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INTEGRATION OF THE NUTRIENT REDUCTION FUNCTION IN RIVERINE WETLAND MANAGEMENT

GUIDANCE DOCUMENT

PROJECT COMPONENT 4.3: MONITORING AND ASSESSMENT OF NUTRIENT RETENTION CAPACITIES OF RIVERINE WETLANDS

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PREFACE

Growing interest in the use of wetlands for nutrient retention (e.g. World Bank projects in Bulgaria and Hungary) was one of the main driving forces to prepare the Technical Guidance on Nutrient Retention Capacities of Wetlands. Scientific evidence, based on experience and understanding of nutrient processes across the Danube River Basin is needed for further steps in integration of wetlands in the programme of measures of the European Union Water Framework Directive.

This Guidance Document serves as an extended summary to the main Technical Report.

The main intention of this document is to emphasize nutrient retention services in riverine wetlands in concert with other services (e.g. flood protection) and link these ecosystem services to ecosystem functions and foster thereby the restoration and conservation of natural wetlands in the Danube River Basin. Benefiting from this linkage also the implementation of the Water Framework Directive will be supported and will have positive effects on the achievements of the goals set therein.

The target audience for this document is wetland and river basin managers and thereby providing a linkage between the environmental conservation and the water management sector. Furthermore the guidance document is an additional tool to implement one special wetland function – the nutrient retention service into the river basin management plan.

Wetlands are generally recognized for benefits such as water storage (flood protection, groundwater recharge), hot spots of biodiversity, local and regional water quality control (riverbank filtration, nutrient storage of inputs from diffusive and point sources), ecosystem production (timber, agriculture). Considering these benefits the exploitation and alterations of riverine landscapes has led to a drastic reduction of natural wetland areas, which has been experienced in the last decades. In context with a sustainable ecosystem perspective considering the basic ecosystem values related to biodiversity, more innovative and integrated management approaches are needed to use the benefits without risking a further degradation of valuable ecosystems in the Danube River basin.

Important to note is that this document is focusing on riverine wetlands. These ecosystems are defined as frequently connected (annually wetted areas close to river channels), while a common border for floodplains is an inundation frequency of one in a hundred years - meaning also a high portion of terrestrial environments.

An important step to emphasize the nutrient retention function of riverine wetlands is the integration of this topic in wetland and also river basin management. Important to note is that optimization of one ecosystem function can lead to a reduction of other functions and thus, needs often a harmonization step. In consequence a prioritization and trade off analysis are important steps in a decision process.

This guidance document compiles current knowledge and provides a guideline how to implement the nutrient retention function. The technical background information to that guidance document is given in the technical report, to be found at http://www.undp-drp.org/drp/themes_wetlands.html. Detailed and more technical information about the scientific state-of-the art and the methodological approach and calculation of the case studies are described therein.

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ABBREVIATIONS

DRB	Danube River Basin
DRP	Danube Regional Project
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
UNDP	United Nations Development Programme
WB	World Bank
EC	European Commission
N	nitrogen
P	phosphorus
TP	Total phosphorus
DIN	Dissolved inorganic nitrogen
WWTP	Waste water treatment plant
NO_3-N	Nitrate - nitrogen

INTRODUCTION

River ecosystems control the transport of nutrients and organic matter from terrestrial sources, produce organic material within aquatic environments, degrade organic matter while transporting it downstream and carry the fingerprint of human activities. Floodplains and other retention zones are the key components of river ecosystems controlling these functions and act as biogeochemical hot spots. They also represent functional retention areas, which control and maintain river water quality. In the line with the water framework directive many efforts and improvements have been done, mainly in the implementation of waste water treatment plants.

While these measures help to reduce surface water pollution from point sources other non point source emissions from diffuse sources, like atmospheric decomposition and fertilization of crop land can still lead to serious water quality problems. Here, riparian zones and wetlands play an important role in the control of the water quality of surface water systems, by reducing nutrient input from the catchment as well as reducing nutrient loads already transported in the river system.

This potentially important role that riverine wetlands can play in improving water quality through retention and modification of dissolved and suspended nutrient pollution has been documented by a number of studies and reports, including several that refer to the Danube River Basin.

In a 1999 report prepared under the UNDP/GEF *Danube Pollution Reduction Programme* (DPRP) the significant loss of wetlands in the Danube River Basin, and the potential effect this had on water quality in the Danube River and Black Sea, was extensively investigated. The report concluded that, "it is an uncontested fact that recent, inundated floodplains have a positive effect on water quality improvement and nutrient input reduction if they are not subjected to intensive agricultural use." The historical loss of riverine wetlands was assumed therefore to have had a negative effect on the water quality in the Danube River and Black Sea. The potentially important role of wetland restoration in an overall Danube River Basin nutrient reduction strategy was noted.

In order to strengthen the understanding of the role of riverine wetlands in nutrient reduction, further investigations and activities were proposed as part of the UNDP/GEF Danube Regional Project (DRP). In phase 1 of the project component 4.3 the main activities have been the evaluation and identification of the most effective monitoring strategies and programmes for assessing nutrient removal capacities of wetlands as a basis for Danube River Basin guidelines, to prepare pilot activities that will be carried out in Phase 2 of the DRP and to set the basis for identifying management measures to optimise the nutrient removal capacity of wetlands in Phase 2 (Tickner et al. 2004).

This report sets out the results from Phase 2 of DRP Output 4.3, *Monitoring and Assessment of Nutrient Retention Capacities of Riverine Wetlands*.

1. RATIONALE AND OBJECTIVES

1.1. Rationale

Nutrient enrichment has grown in importance over the last decades because the subsequent eutrophication appears in increased biomass of algae, species change or loss and also dissolved oxygen depletion, leading to severe loss of ecosystem functions. This kind of pollution is caused due to insufficient water treatment (point sources) or non-point sources (e.g. runoff from agriculture/irrigation) in the catchment and affected river stretches downstream of these sources, but also delta and coastal areas, where increased loads have accumulated. In the Danube River basin the increased nutrient loads impacted the conditions along the Black Sea coast. The ongoing degradation of Black Sea coastal areas has led to a number of scientific and management activities to reduce the nutrient input from the Danube (UNDP/GEF Danube Pollution Reduction Program Report, 1999; Kroiss et al., 2005).

The report of phase 1 describes the nutrient balance of the Danube River Basin in terms of emissions to the river system and emissions from the river system to the Black Sea and the process for selecting pilot sites at which the nutrient removal capacity of wetlands can be assessed in greater depth.

Based on the report of phase 1 of the UNDP/GEF Danube Regional Project (DRP) component 4.3 the explicit aim of this guideline is to list recommendations for future management decisions concerning wetlands in the Danube River Basin (DRB). To do so we use the potential role of wetlands in nutrient removal capacities as one of the ecological functions and societal benefits provided by these ecosystems. The guideline gives the basic background on recent policies and presents results on a survey of wetland projects in the DRB. State-of-the-art information on nutrient dynamics in wetlands and examples of case studies to demonstrate a more detailed picture on different pathways and processes involved and the factors controlling these mechanisms is part of the Technical Guidance Document (TGD) and as result recommendations for future wetland management actions in the DRB.

1.2. Objectives

The objectives of the DRP study were to:

- Summarizing the current policies and the role of wetlands herein and the potential to contribute to these policies by effective wetland management (both in terms of conservation and restoration).
- Summarizing the current knowledge on nutrient retention capacity in wetlands and analyzing case studies from the DRB in detail.
- Identifying the potential of nutrient retention functions in riverine wetland management approaches by evaluating recent, running and near-future projects (including the results from a questionnaire and experience from the demo projects).
- Real world examples how nutrient retention is implemented in wetland management projects (here summaries of 4 demonstration projects will be highlighting different aspects of nutrient retention).
- Formulating the guideline for wetland management (motivation and catchment perspective, implementation and evaluation – monitoring of the nutrient retention functions) in concert with other key ecosystem functions primarily related to biodiversity.

2. WETLAND POLICY AND INTERNATIONAL FRAMEWORK

Over the last 150 years there has been a loss of 80% of Danube wetlands due to canalisation, drainage, etc.. . To prevent further destruction and enhance restoration measures of the Danube River and its wetlands several documents and policies were developed, also in close connection to the European Water Framework Directive..

Following policies and programs are of importance for DRB wetlands:

1. Danube River Protection Convention (DRPC): This document forms the overall legal instrument for cooperation and transboundary water management in the Danube River Basin and came into force 1998. The primary concern is the maintenance and improvement of the water quality and environmental protection of the Danube River and to establish a unified River Basin Management Plan (RBMP). The DRPC also takes into account the specific requirements regarding sensitive and specially protected waters like wetlands in water quality objectives. (Convention on Cooperation for the Protection and Sustainable use of the Danube River, ICPDR, 1994) For the basin wide cooperation between the countries the International Commission for the Protection of the Danube River (ICPDR) was implemented (Strategic Paper for the Development of a Danube River Basin District Management Plan, 2002).

2. EU-Water Framework Directive (WFD): The WFD establishes a framework for water policy based on the principles of integrated river basin management. Wetlands are included in the WFD only if they are in close context to surface water bodies, parts of surface water bodies or a target of the objectives for groundwater bodies. However the EU-Water Directors acknowledge pressures on wetlands and highlight their potential important role in RBM. Due to their functions, like pollution control, alleviation of droughts and floods, and enhancement of groundwater recharge, wetlands can help to achieve the WFD environmental objectives more efficiently.

To achieve the aims of the WFD, a Danube characterization analysis was established and identified four basin wide key water management issues for surface waters:

- organic pollution,
- nutrient pollution,
- pollution resulting from hazardous substances
- and hydromorphological alterations

Such pressures also affect wetlands and causes impacts on the ecological status of water bodies. Therefore measures to manage these pressures had to be a part of the RBMP. Suggested measures can be wetland creation and enhancement, because this delivers sustainable, cost effective and socially acceptable mechanisms for helping to achieve environmental objectives (Issue paper on nutrient pollution, ICPDR). By the end of 2007 also a list with GIS information of disconnected floodplains and wetlands of basin wide relevance shall be provided and included for restoration in the PoM (Issue paper on hydromorphological alteration, ICPDR).

3. Ramsar Convention on Wetlands: An important tool for worldwide wetland conservation and protection is the Ramsar Convention on Wetlands. It came into force 1975 and the main aim is the conservation, restoration and wise use of wetlands. Wise use comprises sustainable utilization for mankind, because wetlands provide many benefits and functions, but without disturbance of the natural properties of the ecosystem.

To achieve and enhance these functions several documents and technical guidelines were provided, such as transboundary cooperation, groundwater management, management planning, implementation of national wetland policies, enhance local people participation and river basin management (www.ramsar.org). About 80 wetlands of the DRB are included in the List of Wetlands of International Importance which is implemented by the Convention. Therefore the presented document will also dwell on several of these Ramsar guidelines.

4. Horizontal Guidance on Wetlands (WFD CIS Guidance Document No 12): Tried to clarify the characteristics of different wetland types and elaborated the role of wetlands in the WFD. It gives the recommendation to integrate wetlands in the Program of Measures (PoM). Basic measures include action directly to protect, enhance or restore wetlands, because they are linked with the ground- and surface water aims. As part of the PoM, wetland creation, restoration and management, may prove a cost-effective and socially acceptable mechanism for helping to achieve the environmental objectives of the Directive, due to the numerous functions and benefits wetlands can offer.

5. ICPDR Joint Action Program (JAP): It formulates short-term and long-term actions to improve the water quality in the DRB and to implement a River Basin Management.

The JAP also highlights the role of wetland functions in nutrient reduction, but at the same time pointed out the lack of knowledge about their long-term efficiency in nutrient removal (Joint Action Programme, ICPDR, 2001).

6. UNDP/GEF Danube Pollution Reduction Program (DPRP): One of the established projects of the ICPDR was the Danube Pollution Reduction Program (DPRP) as a basis for further actions to improve the water quality in the DRB. The identified problems for water pollution were insufficient waste water collection and treatment on municipal level, insufficient waste water treatment of industrial enterprises, water pollution caused by intensive agriculture and livestock breeding and inappropriate waste disposal sites (Danube Pollution Reduction Program, 1999). To minimize these pollutions also the initiating of wetland restoration and creation projects were considered.

In the frame of this project an evaluation of the potential of wetlands and floodplain areas in the DRB have been reviewed. 17 wetland/floodplain sites have been identified for rehabilitation considering their ecological importance, their nutrient removal capacity and their role in flood protection. The estimated nitrogen reduction by these restored floodplains ranged from 34.000 to 49.000t/year and the phosphorus reduction between 4.000 and 5.800 t/ year (Danube Pollution Reduction Program – Evaluation of Wetlands and Floodplain and Areas, 1999).

3. CURRENT KNOWLEDGE ON NUTRIENT DYNAMICS IN RIVERINE WETLANDS

The potentially important role that riverine wetlands can play in improving water quality through retention and modification of dissolved and suspended nutrient pollution has been documented by a number of studies and reports, including several that refer to the Danube River Basin. The following section summarizes the recent literature dealing with nutrient reduction and retention in riverine wetlands and the involved processes.

3.1. Basic processes of nutrient dynamics in wetlands

Nutrient dynamics between the main channel and the riverine wetlands are dominated by four basic processes, affecting the nutrient content of the rivers:

Transport: Concentrations of dissolved nutrients do not change very much in relation to the discharge. Transport of suspended solids and particulate bond nutrients is highly dependent on the flow regime of the river.

Transformation and storage: Although nutrient transformation and/or storage often are only temporary in riverine wetlands, the retention and the timing of subsequent nutrient releases to the main channel may affect water quality there. The key transformation and storage mechanisms and processes are sedimentation, precipitation, adsorption to and filtration through sediments, algal uptake, uptake by terrestrial plants and heterotrophic growth.

Removal: In a strict sense of final elimination of nutrients from the system only denitrification and harvest can be considered as removal. However, also the storage of nutrients over long periods of time (e.g. decades) may be considered as removal, depending on the time horizons under consideration in management plans.

Release: Nutrients stored in wetlands may be released over time through erosion of the sediment/soil layer or re-suspension processes. Stored nutrients may also be transformed into dissolved forms by mineralization, solution and desorption.

Nutrient dynamics within riverine wetlands differ between wetland types and nutrient compounds:

Nitrogen: Vegetation uptake and microbial denitrification, which results in N loss to the atmosphere, are the primary mechanisms responsible for N removal in riverine wetland systems.

Phosphorus: Phosphorus is accumulated in wetlands soils and can not be lost in exchange with the atmosphere. Release or storage of P depends on the overlying water column and associated biogeochemical processes (adsorption/desorption reactions, precipitation, mineralization of organic P, and diffusion of P from the soil to the water).

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

In riverine wetlands the widening and bifurcating flow channel system and adjacent not flowing water bodies as well as the exchange with hyporheic[1] zones and the groundwater provides slow

[1] The hyporheic zone is a region beneath and lateral of river bed, where there is mixing of shallow groundwater and surface water.

water velocities and large submerged surfaces in intense exchange with sediment/soil complexes. According to the nutrient spiralling[2] concept, this situation results in a high cycling rate of matter with increased nutrient transformation and retention due to physical, chemical and biological processes. As a consequence riverine wetlands react conservative to nutrient additions - often referred to as a buffering capacity, thus providing stability to the running water ecosystems.

Dependent on the stream order, different riparian structures are important for nutrient retention. Within smaller rivers (low order rivers) vegetated buffer strips along the surface waters are predominant and form the boundaries to the catchment impacts. A riparian buffer is a streamside area of trees or other vegetation which can intercept surface runoff, subsurface flow and deeper groundwater flows for the purpose of removing or buffering the effects of nutrients, pesticides or other chemicals from upland use, which could otherwise enter bodies of water. In large rivers (higher order rivers) principally broadened wetland areas are found. Wetlands include marshes, swamps and bogs as well as some shallow water portions of rivers, lakes and ponds. They are landscape elements that are permanently or regularly flooded or remain saturated for extended periods of time during the growing season. Therefore, in the following sub-chapters riparian buffer stripes, riverine wetlands and the river channel itself are distinguished in their nutrient retention behaviour.

3.2.1. Nitrogen removal

Riparian buffer strips significantly remove nitrogen, where subsurface flow reduction is greater than surface derived nitrogen reductions. Reductions can reach 100%, and often lie between 60% and 90%. Most of the reduction is assumed to account for denitrification derived losses (resulting in atmospheric loss); one third is due to plant uptake. Dominating forested buffer strips are presumed to have a higher denitrification potential over a year's period than grassland ones. <u>The optimal calculated buffer width for efficient nitrate removal has been found in the literature to be 20-30m</u>

Riverine wetlands have been shown to be important in storing sediment, organic matter, organic nitrogen and phosphorus. Most of these materials are transported during flood events. Even small inundated lowland wetlands are helpful in restricting downstream export. Thus enhancing connectivity between rivers and their wetlands enhances overall retention and reduce N exports from large basins. Also in wetlands of higher order rivers denitrification is often nitrate limited and therefore the potential N reduction is driven by water transport into the wetland. Denitrification also takes place in the **riverbed** itself.

3.2.2. Phosphorus retention

Phosphorus retention strongly depends on sedimentation processes, as most of the transported phosphorus is particle bond. Phosphorus retention appears to be maximised when **buffer strips** are composed of dense herbaceous and woody vegetation where stem density and related <u>sediment deposition explains this P retention efficiency</u>. Riverine buffer stripes may release P to the groundwater during the dormant season, and may 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.

In **riverine wetlands** phosphorus retention during flood events is strongly related to sediment trapping efficiency. Most of the phosphorus is transported during flood events. There are speculations that smaller (annual) flood events lead to the most effective P retention (sediment

[2] Nutrient spiralling is formulated in a conceptual framework and applied to running waters, addressing the nutrient cycling between the water, sediment and the biota, as they are displaced downstream.

trapping) because the floodplain is inundated with low water depth (velocity and shear stress is low).

The **riverbed** itself may also be a site of sedimentation and phosphorus storage. At high flow events nevertheless areas of the river sediment will get mobilized again and fine sediment will get resuspended again.

3.3. Hydrology and retention capacity

The hydrological connectivity of riverine wetlands plays a dominant role in nutrient retention performance. With increasing surface connectivity the sediment load and the relative inorganic content of the suspended solids decreases. In disconnected water bodies, turbidity depends mainly on phytoplankton; its productivity is controlled by nutrient content in the water and at the sediment surface. Dissolved nutrient concentration increases (approaching riverine values) with increasing connectivity to the main channel providing nutrient rich water and sediment input. In disconnected water-bodies the nutrient content also depends on the surrounding land use and the state of succession, which is often related to the characteristics of the fine sediment layer therein.

Alteration in river hydrology

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.

This alters the hydrological exchange and all related processes such as storage or release and the directing of water flows. In canalized rivers with little or no buffer zones higher nitrate concentration are found 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. Natural floodplains with a mosaic of habitat and high landscape diversity have a higher potential for water and nutrient retention. Riverine wetlands which are intensively used by humans may behave either as a source or as a sink depending on type of organic matter and chemical compounds considered.

The characteristic of these processes point to the fact that phosphorus and nitrogen has to be seen as two issues, treated separately to understand the functioning, but finally integrated considering the broad interactions in all management approaches and for their overall nutrient retention efficiency factors like hydrological exchange, morphological structure, age of the wetland and nutrient loading are of key importance.

4. NUTRIENT DYNAMICS IN THE DANUBE RIVER BASIN

For demonstration purposes a Danube stretch between Vienna and Medve was chosen to show the nutrient retention/removal function in three floodplains. Results are compared to the loads transported by the Danube considering different hydrological conditions. Consequently, two years 2002 (wet year, characterized by extremely high Danube discharges, with two HQ_{10} and one HQ_{100}[3]) and 2003 (dry year, characterized 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 are needed to understand the broad variability of nutrient retention/removal capacity of riverine wetlands with respect to hydrological variance, to critically highlight results from single years or events and to give a overview concerning the dimension of nutrient retention/ losses possibly caused by riverine wetlands on a short term perspective. The following section summarizes the conclusions from the case study. A detailed description and results can be found in the long version of the technical report.

4.1. Long term nutrient trends in the Danube River

4.1.1. Phosphorus

TP loads in the Danube were effectively reduced since the 1980. This reduction, was mainly achieved by point source emission reduction (reduction of P containing laundry detergents at the end of the 1980s in Austria and Germany and initiation of P removal at WWTPs beginning in the 1990s).

TP-loads are highly influenced by TP transport at high flow and strongly depend on number and intensity of high flow events.

⇨ **Implication to emphasize monitoring of all phases flood events (including rising and falling limb phases)**

4.1.2. Nitrate

Nitrate loads from 1978 to 1998 do not follow the same trend like the TP loads and show only a slight decrease. The effect of a reduction of NO_3-N loads from point loads (WWTP), by a forced implementation of a denitrification operation step during the 1990s is counteracted by NO_3-N emissions from agriculture, which is the dominant source for nitrate. The dominant pathway for NO_3-N emissions to the surface water is groundwater. Due to slow groundwater velocities measures in agriculture (e.g. optimization of mineral fertilizer application) does led to a reduction of NO_3-N emissions to the surface water with a certain time delay (years-tenth of years).

[3] HQ_{10} and HQ_{100} define the one in 10 years and one in 100 years flood event for this Danube stretch.

NO_3-N loads show significant variations mainly caused by hydrological conditions and seasonal variations. Highest loads are found at high flow conditions during spring with low water temperatures and a low denitrification[4] potential.

⇨ Implication to monitor groundwater flow and groundwater quality and investigate extreme floods

4.2. Impact of hydromorphology on nutrient retention in wetlands

4.2.1. Total phosphorus

TP loads strong depend on the hydrological conditions. A huge amount of the annual TP load can be transported within a flood event, which can last only a few days. During this high flow events in the year 2002 with two (HQ_{10} and HQ_{100}) TP is effectively retained in unrestricted wetland areas. This shows the importance of sedimentation processes during flood events caused by a reduction of the flow velocity and the respective distribution of vegetation (e.g. forests, grasslands, meadows) in the inundated area.

However, it has to be taken into account that this retention processes can be partly reversible. Other flood events can remobilize solids from these fluvial areas again and uptake by terrestrial vegetation leads to transformation of the deposited nutrients. The sedimentation also induces aggregation processes of the floodplain area and considering former land use in the wetland.

4.2.2. Nitrate

During a flood event and raising water levels NO_3-N loads are retained with inundation water. However, this is only a temporary effect because NO_3-N seems to be transported in the same order of magnitude downstream after the flood had passed and inundation water runs off. In case of the observed extreme flood event nitrate losses are of minor importance.Therefore the flood event itself plays only a little role in nitrate retentions in the wetland. Effective losses of nitrate can be expected only at favourable conditions for denitrification like low flow velocities and high temperatures.

Summer periods, characterized by stable low flow conditions, show a continuously decrease of NO_3-N loads in the river along the passage downstream. This is caused by denitrification processes in the main channel itself and connected riparian subsystems (adjacent landscape elements).

4.3. Nutrient retention in two different floodplain types as analysed in the case study

4.3.1. Connected / restored wetland (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

[4] Denitrification is the process of reducing nitrate and nitrite into gaseous nitrogen at oxygen depleted conditions, performed by heterotrophic micro-organisms.

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.

The calculations for nutrient fluxes show following results:

- Retention capacity for sediment and for total phosphorus (TP) rises with discharge.
- The highest nitrate retention is found at low discharges (below mean water).
- Algal productivity is controlled by the hydrologic exchange and not the availability of nutrients

4.3.2. Disconnected wetland (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.

The calculations for nutrient fluxes show following results:

- Nitrate retention peak at higher discharge (elevated mean water flow) and thus, reduced frequency
- No extensive retention capacity, neither for suspended solids nor for TP due to restricted surface inflow during floods
- Algal productivity is controlled by nutrient availability of water and sediment compartments
- Similar pattern are shown for the size of inundated area and shoreline length of all water bodies within the wetlands.

CONCLUSION FOR MANAGEMENT

⇨ Results imply that the annual nutrient load transported into the riverine wetland is very variable and depends highly on the hydrological exchange condition and on the geomorphic settings of in- and outflow areas.

⇨ Any retention capacity is related to the exchange conditions and the existing landscape pattern (e.g. channel complexity, length of channels and their connectivity, vegetation patterns- contribution and distribution of different vegetation patches)

⇨ Restoring connections will allow uncontrolled water exchange related to the riverine discharge. Connection during floods is important for TP retention and sedimentation. Wetland connection during low river discharge is important for the nitrate removal. For both situations the long term development (especially enhanced aggradation of wetlands) need to be considered in all management plans.

⇨ Ecological functioning is closely linked to the nutrient retention function and depends on many factors, like hydrologic exchange (surface and groundwater), water age in the respective water bodies, contribution of shallow areas, sediment conditions (boundary to the subterranean ecosystem), shoreline length (measure of the boundary between aquatic and terrestrial landscape elements) and inundation area.

5. RISKS FOR WETLANDS RELATED TO NUTRIENT RETENTION FUNCTIONS

5.1. Sedimentation

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. Fairly narrow buffer stripes can reduce sediment input to surface waters, but the long-term effectiveness is not fully known. **Wetlands** play a distinct role as a sink for fine sediments, especially during high floods large amounts of transported sediments can be retained.

5.2. Accumulation of toxic substances

The (bio-) accumulation of toxic compounds in wetlands is one of the risks associated with natural occurring retention processes. A complex topic involving e.g. diverse chemical processes, biological hierarchies and food web constellations control these processes. The retention processes of heavy metals may occur in all compartments within a wetland. 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 organisms, biological conversion occurs through assimilation and metabolism of micro-organisms living on and around the macrophyte and plant uptake and metabolism.

The use of wetlands to control pollution by means of e.g. heavy metal retention is considered to accumulate substances, leading to problems in the future because they can only be stored and not depleted / transformed. For example, the destruction or harvesting of wetland biomass is considered to release the stored heavy metals into the environment again. It also has to be considered that processes such as denitrification are negatively influenced by increasing pollution levels.

6. INVENTORY OF NUTRIENT RETENTION CAPACITIES OF RIVERINE WETLANDS WITHIN THE DANUBE RIVER BASIN

The objective of the inventory of nutrient retention capacities of riverine wetlands was the development and demonstration of an inventory methodology to support the harmonised assessment and monitoring of nutrient retention 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 retention capacity and to enable the comparison of wetlands in terms of nutrient retention efficiency.

The questions to be answered by the inventory questionnaire were:

- "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?".

Wetlands in the DRB are recognized in their nutrient control function, but in comparison with other wetland functions, like flood control or recreation, it is still of minor recognition and thus, not integrated in management approaches. In this sense wetlands need a strengthening and a quantitative aspect which can be provided by nutrient budget calculations in the wetlands.

The questionnaire was sent to 44 wetland restoration projects or wetland areas within the DRB and 17 responses were received. The detailed results are found in the detailed Technical Guidance report.

Concluding from the results of the inventory of wetland nutrient retention capacity, the following **recommendations** are made:

- Floodplain restoration activity takes place, but not all wetland functions and the catchment context are taken into account
- Objective, design and monitoring should be optimized
- Groundwater monitoring should be integrated
- Provision of basic information in the national language should be encouraged.
- Outcome for future activities:
  - All wetland managers should receive and complete the inventory questionnaire
  - A complete database should be developed on this basis and made available by the public and by wetland managers for comparisons, evaluation and co-operation development
  - An internet web application should be created for data supply by the wetland managers, and for on-line database development and presentation for the public and interested parties.

7. EXAMPLES FOR INTEGRATED NUTRIENT REDUCTION MEASURES IN WETLAND MANAGEMENT

This chapter deals with real world examples in the DRB. Examples from 4 demonstration sites (Hungary, Bulgaria, Ukraine, and Moldova) underline the broad variety of context, which can cause wetland restoration in the DRB:

> wetland restoration as a necessity (pressures from ecological degradation initiating human health and economical risks)

> wetland restoration as a political measure (environmental protection, nutrient retention, flood control)

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. In the following some characteristics of the demonstration sites are outlined.

<u>Nutrient reduction and ecological revitalization on the wetlands of the Danube-Drava National Park (Hungary, Gemenc and Bèda-Karapancsa)</u>
primary objective: ***nutrient retention and removal***
area: ca. 18000 ha (Gemenc in total)
measures: related to planning unit (Hydrology: e.g. building of weirs, opening of channels)

<u>Wetland restoration and pollution reduction project (Bulgaria, Marshes on Belene Island and Kalimok/Brushlen Marshes)</u>
primary objectives: ***nutrient retention and removal; biodiversity***
area: Belene Island (1500 ha) and Kalimok-Brushlen Marshes (1500 ha)
measures: management plans, farmer transition support program, development of "green" business, strengthening of monitoring programs, rise practical awareness, biodiversity and environmental education program, improve of water management and sustainable management

<u>Monitoring and assessment of nutrient removal capacities of riverine wetlands (Ukraine, Katlabuh Lake)</u>
primary objectives: ***reducing salinity, general improvement of water quality***
area: lake 68 km^2, catchment 1290 km^2
measures: reopening the old channel and reconnection to the Danube

<u>Monitoring and assessment of nutrient removal capacity of riverine wetlands (Moldova, Yalpugh and Cahul wetland areas)</u>
primary objectives: ***improve surface water quality and groundwater quality in the catchment***
area: overall catchment area: 4300 km^2
measures: implementation of nutrient reduction measures on base of nutrient balances by conserving wetland areas, monitoring the effects on water quality in the catchment and ecological conditions within the wetland

8. RECOMMENDATIONS

River riparian zones and riverine wetlands are key landscapes of strategic importance. They provide a wide range of ecological and socio-economic goods and services, including flood retention capacity, groundwater recharge, bioproduction, and aesthetic and recreational values. This document and the following recommendation focus on one ecological function – the nutrient retention. These recommendations are meant to provide the basis for the next step – the integration of all wetland functions in RBM with the aim to identify them and optimize management solutions for individual wetlands. To provide these solutions an evaluation of all wetland functions should be done, followed by a prioritization of these functions decision in the management.

Nutrient retention is partly in contradiction with other functions, so the work needs to be included in a wise use guideline which integrate all functions, analyze trade offs and finally prioritizes certain functions for the managers. To assess nutrient retention function information about the hydrological exchange and the spatial configuration, the contribution and distribution of habitats, is necessary. Therefore nutrient retention interlinks between flood protection concerns and habitat protection (Fig. 1).

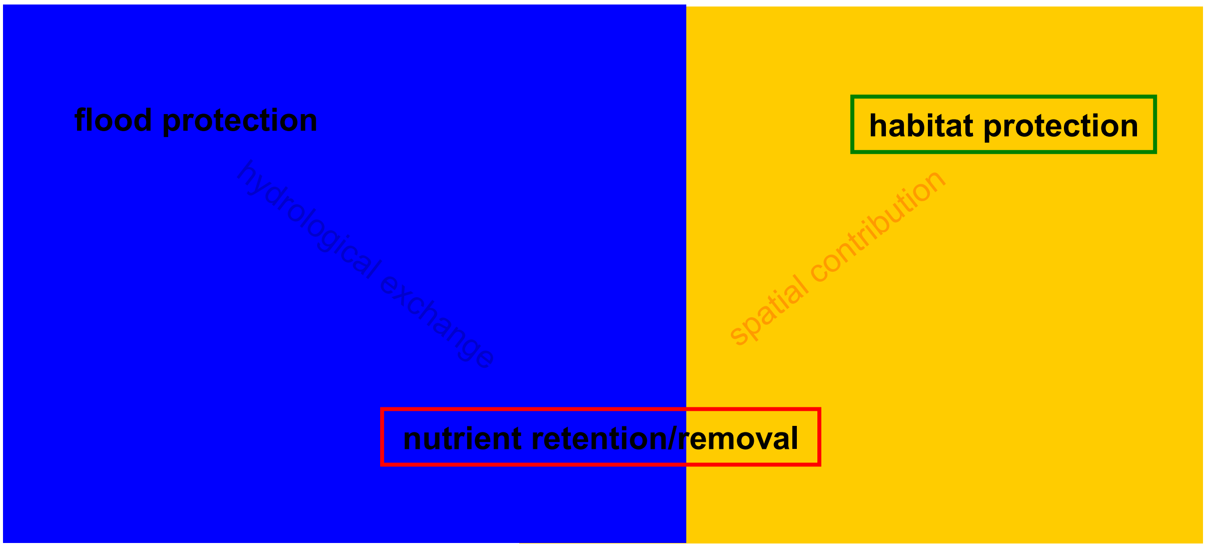

Figure 1 Schematic graphic about the integrative position of the nutrient retention function with flood protection and habitat protection

From the management point of view a catchment related wetland cadastral a prioritisation scheme should support the decision on which wetland should be restored. Obviously this prioritisation scheme can underlie different subjects with various benefits such as, 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.

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. In the long version of the technical report nutrient emission situation is shown based on MONERIS[5] model calculations.

Which types of wetland in the DRB provide good conditions for nutrient retention?

On base of three different modelling approaches considering i) 388 subcatchments of the DRB (MONERIS) ii) the Danube and its large tributaries (Danube Water Quality Model) (Kroiss et al., 2005) and the Danube Delta (Danube Delta Model) (Kroiss et al., 2005) nutrient loss or retention capacity including all surface water bodies was found to vary over a broad range. Although, these result stem from different models with different approaches a comparison, as following is helpful to underline some common but crucial aspects. Results from these models show that wetlands in the vicinity of low order[6] running waters in general provide a higher potential of nutrient retention than wetlands of large tributaries of the Danube due to favourable conditions in the adjacent surface water (small watersheds with high nutrient concentrations and a high discharge dynamic).

The Danube Delta provides also good conditions (e.g. low flow conditions and thus extended residence times, structural diversity) for nutrient retention, but unfortunately, due to river engineering actually 90% of the Danube discharge flows through three main channels, while only 10% of the discharge enters the Delta complex and its favourable conditions for nutrient transformation and retention. As a consequence the retention of nutrients in the Danube Delta seems to be reduced with respect to former times, but its potential for nutrient reduction and transformation is still very high.

In general adjacent wetlands shall provide following conditions to show a high nutrient retention potential:

- High share of surface waters in the wetland
- Partly high nutrient concentrations and accumulation of organic matter
- Morphological diversity (e.g total length of wetland channels, shoreline length)
- High diversity of habitats (vegetation types) – often referred to as the habitat mosaic
- Changing flowing conditions in parts of the wetland (connection during high and low water periods)
- Groundwater-surface water interactions
- Large surface area for sedimentation processes during floods

What retention could be expected from riverine wetlands?

Comparing different wetlands from the literature a wide range in nutrient retention could be found. Nitrate retention range from 31 to 0.0001 t $ha^{-1}a^{-1}$, where the connected floodplain of our case study is in the effective group, while the degraded one is found in the rather ineffective group of floodplains. However these 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 different sites.

Table 1: Ranking of nitrate retention of literature values and the case study sites (Regelsbrunn and Lobau). * the literature values are denitrification rates.

[5] Emission Model MONERIS quantifies nutrient emissions from seven main pathways (Erosion, Surface runoff, Groundwater, Tile drainage, Atmospheric deposition, paved urban areas, Point sources).

[6] Stream order refers to a simple algorithm used to define stream size based on a hierarchy of its tributaries, proposed by Strahler 1952.

site description	maximal nitrate retention ($t\ ha^{-1}a^{-1}$)	reference
bogs and fens (drainage basin Baltic Sea)	31	Jansson et al (1998)*
grass buffer strips	5.8	Groffman et al. (1991)*
connected wetland	0.73	case study Regelsbrunn
riverine floodplain	0.597	Johnston (2001)*
floodplain forest (Morawa/Dyje)	0.224	Phare project (1997)*
restored riparian forest	0.069	Ambus & Lowrance (1995)*
floodplain siol (grass or reed)	0.0548	Venternik et al. (2003)*
degraded wetland	0.04	case study Lobau
riparian wetland	0.038	Hanson et al. (1994)*
riparian wetland	0.016	Hanson et al. (1994)*
forested buffer strips	0.0022	Groffman et al. (1991)*
riverine floodplain	0.002	Johnston (2001)*
forested area	0.0001	Groffman (1994)*

The phosphorus retention ranges from 710 to 1.5 kg $ha^{-1}a^{-1}$, but this high value came from a study on constructed wetlands and no natural riverine one. However our case study shows that also re-connected floodplains have a quite high phosphorus retention, but the same case study shows that a degraded floodplain like the Lobau could be also a source of total phosphorus.

Table 2: Ranking of total phosphorus retention of literature values and the case study sites (Regelsbrunn and Lobau). The negative value at case study site Lobau indicates phosphorus release from the system.

site description	maximal total phosphorus retention ($kg\ ha^{-1}a^{-1}$)	reference
constructed wetlands	710	Braskerud et al. (2002)
connected wetland	50	case study Regelsbrunn
palustrine wetland	30	Reinelt & Horner (1995)
hardwood forest (CZ)	18	Klimo (1985)
restored wetland receiving agricultural runoff	18	Jordan et al (2003)
floodplain meadows (UK)	17.4	Van Oorschot (1996)
constructed wetland	8.5	Kovacic et al (2000)
restorated prairie pothole wetland	3	Magner et al. (1995)
floodplain forest (USA)	1.5	Richardson (1990)
degraded wetland	-5.5	case study Lobau

Fisher and Acreman (2004) suggest in a review that N and P retention requires different wetland types and it is not of great use to use mean estimation for both nutrient fractions in wetland management. For example to enhance phosphorus retention wetland sediments should be oxidized and do not show reducing conditions, which may be in contrast to the conditions required for denitrification.

These aspects should be taken into account when considering the hydrological, sediment and vegetation conditions in riverine wetlands.

How to identify and assess the nutrient retention function in riverine wetlands?

In order to maintain or enhance the role of wetlands in water resource management, it is necessary first to identify and assess the benefits which a particular wetland provides. Three steps are needed in this process:

- - **inventory and description** of the wetlands (refer to RAMSAR Resolution VII.20);
- - **identification** of the particular attributes and functions that may play a role in water management;
- - **quantification** of such functions.

The following, recommendations are made on how a monitoring of the nutrient removal capacity can be implemented at selected restoration sites. It is obvious that a monitoring programme depends on the available resources, availability of time and the local situation (focus of investigation) as well as on the scale under investigation and cannot be designed on a general level. However, it is possible to give some remarks for a draft guideline, using an iterative approach starting with minimum requirements and a stepwise increase of complexity and validity of results but also effort and costs which should encourage wetland managers to consider questions of nutrient retention and losses and point out that even simple measures can be a first step to provide helpful information.

The following four phases are a stepwise approach to implement the nutrient retention topic into RBM. These phases include:

- Objective
- design and implementation of nutrient monitoring
- linkage of wetland functions with the catchment scale
- evaluation

Phase I: Estimating the nutrient retention potential

First it is necessary to evaluate the actual nutrient retention/ removal potential of the wetland and therefore to clarify the **Objective** for nutrient management.

Following topics should be evaluated:

1. *Is the wetland continuously or temporally connected (groundwater or surface water connected)?*

   A good potential for nutrient retention or removal capacity is given, if the wetland is continuous connected to the river at different discharge conditions.

2. *Are there possibilities to estimate the discharge to the wetland considering different hydrological conditions?*

   This question evaluates, if a quantification of the connection is possible.

3. *Does the river stretch adjacent to the riverine wetland show morphological heterogeneity (e.g. meander), or is it canalized?*

   If the former river system in the wetland complex is heavily modified by drainage, ditches and channels, significant amounts of phosphorus can be emitted via groundwater.

4. *Are there significant nutrient sources within the wetland area or close by (intensive agricultural activities-former/actual, settlements, industry, etc.)?*

   Often the P-enriched and degraded soils (e.g. due to intensive agricultural use) show a tendency to release phosphorus especially under a temporally shift of redox conditions (mineralisation processes when falling dry and remobilisation from iron bound P when flooded). Other nutrient emissions can stem from point sources (e.g. industry).

5 *Are groundwater or soil data available?*

Possible autochthonous nutrient sources, which can be remobilised at special process conditions and thus counteract retention or removal of nutrients or even lead to additional nutrient emissions from the system.

This underlines that further information from surface soils, riverbed sediments and groundwater can offer information to estimate the remobilisation potential of nutrients in a wetland.

Phase II: Minimum requirements for nutrient retention calculations – basis for **design and implementation**

Black box approach

The simplest approach to calculate nutrient retention in a riverine wetland is input-output measurements considering discharge, water retention time and water quality data. On base of load calculations nutrient retention or mobilisation at different hydrological conditions can be estimated. The results from this monitoring concept depend on:

- Frequency of sampling
- Number of sampling sites
- Time period under investigation
- Evaluation of different hydrological conditions, especially flood events.

This simple monitoring scheme does not consider the influence of potential emission pathways like groundwater, subsurface flow etc. to or within the system.

Phase III: Emission and balance models as Decision Support Systems (DSS) for specified nutrient reduction in large wetland regions **link to larger scale** (and also the screening of additional pressures)

Using results from emission and balance models like MONERIS (http://danubs.tuwien.ac.at/), SWAT (http://www.brc.tamus.edu/swat/), SWIM (http://www.wiz.uni-kassel.de/model_db/mdb/swim.html) or "material account" can lead to additional information because internal sources, mass flows and the dominant pathways of nutrient emissions, which can heavily influence net retention or loss of nutrients in a huge wetland area, are considered.

In the case of using the material account approach or the emission model MONERIS, the source (e.g. formerly fertilised agricultural soils) will be evaluated, the mobilisation calculated and the flows or emissions will be related to a pathway (e.g. drainage). A rough calibration of the emission model MONERIS can be achieved by a comparison of the total emissions in the region and the loads transported at the outlet of the region using different approaches to consider nutrient retention in the river system (see final report DRP 4.3, phase I). On base of model results, measures can be implemented to reduce internal nutrient flows (e.g. more stable or higher groundwater levels by weir regulations) as well as to reduce the source itself (e.g. harvest, improvement of Waste Water Treatment).

Phase IV: Specific Monitoring for **evaluation**

From results of phase III a more specific monitoring can be implemented, considering the specific situation of the wetland. Thus, beneath surface water monitoring other subjects like groundwater, soils, sediments, inundation water, plants can be included into the programme. A summary of monitoring parameters and approaches are listed in table 1.

General remarks to the phases suggested

It should be emphasized, that monitoring of the nutrient situation in a restoration site is not useful only for the calculation of the nutrient retention, but to understand the functioning of the ecosystem and to derive nutrient management strategies for adjacent point sources and diffuse sources either, which is helpful for wetland as well as river, river basin and environmental management in general. The stepwise approach of these phases is needed to fully integrate this function in the particular wetland management. By the use of these steps an additional benefit is highlighted and this provides also a support for local and regional acceptance.

Based on sound information a full appreciation and integration of this function interlinked with other functions is possible.

Table 3 Summary of the monitoring recommendations of DRP 4.3 part1

	Parameters	sampling site	sampling frequency	note
Hydrology of surface waters	water level, discharge, flow velovity and residence time can be deduced	all relevant inflow and outflow channels	normally beweekly, at high flow or flood events daily	
Hydrology of groundwater	groundwater slope, groundwater depth and conductivity	between the main river and wetland channels or between the wetland channels and the catchment		conductivity of the aquifer is nevertheless a factor of uncertainty so tracer tests might be considered
Transport by surface waters	nutrient loads : TN, DON, NO3-N, (NO2-N), NH4-N, TPfiltered, TPnot filtered, PO4-P retention/transformation processes: SS, POM (FPOM, CPOM), TOC, DOC, Chlorophyll a, O2, pH, T, conductivity, HCO3 qualitative detection of transformation processes: Isotopes as N15 or O18	in all relevant surface water connections between the main river and the wetland and as reference in the main river (at the same places where discharge is measured)	normally beweekly, at high flow or flood events daily	sampling strategy should be designed so that discharge to load (or concentration) functions can be derived for the different locations as a basis for the calculation of yearly loads. This means that event-oriented sampling at high flow/flood conditions is necessary
Transport by groundwater	nutrient loads: TN, DON, NO3-N, (NO2-N), NH4-N, TP, PO4-P retention/transformation processes: TOC, DOC, O2, pH, T, conductivity, (Fe, Mn) , HCO3 qualitative detection of transformation processes: Isotopes as N15 or O18	wells where main groundwater discharge takes place	every 1 – 2 month	
Deposition, N-fixation	Normally it will be sufficient to estimate nitrogen inputs by deposition and N-fixation based on information on regional nitrogen depositions and information on the number of N-fixating plants, in order to check the relevance of this inputs. Only in exceptional cases more detailed investigations will be necessary.			

	Parameters	sampling site	sampling frequency	note
Storage/Transformation	More detailed monitoring for quantitative assessment of specific transformation processes is not of major importance. If possible, these indicators should be measured at additional locations inside the wetland as well.			
Removal by denitrifcation	Denitrification has to be derived from the quantification of the nutrient budget of input minus output flows over longer periods of time. Thus all other input and output flows must be known as well as changes in stock. Achieving this must be the main emphasis of monitoring. Indicators such as oxygen, DOC, Fe or Mn content or change in ^{15}N contents will help the interpretation of results and transformation of results to wetlands with similar conditions for denitrifcation.			
Removal by harvest	harvested areas, the harvested plants, the number of cuts in case of meadows and nutrient uptakes of these plants			the relevance of removal by harvest will be small
Long term storage	long-term monitoring: changes of morphology/relief of the wetland (e.g. silting of surface waters) and the observation of P (and N and organic matter) contents in soils and sediments of wetlands.	monitoring the area affected by sedimentation	sediment samples soon after flood events	
Wetland typology and wetland vegetation	classification scheme contained in the project report DRP 4.3 phase 1			
Flood events	discharge		Representative sampling (daily)	The use of hydrological models to address this issue should be considered

9. FUTURE PROSPECTS FOR THE NUTRIENT RETENTION IN WETLANDS

Natural riverine wetlands are key landscape elements and provide multiple functions also for the benefit of humankind. A well defined and integrated wetland management support the nutrient reduction function and could be linked to other issues like flood protection.

Results from the EC-daNUbs project imply that a reduction of nutrient loads in the Danube River Basin found for the last years is to a large extent related to the economical breakdown of the east European countries. Decreasing nutrient loads transported by the Danube caused a distinct increase of the water quality in the Danube influenced costal area of the Black Sea.

However, economic restructuring forced by the expansion of the EU with a huge cash flow for establishing a higher economic status, will lead to increasing nutrient emissions particularly from the region of the middle and lower course of the Danube.

Implementations of further policies and measures, which significantly can reduce nutrient emissions and retain or transform nutrients, are of outstanding importance to guarantee the advancement or even the confirmation of the favorable present status.

Thereby a mix of measures (e.g. construction of Waste Water Treatment Plants, reconstruction and restoration of riverine wetland sites) seems to be most promising to satisfy the complex socio economical as well as ecological requirements which have to be considered in the future development presumably in the Danube River Basin.

With regard to the natural wetlands in the DRB it has to be emphasized that wetland area is drastically reduced throughout the DRB, remaining wetlands are under risks to loose their basic ecosystem values. In consequence, all suggestions regarding nutrient retention need to be seen as an additional benefit for conservation and restoration activities of natural wetlands without leading to any further degradation of nature conservation values as these are already appreciated to be of major importance, especially in natural wetlands.

Nutrient retention in restored wetlands can play an important role in sustainable management approaches - as results from the case study sites underline - but seems to be a proper measure in particular, because nutrient retention is one positive effect in combination with other ecological and socio economical benefits especially useful in developing, rural regions.

The integration of wetland management in RBM is urgently needed, as well as the catchment perspective for a sustainable management of wetlands.

For a future RBMP for the Danube river basin we suggest following points:

- **Continuation of monitoring programmes of the demonstration sites (long term effects)**
- **Development of an integrated management approach (what are the next steps to be implemented?)**
- **Combined efforts in wetland management in the light of the WFD**

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GLOSSARY

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 no future release from the wetland system to the river will happen. 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