Ecohydrological mechanism of phytoplankton distribution in the water body

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Abstract. The object of the study is the ecosystem of the Novosibirsk reservoir, which is the largest in Western Siberia. The work is aimed at studying the mechanism of the water quality formation. In limnology, it is usually believed that relatively small and low-flow parts of reservoirs are more susceptible to eutrophication, where water warms up better and phytoplankton biomass is more abundant. In the central part of the Novosibirsk reservoir, the opposite effect is regularly observed. The novelty of the study is in simulation of ecological processes in different aquatories of the Novosibirsk reservoir based on reproduction of biogeochemical cycles for limiting elements. The paradox of phytoplankton development in this reservoir is explained by the peculiarity of hydrothermal processes, which was shown by modeling.

1. Introduction
In 1959, the largest water body in Western Siberia, namely the Novosibirsk reservoir, was constructed on the Ob river. Its average depth is 8.2 m; the reservoir volume and water-surface area at the normal affluent level (NAL) - 8.8 km³ and 1070 km², respectively; the volume of the reservoir drawdown makes up 4.4 km³. At NAL, the lake-like part of the reservoir contains 73% of its total water volume. Reservoir drawdowns increase the "lake" aquatory up to 90% [1].

Novosibirsk is the administrative center of Siberian Federal District, which occupies more than 25% of the Russian Federation territory. The Novosibirsk reservoir is the main source of water supply to Novosibirsk, therefore, the peculiarities of water quality formation are of particular importance here. Still, some features of water quality formation in the Novosibirsk reservoir are poorly explained.

For instance, it is reasonable to suppose that relatively small and low-flow parts of reservoirs are more susceptible to eutrophication. In such places, the water warms up better and phytoplankton biomass is significantly higher [1]. In the central part of the reservoir, the depth at the left bank is much less than that at the right bank, through which the main part of the water flow passes from the Ob River to the dam. However, according to long-term observations in August, the phytoplankton biomass on the right bank is several times higher than that on the left bank (Figure 1).
2. Materials and Methods

Trophic status of the Novosibirsk reservoir (in the end of 20th century) was attributed to the oligomesotrophic type [2]. Phytoplankton biomass discharged from the reservoir was low (sometimes 0.68 mg/l). In 1981, its maximum (1.1-1.77 mg/l) was recorded in September. Changes in the species composition of dominant phytoplankton communities repeatedly occurred during the year.

The dynamic distribution of water flows and temperature in the Novosibirsk reservoir was determined due to solving the 3D hydrothermal problem [3] for modeling changes in ecosystem components in different parts of the reservoir.

The box approximation (for example, [4]) is applied to study spatially inhomogeneous dynamic processes. We used a total of 10 water aquatories of the reservoir divided by depth into 3 layers (30 boxes). Seven water aquatories of the reservoir were located lengthwise, along its channel, two - in the shallow water near the left coast of the lake part of the reservoir, and another one - in the Berdsky Bay (Figure 1).

It is assumed that the surface and near-bottom layers are of 1m thick if the reservoir depth exceeds 2 m. In ice conditions, the depth is the distance from the lower boundary to the bottom. With a missing intermediate layer, the top layer thickness remains equal to 1 m at a depth of 1 to 2 m. There is no a near-bottom layer at a depth of less than 1 m.

We calculate average daily parameters for each box, i.e. water temperature; volume, area, length, width and height of a box; contact area with the bottom; ice-free surface area; ice thickness; distance from the box to the water surface or lower ice surface; inflow of water discharged to this box from others.
A comprehensive study of the Novosibirsk reservoir for the years 1981-1982 [2] allowed us to obtain a set of data needed for a preliminary model description of processes in the reservoir ecosystem and the model calibration using the Theil statistical criterion [5]. These data with results [3] characterize the water and thermal regimes, morphometry and actinometry of the reservoir.

In the surface and intermediate boxes, transformation and dynamic behavior of nine \( C_j \) variables are simulated to reproduce the processes of biogeochemical transformation of nitrogen and phosphorus compounds as well as oxygen regime. These variables relate to the water column: \( ZO \) - zooplankton biomass; \( F \) - phytoplankton biomass; \( NH4, NO2, NO3 \) - mineral forms of \( N \); \( D \) - suspended substances; \( C \) - dissolved organic matter (\( DOM \)); \( I \) – mineral \( P \); \( O2 \) – oxygen. Six more variables are added for calculations in bottom boxes. For instance, these are \( CB \) involved in metabolic processes; interstitial forms of phosphorus and nitrogen (\( PB \) and \( NB \), respectively); sorbed on the solid phase (\( PS \) and \( NS \)). Variable \( CN \) is passive organic matter in the bottom sediment (Figure 2).

Figure 2. A scheme of biochemical components transformation in the aquatic ecosystem described by the modified model "Biogen"

The following simplifications [6-7] are used when creating a model:
- the stoichiometric ratios \( C : N : P = 106 : 16 : 1 \) are constant in ecosystem components;
- the \( C \) content is about half of non-living organic mass;
- the soil particles washed from the catchment area are the main source of river suspension;
- the \( DOM \) share is 10% of the total suspension that corresponds to the surface soil at the entrance to the reservoir;
- the dead hydrobionts are the main source of suspension in the reservoir.

These simplifications are used for preparing input data for simulation on the base of water monitoring information.

When describing the compounds transformation in each box, the model equations look as follows [3]:
\[
\frac{d(C'_{i}W_{j})}{dt} = W_{j} \cdot R_{i} + \sum_{k} Q_{kj} C'_{i} - \sum_{q} Q_{jq} C'_{i} + J'_{i} \cdot \Omega_{j} + G'_{i} L_{j}
\]

where \( i = ZO, F, NH4, NO2, NO3, D, C, I, O2; \)

\( C'_{i} \) - the concentration of the \( i \)-th component in the \( j \)-th box;
\( W_{j} \) - the volume of the \( j \)-th box; \( t \) - the time;
\( R_{i} \) - the rate of biochemical transformation of \( C_{j} \) in the \( k \)-th box;
\( Q_{kj} \) - the water discharged from the \( k \)-th box to the \( j \)-th box;
\( J'_{i} \) - the mass flow of the \( i \)-th component through the interfacial surface into the \( j \)-th box;
\( \Omega_{j} \) - the area of the interfacial surface of the \( j \)-th box;
\( G'_{i} \) - the lateral load of the \( i \)-th component in the \( j \)-th box;
\( L_{j} \) - the length of the \( j \)-th box.

In the intermediate and near-bottom boxes, the lateral load \( G_{i} \) is taken to be zero. \( R_{i} \) terms were formulated in [8].

3. Results and Discussion
Simulation of phytoplankton dynamics in the Novosibirsk reservoir (August 1981) indicates that the first paradox is explained by peculiarities of water exchange structure in this part of the reservoir. The dominant component of water exchange in aquatory 5 is the inflow of most part of primary production to aquatory 6. Therefore, in August, aquatory 6 accumulates most phytoplankton, which reaches its annual maximum growth. This fact is illustrated by graphs of phytoplankton biomass variability in aquatories 5 and 6 (Figure 3).

![Figure 3](image-url)

**Figure 3.** Comparison of phytoplankton content in the surface layer of shallow-water aquatory 5 and deep-water aquatory 6 of the Novosibirsk reservoir in 1981
4. Conclusion

From the simulation and analysis results it follows that in the Novosibirsk reservoir, water exchange in August caused the excessive development of phytoplankton biomass in deep aquatory 6 compared to relatively shallow aquatory 5.

Thus, the above-mentioned paradoxes of phytoplankton development in the Novosibirsk reservoir were caused by the peculiarities of hydrothermal processes, which were shown by modeling.

Acknowledgement

The reported research was funded by the State Programs of IWEP SB RAS and ASTU, the Russian Foundation for Basic Research and the government of Altai Krai of the Russian Federation, grant No. 18-41-220002.

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