Modelling the response of the Ivankovo Reservoir ecosystem to changes in the external chemical load

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Abstract. A two-dimensional hydroecological model is used to analyse changes in water quality indicators in the Ivankovo Reservoir due to the response of the reservoir to the doubling of their concentrations in the main tributaries of the reservoir set in the model in the average water content year.

1. Introduction

The main features of water quality formation processes in reservoirs largely depend on the nature of the interaction the reservoir ecosystem and its catchment area. The catchment area determines the chemical load on the reservoir, which depends on the joint action of natural and anthropogenic factors.

The Ivankovo Reservoir is characterized by a relatively high economic utilization of the catchment basin, which contributes to an increase in the flow of chemicals into the reservoir compared to natural undeveloped landscapes. As a result, the reservoir shows clear signs of anthropogenic eutrophication and progressive deterioration of water quality [1, 2, 3]. In this regard for justifying the optimal regulation of water quality in the Volga basin, it is extremely important to estimate the response of the reservoir ecosystem to the influx of anthropogenic pollutants into the tributaries of the reservoir. This problem is very difficult to solve by long-term monitoring of water quality characteristics and the state of reservoir ecosystems, so this problem is usually solved by modelling the water quality of a reservoir [4, 5, 6], in which scenario calculations can quantify the role of individual factors in the functioning of ecosystems.

For scenario calculations, we used the hydroecological model of the GMV-MSU successfully adapted to the Ivankovo Reservoir, which allows us to calculate the spatial and temporal distribution of water quality parameters with a daily step. The most complete description of the model is provided in some publications [7, 8, 9] The diversity of calculated scenarios in modelling is due to differences in the action of anthropogenic external load: the distribution of pollution over the catchment area, the duration of the source of pollution, the intensity of pollution, etc. The simplest scenarios include a direct increase of concentrations in the tributaries of the reservoir, assuming that the main reason for this increase is the action of various sources of anthropogenic pollution of the catchment. The main tributaries of the Ivankovo Reservoir, the Volga and Tvertsa rivers play a leading role in the formation of both water and chemical load, their contribution to the inflow component of the water balance is on average 50 and 25%, respectively [10]. The used model allow calculate the concentrations of the following water quality characteristics in these rivers (WQH): chemical oxygen consumption (COD), ammonium nitrogen (NH₄), nitrate nitrogen (NO₃), phosphates (PO₄), total iron (Fe), and total manganese (Mn). The scenario calculations also provided for the assessment of changes in the...
reservoir of dissolved oxygen (O₂) and the biomass of blue-green algae (cyanobacteria) under the influence of phosphorus load on the reservoir.

2. Materials and methods
The model calculations for the average water regime conditions which took place in 1984 were carried out according to three scenarios.

Scenario 1. Sequential model calculations with a twofold change in the concentrations of each of the considered characteristics in the Volga River throughout the year (Volga-2).

Scenario 2. Sequential model calculations with a twofold change in the concentrations of each of the considered characteristics in the Tvertsa River throughout the year (Tvertsa -2).

Scenario 3. Sequential calculations based on the model with a twofold change in the concentrations of each of the considered characteristics in the Volga River during the flood period (Volga. Spring flood -2).

The response of the reservoir ecosystem to the given changes in the chemical inflow was considered as a change in the average annual values of characteristics and coefficients of their variation in the downstream of the Ivankovo dam (and, accordingly, in the head section of the Moscow canal-the source of water supply in Moscow), as well as a changing in the longitudinal-vertical distribution of the considered characteristics in the reservoir at the middle of the growing season (for August 15).

3. Results and discussion
The calculated values of changes in the average annual concentrations of water quality characteristics are summarized in the table. In this case, the zero scenario is under consideration as the results of calculations performed without making changes to the input files of the model.

| Scenario               | Parameters | COD, mgO/l | NH₄, mgN/l | NO₃, mgN/l | PO₄, mgP/l | Fe_общ, mg/l | Mn, mg/l |
|------------------------|------------|------------|------------|------------|------------|--------------|----------|
| Zero                   | average coefficient of variation | 20.7       | 0.31       | 0.44       | 0.045      | 0.125        | 0.072    |
| Volga -2               | average coefficient of variation | 25.4       | 0.35       | 0.54       | 0.063      | 0.163        | 0.083    |
|                        | relative change of the average, % | 23         | 13         | 23         | 40         | 30           | 15       |
| Tvertsa -2             | average coefficient of variation | 22.1       | 0.33       | 0.51       | 0.053      | 0.147        | 0.072    |
|                        | relative change of the average, % | 7          | 6          | 16         | 17         | 18           | 0        |
| Volga- Spring flood-2  | average coefficient of variation | 23.4       | 0.31       | 0.47       | 0.057      | 0.139        | 0.072    |
|                        | relative change of the average, % | 13         | 0          | 7          | 27         | 11           | 0        |

As can be seen from the results of calculations, the double increase in concentrations in the tributaries of the reservoir corresponds to the values of COD (change in the down-stream - 23%) and nitrates (23%), while the average annual concentrations of ammonium ion in the discharge from the
reservoir increased by only 13%. The increase in phosphate concentrations in the down-stream one
exceeded the scenario "addition" of this nutrient in the inflow and made up to 40%. With a twofold
increase in the concentrations of the ammonium ion in the inflow, a small increase in the closely
related nitrate nitrogen was observed. The within-year variability of the characteristics, submitted by
the coefficients of variation, varied within large range, and for most characteristics, a decrease in the
variability of concentrations was noted.

The increase in the concentrations of chemicals in Tvertsa has a significantly smaller effect on the
regime and the values of the concentrations of these characteristics in the reservoir compared to the
Volga, while the noted features of the reservoir’s influence on the transformation of chemical runoff,
as well as estimates of their variability, is generally repeated.

The third scenario was caused by the need to assess the influence of diffuse pollutants in the most
important phase of the hydrological regime for their action – spring flood. The changes were
calculated only for the pollution of the Volga River during the flood. A noticeable increase in the
influx of chemicals during this period is revealed only in changes in the values of COD, phosphates
and iron. It is characteristics that are most closely related to water runoff, so for them, the high water
period can significantly affect the average annual values of water quality characteristics in the down-
stream of the reservoir.

Special attention was paid to the changes in dissolved oxygen and biomass of blue-green algae the
importance of which in the formation of the water quality of reservoirs is especially high [11, 12].
Calculations, made by Volga-2 scenario show that if changes in dissolved oxygen concentrations
change relatively little with increasing biogenic (phosphorus) load, then the increase in algae biomass
in the first scenario reaches 13%, which indicates a significant increase in the productivity of the
reservoir ecosystem.

To analyse the within-year regime of water quality indicators in the down-stream of the reservoir,
graphs of seasonal changes in indicators for the implemented scenarios are constructed. Examples of
graphs for phosphates and COD values for the zero scenario and the Volga-2 scenario are shown in
figure 1.

![Graphs showing seasonal changes in phosphate concentrations and COD values](image)

**Figure 1.** Changes in phosphate concentrations (a) and COD values (b) in the downstream of the
Ivankovo Reservoir according to scenario calculations.

The within-year fluctuations of the considered water quality characteristics changes slightly in the
scenario calculations of pollution of the Volga and Tvertsa. The total deviation of water quality
concentrations from the zero scenario corresponds well to the average annual data given in the table.
The distribution of manganese, iron, and organic matter is most closely corresponding with the zero
scenario. Biogenic substances – phosphates, nitrates, and ammonium ion-are more variable in the
reservoir. In different seasons, the deviations of the calculations for the scenarios from the zero
scenario are appeared in different ways, which is due to the complex relationships of biogenic
substances with production and destruction processes. Attention is drawn to the disproportionately high deviations of phosphates in the scenario with spring-flood pollution. This is due to the close relationship of phosphates with water consumption, so an increase in the Volga River flow rate in high water leads to a sharp increase in phosphate concentrations. This increase in the period of the most intensive water exchange can be traced up to the downstream body of the reservoir.

To analyse spatial changes in the indicators of the ecological state of the reservoir, changes in their concentrations along the reservoir were analysed according to the Volga-2 scenario. As a characteristic date for the analysis, we selected the date of August 15, corresponding to the middle of the growing season. As the calculations showed, the characteristics that are not related to production processes are distributed almost identically with the zero calculation option, since the main factor from the distribution in reservoirs is the peculiarities of internal water exchange in the considered time period. The distribution of biogenic substances at the end of the growing season differs significantly from the zero scenario – the gradients of changes in their concentrations according to scenario calculations with pollution increase sharply.

4. Conclusions
The analysis of scenario calculations demonstrates the possibility of model estimates of the consequences of an increase in the external chemical load on the reservoir, since this takes into account the changes in the state of ecosystems and the intensity of production and destruction processes that occur in reservoirs. It is important that calculations can be used to determine the quantitative characteristics of these changes and, if there are reliable estimates of diffuse pollution in the reservoir basin, to determine the degree of changes in water quality, taking into account the modelled intra-reservoir processes in reservoirs.

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