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Eutrophication: Status, Trends and Restoration Strategies for Palic Lake

Vera Raicevic, Mile Bozic, Zeljka Rudic, Blazo Lalevic,
Dragan Kikovic and Ljubinko Jovanovic

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1. Introduction

Eutrophication is the general term used by aquatic scientists to describe the suite of symptoms that a lake exhibits in response to fertilization with nutrients [1]. Common symptoms include dense algal blooms causing high turbidity and increasing anoxia in the deeper parts of lakes from the decay of sedimenting plant material. The anoxia can in turn cause fish kills in midsummer [2].

Aging process is a principal characteristic of each lake. This process is generally very slow in geological sense, but the aging of shallow lakes (like Palic lake is) is much faster. Eutrophication is not necessarily harmful or bad; it's a Greek word, which means "well nourished" or "good food." However, eutrophication can be artificially accelerated, eventually leading to the suffering of its inhabitants, as the nutrients input increases far beyond the lake's natural capacity.

Eutrophication of lakes and reservoirs is a degradation process originating from the introduction of nutrients from agricultural run-off and untreated industrial and urban discharges [3]. Accelerated eutrophication of lakes and reservoirs experienced during last century in most parts of the world represents a serious degradation of water quality, not only in the developing countries [4-6], but also in developed countries [7-10].

Surface waters are not isolated from their environment, neither from human activities. Therefore, the inorganic and organic matter continuously feed these waters and consequently accelerate the process of natural eutrophication. Waters coming from treatment plants in Subotica town, have been loading this lake for decades, attributing to high nitrogen and phosphorus loadings of Palic Lake together with numerous diffuse pollutants from surrounding villages and agricultural surfaces. Agriculture has been

identified as one of the primary contributors to non-point source nutrient losses in the USA [11].

Over the past decades, numerous restoration projects have been carried out to control and reduce the negative effects of eutrophication and to improve water quality.

Engineering approaches for improving water quality have focused mainly on control of external nutrient loading, sediment degrading and prevention of the release of phosphorus from sediments through chemical treatments [12]. However, lakes often exhibit a delayed response of a reduction in external nutrition. That situation is likely caused by the release of phosphorus from a pool that has accumulated in the sediment during the period of high nutrient loading [13-14].

Research also suggests that restoring macrophytes could provide long-term improvement in water quality [15]. Thus, in recent years, there has been an increasing focus on the importance of constructed wetlands in ecosystem restoration [16-18]. Possessing multi-functions such as water storage, flood detention, water purification, nutrients transformation, and ecosystem biodiversity, wetlands have been recognized as an important part of aquatic ecosystems [19].

The aim of this review is to compare the water quality parameters of Palic Lake in past 20 years with its quality in 2010, as well as to perceive the possibility to apply ecoremediation technologies in remediation of Palic Lake.

1.1. Lake characteristics, nutrient input and vegetation

The Palic Lake is a shallow Pannonian lake, created million years ago, during creation of pits and dunes by wind erosion. The lake was filled mostly by atmospheric precipitation. It is situated 8 km from Subotica, near the town of Palic and covers an area of 3.8 km².

This area is characterized by continental climate, with a severe winters, hot summers and irregular distribution of precipitation. The average air temperatures are 10.8°C (Table 1), air humidity is 69% and air pressure is 1007mb. Annual number of rainy days is 105 and the average perennial mean precipitation values are 561.1mm, while the number of days with snow cover is 59 per year. This area is also characterized by strong winds (wind speed more than 6 Bf, i.e. 34 km/h), during 104 days per year [20].

jan	feb	mar	apr	may	jun	jul	aug
-0,8	1,2	5,9	11,1	16,8	19,9	21,6	20,9
sep	oct	nov	dec	min	med	max	
16,5	11,1	5,2	0,7	9,6	10,8	12,7	

Table 1. Monthly mean temperatures (°C)

Highest precipitation output [20] is during late spring and beginning of summer (June), and the lowest is in winter time – January, February and March (Table 2).

jan	feb	mar	apr	may	jun	jul
32,5	32,3	33	44,9	53,1	75,3	62,3
aug	sep	oct	nov	dec	year	
59,2	44,1	36,8	43,2	44,4	561,1	

Table 2. Monthly mean precipitation (mm)

This lake is separated into 4 sectors (Fig. 1). Sector 2, which covers the area of 81 ha, has been made to improve the quality of inflowing water from wastewater treatment plant. Sector 4, the biggest part of the lake, is designed for recreational purposes. It covers around 372 ha and the initial depth of lake was 2 m. Nowadays, some parts of the lake are covered with thick sediment layer, causing variations in lake's depth.

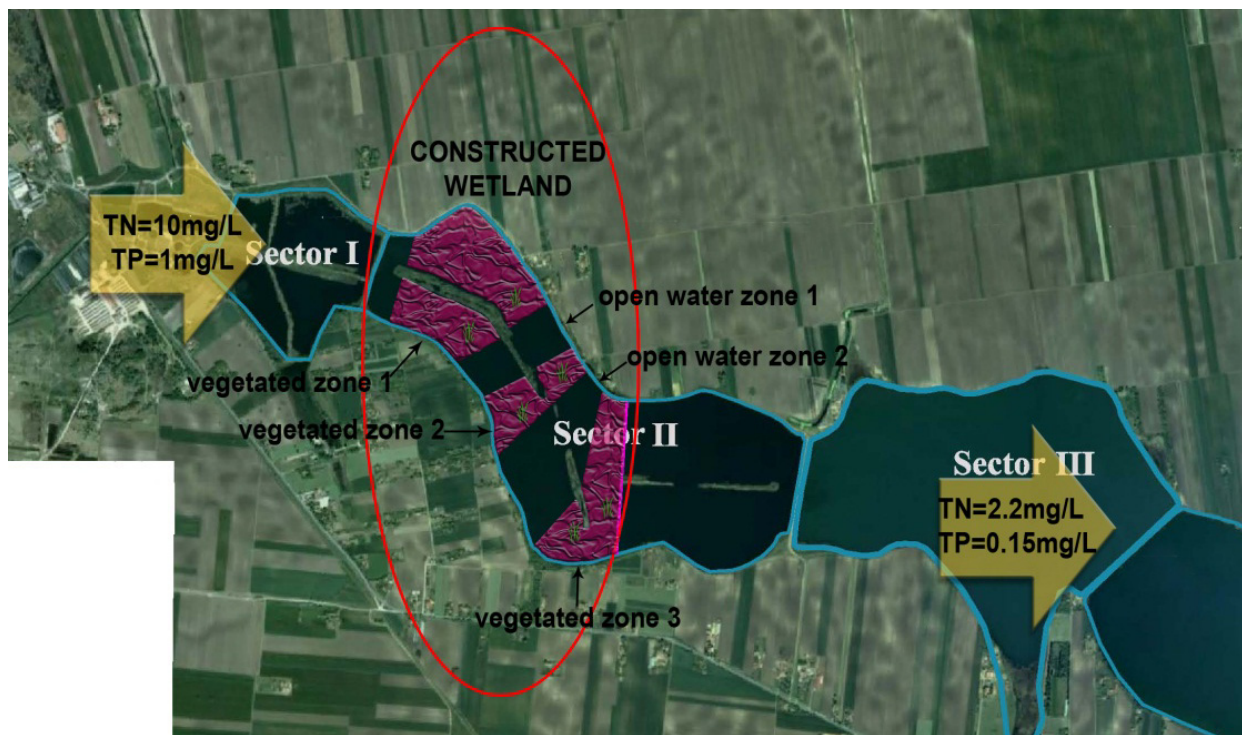


Figure 1. Sectors in Palic Lake (red circle - target place for restoration)

Central section for wastewater treatment of Subotica town lies in the depression of the far west end of Palic Lake. Water from this treatment unit inflows into the lake. Wastewater treatment plant (WWTP) of the city of Subotica was built in 1977, and since then the capacity of the plant was enlarged (in 1983). In 1997 it has been revealed that the amount of influent was 80% higher than the planned one. This excessive wastewater has predominantly originated from precipitation that clogged and blocked the operation of treatment facility unit. In the period of extremely high precipitation, the excess water was transported into lagoons and further on, as untreated water, into the lake. In 1985 the capacity of treatment unit was enlarged, but due to numerous omissions, the so called "treated" wastewaters have been discharged into the lake. The analyzed data show that the lake was loaded with more than 4t of total phosphorus in August 1970.

The new treatment section for wastewaters has been released in 2009, but it wasn't technically accepted until 2011. The quality of treated wastewater, discharged into the Sector 1 of Palic Lake, meets the objectives of Directive 91/271/EEC, according to which the following parameters are being controlled: BOD₅ 25 mg/l; COD₅ 125 mg/l; suspended solids 35 mg/l; total N 10 mg/l; total P 1 mg/l.

The capacity of new WWTP is 36.000m³, while during rainy days it gets enlarged up to 72.000m³. The new treatment facility has shown to be very efficient in achieving good effluent quality regarding all the analyzed parameters. The amount of discharged water from new WWTP into the lake is bigger, but its quality is undoubtably better (Figure 2). This will certainly influence the processes in the lake.

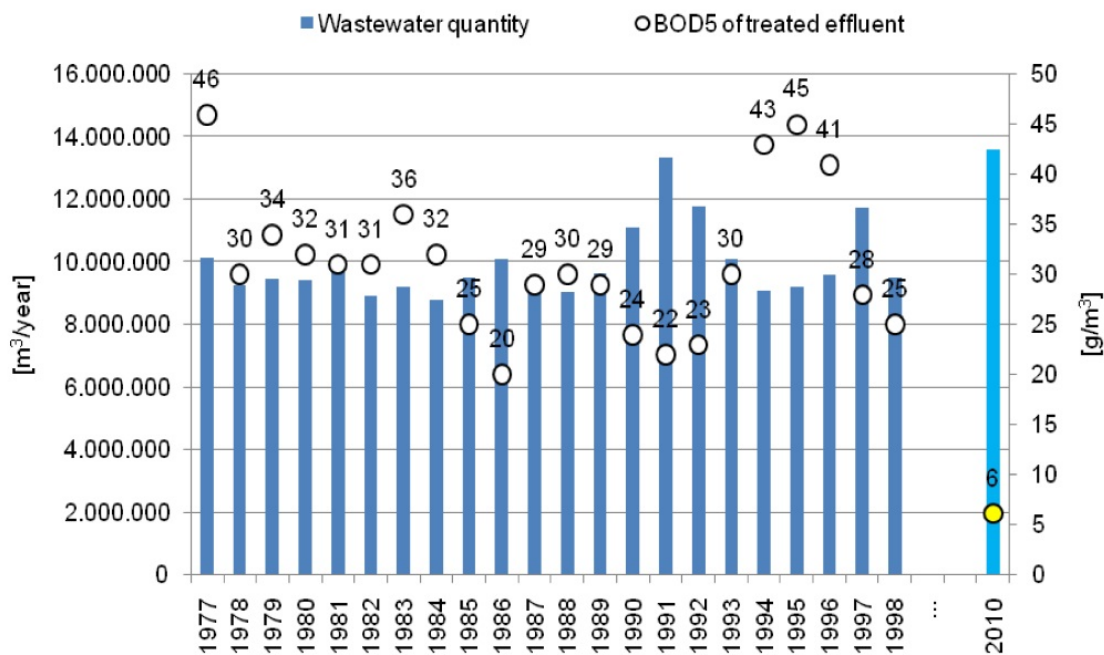


Figure 2. Wastewater amount and effluent quality (BOD₅) during period from 1977-2010

Beside the effluent from the treatment facility being the greatest source of nutrients in Palic Lake (although the treatment of domestic and industrial wastewaters has positive effect), there is contamination from numerous pollutants additionally destroying the biological balance of the lake. There are cultivated areas near the lake with intensive farming, which assumes the application of mineral fertilizers and pesticides; as well as livestock farm without appropriate collection and treatment of wastewaters. There are also resident weekend facilities and rural settlements nearby with catchpits. All the surrounding wastewaters should be collected and transferred to the wastewater treatment plant, before the remediation and cleaning of Palic lake sludge.

In recent years there have been some changes in turistic and recreational characteristics of lake's environment, leading to the deterioration of indigenous vegetation of coastal zone. But land reclamation for establishment of arable agricultural land influenced these changes as well.

There are conditions for survival of community *Ceratophylletum demersi* in 3rd sector, famous for its submerged stands, the indicators of deep and cold waters in warm and eutrophic aquatic ecosystems. The domination of these dense populations of *Ceratophylletum demersi* community, is an indicator of significant nutritional values of this area. The characteristic growth of the community *Lemnetum gibbae* on one locality of Palic lake in reed cover and around reed vegetation, indicates the presence of shallow, warm and trophogenic backwater.

Marsh vegetation is a dominant flora here with reed cover, presented by the association Scipro-Phragmitetum W, Koch, and typical stands (subass: Phragmitetosum Schmale 1939) and stand of timothy grass, i.e. subass: typhetosum (angustifoliae-latifoliae) Soo 1937. Reed and timothy grass are present in the form of dense populations by the coastal edge of the island in the second sector of the lake. They are less frequent in third sector, while in the first sector of the lake they form narrow region around the lagoons and on the lagoon dikes [21].

In geographical aspect aquatic marsh plants haven't got great significance, because they are widely spread in most cases. But their significance lies in the maintenance of ecosystem's balance, and they also represent natural habitat for a large number of birds from the surrounding area. Beside this, semiaquatic coastal vegetation has also the antierosion role. In certain parts of sector 2 in the coastal zone the stand of high yields of order Magnocaricetaria PIGN1953 is fragmentally developed.

The northern loess coast of Palic lake represents one of the rare settlements of the preserved ancient steppe. One part of this rare habitat is permanently exposed to rockslide and total devastation, due to high water levels, which disables the growth of coastal reed belt. Because of formation of pathways for local fishermen and peasants, very near to the coast of the lake, the narrow belt of steppe vegetation is under intensive invasion of weed, especially row weed [21]. Beside these populations, there are some pioneering sand stone species like *Bromus squarrosus* i *Centaurea arenaria*. There is only partial presence of steppe elements like *Festuca rupicola*, *Agropyron cristatum* subssp. pectinatum f. puberulum are, with dense populations of *Allium scorodoprasum* subssp. Waldsteinii. The coast of Palic lake is inhabited by exceptional trees of *Salix alba* and rare individual trees of *Populus alba*. Very invasive species *Eleagnus angustifolia* is grown all around this coastal area. On the islands of the sector 2 there is a stand of *Populus alba*, from which the invasive belt of *Acer negundo* is being spread. Shrubby vegetation covers the high coast of the lagoons in sector 1, which also enters the reed cover of the lake. There are also numerous individual plants like *Sambucus nigra*, *Lonicera caprifolium*, *Rosa canina* and *Spiraea media*. Herb stratum is very well developed, and being followed by the trees of white poplar and white willow.

2. Status and trends: Phosphorus and nitrogen loadings and BOD₅

Lakes are not only a significant source of precious water but also provide valuable habitats to the biological world. The major impact of eutrophication, due to overloading with nitrogen and phosphorus, are changes in structure and functioning of lake's ecosystem, reduction of biodiversity and reduction of fishery and tourism. Impairment of water quality

due to eutrophication can lead to a series of problems and result in loss of ecological integrity, sustainability and safe use of aquatic ecosystems [22]. Phosphorus and nitrogen are major nutrients causing eutrophication.

Phosphorus is usually the main nutrient responsible for eutrophication of freshwater. The results from each lake sectors (X - axes) of average annual phosphorus concentrations have shown to have linear regression (Figure 3). When separately analyzing each single year, the results are regression curves of similar incline angle. Almost all of them are translatory moved in regard to the resulting average for the studied period. These results show that the Palic Lake regulates the content of phosphorus as well as the existence of self-cleaning ability, but also the fact that it is being loaded with excessive amount of phosphorus.

Determination of total phosphorus by ammonium molybdenum and ascorbic acid, have shown the decrease of its total content in 2010 comparing to previous years.

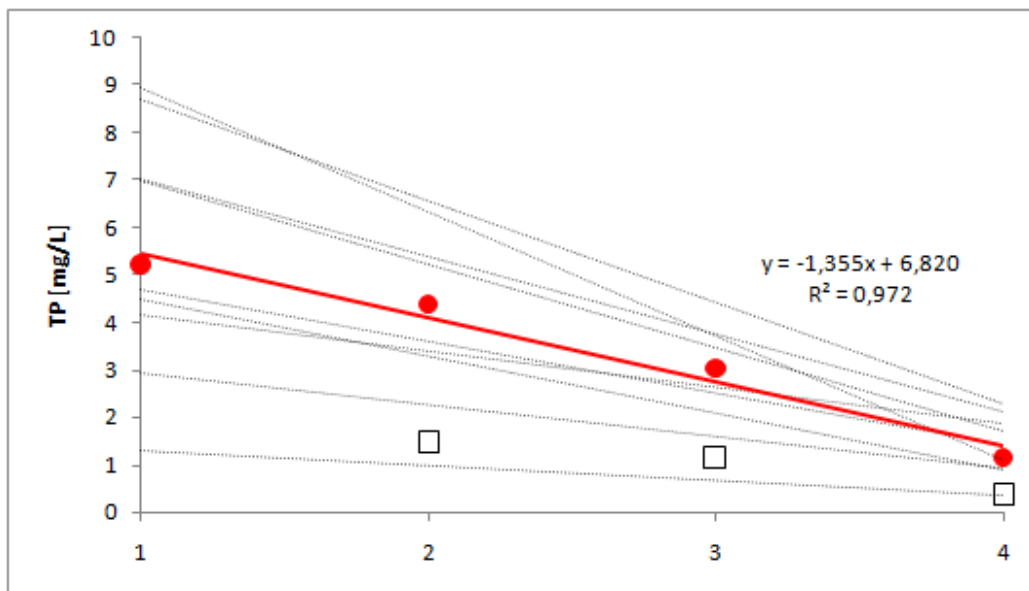


Figure 3. Total phosphorus concentration trends in sectors of Palic lake (mg/l) during period from 1978 – 2010

Nitrogen reaches aquatic ecosystems through direct binding with living organisms, atmospheric precipitation and nitrogen rich inflowing waters. The previous research conducted during period from 1977-1998 show that nitrogen loadings were mainly originating from wastewater treatment facility, with discharges of 591,8 t of nitrogen into sector 1 [23].

The highest amount of nitrogen in Palic Lake is in sector 1, while its content decreases in sector 4. This trend is also noticeable in the year of 2010. These results show the efficiency of lake in reducing total nitrogen content.

Although it should be taken into account that certain portion of generated nitrogen during production of organic matter is being built in live organisms. Hence, after the mineralization of dead organisms it is being returned into the matter cycle in the lake.

The red line (circle) indicates trend in decreasing nitrogen concentrations of each examined year (Figure 4). Thin point lines represent yearly trends (1978 - 2010), and squares indicate the check measurement conducted in 2010.

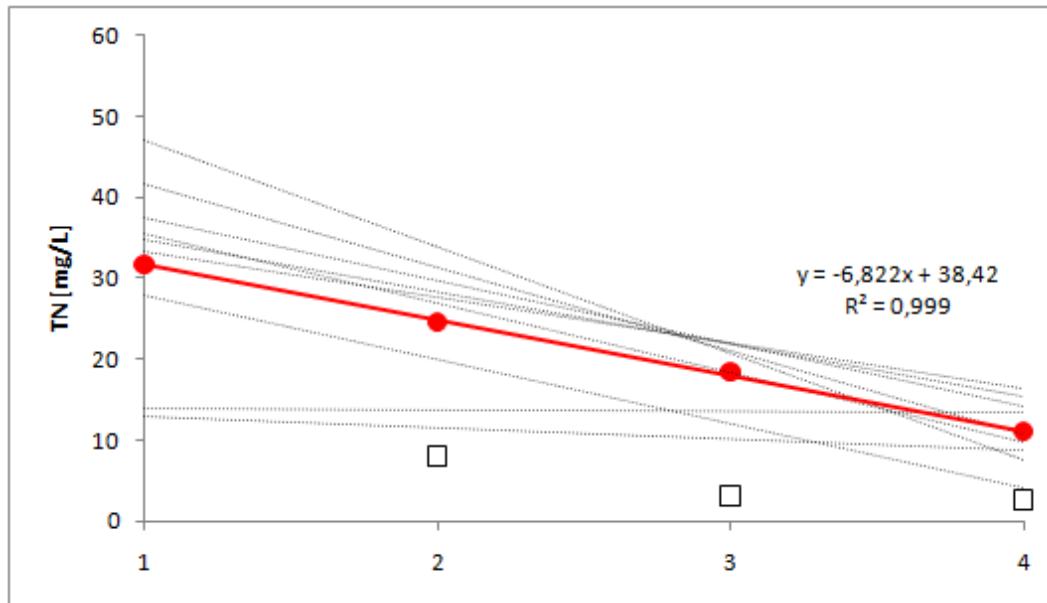


Figure 4. Total nitrogen concentration (mg/l) trends in sectors of Palic lake during period 1978 - 2010

BOD values expressing organic matter loading are rather high for surface water and emphasize the high level of pollution.

In the period before the year 2000, BOD₅ values have been descending from sector 1 to sector 4 (X – axes), but from the beginning of year 2003 these values have been decreasing from sector 1 to sector 3, and then rapidly ascended in sector 4 (Figure 5).

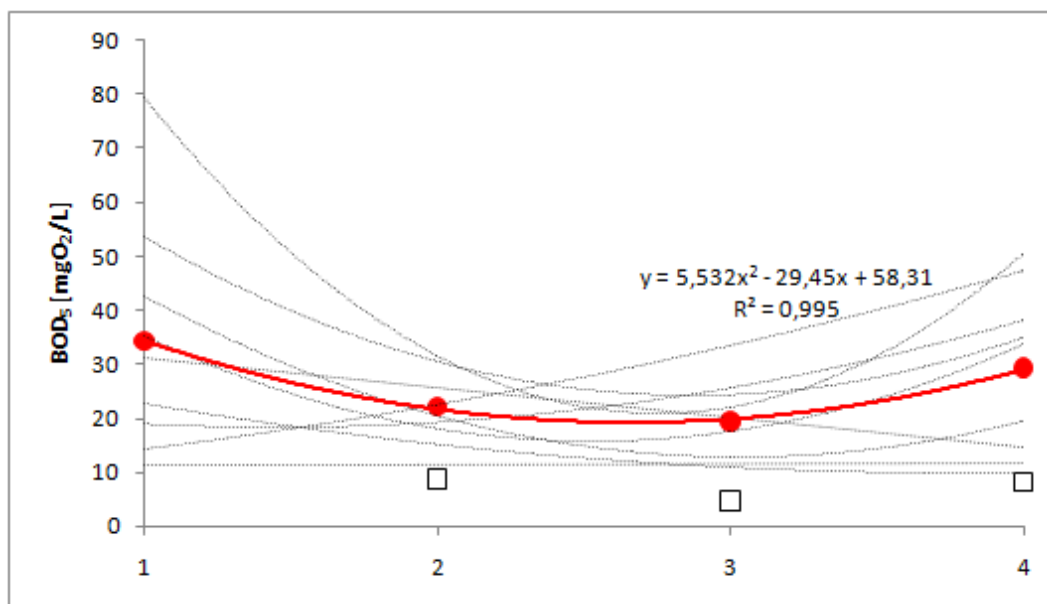


Figure 5. BOD (mg/l) trends in sectors of Palic lake during period 1978 - 2010

These high BOD₅ values are the consequence of biomass hyper production in sector 4. In comparison to measurements from previous 20 years and measurements from the year 2010, it is noticeable to have the decrease of BOD₅ in all sectors of Palic Lake.

3. Restoration of the lake

The following review deals in detail with the quality of water and sediment in sector 2, since this sector is designed to additionally clean the wastewater.

3.1. Methods for determination of water and sediment quality in sector 2 of Palic Lake

Water sampling has been conducted by 3 liters Friedinger bottle, and the undamaged sediment has been taken by "core sampler" method (Eijeklkamp). Two different sediment layers are clearly defined in Palic lake by color and consistency: the black (oily) one, 20-25cm thick and the grey layer which is in contact with water, being 40-45cm thick. All samples were transferred to laboratory during 4h from the ending of sampling. The analyses of easy variable parameters and microbial activity of samples were performed immediately after their receiving in laboratory.

As mentioned previously, the content of total phosphorus has been determined by spectrophotometer using ammonium molybdenum and ascorbic acid. The same method, with N,N-dimethyl-p-phenylendiamine, was used to determine H₂S. Electrochemical methods helped in defining the oxygen saturation, BOD₅, electro conductivity, pH values in the field and laboratory. Chemical oxygen demand (COD) was determined by oxidation of organic matters with KMnO₄ and K₂Cr₂O₇.

Method of thermo catalytic destruction has been used to set out the total nitrogen. Ion chromatography method was used for determination of NH₄⁺, SO₄²⁻, NO₃⁻, NO₂⁻, and Cl.

Total organic carbon was determined by SRPS ISO 8245.1994 method, total sulphides by EPA 9030B method, and carbonates and bicarbonates by SPRS EN 13137:2005 method.

Trace metals as Pb, Cd, Cr, Cu, Ni, Fe, and Mn have been determined by ICP-OES technique after acidic digestion with concentrated nitrogen acid and H₂O₂. Total arsenic was defined by AAS-atomic absorption spectrophotometry/hibrid technique.

The grain-size distribution was determined by using the pipette method and was classified into clay, silt, and sand fractions.

MPN method was used to determine aerobic mesophylic bacteria, fecal and total coliform bacteria, sulphite reducing clostridia and fecal streptococci.

3.2. Water and sediment quality in sector 2 of Palic Lake

Sector 2 of Palic Lake is characterized by water with high phosphorus and nitrogen content as well as high pH values (Table 3).

In sampling period the water was covered with foam which indicates presence the surface active materials in water. This is due to Serbia still used anionic detergent with phosphate which than caused acceleration eutriphication in shallow water. The content of total organic carbon (TOC) is high which indicates the intensive organic output. High concentration of chloride and sulfate are consequence of theirs high content in treated waters from WWTP. The concentration of ammonium ions are moderate high, but nitrite nitrogen had extremely high. Five day (BOD_5) was 2.2 (Table 3) and is due presence of easily biodegradable organic material the, but in sector 4 the sums was 8 [24].

PARAMETERS	VALUES	PARAMETERS	VALUES
pH	8.6	COD - $K_2Cr_2O_7$ (mg/l)	30
Cl^- (mg/l)	163.7	As (mg/l)	0.045
SO_4^{2-} (mg/l)	434.5	Cu (mg/l)	0.006
NH_4^+ (mg/l)	1.24	Zn (mg/l)	0.0027
NO_2^- (mg/l)	0.902	Fe (mg/l)	0.065
BOD_5 (mg/l)	2.2	Cr^{6+} (mg/l)	< 0.05
NO_3^- (mg/l)	5.7	Cr total (mg/l)	< 0.002
total N (%)	7.93	Cd (mg/l)	< 0.0008
Total PO_4 (mg/l)	1.46	Mn (mg/l)	0.024
TOC (mg/l)	9.81	Ni (mg/l)	0.006
H_2S (mg/l)	< 0.02	Pb (mg/l)	< 0.005
COD - $KMnO_4$ (mg/l)	7	Hg (mg/l)	< 0.0005

Table 3. Chemical analyses of water in sector 2

From the results of the content of heavy and toxic metals in water it can be noticed that heavy and toxic metals do not affect significantly the water lake Palic (Table 5, Figure 5). We should also bear in mind that the water in the lake has high pH values which adversely affects the solubility and availability of metals in water.

The accelerated eutrophication in this sector resulted in formation of significant sediment deposit. This sediment is alkaline by its nature with high percentage of inorganic content and nutrients (Table 4 and 5), the same as the water is.

Phosphorus is a major nutrient for aquatic ecology, and its excess supply can lead to eutrophication. When the external loading of P increases, the sediments act like pool and absorb it. However, after the external loading is reduced, the sediments now as a source would release the adsorbed P back into the water. The characteristics of sediments, environmental factors, as well as the concentrations of P in the overlying water, will affect the transfer direction of phosphate on the interface of the sediment–water [25-26].

The supply of nutrients can directly and indirectly limit the metabolic activity of heterotrophic microorganisms. For example, there is evidence for direct positive effects of N and P on bacterial growth [27] and accordingly, the total bacterial biomass is strongly correlated with concentrations of total phosphorus in fresh-water and marine ecosystems.

The deeper parts of the sediment layer have higher concentrations of heavy metals as a result of historical pollution of the lake. The concentration of As and Ni exceed the defined Holland [28] and Canadian [29] limits, as well as the concentration of Cr which is also higher than the recommended limits, while Cu concentration is just a bit above the maximum threshold (Figure 6).

PARAMETERS	SECTOR II OPEN WATER ZONE 1*	SECTOR II OPEN WATER ZONE 2*
pH	8.45	8.71
moisture (%)	51.64	63.48
dry matter (%)	48.39	36.52
organic part (%)	20.12	22.66
inorganic part (%)	79.88	77.34
total P (mg/kg)	7010	24300
TOC (mg/kg)	44000	65900
SO ₄ ²⁻ (mg/kg)	132	69
Cl ⁻ (mg/kg)	75	158
S ²⁻ (mg/kg)	594	263
CO ₃ ²⁻ + HCO ₃ ⁻ (mg/kg)	37540	31650
total N (mg/kg)	4100	6800
aerobic mesophylic bacteria	4000	10000
fecal coliform bacteria	0	0
total coliform bacteria	0	0
fecal streptococci	negative	negative
sulphite reducing clostridia	30000	10000
other isolated microorganisms	saprophytic cocci, <i>Bacillus</i> sp.	saprophytic cocci, <i>Bacillus</i> sp.

* location of open water zones are given in figure 1

Table 4. Chemical and microbiological analysis of sediment in sector 2

layer depth	water in sample (%)	sand			silt	clay
		> 0.2 mm	0.2-0.02 mm	total		
0-20 cm	43.19	13.44	56.86	70.30	21.90	7.80
20-40 cm	44.38	43.50	38.50	82.00	12.80	5.20
40-60 cm	65.72	41.05	45.75	86.80	9.00	4.20

Table 5. Mechanical analysis of sediment from sector 2

Fecal coliforms and fecal streptococcus haven't been detected in the water (Table 4). It should be noted that in some sectors had detected the presence of fecal coliforms [24]. Periodically in the tourist part of the lake, due to the presence of pathogenic bacteria and reduced quality of water it is necessary to prohibit swimming. Continuously monitoring the

presence of potentially pathogenic bacteria in water, as warned in previous investigations [30], the diseases related to water are the main cause of morbidity and mortality worldwide.

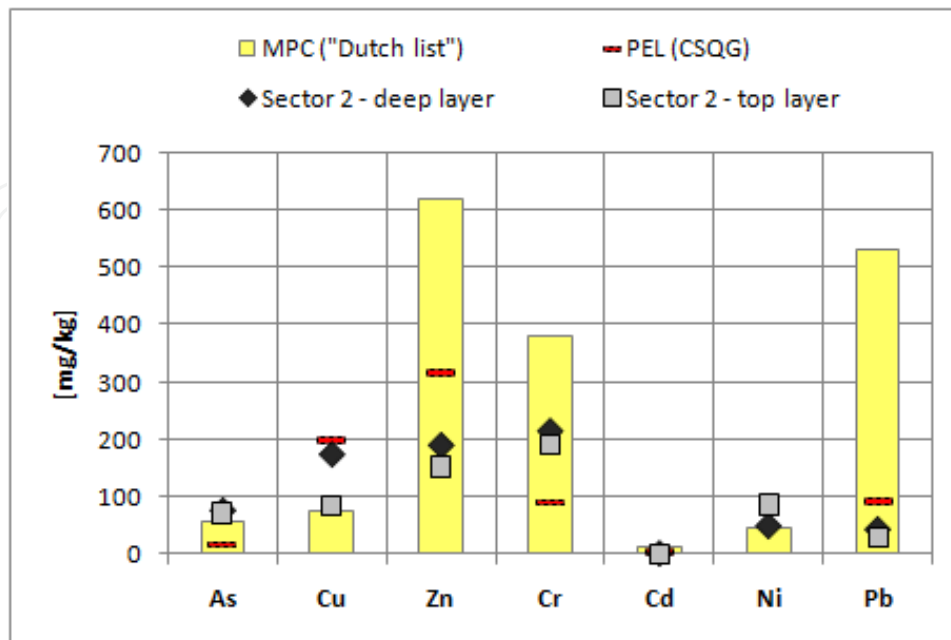


Figure 6. The concentration of As and Ni in Palic Lake (sector 2) compared to Holland and Canadian limits

4. Problem and targets

General problem of Palic Lake is enormous amount of deposited sediment in each sector of the lake (1.9 mil m^3), which is a result of accelerated eutrophication. In the last decades, the wastewater discharge (treated and untreated) mainly increased the nutrient load to the Lake. Human negligence resulted in deterioration of biodiversity and ecological imbalance, i.e. general perturbation of the environment. A restoration of ecological balance and improvement of lake water quality can be achieved by implementation of technical solutions based on ecoremediation principles.

Attempts to manage lake eutrophication have most frequently involved controls of nitrogen (N) and/or phosphorus (P) loads from both diffuse sources [31] and point sources as well as internal loads from lake bed sediments [32].

Hence, essential problems of Palic Lake are inadequate water quality that recharges the lake and abundance of nutrient rich sediment. Construction of wetland in sector 2 would resolve both problems, improvement of water quality and sediment problem. In this manner sector 2 will now have the purpose of additional water treatment. Wetland technology, a design based on natural principles, has the aim of water treatment and water quality improvement using plants, microorganisms, soil and sediment. The additional important role of constructed wetlands is preservation of biodiversity, but also recreation, education, flood control, etc.

Constructed wetland is efficient and reliable technology if properly designed, created and specifically managed. Proper maintenance is also important for their efficiency. Constructed wetlands can remove most of pollutants that are carried by urban, atmospheric and industrial wastewater. Wetland design stimulates a decrease of biological oxygen demand (BOD₅), suspended matter, nutrients (nitrogen, phosphorous), metals (chromium, cadmium, manganese, zinc) and toxic organic pollutants.

Key elements and design criteria are defined in regard to overview and verification of current state [33], systematization and analyses of existing technical documentation and field investigations (survey, geomechanical investigations of soil and sediment, laboratory analyses of physical and chemical characteristics of water and sediment).

1. Sediment:

- sectors 2-4 of the Palic Lake are covered by sediment layer (total volume of 1900160 m³) whose thickness varies in the range 0.3 to 1.5 m; solely in sector 4 there is 1311356 m³ of deposited sediment;
- A portion of inorganic matter in sediment is approximately 80%. Inorganic part consists of 73 % sand (both coarse and fine sand, fraction size 2.0-0.2 mm);
- sediment in sector 3 and 4 is overloaded with plant nutrients – nitrogen and phosphorous, but it is practically free of heavy and toxic metals (concentrations are within acceptable limits, compared to both Dutch and Canadian sediment quality guidelines);

2. Wastewater treatment plant of the city of Subotica (WWTP)

- new WWTP started in year 2009;
- a capacity of new WWTP is 36000 m³/day, up to 72000 m³/rainy day;
- a quality of effluent that flows in the sector 1 is defined according to the Directive 91/271/EEC:

- BOD ₅	25 mg/L
- COD	125 mg/L
- suspended matter	35 mg/L
- total N	10 mg/L
- total P	1 mg/L
- Achieved level of effluent quality in 2011 contributes to lake water quality, without its impairment.

3. Required water quality for sector 4 of the Palic Lake

- required water quality for the Palic Lake, according to Regulation for water classification of the Republic of Serbia, is a class 2a, which means the satisfaction of following standards:

- suspended matter	30 mg/L
- dry matter	1000 mg/L
- pH value	6.8 – 8.5
- BOD ₅	4 mg/L
- most probable number of coliform in 100 ml of water is max 6000
- without smell, colour and visible waste.

- concerning that the effluent is the main source for lake recharge and that annual volume of discharged effluent overrides lake's volume, the quality of the effluent has to satisfy more strict limits than those set by European Union and Serbian legislative. Acceptable values of maximum tolerable risk are:
 - total N 2.2 mg/L
 - total P 0.15 mg/L
- previously listed parameters have to be met at the entrance of the sector 4, to decrease nutrient input and subsequently a risk of accelerated eutrophication.

5. Design elements and technical solution

Basic parameters for design and sizing of future wetland are water quality that is discharged in the lake and requested lake water quality. Since the new wastewater treatment plant started, effluent quality improved significantly, although it still represents nutrient burden for the lake (Table 6).

PARAMETERS	2009	2010	2011
BOD ₅ (mgO ₂ /l)	8.1	6.2	4.4
COD (mgO ₂ /l)	36.5	35.2	41.1
Suspended matter (mg/l)	28.5	14.3	9.5
Total N (mg/L)	16.6	12.8	11.5
Total P (mg/L)	2.1	1.4	1.0

Table 6. Effluent quality (annual average)

The required area for future constructed wetland was calculated using input parameters, effluent quality and demanded remedy level. In addition, sizing was done according to efficiency of particular aquatic plants. Calculation results showed that the minimum area for wetland construction in sector 2 is 50 ha. Nutrient loading from diffuse sources (agricultural fields) is negligible in comparison to WWTP, so it is excluded from calculation.

Hydrology of constructed wetland considerably affects treatment efficiency. Hydraulic retention time must be sufficient for biological purification, but not for too long, due to risk of creating of anaerobic conditions. Retention time in constructed wetland in sector 2 is planned to be at least 3 days (recharge 36000 m³/day without precipitation), up to 5 days (recharge 72000 m³/rainy day).

Hydrological analysis considered influence of the quantity of water that recharges the lake, weather conditions, water loss and evapotranspiration. The efficiency of natural system like this one could easily be decreased due to severe precipitation, increased water flow or shortage of retention time.

Biological community of constructed wetland consists of both plants and microbial population (Table 7). Wide range of different species could be used for planting, which depends on climate and environment. Indigenous plants, well adapted to existing conditions are mostly used for this purpose.

Plant parts	Role
The roots and underground parts	Habitat for microbial population Filtration and adsorption Sediment stabilization Nutrient storage
Plant parts above the ground	Reduction of sunlight and limitation of algae growth Moderation of wind, i.e. gas exchange between water and atmosphere Gas transfer to submerged parts of plant Nutrient storage

Table 7. Roles of plant parts in constructed wetlands

Plant species	pH optimum	Distance (m)	Rooting depth (m)	Nitrogen content (%)	Phosphorus content (%)	Dry matter yield (t/ha)
Emergenced plants						
<i>Typha spp.</i>	4-10	0.60	0.3-0.5	14	2	30
<i>Scirpus spp.</i>	4-9	0.30	0.6	18	2	20
<i>Phragmites spp.</i>	2-8	0.60	0.4	20	2	40
<i>Juncus spp.</i>	5-7,5	0.15	0.3	15	2	50
<i>Carex spp.</i>	5-7,5	0.15	0.2	1	0.5	5
Submerged plants						
<i>Potamogeton spp.</i>	6-10	0.3		2-5	0.1-1	3
<i>P. myriophillum spp.</i>	6-10	0.3		2-5	0.1-1	9
<i>Ceratophyllum spp.</i>	6-10	0.3		2-5	0.1-1	10
Floating plants						
<i>Lemna spp.</i>				6	2	20 t/year

Table 8. Basic ecophysiological traits of proposed plants for future constructed wetland

In studied case, selected plants fulfil following conditions: they are tolerant to high nutrient content and they live in continuous aquatic conditions, i.e. plants that periodically need dry conditions are avoided. Furthermore, it is best to use perennial plants, as well as plants with bigger rate of biomass increase. Plants that have slower growth rate should be grown with bigger density. The best practice is to grow many different plant species, especially the ones that represent important habitat to animals. Monoculture should be avoided, because it can lead to quicker spread of diseases and be attacked by insects. According to data given from other authors [34], the Indigenous plants that are appropriate for future wetland creation in sector 2 of the Palic Lake are chosen together with basic ecophysiological traits and given in table 8.

The purpose of future constructed wetland inflicts a choice of the wetland type. Concerning input parameters and natural processes that occur in wetlands, a sequential model has been chosen. Generally, the basic drawback of this technology is occupation of large area; however in this case this is not a limiting factor.

Designed solution considers hydraulic dredging of deposited sediment in sector 4, and deposition through long pipeline in sector 2. Dredged sediment will be used as a substrate for constructed wetland. Future wetland will consist of indigenous plants. Plant structure is chosen to achieve requested water quality and to remediate sediment/substrate.

Water from the sector 1 inflows the sector 2 through the culvert and overflows the area of 53.5 ha where macrophyte zones interchange with open water zones. Container with biofilters is designed to be placed in the culvert for initial water treatment. Three vegetated zones with emerged macrophytes are designed to cover 30 ha totally. They should be established on substrate formed by dredged sediment, deposited to the elevation 102.0-102.2 m.a.s.l., to provide necessary depth for plants 0.4-0.6 m.

In the open water zone, minimum water depth is 1.4 m. Natural processes of reaeration are facilitated by means of submerged plants existence. Floating wetlands are also planned in this zone. The purpose of floating wetlands is decrease of nutrient and pollution loading naturally. They affect the increase of existing aquatic vegetation and intensify existing interaction between water, plants, microorganisms and atmosphere.

In this manner total area of constructed wetland will have a part in water treatment, which is joint work of all zones, as depicted in Figure 7. All processes that are important for achievement of recommended water quality are increased. Some modifications that encompass introduction of biofilters and floating wetland were also done, to increase efficiency of constructed wetland.

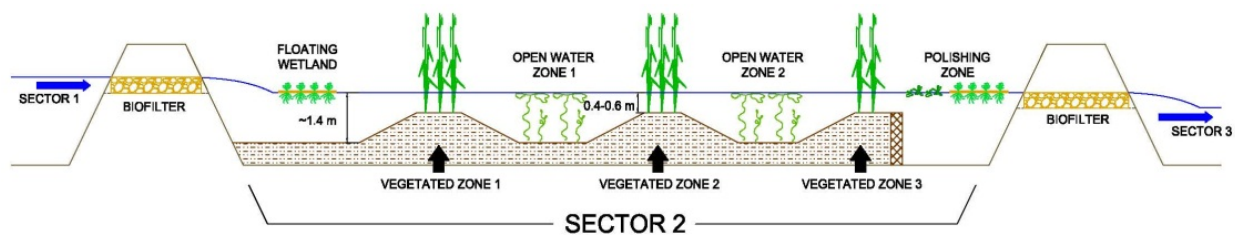


Figure 7. Scheme of the sequential model of wetland in sector 2 (longitudinal section)

Sequential model of constructed wetland makes the most of chemical, biological and physical processes that will further assure improved water quality.

6. Vegetated, open water and “polishing” zone

In the vegetated zone it is necessary to maintain the water depth up to 0.6 m. Retention time in vegetated zones is 3-5 days, which is optimal time for the development of sedimentation and biological processes for nutrient transformation. Several species will be planted in

constructed wetland, with plants successively distributed. It is planned to grow emerged plants that are very common in studied area, e.g. *Typha spp.*, *Phragmites communis*, *Juncus spp.*, *Scirpus spp.*, *Carex spp.*

Suggested plants have branched roots, “airy” stems and leaves. Roots take nutrients from the sediment and transport them in airy parts of the plant. After the wilting of the plant, nutrients are released in the water or in the pore water of the sediment. The largest amount of released nutrients is to be used by epiphytic microflora. Therefore, necessary maintenance measure is timely plant removal from the constructed wetland.

Plants that are considered for future wetland are the following:

1. *Typha spp.* is commonly found in different ecological conditions, which makes it ideal for constructed wetlands. It produces large biomass and after the period of three months it makes very dense vegetation.
2. *Juncus spp.* is a perennial plant that can be found in wet areas, mostly along shores. It is adapted to a wide range of environmental pH. It produces a large biomass during vegetation period.
3. *Phragmites communis* is a perennial plant with large perennial rhizome, the most utilized plant, very efficient in oxygen supply.
4. *Carex spp.* and *Scirpus spp.* are very suitable for planting in constructed wetlands that are located in colder climates. They are effective during periods of low temperatures (around 0°C). During these conditions their efficiency is 20-30% higher in comparison to other plants, which makes their usage in this case compulsory.

Constructed wetland will be planted with quoted plants after sediment stabilization. Plants can be grown from seed, by division, using seedlings or adult plants. Soil in the natural wet habitat in the vicinity can be used as a seed source, because it contains seeds of numerous indigenous species that are well adapted to local conditions. Moreover, indigenous plants have bigger survival rate.

Rhizomes and tubers can also be used for reproduction. They are collected in late autumn, at the end of the growing season, or in early spring, at the beginning of the growing season. Rhizomes can be stored in wet peat or sand until planting. Whole roots with some soil can be taken, by reason of inherent microbial population that are important for future wetland formation. Local plants, as well as local plant nursery are recommended, as the most confident source of planting material. Plant nurseries on the spot are good choice, since they are reliable and their cost is low. For that reason, a part of constructed wetland will be used as a nursery (approx. 5 ha). Also, it is recommended to plant by hand, using regular gardening tools and material. The largest share of seedlings is planted in spring; a process of planting should last between March and July.

In sector 2 large areas are already overgrown with common reed. Around every adult plant there are around 10 sprouts. Design of the constructed wetland anticipates getting half adult plants (with sprouts) from 1 m² of reed bed. Therefore, for 600.000 plants that is necessary for 30 ha of vegetated zones (designed plant distribution is 2 plants/m²), required size of

plant nursery is 4 ha. Reed in so called nurseries will propagate, thus empty places in reed beds will be fulfilled by the end of the year.

Constructed wetland becomes efficient in 2-3 years, as plants completely develop and reach high effectiveness in water treatment. In this manner natural potential of selected indigenous plants is used. Plant production is continuous work, since it is necessary to replace damaged or wilted plants for the duration of wetland.

Maintenance of wetland through regular plant removal is obligatory. Early harvest before nutrient translocation and multiple harvests are significant for nutrient removal and also for extension of wetland endurance. Plant removal/harvest can be done manually or using machinery. Produced biomass can be used for composting, biofilters, energy production or as building material.

Submerged macrophytes alleviate reaeration processes, thus level of dissolved oxygen rises. Oxygen is necessary for oxidation of carbon compounds and reduction of BOD, and further for nitrification of ammonium and nitrates. These reactions are fundamental for nitrogen and phosphorous reduction. On the other hand, this zone has a particulate role in suppression of coliform population.

Open water zone can be planted with submerged macrophytes that are rooted in lake sediment. Photosynthetic parts of submerged vegetation are in the water body, or float on the water surface. Submerged plants remove ammonia from the water indirectly. Plants use carbon dioxide as a carbon source, consequently increasing pH and ammonia diffusion in the atmosphere.

Existing species in open water zone are: *Ceratophyllum*, *Elodea*, *Potamogeton*, etc. Selected species are widespread and adapted to growing even in saline conditions. They propagate fast using rhizomes and have high rate of biomass production. Establishing plants and maintenance in open water zone ought to be done in the similar way as in vegetated zone.

Polishing zone is covered with vegetation and it allows water denitrification process. Nitrification occurs in the water column in presence of aerobic conditions, but denitrification is limited to the sediment area. Floating and decorative plants are dominant in this zone.

Green parts of plants, where photosynthesis takes place, are on water surface, or immediately above it, while roots are in water column, extracting nutrients. Roots of floating plants are great medium for filtration process, adsorption of suspended matter, and furthermore for bacteria growth.

Lemna sp. (Duckweed) grows best in the water whose temperature is around 27°C, consequently doubling the area that covers every 4 days. It consists mainly of metabolically active cells, but it has a low content of structural fibres. Duckweed has a significant role in wastewater treatment, due to nitrogen transformation and competition with algae. In only 2-3 weeks, a quality of wastewater is improved, regarding both organic matter content and dissolved oxygen content. Duckweed contains proteins, fat, nitrogen, phosphorous, which

makes it good supplement for livestock nutrition. Redistribution of these plants requires special attention in order to accomplish complete cover of polishing zone, but also timely harvesting. Due to the chemical composition, harvested crop can serve as animal food or a fertilizer (compost).

7. Biofilters

Biological filters are made of shredded herbal material, i.e. remains. Biofilters are supposed to be put in culverts between sectors: one located between sectors 1 and 2 and another between sectors 2 and 3. Before entering subsequent sector water flows through fine herbal material, leaving suspended matter, nitrogen, phosphorous and metals in it. Their efficiency depends on plant species whose remains are used: wheat, barley, rye, as straw degrades slowly and supply low peroxide concentration. Besides straw, shredded reed remains can be used.

Duration of biofilter effectiveness is at least 6 months. Biofilters can be recharged more frequently, which depends on a degree of nutrient enrichment of water and on time of year. After utilization, biofilter material can be composted and empty containers are refilled with new shredded herbal material. During winter when wetland activity is reduced, the significance of biofilters rises. The floating reed bed together with submerged barley straw in a eutrophic lowland reservoir was used to reduce phosphorous and nitrate as well as to limit algal growth [35].

8. Floating wetlands

Floating emergent macrophyte treatment wetlands (FTWs) are a novel treatment concept that employ rooted, emergent macrophytes growing in a floating mat on the surface of the water rather than rooted in the sediments [36]. This makes CFWs extremely suited for treatment of event-driven waterflows such as storm water or combined sewer overflow water [37].

Floating wetlands increase the effectiveness of indigenous vegetation. Design of this type of wetland strengthens interaction between environment and living organisms. Plant root system, the most active part that is placed in water, have significant active surface for nutrient assimilation. Roots are also important for the development of bacterial populations that take part in nutrient transformation. Wetland capacity is increased by means of functionality of living organisms and providing habitat for fauna. Growing plants in this manner allows strict control of plant growth and for that reason usage of non indigenous plants.

Floating wetlands are more effective in comparison to other types. Large amount of nutrients is assimilated and eliminated from treated water, due to the removal of whole plant from the water, not just above ground parts of plant.

Because the plants are not rooted in soils in the base of the wetland, they are forced to acquire their nutrition directly from the water column, which may enhance rates of nutrient

and element uptake into biomass. Their buoyancy enables them to tolerate wide fluctuations in water depth. This provides potential to enhance treatment performance by increasing the water depth retained during flow events to extend the detention time of storm waters in the wetland [38].

Green salad, clover, alfalfa, mustards, sunflower are some of plant species that can be used for floating wetland creation besides indigenous plants. If used plants are not marsh plants, water below should be aerated. Usage of indigenous plants is common. Planting material that encompasses whole plants and rhizomes is gained locally. Planting is to be done manually on floating beds, made of woods, plastic or styrofoam.

Position of floating wetlands is optional: they can be attached to the dam between sectors or to the shore. After achievement of maximum yield of biomass, floating wetland will be pooled on the shore and plants will be replaced. Removal of whole plants from the water is very important. During growing season, control of plant growth and replacement of damaged plants has to be done on a regular basis. Timely removal or harvest of plants is one of the most important issues regarding every wetland type.

9. Nutrient removal

Collected data that depict the capacity of new WWTP are used as input for further calculation. Generally, WWTP discharges 36000 m³ of effluent loaded with 1 mg/L of total phosphorous (TP). Calculated phosphorous loading is 36 kg TP/day, or 13 t TP/year. Accordingly, calculated nitrogen loading is 360 kg TN/day, or 130 t TN/year.

Constructed wetland design has been conducted according to nutrient loading that originates from the WWTP of the city of Subotica. Moreover, current quality and nutrient enrichment of the lake water has been considered. The lake has considerable autoperification capacity that even in current conditions influences decrease of available phosphorous.

Main mechanisms for phosphorous and nitrogen removal are adsorption, chemical precipitation and assimilation by macrophytes. Plants absorb significant amount of inorganic phosphorous, but after wilting nutrients are released in the water again. Floating wetlands (1 ha) will remove approximately 780 kg TP/year and 6.6 t TN/year. Emerged vegetation (30 ha) assimilate 19 t TP/year and 160 t TN/year (Table 9). Submerged plants assimilate lesser amounts of nutrients: 0.7 t TN/year and 0.5 t TP/year. Floating plants incorporate approximately 1.2 t TN/year and 0.4 t TP/year, which depends on size of area that cover [34].

Since, phosphorus loading is estimated to be the most important factor of lake eutrophication, more detailed calculation relates phosphorous mass balance (Table 9). Inputs of phosphorous are from the WWTP and deposited sediment. Release of phosphorous from sediment depends on environmental conditions, i.e. oxygen content, environmental pH value. Benthic algae and submerged plants intercept sediment phosphorous, i.e. they have a role similar to some products for phosphorous inactivation

[39]. Water column is in contact with active layer of sediment, whose thickness varies from a millimetre to few centimetres. If anaerobic conditions prevail in superficial sediment layer, phosphorous becomes mobile in pore water of active layer that is assumed to be 2 cm. Examined phosphorous loading is derived using concentrations of total phosphorous, thus calculated values represent sediment potential.

Plant species and planned proportion	Area (ha)	Dry matter yield (t/ha)	Dry matter yield (t)	Content TN (%)	Quantity TN (t)	Content TP (%)	Quantity TP (t)
<i>Typha spp.</i> , 30%	9,0	30	270	14	37,8	2	5,4
<i>Scirpus spp.</i> , 15%	4,5	20	90	18	16,2	2	1,8
<i>Phragmites spp.</i> , 30%	9,0	40	360	20	72,0	2	7,2
<i>Juncus spp.</i> , 15%	4,5	50	225	15	33,8	2	4,5
<i>Carex spp.</i> , 10%	3,0	5	15	1	0,2	0,1	0,001
TOTAL:	30,0		960		160,0		19,0

Table 9. Calculation of biomass yield and assimilated quantities of nutrients by emerged plants

Output is a sum of phosphorous that is consumed by plants in vegetated zones of designed wetland and plants in floating wetlands; while one portion is represented as autoperification capacity (Table 10). Here, a portion that is affiliated by submerged plants and free floating vegetation is neglected, due to the fact that it is hard to control this kind of vegetation and predict their effects reliably.

INPUT [t]		OUTPUT [t]	
effluent from WWTP (designed regime)	14	designed wetland (vegetated zones)	19
sediment active layer	27	floating wetlands (per hectare)	0.78
		autoperification capacity in current environment (16%)	2.24
Total	41	Total	22.02
Difference	+18.98		

Table 10. Mass balance of total phosphorous

Input values represent phosphorous reserves and potential for bioavailable phosphorous forms, while output values represent used bioavailable phosphorous which is further incorporated in plant body. Positive difference confirms that it is not possible to remediate water and whole amount of (active) sediment in one year. Roughly, designed wetland is capable of additional water treatment and remediation of nearly one third of sediment active layer. Accordingly, in addition to water treatment, designed wetland will gradually remediate deposited sediment as well.

Macrophytes will assimilate considerable part of phosphorous from lake water, but some will precipitate in sectors 2 and 3, considering high water pH value. Together with proved lake autopurification, it is possible to accomplish requested water quality in sector 4, in regard to phosphorous content. Eventually, nutrient removal can be improved by increasing number of floating wetlands, if necessary. Nevertheless, the aesthetic value of floating wetlands gives them additional advantages.

The design of constructed wetland (Figure 8) depends on many factors but the plant species and microbial populations directly affect the efficiency in water treatment. Starting from the quality and quantity, especially treated water coming from the WWTP into the lake, and in order to obtain the required water quality for the sector 4 we proposed a model of constructed wetland that will maximize the potential of plants and microorganisms.

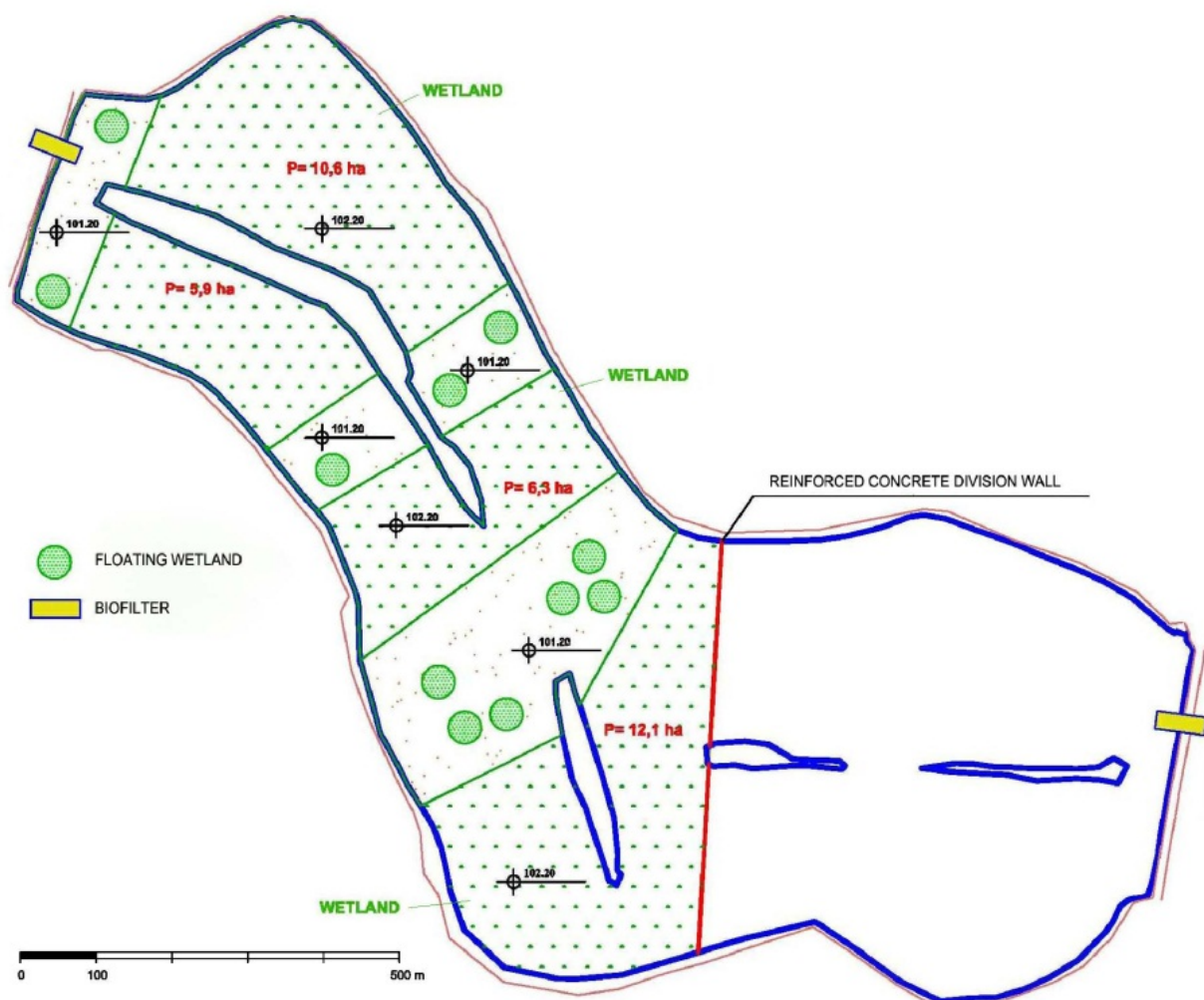


Figure 8. Wetland model in sector 2

We should also bear in mind that decomposition of macrophytes in wetland may also release large amounts of nutrients [40], and thus could reduce wetland treatment efficiency [41]. Plant decomposition plays an important role in nutrient cycling in aquatic ecosystems [43-43]. Harvesting is considered a direct and effective way to solve the re-pollution

problem. Using a numerical model was suggested that harvesting the above-ground macrophyte biomass at the end of the growing season could significantly reduce phosphorus release in the decomposition process of macrophytes in shallow lakes [42]. In previous researches was reported that about 20.1% of nitrogen and 57.0% of phosphorus over nutrient removal was contributed by harvesting of emergent plants [44].

The plants produced within constructed wetlands or on floating islands can be harvested and subsequently used as animal feeds, or even human food, or be processed into biogas, bio-fertilizer and bio-materials. This may justify the practical application of the technology using the potential economic returns [45-46].

10. Conclusions

Over decades the high concentration of nutrients, especially phosphorus, (which arrived in the lake, primarily from treated or untreated wastewater), contributed to the disruption of ecological balance in the lake and the formation of thick layers of sediment. Although constructed wetland building up in recent years throughout the world, in Serbia this is a relatively new concept.

Considering the input parameters of water quality, and current water quality, the proposed model has a few activity zones in sector 2 (plants-water-plants-water...). In this way model achieves the maximum use of all physical, chemical and biological processes that are important for improvement of water quality. In order to increase efficiency a few modification are made as well as applying biofilters (after sector 1 and after sector 2) and floating wetland.

Model used the plants that are tolerant to high levels of nutrients and predominantly indigenous species whose grow in vicinity of lake.

All this will contribute to the cost and environmentally friendly and effective technologies to improve water quality, increase biodiversity and ecological balance in the lake Palic.

Author details

Vera Raicevic* and Blazo Lalevic
*University of Belgrade, Faculty of Agriculture,
 Department for Microbial Ecology, Zemun-Belgrade, Serbia*

Mile Bozic and Zeljka Rudic
Institute for the Development of Water Resources "Jaroslav Cerni", Belgrade, Serbia

Dragan Kikovic
Faculty of Natural Science, Kosovska Mitrovica, Serbia

* Corresponding Author

Ljubinko Jovanovic
 Educons University, Sremska Kamenica, Serbia

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