bed.

Institutional capacities of local authorities in wetland restoration are very limited due to the financial situation, but due a low agricultural value of upper and middle stream wetlands this issue does not seem a problem. At the same time technical capacities in order to estimate real effectiveness of nutrient reduction are also limited due to the lack of relevant equipment, poor statistic, etc.

Personnel of local institutions never had any training on wetland management and their awareness on this issue is very low. That is why their capacities to develop plans on wetland management and restoration are very limited. It is important to organize such training, because local authorities will play crucial role in the implementation of the management plans. Trees planting is organized as a public action and any plans, documents, legislation, etc on wetland management in Moldova are not developed.

Main sources of nutrients in the area of the Yalpugh and Cahul river basins:

- background flow from agricultural lands from watersheds (surface runoff)
- settlements; unathorised waste disposal, septic tanks, domestic animals, overgrazing, etc
- improper use of river bed (deepening of the Yalpugh river bed in upper part of the river)
- former stocks of manure near animal farms and organic fertilizers application on agricultural soils (1 ton per ha). Partially mineral fertilizers could be also considered to be a potential source, because plans for agricultural development of the region presume increasing of their application till 30 kg/ha in the nearest 5 years on watersheds.

Effect of wetland restoration on water quality

Based on estimated nutrient removal capacity one could estimate reduction of nutrient contents in the waters for 15-20%. At the same time sediment control could also lead to reduction of siltation of the rivers and water bodies and thus instead of 3% of annual growing of sediments one could expect till 2% of annual siltation rate. So totally due to wetland restoration it could be possible to expect reduction of nutrient content in the waters till 25%.

4.4.8. Lessons learned and outlook

- there is a strong commitment from local authorities to perform wetland restoration activities
- necessity in development of the network of protected areas and green carcasses in the flood plains of the studied rivers
- animals grazing in the wetlands is a strong issue affecting the state of biomass in the wetland
- deepening of the river bed negatively affects hydrological regime of wetland and urgent steps for its stopping have to be undertaken
- nutrient reduction measures such as: construction of platforms for stocking of organic wastes in rural localities, composting of organic wastes and organizing of the sanation of the territory of localities could contribute to the nutrient reduction on water ecosystems

4.4.9. Database

There is no special data base on nutrient reduction by wetlands in Moldova and in the region. The database for project is presented in the annex to main report on Case Study: - "Monitoring and Assessment of Nutrient Removal Capacity of Riverine Wetlands

5. METHODOLOGY AND APPROACH FOR THE GUIDELINE AND RECOMMENDATIONS FOR WETLAND NUTRIENT MANAGEMENT

From the management point of view on base of a catchment related wetland cadastral a priorisation scheme should support the decision which wetland most usefully should be restored. Obviously this priorisation scheme can underlie different subjects with benefits like biodiversity, flood control, nutrient retention, eco-tourism etc. but should also consider possible primary pressures as endangerment of human health by environmental pollution or excess of nutrients due to intensive agricultural use, which can strongly alter the former character of such a region and in this case can be a clean up site more than a restoration site. Furthermore, the alteration of soils by intensive use can cause short term phosphorus mobilisation after reflooding and will act as nutrient sink primary in a mid term perspective. However, both, clean up (hot spots of pollution) and restoration can coincide in general.

5.1. Potential areas for nutrient reduction in the DRB

The Ramsar Convention on Wetlands (Principles and guidelines for wetland restoration 2002) recommends for use spatial analyses of catchments to identify areas with a need for wetland restoration.

The catchments where wetland restoration seems to be most promising with respect to nutrient loss or retention will be regions with high nutrient emissions which will, in relation to their specific runoff, lead to high nutrient concentration in surface water. A spatial aspect is that degraded or modified wetlands in the catchment are situated at strategically important points (e.g. nutrient rich rivers) and that these wetlands or a sequence of wetlands can retain an appreciable volume of water, especially during flood events.

To give an overview concerning the nutrient situation in the Danube River catchment in the following results from MONERIS emission modelling for the years 1998-2000 performed within the EC-project daNUbes (http://danubs.tuwien.ac.at/) are presented. Within the emission modelling different nutrient sources as well as different pathways for nutrient emissions (TN, DIN, TP) (see figure 36) are calculated using data aggregated to 388 subcatchments.

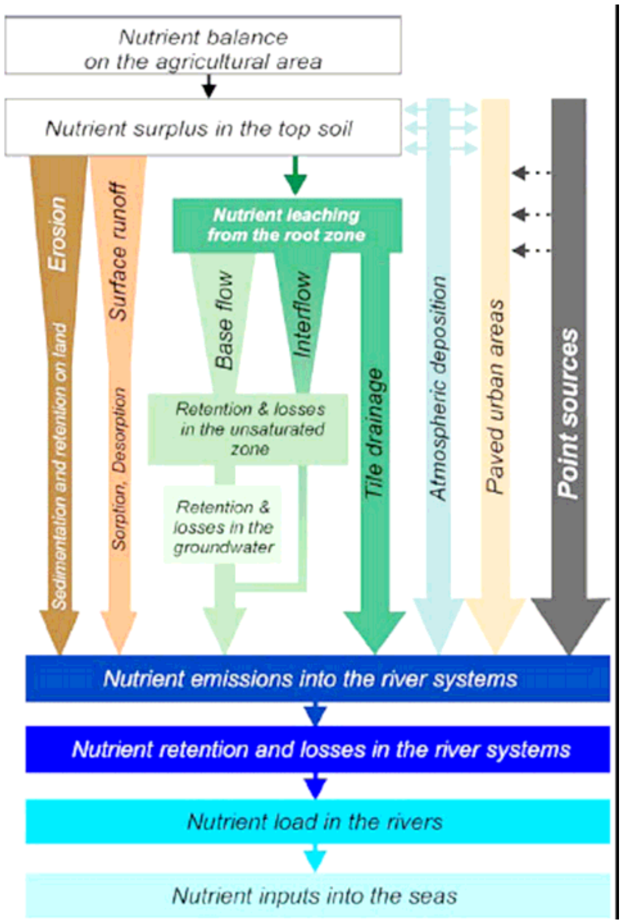

Figure 36 Pathways and processes considered within MONERIS (Behrendt et al., 2004).

A detailed description of the model, the main sources and the dominant pathways of nutrients emitted to the surface water in the Danube River Basin are given in Schreiber et al. (2003) as well as in Behrendt et al. (2004) available at http://danubs.tuwien.ac.at/.

Figure 37 and 38 illustrate the specific nutrient emission situation (TP and DIN) within the Danube River Basin. While from the Danube River Basin catchment perspective these regions are favourable for strengthen the nutrient retention capacity in the river system, this figures do not specify the need or the possibility of a forced nutrient retention capacity in the subcatchment itself, because it does not provide information on the water quality situation and wetland area. For a more differentiated evaluation with respect to the water quality situation in the single subcatchment it would be necessary to consider the runoff of the subcatchment which expresses the dilution capacity as well as the retention capacity inside the subcatchment. Another prerequisite would be a wetland cadastral for each subcatchment to estimate potential areas where improved nutrient retention or removal can be possible. This should be realised in the cultivation plans as a requirement of the WFD until 2009.

It is obvious that the spatial distribution of emissions for nitrogen and phosphorus differs, due to different mobilisation processes and emission pathways (e.g. dominant pathway for nitrogen is groundwater and point sources, for phosphorus it is erosion and point sources).

However, for some catchments a critical nutrient situation considering both, nitrogen and total phosphorus emissions can be stated, which is mainly caused by the presence of capital cities leading to an extended share of point source emissions from Waste Water Treatment Plants (=WWTP´s) within these catchments. Beyond catchments with big cities situated for nitrogen, especially the German and Austrian part of the Danube River catchment show increased nitrogen emission which is mainly caused by high rates of groundwater exfiltrating to the river systems.

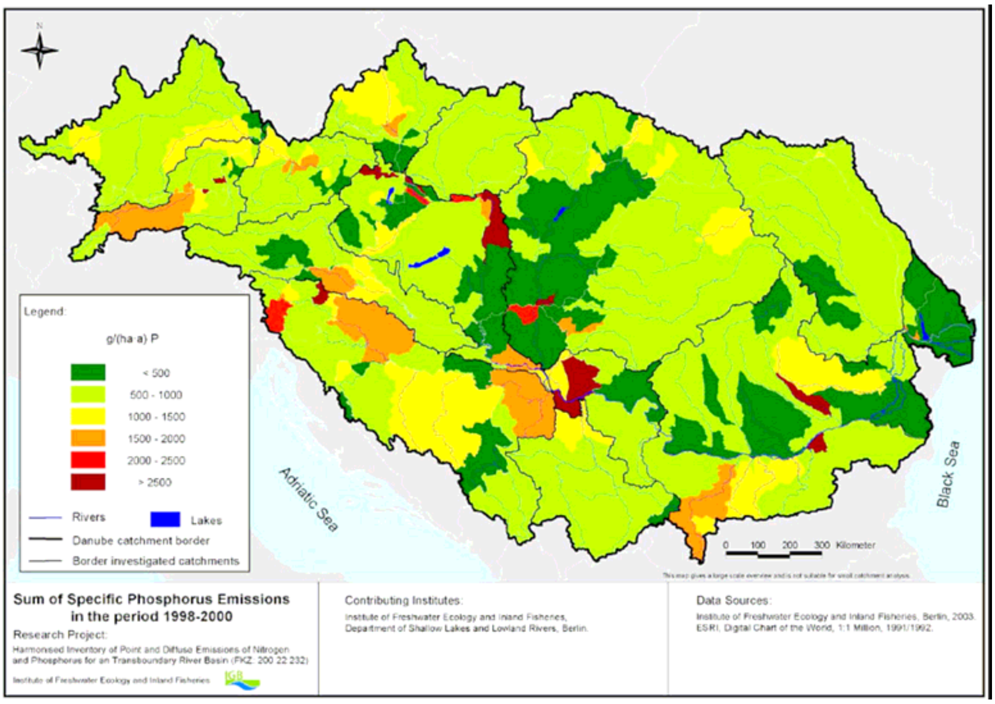

Figure 37 Total specific phosphorus Emissions in the period 1998-2000 (Schreiber et al., 2003).

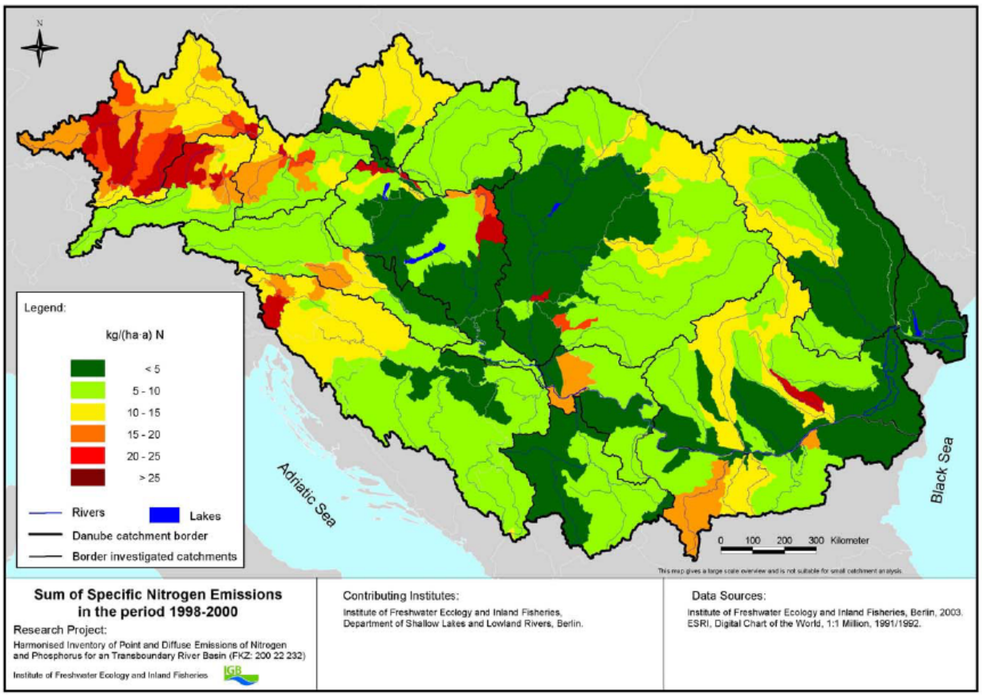

Figure 38 Total specific nitrogen emissions in the period 1998-2000 (Schreiber et al., 2003).

5.1.1. Nutrient retention in the river system of the Danube catchment

Above emission modelling using MONERIS the EC-daNUbes project performed water quality modelling coupling different models:

- Danube Water Quality Model (= DWQM) considering the Danube and its main tributaries
- Danube Delta Model (= DDM) considering the region of the Danube Delta with its manifold water ways.

Results from the coupled models with respect to nutrient retention shown in Figure 39 give some references for river basin managers, but also for wetland managers to consider, when implementing measures to reduce nutrient loads.

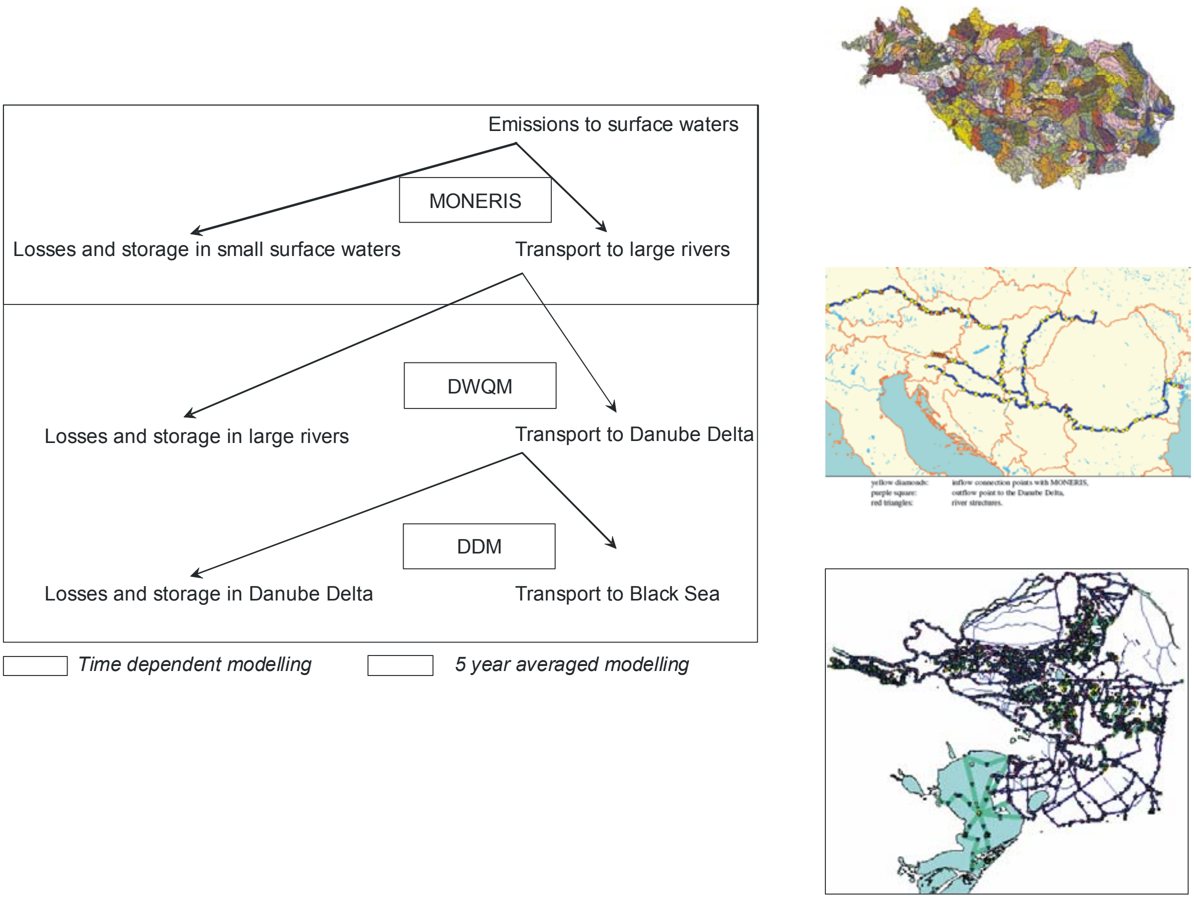

Figure 39 Loss and retention calculation in the Danube river basin using three coupled models. MONERIS= 5 year averaged modelling, DWQM+DDM = time dependend modelling (daNUbes Final report, 2005).

Results imply that rather 40% of nitrogen and 65% of total Phosphorus emitted to the surface water system is retained or lost within the Danube catchment (detailed information on http://danubs.tuwien.ac.at/. It was found that a catchment wide differentiation into small river systems (related to 388 subcatchments), the Danube and its large tributaries and the Danube Delta leads to rather different results in terms of nutrient loss or retention capacity. Although, these result stem from different models with different approaches to estimate nutrient retention or losses, a comparison, as following is helpful to underline some common but crucial aspects.

5.1.1.1. Loss and retention of nutrients in small surface waters

The most effective loss and retention of nitrogen (34%) and phosphorus (53%) occur in small surface waters due to favourable conditions, such as:

- High share of surface waters
- Partly high nutrient concentrations
- Morphological diversity
- Flow conditions
- Groundwater-surface water interactions
- Large surface area for sedimentation processes

5.1.1.2. Loss and retention of nutrients in the Danube and its large tributaries

The loss and retention of nutrients in large rivers was found to be much lower (nitrogen = 4%; and phosphorus = 11%).

5.1.1.3. Loss and retention of nutrients in the Danube Delta

The overall loss and retention of nutrients in the Danube Delta was found to be even lower, with (nitrogen 2% and phosphorus 3%) but shows a significant variation. Results explain that in the water volume which enters the Delta complexes with side arms, low flow conditions and thus extended residence times, structural diversity, high amounts of carbon etc., retention of Total nitrogen (30%) and Total phosphorus (25%) was significant.

Unfortunately, due to river engineering actually 90% of the Danube discharge flows through three main channels (see Figure 40) while only 10% of the discharge enters the Delta complex and its favourable conditions for nutrient loss and retention. As a consequence the retention and loss of nutrients in the Danube Delta seems to be reduced with respect to former times, while its potential for nutrient reduction and transformation is still very high.

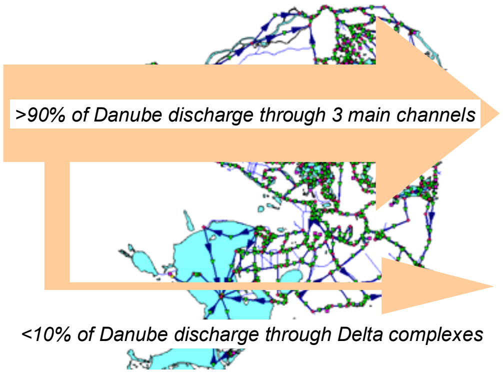

Figure 40 Discharge through the Danube Delta (results from hydraulic modelling, daNUbes Final report, 2005).

5.1.1.4. General Remarks

The results from the Danube Delta give a synthesis for the whole river system under investigation. While small surface water systems (especially in the Danube Delta) in general are characterised by a high grade of self purification due to a wide range of structural variety, extended residence times, groundwater interactions, temporally flooding (see chapter retention processes). Modification of natural surface water courses e.g. canalisation and damming will lead to a loss of the self purification capacity. In large rivers the structural variety necessary for nutrient retention or transformation mainly found in its littoral or the riverine wetlands is often diminished by hydraulic engineering.

It is obvious that nutrient reduction potential of a region can be as favourable as possible but without any significant nutrient reduction or storage effect, as long as the discharge brought into this system is negligible, as results from the Danube Delta impressively underline. During flood events (see chapter case studies) the retention or transformation of nutrients can significantly increase. However, the small actual share of nutrient retention and losses in the large river system of the Danube river basin points out the urgent need of reconstruction and restoration of riverine floodplains (Figure 41) to reconnect large regions to the Danube and thus create basic prerequisite for an extended nutrient retention capacity.

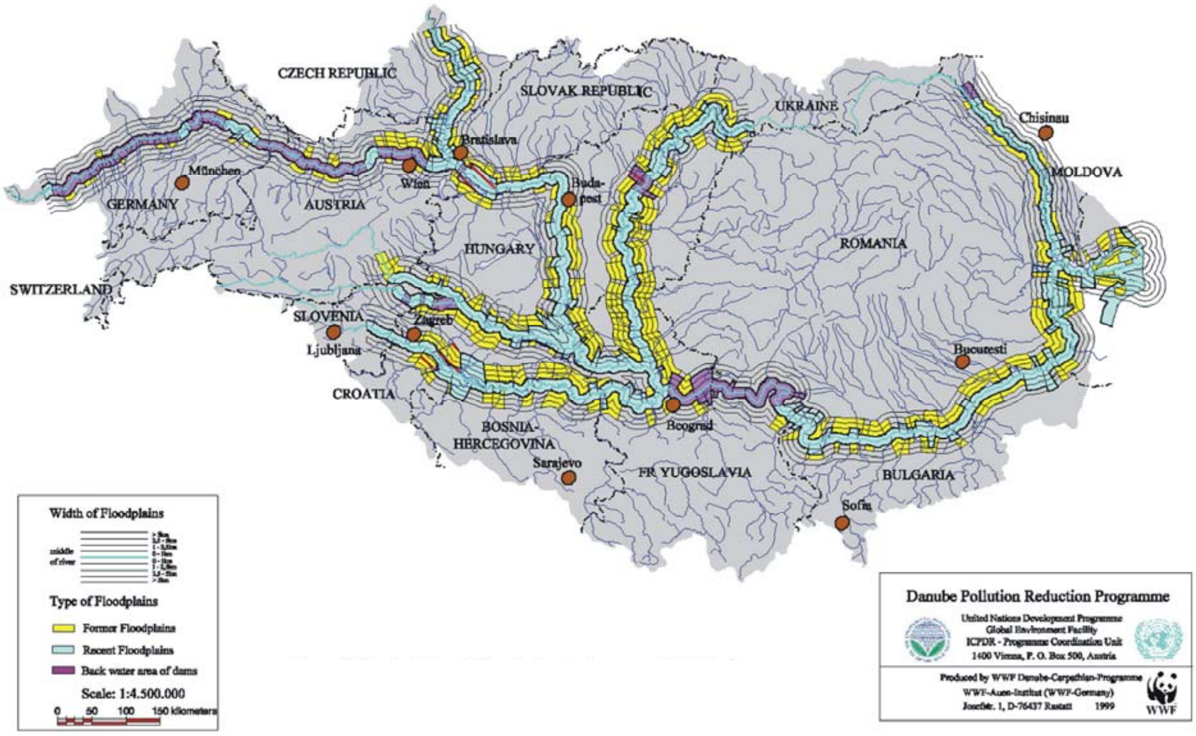

Figure 41 Former and actual occurrence of floodplains in the Danube river basin (Danube Pollution Reduction Programme, 1999).

GLOSSARY

Anammox - acronym for anaerobic ammonium oxidation. In this biological process, nitrite and ammonium are converted directly into dinitrogen gas. This process makes up a major proportion of dinitrogen conversion in the oceans.

Autochthon – Material or organic matter which is produced in the river/ water body itself e.g. phytoplankton which is the food basis for zooplankton. The contrary is allochthon e.g. leaves / litter from the surrounding trees.

Bifurcation - The separation of a stream into two parts. The creation of distributaries is the consequence of bifurcation

Constructed Wetlands – Constructed wetlands are wetlands specifically built to act as natural pollution control plants and are not directly comparable to natural wetlands.

HQ 1 – HQ 100 – Statistic expectation for the discharge at flood events, based on long term monitoring. The numbers stand for the annularity and the probability that this event takes place.

Hyporheic zone - Defined as a subsurface volume of sediment and porous space adjacent to a stream through which stream water readily exchanges. Although the hyporheic zone physically is defined by the hydrology of a stream and its surrounding environment, it has a strong influence on stream ecology, stream biogeochemical cycling, and stream-water temperatures. Thus, the hyporheic zone is an important component of stream ecosystems.

Mineralization – A process where a substance is converted from an organic substance to an inorganic substance caused by microorganisms. Two important mineralization processes are the ammonification and the nitrification.

Nutrient Retention – The term nutrient retention is often used as a substitute for storage and has a similar meaning.

Nutrient Removal - In contrast to "storage", "removal" is the final elimination of nutrients out of a river by wetland system in a way that <u>no future release from the wetland system to the river will happen</u>. In this sense only denitrification and harvest can be considered as "removal" out of the river and wetland system. Storage (retention) of nutrients over long periods of time (e.g. decades) may also be considered as removal, depending on the time horizons under consideration.

Nutrient spiraling concept - A concept to explain the transport and transformation of nutrients along river stretches

Nutrient Storage - Storage can be considered as temporary (although often long lasting – i.e. years or decades) retention in the wetland system. Main mechanisms and processes that lead to storage are: sedimentation, precipitation, adsorption and filtration to sediments, algae and plant uptake, as well as heterotrophic growth.

Nutrient Transformation – Are the processes by which nutrients are altered in their state i.e. denitrification or incorporation into plant matter.

Redox potential (reduction potential) - In aqueous solutions, the reduction potential is the tendency of the solution to either gain or lose electrons when it is subject to change by introduction of a new species. A negative redox potential indicates reducing conditions whereas a positive indicates oxidizing conditions. Reducing condition lead e.g. also to phosphorus re-solution from the sediment into the water column which may enhance eutrophication processes.

Riverine Wetlands - Riverine wetland are those wetlands situated by channels with moving water, and also near deepwater habitats. In some parts the average depth of the channel is at least 2 meters. Here we concentrate on riverine wetlands with connected (currently or formerly) palustrine and/or lacustrine systems in the whole catchment. In this sense it is including also floodplain, even former. We can call it riverine wetland system sensu lato.

Shear stress – a parallel or tangential force to the surface of the river bed with an abrasive effect

Stream Order – The stream order system is a simple method of classifying stream segments based on the number of tributaries upstream. A stream with no tributaries (headwater stream) is considered a first order stream. A segment downstream of the confluence of two first order streams is a second order stream. Thus, a nth order stream is always located downstream of the confluence of two (n-1)th order streams.

Water age – Number of days the water of the river is in the wetland. River water = day 0

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