Transformation of the flow of matter in valley reservoirs as a factor of improving their ecological condition

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Abstract. The results of perennial studies of the valley reservoirs of the Moskva River (Mozhaysk, Ruza and Ozerna reservoirs) have shown that the influx of river waters bringing nutrients leads to eutrophication of the upper parts of the reservoirs. However, as water moves, this matter is extracted by phytoplankton and zooplankton and undergoes sedimentation. The content of the suspended materials, iron, true colour of water near the dam are two times lower than in the upper reaches of the reservoirs; the concentration of mineral silicon and phosphorus decreases by nearly one-fourth, and that of organic matter, by 10-15%. As a result, in the near-dam zones of the water reservoirs biological productivity decreases: the biomass of phytoplankton and bacteria in water decreases by nearly 40%. Thus, transformation of the flow of matter along the length of the valley reservoirs results in essential improvement of the quality of water and reduction of the degree of eutrophication, which is especially important for the reservoirs which serve as sources of water supply for the city of Moscow.

1. Introduction
It is known that flows of matter and energy have the determining significance for the existence of many natural bodies. In the opinion of Eugene Odum, a flow of energy leads to clearly defined trophic structure, biotic diversity, and material cycles (i.e. exchange of materials between living and non-living parts) in an ecosystem [11]. The studies by A.P. Lisitsyn have shown the essential role of the river runoff in forming zones of increased biological productivity in the estuarial areas of seas and oceans [8]. There is information on increased productivity and eutrophication of water masses in the estuarial areas of reservoirs [5].

For their hydrological parameters, reservoirs occupy an interim position between lakes and rivers [2]. In lakes, the processes taking place in the water bodies - exchange of materials between water and the bottom sediments and between layers of water – are significant [4]. River ecosystems largely depend on the inflow of materials from the outside, the catchment area [13].

In a valley reservoir, the major volume of the river water normally comes to the upper part of the reservoir, where conditions are formed close to those in the river. In the direction of the dam, the flow velocity slows down, the reservoir becomes deeper, and the water reservoir becomes more similar to a lake. That means, along the length of the reservoir transition from the river conditions to lacustrine conditions take place, i.e., from the transit type of the ecosystem’s functioning to the lake type.
should affect the flows of materials coming with the river runoff and the biotic productivity of the water body [16].

The valley reservoirs discussed – Ruza, Ozerna, and Mozhaysk water reservoirs – are the most essential sources of water supply for Moscow, they are well-investigated [3, 12]. At the same time, the issue under study is insufficiently discussed in literature. This is relevant not only for the reservoirs of the Moskva River but also for other reservoirs [9, 1]. The goal of this study was to investigate how the flow of materials varies along the length of valley reservoirs and how this affects their ecological condition and, in particular, eutrophication.

2. Materials and methods

The reservoirs in question, Mozhaysk, Ozerna, and Ruza reservoirs, are located 100-150 km west of Moscow. They have elongated shapes, and the main inflow of water occurs in the upper parts from the Moskva, Ozerna, and Ruza Rivers. Table 1 represents the basic morphometric and hydrological characteristics of the reservoirs.

Table 1. The major hydrological parameters of the Ruza, Ozerna and Mozhaysk reservoirs [12].

| Parameters                        | Ruza  | Ozerna | Mozhaysk |
|-----------------------------------|-------|--------|----------|
| Full reservoir area at full water supply, \(\text{km}^2\) | 32.7  | 23.1   | 30.7     |
| Full reservoir volume, \(\text{mln} \text{ m}^3\) | 219   | 143    | 235      |
| Maximum depth, m                  | 21.2  | 20.5   | 22.1     |
| Reservoir length, km              | 32.8  | 19.2   | 28       |
| Maximum width, km                 | 3.6   | 2.3    | 3.5      |
| Maximum depth, m                  | 6.7   | 6.2    | 7.7      |
| Flushing rate, year\(^{-1}\)      | 1.5   | 1.4    | 1.8      |

In this study, hydrochemical and hydrobiological materials of the many years’ monitoring conducted by Mosvodokanal (1984-2010), as well as our own data, were used. The observations at the reservoirs were conducted 2-5 times a month. The assays were analysed in accordance with the commonly used methods [10, 14, 17].

3. Results and discussion

The results show that, as the river water mass moves along the reservoir, its essential change takes place (table 1). In Ozerna Reservoir, the concentration of suspended matter reduces as the water mass moves along the reservoir (based on the mean perennial data for the vegetation period) as follows: 8.8 mg/l – 6.6 mg/l – 5.3 mg/l – in the upper, middle and lower parts of the reservoir. The concentration of organic matter (the chemical oxygen demand determined by the permanganate method (COD\(_\text{Mn}\)) in these regions is 9.7 mg/l – 8.8 mg/l -8.2 mg/l; biological oxygen demand BOD\(_5\): 3.9 mg/l -3.3 mg/l – 3.0 mg/l, respectively. Reduction of the concentration of suspended matter is related to sedimentation and to the filtration activity of the aquatic organisms (Cladocera, Bivalvia, Bryozoa). Reduction of the concentration of organic matter is related not only to sedimentation of organic materials but also to their consumption by the aquatic organisms. At the same time, reduction of the amount of organic matter contributes to reduction in the mass of saprophyte bacteria feeding on it: 181.0 – 125.2 – 119.8 cl/ml (in the upper, medium and near-dam regions of the reservoir, respectively).

Along the length of Ozerna Reservoir, the decrease in the concentration of phosphates (0.049 – 0.046 – 0.039 mg/l), mineral silicon (3.2 – 2.8 – 2.5 mg/l), and iron compounds (0.17 – 0.12 – 0.09 mg/l) occurs. The mineral silicon is actively consumed by diatoms, and phosphorus is consumed by all the autotrophs. Therefore, the mean phytoplankton biomass value decreased along the length of the reservoir: 9.7 – 8.0-6.3 mg/l in the upper, middle and lower regions of the reservoir. A similar situation is observed in the other reservoirs of the Moskva River tributaries.
To take an example, in Ruza Reservoir, the phytoplankton biomass gradually decreases from the upper parts to the dam area, being 5.2 mg/l (near the village of Ostashevo, the area of the upper part of the reservoir), 4.6 mg/l (near the village of Shcherbinki, the area of the middle part) and 2.6 mg/l in the near-dam part (according to the mean perennial data for the vegetation seasons). In a similar way, the concentration of saprophyte bacteria varies: 164 cl/ml – 134 cl/ml – 98 cl/ml (table 1). Such a character of the distribution of bacteria and algae may be explained by the fact that the Ruza River constantly brings mineral and organic materials to the upper parts of the reservoir from the river catchment.

Indeed, it can be seen from table 2 that the upper parts of Ruza Reservoir contains much suspended and organic matter (determined by CODMn and BOD5), and the high true colour of water. From the upper part of the reservoir to the dam, the concentration of phosphates, mineral silicon, and iron decreases. At the same time, the differences in the concentration of nitrogen and the pH value are insignificant.

The water temperature in the areas in the vegetation season is approximately the same; however, the upper part of the reservoir gets warm faster in spring and gets cooler in autumn earlier. For example, the water temperature in May near Ostashevo is 13.0 °C, near Shcherbinki, it is 12.0 °C, and near the dam, it is 11.3 °C; in October, respectively, it is 7.9 °C, 8.0 °C and 9.5 °C (according to the mean perennial data, in the water surface layer).

### Table 2. Parameters of the water composition in the upper, middle and lower parts of the reservoirs of the Moskva River tributaries (the mean perennial data for the vegetation season).

| Indicators          | Ozerna Reservoir | Ruza Reservoir | Mozhaysk Reservoir |
|---------------------|------------------|----------------|--------------------|
|                     | top              | middle         | bottom             | top              | middle         | bottom             | top              | middle         | bottom             |
| Turbidity, mg/l     | 8.83             | 6.58           | 5.33               | 6.60             | 5.20           | 3.60               | 9.87             | 5.91           | 3.86               |
| pH                  | 8.44             | 8.35           | 8.30               | 8.10             | 8.10           | 8.10               | 8.30             | 8.33           | 8.37               |
| Temperature, °C     | 15.94            | 15.42          | 14.51              | 14.67            | 15.10          | 14.95              | 14.93            | 14.60          | 15.02              |
| % True colour       | 36.64            | 30.50          | 26.92              | 36.00            | 30.00          | 26.00              | 45.05            | 30.36          | 26.60              |
| CODMn mgO2/l        | 9.72             | 8.75           | 8.22               | 9.10             | 8.80           | 8.20               | 9.83             | 8.67           | 8.09               |
| Alkalinity, mg/l    | 3.02             | 2.60           | 2.57               | 2.91             | 2.68           | 2.58               | 3.13             | 2.30           | 2.32               |
| Iron, mg/l          | 0.17             | 0.12           | 0.09               | 0.17             | 0.11           | 0.08               | 0.21             | 0.11           | 0.07               |
| Nsum, mg/l          | 0.49             | 0.50           | 0.54               | 0.63             | 0.63           | 0.61               | 0.51             | 0.46           | 0.49               |
| P-P04, mg/l         | 0.05             | 0.05           | 0.04               | 0.05             | 0.05           | 0.04               | 0.06             | 0.05           | 0.04               |
| SiO2, mg/l          | 3.19             | 2.82           | 2.52               | 3.30             | 2.80           | 2.50               | 3.90             | 3.31           | 3.01               |
| O2, %               | 97.12            | 94.88          | 89.56              | 87.10            | 85.20          | 81.80              | 87.57            | 93.03          | 91.47              |
| BOD5, mg/l          | 3.93             | 3.33           | 3.01               | 3.30             | 3.10           | 2.90               | 2.73             | 3.33           | 2.99               |
| Saprophytes, cl/ml  | 181.0            | 125.2          | 119.8              | 164.0            | 134.0          | 98.0               | 209.6            | 124.4          | 102.9              |
| Phytoplankton biomass, mg/l | 9.70   | 8.00           | 6.31               | 5.20             | 4.60           | 2.60               | 5.86             | 3.93           | 4.35               |

a True colour – was determined by comparison with the Pt–Co scale.
b CODMn – the chemical oxygen demand determined by the permanganate method.
c Nsum – total mineral nitrogen.
d BOD5 – biological oxygen demand for 5 days.

Shown in figure 1 are seasonal variations in the water parameter in different areas of one water reservoir, Ruza Reservoir. The graphs show the increase in turbidity, the CODMn, the proportion of phosphates and mineral silicon in spring and in autumn. In the upper reaches, this is caused by the inflow of materials with the river waters in the periods of high water, and in the lower reaches, it is caused by convective and aeolian mixing of the water mass. Reduction of concentration of nutrient
elements in the summer season and increase of CODMn at this time may be considered as a result of photosynthesis.

The seasonal variations of phytoplankton in Ruza Reservoir (as well as in the other reservoirs of the Moskva River tributaries) also demonstrate the differences between different regions of the reservoir (figure 1-F). In the near-dam region, changes characteristic of mesotrophic reservoirs are observed: the spring and late summer peaks of phytoplankton growth, with the minimum value of the early summer [15], caused by decrease in the number of nutrient elements and by active filtration activity of daphnia [6]. In the upper part of the reservoir (near Ostashevo), the large amount of the phytoplankton biomass (4.5-8.3 mg/l) is observed throughout the entire vegetation period, which may be explained by permanent supply of nutrient elements from the Ruza River to the algae. The seasonal variations of phytoplankton in Shcherbinki have an interim character.

The seasonal variations of saprophyte bacteria (figure 1-E), the nutrition of which is based on organic materials, are similar to the variations in the other parameters. It seems that the increase in the amount of bacteria is related to the periods of the high water, when many organic materials are carried into the reservoir, and also to the mass growth of phytoplankton in spring and in summer, phytoplankton being the source of autochthonous organic matter.

**Figure 1.** Seasonal variations in the water parameters in Ruza Reservoir (the mean perennial values). A – turbidity, B – CODMn, C – P-PO₄²⁻, D – SiO₂, E – saprophytes, F – phytoplankton biomass.

In a similar way, the characteristics discussed vary in the other reservoirs, as well. For instance, in the upper region of Ozerna Reservoir the phytoplankton biomass is much larger than in the near-dam region throughout the entire vegetation season – figure 2. There is similarity between these regions: in both regions, the spring peak of the biomass growth is caused by diatom algae and the summer peak, by the blue-green algae, which are generally characteristics of many water bodies in the temperate climate zone [7]. In early summer, decrease of the biomass is observed, more expressed in the near-dam region, where there is a shortage of nutrient elements, unlike in the upper regions, constantly fed by the inflow of the river waters.
Figure 2. The seasonal variations of phytoplankton biomass in Ozerna Reservoir (the mean perennial values for the main groups of algae). A – the upper region of the reservoir, B – the lower part of the reservoir.

4. Conclusions
The conducted study has shown that the concentration of different materials in the Moskva River reservoirs decreases in the lower regions compared to the upper regions: turbidity, the true color and the iron concentration decrease almost two times; that of phosphates and mineral silicon decreases by approximately 25%, BOD₅, COD₅ₐₙ, and alkalinity go down by 10-20%. This leads to a decrease in the amount of saprophyte bacteria and phytoplankton biomass by approximately 40%. Improvement in the quality of water and decrease of its blooming are of great importance, as water is supplied from the reservoirs in question via the Moskva River to the Rublevka water supply plant, which supplies drinking water to the city of Moscow.

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