The ecological condition of the Motovilikha pond, Perm

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Abstract. The article gives a hydrographic description of the pond, the results of bathymetric work in the summer of 2017. Examines the factors that shape the environment. A detailed description of the chemical composition of water is given. The degree of pollution of a reservoir on its separate sites is revealed. It is shown that bottom sediments play an important role in the formation of the Motovilikha pond ecosystem. They accumulate pollutants and trace elements, so they can be considered as a marker of water quality and at the same time a source of secondary pollution.

1. Introduction
The Motovilikha Pond is the largest pond of the city, built between 1736 and 1738 on the Bolshaya Motovilikha river (at the distance of 1.1 km from the estuary). In 2010, following the decision of the City Duma in Perm, an SPNA (Special Protected Natural Area) of the local significance - a historical and natural complex “The Motovilikha Pond” with an area of 21.2 hectares - was organized. A recreation area for children and adults was created on the territory adjacent to the reservoir. However the recreational use of the pond is hindered by its extensive siltation. Being artificial reservoirs with slow water exchange, ponds contribute to the accumulation of bottom sediments in them. The latter are an active component of the reservoir ecosystem and represent an environment where matter and energy are exchanged between living organisms and water masses, while largely shaping the process of secondary pollution and self-purification [4]. Chemical composition of the water masses together with body sediments are indicators of the ecological state of the water bodies. Their study is the main purpose of this work.

2. Materials and methods
The main research methods are field observations and laboratory analysis of the water samples and bottom sediments. The data of our own field observations, carried out between 2014 and 2017, and the bathymetric survey done in 2000 by Permgiprovodhoz were used as source materials.

3. Results and discussion
The ecological state of the pond is formed by the tributary waters and intrabasin processes that occur in the pond itself. The largest lateral tributaries are the Bol’shaya Motovilikha and the Malaya Motovilikha rivers. But the biggest contribution to the formation of the water regime and the ecological state of the pond is made by the Bolshaya Motovilikha River [10]. This river, being left-bank tributary of the Kama River, is attributed to the small rivers of the city. The length of the river is 8.5 km, the total catchment area is 28.1 km². The boundaries of the
catchment area are clearly outlined. The river-valley is narrow along its entire length – in the upper reaches it is 50–100 m, in the middle reach it gets to 100–200 m, and up to 500–700 m in the lower reach. The valley is V-shaped and cuts deeply – starting from 10–15 m in its upper part and up to 50–70 m at the bottom. The upper part of the basin is covered with forest, the total extent of which is 30% of the area. The floodplain, the bottom and the slopes of the valley in the middle part of the basin are mostly covered by meadow vegetation, shrubs and, to a lesser degree, by forest. There is an apartment block in the lower reaches of the river [9]. Meltwater mostly contributes to the alimentation of the river (nearly 70% of it), the rest is rainwater and groundwater. The annual course of the river level is characterized by two risings: strongly pronounced changes of the level followed by the periods of rainfall floods in summer and autumn. The described watercourse has a constant flow [4, 10].

According to the calculation of hydrological characteristics of the Bolshaya Motovilikha river-flow and its tributaries, the main inflow of the pond springs from this river. With the same constant unit discharge, its average annual discharge is 3 times higher than the lateral inflow. The same goes for the seasonal flow volume. Consequently, the ecological state of the Motovilikha pond will be formed by the waters of the Bolshaya Motovilikha River and the intrabasin processes that occur in the pond itself.

The average annual water discharge in the pond dam site is 0.216 m³/s. The water level in the pond goes through minor fluctuations (up to 15-20 cm during summertime; almost constant in winter, but can decrease for 1 m and more in comparison to the summer period). In winter the reservoir does not freeze through. The surface of the pond is completely covered with ice 5-7 days later than the watercourses. On average, the ice depth in winter reaches 60–90 cm. Ice formation is built up without ice drift, by the means of landfast ice enclosure. Therefore, dynamic processes are not especially active, although there is an ice-hole of a dynamic origin below the dam on the Motovilikha River throughout winter [4].

The bathymetric survey of the pond in 2015 allowed to carry out its aquatic zoning according to the scheme offered by S.L. Vendrov (1953). From top to bottom current wise, the outlined areas are: 1) shallow-water, which includes the estuary of the Bolshaya Motovilikha river; 2) intermediate (mid depth zone); 3) deep water (located near the dam), which includes the area of the Malaya Motovilikha inflow. The depths of the pond vary from 0.2 to 3.0 m, the maximum value is observed near the dam and reaches 3.1 m (figure 1A).

The study of the chemical composition of the main water tributaries showed that in terms of mineralization, principle ions content, as well as concentration of nitrates and nitrites, the pond waters meet the sanitary standards (table 1). Dissolved oxygen concentration and oxidability values during the said period also meet the sanitary requirements [14].

Earlier studies (2008) showed that the largest amount of pollutants enters the pond with the waters of the Malaya Motovilikha River. For instance, the contents of Cl at the entrance of the Bolshaya Motovilikha to the pond is 24 mg/dm³, while near the Malaya Motovilikha river it reaches 36 mg/dm³. A similar ratio is observed for mineralization: 539.4 and 630 mg/dm³ accordingly. The change in the concentration of the chemical elements inside the pond is insignificant, compared to the influent river waters.

Data comparison at the inlet and outlet of the pond indicates a slight dilution of the water in the researched reservoir, which leads to a decrease in mineralization, hydrocarbonates, sulphates, calcium and nitrates. General water hardness is also decreased. Inlet and outlet waters of the pond are characterized as alkalescent (pH varies from 8.19 to 8.32). The degree of water hardness in the Bolshaya Motovilikha (its outlet and inlet) is average (7.00 and 5.97 mEq/L). Water hardness in the Malaya Motovilikha river is higher (8.28 mEq/L) and its waters are closely bordering with those of average and high hardness levels. The waters of the pond itself are fresh and belong to the HCO₃–Ca – SO₄ phase. They have an average hardness (5.76–5.98 mEq/L), and are slightly alkaline (pH 8.35–8.39). Available materials indicate that there is no significant difference in the amounts of the studied ingredients of the chemical water composition in different parts of the pond. However its ecological state in the open channel period and the depth of particular indicators of the chemical water composition show different stages of pollution: from very clean to moderately polluted.
Table 1. Chemical composition of the water and bottom sediments of the Motovilikha Pond, July 2015.

| Indicator, unit of measure | Chemical analysis result | Limiting concentration | Chemical analysis results of benthal deposit |
|---------------------------|--------------------------|------------------------|--------------------------------------------|
|                           | In the area of the B. Motovilikha inflow up | Near the dam | 1000-1500 | - |
| Nonvolatile Residue, mg/dm³ | 335.3 | 338.3 | - | - |
| pH                        | 8.19 | 8.32 | 6-9 | - |
| Cl, mg/dm³                | 23.8 | 24.6 | 350 | - |
| SO₄₂⁻, mg/dm³             | 66.1 | 63.5 | 500 | - |
| NO₂⁻, mg/dm³              | 0.10 | 0.19 | 3.3* | - |
| NH₃, mg/dm³               | <0.5 | <0.5 | 1.5* | - |
| NO₃⁻, mg/dm³              | 8.9 | 7.6 | 45 | - |
| Cu, mg/dm³                | 0.0024 | 0.0017 | 1 | 42.1 |
| Zn, mg/dm³                | 0.007 | 0.008 | 1.0* | 72.5 |
| Mn, mg/dm³                | 0.01 | 0.01 | 0.1* | 753.0 |
| PO₄³⁻, mg/dm³             | <0.05 | <0.05 | 3.5 | - |
| Specialties, mg/dm³       | <0.04 | <0.04 | 0.1 | 287.0 |
| Pb, mg/dm³                | - | - | - | 16.3 |
| Chemical oxygen demand (COD), mgO₂/l | 98 | 60 | - | - |
| Biological oxygen demand (BOD₅), mgO₂/l | 2.4 | <0.5 | - | - |
| Dissolved oxygen, mg/l    | 11.8 | 14.4 | - | - |
| Fe Total, mg/dm³          | 0.10 | 0.07 | 0.3* | 11550 |

Note: *compared to [7]

Thus, the content of dissolved oxygen varies from 13.2 mg/dm³ in the area of the Bolshaya Motovilikha inflow and up to 14.6 mg/dm³ near the dam at the beginning of summer. From 11.8 and up to 14.4 mg/dm³ in the middle of summer. It shows that the water is well saturated with oxygen, but the amount is decreased in several times in deeper parts of the pond (up to 4-6 mg/l). The BOD₅ quantity varies from 3.9 mg O₂/dm³ in the area of the Bolshaya Motovilikha inflow up to 3.5 near the dam in the beginning of summer, and from 2.4 to <0.5 mg O₂/dm³ in the middle of summer. Consequently, the degree of pollution changes from very clean to moderately polluted. The most informative indicator of anthropogenic pollution is COD, the value of which depends on the amount of almost all the organic substances. Its value varies from 33 mg O₂/dm³ in the area of the Bolshaya Motovilikha inflow up to 98 near the dam in the beginning of summer, and from 17 up to 60 mg O₂/dm³ in the middle of summer. Therefore, the waters of the pond can be characterized as very polluted (table 1).

During the assessment of the ecological state of water bodies, bottom sediments are one of the most informative research objects. The nature of their accumulation and distribution, as well as their mechanical and chemical components reveal the entirety of processes that occur in the reservoir [1].

Sediments play an important role on the quality of aquatic ecosystems, notably in the reservoir areas where they can either be a sink or a source of contaminants, depending on the management and hydrological conditions [11]. It also allows us to determine the likelihood of its secondary pollution [3, 6]. Unfortunately, no consensus criteria have been developed to determine the quality of bottom sediments [1]. Due to this fact, different standards for soil assessment are used (for instance, HS 2.1.7.2511-09 «Approximate permissible concentrations (APC) of chemical substances in the soil» [8]). The pollution of the bottom sediments in the Motovilikha pond was determined by the presence and content of heavy metals, as they are susceptible to accumulation and are not much involved in...
motion. The results of the chemical composition of bottom sediments in the pond are presented in table 1.

Sediment accumulation is characteristic for all the areas of the pond, i.e. it is gradually being silted and as a result is decreased in depth (figure 1B). This accumulation reaches its highest values in the upper shallow water zone of the pond and makes up 1.3 m for the last 15 years. It can be noted that generally the speed of siltation is decreased along the pond, in the direction to the dam, changing from 0.09 to 0.02 m per year. A dislocation of maximum depths from the centre to the left shore of the pond can be observed in its lower zone (near the dam). The total amount of bottom sediments for the last 15 years (from 2000 to 2015 r.) is 78.7 thousand m$^3$. Consequently, the accumulation speed of body sediments is 0.07 m per year $[10]$. A formation of sandy sediments can be noticed in the areas of increased hydrodynamic activity, i.e. where the Malaya Motovilikha flows in the pond. But most of the pond area is covered in silt.

Analysis of the literature on water sedimentation showed that the general direction of bed formation is the same for the majority of ponds and water bodies, while the differences in timing and extent of the sediment areal distribution are determined by morphometric and hydrological features of different water body types $[2, 3, 5, 12]$. The main types of bottom sediments for the Motovilikha pond are transformed and secondary soils which are partly formed by the solid flow from the catch basin that comes with lateral inflows. The Bolshaya Motovilikha and Malaya Motovilikha rivers are the main suppliers of suspended materials and bed silt. One of the sources is the destruction of the slopes of the valley by streams of rain melt waters, which causes the development of ravine and landslide activities. A significant part of the sediments comes during the spring flood, when the spates reach 0.02 km, and the flood plain itself is flooded to a depth of 0.10 m. Organic residues make up the most part of the materials that form the bottom sediments.

Figure 1. Scheme of the Motovilikha Pond: A) according to the results of the bathymetric survey in 2015 with the designated zones (from top to downstream): 1) shallow water, 2) intermediate, 3) deep water; B) the thickness of bottom sediments for the period from 2000 to 2015.
Spatial distribution of the bottom sediments in the order of their concentration is shown in figure 1B. It is known [13] that river sediments of small fractions with high sorptivity accumulate the whole variety of chemical elements in the water, in the process of their movement or concentration in the river bed. Concentration of polluting chemical elements in sediments with a size of less than 0.020 mm (clay and silt) exceeds their concentration in the river water by 5-10 times.

The results shown in table 1 show that bottom sediments do not exceed normal amounts of heavy metals, iron or petroleum products, but their concentrations exceed the concentrations in the water. Consequently, a gradual accumulation of polluting elements in bottom sediments is happening.

Hydrobiological studies were conducted at the same time. The results of their joint analysis are given in table 2, according to which one can estimate the ecological state of the Motovilikha pond.

**Table 2. Characteristics of the ecological state of the Motovilikha Pond**

| Characteristics                  | Shallow-water, which includes the estuary of the B. Motovilikha river | Intermediate (mid depth zone) | Deep water (located near the dam), which includes the area of the M. Motovilikha inflow |
|----------------------------------|-----------------------------------------------------------------------|-----------------------------|--------------------------------------------------------------------------------|
| The chemical composition of water| The amount of mineralization of water, ions content, as well as the concentration of nitrates and nitrates, oil products, dissolved oxygen meet the sanitary standards. |
| BOD$_5$ - in early summer        | 3.9 mg O$_2$/l - polluted water                                       | -                           | 3.5 mg O$_2$/l - polluted water                                                  |
| BOD$_5$ - in mid-summer          | 2.4 mg O$_2$/l - moderately polluted                                 | <0.5 mg O$_2$/l - very clean |
| COD - in early summer             | 33 mg O$_2$/l - very polluted                                        | -                           | 98 mg O$_2$/l - very polluted                                                   |
| COD - in midsummer               | 17 mg O$_2$/l - very polluted                                        | -                           | 60 mg O$_2$/l - very polluted                                                   |
| Overgrowing percentage of total area | 72%                                                                   | 20 %                        | 26 %                                                                            |
| Silting velocity, m/year          | 0.09 m/year                                                          | 0.02 m/year                 | 0.02 m/year                                                                     |
| Muddiness of water                | Mildly silty water                                                   |                              | Opalescence                                                                     |
| Water transparency                |                                                                       |                              | 55-60 cm                                                                        |
| Vertical sensing of water temperature |                                                                     |                              |                                                                                 |

**Inspection of higher aquatic vegetation** In thickets of the shipped highest water vegetation dominates: *Potamogeton angustifolium* L., *Potamogeton perfoliatiat* L., *Potamogeton pectinatus* L. On coast grow: *Typha latifolia* L., *Scirpus lacustris* L. and aquatic horsetails unidentified species (genus *Equisetum*).

**Zooplankton**

- **Taxonomic composition of zooplanktocosenes**: Rotifers (Rotifera type) - 9 species; Crustacea crustaceans (Cladocera squad) - 7 species, copepod crustaceans (Copepoda squad) - 3 species

- **Quantitative development of zooplankton**: The number is 356.97 thousand ind. /m$^3$; Biomass - 1.67 g m$^3$; The number is 800.97 thousand ind. /m$^3$; Biomass – 4.32 g/m$^3$
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4. Conclusions
1. High COD numbers (up to tens of mg/l) indicate high contents of organic substances (both of natural and anthropogenic origin), confirm the high trophic status of the reservoir (hyper-eutrophic) and its biological situation (development and decay of aquatic macrovegetation). Consequently, the pond is undergoing constant organic pollution.

2. The intensity of formation, thickness, granulometric and chemical components of the bottom sediments in the Motovilikha pond mostly depend on anthropogenic conditions of the reservoir and the complex of processes that occur in it. There was no excess in the contents of heavy metals, iron or petroleum products in the bottom sediments, but their concentrations exceed those in the water. Therefore, a gradual accumulation of polluting elements in the bottom sediments is taking place, which can be the source of secondary water pollution.

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