DIPLOMARBEIT

Titel der Diplomarbeit

COMPARISON OF THE WATER QUALITY STATUS OF SELECTED WETLANDS IN THE DANUBE RIVER BASIN

angestrebter akademischer Grad

Magister der Naturwissenschaften (Mag. rer.nat.)

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Matrikel-Nummer:	0203154
Studienrichtung/Studienzweig (lt. Studienblatt):	Biologie/Ökologie
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Wien, im Juni 2009

Danksagung

Bedanken möchte ich mich bei meinem Betreuer Privatdozent Dr. Thomas Hein, der mir die Mitarbeit am Projekt „BioWetMan" und somit diese Diplomarbeit erst ermöglicht hat und mir in den vergangenen zwölf Monaten bei unzähligen Treffen mit seinen Ideen und Vorstellungen eine große Hilfe darstellte. Auch investierte er viel Zeit und Energie in die Durchsicht meiner Arbeit, wofür ich mich recht herzlich bedanken möchte.
Weiters möchte ich mich bei Dr. Gabriele Weigelhofer, die mich am Beginn meiner Auswertungen sehr unterstützt hat und mich durch ihre hilfreichen Anregungen ein gutes Stück vorwärts gebracht hat.

Bei meinen Eltern Melitta und Franz Edinger möchte ich mich für die finanzielle Unterstützung während meines Studiums bedanken. Danke, dass ihr meine Entscheidungen immer respektiert und unterstützt.
Mein besonderer Dank gilt jedoch meiner Freundin DI Sabine Wimmer – vor allem für ihr Verständnis für die annähernd tausend Arbeitsstunden in den letzten zwölf Monaten, ihr offenes Ohr in Bezug auf Probleme bei der Arbeit, ihre alltägliche Hilfe und Unterstützung. Danke, dass du immer da bist!

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Zusammenfassung

Ein Großteil der Auen im Einzugsgebiet der Donau werden anthropogen stark beeinflusst, sei es durch Hochwasserschutzmaßnahmen oder geänderter Landnutzung. Dies führt zu Änderungen in der Konnektivität der Auen an Fließgewässer. Es wird davon ausgegangen, dass weniger stark beeinflusste Auen höhere Ökosystemfunktionen und -leistungen hinsichtlich der Wasserreinigung darstellen und in Folge dessen die Wasserqualität des Flusses erhöhen können.

Das Ausmaß der hydrologischen Konnektivität beeinflusst die Wasserqualität und damit verbundene Ökosystemleistungen (wie zum Beispiel Nährstoffreduktion) von Auen. Hohe Nährstoffkonzentrationen können während hoher Wasserführungen gemessen werden. Hohe Nährstofffrachten werden somit in stark angebundenen Auen (durchströmte Seitenarme) erwartet, wobei diese im Vergleich zu weniger stark angebundenen Auen (Flachwasserseen) eine höhere Nährstoffaufnahmekapazität zeigen.

Die Ziele der Arbeit sind eine Abschätzung der durchschnittlichen hydrologischen Konnektivität, das Sammeln von Daten zur Wasserqualität sowie das Aufzeigen von Auswirkungen der Konnektivität auf den Nährstoffstatus ausgewählter Auen entlang der Donau, welche hinsichtlich des Managements, der Nutzung und der Restaurierung unterschiedlich stark beeinflusst sind.

Die Klassifikation der ausgewählten Auen hinsichtlich ihrer Hydrologie und Konnektivität zeigte verschiedene Anbindungsdauern zum Hauptfluss. Die Analyse der einzelnen Auen zeigte, dass die elektrische Leitfähigkeit ein geeigneter Indikator für das Einströmen von Wasser in die Au darstellt. Die Beziehung von Konnektivität und Nährstoffen wies unterschiedliche Muster bei verschiedenen Auen auf.
Der Vergleich zweier österreichischer Auen, von denen eine eine veränderte hydrologische Konnektivität aufweist und die andere wieder angebunden wurde, zeigte eine positive Korrelation zwischen Wasserführung und Nährstofffrachten.

Dabei zeigte die restaurierte Au höhere Nährstoffretentionen. Daran lässt sich erkennen, dass die Dauer der Konnektivität zum Hauptfluss positiv mit dem Retentionsvermögen einer Au korreliert.
Berechnungen zeigten, dass Nährstofffrachten innerhalb der beiden österreichischen Auen den kritischen Level für Phosphat und Stickstoff in den Untersuchungsjahren überschritten hatten. Hohe Nährstofffrachten können zu einer Verringerung der Nährstoffretention und damit zum Rückgang einer wichtigen Ökosystemleistung führen.

Abstract

Most wetlands within the Danube River Basin are highly impacted by human activities, for instance due to flood defence measures and land use change. This results in an altered connectivity of the wetlands to the main channel. Less impacted wetlands are expected to perform higher ecosystem functions and services concerning water purification and therefore, might improve the water quality of the river to a higher degree.

The extent of hydrological connectivity impact the water quality status and related ecosystem services (such as nutrient reduction) of riverine wetlands. High nutrient concentrations can be measured during higher discharges. Therefore, higher nutrient loads are expected in higher connected wetlands (side channel type) compared to more isolated ones (shallow lake type). The difference between connected and disconnected phases is expected to be higher in more dynamic wetlands (side channel type), thus, indicating a higher uptake capacity in these wetlands compared to shallow lake type ones.

The objectives of this work are to estimate the status of the mean hydrological connectivity to the main channel of the Danube River, to collect water quality data and to show the effects of connectivity on the nutrient status of different Danube River wetlands, varying by the extent of water management and intensity of utilization and restoration. Based on load calculations at two Austrian wetlands the ecosystem service concerning nutrient reduction is estimated and compared with each other.

The categorization scheme of the selected wetlands towards hydrology and connectivity showed various durations of connectivity to the main river. The analysis of individual wetlands showed that the conductivity was a suitable indicator in all wetlands for water inflow into the wetland. The relation of connectivity and nutrients showed different patterns depending on the observed riverine wetland.

The site comparison between two Austrian wetlands, of which ones hydrological connectivity was altered and one wetland was reconnected, showed a positive correlation between discharge and nutrient loads. The restored wetland showed a higher nutrient retention compared with the managed wetland. This indicated that the duration of connectivity to the main river is positive correlated with the retention capacity of wetlands.

Calculations showed that the nutrient loads within the two Austrian wetlands surpassed the critical levels for phosphate and nitrogen in the years of investigation. High nutrient loads can lead to a reduced nutrient retention and therefore to a loss of this important ecosystem service.

1. Introduction

1.1. Definition of "Wetland" and types of wetlands

Wetlands comprise of a rather diverse group of aquatic ecosystems. To point out, how wetlands are defined and how wetlands can be classified, the Ramsar Convention on Wetlands provides a definition of "Wetland" as well as a classification scheme for the various types of wetlands.

Definition of „Wetland"

In the Ramsar Convention of 1971 (Article 1.1), wetlands are defined as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" (Batzer, 2006 after Navid, 1989).

Wetlands types

The Ramsar Classification System for Wetland Type distinguishes three main groups of wetlands. Each of these groups covers many different wetland types, which are counted in brackets.

1. Marine/Coastal wetlands (12)
2. Inland wetlands (20)
3. Human-made wetlands (10)

Recording to another classification scheme available on http://www.ramsar.at, which is based on the Ramsar Classification System for Wetland Type, natural wetlands can be distinguished into five main categories:

1. Marine-systems, which are coastal wetlands including coral reefs
2. Estuary-systems, which are intertidal marshes and mangroves
3. Lake-systems, which are wetlands related to lakes
4. River-systems, which are wetlands related to rivers, streams and creeks
5. Marsh-systems, which are moors, swamps and marshes

Additionally to these five categories, there are artificial wetlands like fish ponds, tice fields, reservoirs, canals, etc. (http://www.ramsar.at).

The following chapters will focus on the importance of riverine wetlands, the ecosystem functions and ecosystem services they offer, but also on threats wetlands suffer from.

1.2. Ecosystem functions and services of riverine wetlands

Importance of riverine wetlands

As riverine wetlands offer many ecosystem functions and ecosystem services, which are described in the following chapters, they are very important for living organisms like human beings, but also for other organisms. But in Europe there is a widespread loss of wetlands. About two thirds of the wetlands, which existed at the beginning of the 20^{th} century have been lost until the year 1995 (Communication from the Commission to the council and the European Parliament, 1995). Such a trend can also be observed especially for the Danube River Basin (Communication from the Commission to the council and the European Parliament, 1995, Tockner & Stanford, 2002, Hein et al., 2005). Therefore an integrated research approach aiming for the protection and restoration of wetlands is very important for these threatened ecosystems. The following section gives an integrated view of ecosystem functions and services, which justify the protection and restoration efforts.

Ecosystem functions and ecosystem services of riverine wetlands

Riverine wetlands offer manifold crucial ecosystem functions and services (Lazowski, 1997 after Wendelberger, 1975), some examples are:

- climatic regulation: increased humidity, temperature compensation
- transformation of nutrients
- highly productive ecosystems, fishery and hunting
- high biodiversity, ecotones between land and water
- spawning grounds, shelter for organisms such as fish

Ecosystem functions, which contribute to human well-being are called ecosystem services. These ecosystem services can be defined after the Millennium Ecosystem Assessment (2005) as follows:

„Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits."

The following subchapters describe ecosystem functions and services related to hydrology, morphology, water quality, gas regulation, and other ecosystem services.

1.2.1. Ecosystem functions and services related to hydrology

Riverine wetlands can even out flood peaks by storing surplus water from precipitation events and holding back water runoff, which can be seen in Figure 1 (ICPDR, 2008; Communication from the Commission to the council and the European Parliament, 1995; Hruby, 1999). Due to increased water retention within the wetlands municipals downstream can be protected against severe flood damages.

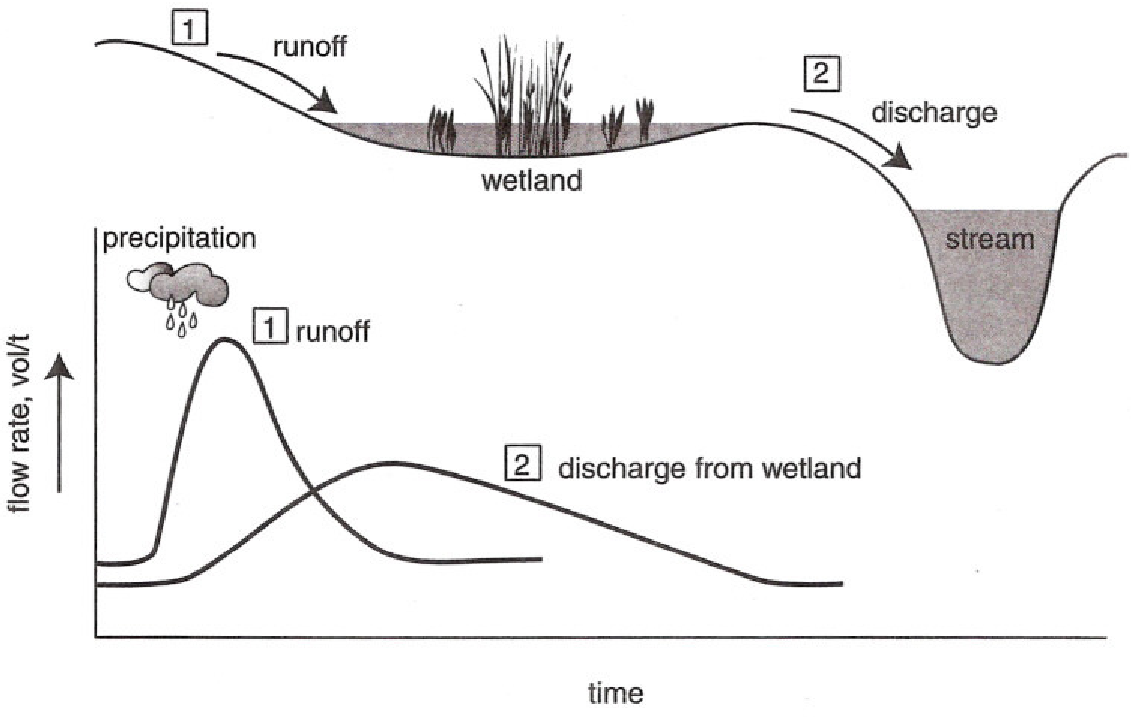


Figure 1: Changes of the discharge after precipitation events due to wetlands (Mitsch & Gosselink, 2000).

Drought control by recharging groundwater is another ecosystem service of riverine wetlands due to holding back water, which enters the wetland and increase the interaction with the adjacent groundwater body (Hruby, 1999). This helps to maintain drinking water and water used for irrigation of farmland at dry periods.

In some European countries the problems due to a lack of wetland areas along the Danube River became visible in years of high floods and years of droughts.

1.2.2. Ecosystem functions and services related to morphology

The riparian vegetation in wetlands can stabilize shorelines. There are two reasons for the shoreline stabilization. First, the root systems of the wetland vegetation bind soils. Second, the plants can dissipate waves and therefore reduce erosion due to reduced wave energy (Adamus, 1991). Hruby (1999) also described the binding of soils as a physical filter. Additionally also water plants can reduce suspended solids in wetlands. Gereta et al. (2004) mentioned a reduction of the turbidity resulting from trapped suspended sediments from the surface water flowing into the wetland. Riverine wetlands reduce the sediment erosion by reducing the duration of erosive flows, which are flows transporting a high water capacity with a high velocity (Hruby, 1999). A service of floodplain forests is the protection of adjacent farmland areas against soil erosion due to wind forces and drying up (Gren, 1995).

1.2.3. Ecosystem functions and services related to water quality

Nutrients can be removed from surface water within riverine wetlands due to trapping sediments containing phosphorus, soil adsorption of phosphorus on soils high clay content or organic matter, and due to nitrification/denitrification processes, which removes nitrogen (Hruby, 1999; Verhoeven et al., 2006). McClain (2002) described South American rivers and wetlands, which are more natural compared to northern rivers and wetlands and show higher self-purification capacities. McClain (2002) investigations in the Amazon River Basin indicated nutrient reductions, as follows. Nutrient-rich river water with high nitrate and phosphate concentrations entered a wetland lake. The water showed lower concentrations at the downstream end of the lake.

Regarding phosphorus, Hein et al. (2005) found that wetland restoration can cause a decrease of phosphate in downstream reaches due to increased nutrient storage and transformation processes in inundated areas. Hein et al. (2005) described an increased phosphate transformation after reopening a side-arm of the Danube River downstream of Vienna at Regelsbrunn due to an increased algal uptake. Such an uptake cannot change the net balance of phosphorus input in and output out of a riverine wetland, but it can decelerate the time of nutrient release (Hruby, 1999). Hein et al. (2005) stated that "most of the yearly phosphorus transport occurs during flood events because of soil erosions" (description had been done by Zessner et al. 2005). This shows the importance of connected wetlands as nutrient traps.

Regarding nitrogen, the denitrification process, which occurs intensely in riverine wetlands, removes nitrogen as N_2O or N_2 gas from the ecosystem (Verhoeven, 2006; Batzer, 2006) (also see chapter 1.2.4.). Therefore McClain (2003) described wetlands as "hotspots of denitrification".

Problematic substances

Harmful substances like toxicants, oils, heavy metals, etc. from industry and urban areas, which end up in rivers, can also cause damages to these ecosystems (Mitsch & Gosselink, 2000). In the face of danger, riverine wetlands are very important for these impacted rivers, because they can enhance the water quality by accumulating these toxic substances (Communication from the Commission to the council and the European Parliament, 1995), which on the other hand pollute the wetlands themselves.

1.2.4. Ecosystem functions and services related to gas regulation

Wetlands can play an important role regarding climate regulation. Gren et al. (1995) described the higher evaporation and the regulation of the temperature during droughts, which can be a benefit for adjacent farmland and ecosystems.

Otherwise due to the denitrification, wetlands capture a sink function for nitrogen. In this process, dead organic material is decomposed by bacteria using nitrate under anaerobic conditions. But if the bacterial process is hindered due to high nitrate loads, nitrous oxide N_2O, which is a strong greenhouse gas, can be released as the end product of this process in higher portion (Verhoeven et al., 2006). This process removes nitrogen from the ecosystem.

1.2.5. Other ecosystem functions and services

Shelter – basis for biodiversity

Due to the ecotonal character of wetlands, a high biodiversity of species can be found in these ecosystems. This "edge effect" was first described by Odum, 1979 (Mitsch & Gosselink, 2000). Wetlands offer habitats for different species, which need more than one habitat during their life-cycles (Amoros & Bornette, 2002), such as fish species. A lot of migrating species use these connected areas for feeding, spawning, and nursery (Ward, 1998). Therefore riverine wetlands accommodate a unique mix of species (ICPDR, 2008).

Riverine wetlands are also well known as habitats for birds like waterfowls, herons, and shorebirds, providing them food, shelter, breeding, and resting areas (Hruby, 1999). Mammals, for example the beaver *Castor fiber*, also live in riparian ecosystems. Beside the animal species, wetlands also harbour a unique mix of native plant species (Hruby, 1999), for example *Populus nigra* and *Salix alba*.

Recreation and culture

Wetlands provide opportunities like walking, cycling, bird watching, swimming, nature photography, but also hunting and angling. (Communication from the Commission to the council and the European Parliament, 1995). As some large wetlands are administrated by National Park Managements, nature conservation plays an important role beside the above mentioned recreational opportunities. Therefore education is very important and many National Parks offer learning opportunities for children and adults, which are aimed at the protection of these ecosystems and living organisms. The Nationalpark Donauauen, for instance, received an award from the UNESCO called "United Nations Decade of Education for Sustainable Development (2005-2014, DESD)" in December 2007 (Nationalpark Donauauen, 2008) for integrating the question of sustainable development into educational efforts.

1.3. Wetlands threatened by human activities

In the USA, more than 50 % of the wetlands were lost during the last centuries (Leschine et al., 1997), while other areas were even more affected by the excessive water withdrawals, dams, and industrial development: the Mesopotamian marshes decreased from 15,000 – 20,000 km^2 in the 1950's to about 400 km^2, while the water volume in the Aral Sea basin decreased by 75 % since 1960s (Millennium Ecosystem Assessment, 2005).

As wetlands are threatened worldwide, the riverine wetlands along the Danube River Basin are also impacted. The WWF (1999) stated that about 80 % of the original floodplain areas within the Danube River Basin are lost today. Though the river ecosystems adapt to the existing pressures, the new challenges raised by the climate change and the increasing navigation pressure is pushing many species above their survival limits, threatening their existence.

But also a shift of climatic conditions can have an effect on riverine wetlands. As a consequence of climate change, a shift of precipitation regime occurred in Europe: an increase by 10 to 40 % in northern areas, seasonal shifts in Central Europe, and a decrease of up to 20 % in the southern part (DEFRA, 2005; IPCC, 2007). Reduced precipitation in the southern part lead to a decreasing trend of Danube discharge in the last decades (Michaylova, 2004), which affected the water table in wetlands along the Lower Danube River (Sandu et al., 2008).

In the following, two examples for human impacts – constructional measures and agriculture/industry – will be described in detail.

<u>Constructional measures</u>

Within rivers lateral dams for flood defence (Communication from the Commission to the council and the European Parliament, 1995), dams and weirs for hydropower generation, and navigation have negative effects like drying-out of adjacent wetland areas or changes in the typical set of species (Lazowski, 1997) on the riparian ecosystems. These impacts can cause flow rate reductions, changes in the natural sediment transportation, and reduced migration of animals, in particular fishes (ICPDR, 2008).

Reservoirs, which are used for example for hydroelectric power generation or flood control, and lateral dikes, which protect the adjacent land against flooding, both interrupt the lateral connectivity of the main river with the wetlands and also reduce the retention volumes and the exchange of matter to short periods of high floods (Tockner et al., 1999). Larger reservoirs can also have an effect, because of an unnatural flood regime downstream of the dam (Ward, 1998; Batzer, 2006).

Figure 2 shows free flowing, strongly regulated, and impounded stretches of the Danube River due to major dams and weirs (ICPDR, 2005). The two large dams impounding the Danube River are the Gabcikovo dam downstream of Bratislava, built in 1992 and the Iron Gate Dams on the Romanian-Serbian border, which were built in 1970. The hydropower plant Gabcikovo uses 80 to 90 percent of the water flow, whereas the original river channel receives only ten to 20 percent of the total water flow. This impact leads to desiccation and drawdown of water table in the pristine river stretch. Problems concerning Iron Gates I and II are downstream erosion and sediment trapping, but also nutrient sink and pollutant deposition (ICPDR, 2008). Kalchev et al. (2008) also described alterations in the Lower Danube (Bulgarian-Romanian stretch) due to dam, weir, and dyke building, which resulted in the above mentioned irreversible loss of wetlands.

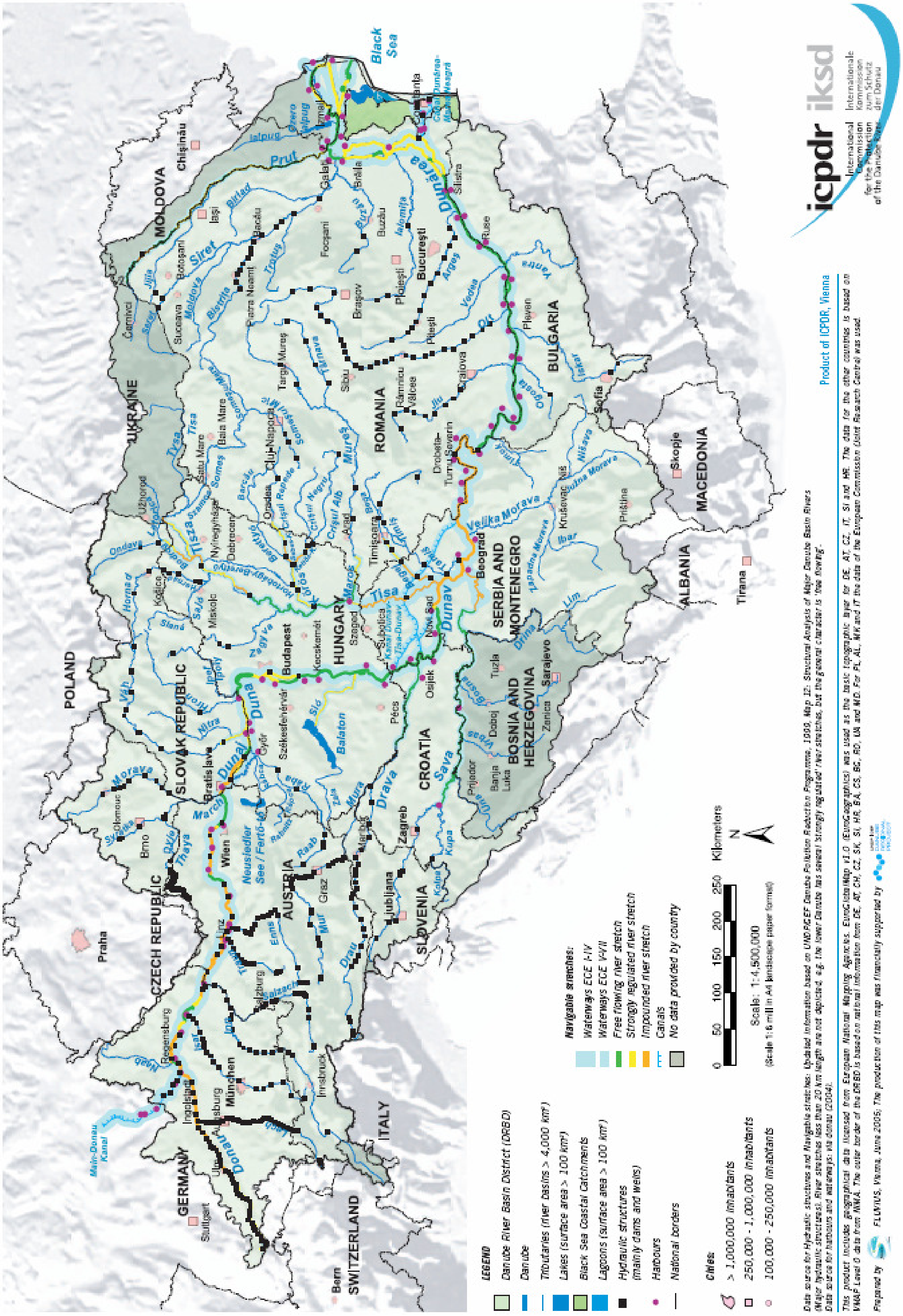


Figure 2: The Danube River Basin and the major hydraulic structures within the Danube River (ICPDR, 2005).

Agriculture and industry in the Danube River Basin

Eutrophication is the result of excessive nutrient input, particularly nitrogen and phosphorus, and subsequent increased primary production in an ecosystem (ICPDR, 2008). A lack of wetlands, which are buffer zones of riparian ecosystems, can lead to eutrophication of rivers and estuaries due to an increased input from agricultural activities (Verhoeven, 2006).

Agricultural activities can also cause other environmental problems. Large wetland areas are drained because of the transformation to farmlands. Other problems are water consumption through irrigation (ICPDR, 2008; Communication from the Commission to the council and the European Parliament, 1995). Irrigation of farmland causes the largest portion of water consumption by humans. The industry, in contrast, is the biggest water user within the Danube River Basin. Water consumption implies that the quantity of the water is reduced by evaporation. Water use means that the quantity of the water remains constant (ICPDR, 2008). Schemel et al. (2004) also found this impact on the Sacramento River, California, U.S.A., where water for both, water consumption for agricultural purposes and water use for cities, is taken from the river.

Increases of nitrogen and phosphorus within the Danube River Basin since the 18th century caused eutrophication of rivers and estuaries (Hein, 2005; Communication from the Commission to the council and the European Parliament, 1995). Verhoeven (2006) mentioned an increase of nutrient loads by a factor of 10 to 20 from 1960 to 1990 within European rivers due to changes in land use. Therefore, wetlands are important to improve water quality in riverine systems, because nutrients like nitrogen and phosphorus are accumulated in the vegetation of riparian wetlands and are transformed by microbial communities (Verhoeven, 2006; Gereta, 2004). For the recent past Kalchev et al. (2008) could show a decrease of nitrogen and phosphorus since 1995 in the Lower Danube River because of a decrease in agricultural activity in the lower Danube countries.

Because of this series of influences, wetlands are the "most threatened habitat type in all European Union countries" (Communication from the Commission to the council and the European Parliament, 1995; Tockner & Stanford, 2002). This is due to changes in land use, which lead to deterioration. This again can impact the above-mentioned ecosystem services, which are provided by riverine wetlands, but also the existence of riverine wetlands themselves. These impacts lead to a need for improvement and restoration of riverine wetlands.

1.4. The hypothesis of this work

Most wetlands within the Danube River Basin are highly impacted by human activities, for instance due to flood defence measures and land use change. This results in an altered connectivity of the wetlands to the main channel. Less impacted wetlands are expected to perform higher ecosystem functions and services concerning water purification and therefore, might improve the water quality of the river to a higher degree. The higher the hydrological connectivity between wetland and river channel, the higher is the extent of nutrient retention within the riverine wetland.

Hypothesis

The extent of hydrological connectivity impact the water quality status and related ecosystem services (such as nutrient reduction) of riverine wetlands. High nutrient concentrations can be measured during higher discharges. Therefore, higher nutrient loads are expected in higher connected wetlands (side channel type) compared to more isolated ones (shallow lake type). The difference between connected and disconnected phases is expected to be higher in more dynamic wetlands (side channel type), thus, indicating a higher uptake capacity in these wetlands compared to shallow lake type ones.

To verify this hypothesis the objectives of this work are to estimate the status of the mean hydrological connectivity to the main channel of the Danube River, to collect water quality data and to show the effects of connectivity on the nutrient status of different Danube River wetlands, varying by the extent of water management and intensity of utilization and restoration. Based on load calculations at two Austrian wetlands the ecosystem service concerning nutrient reduction will be estimated and compared with each other.

2. Material and methods

2.1. The Danube River Basin

The Danube River Basin is the second largest in Europe with a total area of 801,463 km^2. 19 countries with 83 million people share the Danube River Basin. Along the length of 2,857 km, the Danube River can be distinguished in an Upper, Middle, and a Lower reach (Literáthy, 2002). The Upper Basin reaches from the source in Germany to Bratislava in Slovakia ("Porta Hungarica"), the Middle Basin from Bratislava to the Iron Gate gorge at the Serbian-Romanian boundary, and the Lower Basin from the Iron Gates to the Danube Delta in Romania, which is the second largest delta in Europe with an catchment area of 4,560 km^2 (ICPDR, 2008; Sommerwerk et al., 2009). The average annual discharge of the Upper Danube is about 801 km^3, of the Middle Danube 3,992 km^3, and of the Lower Danube 5,948 km^3 (measured with subcatchments) (Sommerwerk et al., 2009).

As the Danube River Basin encompasses 19 European countries, navigation has an economic importance for some of them. Due to canalization, mainly in former days, 87 % of the Danube River is navigable today, from the city of Ulm in Germany to the Danube Delta in Romania. Because of improving efforts to the international waterway, some projects will threaten the Danube River. The Danube–Odra–Elbe Canal is one example, which would improve the navigation between western and eastern Europe, but therefore would have an impact on 46,000 hectars of protected areas within the Danube River Basin. Another project is the EU-project "Corridor VII" of the Trans-European Networks for Transport (TEN-T), which aim is the removal of bottleneck stretches within the Danube River. One example of a bottleneck is the free-flowing stretch to the east of Vienna, which is part of the last major wetland within Central Europe called Donau-Auen National Park (Sommerwerk et al., 2009).

<u>Water quality status of the Danube River</u>

The concentrations of ammonium are on the limit of quantitation, with exception for a small increase in the Iron Gate reservoir. Some tributaries showed higher concentrations. An example is the mouth of the Arges River with a concentration of ammonium of 7.2 mgl^{-1} caused by untreated municipal wastewater from the sewage system of Bucharest (Liška et al., 2008). Nitrites concentrations decreased in the Upper Danube, and showed a peak in the Iron Gate reservoir. The nitrates concentrations were maximum upstream of the confluence of the Inn River in Austria, but then decreased to a constant level. The orthophosphate concentrations decreased significantly downstream of the confluence of the Inn River in Austria. In the Middle Danube the concentrations showed a small increase, which was followed by a decrease until minimum concentrations at the confluence of the Tisa River. The Lower Danube showed slightly increased orthophosphate concentrations due to municipal wastewater discharges with P-containing detergents.

A chronological comparison with the Joint Danube Survey 1, which was undertaken from August to September 2001, showed that ammonium and nitrates were nearly similar for both surveys. The nitrate concentrations were higher than 2001, with exception of downstream of the Jantra at rkm 532. The concentrations of orthophosphate were lower than during Joint Danube Survey 1, except a few sampling sites in the Middle Danube.

The assessment of the water quality in the Danube River followed three different approaches. The Austrian classification scheme classified all sample sites in the Danube River in the ecological classes "high" or "good", after the Czech classification scheme six sampling sites did not obtain the ecological class "good". The classification after the Trans-National Monitoring Network (TNMN) of the International Commission for the Protection of the Danube River (ICPDR) classified all sampling sites in Class I (reference) or Class II (target value) (Liška et al., 2008).

Danube River study sites

For the comparison of water chemistry parameters of individual wetlands with the Danube River, chemistry data near inflow area Greifenstein (GUS), at gauge Orth (LOB, REG), and at gauge Silistra (SRL) have been used. Two sampling points were not situated in the Danube River: dam 4 within the Gießgang (GLS), and Hulovo Channel (LSA) (Figure 3).

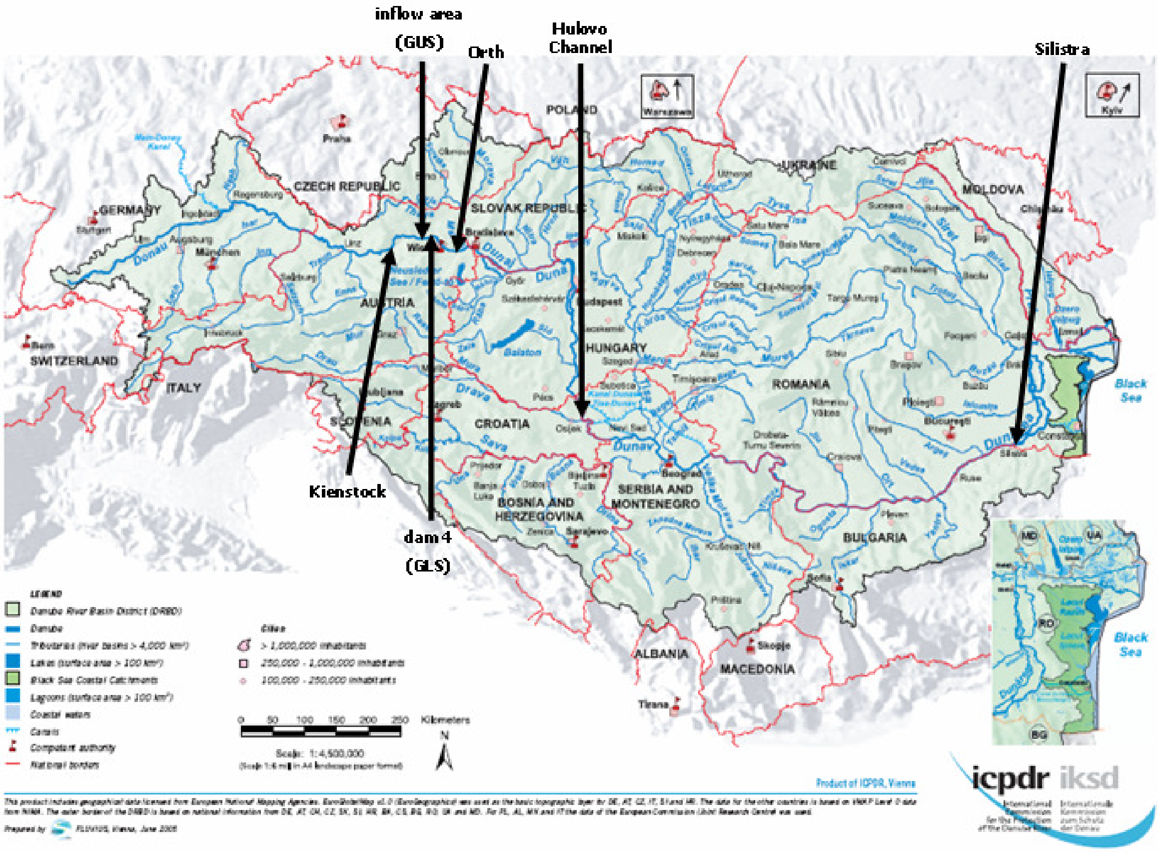


Figure 3: Sampling sites used for comparison with the individual wetlands regarding water chemistry data:
sampling site inflow area (GUS) compared with dam 8 at GUS, dam 4 (GLS) with dam 1 (GLS), Orth with LOB and REG, Hulovo Channel with LSA, Silistra with SRL. Danube River discharge data from the gauge station Kienstock was used for load calculation (see chapter 2.5.).
(GUS = Greifenstein upper stretch, GLS = Greifenstein lower stretch, LOB = Lower Lobau, REG = Regelsbrunn, LSA = Lake Sakadas, SRL = Srebarna Lake)

2.2. Description of the selected wetlands

2.2.1. Map of the selected study sites

Figure 4 shows the selected study sites within the Danube River Basin. More detailed descriptions can be found in the following chapters.

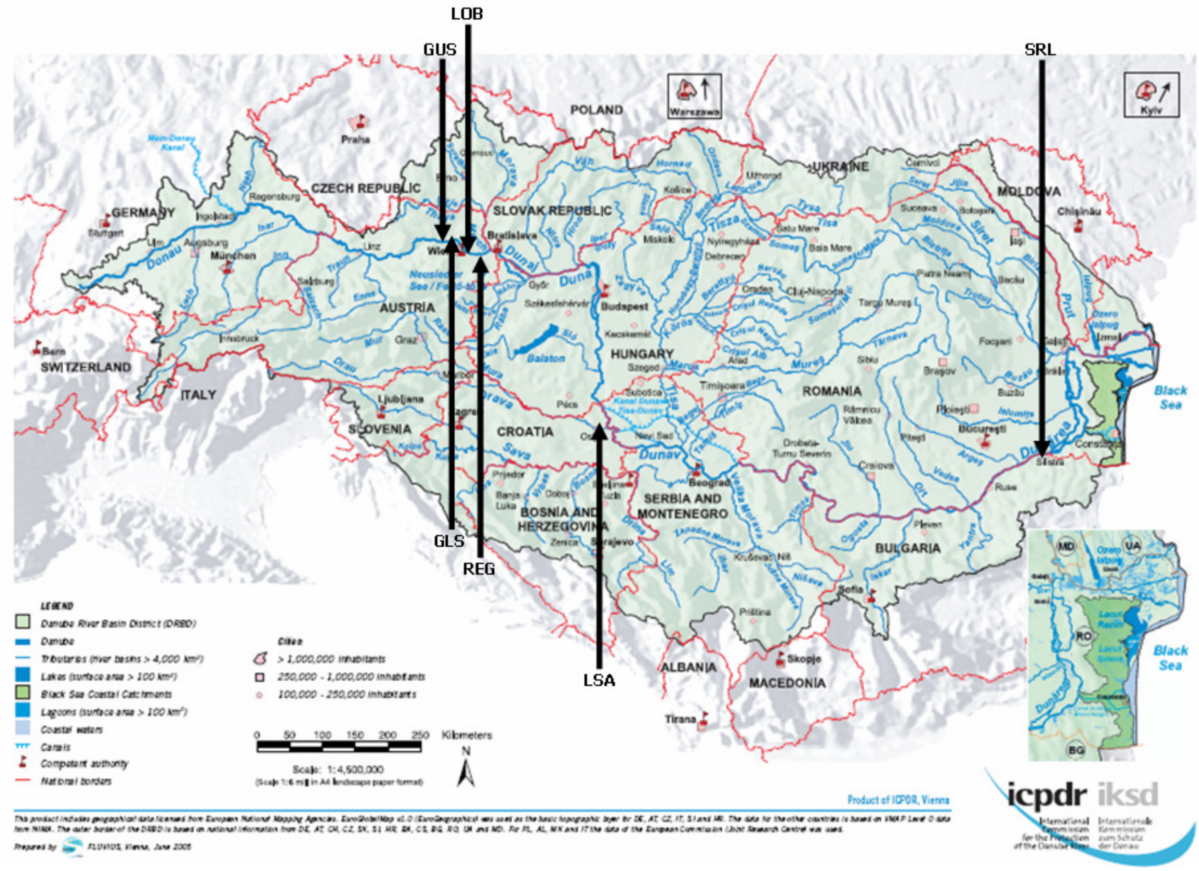


Figure 4: Overview of the selected study sites.
(GUS = Greifenstein upper stretch, GLS = Greifenstein lower stretch, LOB = Lower Lobau, REG = Regelsbrunn, LSA = Lake Sakadas, SRL = Srebarna Lake)

2.2.2. Austrian study sites

The Danube River Basin is draining over 96 percent of Austria's territory (ICPDR, 2008). The selected case study areas are situated upstream and downstream of Vienna (Figure 5).

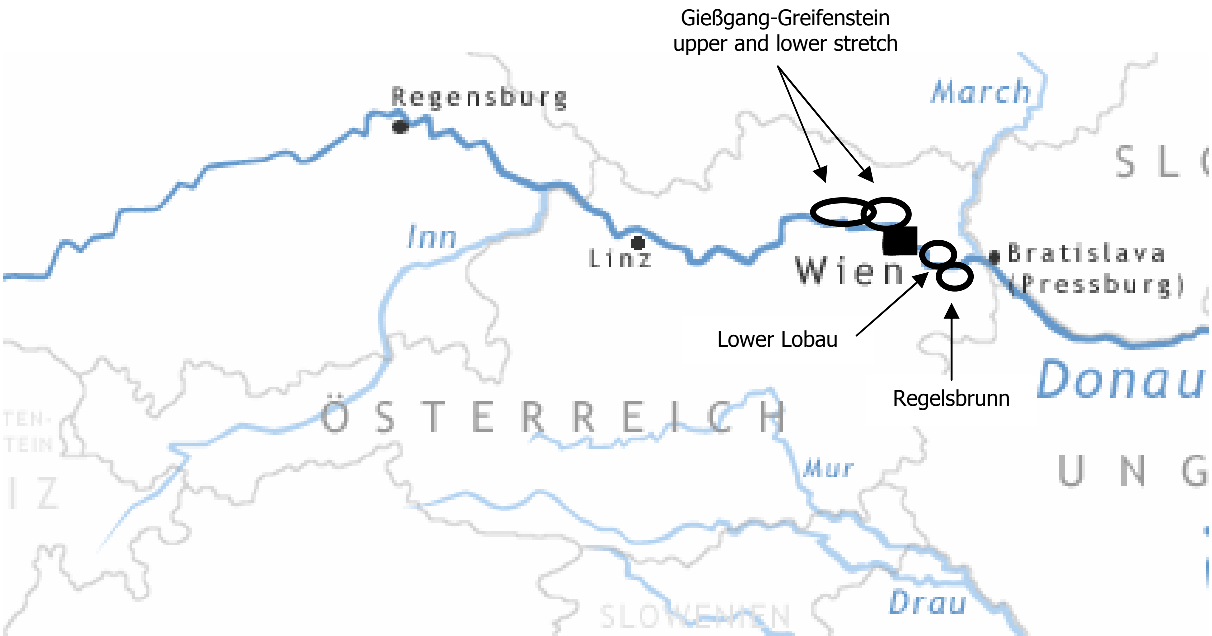


Figure 5: Selected Austrian wetlands.

<u>Riverine wetlands at Greifenstein</u>

The Tullnerfelder Donau-Aue upstream of Vienna has a total area of 560 km^2. The wetland we focussed on, called "Gießgang-Greifenstein" (rkm 1,943), is situated on the left shore between two hydroelectric power plants Altenwörth and Greifenstein and is connected to the Danube River through an artificial channel system called "Gießgang" (Figure 7). The groundwater level between the Danube River and the Gießgang varies up to 2 m, at the Gießgang it varies up to 0.5 m. Landside groundwater run in the area from the northwest. A special inflow area called "Einlaufbauwerk 8" is closed by man from October to first week in December to lower down the groundwater levels in autumn. Therefore the change of groundwater level is maximized to simulate the natural regime of the Danube River.

The geographical coordinates of the area are 48°20' north latitude and 16°19' east longitude. The Gießgang is a connection of artificial and natural water channels with a length of 42 km, a slope of 16 m, and 25 dams with culverts. There is a minimal inflow of water (up to a Danube River discharge of 3,100 m^3s^{-1}) of 1-1.5 m^3s^{-1} from the side-arm system Altenwörth, an additional surface water contribution of 1.5 m^3s^{-1} from tributaries (Göllersbach, Schmida), and an inflow of seepage water in the range of 2-2.5 m^3s^{-1} from the Danube River. Additionally to these inflows, surface water from the Danube River can enter the wetland area via inflow areas called "Flutmulde" at higher flows on average 23 days per year (up to 80 days) in the years 1983/84 to 1996/97, with an average discharge of 38.4 m^3s^{-1} (Janauer et al., 1999). Figure 6 figures the inflow area at rkm 1,976.25 to 1,976.50. Between a Danube discharge of 3,100 m^3s^{-1} and 4,300 m^3s^{-1} water enters the area via a 30 m long part of the inflow area with an inflow volume up to 10 m^3s^{-1}. From 4,300 m^3s^{-1} to 6,000 m^3s^{-1} up to 60 m^3s^{-1} of Danube water enters the Gießgang system. If the Danube discharge increases 6,000 m^3s^{-1} up to a few hundred m^3s^{-1} flow into the area. An inflow of river water via the downstream overflow area occur at Danube water discharges over 5,200 m^3s^{-1} (Wassermann, 1999).

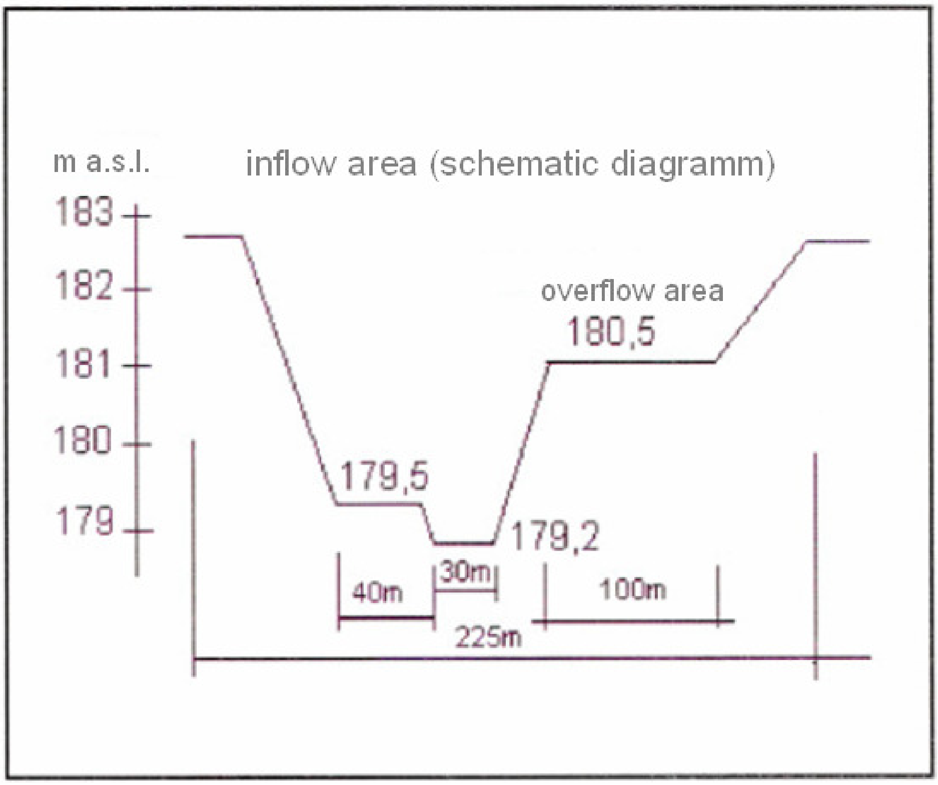


Figure 6: Schematic diagramm of the inflow area at rkm 1,976.25 to 1,976.50. (after Wassermann, 1999)

The river water flows from the upstream to the downstream end of this system. The area shelter nearly 550 vascular plant species, nearly 50 mammalian species, more than 100 breeding bird species, seven reptilian species, 14 amphibian species, and about 50 fish species (Janauer et al., 1999; Kummer et al., 1999; Trauttmansdorff, 1999).

For water chemistry analysis the Gießgang was divided into two segments (Figure 7), called "Gießgang-Greifenstein upper stretch" (GUS) (from the inflow area to dam 8, sampling points in the Danube River near the inflow area and at dam 8) and "Gießgang-Greifenstein lower stretch" (GLS) (from dam 4 to dam 1, sampling points at dam 4 and dam 1), because of clearly distinguishable different water chemistry of these two stretches due to the inflow of the tributary Schmida. This indicates that adjacent land use affects the wetland. Other pressures were due to a road construction in the north, where parts of the wetland were severed and converted to farmland, or increasing density of people, which interrupted some animals. Due to the construction of the power plant Greifenstein, the wetland was severed from the Danube River, but also the fish migration was impeded (Wassermann, 1999). Therefore the Gießgang was very important to connect the wetland to the main river.

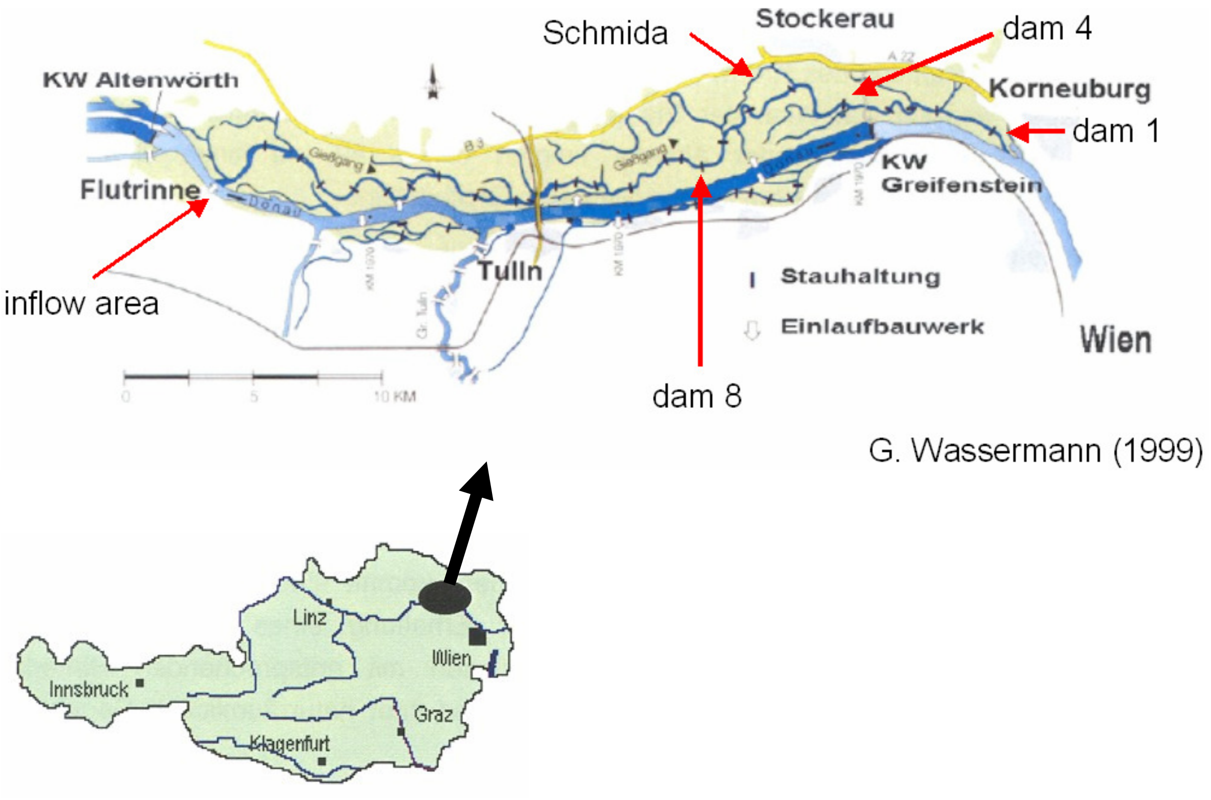


Figure 7: Study sites Gießgang-Greifenstein.

The Donau-Auen National Park downstream of Vienna (http://www.donauauen.at/), which was founded in 1996, covers a total area of 93 km^2. This freely flooded riparian ecosystem is the last major wetland within Central Europe with more than 800 vascular plant species, more than 30 mammalian species, about 100 breeding bird species, 8 reptilian species, 13 amphibian species, and about 60 fish species. Within the National Park we focus on two case studies called Lobau and Regelsbrunn.

Lobau

The Lobau (rkm 1,907) (Figure 8) is a wetland in Vienna on the left shore of the DR with an extension of 2,088 ha. Its geographical coordinates are 48°07’ north latitude and 16°39’ east longitude. The Lobau is nearly isolated from the Danube River.

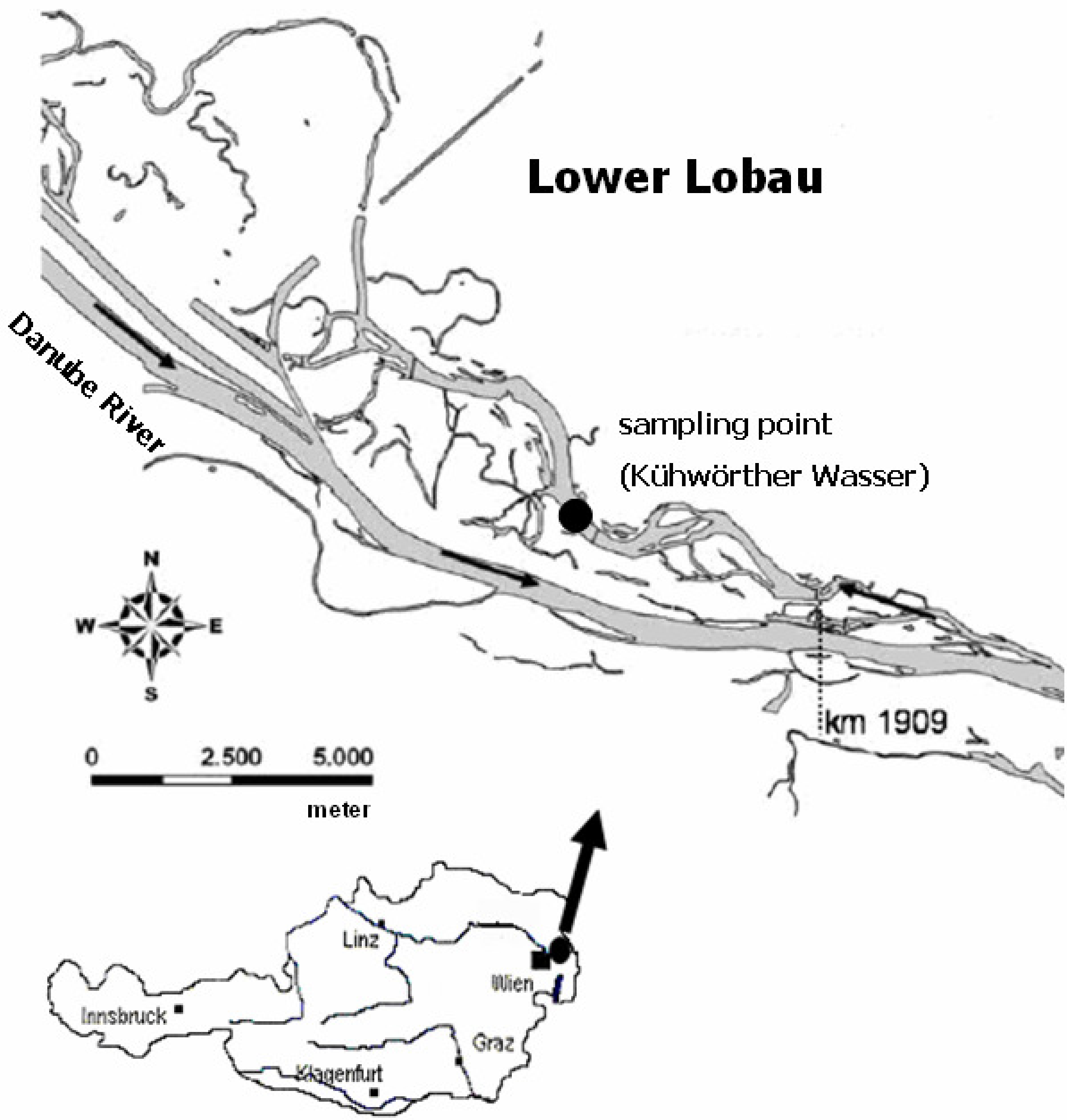


Figure 8: Study site Lower Lobau. grey: water area, water chemistry data for sampling point Kühwörther Wasser (after Leichtfried, 2008).

Due to its vicinity to Vienna, there is an intense utilization of this area (e.g. flood protection, removal of drinking water, recreation). Erosive floods, geomorphologic dynamic, duration of connectivity, and groundwater level are reduced because of these human activities. This can lead to aggradation and loss of aquatic habitats (Weigelhofer et al., 2007). As it was very important that this ecosystem persist, it has been managed since years. About 50 ls^{-1} of surface water enters the Upper Lobau through a water enhancement scheme and occasionally reach the Lower Lobau. The Lower Lobau itself is downstream connected to the main channel via the Schönauer Schlitz and filled during flooding. The downstream opening is connected above mean water level (Bondar, 2007). Thus, the hydrology of this system can be compared with a shallow floodplain lake system. The inflow area at the downstream end of the wetland also acts as the outflow area during decreasing water levels, thus draining of the wetland water.

The sampling station in the Lower Lobau (LOB) was located in the "Kühwörther Wasser" (48 08 40 N 16 24 30 E), which was connected to the Danube River for nearly 40 days per year in average until the mid of the year 2001. After a new weir construction and adapted weir management the backwater section was connected for more than 100 days per year on average (Hein et al., 2006).

Regelsbrunn

Regelsbrunn (REG) (rkm 1,896) (Figure 9) is a wetland on the right shore between rkm 1,895.5 and rkm 1,905. Its geographical coordinates are 48°07′ north latitude and 16°47′ east longitude. It is a re-connected side-arm with an area of about 500 ha, of which are 411 ha within the National Park. The lateral connectivity was enhanced by lowering the riverside embankments at the upstream parts and by increasing flow capacities between backwater sections through culverts to more than 180 days per year (Schiemer, Reckendorfer & Hein, 2004). Due to these restoration activities the Regelsbrunn area is connected at water levels 0.5 m below mean water. At low water level 0.1 % of the discharge of the Danube River enters the area (seepage, groundwater), 0.8 % of the river discharge enters the area at mean water level and 12 % at high water level at a main river discharge of 5,000 m^3s^{-1} (Schiemer et al., 2000). As the figure shows, there is agriculturally used land and settlements nearby the wetland (Figure 9). The sampling site of the water chemistry data is called "Regelsbrunner Traverse" and situated at the downstream end of the wetland.

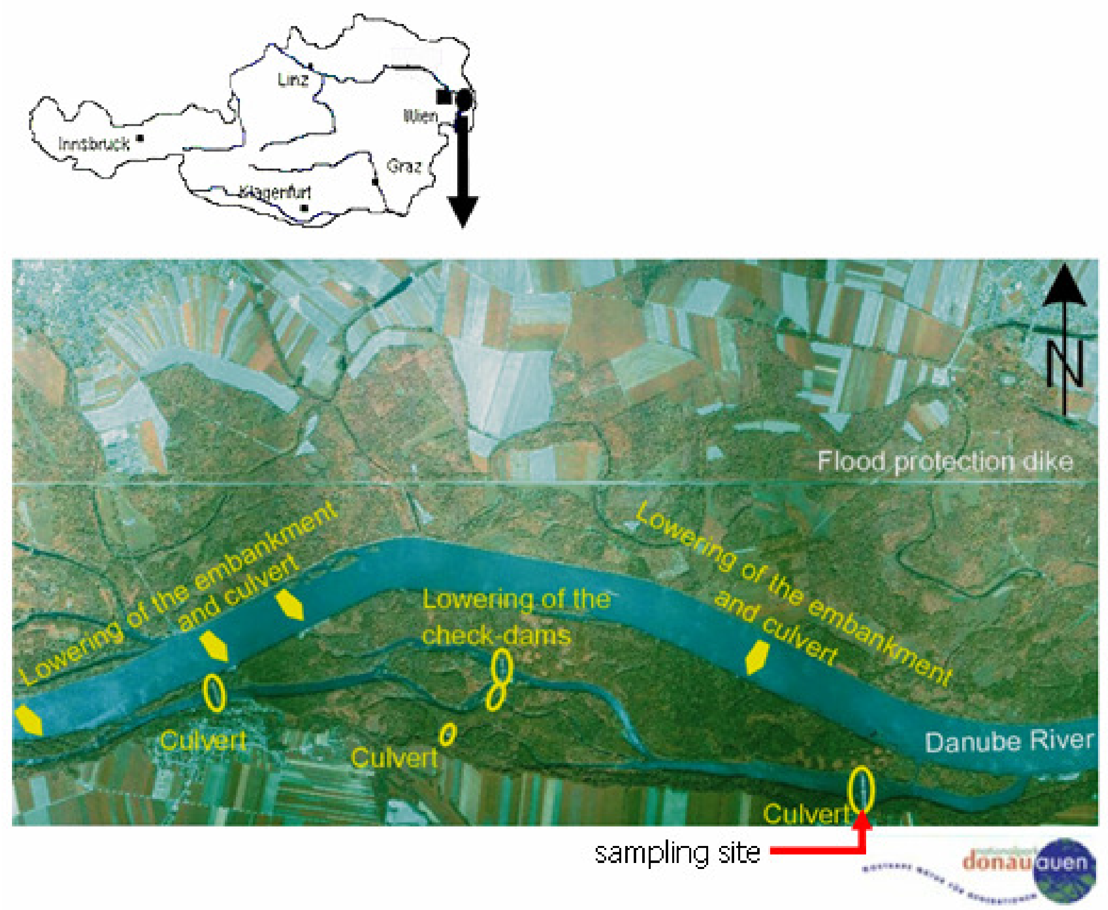


Figure 9: Study site Regelsbrunn - Restoration scheme in the Regelsbrunn area between rkm 1896 and 1905. The sampling site "Regelsbrunner Traverse" is situated at the downstream end of the wetland. (Donau-Auen National Park, http://www.donauauen.at/)

For the above mentioned Austrian wetlands different investigations were carried out. The following list shows some published reports:

- Integrated research after 10 years of the implementation of the artifical side-channel at Greifenstein (Trauttmansdorff, 1999; Wassermann, 1999)
- Water enhancement scheme Lobau (Hein et al., 2004 & 2006)
- The Danube Restauration Programme at Regelsbrunn (Schiemer & Reckendorfer, 2000 & 2004)
- Integrated River Engineering Project (Reckendorfer et al., 2005)

2.2.3. Croatian study site – Lake Sakadaš

The investigated Lake Sakadaš (LSA) (Figure 10) is a part of a natural floodplain along the River Danube (rkm 1,383 – 1,410) belonging to the Kopački Rit Nature Park (Croatia). Its geographical coordinates are 45°36′ north latitude and 18°48′ east longitude. The inundation area is clearly delineated by embankments constructed in the middle of the last century and covers approximately 16 km^2. Another pressure on the ecosystem is the land use of adjacent agricultural areas. The National Park is also a place for recreation with walking trails, bicycle trails, boat tours, and fishing areas. Due to the hydrological connectivity with the main river channel it can be divided into two subsystems (Figure 10). The subsystem A is impounded by the river through the backwater system (side arm), and subsystem B through a network of perennial channel networks. Within the different types of water bodies in the subsystem B the deepest lake is Lake Sakadaš, which has an average depth of about 5 m (4 – 7 m) at mean water levels, with a surface water area of about 0.15 km^2. Flooding of the lake begins when the Danube water level at gauge station near Apatin (rkm 1401) rises above 3 m (Mihaljević et al., 1999). Flooding occurs usually in spring and early summer (potamophase), while during low water conditions (limnophase), the lake is an isolated water subsystem in the floodplain. As the lake shows a high trophic level, it is diluted by water inflow of the Danube River during floods.

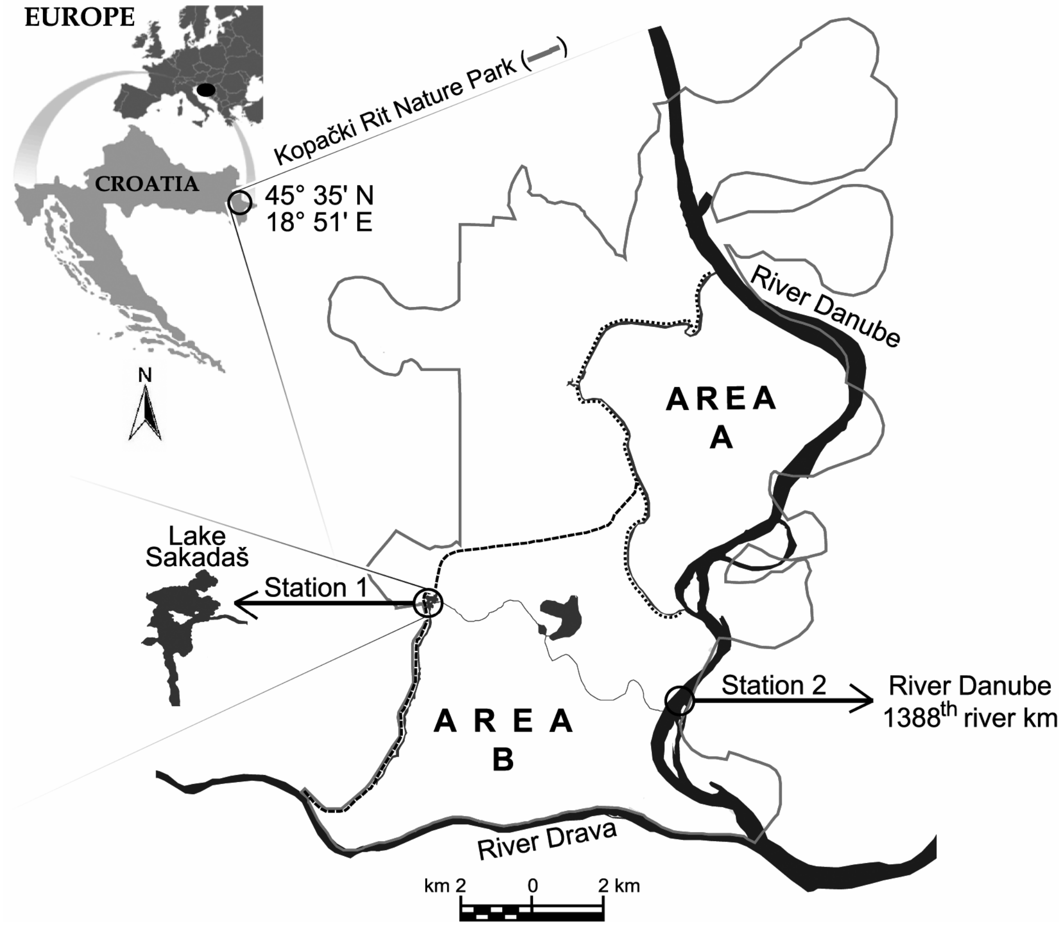


Figure 10: Study site – Lake Sakadaš, a part of the Danubian floodplain area of the Kopački Rit Nature Park.

The Kopački Rit Nature Park gives shelter to 425 vascular plant species, 746 algae species, 55 mammalian species, nearly 290 bird species, 10 reptilian species, 11 amphibian species, and 44 fish species.

2.2.4. Bulgarian study site – Srebarna Lake

The Srebarna Lake (SRL) (Figure 11) is situated on the right bank of the Danube River between river kilometers 391 and 393. Its geographical coordinates are 44°07′ north latitude and 27°04′ east longitude (Hiebaum et al., 2000). The lake's altitude is about 10 m a.s.l., the water surface 0.7 km^2 and the mean depth is 2.1 m (0.5 – 4.8 m).

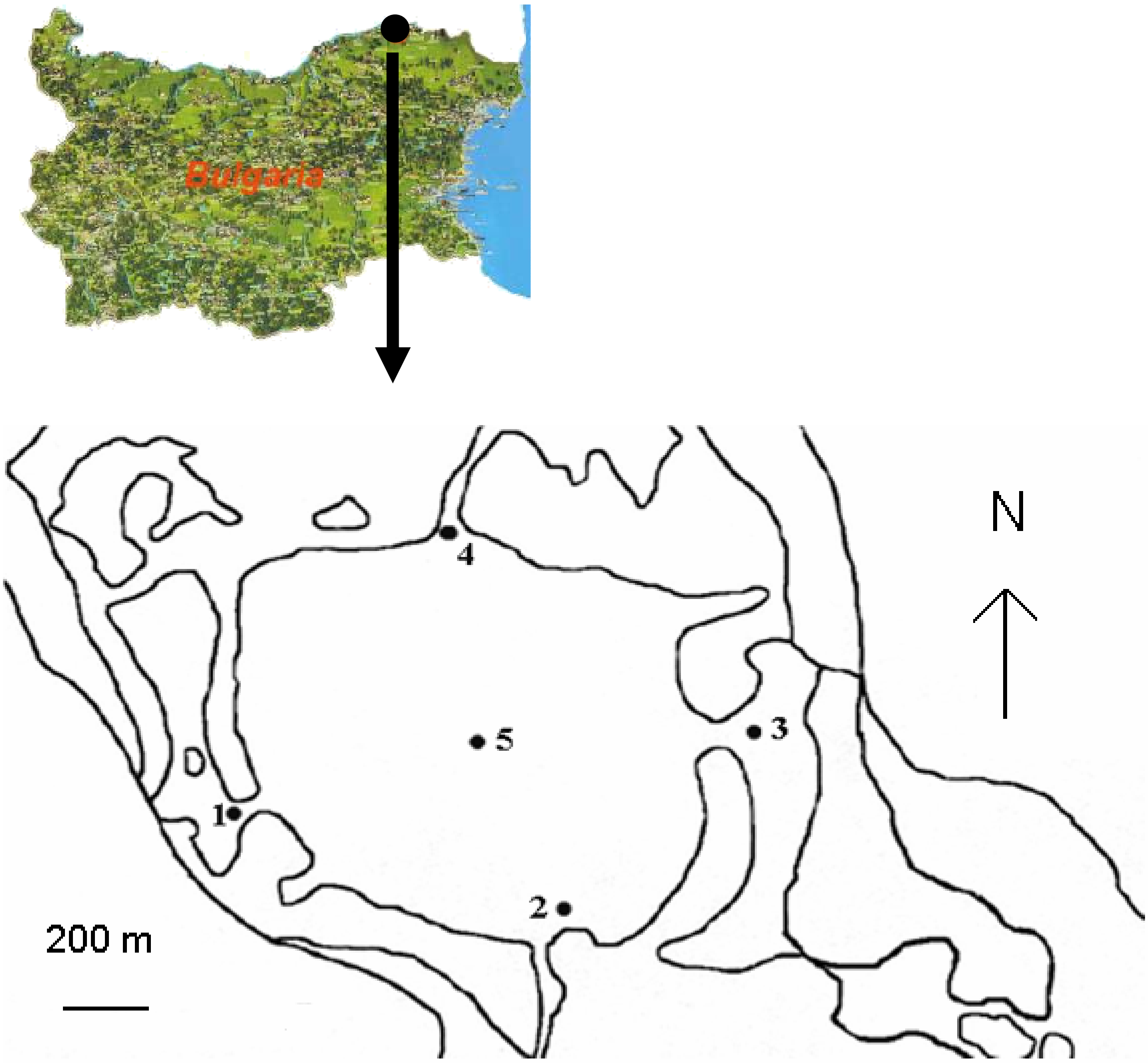


Figure 11: Position and scheme of Srebarna Lake with sampling site locations; The Danube River is situated in the north in about one km distance from the lake shore.

The Srebarna Lake is a reserve according to national and international law (Ramsar site). The free aquatic area is surrounded by an extended area densely overgrown by reeds and other emerged macrophytes. In 1949 the wetland was completely isolated by dyke from the Danube River. The lack of floods led to accumulation of sediments in the lake. Since 1994 the connectivity of Srebarna Lake with the Danube River was restored but ecological status has improved slowly as shown by more or less regularly monitoring activities since 1998. Inflow of water from the Danube River and outflow of water from the lake is realized by a single channel, which is operated by man. This channel serves as in- and outflow connection to the main channel simultaneously and does not provide any opportunity for flow through effects even at high river water levels. The connectivity is operated by man in a way aimed to achieve maximum retention of high water level in the lake. As a rule, the two sluices are opened at high river levels remaining open for an arbitrary time interval to raise the water level of the lake. As a result the connectivity pattern between lake and river is functioning in a quite different manner. This kind of operation allows sustaining of considerably higher lake water level than before the reconnection but the short time of sluice opening and lack of flushing effect do not allow sufficient fish invasion and removal of year long accumulated silt. Main pressures are the constructional measures and the input of nutrients due to adjacent land use.

The monitoring activities of Srebarna Lake Reserve started since its reconnection include comprehensive studies of aquatic chemistry, bacterio-, phyto- and zooplankton, macrozoobenthos, fishes, water fowls as well as of terrestrial flora and fauna from lake surroundings. The Srebarna Lake Reserve gives habitat to more than 50 mammalian species, over 170 bird species, 12 amphibian species, and 24 fish species.

2.3. Categorization of the selected wetlands towards hydrology and connectivity

The selected wetlands were ranked due to hydrology and morphology because of information from the literature used. The literature supplied approximations of the average connectivity in days per year for the selected wetlands (information of height levels of inflow areas and hydrological data), and information regarding the morphology ("lake-type systems" versus "side-channel system"). As connectivity changed due to wetland restoration, the adequate duration of connectivity regarding to the available chemistry data has been taken for the categorization scheme.

For the study sites the following publications have been used to get this information:

- Integrated research after 10 years of the implementation of the artifical side-channel at Greifenstein (Janauer et al., 1999; Donabaum, 1999)
- Water enhancement scheme Lobau (Hein et al., 2004 & 2006)
- The Danube Restauration Programme at Regelsbrunn (Schiemer & Reckendorfer, 2000 & 2004)
- Mihaljevic et al., 2008
- Vasilev et al., 2008

2.4. Water chemistry data collection

Data of the following parameters have been measured and analysed for all wetland stations: conductivity, dissolved oxygen, chlorophyll a, ammonium, total nitrogen, and orthophosphate. Table 1 shows the chemical parameters used for the statistical analysis of all sites plus the parameter nitrate and total phosphorus, which were used for load calculation in GUS (see chapter 2.5.).

Table 1: Chemical parameter.

Parameter	Indicator	Unit
conductivity	Cond.	µS cm^{-1}
dissolved oxygen	O_2	mg l^{-1}
chlorophyll a	Chl a	µg l^{-1}
ammonium	NH_4-N	mg l^{-1}
nitrate	NO_3-N	mg l^{-1}
total nitrogen	N_{tot}	mg l^{-1}
orthophosphate	PO_4-P	mg l^{-1}
total phosphorus	P_{tot}	mg l^{-1}

In Greifenstein 19 samples from April 1996 to October 1997 (Donabaum, 1999) were used (Table 2). These samples were taken at the Danube River near the inflow area and at dam 8 for the upper stretch, and dam 4 and dam 1 for the lower stretch. For the Kühwörther Wasser at the Lower Lobau and the Danube River at Orth analyses were made for at most 90 samples from April 1996 to June 2001, for Regelsbrunn (at Regelsbrunner Traverse) and the Danube River at Orth rkm 1901 at most 85 samples were used for analysis from March 1997 to November 2003 (Table 2).

For Lake Sakadas nine sampling dates were available for the period from March to November 2004, for Hulovo Channel from March to July 2004. Eight samples of Srebarna Lake and from the Danube River at Silistra from 1999 and 2000 were available for this comparison (for the sampling sites 1 to 5). The chemical parameters of the sampling point Silistra have been investigated by the Trans-National Monitoring Network (TNMN) available at http://danubis.icpdr.org/ (Table 2).

Table 2: Chemistry data of published investigations used for analysis.

Wetland station	No. of samples	Period	Frequency	Publication/ source
Greifenstein upper stretch	19	April 1996 to October 1997	monthly	Donabaum, 1999
Greifenstein lower stretch	19	April 1996 to October 1997	monthly	Donabaum, 1999
Lower Lobau	90	April 1996 to June 2001	monthly	Hein et al., 2004 & 2006, several unpublished monitoring reports
Regelsbrunn	85	March 1997 to November 2003	monthly	Schiemer & Reckendorfer, 2004, Hein et al., 2004, several unpublished monitoring reports
Lake Sakadas	9	March to November 2004	monthly	Mihaljević et al., 2008
Srebarna Lake	7	March to September 1999, November 2000	monthly	Beshkova et al., 2008, Transnational Monitoring Network

2.5. Load calculation

To calculate the load for GUS, the discharge of the Danube, the discharge into the Gießgang, the discharge from the Gießgang at dam 8 and the nutrient concentrations are needed. The Danube discharge at gauge Kienstock upstream of GUS was provided by via donau (Figure 3). The discharge via the inflow area to the Gießgang was ascertained regarding to Table 3. A linear fit described the discharge into the Gießgang within the two classes 3,100 m^3s^{-1} to 4,300 m^3s^{-1} and 4,300 m^3s^{-1} to 6,000 m^3s^{-1}. The discharge to the Gießgang for higher Danube discharges (> 6,000 m^3s^{-1}) were stated with 190 m^3s^{-1} (October 1996), 200 m^3s^{-1} (July 1997), and 175 m^3s^{-1} (also July 1997) (Wassermann et al., 1999). The discharge out of GUS at dam 8 was estimated to be 3 m^3s^{-1} (= discharge from the side-channel Altenwörth and from the Tullner Brücke considering the evaporation) for Danube discharges < 3,100 m^3s^{-1}.

Table 3: Danube discharge and discharge to Gießgang.

Danube discharge [m^3s^{-1}]	discharge into Gießgang [m^3s^{-1}]
< 3,100	3 (minimal inflow)
3,100 to 4,300	3 to 10
4,300 to 6,000	10 to 60
> 6,000	up to a few hundred

To calculate loads, which can be compared with existing calculations for REG (Bondar et al., 2007) concentrations of total phosphorus and nitrate for the years 1996 and 1997 were needed. As n = 19 for these two years, it was necessary to estimate concentrations for most of the days where no data were available. Therefore the mean of the concentrations were calculated for classes. For a Danube discharge < 3,100 m^3s^{-1} and a minimal inflow into the Gießgang n = 17, for a Danube discharge > 3,100 m^3s^{-1} n = 2. The calculated means were multiplied with daily discharges and summed up for the year 1996 and 1997, separately.

2.6. Statistical analysis

Statistical analyses were done with the statistical analysis software SPSS add version. To avoid problems with the software SPSS the number of samples were adapted by summing-up the values to one average value per month.
To prove the adequacy of the correlation matrix of the factor analysis a Kaiser-Meyer-Olkin Measure was done. The water chemical parameters, which are shown in Table 1, were analysed with a Principal Component Analysis (PCA). A Rotated Factor Matrix with Varimax-rotation was created.

With the Tamhane procedure (Post-Hoc-Test) pairwise comparisons of the different study sites were done, separately for factor 1 and factor 2.

To analyse concentrations of different parameters of individual wetlands the nonparametric Mann-Whitney U Test indicates a significant difference between two group means (isolated/connected to the main river). If the 2-tailed asymptotic significance values are < 0.05, the two groups, isolated and connected, are significantly different.

The concentrations of the wetland and the Danube River were compared. For LSA, the sampling site "Hulovo Channel", which connects the Danube River with the wetland, was compared with the wetland. The values for the wetland of the side-channel systems were taken from the downstream end of the study sites. As above mentioned, the nonparametric Mann-Whitney U Test indicates a significant difference between two group means, in our case of the differences between the isolated and connected periods for the differences wetland and Danube River. Box-Plots for selected parameter of some wetlands were used to show trends. Positive differences indicate higher concentrations in the wetland, negative differences indicate lower concentrations in the wetland.

3. Results

3.1. Danube River discharge

To get an overview of the discharge along the Danube River, Table 4 showed daily average discharges (in m^3s^{-1}), minimum and maximum values, and number of measurements for the years, of which chemistry data were available. For the Upper Danube River the daily average discharge was determined at gauge Bratislava at rkm 1,869, for the Middle Danube River at gauge Bazias at rkm 1,071, and for the Lower Danube at gauge Silistra at rkm 375 from the Trans-National Monitoring Network (TNMN) available at http://danubis.icpdr.org/.

Table 4: Discharge of the Upper, Middle, and Lower Danube for the years of investigation. Minimum and maximum values in brackets. (TNMN, http://danubis.icpdr.org/)

year	daily average discharge [m^3s^{-1}]		
	Upper Danube (Bratislava, rkm 1,869)	**Middle Danube (Bazias, rkm 1,071)**	**Lower Danube (Silistra, rkm 375)**
1996	2,015.0 (825.3 – 6,212.0) n = 366	no data	no data
1997	2,033.0 (887.5 – 7,269.0) n = 364	5,415.0 (2,454.0 – 8,800.0) n = 365	6,263.0 (2,990.0 – 10,000.0) n = 364
1998	1,970.0 (944.4 – 5,443.0) n = 364	5,489.0 (2,570.0 – 10,280.0) n = 361	6,167.0 (2,719.0 – 10,850.0) n = 361
1999	2,387.0 (1,014.0 – 5,763.0) n = 365	6,397.0 (2,850.0 – 11,100.0) n = 365	7,319.0 (3,590.0 –12,300.0) n = 365
2000	2,338.0 (1,096.0 – 4,916.0) n = 366	5,449.0 (2,496.0 – 11,950.0) n = 366	6,198.0 (2,800.0 – 12,800.0) n = 366
2001	no data	no data	no data
2002	2,683.0 (1,182.0 – 10,170.0) n = 365	5,632.0 (2,800.0 – 8,400.0) n = 365	6,100.0 (3,162.0 – 8,960.0) n = 365
2003	1,647.0 (820.4 – 4,326.0) n = 365	3,923.0 (1,500.0 – 9,200.0) n = 365	4,571.0 (1,587.0 – 9,622.0) n = 365
2004	1,852.0 (837.7 – 4,405.0) n = 366	5,469.0 (2,300.0 – 10,800.0) n = 366	6,088.0 (2,927.0 – 11,300.0) n = 366

3.2. Categorization scheme of the selected wetlands towards hydrology and connectivity

The study sites were ranked as follows: First, the case studies were distinguished as to the type of hydrological exchange with the adjacent Danube River (Table 5). The next step was to rank the systems towards the mean connectivity to the main river from low to high connected (Figure 12).

Table 5: First step of the categorization: type of hydrological exchange with the main river.

lake-type system	side-channel system
Lower Lobau	Greifenstein upper stretch
Lake Sakadas	Greifenstein lower stretch
Srebarna Lake	Regelsbrunn

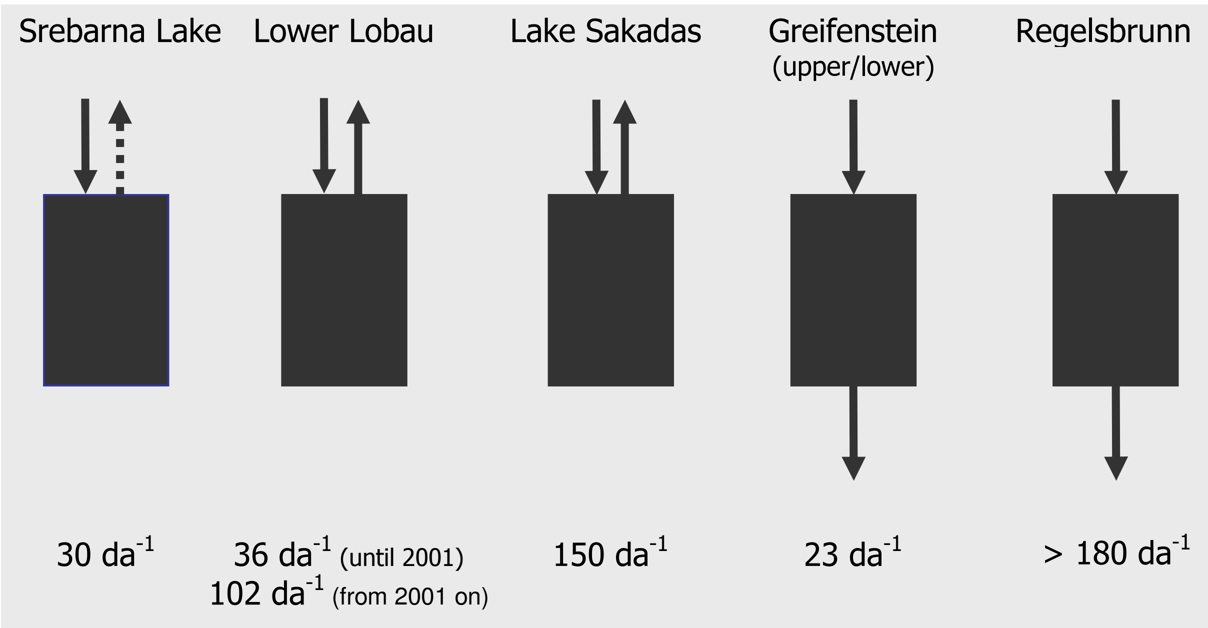


Figure 12: Scheme of hydrological connectivity and estimated average connectivity in days per year of the selected wetlands.

SRL is a system with one controlled opening to the main river. The wetland-lake was connected for about 30 days per year. The LOB is also lake-type system and was inundated at the sampling station on average 36 days per year until the year 2001 (weir altitude of 149.45 m a.s.l.). LSA is comparable to LOB, because it is lake-type system. LSA was connected to the main river for about 150 days per year. For the years 1996 and 1997 the Greifenstein study sites, GUS and GLS, were connected on average 23 days per year (from 1983/84 to 1996/97) (maximum of 80 days per year). These two sites are side-channel systems. REG was highly connected to the Danube River with more than 180 days per year. Like the Greifenstein study sites, REG is also a side-channel system.

3.3. Site comparison

Principal Component Analysis (PCA)

Table 6 shows the mean, standard deviation and the number of samplings of the parameter analysed with the Principal Component Analysis (PCA) separately for all study sites.

Table 6: Mean, standard deviation and number of samplings for each site. PO_4-P = orthophosphate, Cond.= conductivity, NH_4-N = ammonium, O_2 = dissolved oxygen, Chl a = chlorophyll a.

study site	parameter	mean	standard deviation	number of samplings n
GUS	PO_4-P (µg l^{-1})	7.26	5.47	19
	Cond. (µS cm^{-1})	437.58	80.31	19
	NH_4-N (µg l^{-1})	32.90	25.80	19
	O_2 (mg l^{-1})	9.29	2.15	19
	Chl a (µg l^{-1})	17.62	10.65	19
GLS	PO_4-P (µg l^{-1})	94.58	42.10	19
	Cond. (µS cm^{-1})	707.47	139.40	19
	NH_4-N (µg l^{-1})	149.16	94.59	19
	O_2 (mg l^{-1})	8.85	2.12	19
	Chl a (µg l^{-1})	18.58	14.27	19
LOB	PO_4-P (µg l^{-1})	2.09	2.59	27
	Cond. (µS cm^{-1})	449.79	60.83	27
	NH_4-N (µg l^{-1})	24.56	37.70	27
	O_2 (mg l^{-1})	10.70	1.83	27
	Chl a (µg l^{-1})	10.46	7.11	27
REG	PO_4-P (µg l^{-1})	10.41	9.89	30
	Cond. (µS cm^{-1})	421.40	57.47	30
	NH_4-N (µg l^{-1})	59.31	41.06	30
	O_2 (mg l^{-1})	11.72	2.26	30
	Chl a (µg l^{-1})	24.34	14.81	30
LSA	PO_4-P (µg l^{-1})	70.37	121.14	9
	Cond. (µS cm^{-1})	560.00	125.37	9
	NH_4-N (µg l^{-1})	175.08	300.93	9
	O_2 (mg l^{-1})	8.04	4.72	9
	Chl a (µg l^{-1})	69.74	56.60	9
SRL	PO_4-P (µg l^{-1})	98.88	60.46	8
	Cond. (µS cm^{-1})	478.78	51.17	8
	NH_4-N (µg l^{-1})	233.75	126.90	8
	O_2 (mg l^{-1})	10.19	3.90	8
	Chl a (µg l^{-1})	17.40	15.82	8

The Principal Component Analysis (PCA) yielded two factors with a cumulative variance of 63.481 % (Table 7). Factor 1 is the nutrient factor (orthophosphate, conductivity, ammonium), and factor 2 describes the primary production (dissolved oxygen, chlorophyll a). The result of the Kaiser-Meyer-Olkin test was 0.661 and therefore showed the suitability of the parameters for Principal Component Analysis.

Table 7: Correlation of the parameters to factor 1 and factor 2 of the Principal Component Analysis. Bold values show high correlation.

factor	**1**	**2**
Eigen value	2.070	1.104
parameter	**"nutrients"**	**"primary production"**
	41.391 %	**22.090 %**
PO_4-P	**0.837**	8.262E-02
Cond.	**0.777**	-6.66E-02
NH_4-N	**0.736**	-1.33E-03
O_2	-0.308	**0.754**
Chl a	0.358	**0.725**

The scatter plot (Figure 13) shows factor 1 (nutrients) in relation to factor 2 (primary production) for the six study sites. The three Austrian sites GUS, LOB, and REG showed comparable patterns (< 0 for factor 1, < 2.5 for factor 2), whereas the residual wetlands GLS, and SRL were more similar to each other regarding factor 1 "nutrients" (> 0 for factor 1), but differed regarding factor 2 "primary production" (wide range for factor 2). The variability of these wetlands, especially of SRL, was higher than the variability of the three Austrian sites mentioned first. LSA differed from the other wetlands and showed the highest variability.

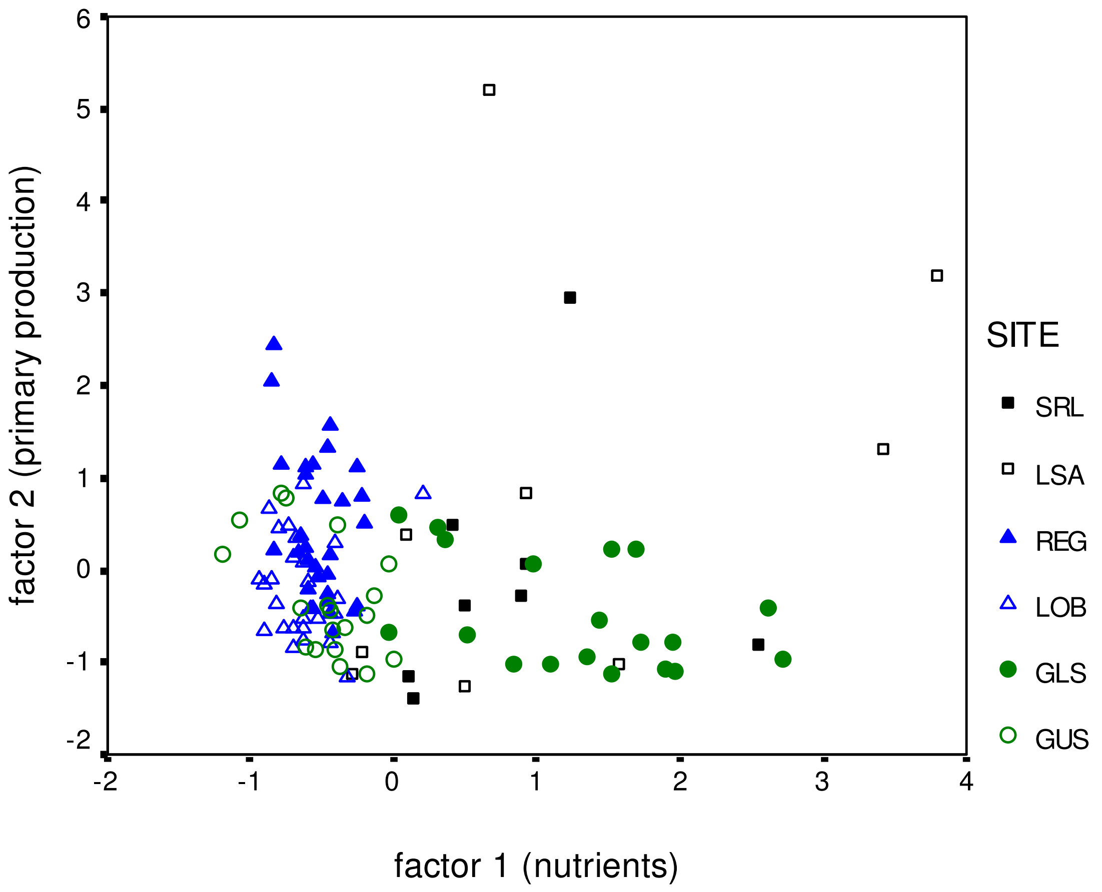


Figure 13: PCA: factor 1 (nutrients) versus factor 2 (primary production) for all sites. SRL = Srebarna Lake, LSA = Lake Sakadas, REG = Regelsbrunn, LOB = Lower Lobau, GLS = Greifenstein lower stretch, GUS = Greifenstein upper stretch.

<u>Comparison via factors</u>

With a pairwise Post-Hoc-Test a comparison of the six study sites were done, separately for factor 1 "nutrients" and factor 2 "primary production" (Table 8). For factor 1 (nutrients), GUS differed significantly from GLS, and from SRL. GLS differed significantly from the residual Austrian study sites. The LOB differed significantly from GLS, and SRL. The mean difference of LSA did not differ from any other study site. SRL differed significantly from the Austrian sites, except for GLS.

For factor 2 (primary production) REG differed significantly from the other Austrian sites and vice versa.

Table 8: Post-Hoc-Test (Tamhane): pairwise comparison of the study sites for the dependent variables factor 1 "nutrients" (a) and 2 "primary production" (b). Bold values for the significance < 0.05 indicate mean differences between two sites. Denotation: GUS (1), GLS (2), LOB (3), REG (4), LSA (5), SRL (6).

a) factor 1 "nutrients"

(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95 % Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	**-1.7654961***	.1953905	.000	-2.4116341	-1.1193580
	3.00	.1570235	.1803373	.712	-.1175400	.4315870
	4.00	4.366186E-02	.1765736	1.000	-.2165293	.3038530
	5.00	-1.6355945	.2436948	.159	-3.6864495	.4152605
	6.00	**-1.3152277***	.2538197	.029	-2.5102001	-.1202553
2.00	1.00	**1.7654961***	.1953905	.000	1.1193580	2.4116341
	3.00	**1.9225196***	.1803373	.000	1.2927483	2.5522908
	4.00	**1.8091579***	.1765736	.000	1.1837768	2.4345391
	5.00	.1299015	.2436948	1.000	-1.8966635	2.1564666
	6.00	.4502683	.2538197	.967	-.7442985	1.6448352
3.00	1.00	-.1570235	.1803373	.712	-.4315870	.1175400
	2.00	**-1.9225196***	.1803373	.000	-2.5522908	-1.2927483
	4.00	-.1133616	.1597571	.528	-.2861282	5.940496E-02
	5.00	-1.7926180	.2317999	.103	-3.8494361	.2642001
	6.00	**-1.4722512***	.2424222	.016	-2.6806520	-.2638505
4.00	1.00	-4.3661859E-02	.1765736	1.000	-.3038530	.2165293
	2.00	**-1.8091579***	.1765736	.000	-2.4345391	-1.1837768
	3.00	.1133616	.1597571	.528	-5.9404959E-02	.2861282
	5.00	-1.6792564	.2288841	.142	-3.7381037	.3795910
	6.00	**-1.3588896***	.2396356	.027	-2.5725877	-.1451915
5.00	1.00	1.6355945	.2436948	.159	-.4152605	3.6864495
	2.00	-.1299015	.2436948	1.000	-2.1564666	1.8966635
	3.00	1.7926180	.2317999	.103	-.2642001	3.8494361
	4.00	1.6792564	.2288841	.142	-.3795910	3.7381037
	6.00	.3203668	.2926331	1.000	-1.7558771	2.3966107
6.00	1.00	**1.3152277***	.2538197	.029	.1202553	2.5102001
	2.00	-.4502683	.2538197	.967	-1.6448352	.7442985
	3.00	**1.4722512***	.2424222	.016	.2638505	2.6806520
	4.00	**1.3588896***	.2396356	.027	.1451915	2.5725877
	5.00	-.3203668	.2926331	1.000	-2.3966107	1.7558771

b) factor 2 "primary production"

(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95 % Confidence Interval	
					Lower Bound	Upper Bound
1.00	2.00	.1613426	.3027102	1.000	-.4639560	.7866412
	3.00	-.1460650	.2793888	1.000	-.7071222	.4149923
	4.00	**-.7903179***	.2735580	.005	-1.4215677	-.1590680
	5.00	-1.0578153	.3775459	.963	-4.0810487	1.9654181
	6.00	-.2624846	.3932320	1.000	-2.3000250	1.7750559
2.00	1.00	-.1613426	.3027102	1.000	-.7866412	.4639560
	3.00	-.3074076	.2793888	.737	-.8513383	.2365230
	4.00	**-.9516605***	.2735580	.000	-1.5685784	-.3347426
	5.00	-1.2191579	.3775459	.900	-4.2441093	1.8057934
	6.00	-.4238272	.3932320	1.000	-2.4642999	1.6166455
3.00	1.00	.1460650	.2793888	1.000	-.4149923	.7071222
	2.00	.3074076	.2793888	.737	-.2365230	.8513383
	4.00	**-.6442529***	.2475048	.011	-1.1936260	-9.4879696E-02
	5.00	-.9117503	.3591178	.988	-3.9449314	2.1214307
	6.00	-.1164196	.3755744	1.000	-2.1723805	1.9395413
4.00	1.00	**.7903179***	.2735580	.005	.1590680	1.4215677
	2.00	**.9516605***	.2735580	.000	.3347426	1.5685784
	3.00	**.6442529***	.2475048	.011	9.487970E-02	1.1936260
	5.00	-.2674974	.3546004	1.000	-3.2904026	2.7554077
	6.00	.5278333	.3712573	.997	-1.5087049	2.5643715
5.00	1.00	1.0578153	.3775459	.963	-1.9654181	4.0810487
	2.00	1.2191579	.3775459	.900	-1.8057934	4.2441093
	3.00	.9117503	.3591178	.988	-2.1214307	3.9449314
	4.00	.2674974	.3546004	1.000	-2.7554077	3.2904026
	6.00	.7953307	.4533640	.999	-2.3435188	3.9341803
6.00	1.00	.2624846	.3932320	1.000	-1.7750559	2.3000250
	2.00	.4238272	.3932320	1.000	-1.6166455	2.4642999
	3.00	.1164196	.3755744	1.000	-1.9395413	2.1723805
	4.00	-.5278333	.3712573	.997	-2.5643715	1.5087049
	5.00	-.7953307	.4533640	.999	-3.9341803	2.3435188

Nutrient loads

Annual loads in tons per year are shown for total phosphorus (Table 9) and nitrate (Table 10), which were calculated for GUS. The loads for REG were calculated by

Bondar et al. (2007), separately for total phosphorus (Table 11) and nitrate (Table 12).

Table 9: Calculation of annual P_{tot} loads for GUS.

year	annual P_{tot} load [ta^{-1}]		
	Danube River at gauge Kienstock	inflow to Gießgang	outflow at dam 8
1996	4,703.5	11.2	4.9
1997	4,882.7	14.7	4.8

Table 10: Calculation of annual NO_3-N loads for GUS.

year	annual NO_3-N load [ta^{-1}]		
	Danube River at gauge Kienstock	inflow to Gießgang	outflow at dam 8
1996	96,605.0	202.8	102.9
1997	97,876.1	239.4	102.6

Table 11: Calculation of annual P_{tot} loads for REG (Bondar et al., 2007).

year	annual P_{tot} load [ta^{-1}]		
	Danube River at gauge Nussdorf	inflow to REG	outflow of REG
2002	18,400.0	74.3	53.3
2003	4,000.0	16.6	12.2

Table 12: Calculation of annual NO_3-N loads for REG (Bondar et al., 2007).

year	annual NO_3-N load [ta^{-1}]	
	Danube River at gauge Nussdorf	inflow to REG – outflow of REG
2002	165,000.0	308.3
2003	109,000.0	111.0

The loads of total phosphorus and nitrate at gauge Kienstock were similar for the years 1996 and 1997. The loads at the inflow to the Gießgang were nearly similar with 11.2 ta^{-1} in the year 1996 and 14.7 ta^{-1} in 1997 for total phosphorus, and

202.8 ta^{-1} in 1996 and 239.4 ta^{-1} in 1997 for nitrate. Bondar et al. (2007) calculated the P_{tot} loads at gauge Nussdorf for the wet year 2002 and the dryer year 2003 with 18,400.0 ta^{-1} and 4,000.0 ta^{-1}, respectively. The nitrate loads at Nussdorf were calculated with 165,000.0 ta^{-1} for 2002 and 109,000.0 ta^{-1} for 2003. The total phosphorus loads of inflow to REG and outflow of REG differed considerably for the two years of investigation with 74.3 ta^{-1} (2002) and 16.6 ta^{-1} (2003) at the inflow and 53.3 ta^{-1} (2002) and 12.2 ta^{-1} (2003) at the outflow. For nitrate Bondar et al. (2007) calculated the total loads (loads at inflow – loads at outflow) with 308.3 ta^{-1} for 2002 and 111.0 ta^{-1} for 2003.

Annual loads in tons per hectar and year are shown for total phosphorus and nitrate for the study sites GUS (Table 13) and REG (Table 14). As the whole wetland Gießgang-Greifenstein has a water area of about 1,000 ha (Wassermann, 1999), the estimated water area for GUS is about 650 ha. Bondar et al. (2007) calculated with a moistened area at mean water level of 69 ha for REG.

Table 13: Calculation of annual loads per hectar for GUS.

year	**parameter**	**annual load [$tha^{-1}a^{-1}$]**		
		inflow to Gießgang	**outflow at dam 8**	**inflow to GUS – outflow of GUS**
1996	**P_{tot}**	1.72E-02	0.75E-02	0.97E-02
1997	**P_{tot}**	2.27E-02	0.75E-02	1.52E-02
1996	**NO_3-N**	0.31	0.16	0.15
1997	**NO_3-N**	0.37	0.16	0.21

Table 14: Calculation of annual loads per hectar for REG (Bondar et al., 2007).

year	**parameter**	**annual load [$tha^{-1}a^{-1}$]**
		inflow to REG – outflow of REG
2002	**P_{tot}**	0.34
2003	**P_{tot}**	0.06
2002	**NO_3-N**	5.03
2003	**NO_3-N**	1.65

The calculation of annual loads per area showed differences between GUS and REG. At GUS 0.0097 $tha^{-1}a^{-1}$ (1996) and 0.0152 $tha^{-1}a^{-1}$ (1997), at REG 0.34 $tha^{-1}a^{-1}$ (2002) and 0.06 $tha^{-1}a^{-1}$ (2003) of total phosphorus remained in the wetland. At GUS 0.15 $tha^{-1}a^{-1}$ (1996) and 0.21 $tha^{-1}a^{-1}$ (1997) of nitrate remained in the wetland, at REG 5.03 $tha^{-1}a^{-1}$ (2002) and 1.65 $tha^{-1}a^{-1}$ (2003) remained. Due to data availability (see chapter 2.5) the high flood events at GUS got underestimated, but also Bondar et al. (2007) did not take large floods into account at REG.

3.4. Analysis of individual wetlands

Isolated versus connected periods

To compare the chemical parameters of individual wetlands (differences between isolated and connected periods) the nonparametric Mann-Whitney U Test was used.

The GUS showed differences between isolated and connected periods for the parameters conductivity, ammonium, and orthophosphate (Table 15, a), GLS for conductivity, and orthophosphate (Table 15, b). The conductivity of the LOB differed (Table 15, c). For REG, all of the analysed parameters, with exception of chlorophyll a, differed significantly (Table 15, d). LSA showed differences for conductivity, and orthophosphate (Table 15, e). For SRL no significant difference between isolated and connected periods could be found (Table 15, f).

Table 15: Mann-Whitney U Test for isolated and connected periods of individual wetlands (a-f). Bold values for the asymptotic significance (2-tailed) < 0.05 indicate differences between isolated and connected periods for particular parameters.

a) Greifenstein upper stretch	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	4.000	21.000	28.500	10.500	.000
Wilcoxon-W	19.000	126.000	43.500	25.500	36.000
Z	-2.870	-1.296	-.602	-2.272	-2.461
Asymp. Sig. (2-tailed)	**.004**	.195	.547	**.023**	**.014**

b) Greifenstein lower stretch	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	.000	30.000	30.000	15.000	24.000
Wilcoxon-W	21.000	51.000	51.000	36.000	45.000
Z	-3.421	-.789	-.790	-2.105	-1.316
Asymp. Sig. (2-tailed)	**.001**	.430	.430	**.035**	.188

c) Lower Lobau	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	21.000	64.000	80.000	76.500	76.500
Wilcoxon-W	66.000	254.000	251.000	286.500	286.500
Z	-3.253	-1.058	-.051	-.637	-.645
Asymp. Sig. (2-tailed)	**.001**	.290	.959	.524	.519

d) Regelsbrunn	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	23.000	39.000	55.000	50.000	34.000
Wilcoxon-W	323.000	75.000	76.000	95.000	79.000
Z	-3.436	-2.393	-.881	-2.345	-2.998
Asymp. Sig. (2-tailed)	**.001**	**.017**	.378	**.019**	**.003**

e) Lake Sakadas	Cond.	N_{tot}	Chl a	NH_4-N	PO_4-P
Mann-Whitney-U	.000	6.000	6.000	6.000	1.000
Wilcoxon-W	10.000	16.000	16.000	16.000	11.000
Z	-2.449	-.980	-.980	-.980	-2.205
Asymp. Sig. (2-tailed)	**.014**	.327	.327	.327	**.027**

f) Srebarna Lake	Cond.	N_{tot}	Chl a	NH_4-N	PO_4-P
Mann-Whitney-U	2.000	-	6.000	8.000	2.000
Wilcoxon-W	12.000	-	16.000	18.000	12.000
Z	-1.732	-	-.577	.000	-1.732
Asymp. Sig. (2-tailed)	.083	-	.564	1.000	.083

The difference of conductivity between outflow (= wetland water) and inflow (= Danube River water and dam 5 at GLS, respectively) of isolated and connected periods for the study sites GUS and SRL differed significantly (Table 16, a). REG showed significant differences for all parameters, with exception of chlorophyll a (Table 16, d). For GLS, LOB, and LSA no significant difference between isolated and connected periods could be found (Table 16, b, c, and e).

Table 16: Mann-Whitney U Test for isolated and connected periods of the differences of individual wetlands (a-f) to the Danube River. Bold values for the asymptotic significance (2-tailed) < 0.05 indicate differences between isolated and connected periods for the particular parameters.

a) Greifenstein upper stretch	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	.000	28.000	33.000	19.500	32.500
Wilcoxon-W	15.000	133.000	48.000	34.500	137.500
Z	-3.245	-.648	-.185	-1.438	-.232
Asymp. Sig. (2-tailed)	**.000**	.517	.853	.150	.817

b) Greifenstein lower stretch	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	30.500	39.000	35.000	27.000	39.000
Wilcoxon-W	51.500	60.000	126.000	48.000	60.000
Z	-.746	.000	-.351	-1.052	.000
Asymp. Sig. (2-tailed)	.456	1.000	.726	.293	1.000

c) Lower Lobau	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	22.000	27.000	18.000	17.000	24.000
Wilcoxon-W	43.000	42.000	63.000	32.000	39.000
Z	-1.491	-.057	-.600	-1.528	-.398
Asymp. Sig. (2-tailed)	.136	.955	.549	.127	.691

d) Regelsbrunn	**Cond.**	**N_{tot}**	**Chl a**	**NH_4-N**	**PO_4-P**
Mann-Whitney-U	40.000	27.500	60.000	42.000	27.500
Wilcoxon-W	340.000	48.500	360.000	78.000	63.500
Z	-2.439	-2.235	.000	-2.351	-2.984
Asymp. Sig. (2-tailed)	**.015**	**.025**	1.000	**.019**	**.003**

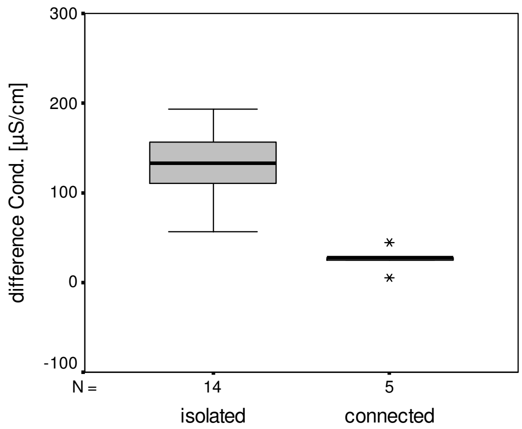
e) Lake Sakadas	Cond.	N_{tot}	Chl a	NH_4-N	PO_4-P
Mann-Whitney-U	.000	1.000	-	1.000	2.000
Wilcoxon-W	10.000	2.000	-	11.000	12.000
Z	-1.414	-.707	-	-.707	.000
Asymp. Sig. (2-tailed)	.157	.480	-	.480	1.000

f) Srebarna Lake	Cond.	N_{tot}	Chl a	NH_4-N	PO_4-P
Mann-Whitney-U	.000	-	-	6.000	7.000
Wilcoxon-W	10.000	-	-	16.000	17.000
Z	-2.309	-	-	-.577	-.289
Asymp. Sig. (2-tailed)	**.021**	-	-	.564	.773

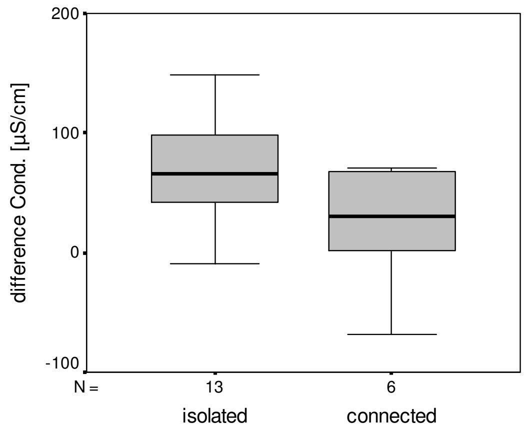
Box-Plots for selected parameter of a side-channel system and a lake-type system were used to show trends of concentrations for isolated and connected periods. Negative values were due to differences between the wetland and the Danube River and indicated lower concentrations in the wetland.

The difference of conductivity showed higher values for isolated periods than for connected periods for both side-channel and lake-type system (Figure 14, a-b). The difference of total nitrogen showed higher negative values for isolated periods. During connected periods, the difference between wetland concentrations and Danube River concentrations was smaller (lower negative values) in GUS and LOB (Figure 14, c-d). For GUS the difference of chlorophyll a between wetland and Danube River was nearly the same for isolated and connected periods. The positive mean indicated higher concentrations in the wetland (Figure 14, e). The difference of chlorophyll a at LOB showed higher negative values for isolated periods than for connected periods. During connected periods there were nearly no difference of the mean (Figure 14, f). The difference of ammonia was positive during isolated periods and negative during connected periods (Figure 14, g). For LOB the mean of ammonia was higher negative for connected periods (Figure 14, h). For GUS the difference of orthophosphate showed nearly the same negative value for isolated and connected periods (Figure 14, i), which indicated lower wetland concentrations. The orthophosphate difference for LOB showed a higher negative mean for connected periods (Figure 14, j).

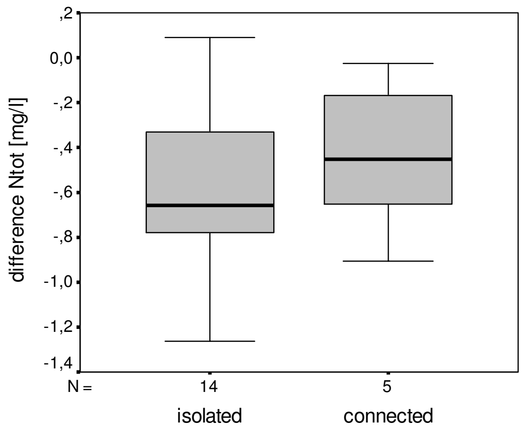
The variability of nearly all parameters changed between isolated and connected periods. At GUS, the variability of all parameter, with exception of orthophosphate, decreased during connected periods. At LOB, the variability of total nitrogen and ammonia increased during connected periods, and the variability of orthophosphate decreased.



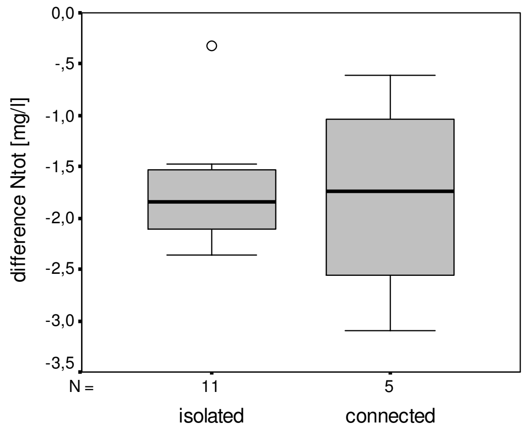
a) GUS: differences of the conductivity between isolated and connected periods.



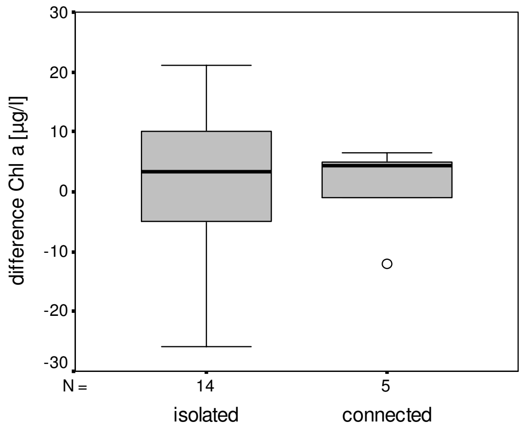
b) LOB: differences of the conductivity between isolated and connected periods.



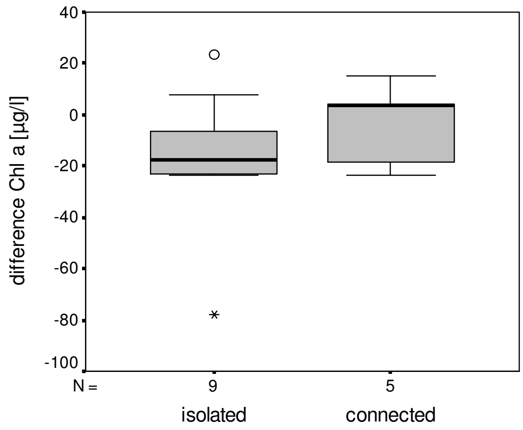
c) GUS: differences of total nitrogen between isolated and connected periods.



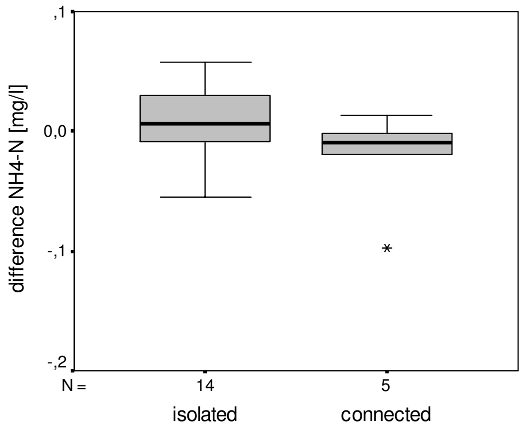
d) LOB: differences of total nitrogen between isolated and connected periods.



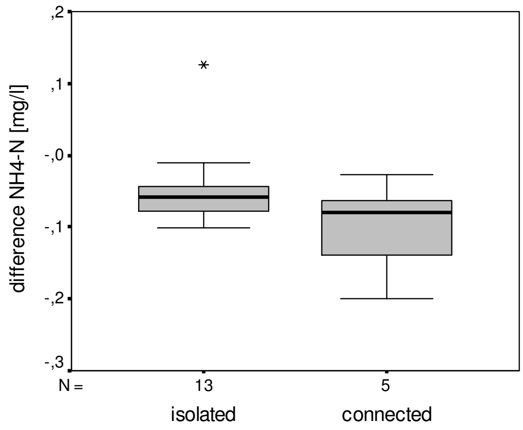
e) GUS: differences of chlorophyll a between isolated and connected periods.



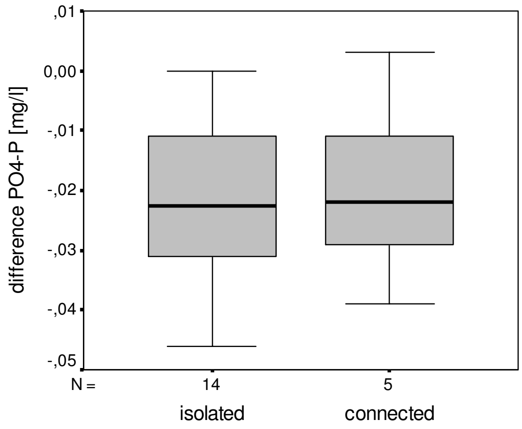
f) LOB: differences of chlorophyll a between isolated and connected periods.



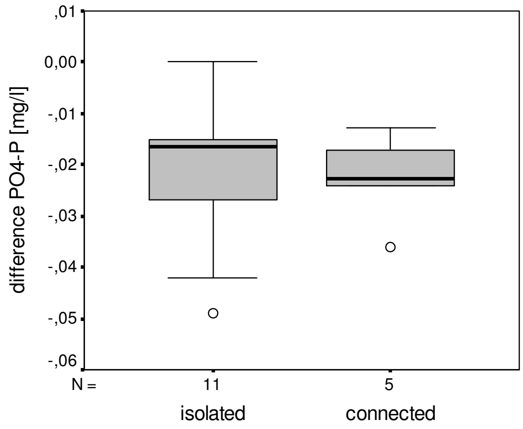
g) GUS: differences of ammonium between isolated and connected periods.



h) LOB: differences of ammonium between isolated and connected periods.



i) GUS: differences of orthophosphate between isolated and connected periods.



j) LOB: differences of orthophosphate between isolated and connected periods.

Figure 14: Trends of differences of parameters between the individual wetland and the Danube River for isolated and connected periods. Positive differences indicate higher concentrations in the wetland, negative differences indicate lower concentrations in the wetland. Differences at GUS (a, c, e, g, i) and LOB (b, d, f, h, j) of parameter: Cond.= conductivity, N_{tot} = total nitrogen, Chl a = chlorophyll a, NH_4-N = ammonium, PO_4-P = orthophosphate. N = number of samplings.

4. Discussion

4.1. Connectivity and nutrient status

The duration of connectivity is a crucial factor for the nutrient status of riverine wetlands. An inundation event leads to input of nutrient-rich water into the wetland (Hein et al., 2004b). The results for REG confirmed these findings, where the nutrient concentration increased during connected periods (Table 15, d; Table 16, d). The trend of increasing nutrient concentration could also be shown for total nitrogen at GUS and LOB (Figure 14, c, d). Additional to these results, Hein et al. (1999) found low nitrate concentrations in REG after floods, which were due to increased primary production and denitrification.

Table 17 gives an additional overview of differences between isolated and connected periods after Mann-Whitney U Test. The codes "a" and "b" distinguish different tests. The "a" shows a significant difference between isolated and connected periods of the respective parameter within the wetland, the "b" stands for a significant difference between wetlands – Danube River at isolated and connected periods, respectively. In that context, REG showed significant differences for the nutrient concentrations, i.e. the water chemistry indicated Danube-like water during inundation. The conductivity was a suitable indicator in all wetlands for water inflow into the wetland (Table 17). This could also be shown for example by Schemel et al. (2004), where a distinct decrease of the conductivity indicated the water inflow from the Sacramento River to Yolo Bypass.

Table 17: Differences after Mann-Whitney U Test between isolated and connected periods. a = significant difference between isolated and connected periods, b = significant difference of difference wetland-Danube River between isolated and connected periods. A diagonal slash distinguish between the two tests (difference/difference of difference wetland-Danube River).

Study site	Cond.	N_{tot}	Chl a	NH_4-N	PO_4-P
GUS	a/b	no difference	no difference	a	a
GLS	a	no difference	no difference	a	no difference
LOB	a	no difference	no difference	no difference	no difference
REG	a/b	a/b	no difference	a/b	a/b
LSA	a	no difference	no difference /no data	no difference	a
SRL	b	no data	no difference	no difference	no difference

The analysis of the highly eutrophic LSA showed noticeable results. As the inflow of Danube River water increased the nutrient concentration of other wetlands, the Danube River water reduced the nutrient concentrations in LSA. This dilution could be shown for nearly all concentrations, for two of them even (conductivity and orthophosphate) significantly lower (Table 17).

For LOB four out of five parameters did not show significant differences between isolated and connected periods (Table 17), while other investigations at LOB indicated highest nutrient concentrations during higher flood events (e.g. Hein et al., 2002; Hein, 2004b). At REG, Tockner et al. (1999) also found a positive relationship between discharge and nitrate. During increased water levels in REG, where the nitrate concentrations were close to the Danube River, short-term peaks of nitrate concentrations were observed within REG (Tockner et al., 1999).

GLS showed elevated nutrient concentrations at dam 4 due to the tributary Schmida (Wassermann, 1999, p. 48). Like LSA nearly all concentrations decreased in GLS during high water levels due to dilution effects, two of them (conductivity and ammonium) significantly (Table 17).

SRL is an intensely managed system, connected to the Danube River during opened sluices. With exception of the difference between wetland – Danube River for conductivity, no significant differences between isolated and connected periods could be found (Table 17) for this highly eutrophic wetland-lake. The high trophic level of the lake water seems to be due to nutrient input from adjacent farmland (Table 6).

This may be a reason why no differences between isolated and connected periods have been seen after statistical analysis with Mann-Whitney U Test (Table 17).

4.2. Primary production within wetlands

There were no significant differences for chlorophyll a between isolated and connected periods for all study sites (Table 17, Figure 14). At LOB, for example, negative differences of chlorophyll a indicated lower concentrations in the wetland during isolated periods. During connected periods there were nearly no differences between the concentrations of chlorophyll a between wetland water and Danube River water. Chlorophyll a is a biological active parameter and is related to the biomass of primary producers. For this reason, beside a dilution due to flood events, there are also seasonal effects, which result for example in low chlorophyll a concentrations during the clear water state in May and June. Because of the coexistence of these effects, it was not possible to show remarkable relations between the concentration of chlorophyll a and changing periods (isolated or connected) for all wetlands.

Investigations of Schemel et al. (2004) at the Yolo Bypass showed the dilution of incoming water from the Sacramento River, which resulted in decreasing chlorophyll a concentrations, followed by a considerably phytoplankton growth after the inundation event. Changing chlorophyll a concentrations could also be shown by Hein et al. (1999) for REG. Hein et al. (1999) found low chlorophyll a concentrations during and short time after a flooding event, but observed a chlorophyll a peak in REG seven days after a flood pulse. Furthermore Hein et al. (2004b & 2005) could show a strong negative correlation between chlorophyll a and orthophosphate, which indicated the uptake of orthophosphate by phytoplankton during the first days after a flood.

As detailed analysis of SRL showed that the mean of chlorophyll a was underestimated in Table 6, under inclusion of all samples of chlorophyll a at SRL, the mean was (49.45 ± 79.93) $\mu g l^{-1}$ for a n = 25. This showed again the eutrophic character of this lake. To avoid eutrophication of the SRL, it would also be important to prolong the duration of connectivity to the Danube River, which could be shown by Vasilev et al. (2008). In the dry years 1998 and 2001-2003, when SRL was isolated from the Danube River, the lake was hypertrophic. In contrast, in wet years

(1999 and 2000), the lake was eutrophic. The relation between trophic level and connectivity could also be shown for REG in the course of the "Danube Restoration Project" in 1995 and 1996 by Hein et al. (1999).

The profile of the reactive parameter orthophosphate in GUS, REG, and SRL behaved like chlorophyll a in LOB (Figure 14). The negative differences of orthophosphate showed higher values in the wetland during isolated periods. The small differences between wetland and Danube River during connected periods indicated the inflow of water from the Danube River to the wetland. Hein et al. (2005) mentioned the control of primary producers during connected periods, which results in a higher orthophosphate concentration due to reduced uptake by primary producers. During isolated periods wetlands showed lower concentrations of orthophosphate due to the fast uptake of primary producers.

4.3. Ecosystem service regarding nutrient reduction

Ecosystems perform natural functions, which also form the base for use as ecosystem services. These ecosystem services are defined by the Millennium Ecosystem Assessment (2005) as follows:

> "Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits."

Therefore the assessment of one ecosystem service, in our case "nutrient reduction", of the multitude of ecosystem services was done by comparison of two Austrian wetlands, GUS and REG. GUS is a wetland with an altered hydrological connectivity and REG is a reconnected side-arm channel (as mentioned in chapter 2.2.1.). As these two study sites differed in size, different loads for total phosphorus and nitrate were found (Table 9, Table 10, Table 11, and Table 12). For GUS mainly the base load was calculated, because higher discharges were underestimated due to the low amount of available data. As Bondar et al. (2007) also did not take higher floods in

REG into account, the comparison of the loads of the two wetlands would give comparable values.

Retention of total phosphorus

By considering the base flow at GUS, 6.3 ta^{-1} in 1996 and 9.9 ta^{-1} in 1997 were retained. Bondar et al. (2007) calculated a total phosphorus retention of 21 ta^{-1} for the wet year 2002 and 4.2 ta^{-1} for the dry year 2003 without taking high flood events into account. But, Hein et al. (2005) calculated the load retention of total phosphorus at REG including the high floods and received 175 ta^{-1} for the wet year 2002 and 58 ta^{-1} for the dry year 2003. This showed that high loads are transported during high floods. At Danube discharges > 3,200 m^3s^{-1} about 96 % of the annual total phosphorus load was transported to REG in 2002. In the dry year 2003 in ten days with Danube discharges > 3,200 m^3s^{-1} about 70 % of the annual total phosphorus load was transported into REG. Bondar et al. (2007) estimated the retention of total phosphorus in REG to be about 480 t and 15 t for the years 2002 and 2003, respectively. The results of Hein et al. (2005) and Bondar et al. (2007) underline the importance of inundated wetlands for nutrient reduction. Therefore the comparison between the GUS and REG showed differences, but it has to be considered that the observed years were characterized by different pattern of Danube River discharges (Table 4) (between mean values of 1,647.0 m^3s^{-1} to 2,683.0 m^3s^{-1} at gauge Bratislava).

A comparison of the 480 ta^{-1} at REG with the Vienna Main Wastewater Treatment Plant showed that the Treatment Plant eliminates 1,200 ta^{-1} of phosphorus from the Viennese sewage (Zessner & Hein, 2007). This showed that wetlands have an impact on water quality. But wetlands are unable to cope with excessive nutrient loads. If nutrient loads are too high, it can lead to eutrophication and aggradation, which on the other hand can lead to a decrease of the biodiversity within the riverine wetlands (Zessner & Hein, 2007). This indicates that wetlands cannot substitute modern Wastewater Treatment Plants, without showing serious consequences.

The annual loads within the Danube River showed comparable values for the years 1996, 1997, and 2003. The wet year 2002 showed higher annual loads for both, total phosphorus and nitrate. The relation of the retention of total phosphorus and nitrate within the wetland and annual loads transported in the Danube River showed values between 0.01 % and 0.21 % (without taking high floods into account). This means that only 0.01 % to 0.21 % of the loads in the Danube River retained within wetlands, independent from the years of investigation.

The relation of the retention of total phosphorus and nitrate within the wetland and annual loads transported into the wetland GUS showed values between 48.4 % and nearly 67.0 % (without taking high floods into account), for both phosphorus and nitrogen loads. This indicates that between 48.4 % and nearly 67.0 % of phosphorus and nitrogen loads flowing into GUS, retained within the wetland. Calculations for the Rönneå catchment in Sweden revealed that a wetland area covering 5 % of the total catchment would remove 40 % of the nitrogen within the wetland (Verhoeven et al., 2006).

Retention per area

The inclusion of areas into the calculations also showed different loads at the two wetlands (Table 13, Table 14). The study site REG retained more total phosphorus and nitrate per area compared to GUS for the selected years, independent from the hydrology of the year of investigation. As no higher floods were taken into account, the loads seemed to be underestimated. Hein et al. (2005) showed for REG annual total phosphorus retentions for the years 1997 to 2002, ranging from 19 $kgha^{-1}d^{-1}$ to 60 $kgha^{-1}d^{-1}$, which is about 6.9 $tha^{-1}a^{-1}$ to 21.9 $tha^{-1}a^{-1}$.

This indicated again that the duration of connectivity to the main river impacts the retention capacity of wetlands. This was shown for both wetlands, GUS and REG. Whereas GUS is a managed wetland with an altered hydrological connectivity (as mentioned in chapter 2.2.1.) and therefore showed a lower nutrient retention capacity, REG, which is a reconnected side-arm channel (as mentioned in chapter 2.2.1.), showed a higher nutrient retention capacity.

Verhoeven et al. (2006) pointed out critical nutrient loads. If a critical loading rate is surpassed, a change of the ecosystem functions and services and of the species composition will rapidly occur within a wetland. For wetlands, critical loads of 0.01 $tha^{-1}a^{-1}$ for phosphorus and about 0.025 $tha^{-1}a^{-1}$ for nitrogen had been proposed. This showed that the loads within the two Austrian wetlands GUS and REG surpassed the critical levels for phosphate and nitrogen in the years of investigation (without taking higher flooding events into account) (Table 13, Table 14).

Verhoeven et al. (2006) mentioned that nutrient-poor wetlands react more drastically compared with nutrient-rich ones. This can result in a change in nutrient dynamics and a shift in species composition in nutrient-poor systems and in increased productivity in nutrient-rich systems. Independent of the system, high nutrient loads can lead to a reduced nutrient retention and therefore to a loss of this important ecosystem service. This was shown for a wetland system in the Everglades due to agricultural nutrient input (Verhoeven et al., 2006).

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Acknowledgements

This thesis was related to a project with the project title "BioWetMan: A science based approach to understand biodiversity driven functions and services for wetland management", project number 4-25-2008, which was financially supported by the Austrian Science and Research Liaison Office (ASO). I would like to thank R.K. Kalchev, M. Mihalevic, and C. Sandu for the contributions to chapters 2.2.3., 2.2.2., and 1.3., respectively. Special thanks go to R. Renner from the Austrian Hydro Power for the provision of data from Gießgang-Greifenstein.

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