Assessment of the Ecological State of the Water Bodies in Shishkinskiye Ponds" Complex (Yelabuga) According to Hydrochemical Indicators

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Abstract: The town of Yelabuga in the Republic of Tatarstan, due to its special historical significance, is one of the major regional tourist centres. The majority of the town visitors visit "Shishkinskiye ponds" park zone located on the main tourist routes and being a place of mass town events. However, the ecological condition of the park's ponds does not match this popularity: the ponds look unmaintained due to the rapid development of algae in them and the overgrowing of the surface with weeds from the beginning of summer. The planned renovation of the area prompted a study to determine the ecological condition of the ponds and make recommendations for their renewal in accordance with the natural laws of small ponds' development and functioning. The assessment of the state of ponds was carried out according to a complex of hydrophysical and hydrochemical indicators with further correlation of the obtained values with the quality classes of natural waters. The results of observations showed that eutrophication processes are intensifying in ponds, and therefore the main directions of their restoration should be measures aimed at reducing the entry of biogenic elements into the water of ponds and organizing processes of natural self-renewal and self-regulation in them.

1 INTRODUCTION

Historically, ecologists and hydrobiologists have been interested in large aquatic ecosystems - medium and large rivers and lakes, as well as artificially created water bodies - reservoirs. There are two reasons for this:

1) these ecosystems are a major source of fresh water for human nutrition, agriculture, domestic and industrial use; they serve as communication and transportation routes for raw materials and manufactured products, as a source of construction materials and fish; the regulated movement of water is used to generate electricity;

2) intensive anthropogenic activity and exploitation of large water bodies has naturally led to a serious deterioration of their condition. However, since all the above-mentioned processes depend on this condition, mankind has faced the question of the necessity to study the water bodies that support its vital activity with the aim of their further systematic exploitation and prolonging the possibility of their use without serious deterioration of water quality (Volkova, 2021).

Small water bodies have been left without proper attention and study for a long time. At the same time, their ecological significance is no less than that of large aquatic ecosystems. Thus, small water bodies:

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– affect the hydrological regime of the large water bodies to whose basins they belong (especially the small rivers that determine the water content of the medium and large rivers into which they flow);

– soften the microclimate in the territories adjacent to them (through a decrease in the difference between day and night temperatures and an increase in air humidity);

– act as a major factor in the formation of local ecosystems and determine the high diversity of all forms of life within them (in turn, high biodiversity is always the root cause of the resilience of natural complexes to stresses of natural and anthropogenic origin).

Due to the reassessment of the ecological significance of small water bodies and the fact that their size makes them extremely vulnerable to human activity, they have begun to receive more attention (Muravyeva, 2022).

An analysis of the literature sources devoted to the problem of hydrochemical and ecological studies of small water bodies over the past decade convinced us that most of the works present the results of the study of small rivers, to a lesser extent - small lakes, single works are devoted to the analysis of the state of ponds and streams. Meanwhile, it is the ponds that act as indispensable elements of the landscape and architectural systems of cities and participate in the formation of their landscape appearance. In the first case, their significance is associated with water disposal - they become part of the structures for the implementation of surface and drainage runoff of cities. In the second case, the ponds form the aesthetic appeal of the urban area and become a recreational space for the population. In addition to these two functions, ponds are used in agriculture as a source of fresh water for livestock and soil irrigation, as a place for the collection and subsequent treatment of livestock runoff, in civil defense - as a water depot for extinguishing fires, in industry - as a place for cooling heated industrial water and, etc. Many ponds have cultural and historical significance - they serve as a means of educating people and restoring their connection with the natural environment, its flora and fauna (Martins, 2019; Rileya, 2018).

Researchers who have been studying ponds for a long period of time note that in recent years the number of ponds has been rapidly decreasing (Ivanyutin, 2020). For example, in European countries their losses are around 90% (Mimouni, 2015). The main reasons for the disappearance of ponds are global warming and intense anthropogenic pressure on them. All this led to the fact that ponds began to become important objects of environmental research, monitoring, protection and restoration (Trifonova, 2021).

The objects of this study were two ponds belonging to the park area “Shishkinskiye Ponds” in the town of Yelabuga of the Republic of Tatarstan. The uniqueness of these ponds is determined by the history of their occurrence.

Yelabuga is a unique Russian town. The study of its history leads to the understanding that with the help of the dynasties of merchants Girbasovs, Stakheevs, Ushkovs and Shishkins, scientific and engineering inventions appeared and were implemented in it before some provincial cities. As a result of the merchants' patronage, cultural and educational activities, a unique cultural layer was formed in the city, an element of which was the Shishkinskiye ponds. In the 1830s, they were built for the rest of the townspeople on personal savings by the head of the city, the merchant I.V. Shishkin (father of the landscape painter and artist I.I. Shishkin) (Sudovikov, 2011).

In addition to the rich heritage left by Yelabuga merchants, the history of the provincial town is invariably associated with the names of Nadezhda Durova, a participant in the Patriotic War of 1812, the poetess Marina Tsvetaeva, the famous physiologist Vladimir Bekhterev and many others. For the desire to preserve this heritage in 1970, Yelabuga received the status of “Historical Place of Russia”, in 1990 the Yelabuga State Museum-Reserve was created, which is often called a city-museum under the open sky, in 2000 the city was awarded the “Palm of the World” from UNESCO, and since 2013 the museum-reserve has become a member of the Association of Tourist Operators of Russia (Fazleev, 2016).

During the period of the Soviet Union, the ponds and surrounding meadows were abandoned, leaving the area heavily waterlogged and overgrown with moisture-loving woody and shrub vegetation. In recent history, the development of tourism and the free economic zone “Alabuga” led to the fact that in 2005 the territory was reconstructed and the ponds received a “second life”. After restoration, the Shishkinskiye Ponds have become a popular recreation place for residents and guests of Yelabuga (Khusnutdinova, 2016). However, by 2018-2019, the park had lost its appeal again due to the lack of maintenance work. The area is being visited less frequently by town residents. The water surface has been completely covered with duckweed for the past two years since June, the adjacent meadows look untidy. However, this is happening against the background of the ongoing development of tourism, the holding of the annual All-Russian Spassky Fair

and the All-Russian Bell Ringing Festival on the territory of Shishkinskiye Ponds. In this context, planning for the redevelopment of this park area began in 2020 (scheduled for autumn 2023), and we have a unique opportunity to study the condition of these ponds in order to recommend to the town administration the restoration and maintenance of their ecological well-being, as an open-air museum town should have an attractive appearance.

The scientific and practical interest in ponds as ecological systems that are losing their state of equilibrium has led us to formulate the aim of our research: to assess the ecological condition of water bodies in the "Shishkinskiye Ponds" park complex using a set of hydrophysical and hydrochemical indicators and to propose measures for their restoration.

2 METHODS

The objects of the study were two ponds in "Shishkinskiye Pond" Park (Yelabuga, Republic of Tatarstan, Russia). For ease of description of the ponds and analysis of the data obtained during the study, we designate these ponds as follows:

No. 1 - a small pond located under the slope of a hill, on top of which is Naberezhnaya Street and the house of the merchants Shishkins;

No.2 is a large pond located in close proximity to the Toyma River (Fig.1).

Figure 1: Ponds of the "Shishkinskiye Ponds" park area: satellite image.

Measurement of hydrophysical and hydrochemical indicators of water bodies was carried out for two years (from spring 2021 to autumn 2022), water sampling and analysis were carried out monthly (for indicators 4-6) or once a season (for indicators 1-3 and 7-10) in accordance with the Recommendations of Federal Hydrometeorology and Environmental Monitoring Service (Roshydromet) R 52.24.353-2012. Standard techniques were used to investigate the ponds:

1) turbidity (transparency) of water - by type (guidance document 52.08.104-2002);

2) odour – by the sensations of inhaling the vapors of heated water (guidance document 52.24.496-2018);

3) chromaticity – by photometric method (GOST (state standard) 31868-2012);

4) hydrogen index pH – by potentiometric method (guidance document 2.24.495-2017);

5) dissolved oxygen - by the iodometric method (R 52.24.419-2019);

6) permanganate value (permanganate oxygen demand, with permanganate as the oxidant) – by titrimetric method (GOST (state standard) 55684-2013);

7) phosphate content - by photometric method (guidance document 52.24.382-2019);

8) ammonium nitrogen – by photometric method using Nessler's reagent (GOST (state standard) 33045-2014);

9) nitrates – by photometric method using sodium salicylate (GOST (state standard) 33045-2014);

10) nitrites – by photometric method using sulphanilic acid (GOST (state standard) 33045-2014).

To obtain a general idea of the ecological state of the ponds, each individual studied indicator was assigned a score in accordance with the ecological classification of the quality of land surface waters according to O.P. Oksiyuk and V.N. Zhukinsky (1993). The values of individual indicators were compared with MPC (maximum permissible concentration) for fishery water bodies.

3 RESEARCH RESULTS

Urban ponds are of artificial origin: both with I.V. Shishkin and at present, the ponds are dug. Their main source of supply is groundwater, but of equal importance are floodwaters (the nearby River Toyma floods both ponds and their surroundings during spring flooding) and surface runoff water. The ponds have an almost regular rectangular shape with rounded edges. The dimensions of the ponds are

given in Table 1. Both ponds belong to the Toyma River basin.

Table 1: Morphometric parameters of the ponds of the park complex.

pond	length (m)	maximum width (m)	average depth (м)	average surface area (m^2)	average water volume (m^3)
1	48.4	22.6	1.9	1072.0	2078.3
2	99.8	43.8	2.5	4283.8	10928.1

According to the given data, it can be seen that the ponds differ quite a lot from each other, both in terms of water surface area and the volume of water they contain. It is logical to assume that, due to the small size, the ponds may be more susceptible to the process of eutrophication.

Natural and climatic conditions can also contribute to this: ponds are closed on the north side from cold winds by a fairly high elevation; the same hill forms a zone of elevated temperatures at the location of the ponds due to the accumulation and slow dissipation of the thermal energy of the sun.

The timing of the study coincided with two hot and dry years when precipitation, part of the feeding regime of the water bodies, was very scarce (especially in 2021) (Figures 3-5).

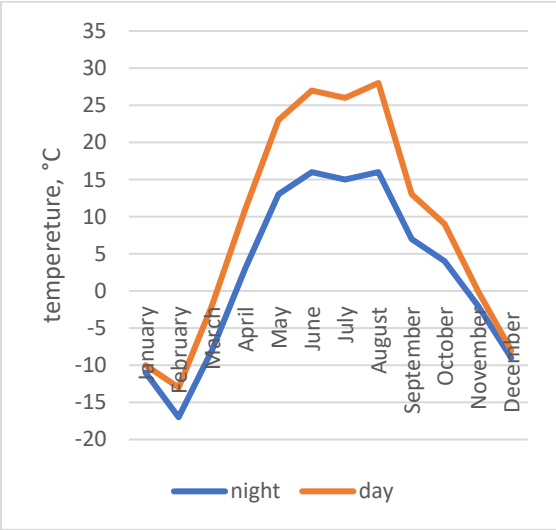

Figure 2: Average night and daytime temperatures in 2021 (by month).

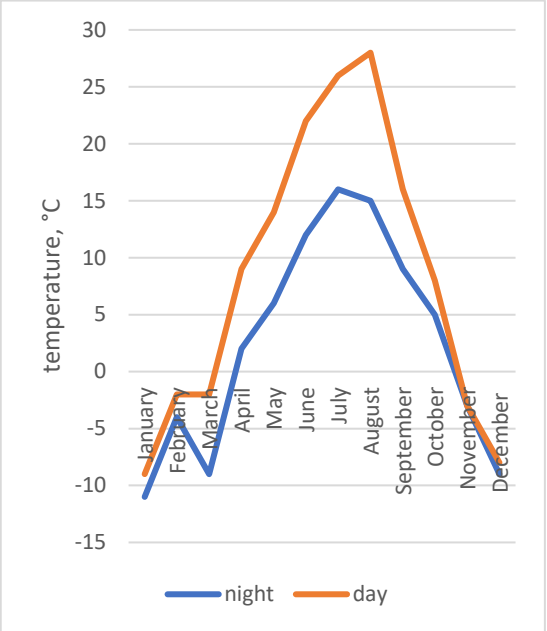

Figure 3: Average night and daytime temperatures in 2021 (by months).

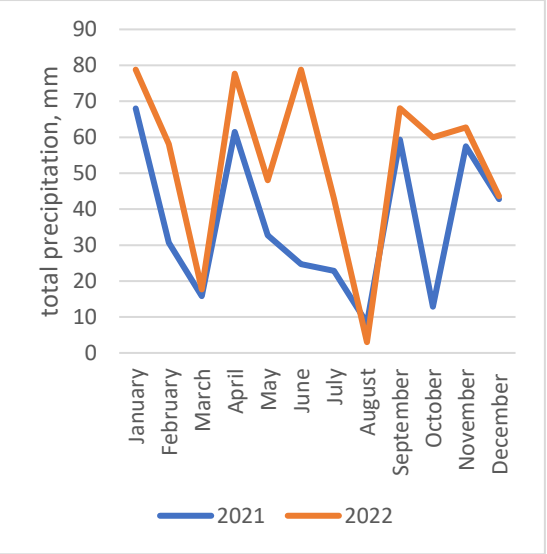

Figure 4: Total precipitation in 2021-2022 in the study area (by months).

The hot summer seasons contributed to the heating of the ponds' water (Fig. 5). The warming of the ponds generally corresponded to the warming of the air, but due to the small size of the ponds, the water temperature in them was higher than the atmospheric temperature in all the studied months. Pond №1, located directly under the northern slope, was warmer in both years than pond №2, located near the Toyma River.

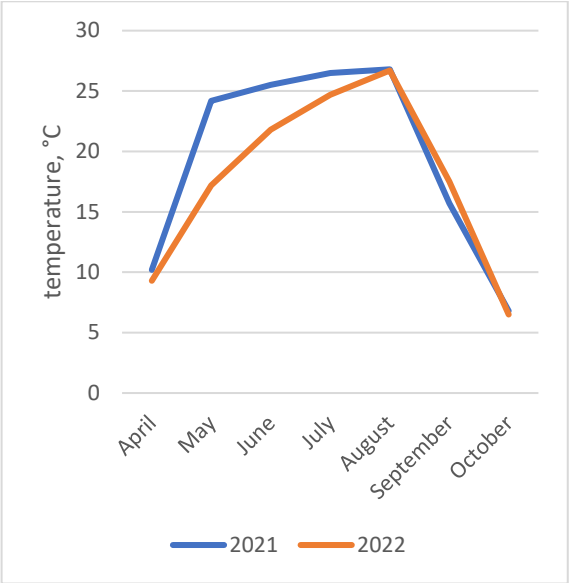

Figure 5: Water temperature in pond №1 (by months).

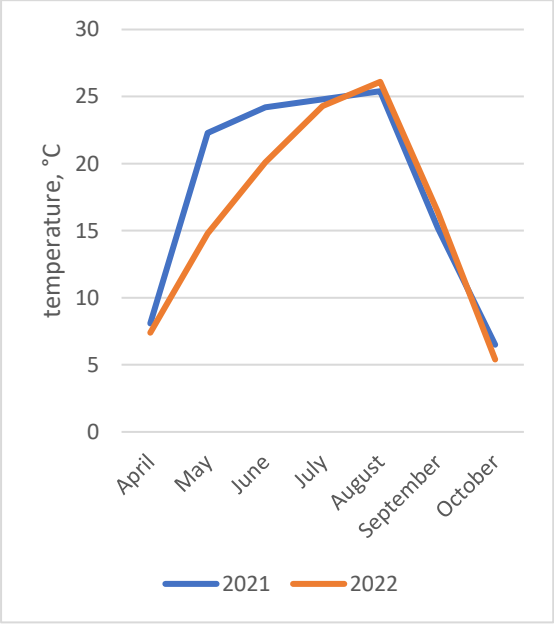

Figure 6: Water temperature in pond №2 (by months).

The considered conditions of water bodies and their morphometric characteristics (relatively small size) can cause eutrophication.

During the entire snowless period, the water of the ponds was characterized by an undersaturation of oxygen (relative to the optimal value of 10 mg/l), although in general its concentration in the water changed naturally: it was high after the water bodies were freed from ice, remained at the same values in May-July and fell almost to the maximum permissible minimum in August (MPC = 6 mg/l). The high concentration of dissolved oxygen in April is due to the saturation of the pond water with oxygen-rich meltwater. In the following months the high oxygen content is due to the photosynthetic activity of aquatic plants. At the peak of photosynthesis, water bloom also occurs, the first signs of which begin to be observed in early June. In August, there is a drop in oxygen concentration due to the oxidation of accumulated organic matter (dying algae) (Fig.7).

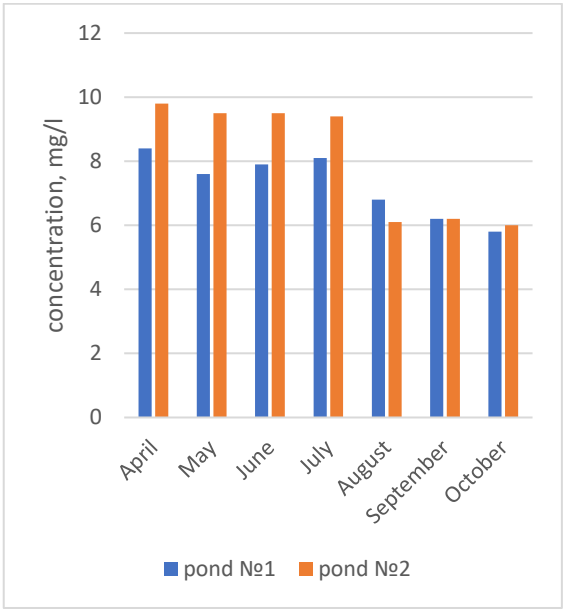

Figure 7: Concentration of dissolved oxygen in pond water (by months).

According to this indicator, pond water is characterized by oxygen undersaturation throughout the entire study period: it is less than 10 mg/ l even at the peak of photosynthetic activity, but at the same time there is no drop below the MPC in the months when there is intensive decomposition of dead organic matter.

The absolute values of the other hydrochemical indicators studied were assigned classes and categories of the quality of land surface waters according to O.P. Oksiyuk and V.N. Zhukinsky (Table 2).

The results of the analysis of laboratory research data in accordance with the presented classification are given in the table 3.

The indicator “odour” was not included in the summary table due to its absence in the system of integrated assessment of water bodies. However, we

evaluated it outside the considered system. The research results are shown in the table 4.

Table 2: Classes and categories of land surface water quality.

	water quality classes								
	extremely pure	pure		satisfactorily clean		Polluted		Dirty	
designation	1	2		3		4		5	
	water quality grades								
	extremely pure	very clean	quite clean	clean enough	lightly polluted	moderately polluted	heavily polluted	very dirty	extremely dirty
designation	1	2a	2b	3a	3b	4a	4b	5a	5b

Table 3: Assessment of pond water quality according to basic hydrophysical and hydrochemical indicators.

			hydrophysical								
			transparency	chromaticity	pH	NH_4^+	NO_3^-	NO_2^-	P_{total}	O_2	permanganate oxidizability
2021	spring	pond №1	3b	3b	2a	4a	5a	4a	5a	3b	4a
		pond №2	3b	3a	2a	3b	4a	3a	3b	2b	3a
	summer	pond №1	3b	4a	2b	4a	5a	4a	5a	4a	4a
		pond №2	3b	3b	2a	3b	4a	3a	3b	3b	3a
	autumn	pond №1	3b	3b	2a	4b	5a	4a	5a	4a	4a
		pond №2	3b	3a	2a	3b	4a	3a	3b	3b	3a
2022	spring	pond №1	3b	3b	2a	4a	5a	4a	5a	3b	4a
		pond №2	3b	3a	2a	3b	4a	3a	3b	2b	3a
	summer	pond №1	3b	4a	2b	4a	5a	4b	5a	4a	4a
		pond №2	3b	3b	2a	3b	4b	3b	3b	4a	3b
	autumn	pond №1	3b	3b	2a	4b	5a	4b	5a	4a	4a
		pond №2	3b	3a	2a	3b	4b	3a	3b	4a	3b

Table 4: Results of pond odour measurements.

water samples	measurement temperature			
	20°C		60°C	
	odour classification	odour intensity	odour classification	odour intensity
pond №1	marshy (muddy, oozy)	1 point - very weak	marshy (muddy, oozy)	2 points - weak
pond №2	there was no odour	0 point - no odour	fish (fish oil)	2 points - weak

When the water samples were heated, a faint natural odour was noted, but in sample 1 it was characterised as muddy, i.e. confirming the initial processes of waterlogging in the pond.

4 DISCUSSION OF RESULTS.

The studied water bodies are classified as stagnant water bodies. Together with their small size, this leads to a slowdown in water exchange in them and a slowdown in self-purification processes. If these ponds were subjected to technogenic impact, these two factors would cause the accumulation of pollutants in them. However, water bodies do not experience anthropogenic load, although their apparent state is deteriorating. This is due to natural reasons: stagnant water bodies, their small size, good warming in the spring-summer period, sufficient content of organic matter that enters the water with runoff from coastal areas and as a result of the flood of the Toyma River, the lack of measures to support water bodies led to the fact that in algae and duckweed develop in large quantities in them. Their death leads to the accumulation of organic matter in water bodies, which initiates even greater growth of algae and duckweed in the following years. As a result, water bodies become untidy, and Pond № 1 even begins to exude an unpleasant marshy odor and show traces of anaerobic fermentation (in the form of bubbling zones near the banks).

A sufficiently high content of organic substances in water is confirmed by the results of the analysis: the MPC values for permanganate value (5.0 mgO2/l) are exceeded, and for a small reservoir - more than 2 times. Pond 2 is characterized by cleaner water, but it can be seen that, in the second year of the survey, by mid-summer, water quality has changed from class 3a to class 3b.

The chromaticity and transparency of water also classifies it as "slightly polluted" and “moderately polluted”.

The pH values of the ponds characterize them as clean.

The norm for ammonia/ammonium ion content in the fishery water is 0.39 mg/l. In the water of pond №1 its content is exceeded and reaches a maximum (1.34 mg/l) at the end of summer and beginning of autumn. In the water of pond №2 the concentration of ammonia nitrogen is kept at MPC level, slightly exceeding it in summer-autumn period.

An excess of ammonium ion in natural waters is possible in two cases:

1) ammonia / ammonium is introduced into water from runoff from livestock farms, agricultural fields, industrial plants;

2) ammonia / ammonium is formed as a result of the mineralization of organic matter - the result of the photosynthetic activity of aquatic organisms.

The first way for ammonia substances to enter water bodies is excluded, since there are no enterprises and residential complexes near the ponds that discharge water into them. Accordingly, they are formed as a result of the ammonification of dead algae and duckweed.

Although the nitrate ions in the pond water do not exceed the norm (MPC = 40 mg/l), their concentration is too high to describe the ecological well-being of the ponds: the pond water is classified as class 5 (Pond №1) and class 4 (Pond №2) for this particular parameter. The source of nitrates in the water is intensively decomposing dead plant organisms (in the summer of 2022, the small pond (object №1) was 100% covered with duckweed by mid-June and showed signs of water bloom by mid-June.

Nitrite ions slightly exceeded MPC (0.08 mg/l) only in the water of Pond №1. However, as in the case with nitrate, the concentrations of these ions correspond to classes 4 (Pond №1) and 3 (Pond №2) of ecological water quality. There is also an increase in the amount of nitrite by the end of the 2nd research season. Nitrites appear in water as a result of the biochemical transformation of nitrates with a lack of oxygen dissolved in it (which is observed in the studied water bodies, and is also confirmed by measuring the oxygen concentration in them).

The content of the main limiting biogenic element - total phosphorus - in Shishkinskiye Ponds is exceeded (MPC = 0.2 mg/l) in pond №1 by more than 4 times, and in pond №2 it is on the border of standard values. In accordance with this, the first water body is eutrophic in terms of this indicator, and the second is mesotrophic with a transition to the eutrophic level.

5 CONCLUSIONS

The physical and chemical analysis of the water of the studied ponds, important elements of the urban landscape and objects of historical heritage, allowed us to classify them as dirty (pond №1) and polluted (pond №2). Biogenic elements are the main pollutants in water bodies, as it is their quantitative characteristics that exceed ecological standards (water assessment for mineral components (chloride, sulphate, total iron, hardness salts) was also carried out, but their values were optimal). Classes 4 and 5 of water quality according to the considered hydrochemical and some hydrophysical indicators correspond to eutrophic (pond №2) and polytrophic (pond №1) water bodies. Visual signs of their increased eutrophication are the increase in water

chromaticity and the increase in plant biomass. Thus, the ponds of the “Shishkinskiye Ponds” complex are not environmentally safe and require a conscious approach to reconstruction in order to slow down the processes of eutrophication and subsequent waterlogging.

Based on the findings of this study, we have formulated and forwarded to the city administration a number of proposals for the restoration of the ponds as part of their renovation. These include the followings:

1) removal of excess sludge from ponds;

2) deepening the bottom of water bodies to 3.0-3.5 m in order to reduce the rate of warming in the summertime;

3) strengthening the natural shoreline to prevent organic-rich soil from washing into the ponds;

4) organizing a system of additional water circulation, represented by elements of recharging the ponds with river or spring water and discharging water from the ponds into the river Toyma. It is not difficult to organize both recharge and discharge, since there are a large number of unorganized low-power springs in the adjacent territories, and a nearby river is used to divert water;

5) maintaining a meadow lawn in good condition (from wild grasses of floodplain meadows), as well as planting perennial, shrub and tree vegetation in coastal areas for additional purification of surface runoff from dissolved organic substances and the upper fertile soil layer;

6) Formation of a pond ecosystem that is as close as possible to natural ecological systems and effectively performs the function of self-purification of the water body; settlement of water bodies with hydrobionts (especially herbivorous fish species), shorelines with active hydrophytes (narrow-leaa cattail (typha angustifolia), lakeshore bulrush (schoenoplectus lacustris), sedges);

7) organizing of environmental monitoring of the state of ponds with the formation of an annual report with proposals for changing the negative manifestations of the development of pond ecosystems.

The reconstruction of the Shishkinskiye ponds, based on ecological and biological recommendations, should bring them to a state of ecological balance.

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