Current assumptions of characteristics for different-type Siberian water objects in modeling and forecasting of their aquatic-ecological state

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Abstract. The application of mathematical estimates and models for different types of Siberia water objects in extrapolation cases is discussed. The anthropogenic component of hydrochemical runoff of the Ob river is assessed for different time periods. A prediction algorithm for reservoir ecosystem state consists of the determination of input data sets, the use of internal model parameters for the reservoir - analogue and simulation. Developed for the water bodies of the Upper Ob basin, this algorithm is used in assessment of ecological consequences under river regulation.

1. Introduction
Currently, predictive models [1] are important tools in solving the problems of ecology [2] and water use [3]. However, the lack of clear arguments indicating the efficiency of mathematical estimates and models in extrapolation cases often hampers their solution [4]. In water resources conservation, it is customary to pay much attention to objects typification [5]; the Upper Ob basin is not an exception [6-8].

Typification and comparison (for similarity) precede the selection of a reservoir-analogue [9]. Recently, they have become particularly relevant due to development of simulation modeling and forecasting the state of aquatic-ecological systems [10, 11].

The paper presents specific examples of application of model relationships able to assess the important characteristics of different- type water objects of Siberia. Nowadays, the issue of the Tom’ river regulation in the site between cities Novokuznetsk and Kemerovo to improve water supply to the industrial region is often raised. The total and dead volumes of the designed Krapivino reservoir are expected to be 11.7 km$^3$ and 2.0 km$^3$, respectively. The operating storage of the reservoir (9.7 km$^3$) makes up 30% of normal runoff. The designed operation mode should maintain discharge rate of 600 m$^3$/s in the period of winter low water and, thus, fully satisfy the present needs of Kemerovo enterprises and its municipal water utilities. Decision making on such a large-scale anthropogenic interference in natural processes requires a sound estimate of probable environmental consequences [12].

2. Materials and Methods
2.1. Similarity of an aquatic ecosystem in time is a fairly common argument under assessing the surface water quality. A vivid example is specifying the anthropogenic component of biogenic runoff A [13].
The ratio of dissolved mineral silicon weakly exposed to anthropogenic factors and annual water runoff effects to other biogenic elements, including genetically closely related pollutants, is used:

\[ K = \frac{S_i}{C_o}; \]  

\[ A = B - \frac{S_i}{K}, \]

where \( K \) is empirical coefficient equal to the ratio of long-term average annual concentrations of silicon and pollutant for the initial period, \( Si_o \) and \( Si \) - silicon runoff for the initial and calculated periods, \( t \); \( C_o \) - runoff contaminants for the initial period, \( t \); \( B \) - pollutant runoff for the calculated period, including natural and man-made components, \( t \).

As the basic empirical coefficients for estimating a varied anthropogenic component, the ratio of silicon and pollutants concentrations for the initial period is used.

2.2. Spatial similarity of aquatic ecosystems is a commonly used argument in forecasting water quality at the stage of a reservoir design [14].

The genesis similarity is defined through comparability of major features of reservoirs-analogues, i.e. engineering-geological and hydrogeological, climatic and geographical conditions, types and forms of objects, parameters of water exchange, etc. The same catchment and kinship of species composition of aquatic communities in tributaries promote similar chemical-biological and physical-chemical processes in aquatic ecosystems under study. Therefore, the projected Krapivino reservoir is similar to the Novosibirsk one, which is also located in the Upper Ob basin.

The models for Krapivino and Novosibirsk reservoirs based on matter and energy conservation laws are not identical. They are similar in structure and comparable in rates of biogeochemical transformation of nutrient compounds. These assumptions are the basis for the assessment of aquatic ecosystem state of the projected reservoirs after its stabilization.

3. Results and Discussion

3.1. Assessment of changes in the anthropogenic component of chemical runoff for the Ob-river below Barnaul

We used the following compounds: \( SO_4^{2-} \), \( PO_3^{3-} \), \( Fe^{3+} \), \( NO_2^- \), \( NO_3^- \), \( Mg^{2+} \), \( Cl^- \), \( Ca^{2+} \) from observation data.

Calculations of water and pollutant runoff were made due to monitoring observations of (1) the cross-section near Kamen’-on-Ob, (2) the cross-section below Barnaul. The calculation was performed for three time periods (i.e. I - 1955-1970, II 1982-1985, III - 1986-1990. IV - 1995-1998) with changes in the anthropogenic component.

Prior to these calculations, we tested the hypothesis of constant specific silicon runoff in the catchment area, as chemical runoff showed a good correlation with water discharge. The Fisher coefficient was less than the tabular one: \( F (95\% ; 3.32) = 1.44 < 2.89 \) for the cross-section below Barnaul and \( F (95\% ; 2.21) = 0.79 < 3.49 \) for the cross-section near Kamen’-on-Ob. We assumed that average specific annual runoff of silicon was constant.

To evaluate the anthropogenic component of ion runoff, hydrocarbonate ion \( HCO_3^- \) was used as a "reference" one, concentrations of which remained stable under any anthropogenic load [15].

The analysis of temporal trends showed (Table 1):

- the anthropogenic component of hydrochemical runoff for the majority of chemical elements actively involved in natural biogeochemical cycles was negative and prone to decrease. This is due to the fact that intensive (mainly, agricultural) production previously occurred here during the initial period brought to erosion development and intensive leaching of nutrients from soil;
- steadily high anthropogenic load for chemically inert substance (iron) in the cross section below Barnaul was induced either by the lack of treatment facilities at Altai Krai enterprises, or insufficient waste treatment.
In the study, we used the assumption of "reference" runoff components (not depending on anthropogenic load fluctuations), which became a theoretical basis for the change estimates in the anthropogenic component of the Ob river runoff for different time periods.

Table 1. Fluctuations in the anthropogenic component of chemical runoff in the cross section below Barnaul, th. t/year.

|    | Mg  | Cl  | Ca  | SO₄ | PO₄ | Fe  | NO₃ | NO₂ |
|----|-----|-----|-----|-----|-----|-----|-----|-----|
| II | -83.83 | -21.92 | -396.96 | -61.09 | -1.17 | 47.57 | -23.85 | -2.16 |
| III| -143.84 | -25.75 | -1133.83 | -270.18 | -1.13 | 34.25 | -42.44 | -1.15 |
| IV | -306.40 | -67.66 | -1049.02 | -599.78 | - | 19.11 | - | - |

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3.2. Modeling of aquatic ecosystem state of the designed Krapivino reservoir after its stabilization.

Model calculations of three scenarios for 1985–1986 hydrological year with average water runoff were implemented (Figure 1) with:

1. actual values for hydrochemical observations (1985–86 hydrological year, at the cross-section Slavino) were used as monthly averages;
2. average monthly concentrations of simulated variables for long-term observations on the Tom’ river were used for the surface inflow;
3. values of hydrobiota biomass, which is fourfold less than that in the tributary (as compared to option 2). It was made for assessing model sensitivity [16] to probable variation of plankton species biomass in the tributary.

The study results suggest

- by phytoplankton content, Novosibirsk and Krapivino reservoirs are expected to be similar after stabilization of the latter. In summer, the average volume of phytoplankton biomass in the designed reservoir may reach 0.3, and in some periods - 1.8 mg/l;
- the content of mineral forms of nitrogen (ammonium, nitrites, nitrates) in the reservoir will vary during the year (within MAC) and decrease as compared with that in the river cross-section near Slavino almost all the year round;
- fluctuations of average oxygen concentrations (7-12 mg/l) in the reservoir during the year are expected
- the content of suspended forms of nitrogen and phosphorus in runoff from the reservoir will be 18-26% of concentrations near Slavino. Most suspended substances will intensively settle to the bottom; their partial return to the water may act as "secondary pollution".

Thus, the preliminary assessment of ecological state of the projected reservoir is feasible due to

- the simulation model developed for cycles of nutrient biogeochemical transformation of substances limiting hydrobiota development;
- the application of reasonable simplifying assumptions;
- the use of characteristics of a reservoir-analogue as internal model parameters;
- making of simulation with input data sets for different basic approaches.
4. Summary and Conclusion

The study presents assessments for different types of Siberian water objects in extrapolation cases.

Using the relationship of concentrations of "reference" elements and pollutants, the anthropogenic component of Ob river hydrochemical runoff near Barnaul and Kamen’-on-Ob for various periods was identified.
The algorithm for predicting ecosystem state of the projected reservoir is formulated based on simulation modeling, the selection of input data sets and the use of internal model parameters for the reservoir-analogue. This algorithm was used in the assessment of probable ecological consequences of the Ob river regulation in the Kemerovo administrative region.

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