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Restoration of ponds in the municipal park in Zduńska Wola, Poland

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Abstract

The historic municipal park located in Zduńska Wola is covered in the central and northern part by conservator protection through an entry in the register of monuments and on the basis of an entry in the local spatial development plan. In terms of nature, the area has significant values due to old trees and the water system, which consists of two ponds fed by the Pichna River.

As part of the preparatory work for the revalorization of the park, several studies and analyses were carried out, including assessment of the sanitary state of waters of Pichna River that supplies reservoirs. Degree of the river pollution made it impossible to restore the water system, the most important element of the park, while further supplying the ponds with river water. In order to ensure a satisfactory degree of purity and transparency of water in ponds, a decision was made to apply complex and modern technological solutions enabling the renovation of the water system.

Project documentation was developed in 2015. After two years, they began to implement the project. Banks of both ponds were formed more gently, and the basins were deepened. Selection of vegetation around the reservoir and in the reservoir itself was based on the principle of biocenotic assumptions. The designed system is equipped with a circulation pump, skimmers, bottom drains, mechanical-mineral filter, swamp filter. This was to ensure adequate purification of water in ponds, based on natural processes, stimulated by the use of new, pro-ecological technologies.

Key words: *park ponds, park revalorization, water quality monitoring, water system renaturalization*

INTRODUCTION

The historic municipal park located in Zduńska Wola is covered in the central and northern part by conservator protection based on an entry in the local spatial development plan and through an entry in the register of monuments. The park is characterized by varied topography, the highest point of which is in the north and slopes to the south, towards the Pichna River valley, supplying two park ponds that are the closure of the compositional axis. In terms of nature, the area has significant values due to old trees and the water system.

As part of the preparatory work for the revalorization of the park, a number of studies and analyses were carried out, including assessment of the sanitary state of the waters of the Pichna River that supplies reservoirs and flows through the park. On this basis, it turned out that degree of the river pollution (among others, as a result of the discharge of untreated water from nearby traffic routes) makes it impossible to restore the water system while further supplying the ponds with river water. In order to ensure a satisfactory degree of purity and transparency of water in both ponds, a decision was made to apply complex and modern technological solutions enabling their renovation. The adopted solutions gained the favor of the Provincial Fund for Environmental Protection and Water Management [MILECKA, WIDELSKA 2018].

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The purpose of the restoration of the water system within the municipal park in Zduńska Wola is to bring about a relative purity and appropriate quality of water in the ponds while maintaining and protecting the park's historical, cultural and natural values. Water treatment in ponds is closely related to preventing from the eutrophication. Its main reason is the increasing load of biogenic elements, primarily phosphorus and nitrogen. This increases the trophy, i.e. water fertility, which results in the development of phytoplanktonic organisms, causing surface blooms and reduction of water transparency, which leads to deterioration of light conditions for littoral plants, as well as oxygen conditions in the bottom layers.

Research on surface water quality, carried out as part of the State Environmental Monitoring, for the Pichna River near Zduńska Wola, which has been supplying park ponds so far, has shown that the tested flow is a heavily modified unit. The river flows through Zduńska Wola, later through arable fields and forests. Municipal sewage and rinse water from a knitting plant and cooling water from a combined heat and power plant are discharged from the city. Municipal sewage from neighboring municipalities is also discharged into this water body. Sewage from the city and commune of Szadek is introduced through the right-hand tributary – Pichna Szadkowicka River [SOBCZAK *et al*. 2013]. The state of water purity is changing dramatically.

Hence the idea that the reconstruction of the existing ponds system would be based on Western European solutions used in municipal bathing ponds with natural water purification. The concept adopted in the project is based on the appropriate shape of the tank, the use of natural mineral-plant filters and proper water circulation to intensify the natural processes of self-purification of water many times.

In conventional solutions (e.g. swimming pools), biological life is eliminated by the addition of chlorine, while in bathing ponds, biogenic elimination is sought using sorption and ion exchange phenomena of the mineral filter bed, a huge biologically active surface and competition for nutrient compounds between algae and marsh plants [MILECKA, WIDELSKA 2018].

MATERIALS AND STUDY METHODS

For the purpose of developing the project documentation, a "Geotechnical opinion" was issued for the project of renovating the water reservoirs in the municipal park of the city of Zduńska Wola, area of ul. Parkowa [STERNICKI 2015]. As part of the geotechnical study, five test wells with a depth of 2.5–4.0 m, macroscopic analysis of soil samples collected during drilling and hydrogeological measurements were made.

It was found that the ground is formed by layers of homogeneous soils, without adverse geological phenomena. Park surfaces are built of humus embankments with an admixture of debris. The thickness of embankments reaches 1–2 m. Below, there are water-glacial sands, medium and fine, light gray and yellow. Sandy sediments occur up to a depth of every 2–3 m. Their bedding is made of gray silty clays.

Free groundwater table was drilled in June 2015 at a depth of 1.2–1.5 m at ordinates 171.1–171.4 m above sea level. It is seasonally low water level. After abundant surface feeding, the water level will increase. Given the weather anomalies that have occurred in recent years, it is difficult to forecast the maximum water level.

The aquifer consists of medium and fine-grained sands with medium water permeability ($k \approx 5$–$10\ \mathrm{m \cdot d^{-1}}$). Surface embankments contain significant admixture of humus, therefore their water permeability is much lower [STERNICKI 2015].

The design concept assumed the rebuilding of municipal ponds together with the surrounding area, with particular emphasis on the optimal solution for sealing, filling and maintaining the purity of water in the ponds (Fig. 1). Therefore, in 2015, it was developed detailed design documentation, taking into account a series of processes that promote the natural purification of water in ponds. In spring 2017, the project was started.

Prior to profiling the bottom of the ponds, the water and marsh vegetation as well as permanent weeds were removed, and the concrete slabs that had previously protected the pond slopes, were removed. The subsequent step was to remove the layer of silts and peat from the bottom of the ponds and to prism them for the use in coastal areas. Appropriate control and drainage was installed at the bottom of the ponds to monitor subcutaneous waters during sealing of the ponds. Then, the bottom of ponds was properly shaped in accordance with the designed profiling. Each 30-centimeter layer of soil was compacted so that the formed slopes would not erode at a later stage of use.

The earthworks also included the excavation necessary to lay the pressed pipeline running from the pond located in the western part (recreational pond) of the developed area to the filtration zone in the pond located in the eastern part (the pond being the regeneration tank). The pipeline supplying free discharge in a smaller pond was laid on the seal in accordance with the contour lines and secured with a gravel spread. Backfilling excavations for the pipeline was carried out in layers with each compaction of individual soil layers.

Surface of the bottom of the pond had to be leveled and thoroughly compacted (larger depressions were buried in layers and compacted), free of sharp objects – stones, glass, etc. Sealing of the pond consisted in spreading 400 $\mathrm{g/m^2}$ of geotextile. For a proper sealing of the pond, EPDM foil 1.02 mm thick with a certificate of neutrality with respect to flora and fauna in the ponds, was used (Photo 1). In order to maintain the water table at a constant, designed level, it was necessary to permanently stabilize the edges of the pond at the appropriate level (deviations from the level could not be more than 1 cm). The entire bottom of the tanks, including the pond shore (about 1 m wide), was lined with twice washed gravel (16–32 mm fraction) with a 20 cm thick layer.

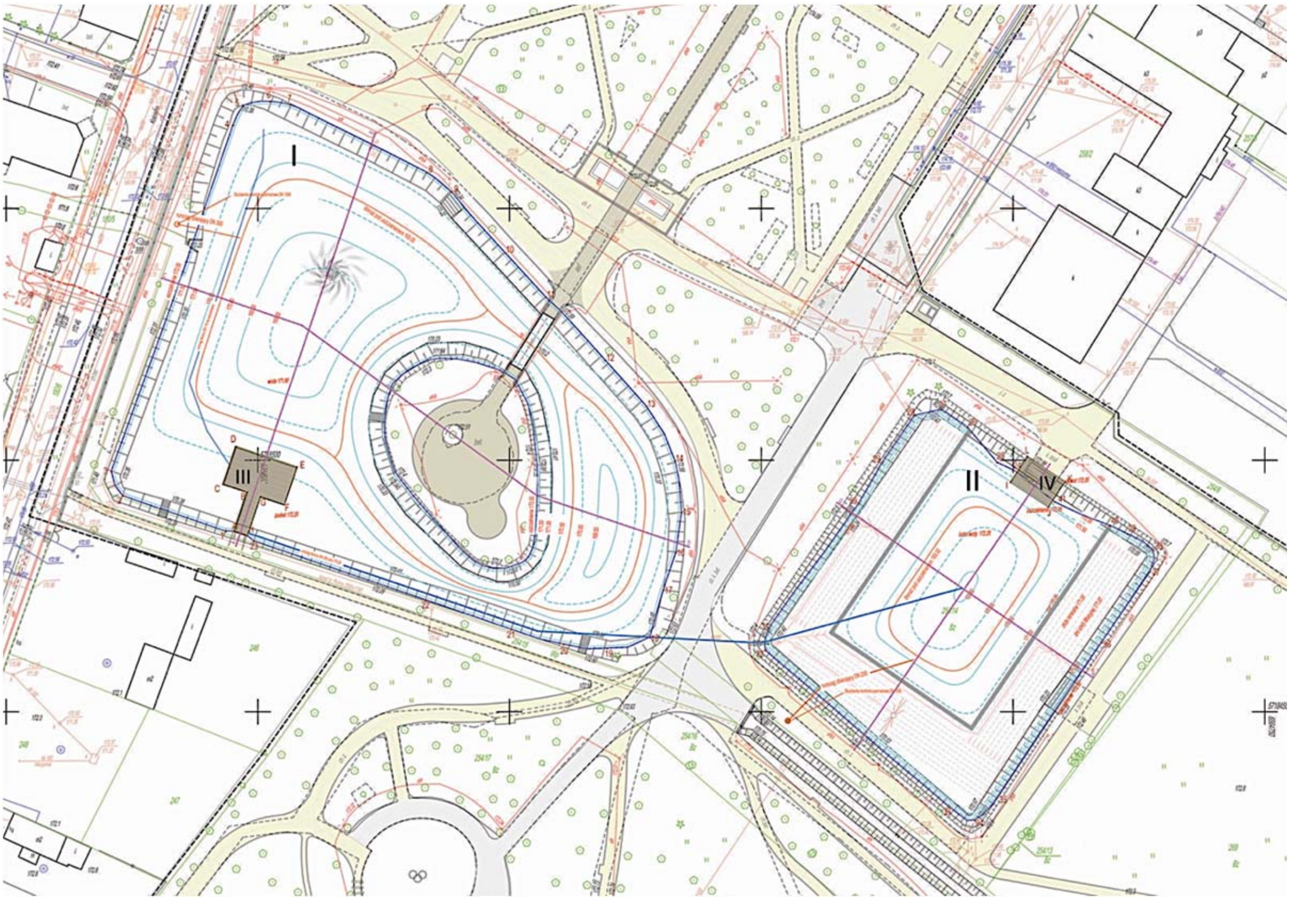

Fig. 1. Fragment of the park restoration project including solutions for the renaturization of the water system; I = observation and recreation tank, II = regeneration tank (mineral-plant filter), III = technical bridge with pumping station and mineral filters, IV = wooden platform; source: own elaboration

Photo 1. Profiling and sealing the bottom of the recreational reservoir (photo *W. Walczak*)

The key element of the entire water system conditioning the purification of water in the ponds was the implementation of the mineral-plant filter (regeneration tank). On the leveled and sealed bottom of the mineral-plant filter and 10 cm ballast from the washed mineral substrate (8–16 mm fraction), drainage filter pipes DN 80/92 with 2×5 mm holes at a distance of approximately 1 m are laid, which are connected to a reduction adapter collector DN 160, and the filtered water was led to a PVC DN 600 sump with a sealed bottom and a technical hatch. Drainage pipes were sprinkled with 8–16 mm substrate to a height of 20 cm from the bottom of filters.

Another, the most important layer, 70 cm thick, was the mineral substrate – a substrate composed of natural ion-exchange minerals as well as nitrogen, phosphorus and heavy metal absorbents. The last 10 cm layer was twice washed 16–32 mm gravel.

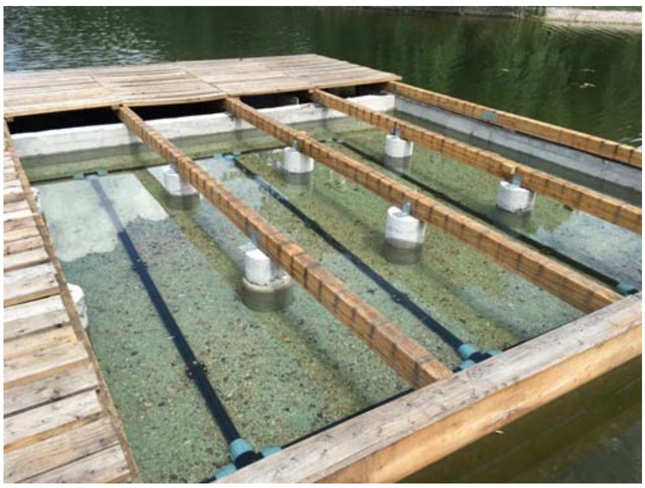

Photo 2. Chamber with mechanical-mineral filter under the platform in recreational pond (photo: *W. Walczak*)

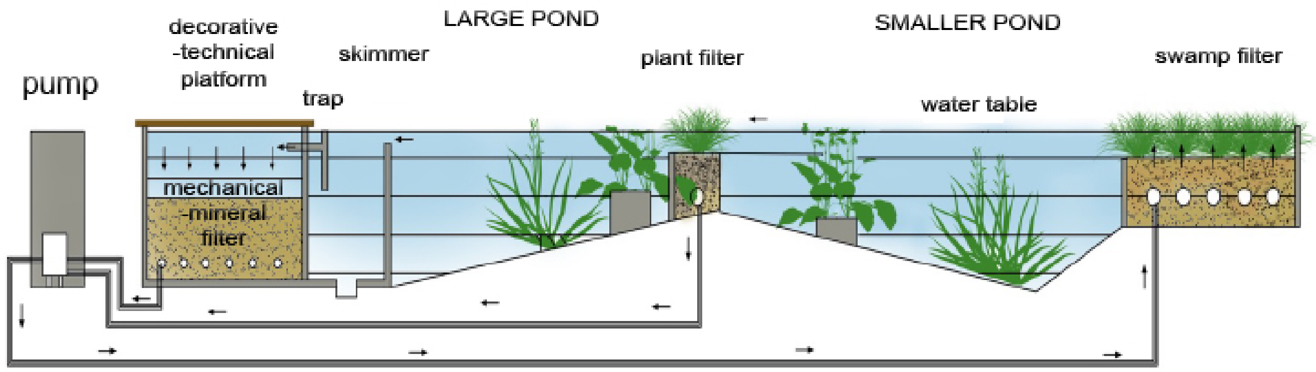

Fig. 2. Diagram of pond water circulation;
source: own elaboration

In autumn 2017, tanks were filled with water for the first time after reconstruction. Water quality, when using biologically active sorption filters, depends on the material used, its adsorption properties and intensity of biochemical processes (Photo 2). It is extremely important in the process of effective removal of organic compounds (above all, phosphorus and nitrogen compounds) as well as elements present in trace amounts (e.g. heavy metals) [PRUSS *et al.* 2009]. Therefore, the mineral substrate Biozamonit® (4–16 mm fraction) was used, which is the nitrogen, phosphorus and heavy metals as well as parasites sorbent with the addition of FerroSorp® iron hydroxide (phosphorus absorbent). This trade name includes lime-silica rocks (bedrock), zeolite, dolomite or limestone grits in appropriate proportions [WALCZAK 2015].

Due to the high calcium content, it is the bedrock that is one of the most effective reactive materials used to remove phosphorus from aqueous solutions [BUS, KARCZMARCZYK 2014]. Furthermore, during thermal treatment, its sorption capacity increases significantly (from 60.5 g $P \cdot kg^{-1}$ at 250°C to 119.6 g $P \cdot kg^{-1}$ at 1000°C) [BROGOWSKI, RENMAN 2004] due to the breakdown of calcium carbonate into calcium oxide and carbon dioxide. As the firing temperature increases, the reaction also increases: from 6.80 to 12.4 after roasting at 900–1000°C [BROGOWSKI, RENMAN 2004; CUCARELLA *et al.* 2007].

Water pollution can be removed using mechanical, physicochemical and biological methods. Therefore, in parallel with the use of physicochemical methods, a biologically uncomplicated method, which is phytoremediation, was used. It is a technology for the purification of ground and surface waters, and even soil and air, which uses the natural predisposition of specific taxa of plants capable of growing and developing in ecosystems contaminated with inorganic and organic substances, as well as for their uptake, accumulation or biodegradation [KOŹMIŃSKA *et al.* 2014].

Purification of water in ponds is based primarily on the proper selection of filtration material (mineral in properly developed proportions adapted to the content of elements in the water supplying the tanks) and forcing water circulation in a closed system, equipped with pumps, overflows, mechanical-mineral filter and relevant from phyto- and rhizo-filtration point of view – swamp filter (mineral bed planted with plants) (Fig. 2).

Photo 3. Mineral-plant filter with visible plantings of purple loosestrife, bulrush and calamus (photo: *W. Walczak*)

Therefore, several habitat zones have been arranged in the pond. In the open water, plants with delicate, flabby stems and fine leaves (adapting their requirements to the depth of the zone) were planted (Photo 3). Waterlily with decorative leaves and flowers were planted in the bottom layer. There are also numerous zooplankton species in this zone, which very effectively support water filtration [SPIEKER 2008]. The banks were planted with iris, calamus and other littoral species, as well as plants from wetland habitats – sedge, horsetail and mint [MILECKA *et al.* 2015]. All species were selected according to the habitat requirements criterion.

RESULTS

The idea of a recreational pond is to create or use an existing reservoir that has been isolated from the hydrogeological environment by impermeable material. Its functioning is based on the use and intensification of natural water self-purification processes. The reservoir of this type, or a more complicated water system, includes a recreational and regenerative part (mineral-plant filter), inhabited by plants participating in self-purification water processes. The whole system also consists of many devices, both mechanical and specially constructed swamp filters, that are used to maintain the proper level of water quality [GĄSIOROWSKI 2013].

The use of a mineral-plant filter bed in the ponds in Zduńska Wola was aimed at eliminating the most adverse biogenic compounds (phosphorus and nitrogen) and maintaining optimal physical and chemical parameters of water (similar to those found in natural oligotrophic reservoirs). Artificial stimulated conditions served to limit the development of unicellular and filamentous algae, determining the natural and scenic values of ponds (Photo 4) (each additional gram of phosphorus above the allowed norm can generate the development of filamentous algae weighing 250 kg).

For this purpose, a natural mineral substrate Biozamonit® was used as an absorbent of phosphorus, nitrogen and heavy metals. Composition of the above mineral deposit contains, among others, bedrock, roasted rock, zeolite, calcareous grits, ferrosorp, and dolomite grits in appropriate proportions. Biozamonit® contains, among others, additions of roasted rock, which according to tests, has a contents of CaO and SiO_2 of 238.6 and 550.1 $g \cdot kg^{-1}$, respectively. Therefore, the efficiency of PO_4-P removal from an aqueous solution with an initial concentration of 1.84 and 2.88 $mg \cdot dm^{-3}$ by the roasted rock is 88% and 70%, respectively [KARCZMARCZYK, BUS 2013]. It is also important to place the substrate in the appropriate parts of the filter bed, because the filtration processes in the mineral-plant bed take place through the vertical forced flow of water through the mineral bed.

It was the filtration, ion exchange and buffer properties that determined the use of the above mixture as the best for this type of pond, successfully used in other projects of reservoirs of a scenic and recreation nature. The filter bed is also a habitat supporting the growth of nitrifying bacteria that are very important in the process of ammonia decomposition.

In order to increase sorption properties, the bed was planted with water and marsh plants with the best properties of absorbing the biogenic compounds from water. Plants that are used for the biological purification of water belong to the group of the so-called repository plants, highly effective also in removing toxins, protecting banks, reclamation, cleaning soil or water. They capture pollution, pathogens, phosphates dissolved in water and at the same time strive to stabilize water chemistry. Among the most commonly used plants for this purpose, there are, e.g. helophytes (marsh plants), emery hydrophytes and submersible hydrophytes that live completely under the water [GĄSIOROWSKI 2013]. Both reservoirs were planted with aquatic and underwater plants, including those with a covering function. Among them are: calamus (*Acorus calamus* L.), bottle sedge (*Carex rostata* Stokes), galingale (*Cyperus longus* L.), yellow iris (*Iris pseudoacorus* L.), purple loosestrife (*Lythrum salicaria* L.), waterlilies (*Nymphaea* sp. L.), lakeshore bulrush (*Scirpus lacustris* L.), narrowleaf cattail (*Typha angustifolia* L.), bromeliad (*Chara fragilis* Desv.), creeping jenny (*Lysimachia nummularia* L.), water mint (*Mentha aquatica* L.), parrot's-feather (*Myriophyllum aquaticum* Vellozo) and shining pondweed (*Potamogeton lucens* L.).

Before designing and determining the proper parameters of the filter beds, the water was intended to be used to supply the ponds. After making ponds and all system components, the water test was repeated before the tanks were filled. This was important due to the assessment of the physicochemical properties of water and checking whether the proportions of the substrate in the mineral deposit (mechanical filter) and mineral-plant (regeneration tank) were properly selected. In order to monitor the state of water in ponds, in the spring of each year the tanks are used, such tests are performed.

As a result of the sorption properties of the mineral-plant filtration bed (regeneration tank) in the first and second year of using the ponds, the amount of dissolved phosphorus (P), one of the biogenic factors, decreased 10-fold compared to the amount contained in tap water used to fill the ponds. Thus, as the table above shows, it has come close to the European standards regarding the purity of water in bathing tanks. The amount of nitrates decreased 4-fold and ammonium 3-fold. The carbonate hardness remains at the right level around 6 dH and the pH of the water is optimal. The complete elimination of harmful nutrients is impossible, because they are periodically influenced by the evapotranspiration process, feces of water birds, plant pollen or small particles of airborne pollutants.

Table 1. Summary of water test results

Physicochemical parameter tested	Measurement unit	Tap water	Pond water I season (spring 2018)	Pond water II season (spring 2019)	Recommended values according to FLL standard [MAHABADI 2017]
pH	–	7.3	7.8	7.9	6–9
Manganese	$mg \cdot dm^{-3}$	0.023	0.01	0.02	<0.05
Ammonia	mg $NH_4 \cdot dm^{-3}$	<0.060	0.04	0.02	4
Nitrate	mg $NO_3 \cdot dm^{-3}$	2.05	0.8	0.5	10–30
Nitrite	mg $NO_2 \cdot dm^{-3}$	0.01	0.02	0.02	0.01
Electrical conductivity	$\mu S \cdot cm^{-1}$	452	357	223	200–1000
Turbidity	NTU	0.51	0.8	0.65	< 10
Total hardness	dH	12.65	7	6	5.6–14
Carbonate hardness	dH	4	6	6	5–10
Colour	$mg \cdot dm^{-3}$ Pt	5	8	8	–
Chloride	$mg \cdot dm^{-3}$	<5.0	5.5	8.6	250
Sulfide	mg $SO_4^{2-} \cdot dm^{-3}$	<20	< 20	< 20	60
Soluble phosphorus	$mg \cdot dm^{-3}$	0.05	0.006	0.005	0.01
Total phosphorus	$mg \cdot dm^{-3}$	0.25	0.035	0.025	0.03

Source: own study.

As experience from other water reservoirs with scenic and recreational functions (scenic and recreation pond in Ostrów Mazowiecka and Goliana ponds in Grodzisk Mazowiecki [DĄBROWSKI *et al*. 2008]) shows, the use of effective mineral and plant beds with appropriately selected physicochemical properties contribute to the effective filtration of water in ponds.

Photo 4. Recreational pond after two years of operation (phot. *W. Walczak*)

DISSCUSION

Park ponds in Zduńska Wola have been supplied with water from the Pichna River for years. Unfortunately, the assessment of the sanitary state showed that the degree of pollution of the river would not prevent effective revalorisation of the water system, while further supplying the ponds with river water. The main reason was the constantly increasing load of biogenic elements, primarily phosphorus and nitrogen, which resulted in an increase in trophism. The analyzes showed that it is impossible to achieve optimal purity of water in ponds due to the strong pollution of the river. In addition, geotechnical tests showed a significant thickness of soils and the need to completely seal the tanks.

Due to the park's nature of the establishment, one of the important aspects was obtaining the natural character of the reservoirs. Hence the choice of technology whose main assumption is the simulation of the natural process of self-purification of water through the use of appropriate minerals and plants. This solution also allows to preserve the flora and fauna in good condition. Chemical treatment does not allow maintaining proper pond biology, affecting many valuable processes for ecological reasons. Dosing of chemical preparations, containing, among others chlorine also does not allow maintaining adequate stability of the entire system, which is achieved by arranging natural processes occurring in oligotrophic tanks.

Research indicates that this technology helps maintain proper physico-chemical parameters of water, without adverse effects on aquatic organisms. This is also important from the point of view of ecology and efforts to supply natural system, not its weakening.

Observations of other reservoirs made in the so-called technology natural bathing ponds have shown that this method can be successfully used in recreational reservoirs, while maintaining the landscape character.

CONCLUSIONS

The restoration project was developed by a large group of specialists dealing with water systems for years. Every effort has been made to comply with the current purpose and use of the area, as well as the provisions of the current local spatial development plan. It was decided to put a lot of emphasis on the use of ecological solutions that will guarantee the maintenance of good soil and water conditions and allow the restoration of a proper sanitary status of water in both ponds. Appropriate shaping of the shoreline and the introduction of swamp vegetation ensured the natural appearance of the ponds that harmoniously inscribed in the surrounding landscape. Two park ponds were designed as a structure completely isolated (through appropriate sealing) from the ground and separated from the polluted river (by closing existing water supply devices to the ponds). The reservoirs are a separate system that has been designed to ensure circulation and purification of water inside ponds without affecting groundwater and soil. This solution enabled achieving the expected effect of clean water in ponds already at the time of the investment. Reservoir condition monitoring, aquatic vegetation care and water testing confirmed the effectiveness of the adopted solution.

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