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To cite this article: L M Bukhman and E L Vasileva 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **272** 022240

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Geotechnical and Hydrological Characteristics of Urbanized Areas in the Development of Activities for Water Object Rehabilitation (Samara)

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Abstract. The peculiarities and main problems of the urban systems, the most important element of which are water objects, have been described. Using the example of the park Voronezhskie ozera (Voronezh lakes) (Samara) located inside the residential area such consequences of a negative impact on the small water bodies in the city as the contamination of ponds, their shallowing and overgrowth have been shown. The main tasks for the ecological rehabilitation of the Voronezh lakes area have been specified and divided into groups. The first group of the tasks includes cleaning the pond basins and the general sanitation of the strand. The second is related to the problem of restoring the water content of ponds in the conditions of a decrease in the volumes of influent surface runoff. The third group of the tasks is aimed at restoring the ecological balance of the parkland. When solving these problems, it is supposed not to be limited to the analysis of the state of water bodies, but to make an integrated survey of the urbanized areas they are located in. The necessity of developing projects for cleaning small and middle-sized ponds taking into account a complex of geotechnical and hydrological characteristics has been substantiated. A complex of engineering surveys has been offered for drawing up the project of ecological rehabilitation of the ponds, including specified work activities. Based on the results of on-site surveys, a number of recommendations have been provided for clarifying the program for the integrated rehabilitation of water bodies in the urban areas.

1. Introduction

The world trends in the development of the urban environment through the creation of recreational zones in urban areas has currently become widespread in Russia. Of particular interest are the water bodies of urban recreational areas the level of living and well-being in a metropolis depend on. The water areas of the ponds surrounded by residential areas are constantly and very intensively used by the residents of the adjacent areas [1]. For a city, the value of water bodies depends on an increase in the quality of the environmental components of the objects already exploited, the emergence of new recreational areas and the formation of a landscape architectural environment with favorable videoecological characteristics [2].



At the same time, the water bodies located within urban areas are under a powerful negative influence of urbanization itself. To a greater extent, this effects the small water bodies located in an urban area, among which ponds are the most common [3]. According to [4], 72% of the 25 metropolitan ponds studied by the staff of the Department of Hydraulic Structures of the Russian State Agrarian University - Moscow Timiryazev Agricultural Academy in 2013-14 were either shallowed or drained. The ponds are filled with surface (rain, melt) or ground waters and are a limited amount of water with specific vegetation, fish and aquatic animals [5]. Pond ecosystems, including urban pond ecosystems as the active elements of urban landscape, are studied in a lot of countries [6-9]. The inclusion of a reservoir in the urban environment results in a change in its recharge [10] and species diversity [11].

2. Relevance and scientific significance of the issue

The development of measures for the rehabilitation of water bodies in urban areas is a relevant task in a lot of cities, including Samara. In recent years, examples of well-implemented projects and projects for the rehabilitation of ponds with negative consequences for a reservoir, as it happened in Samara, have been published [12-14]. In the urban district of Samara, the detailed study of numerous ponds, among which there are several intermittent ones, began at the end of the twentieth century [15]. The articles [14, 16] give the estimation of recreational objects, including water ones, and consider the issues of an increase in the level of their ecological safety. The study [17] provides an analysis of recreational loads and the state of the considered specially protected natural reservations using the example of the limnological complexes of the city of Samara.

The study of the current state of the ponds in the city of Samara gives an idea that a complex solution of engineering, technical and environmental problems is required to rehabilitate these water bodies. At the same time, a problem has been revealed - there is no unity of approaches in the municipal program for the integrated ecological rehabilitation of water bodies and the simultaneous provision of the adjacent area with the necessary facilities. As is known, the state of a reservoir is determined by the state of its catchment basin. Changes in the state of the adjacent area result in the contamination and shallowing of water bodies and their vanishing in future. Urban areas are an example of an unbalanced impact on the geological environment of the man-made factors that violate the hydrogeological and geoecological conditions of an area. Therefore, these areas should be considered in the most detailed manner.

3. Formulation of the problem

The study is aimed at revealing the role of the engineering, geological and hydrological surveys conducted in urban areas when developing measures for rehabilitating the small water bodies located in these areas.

The objects of the study are the ponds of the Voronezhskie Ozera [Voronezh Lakes] park. There are three ravine ponds here different in shape and a number of other features. The dimensions of the upper (northern) pond (No 1) are 100x30 m at a depth of 1.6-2.1 m; the dimensions of the southern one (No 2) are 120x60 m at a depth of 1.8-2.0 m; and the dimensions of the lowest, the deepest one (No 3), are 140x40 m at a depth of 3.1-2.5 m (see figure 1).

4. Theoretical part

The total area of the Voronezhskie Ozera park is 14.605 hectares, the total water surface area is 1.76 hectares, the area of various types of green plantations are 3.34 hectares and the area of other lands is 9.550 ha. According to the decision of the Samara City Executive Committee of 12/24/91, the Voronezhskie Ozera park is a natural monument of local (urban) significance. The group of artificial ponds in the park was created in the early 1910s of the last century. The basis for the three ponds was the thalweg of a natural ravine with a characteristic V-shaped branching in its upper part. By pouring out earth dams 2.0-6.0 m high and up to 10 m wide, three ponds with different water surface areas and depths were formed in the branch connection area and the main thalweg, and also a little below.

According to the design, these ponds belong to dammed ones [3]. In the body of each earth dike, pipes 700 mm in diameter are laid that connect the lakes in pairs. In the 1980s, a fourth pond with a protective earth (dug) bank was opened in the upper part of the left branch of the main thalweg of the ravine. This pond is dry and it is not recharged by ground waters. The depth of its excavation is 3.0 m.



Figure 1. Voronezhskie Ozera park (a – a scheme, b – a view from above).

When creating ponds in the early twentieth century, the catchment area of the Voronezh ponds group was 1.23 km². After building the surroundings of the ponds and creating obstacles to the natural gravitational current of ground waters in the form of basement and foundation structures below ground, the total catchment area decreased to 0.13 km². The surface runoff from the surroundings is largely intercepted and redistributed by driveways, streets and storm drainage structures. Hence, the total average annual volume of surface runoff of the ponds decreased, but the specific percentage of recharge of the ponds by ground waters increased. However, the colmatation of springs at the bottom of the ponds with cumulative dense silt masses reduces this index in absolute terms as well. After the construction of a group of shopping centers in 2002 that dammed the flow of ground waters of the upper (deluvial) aquifer from the watershed to the ponds, the ponds of the northern group began to dry out gradually.

The lithological structure of the catchment area of the Voronezh ponds is characterized by the deluvial deposits from the loams of brown, light brown and gray clays with the sand interlayers 2.0-5.0 cm thick incorporated with grass (up to 10%) and limestone. In the northern, western and southern parts of the area from the surface to a depth of 1.1-2.4 m, there are fill soils - a mixture of black soil with the loam that contains up to 10-20% of incorporated debris.

Within the framework of the present study, a complex of engineering, geological and hydrogeological surveys has been carried out in accordance with the provisions of [18] and [19] by drilling geological wells 159 mm in diameter and 6.0-8.0 m deep. The drilling depth in the zone of the proposed placement of artesian wells is 15.0-20.0 m. The sampling of the soils of the disturbed and undisturbed (monolithic) structures has been carried out with an interval of 3.0 m. A standard analysis of physicommechanical properties of soils has been carried out for the selected samples. According to a type, genesis and general physical and mechanical properties the following engineering and geological elements can be distinguished in characteristic engineering and geological terms: fill soil, vegetable ground and top soil, free-flowing silt, semi-hard and stiff loam, high-plastic and very soft loam, semi-hard and stiff clay, high-plastic and very soft clay.

Within the framework of the engineering and hydrogeological surveys, the levels of ground waters in the drilled wells, their specific flow rates, actual filtration and water permeability rates for individual layers have been determined, and the general hydrogeological regime of the survey area has been described. The ground waters have been found at a depth of 1.5-4.0 m. At a certain distance from the immediate location of the lakes, the groundwater level (in the western and north-western part of the area) decreases to 5.6-5.9 m from the daylight surface. During the high-water period, the level of ground waters throughout the area increases on average by 1.0-1.5 m. The water-bearing rocks for the upper aquifer are light and medium-textured loams and clays. The waterproof rock is composed of the clays of the Tatarian stage of Upper Permian deposits at a depth of 30-40 m from the daylight surface. The upper aquifer is recharged mainly due to the infiltration of atmospheric precipitation and the leakage from the utility lines. The ground waters are discharged in the lower aquifer in places where there is no waterproof rock and in the existing ponds. The filtration rate of water-bearing rocks is from 10 m a day to 80 m a day (due to various fracture density). The water-transmitting capability varies within 800-1600 m³ a day.

The surface waters are fresh and hydrocarbonate-calcic. In relation to concrete engineering structures, these waters are non-aggressive. In chemical composition, the ground waters are hydrocarbonate-sulfate and magnesium-calcium with the total mineralization of 931-1149 mg/l. The sulfate content is from 350 mg/l to 600 mg/l. Closer to the watershed, the waters become sulfate and chloride-sulfate.

To estimate the state of the surface waters of the pond cascade and the biochemical composition of bottom sediments, sampling has been carried out within the framework of this study. At a distance of 3 m from the shore from a depth of 0.4 m, 3 samples of water with a volume of 5 liters have been taken. The water sampling has been carried out in accordance with the provisions of [20]. At the same points, 3 samples of bottom sediments weighing 1.0 kg have been taken from a depth of 1.5-2.3 m from the surface of the water. The composition of bottom sediments is represented by flowing black silt 0.3-1.3 m thick incorporated with construction and daily waste. The sampling of bottom sediments has been carried out without stratification violation in accordance with the requirements of [21]. The following parameters have been determined in the area: the ambient air temperature when sampling, the temperature of surface water samples and the pH value of water samples. The surface water samples and the bottom sediments have been analyzed by the laboratory of the State Budgetary Institution of the Samara Region "Environmental Protection Center" (the accreditation certificate POCC RU.0001.517580 dated 02/07/2013). The water samples have been analyzed according to 13 indicators. A number of complex indicators have additionally been determined, in particular the content of suspended and surface active (anionic) substances, oil products and dry residue in the water. The state of the surface waters has been estimated on the basis of the comparison of the obtained characteristics with the normative values of the maximum permissible concentration for each ingredient for fishery water bodies (since there is an aquatic ichthyofauna in the ponds that has become part of biocenosis). The bottom sediment samples have been analyzed according to 8 indicators. The results of the analyses were compared with the normative values of the maximum permissible concentration for soil and subsoil.

According to the chemical analysis, no toxic substances and chemical toxins have been found in the bottom sediments and water samples. According to the content of heavy metals, the bottom sediments of the Voronezh ponds do not exceed the maximum permissible concentration for any of the ingredients. However, the bottom sediments of all the three ponds contain the doses of oil products that completely exclude their economic use: 3483 mg/kg for the northern pond; 2853 mg/kg for the southern pond and 5379 mg/kg for the lower pond. All the bottom sediments removed when cleaning the pond basins are to be taken out to an SDW landfill.

5. Practical significance and suggestions

All the main tasks of ecological rehabilitation of the area of the Voronezhskie Ozera can be divided into three groups.

The first one deals with cleaning the pond basins and the total sanitation of the coastal strip. The bottom of the lakes need to be cleaned from the accumulated bottom sediments and debris. However, mere mechanical purification in the form of the elementary withdrawal of certain volumes of soil will be ineffective in restoring the natural biological balance. Along with cleaning, measures should be taken to design the bottom and sides of the lakes, to prepare the bed and to provide the basic volume of the bottom layer the lacustrine vegetation could develop on in the shortest possible time after cleaning. Cleaning the spring outlets would increase the natural filling rate of the ponds. The areas of spring outlets should preferably be covered with sandy soil not less than 15-20 cm thick.

The second one deals with the problem of restoration of the water content of the lakes in the conditions of irretrievable reduction of the volumes of influent surface runoff. The supply of a pond with water can be provided by using the drainage systems through which the water is collected in the pond from the catchment area. This, by the way, can partially discharge the storm drain. In France, for example, the similar storm drain control projects are implemented, when rainwater in populated areas is fed into specially constructed reservoirs. Nevertheless, the data on the water regime of the Voronezh ponds that indicate the volumes of spring and rain floods, characteristic water levels for each pond and the calculation of actual catchment areas testify to the fact that it is not possible to increase the volume of surface runoff to the acceptable values. An option of artificial recharge of the upper lakes by means of ground waters should be considered. An artesian well with an adjustable runoff can be an alternative source of recharge.

The third group of tasks deals with the restoration of the ecological balance of the park area. The indicators of the hydrological regime of lakes are also closely related to the factor of the development of water erosion of the slopes of ponds and coastal territory. To consolidate the soils of coastal slopes and interpond area and prevent water erosion processes, it is necessary to perform forest improvement measures on the drainage slopes and meadow improvement works on sowing the area with perennial grasses.

Taking into account all the above, the most preferable for the group of the upper (southern, northern and dug) ponds is a mechanical method for cleaning with water drain using pumping units (or motor pumps) in the lower pond. The lower pond can be cleaned using two methods – a mechanical (similar to all other ponds, bleeding all the water into the municipal storm drain) or a hydromechanical one (using amphibians with hinged replacement equipment). The approximate volumes of the soil extracted when cleaning the Voronezh ponds are as follows: 4890 m³ for the upper (northern) pond, 11,150 m³ for the southern pond and 9910 m³ for the lower pond.

The provision of an alternative source of pond filling is also of interest. For periodic pond filling, it is proposed to create a disconnectable artesian well with an adjustable rate and the branches of supply pipelines to the ponds of the upper group to the north-west of the southern and northern ponds. The lower pond will be replenished automatically when the water is supplied to the upper ponds of the cascade. It is also recommended to install shut-off valves on the supply lines to each pond for more adaptive control of rate volumes.

6. Conclusion

A complex survey of urban areas has been carried out using the example of the Voronezhskie Ozera park where ponds are located. To develop a pond cleaning project, a necessity has been justified to take into account a complex of engineering, geological and hydrological characteristics of the catchment area. The groups of tasks for drawing up an ecological rehabilitation project for the Voronezh ponds, including particular types of works, have been determined. All the task groups are interrelated and should be accomplished as complex as possible in order to restore the biological balance system. Based on the results of the field surveys, several recommendations for clarifying the program for the complex rehabilitation of ponds and the adjacent area of the Voronezhskie Ozera park have been given.

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