PRE-RESERVOIRS FOR REDUCING NUTRIENT INPUTS FROM DIFFUSE SOURCES—A CASE STUDY

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Contents

Summary

This paper evaluates the applicability of pre-reservoirs for reducing diffuse nutrient loads to lakes using the example of Lake Balaton and the Kis-Balaton Reservoirs, Hungary. Operational experience of the Kis-Balaton Reservoirs is presented from the point of view of both nutrient retention and nature protection. On the one hand, the open water Upper Reservoir contributed to the 40% reduction in total P load to Basin 1 of Lake Balaton, and thereby to the recovery of the lake. On the other hand, partial inundation of the Lower Reservoir sharpened the conflict between water quality management and nature protection. The main reasons behind the protests from nature protection organizations were deterioration of the physiological status of reed in the inundated area (the Ingói wetland), the expected loss of wet meadows in the area of the

Lower Reservoir to be inundated in 2003, as well as the lack of data and intention to predict ecological changes associated with inundation.

The paper concludes that pre-reservoirs do not replace but efficiently supplement comprehensive measures taken to reduce transfer of P from terrestrial to aquatic environments. A key element of the latter is environmentally sound management of the agricultural production. This is, however, a long-lasting process that requires continuous testing of both environmental and socioeconomic impacts. Pre-reservoirs allow time for developing and realizing integrated watershed management approaches, and they are capable of polishing otherwise uncontrollable loads.

1. Introduction: The Objective

Lake Balaton is an internationally recognized recreational lake that, at the same time, possesses outstanding ecological values. The watershed is primarily agricultural. Elevated nutrient loads resulted in a rapid eutrophication during the 1970s. Large-scale management measures taken from 1985 led to a 40–50% reduction of the phosphorus (P) load to the lake. Recovery could be observed from the mid-1990s, when the algal biomass decreased significantly and gradual regeneration of the aquatic communities from the phytoplankton to the fish was recorded.

Loads from point sources were decreased by sewage diversion from about one-third of the shoreline area (Figure 1) and by introducing P precipitation at the largest sewage treatment plants of the watershed. The Kis-Balaton pre-reservoirs were planned and partially implemented in order to manage diffuse loads from agricultural sources (Figure 1). Although the Upper Reservoir indisputably contributed to the reduction of the nutrient loads to Lake Balaton, several questions arose from the viewpoint of both managing diffuse loads and compromising between nature protection and water quality management. This paper discusses the significance of pre-reservoir construction within a broader watershed context focusing on the positive experience and outlining strategic problems that are created or cannot be solved by pre-reservoirs.

2. Description of the System

2.1 Historical Aspects

Lake Balaton (Figure 1) is a relatively young (10 500 to 12 000 years) glacial formation. Since the lake is naturally undrained, historical water level fluctuations exceeded 10 m. The largest tributary, the Zala River, used to form an inland delta in the lower Zala River Valley. Long-term climatic fluctuations resulted in periodic extensions and retreats of the open water and wetland areas. Distribution and chemical composition of generic soil types indicate that the present Upper Kis-Balaton Reservoir might repeatedly switch between wetland type and terrestrial habitats at geological timescales. The water level of the lake was lowered by 3 m during the last century in order to protect from floods the Southern Railway, which connected the capital of Hungary, Budapest, with the single harbor of the Austro-Hungarian monarchy, Fiume. As a consequence, the lower Zala River Valley lost its functional connection to the lake. An open water area of 15 to 20 km^2 and the surrounding wetlands of 60 to 80 km^2 were partially drained. Repeated attempts to gain agricultural land failed. The Lower Kis-Balaton developed into a diverse wetland habitat where the first Hungarian National Reserve was founded in the early 1950s. Reed stands occupied the deepest area, that is, the present Ingói and the downstream part of the Lower Reservoir (Figure 1). Frequent inundations maintained wet meadows in the southern areas of the Lower Reservoir.

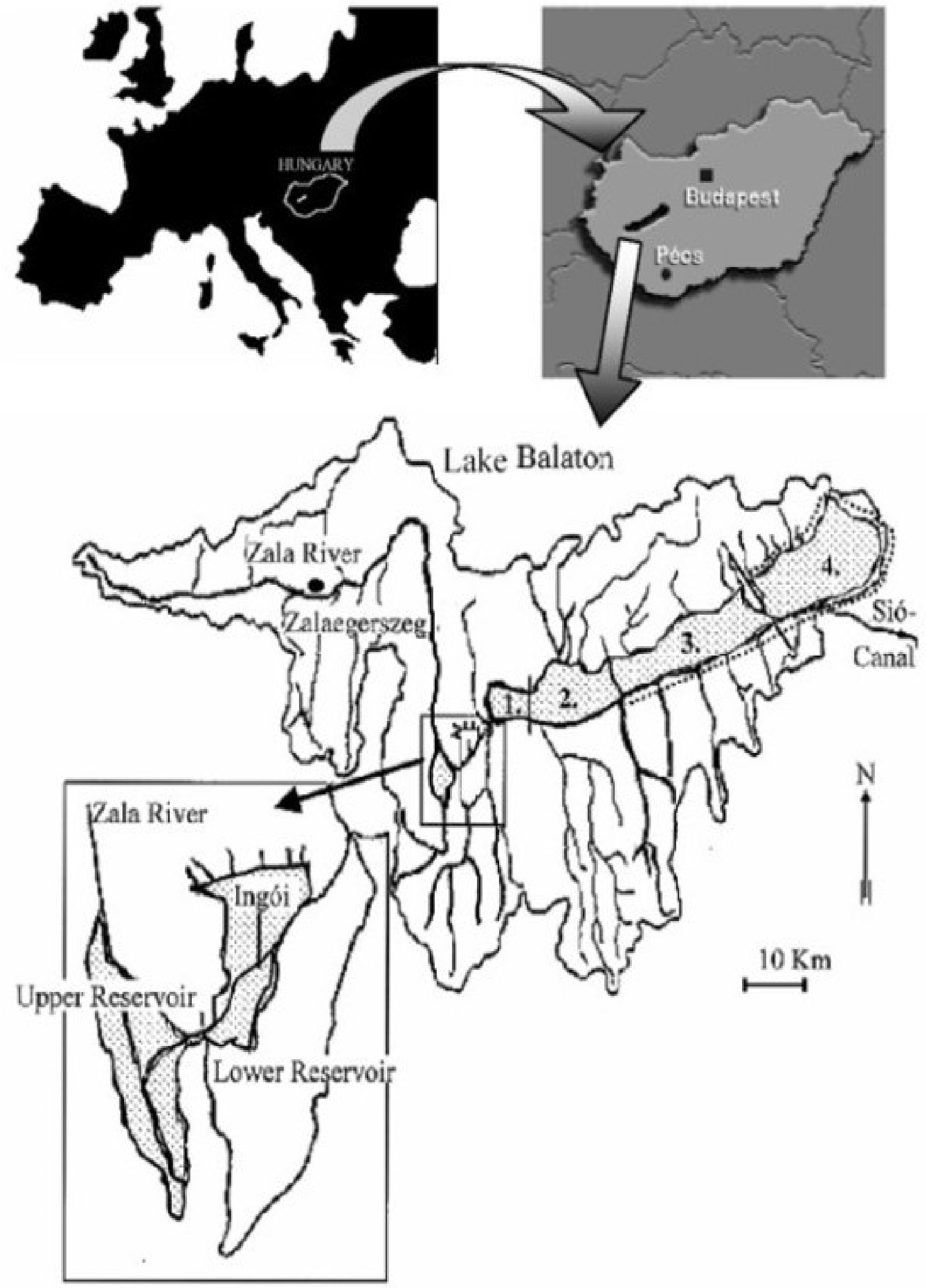

Figure 1. Lake Balaton and its watershed area

2.2. Limnology of Lake Balaton

Lake Balaton is the largest shallow lake in central Europe (Figure 1, Table 1). The elongated lake can be divided into four basins. The Zala River with a mean water discharge of 7.8 $m^3 s^{-1}$ (1976–1997) drains about half of the total watershed into the smallest Basin 1. The only outflow, the Sió Canal, connects Basin 4 with the Danube. The water level of the lake is regulated within a narrow range (±20 cm).

	Volume	**Mean depth**	**Surface area**	**Area of subwatershed**	**B/A**
	($\times 10^6$ m^{-3} y^{-1})	**(m)**	**(A, km^2)**	**(B, km^2)**	
Balaton	1907	3.2	596	5180	9
Basin 1	82	2.3	38	2750	72
Basin 2	413	2.9	144	1647	11
Basin 3	600	3.2	186	534	3
Basin 4	802	3.7	228	249	1
Upper Reservoir	21	1.1	18	1779	99
Lower Reservoir	80	1.2	67	837	12
Ingói	~10	~0.6	16	87	5

Table 1. Morphometric features of Lake Balaton and the Kis-Balaton Reservoirs

On a dry weight basis, 50% of the sediments are carbonates, whereas iron and organic matter contents are low. Intense wind-induced water motion restricts growth of higher plants to a narrow shoreline area. The water contains about 400 g m^{-3} of calcium and magnesium bicarbonates; the mean pH is 8.4. Phosphorus is the most important limiting nutrient for algal biomass. The concentration of soluble reactive phosphorus (SRP) is typically close to the limit of detection (1 to 2 mg P m^{-3}). Transparency varies between 20 and 80 cm as a function of calcite formation, frequent sediment resuspension, and algal blooms. The characteristic summer alga is *Ceratium hirundinella*. The N_2-fixing, toxic cyanobacterium *Cylindrospermopsis raciborskii* became the key species during eutrophication. The biomass of zooplankton is low; primary production is mostly channeled to fish through the benthic food chain. Energy dissipation is significant along the food web. Fish production makes up only 0.3–0.4% of the primary production. Most (70–80%) of the commercial catch (1200 tons y^{-1}) is bream. The top predator is pikeperch, which comprises 6–12% of the annual harvest.

2.3 Socioeconomic Trends and Major Sources of the Present P Load

The tourist trade rose by a factor of 14, and the number of permanent inhabitants doubled in three decades from the 1950s. The beautiful surroundings (Figure 2), high number of sunny days, warm water, and excellent vines attracted 2 million tourists each summer to the recreational area during the 1980s. Yearly income from tourism represents one-third of Hungary's total tourist income. Sewerage construction started in the mid-1950s, but only 15% of the utilized water received secondary treatment in 1975. Sewage diversion and introduction of P removal decreased direct sewage load of P from 45 tons P y^{-1} in the late 1970s to 3 tons P y^{-1} in the 1990s. Sewage P load transported by the tributaries is still high (about 65 tons P y^{-1}) and represents one-third of the present load. The sewage treatment capacity of 81 000 m^{-3} d^{-1} is to be developed by 7000 m^{-3} d^{-1} during the next decade in the watershed of Lake Balaton. Sewage P load should further be decreased by lowering the present effluent standard of 1.8 g P m^{-3} to 0.5 g P m^{-3} in the largest treatment plants.

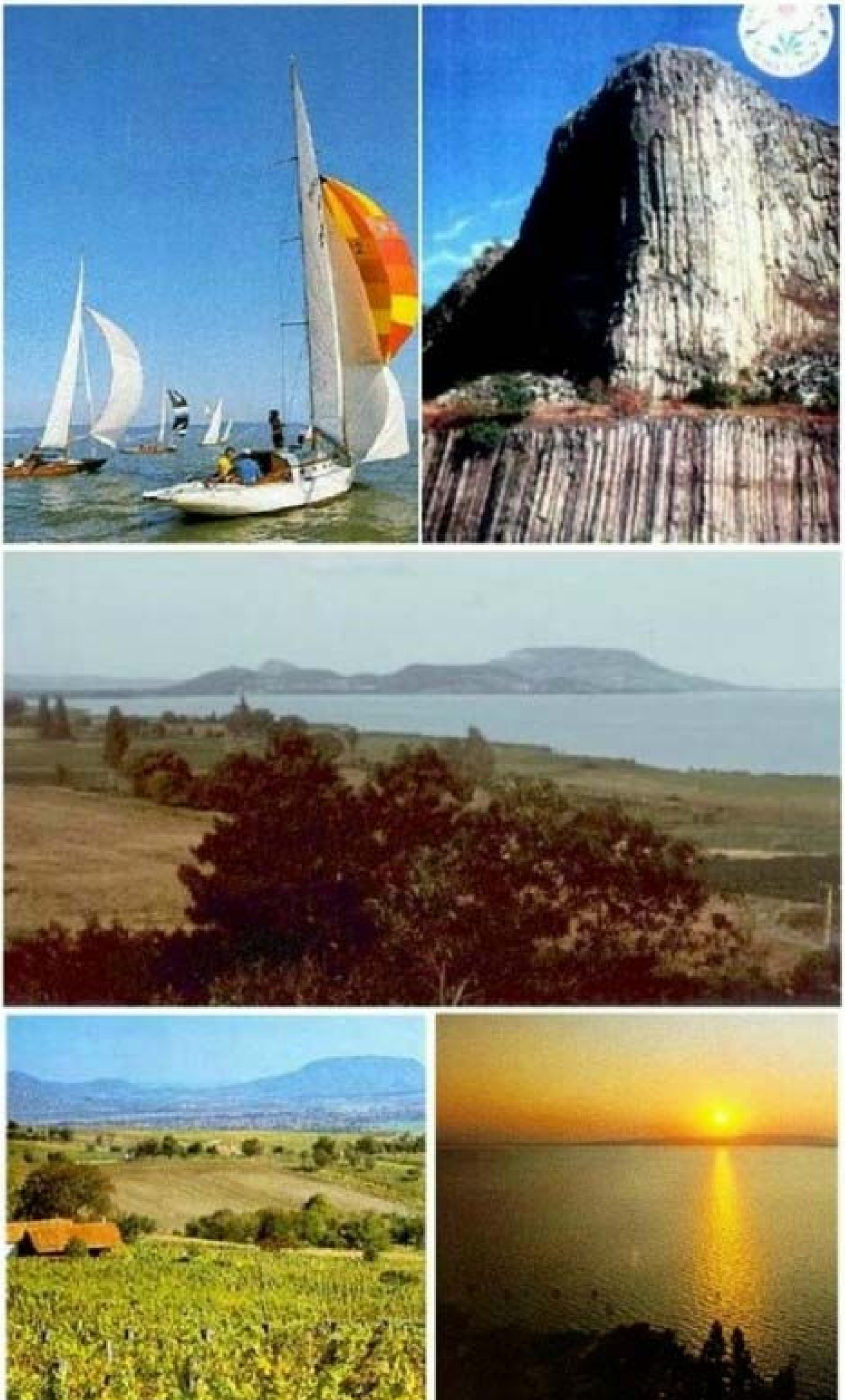

Figure 2. Lake Balaton in pictures

More than half of the watershed is cultivated (Figure 3, Table 2). Livestock breeding is strictly controlled, new animal farms are not allowed. Soil erosion and fertilizer application supply about one-third of the present P load to Lake Balaton. In the watershed of the Zala River, the ratio of diffuse P load may reach 50%, whereas that of the diffuse N load is 60–70%. Soils are strongly eroded in the watershed of the Zala

River and in the northern subwatershed of Lake Balaton, particularly when they are used as arable land, orchards, and vineyards. The majority of the traditional vine-producing areas is situated on the southern slopes of volcanic hills along the northern shoreline. Thus, the transport route of loads carried by surface runoff is very short from areas with the highest rates of specific P emission. Annual soil loss ranges between 4 and 6 thousand tons km^{-2}, and the highest rate can reach 17 thousand tons km^{-2}. Fertilizer application (Table 3) in excess of the plant requirements increased the P content of the soils by 20–25% between the 1960s and the 1980s. After the major political change in 1989, the concept of agricultural development changed radically. Instead of quantitative production, quality, efficiency, economy, and environmental protection became prime issues. The transition to the new agricultural policy is still in progress. Undesirable and chaotic features are often characterized the process. Thus, privatization drastically decreased the size of farming units and fields to a mean size of only 1 to 2 ha, that is, far beyond the limits of the contemporary agrotechnological means. The sudden withdrawal of the previously high state subsidy from mineral fertilizers reduced the rate of fertilizer application to levels that led to a negative net budget and would not maintain the former yield in the long run.

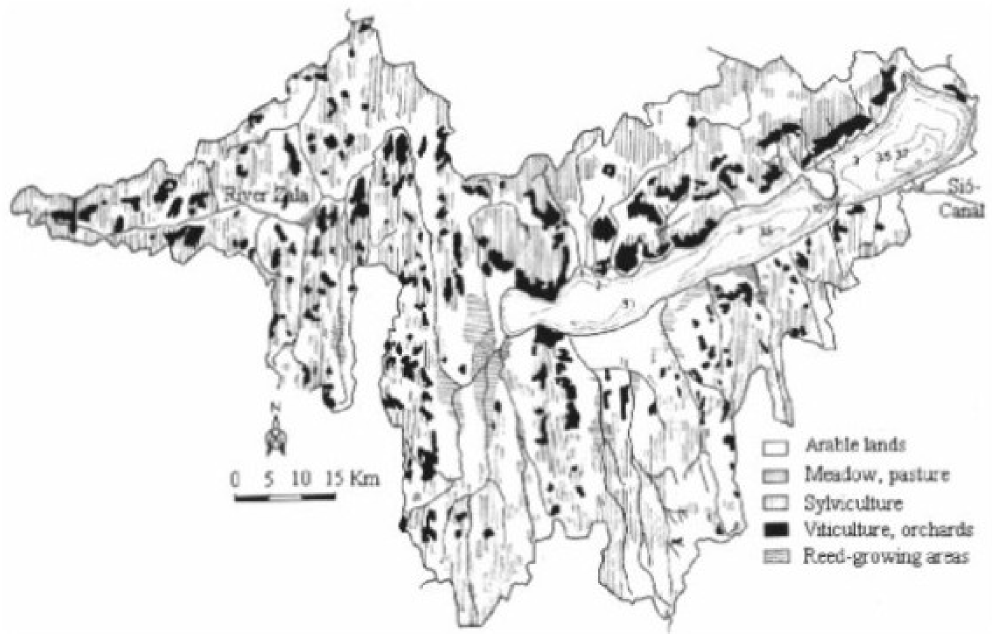

Figure 3. Land use in the watershed of Lake Balaton

Land-use type	**Percentage of catchment**	**Percentage distribution in slope categories**				
		<5	**5–12**	**13–17**	**18–25**	**>25**
Arable land	39	68	20	8	3	1
Meadows	7	100	0	0	0	0
Pasture	6	73	12	5	7	3

Orchard and vineyard	7	41	28	17	11	3
Forest	28	25	40	30	3	2
Uncultivated	13	90	0	0	0	10

Table 2. Slope distribution of various land-use types

Period	**Manure**	**Mineral fertilizers**		
	($\times 10^3$ tons y^{-1})	**($\times 10^3$ tons N y^{-1})**	**($\times 10^3$ tons P y^{-1})**	**kg ha^{-1}**
1931–1940	1023	0.03	0.14	2
1951–1960	968	1.55	0.66	15
1961–1965	941	6.64	1.96	57
1966–1970	1014	12.40	3.49	109
1971–1975	676	18.88	5.79	218
1976–1980	653	23.45	6.90	250
1981–1985	710	23.55	7.10	282
1986–1990	621	25.00	6.00	230
1991–1995	155	5.79	0.28	55

Table 3. Fertilizer application in the watershed of Lake Balaton

The remaining one-third of the P load originates from urban runoff, primarily from the direct watershed of the lake. Besides tourist pressure, this is a result of unfavorable infrastructure developments during the past 150 years. Railways, roads, recreational areas of settlements concentrate all along the shoreline. When collected, storm water enters the sewerage.

Industry does not play a major role in the watershed. Consequently, pollution of the lake by heavy metals and other toxic chemicals is negligible. Cessation of the bauxite mining and the associated discharge of karstic water into surface flows of Lake Balaton in 1988 decreased the hydraulic load of Basin 2 by 40% and that of Basins 3 and 4 by more than 60% relative to the period 1976–1987. Decreased hydraulic load led to a dramatic increase in the theoretical water retention time in the early 1990s. The prescribed water level of the lake could only be maintained by abandoning the drainage through the Sió Canal in 1991 and 1993.

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Biographical Sketch

Dr. Vera Istvánovics received her MSc in Biology from the Loránd Eötvös University, Budapest. During 1979–1997 she was a staff member of the Balaton Limnological Research Institute of the Hungarian Academy of Sciences. Since 1998 she has been a member of the Water Research Group of the Hungarian Academy of Sciences hosted by the Department of Sanitary and Environmental Engineering, Budapest University of Technology and Economics. She took her Ph.D. degree in 1987, and her DSc degree in 2000. Major topics of her research include phosphorus cycling in different lakes and wetlands, as well as ecological problems associated with water resources management. She had two major topics of research. (1) She studied the magnitude, mechanisms, and the role of internal phosphorus load in different types of aquatic ecosystems by the means of laboratory and field measurements, as well as by using simple mass balance models. (2) She investigated phosphorus uptake by planktonic microorganisms and aquatic macrophytes. She developed a new approach for evaluating uptake data obtained by measuring ^{32}P uptake kinetics of the phytoplankton. Applying this approach, distinct P uptake and growth strategies of phytoplankton groups could be identified during algal succession. In order to understand mechanisms of bloom formation, she studied P uptake of various cyanobacteria (*Gloeotrichia echinulata*, *Cylindrospermopsis raciborskii*). During the last decade, she has supervised one to three projects each year. The most important international project in which she takes part started in February 2000. This is a cooperative research project between Israel, Hungary, Sweden, and Germany financed by the European Community. The title is “Interactive regulation of phytoplankton succession by physical forcing and internal phosphorus loading: a comparative study in eutrophic freshwater lakes” (EVK1-CT-1999–00037). She has published over 55 papers, most of them in recognized international journals.