Water bodies in Hungary – an overview of their management and present state

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Abstract
Due to its geographical position and climatic characteristics Hungary has many types of surface waters ranging from large rivers to small streams, or from large steppe lakes to small soda pans. These waters have diverse flora and fauna, and provide various ecosystem services for human well-being. Differences among the water types in size, depth, chemistry or biology determine their differential responses to anthropogenic disturbances, and thus their restoration or protection requires different management strategies. With this study the authors aim to review the water-related problems had to be faced and resolved by the experts during the last centuries, and show the achievements reached in the field of water quality management in Hungary.

Keywords
Water types, pollution, restoration.

INTRODUCTION

Waters of the Carpathian Basin played a significant role in the evolution of the landscape, and thus, in the socio-economic life of the population. The ancestors of the Danube, Tisza and Drava rivers created the Great Hungarian Plain which is one of the largest alluvial plains in Europe, covering an area of approximately 100,000 km^2. Due to the low runoff and partly to human activities extended wetlands developed on the river flats, which occupied more than 20% of the plain up to the middle of the19th century. At this time, the increasing demand for arable lands and improvement of transport infrastructure (roads and railways) in the Tisza valley required to initiate one of the largest river regulations in Europe. As a result of this comprehensive engineering work many meanders were cut off, the straightened rivers were embanked and the wetlands were drained. Now the length of the embankments and the extension of the area protected from the floods are larger than those in the Netherlands. Although extension of the water-related ecosystems decreased in Hungary during the last two centuries, many unique types of water bodies still can be found here (*Borics et al. 2014*). Lake Balaton, which is the largest shallow lake in Central Europe or Lake Velencei and Lake Fertő, which are the westernmost representatives of the large saline steppe lakes of the Eurasian steppe zone have high conservation value and play important role in the economy of the country. The remaining wetlands, hundreds of oxbows, artificial reservoirs and pit lakes are characteristic parts of the landscape and have also significant local interest. The astatic soda pans constitute a special type of the inland saline waters. Effective managing of the conservation and rational use of the various types of waters is a really challenging task for the experts, because these tasks require type or site specific approaches. The aim of this study is to give an overview of the relevant types of waters in Hungary, and to show the results of those measures that were implemented to restore and improve their quality.

RESULTS

River Danube

The Danube is the second-longest river of Europe (after the Volga River), originating at Donaueschingen, Black-Forest (Germany) where the two small creeks, the Breg and Brigach confluence (*Liepolt 1967*). Then the Danube flows southeast for 2,850 km, passing through 10 countries including Hungary before entering the Black Sea. The Danube flows through many cities, including four national capitals (Vienna, Bratislava, Budapest and Belgrade) more than any other river in the world. Its banks, lined with castles and fortresses, formed the boundary between great empires, and its water served as a vital commercial highway between nations. Since the completion of the German Rhine–Main–Danube Canal in 1992, the river has been part of a trans-European waterway from Rotterdam on the North Sea to Sulina on the Black Sea, ranging a distance of 3,500 km.

The Danube enters Hungary at the Little Alföld plain. There the river stream slows down abruptly and loses its transporting capacity, so that enormous quantities of gravel and sand settle on the bottom. Later Danube enters the Visegrád Gorge, the wooded hills of Pilis, Visegrád and Börzsöny. The meandering Danube created a wonderful landscape that became nature lovers' paradise. The Danube then flows through Budapest, and across the vast Great Alföld plain. The whole area of Hungary is the part of its drainage basin. The length of the main channel of the river in Hungary is 417 km, therefore the Danube is the dominant element of the country's hydrography. The natural regime of river runoff changes constantly as a result of the introduction of stream-regulating equipments, including dams and dikes such as the Gabčíkovo Dam. Because of the dam we have to face the following environmental consequences: intensive degradation of the Danube River bed downstream (especially at the Old Danube river bed); decreased water level; increased sediment supply; increased amounts of bedload and higher intensity of bedload movements; reduced flood capacity; decreased channel stability.

Tourism and natural spots are important along the Danube. Also especially travel cruises and shipping transport on the river are of significance, especially on the frequented route between Vienna and Budapest. The Danube Banks in Budapest are a part of Unesco World Heritage sites; they can be viewed from a number of sightseeing cruises offered in the city. Despite extensive development of Hungary some of the original floodplain ecosystems survive (*Fig. 1*). Reminders of the primeval landscape, floodplain forests such as those in Gemenc area of Hungary provide habitats of birds, e.g. white-tailed eagle, black stork, black kite, night heron.

Figure 1. Danube River at Göd

Today, we should find the harmony between the shipping, drinking water and energy production, recreation needs - to mention only the most important ones - although these issues require different management approaches. One of the main problems is the establishment of reservoirs of the power plants, which hold the suspended solids and debris, and thus lower the river bed at the downstream sections, which hampers the water supply of Budapest. It can also be observed in Gemenc region where as a result of the decreasing water level, the side arms detached from the main channel and now form a typical backwater.

In the 1950s, '60s due to the industrial development and to the increasing use of agricultural fertilizers the Danube became enriched with nutrients. In the 1960-70s large-scale power plant dam construction programs began, which meant a drastic reduction in rolling and transporting suspended sediment. The suspended solid deposition resulted in improved light conditions, so in addition to the abundance of plant nutrient supply, significant eutrophication (algae) occurred (*Kiss 1994, Kusel-Fetzmann et al. 1998*). At the Hungarian section in 1980s the chlorophyll-a concentration was often larger than 100 μgL^{-1}, and even the yearly average often reached or exceeded the 50 μgL^{-1} (*Fig. 2*) caused mainly by centric diatoms (*Kiss et al. 2012*).

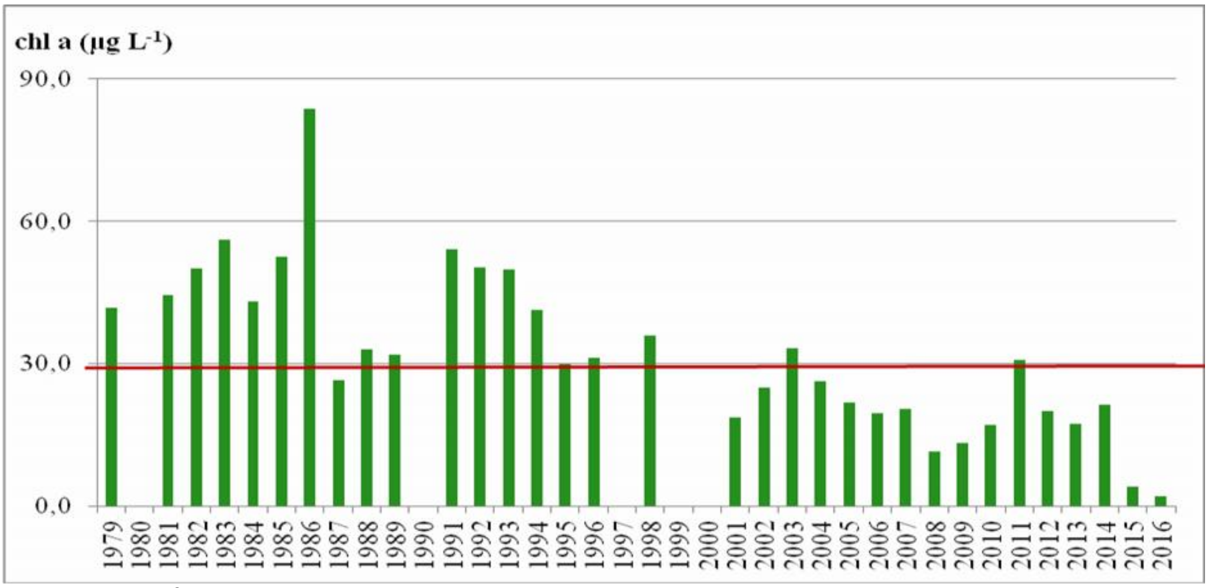

Figure 2. Changes of yearly average chlorophyll a concentration in Danube River at Göd, measured in the vegetation periods. Red line indicates the good/moderate border

The values in the Szigetköz and Gemenc side arms sometimes reached 200-300 μgL^{-1}. After the political changes at the beginnings of 1990-es the industrial and agricultural production has fallen significantly, which considerably reduced the use of fertilizers. Thanks to the European Union Water Framework Directive a lot of big cities, municipalities developed an effective wastewater treatment. As a result of these actions, nutrient supply dropped to one third of the previous values and water quality of theDanube started to improve. The largest environmental investment implemented in Central Europe fundamentally modernised the wastewater treatment system of Budapest, ensuring cleaner waters for all those living along the banks of the Danube.

Although eutrofication of the river Danube successfully controlled, in the recent years increasing amount of evidences indicated that other forms of pollutions frighten the quality of the Danube. Various persistent micro-contaminants (drugs, pesticides etc.) which cannot be eliminated in the wastewater treatment plants have become the focus of interest. Increasing occurrence of non-native, invasive organisms means acute problem in the Danube river valley, because these taxa can be disease carriers or occasionally replace the elements of the native flora and fauna causing ecosystem-level changes and undesirable consequences.

Tisza River

The Tisza takes its source in the Eastern Carpathians (Ukraine) crosses the Great Hungarian Plane and finishing its 962 km long route enters the Danube in Serbia. Development of the present state of the Tisza valley can be dated back to the mid-19th century when comprehensive regulation of the river started. The originally 1419 km long river has been shortened, embanked, and more than 20,000 km^2 area became protected from floods. Besides the positive impacts of this huge engineering work negative outcomes also occurred. Drying out of the valley threatened the safety of the agricultural production and became an urgent problem by the middle of the 20th century. This necessitated the building of two river barrages (Tiszalök 1959; Kisköre 1974) and several canals in the middle part of the valley. Although the danger of annually arriving devastating floods has been greatly reduced, deforestation of the upper catchment and the extreme events of precipitation in the Carpathian Basin contributed to the development of extreme floods and low discharge periods in the recent years (*Fig. 3*).

Figure 3. Forest on the Tisza floodplain (Photo: Béla Csányi)

These new challenges required the rethinking of previous measures and called into being new strategies in river management. Several off-river storage reservoirs have been planned and established in the middle Tisza valley to reduce floods and to store water in dry periods. Despite the engineering works substantially altered the landscape in the Tisza valley the river and its immediate surroundings managed to preserve their natural character. Although the large wetlands that formerly characterised the Tisza valley have been drained, many water related natural and semi-natural areas have been preserved, restored or established newly, which act as green corridors.

Due to urbanization, industrial development and the intensification of agriculture water quality of the Tisza and its tributary rivers considerably worsened from the middle of the last century. The untreated sewage effluents caused drastic organic and (after their degradation) nutrient load, which led to the eutrophication of the rivers with its all negative consequences. This negative tendency changed from the 1990-ties when several factories were closed and hundreds of sewage treatment plants were established in the region. The water quality and ecological state of the river considerably improved. The enhanced recovery potential of the Tisza river is clearly indicated by the quick recovery of the biota after the serious cyanide pollution that occurred after an industrial accident in Romania in 2000.

Small streams

During the comprehensive regulation of rivers in the Tisza valley the flooded areas in plains were almost totally eliminated. The landscape has been affected by the digging of ditches and the drainage of wetlands for agriculture. Lowland streams have been straightened, deepened and widened to facilitate land drainage and to prevent local floods. Consequently, the trees in the shoreline were diminished, buffer zones were eliminated and the level of groundwater decreased.

These small streams are vulnerable to changes that anyway have little effect on larger water bodies. They have sufficiently large catchment area to be adversely affected by human impacts. Small rivers with a small volume of water have only a limited ability to dilute and retain pollution, and therefore they are highly susceptible to inputs of pollutants from their surroundings, such as nutrients and pesticides from agriculture. Excessive sediment movement caused by erosion of streambed is also a factor affecting the ecological status of water bodies, particularly in small lowland streams. In addition, dry periods and water abstractions can greatly reduce their water flow and water level. Therefore, these small streams generally have poor ecological quality.

There are, however some parts of the Tisza valley where the small lowland streams were less affected by human impacts (*Fig. 4*). The streams which show the features of former natural ones represent unique and important ecological systems. They support specific and important hydrological, chemical and biological processes and provide proper habitats for a wide spectrum of plants and animals. However those few small lowland streams that are still in good ecological state are also exceptionally vulnerable to climate change impacts. The increasing water temperature and the likelihood of water scarcity and droughts can seriously affect the ecological status of small streams.

Figure 4. Small lowland stream in natural state

Unfortunately, achieving of the good ecological status of the small lowland streams in Hungary, among others, is impeded by the low stream gradient (slope of the stream), flow periodicity, fluctuation of water level, relatively low water depth, excessive water abstraction and lack of buffer zones. Although there is now an urgent need to pay more attention to the conservation-oriented management of small streams, it is in conflict with the objectives of the agriculture.

Lake Balaton

Lake Balaton – the largest lake of Central Europe – lies almost exactly in the centre of Transdanubia, the ancient Roman province of Pannonia. The mean lake level is 104.8 m above the Adriatic Sea level. At mean lake level the surface area is 596 km^2, the mean depth is 3.25m, so that Lake Balaton is a shallow lake having a large surface area. This lake has an elongated shape with a length of 78 km and an average width of 7.6 km. Along the longitudinal axis the depth decreases gradually to the SW-end. The northern shore decorated by a range of picturesque hills (extinct volcanoes in the Tapolca basin) (*Fig. 5*) while its southern shore is a fertile flatland.

Figure 5. Lake Balaton with extinct volcanoes in the background

The southern shore is a sandy beach, the bottom drops steeply here, along the northern shore, the bottom of the lake deepens sharply. The catchment area covers 5775 km^2. The lake has 51 inflows but the only outflow is the Sió Canal at the south-eastern end of the lake. One-half of the inflow iinto the lake is the River Zala, which flows into the smallest westernmost basin. The Zala River drains an area of 2622 km^2.

Limestone and dolomitic rocks predominate in the catchment area, consequently the waters discharged the lake predominated by calcium-, magnesium- and bicarbonate ions. The concentration of total dissolved solids is quite high, about 500 mg/L, and the typical pH of the water is 8.4. Almost one-half (110 km) of the shoreline covered by a dense reed stands. The total area of the reed cover is 15 km^2 (*Herodek et al. 1988*). The water temperature is normally above 20 ºC from the end of May to early September, and this period is considered suitable for bathing and aquatic sports. Lake Balaton is one of the greatest natural assets and main touristic destination in Hungary due to its sweet water, mild climate, and picturesque landscape. The eutrophication of Lake Balaton has become a serious problem in the eighties of the last century. Summer blooms of nitrogen-fixing filamentous cyanobacteria became frequent phenomenon in the western part of the lake, as a consequence of the large phosphorus load of River Zala. The large scale eutrophication control measures (sewage water diversion, phosphorus removal at the sewage treatment plants, construction of pollution control reservoirs on the catchment area) resulted in a significant decrease of the external phosphorus load and phytoplankton biomass of the lake (*Clement et al. 2005*). During the 1980s the summer maximum of the chlorophyll a concentration usually exceeded the 200 µg/L, nowadays it is far below the 50 µg/L in the most productive western basin, which means that the whole lake is suitable for bathing (the WHO limit is 75 µg/L in case of cyanobacteria dominance) (*Fig. 6*).

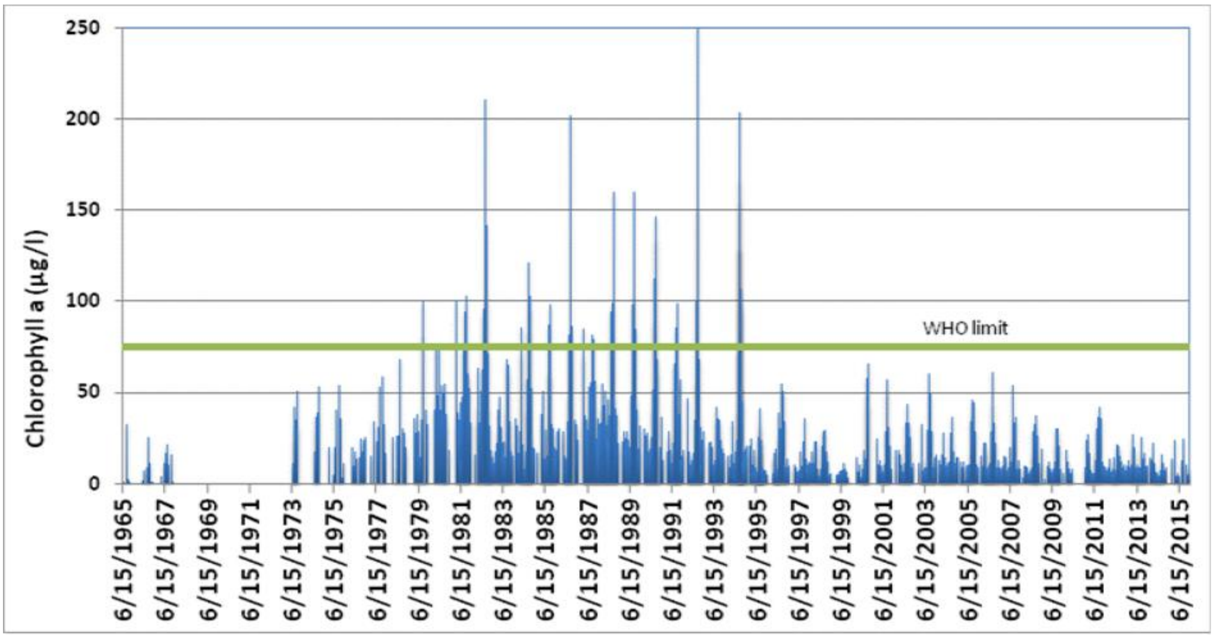

Figure 6. Long-term changes of the phytoplankton biomass (chlorophyll a concentration) in the most productive western basin of Lake Balaton

Lake Fertő

Lake Fertő/Neusiedlersee is a wind-exposed, extremely shallow steppe lake (~ 1.3 m), straddling the Austrian-Hungarian border at 166.5 m above Adriatic Sea level (*Löffler 1979, Dokulil and Herzig 2009*). The lake basin covers a total area of 315 km², of which 76% (240 km²) are on the Austrian and 24% (75 km²) are on the Hungarian territory. The lake has an elongated shape with a maximum length of 36 km and a maximum width of 12 km. Two major inflows are River Wulka and Rákos stream. Originally, the lake has no natural outflow, but at the end of the 19^{th} century an artificial channel (Hanság channel) was constructed. Nowadays, the lake water level is regulated by a sluice on Hungarian territory near Fertőújlak, and bilateral issues are dealt with by the Austro-Hungarian water commission which was established in 1956 (*Loiskandl et al. 2012*). In the 18th century the lake had dried out four times and the last vanishing was from 1864 to 1870 (*Loiskandl et al. 2012*).

More than half (ca. 55%, i.e. 171 km^2) of the surface area is covered by emergent vegetation, mainly reed (*Phragmites australis* (Cav.) Trin. ex Steud). In Hungary, reed comprises a significantly larger area along the shoreline (up to a width of >5 km), than in Austria (up to 2 km). Degradation of the reed stands has been documented from the early 1980s (*Dinka et al. 2010*).This problem is more aggravated in the Hungarian part: while in Austria only 10% of the reed stands are degraded, in Hungary this proportion is 30% (*Márkus et al. 2008, Wolfram et al. 2014*). As a result, there are numerous reedless brown-water ponds (inner lakes) of variable size within the reed belt, which is intersected with artificial canals connecting the inner ponds with the open water areas (*Fig. 7-8*). Electric conductivity is about 2,200 μScm^{-1}, and the pH varies around 9. The dominant salt is sodium bicarbonate ($NaHCO_3$) and thus, Lake Fertő classified as a soda lake (*Wolfram et al. 2014*). As a result of wind-induced sediment resuspension, the open water of the lake is characterized by high inorganic turbidity and usually low Secchi-disk transparency (*Löffler 1979*). Within the reed cover, water is not turbid due to less exposure to wind and brown in colour due to humic substances (*Löffler 1979, Wolfram et al. 2014*).

Figure 7-8. The open water and the reed belt of Lake Fertő/Neusiedlersee

The lake underwent strong eutrophication during the 1970s and 1980s, when phosphorus concentrations have shown a pronounced rise due to increase in tourism and economic development in the catchment as well as an enhanced consumption of fertilisers in the intensified agriculture (*Dokulil and Herzig 2009, Wolfram et al. 2014*). In the open water, annual mean concentration of total phosphorus rose from about 40 μgL^{-1} to more than 160 μgL^{-1} at the peak of the eutrophication period (*Wolfram et al. 2014*). Due, however, to extreme light limitation of algae, enhanced nutrient availability did not induce a significant increase in phytoplankton biomass, and algal blooms were mainly restricted to sheltered areas. Various management measures were taken to reduce the nutrient input into the lake. These have significantly reduced anthropogenic nutrient loads since the beginning of the 1980s. Total P loads fell from about 80 t in the beginning of the 1980s (only Austrian part of the catchment area) to less than 20 t around 2000 (total catchment area). As a consequence, phosphorus concentrations have also decreased since the 1980s (*Wolfram et al. 2014*).

During the last century, the fish community has experienced significant changes, mainly due to fisheries and introduction of exotic species (topmouth gudgeon, pumpkinseed). Stocking with eel was clearly one of the most serious impacts on the autochthonous fish community from the middle of the 20^{th} century (*Wolfram et al. 2014*). It resulted in local extinction of small-sized fish, like mudminnow and weatherfish. Since the beginning of the 21^{st} century, when stocking of glass eel was stopped, the density of eel has significantly decreased. Recently, species, which had become locally extinct, were re-introduced in the Hungarian part of the lake, e.g. the weatherfish (*Wolfram et al. 2014*).Today, there are less than 15 professional fishermen in Austria, while about 40-50 of them worked in the whole lake at the end of the 19^{th} century. Angling and fishing on the Hungarian side has never been as important as in Austria, due to the large extension of the reed covered area.

Because of the environmental diversity the Lake Fertő region provides habitats for many wildlife species especially birds and an important wetland in Central Europe. For conservation and wise use of the wetland and its resources the “Neusiedler See-Seewinkel” is designated to the Ramsar Convention on Wetlands in 1982. Aside from that, for nature and natural resources conservation a national park “Neusiedler See-Seewinkel” was founded in 1993 and co-managed with the Hungarian national park “Fertő-Hanság”, founded in 1991 (*Loiskandl et al. 2012*).

Lake Velencei

Lake Velencei, having unique value from geological, nature conservational and ecological viewpoint, is the second largest soda lake in Hungary (area: 24 km^2, mean depth: 1.6 m; Electrical conductivity: ~3000 μS cm^{-1}) and an important touristic and recreational centre (*Reskóné 1999*). In the past the lake was characterised by drastic water level fluctuations; occasionally dried up, or since it has no natural outlets, flooded its surroundings. To lower these extremities the first interventions were implemented in 1880 when the extended wetlands on the south-western part of the lake were drained and a natural outlet was established, by which an effective water level regulation could be achieved. From the 1930s due to the development of holiday resorts around the lake the anthropogenic effects became more intense, accelerating the process of natural eutrophication that was already in advanced stage independently of anthropogenic load. The reed-bed proliferated more and more both along the shore and in the inner parts of lake-basin and the mud that accumulated in the midst of roots of the reed arrested the movement of the floating marshes that were characteristic formations of the western part of the lake. (*Gorzó 1990*). By the beginning of 1960s, the 59% area of the lake was already covered by reed, while in the open water areas the mass proliferation of algae resulted in water blooms; which frightened tourism and water uses. To overcome these undesirable processes a comprehensive rehabilitation of the lake (reed-cutting, dredging of the basin and shore regulation) started in the 60ties. In the course of dredging, 9 million m^3 of mud was removed from the basin. This mud was used for banking up one part of the shore and creating two small artificial islands. Parallel with this a shoreline regulation (1962-1985) was also done. In the catchment area of the lake two reservoirs were built, which can supply the lake with water in dry periods. Due to these measures the water level of the lake can be regulated safely.

At present, Lake Velencei can be divided into two, clearly separable parts. The reedy-marshy Bird Nature Reserve of the western basin (*Fig. 9*) covers approximately one-third of the lake. The other, eastern part turned into a large, open water area (*Fig. 10*) after the reconstruction, and now it is an important recreation area. Despite the measures taken during the last decades several problem still have to be faced, i.e. cyanobacterial blooms, or occasionally occurring imbalance between the wetland and open water areas of the lake, which creates undesirable processes concerning the lake's chemical and biological processes (*Reskóné and Törökné 2000, Reskóné et al. 2001, Ács 2007*). These highlight the need for deeper understanding and protection of the delicate biological system of the lake.


Figure 9-10. The Western (laeft) and Eastern (right) parts of the Lake Velencei with wetlands and open water areas

Soda pans

Soda dominated waters are characterized by large amounts of sodium hydro-carbonate/carbonate and usually hypersaline with high alkalinity (pH>9), which property clearly distinguishes them from other inland saline waters. Soda lakes/pans can be found in each continent of the World, but their distribution is confined to specific geographic regions. The Carpathian Basin is the western border of the soda lakes/pans distribution (Austria, Hungary and Serbia) in Eurasia, and they can be found only in few regions of Asia. The intermittent (astatic) soda pans are very shallow (water depth >1m) and small (open water 1−200 ha), which were formed on various geological substrates by specific climatic, geologic and hydrologic environment in the Carpathian Basin at the end of Pleistocene and the beginning of Holocene, which were influenced by human impact in the last two centuries. The intermittent soda pans are situated in the groundwater discharge areas of a closed hydrographic (endorheic) basin, in which groundwater inflow exceeds the surface-related watershed inflow and precipitation.

The most important ecological criteria of the intermittent natural soda pans are listed below (*Boros et al. 2014*):

- Shallow astatic open water bodies with bare pan bed (emerged and submerged macrophytes are sparse or absent);
- Annual average of salinity exceeds 1 g/L;
- The presence of characteristic species of flora and fauna.

The most frequent type of soda pans is the basic alkaline type (Na-HCO_3), the second and third subtypes are the chloride and sulphate, beside the hydro-carbonate/carbonate dominance. Magnesium sometimes arises as a secondary dominant cation beside sodium.

Salinity varies widely in sub- (0.5–3 g/L) and hypersaline (>50 g/L) ranges, while the pH varies in 8–10 range. Beside the high alkalinity, the high inorganic turbidity (Secchi depth 0.5−30 cm), polyhumic concentration of dissolved humic substances, hypertrophic conditions of the soda pans represent a unique aquatic ecosystem in Hungary (*Boros et al. 2013, Boros et al. 2014*) (*Fig. 11*).

Figure 11. Soda pan in the Danube-Tisza Interfluve

Due to their lower salinity, biodiversity of soda waters is generally higher than other continental saline waters with characteristic flora and fauna, benthic and planktonic communities reflect a strong structuring role of salinity, turbidity and trophic state, and the intermittent standing water incapable of supporting resident fish populations. The characteristic soda pan habitats are listed in Annex 1 of the EU Habitat Directive (92/43/EGK) and are thus considered to be of high priority (Natura 2000 Network). Coupled with the characteristic physical and chemical conditions the waterbirds have an important role in the regulation of trophic relationships of the soda pans (*Boros et al. 2008a, Boros et al. 2008b, Vörös et al. 2008*), and several of them have been designated as Wetlands of International Importance by the Ramsar Convention on Wetlands and as Special Protection Areas for birds. Because of the significant (85%) loss of these habitats during the last 60 years in the Carpathian Basin, they are “ex lege” protected in Hungary. Due to to unstable water balance and small size these pans are particularly threatened by the climate change combined with human activities.

Oxbow lakes

The oxbows are characteristic parts of the landscape in the Great Hungarian Plane. Although some of them are formed naturally, most oxbows were created in the second half of the 19th century, during the comprehensive regulation of rivers in the Tisza valley. More than 100 meander loops were cut off, resulting in hundreds of oxbows with a total length of 589 km and with an area of about 3000 ha. Oxbows of the floodplain are quickly filled with sediment, but those ones which are separated from the watercourses by flood protection embankments can keep their open water character for centuries. (*Fig. 12*)

Now the oxbows in Hungary occupy the complete range of successional stages, from the relatively deep open water lakes to the shallow marshlands (*Krasznai et al. 2010*) and provide habitats for many rare and protected plants and animals. However, oxbows are very sensitive ecosystems. Most of them have left their direct contact with the living river, and thus, total exchange of water in the lake basin with fresh water is not possible. The other important hydromorphological characteristic of these lakes is the small surface area to shoreline ratio which means, that oxbows are extensively exposed to anthropogenic disturbances.

Figure 12. Oxbow lake at Tiszadob village

Ecological state of these water bodies is strongly determined by the type of land use in the immediate catchment. Oxbows surrounded by arable lands are the most threatened because of agricultural diffuse pollution from fertilisers. The enhanced nutrient input accelerates the filling succession of the lake basin, and drives the system towards an unstable hypertrophic state, which is characterised by dense marshy vegetation and extreme values in water quality. The other threat to the oxbows is the intensification of sport fishing, which coincides with the drastic artificial modification of the fish fauna, increased pollution caused by the feeding of fish, and ultimately, with enhanced algal blooms (*Borics et al. 2013)*. Several oxbows were dredged and restored in the recent years, and now because of their unique flora and fauna many of them are under nature protection. However the multiple uses of these waters results in conflicts between stakeholders (local residents, fishermen, conservationists, agriculturists), therefore restoration and conservation of these valuable aquatic systems will require the development of comprehensive ecologically-based management strategies in the near future.

Wetlands

Great Plain wetlands are remnants of the former extensive floodplains of river Tisza and its tributaries. Before river regulation (mid-19th century), inundation by floods was part of the natural dynamics of the vast Tisza floodplain. Floods represented periodically occurring disturbances that led to the formation of a mosaic of habitat types ranging from constant marshes through periodically flooded marshes to irregularly flooded marshes and meadows (*Aradi and Lengyel 2003*). Descriptions from the 18th and 19th centuries attest that floodplain wetlands were used for fishing, egg collecting, plant collecting, reed harvesting and livestock grazing. Regular floods and the variety of land use ensured that the mosaic habitat complexes of wetlands hosted highly diverse communities of plants and animals on which people depended.

Today, Great Plain wetlands are the last representatives of the former extensive active floodplains of the Tisza valley. These wetlands provide refuges to a high diversity of marsh and meadow vegetation types and many species, especially of aquatic plants and insects (e.g. dragonflies), some rare fish species (e.g. loaches), amphibians (frogs, toads, newts) and waterbirds (*Aradi et al. 2003*) (*Fig. 13*). The persistence of wetland diversity depends on the quantity and dynamics of water supply and proper management. In the absence of management, constant water supply leads to the homogenisation of the vegetation and reed (*Phragmites communis*) often forms extensive, species-poor reedbeds. National park authorities thus control water supply to mimic the natural flow dynamics of Tisza as much as possible, and introduce management to mimic the disturbances that were once essential in maintaining the diversity of habitats and species.

Figure 13. Hagymás weltland in Hortobágy

Cattle-grazing in marshes, a traditional way of managing wetlands has been restored in several lowland wetland areas (Hortobágy, Kiskunság and Körös-Maros National Parks). In addition, burning (prescribed fire) in the late summer, when the reed plant is blooming, is also used occasionally for reed management. Recent studies, however, suggest that burning has only a temporary effect as it leads to the rejuvenation of the reedbed, therefore, it has to be repeated once every two or three years. Cattle-grazing, even in low densities, has a longer-lasting effect because cattle effectively inhibit the growth and spread of the reed through their trampling and reed consumption. A combination of burning and cattle-grazing was effective in increasing marsh diversity, which in turn increased the abundance and number of species of amphibians (*Mester et al. 2015*). Newly burned areas devoid of reed were favoured mostly by waterbirds, and grazed areas were favoured by farmland birds, whereas non-burned, non-grazed areas rich in old reed were favoured by reedbed passerine birds, providing an example for mosaic-like management benefitting several groups of species at the same time (*Mérő et al. 2015*). In recent years, awareness of the combination of pasturing and conventional nature protection actions can be regarded as one of the greatest progresses in wetland management.

Pit lakes

The Carpathian basin was filled with heterogeneous fluvial deposits i.e., gravel, sand, silt and clay. Increasing demand of the industry for these materials triggered intensive mining operations in the region. Open cut mining resulted in hundreds of pit lakes that range in area from< 1 to 300 ha surface area,< 10 to 70 m depth and 5-100 years in age. These pit lakes are considered as end use of mining, and serve primarily as recreational areas. (*Fig. 14*) However pit lakes have very special hydro-geological and limnological characteristics, which strongly determine the details of the tools that are applied to restore their quality (*Borics et al. 2015*). Since the fluvial deposits in Hungary are chemically inert materials water quality of the pit lakes are determined primarily by the quality of ground water, which is the most important part of the water balance. The groundwater flow in coarse-grained alluvial deposits is very intensive, which means that any pollution of the catchment area will quickly appear in the water of pit lakes, and vice versa, pit lake pollution directly threatens the quality of the ground water. This is especially important because 90% of the drinking water supply in Hungary is primarily based on ground waters. Pit lakes are deep and have small surface area to depth ratio, which results in stable thermal stratification of the water column. The relatively large water volume can buffer the negative consequences of pollution for a short period of time, and stratification of lakes conceals the undesired processes running in the deep layers and having serious consequences for the lake biota.

Figure 14. Gyékényes gravel pit lake along the Drava River

Monitoring, assessment and management of these lakes therefore needs special approaches that are different from those applied for shallow lakes. Many of the large deep pit lakes are still considered the best quality surface waters in Hungary, however without comprehensive management actions their quality can decrease quickly. Recreational fishing, stocking of invasive fish, use of fertilisers in the catchment resulted in adverse processes in several pit lakes which are indicated by enhanced production of phytoplankton and depletion of oxygen in the deeper layers. Local measures have been proposed and implemented in the recent years to protect pit lakes' water quality, but nationwide accepted comprehensive post mining management of pit lakes is still lacking.

Fish ponds

Large scale river regulations resulted in a continuous degradation of traditional fishery starting from the 19th century. Fish ponds became the main sources of fish production and utilization, which were established on natural streams and canals (*Specziár and Erős 2015*). Consequently, at present, aquaculture mainly utilizes natural water resources by capturing the water of streams in valley dammed reservoirs and artificial pond systems on an area of cca 25,000-30,000 ha. By far the most important fish species produced in aquaculture in Hungary is the common carp (*Cyprinus carpio*) and the most important supplementary species are the silver carp (*Hypophthalmichthys molitrix*) and the grass carp (*Ctenopharyngodon idella*). Species with relatively low contribution are the pikeperch (*Sander lucioperca*), the Northern pike (*Esox lucius*), the European catfish (*Silurus glanis*), the tench (*Tinca tinca*), the bighead carp (*Hypophthalmichthys nobilis*) and some other, especially Cyprinid or Percid species. Unfortunately, many fish pond systems are age-worn and especially their sluicing is inappropriate to prevent the escape of cultured fish into natural habitats. This yields the escape of non-native species to natural stream segments. Reservoir dams also cause the fragmentation of stream segments. Therefore, one of the greatest challenges of environmental management in future decades will be balancing between multiple ecosystem services including water retention, fishery production, recreational fishing, and biodiversity conservation while also maintaining good ecological status in stream-reservoir systems.

Kisköre Reservoir

Kisköre Reservoir is the largest artificial lake in Hungary. The first dam on the Hungarian stretch of Tisza was constructed in 1954 at Tiszalök. The second water barrage system with the Kisköre Reservoir was built between 1967 and 1973. By damming up the section between Kisköre and Tiszavalk, Kisköre Reservoir has been established in the middle stretch of the Tisza, which with its 127 km^2 extension has become the second largest stagnant water of the Carpathian Basin. This reservoir was built for a power station and as a source of water for irrigation. Beside these, it functions as an important bird refuge and nature protection area (*Fig. 15*).

Figure 15. Kisköre Reservoir (nature reserve area)

The form of the recent image of the Kisköre Reservoir is the result of a longer process, which created isolated water bodies within the system differing sharply from each other in appearance, hydrological and hydrobiological features. Looking at the Kisköre Reservoir from an ecological point of view it can be considered as a shallow-lake type reservoir, of which large scale mosaicity is well represented by marshes, shallow-lakes, water pits excavated by floods, large and medium sized small water courses.

Changes of environmental conditions cause qualitative and quantitative changes of planktonic and benthic elements of the flora and fauna. Because the concentration of plant nutrients in the Tisza river is high, main limiting factors of phytoplankton are the temperature and the suspended solid content. Annual changes of the latter variable can be linked to floods. In flood periods low number of species and individuals is typical. In summer the composition of the plankton is similar to that of other large reservoirs both in terms of number of species and individuals. Benthic fauna of the reservoir can be considered relatively rich in species. Dominance of stagnant water fauna is typical. Similarly to plankton the benthic flora and fauna shows pronounced differences among the basins of the reservoir. Currently about 50 % of the total reservoir surface is covered by plants. In waterweed vegetation of the reservoir water chestnut and in the marshy vegetation reed are stand-forming. Kisköre Reservoir with its diverse natural surroundings is an all-season fishing paradise with high catch rates. It has a wide variety of water depths, the zigzagging canals and the calm water of the reservoir provide ideal habitat for different kinds of fish. Most native Hungarian fish species can be found and relatively easily caught here.

Ecological state of the reservoir is continuously monitored by the water authorities. The filling succession of the reservoir basins is controlled by dredging and cutting of the macrophytes, thus the operation of the reservoir and its services are sustainably ensured.

DISCUSSION

Although there are many evidences that human activities in the Carpathian Basin had pronounced impact on the waters even in the medieval period, the comprehensive alteration of rivers and lakes started only in the 19^{th} century. The huge wetlands that covered approximately 20% of the Great Hungarian Plain were drained, water level of the large lakes i.e. Lake Balaton, Lake Fertő were stabilised. The large rivers Danube, Tisza and each of their tributaries were regulated and an extended network of channels and embankments were established to satisfy the demands of safety, and the new agriculture, industry and trade. By the end of the 19^{th} century the existing water network had been developed and successfully managed from hydrological point of view, but especially from the second half of the last century the growth of industry, the industrialised agriculture, the overuse of waters resulted in serious pollution in lakes and rivers, which frightened and destroyed the health of the ecosystems and jeopardized the rational use of water resources. As it was shown above solution of these problems required measures that were specific to the type of pollution and to the type of water bodies. Due to these efforts quality of the surface waters has greatly improved in Hungary. However, a number of problems have not been solved yet. The global warming results in several problems i.e., unpredictable precipitation regime and thus water level fluctuation in lakes and rivers, or invasions of alien species both plants and animals that not only endanger the elements of the native flora and fauna, but can cause serious water quality and health problems. These factors mean a great challenge for water management in the near future.

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