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Information–Modeling Complex for Assessing the Hydroenvironmental Conditions of Reservoirs

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Abstract—An Information–Modeling Complex has been developed for the information support of managerial decision making in the field of rational use, protection, and restoration of reservoir ecosystems. The system successively implements three mathematical hydroenvironmental models of the system Nizhnekamskoe Reservoir Drainage Basin—the Nizhnekamskoe Reservoir—the Kuibyshev Reservoir. The complex of models is an effective tool for studying the response of the ecological conditions of reservoirs to natural changes and anthropogenic impact. The use of the complex as a tool for environmental forecast or an expert system in scenario simulation of natural processes is the most promising way to solving the problems of water quality management and reservoir production.

Keywords: river basin, reservoirs, simulation, pollutants, water quality

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INTRODUCTION

The program Restoration of the Volga is aimed to develop and implement measures for preservation and improvement of water quality and hydroenvironmental conditions of reservoirs in the Volga–Kama Chain (VKC). The extremely complex and diverse processes of the formation of water quality and quantity and the functioning of reservoir ecosystems are governed by the permanent interaction between the water body (the reservoir) and its drainage basin. The high economic development of the drainage basins of Volga reservoirs contributes to the growing anthropogenic load onto reservoirs by pollutants, resulting in a poorer state of their ecosystems and water quality. A necessary step in solving the problems of regulation and control of water quality in the Volga basin is a reliable estimate of the response of reservoir ecosystems to external load.

The scientifically sound forecasting of the environmental response to anthropogenic impact in VKC, assessing the efficiency of various managerial decisions in the rational use, protection, and restoration of reservoir ecosystems are impossible without mathematical models of water quality in both the drainage basin and the reservoir. The use of such models as a tool for environmental forecasting or an expert system within the framework of scenario modeling of natural processes is the most promising way for solving management problems for water quality and reservoir production. In the development of the strategy of water quality management, mathematical models enable taking into account the relationships between ecosystem components and assessing the direction of changes in its behavior, depending on the character and intensity of external loads.

The developed Information–Simulation Complex (ISC) implies the successive implementation of three mathematical models of the system: the drainage basin of the Nizhnekamskoe Reservoir—the Nizhnekamskoe Reservoir—the Kuibyshev Reservoir with the aim to assess the effect of the drainage basin of the largest tributary to the Nizhnekamskoe Reservoir—the *Belaya River*—on water quality transformation and the state of ecosystems in Volga reservoirs in the case of the high-flow Niznekamskoe and the largest in the chain, the Kuibyshev, reservoirs. This system can be regarded as a prototype of an expert instrument for determining the expediency and effectiveness of managerial decisions aimed to preserve and improve water quality in the water bodies under consideration.

THE MODEL OF FORMATION OF WATER AND CHEMICAL RUNOFF IN THE DRAINAGE BASIN OF THE NIZHNEKAMSKOE RESERVOIR ECOMAG

Model Structure

ECOMAG model (ECOlogical Model for Applied Geophysics) [9, 16, 23], which has been developed to become a technological instrument for large river basins in Russia, can be used to reproduce and forecast the dynamics of the fields of hydrological and hydrochemical variables (river runoff, the characteristics of snow cover, soil moisture content, water pollution, etc.) with a high space and time resolution and with accuracy sufficient by the accepted criteria; at the same time, the model is based on the data of standard domestic hydrometeorological and hydrochemical monitoring. This feature is of particular significance because of the limited potentialities of the hydrological models developed abroad as applied to basins in Russia as these models have been designed in most cases for the conditions of runoff formation other than those in Russia and based on the source data that differ from the same in Russia in its composition and accuracy. Studies [11, 24] use river basins in different physical-geographic conditions to discuss applications of the model to current problems of river basin hydrology, including the estimation of changes in water and hydrochemical regime under the effect of climate changes and anthropogenic load, management of water resource systems now in operation, the effectiveness of flood-control measures, etc., as well as to the problems of operational hydrological forecasts.

ECOMAG model consists of two major blocks: a hydrological submodel of runoff formation and a hydrochemical submodel of pollutant migration and transformations in river basins. The former submodel describes the processes of the continental hydrological cycle: snow cover formation and melting, freezing up and thawing of soils, infiltration of snowmelt and rain water into soil, evaporation, the dynamics of soil moisture content, the formation of surface, subsurface, soil, and river runoff. The equations, algorithms, and test results of this model block as applied to largest river basins in the northern hemisphere (the Volga, Lena, Amur, Mackenzie, etc.), located in different geographic zones with different runoff formation conditions, and the types of nourishment and hydrological regimes of water bodies have been described in many studies [6, 9–11].

The hydrochemical submodel, designed to describe the regularities of pollutant migration and transformation in river basins, takes into account the processes of their accumulation on the surface of river basin, dissolution by snowmelt and rain water, seepage of dissolved pollutants into the soil, and the interaction with soil solution and solid phase [16, 23, 24]. The rate of pollution input into the surface flow is calculated as a linear function of the difference between pollutant concentrations in the soil and water flow. In the presence on the basin surface of pollutants, precipitating from the atmosphere as a dry residue, the process of their dissolution by liquid precipitation and snowmelt water is described by a linear dependence of the flow of dissolved matter on the difference of maximally possible and current concentration in the flow. The process of sorption–desorption of chemicals by soil is described by Freundlich sorption isotherm, which relates the amount of the absorbed matter with its concentration in solution. In the case of nutrients (nitrogen, phosphorus), processes of biochemical cycles in geosystem components in the river basin are taken into account.

The transport of dissolved pollutants in a river basin, depends on the rates of hydrological processes; it is based on surface, subsurface, subsoil, and river flow. Therefore, the hydrological characteristics, determined in the hydrological module, are used as inputs for the hydrochemical submodel.

In the model schematization of a river basin, its surface is divided by an irregular grid into elementary drainage areas, considering the features of relief and river network structure. The simulation of hydrological and hydrochemical processes at each elementary drainage area is carried out for four levels: in the zone of surface flow formation, for the surface soil layer (horizon A), for the underlying deeper layer (horizon B), and for the subsoil water storage. The scheme is completed by the consideration of transformation processes in river network.

For convenience of calculations under various projects of information support in water resources management, forecasting water and hydrochemical regime, and researches, a computer–technological complex (CTC) ECOMAG has been developed. The complex incorporates a calculation module of the physically based ECOMAG model and the means of data and technological support of the operation of this module: thematic digital electronic maps, technology of automated separation of the drainage basin into individual drainage areas and schematization of river network, databases of various land surface characteristics, databases of hydrometeorological, hydrochemical, and water management data, instruments for database management and geoinformation data processing, and a management module. The management module serves to combine the GIS data for the area with database information, to configure the required version of calculations, to start model calculations and to show calculation results on computer monitor in the forms of various plots and schematic maps of the territory, including the cartographic base, calculated hydrological maps, and maps of pollution of river basin and channel network. In terms of their volume and the spatial coverage of the territory of Russia, the information resources available in CTC are enough to construct regional hydrological models and to carry out calculations for any large river basin in Russia. CTC ECOMAG is intended for a wide range of hydrological and nature-protection applied problems of diagnostics and forecasting.

The model schematization of the drainage area and river network in the basin is carried out with the use of CTC ECOMAG based on digital thematic maps of the region: digital relief model, hydrographic network, soils, and landscapes. Automated regime enables the construction of a model tree-like structure of river network and the identification of water-divide lines as boundaries of model (elementary) drainage areas. In the modeling complex CTC ECOMAG, each model element is assigned appropriate model parameters (soils, vegetation, etc.).

Adaptation of CTC ECOMAG to the Drainage Basin of the Nizhnekamskoe Reservoir

The total drainage area of the Kama at the section of the Nizhnekamskii Hydroengineering Structure is 366 thous. km^2, and the partial catchment of the Nizhnekamskoe Reservoir (NKR) between the Nizhnekamskii and Votkinskii hydroengineering structures, located in the South Ural region of Russia, is 186 thous. km^2 in area. The drainage basin shows high concentrations of heavy metals (HM) in natural waters because of the considerable concentration of ore-forming elements in soils and rocks.

The drainage area and river network in NKR basin were schematized and the majority of physically sound model parameters were specified using thematic maps of the region with the use of ISC ECOMAG.

Calculations with the use of ECOMAG model are based on the meteorological data with a daily time step. The fields of meteorological data (daily precipitation, mean daily temperature and air humidity deficit) in basin territory is the input to the model. The model calculates, in a continuous mode, the fields of snow cover, snow melting, soil moistening and freezing, evaporation, and genetic runoff components. Runoff hydrographs at gages, water inflow into reservoirs over previous periods, the fields of snow cover derived from snow surveys, and the fields of soil moisture content and freezing depth by measurements at agrometeorological stations are used in the model to calibrate its parameters and assess the accuracy of the hydrological block of the model.

In the hydrochemical submodel, the initial conditions for pollutant concentration in soils in NKR were specified based on maps of the concentrations of chemical elements in the plowed soil layer given in the Atlas [19]. Pollutant concentrations in atmospheric precipitation and confined subsoil water, which feed perched water in the aeration zone of soils, were taken from regional reference books. Data on point anthropogenic pollution sources for river water were taken from data on pollutant discharges with wastewater in populated localities in Belaya River basin given in the statistical report forms 2-TP (vodkhoz). Long-term data on the dynamics of pollutant concentrations in river water at 34 gages on the Belaya River and its tributaries, collected by Roshydromet services were used to calibrate parameters and test the hydrochemical submodel (Fig. 1).

The results of numerical experiments with ECOMAG model for the drainage basin of the Nizhnekamskoe Reservoir [22, 24] were used

to assess the contribution of natural and anthropogenic components to the formation of the hydrochemical runoff of pollutants;

to calculate the fields and construct maps of normal annual modules of water runoff and chemical pollutant runoff;

to compile maps of normal annual concentrations of pollutants in watercourses in the NKR basin, including river reaches not covered by hydrochemical observations;

to evaluate the contributions of wastewater to river water pollution at different volumes of point pollutant discharges in the drainage basin.

The runoff hydrographs and the dynamics of pollutants calculated by ECOMAG model for the mouth of the Belaya River along with the inflow into some sections of NKR were used as inputs to GMV-MGU model.

THE HYDROLOGICAL MODEL OF WATER QUALITY TRANSFORMATION IN THE NIZHNEKAMSKOE RESERVOIR (GMV-MGU)

The Nizhnekamskoe Reservoir was constructed in 1978 in the Kama R. valley by damming the river (November 1, 1978) and filling the reservoir by 1979 up to the temporary level of 62.0 m BS (the design mark of 68.0 m BS). The total volume of the reservoir at a mark of 62.0 m BS is 2.9 km^3, and its water area is 1.08 thous. km^2. The maximal width of the reservoir is 15 at the average of 4 km. The length of the reservoir is 185 km.

The Nizhnekamskoe Reservoir is a complex water body in either the morphological or hydrodynamic and ecological respects. The major part of water inflow into the reservoir enters it through the Kama River (64%) from the Votkinsk Reservoir and through the Belaya River (31%), while the rest of its recharge is due to the lateral inflow of small rivers in its basin. The reservoir is operated under the conditions of permanent water deficiency with its level 5–6 m below the design normal reservoir water level; because of this, the area of shallows with depths up to 2 m is up to 50% of the total reservoir water area, producing an adverse effect on water quality.

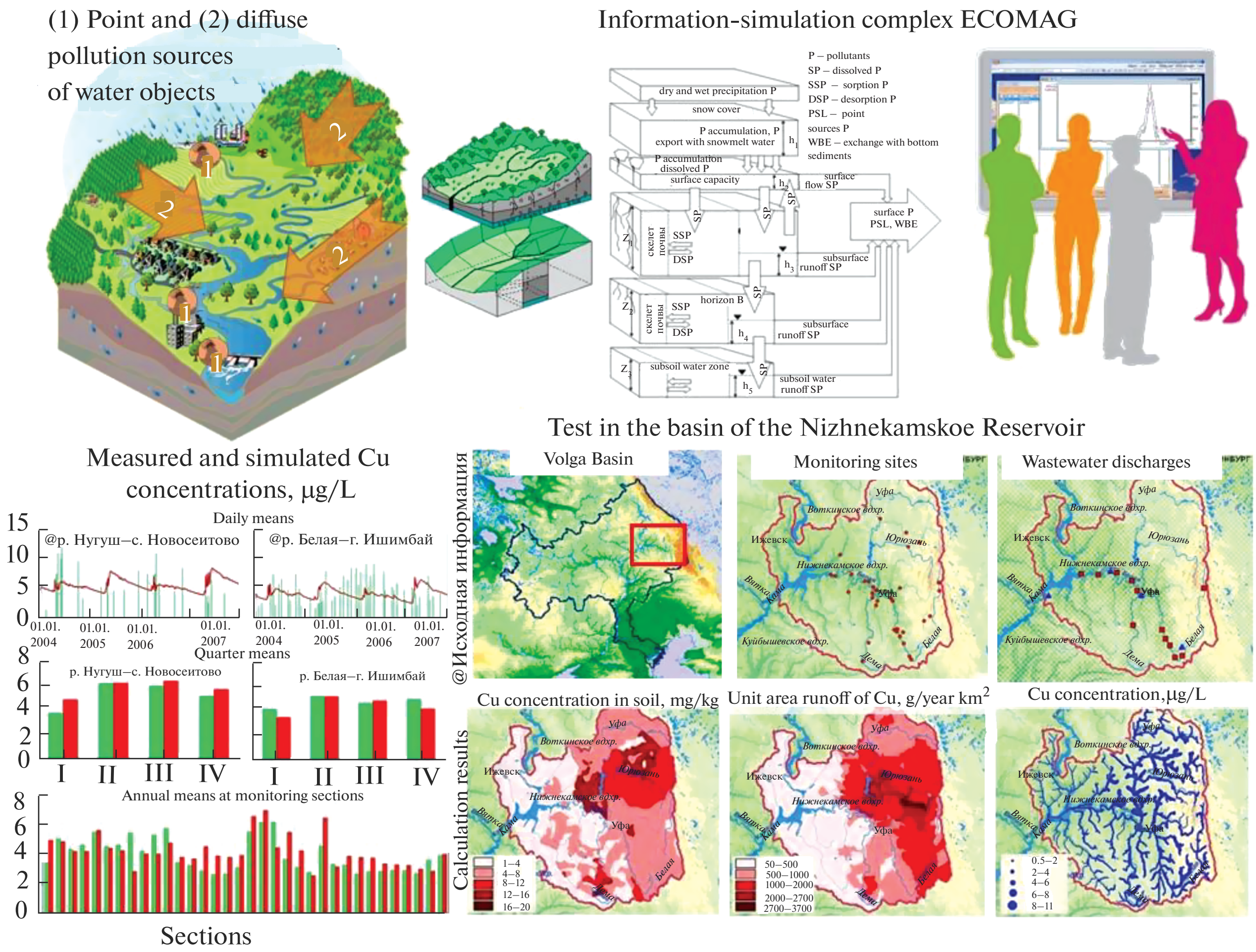

Fig. 1. Schematic structure of model hydrochemical block, location of hydrochemical monitoring sites, and the representation forms of the simulated hydrochemical data.

The Design and the Structure of the Model

The hydrological model of reservoirs (GMV-MGU), developed at the Chair of Land Hydrology, Faculty of Geography, Moscow State University, is a box-type quasi-two-dimensional longitudinal–vertical model of a reservoir, including blocks for calculation of heat- and mass-exchange (HME) and the characteristics of water quality and production of the reservoir (ecological block) [3, 13, 25].

The model is based on the following requirements to calculation algorithms:

(1) reservoir schematization should take into account its morphological structure and the hydroengineering features of water intakes of the hydropower units;

(2) the numerical algorithms for solving the equations are to be simple;

(3) the major processes that determine the hydrological regime of the reservoir are to be adequately reproduced and, as far as possible, taken into account;

(4) the calculations should reproduce the vertical structure of the water mass of individual pools—sectors of the reservoir with a depth step of 1 m and its changes over time with a step of 1 day throughout the annual cycle;

(5) the description of hydrometeorological processes in the model should follow the procedures recommended for hydrological and water-management calculations used in reservoir design process;

(6) the model calculations should be based on the standard hydrometeorological data of Roshydromet and the monitoring network of environmental pollution.

The Nizhnekamskoe Reservoir is schematized in the model in the form of four lobes, divided into 11 pools (Fig. 2). Each lobe is divided into model pools, taking into account their hydrodynamic and morphometric features. All pools are divided into horizontal boxes (Fig. 2b). The bathygraphic curves and the morphometric characteristics of the pools were obtained by planimetry of pilot charts of the Kama

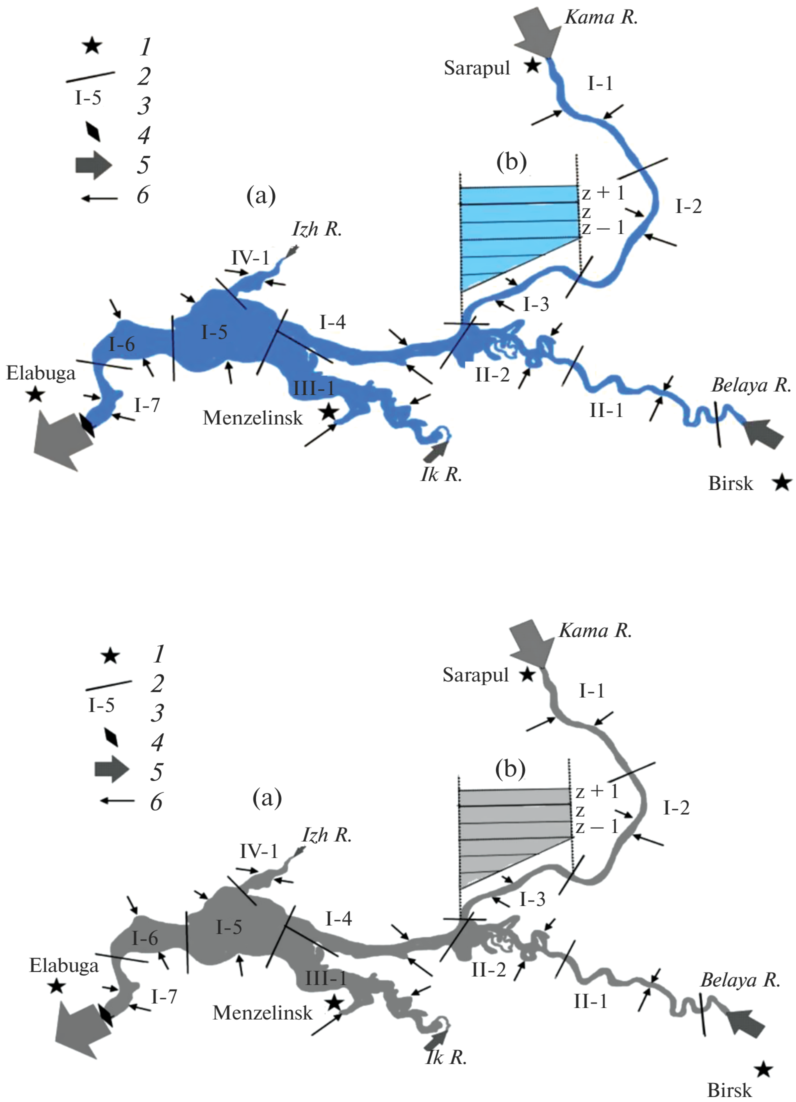

Fig. 2. Schematization of the Nizhnekamskoe Reservoir: (a) division of the reservoir into sections; (b) division of a section into model boxes. (*1*) weather station, (*2*) boundaries of identified sections, (*3*) numbers of the model lobe-sections, (*4*) Nizhnekamskaya HPP, (*5*) inflow-flow of major rivers, (*6*) lateral inflow into sections

and Belaya rivers [1, 2] with correction of the obtained results by tables of areas and static volumes of the reservoir [12]. The water mass within each box is assumed homogeneous. The thickness of the boxes is constant (1 m), except for the surface box, the thickness of which varies within 0.5–1.5 m.

At the successive implementation of calculations from one pool to another, starting from the upper reaches of the reservoir, an algorithm of the classical one-dimensional (in the vertical direction) model, described in detail in [20], can be applied to each pool. Changes in the characteristics of water mass in a box are described by balance equations accounting for the continuity of the water medium and the conservation law of matter and energy in each box of the pool under the condition of complete mixing of inflowing water with that contained in the model box. The equation of state of water is represented by the dependence of its density on temperature and electric conductance for fresh water of hydrocarbonate and sulfate classes [3]. Water discharge from the reservoir is specified through different-level outlet sluices, taking into account the selectivity of the water intake by Bohen and Grace [17].

The model algorithm is structured in the form of four blocks (Fig. 3).

Calculations by the model are based on the superposition method in the following order for each calculation time step:

estimating transformations of weather data over water surface of the pools;

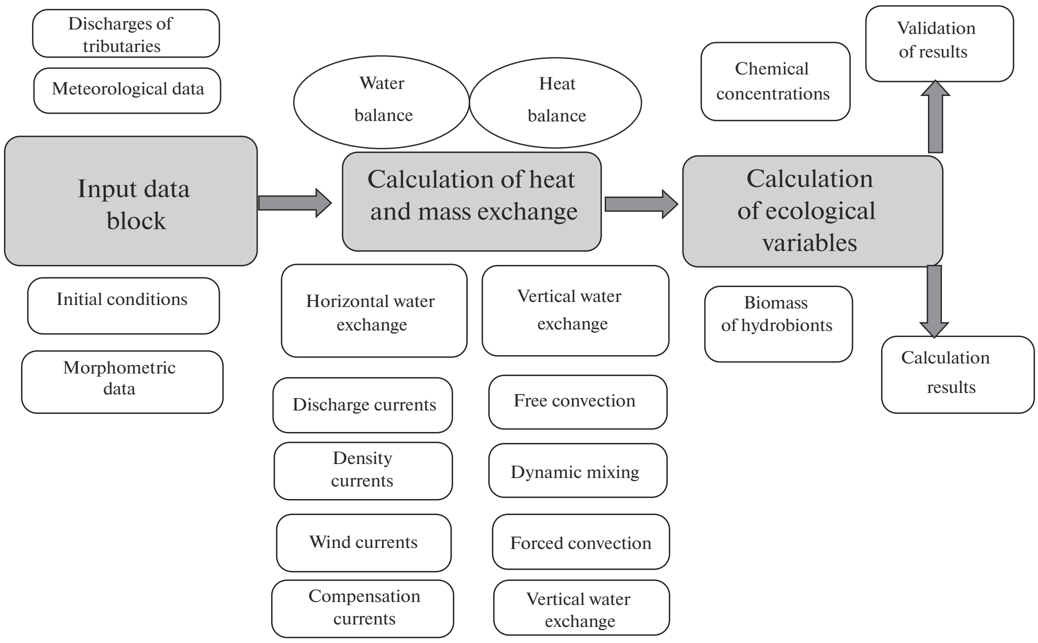

Fig. 3. Block scheme of the algorithm of GMV-MGU.

water balance and new water level in the reservoir;

within-mass transformation of water quality characteristics in pool boxes;

heat balance and snow-ice-cover dynamics;

effective wind mixing;

forced convection in the form of Langmuir circulation;

free convective mixing;

water exchange due to discharge currents;

dynamic mixing;

water exchange due to density, wind, and compensation currents;

formation of files with calculation results.

At the end of each calculation step, matter and energy balance is calculated for pools.

Model Adaptation to the Nizhnekamskoe Reservoir

All input data in the model were divided into three groups: files of basic and initial conditions and file of current data. The basic file contains data on the simulated object, its schematization, the morphometry of the chosen pools, drainage basins of the tributaries of the water body, partial drainage areas of the pools, weather stations and their attribution to the pools, water intake characteristics, the constants of chemical and biological reactions, hydrochemical characteristics of subsoil water and precipitation in the region near the reservoir.

The input data file contains information about the state of the water surface (the presence or absence of ice), the vertical distribution of hydrophysical, hydrochemical, and hydrobiological characteristics of water in each pool at the start of calculations. The hydrological regime of the Nizhnekamskoe Reservoir is calculated for a long period.

The file of current data contains mean daily weather data for each calculation day at four weather stations (in the cities of Elabuga, Sarapul, Birsk, and Menzelinsk), located in the immediate vicinity to the reservoir (Fig. 2). Water inflow into the reservoir through the major rivers and from lateral drainage areas of the pools is specified based on calculations by runoff formation model ECOMAG.

The hydrological information is supplemented by data on water quality characteristics (WQC) for each flow entering the model pool. WQC for the Kama River were specified using the results of spline interpolation of their mean monthly values obtained by observations in the lower pool of the Votkinsk Hydroengineering Structure in 1986–2001. The WQC of the lateral inflow into the pools and in the major rivers was specified using the water chemistry calculated by the model of runoff formation on reservoir drainage basin.

Calculated Data

The hydrological block of the model calculates the transformation of weather characteristics over water surface, water balance and level variations in the reservoir, heat exchange with the atmosphere and bed soils, the dynamics of snow and ice cover, and the distribution of incoming solar radiation over the depth of model pools. The calculations are based on procedures described in detail in [14].

The ecological block of the model calculates the transformation of nonconservative characteristics, the values of which vary under the effect of a combination of physicochemical, chemical, and biochemical processes. The algorithm of this block enables the calculation of the following WQCs: the biomasses of three phytoplankton groups (cold-loving diatoms, blue-green, and other species), dissolved oxygen, the concentrations of phosphate, ammonium, and nitrate ions, unstable (readily oxidizable) and stable organic matter (OM), zooplankton, ichthyofauna, detritus, and the concentrations of mineral and organic particulate matter. The calculations follow mass balance equations in accordance with the conceptual schemes of interrelationships between these variables in aquatic ecosystems [20].

The nutrients simulated in the model are elements of greatest importance for the development of phytoplankton: i.e., phosphorus, nitrogen, and silicon. Phosphorus occurs in the form of phosphate-ions (PO_4^{3-}), and nitrogen, in the form of ions of ammonium (NH_4^+), nitrates and nitrites (NO_2^- and NO_3^-). Ammonium form is considered as preferable in alga nutrition [4].

The calculation of nutrient concentrations in model boxes takes into account the following processes: their consumption by phytoplankton; decomposition of detritus, unstable and stable OM; respiration of phytoplankton, zooplankton, and fish; export from bottom sediments under anaerobic conditions; nitrification and denitrification; sorption and coprecipitation. The processes of sorption are described by classical Langmuir kinetics. Changes in silicon concentration in the water body are determined by diatom production.

Among other elements involved in biochemical processes in the water body, the model simulates the regime of manganese, iron, sulfur, inorganic carbon, carbon dioxide, and hydrogen ions.

Mineral nitrogen and phosphorus accumulate in bottom deposits because of detritus decomposition and sedimentation of suspension and leave them under anaerobic conditions.

The OM dissolved in water is represented by biochemically stable and biochemically unstable OM, which differ in the rates of their decomposition.

Modeling Results

The model was used for diagnostic, prognostic, and scenario hydroecological calculations. The validation of GMV-MGU was based on the results of calculations of hydrological regime in many reservoirs; it was most detailed in reservoirs in Moscow oblast, where the amount of observation data was large enough to evaluate the quality of model calculations by statistical criteria. For the majority of analyzed WQCs, the quality of their calculation could be considered "satisfactory" [3].

The values of all WQCs were calculated at daily basis in the form of their vertical distributions in the pools along the vertical axes of the lobes of the water body. In addition, the model can be used to calculate WQC values in the lower pool of the reservoir, a feature which is of extreme importance for assessing the effect of the reservoir on water quality transformation in this pool. Figure 4 exemplifies the course of variations of WQC values in the lower pool of the Nizhnekamskii Hydropower Structure in 2012.

3D SIMULATION OF HYDROPHYSICAL AND CHEMICAL–BIOLOGICAL PROCESSES IN THE KUIBYSHEV RESERVOIR

The Kuibyshev Reservoir is the largest on the Volga, it ranks third in the world and first in Europe in terms of water area. It was created in 1955 after the construction of the dam of the Zhigulevskaya HPP, which dammed the Volga valley at Tolyatti City. The length of the reservoir is 467 km along the Volga and 280 km along the Kama. Its maximal width is ~26 km (near Kamskoe Ust'e), average depth is 9.3, and maximal depth is 41 m (at the dam of the Volzhskaya HPP). The total length of its shoreline is 2604 km. Reservoir water area is 6.45 thousand km^2. The main objectives of the reservoir construction are seasonal runoff regulation, power production, improvement of navigation, water supply, and irrigation.

Model Structure

Because of the large water area of the Kuibyshev Reservoir and the areas with heavily indented shoreline it contains, the hydrophysical and chemical–biological processes in it show pronounced space and time heterogeneity. To correctly reproduce processes in the ecosystem of the Kuibyshev Reservoir, including the processes of biogenic load formation requires the application of 3D-approach (three-dimensional), which originally has been used in meteorology and oceanology and later in hydrology. The history of application of 3D-approach to the simulation of different types of freshwater bodies is given in monograph [8].

In the recent years, a mathematical model of inland sea hydrodynamics (MMIS), developed in the Marchuk Institute of Numerical Mathematics, Russian Academy of Sciences [5] have become popular (at least in Russia). The model has been successfully tested in the simulation of the thermohydrodynamic regime of the Caspian Sea. The equations of hydrodynamics were discretized in this model using the finite volume method (FVM). The basis of the FVM is the integral formulation of the conservation laws of mass, momentum, energy, etc. The balance relationships are written for a small control volume, their discrete ana-

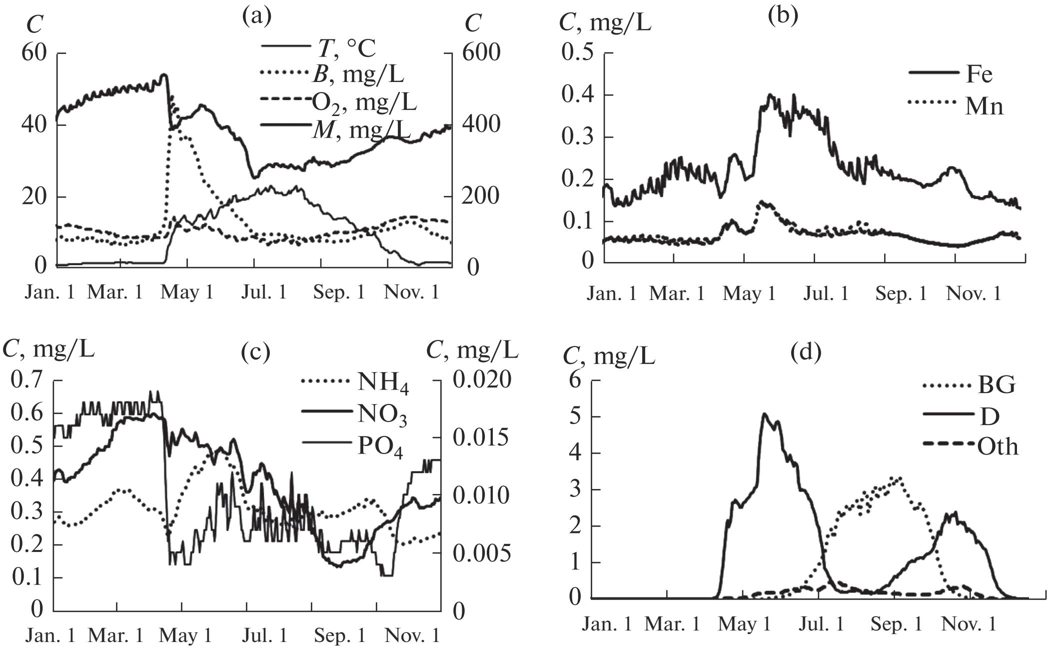

Fig. 4. Variations of the concentrations of (C) WQC in the lower pool of the Nizhnekamskii Hydroengineering Structure in 2012: (a) temperature (T), total dissolved solids (TDS), suspended matter (SM), oxygen concentration (O_2); (b) iron (Fe) and manganese (Mn); (c) ammonium (NH_4), nitrates (NO_3) and phosphates (PO_4); (d) blue-green (BG), diatoms (D), and other (Oth) phytoplankton species.

logue is obtained by summing the fluxes of mass and momentum over all sides of the identified volume. As the integral formulation of the conservation laws does not impose limitations on the shape of the control volume, FVM can be used to discretize hydrodynamic equations on either structured or not structured grids with different shape of cells, which, in principle, fully solves the problem of complex geometry of the model domain [15].

Seawater circulation in a basin of arbitrary geometry is described by three-dimensional thermohydrodynamic equations. The water–air interface is free; the spatial variation of sea surface topography and variations of the mean sea level are reproduced. The interaction between the atmosphere and the sea is described by the fluxes of momentum, heat, and moisture. When conditions become favorable for the formation of ice, ice model is introduced to describe the thermodynamic processes in the ice (temperature variations, freezing over, and melting). The model explicitly describes the flows of water and its properties (salinity and heat content) through the lateral boundaries (river runoff and exchange through straits) and the water–air interface (evaporation, precipitation). When domains with open boundaries are simulated, radiation conditions are specified on them.

The thermodynamic state of the inland sea is described by three-dimensional functions of temperature, salinity, and flow velocity components, as well as a two-dimensional function of the height of the inland sea level. The model includes three-dimensional complete equations of geophysical hydrothermodynamics.

Model Adaptation to the Kuibyshev Reservoir

MMIS model was adapted for the use for the freshwater Kuibyshev Reservoir. In particular, to account for freshwater having a temperature of maximal density, the constitutive equations for seawater was replaced by a quadratic equation of the state of low-mineralization water [21]. Necessary works were carried out to construct a model grid for the Kuibyshev Reservoir with a size of 170 × 302 in horizontal plain and 8 levels in the vertical direction. To account for chemical and biological processes, the hydrodynamic part of the model was supplemented by equations describing the seasonal dynamics of phytoplankton, OM sedimentation onto the surface of bottom sediments, the burial and mineralization of OM, mechanical resuspension of the top layer of bottom sediments, etc. Figure 5 gives a block scheme of a modified model, which was used for calculating hydrophysical and chemical–biological characteristics of the Kuibyshev Reservoir.

Modeling Results

The consistency of the model and its agreement with the natural processes was checked by several numerical experiments aimed to calculate the hydro-

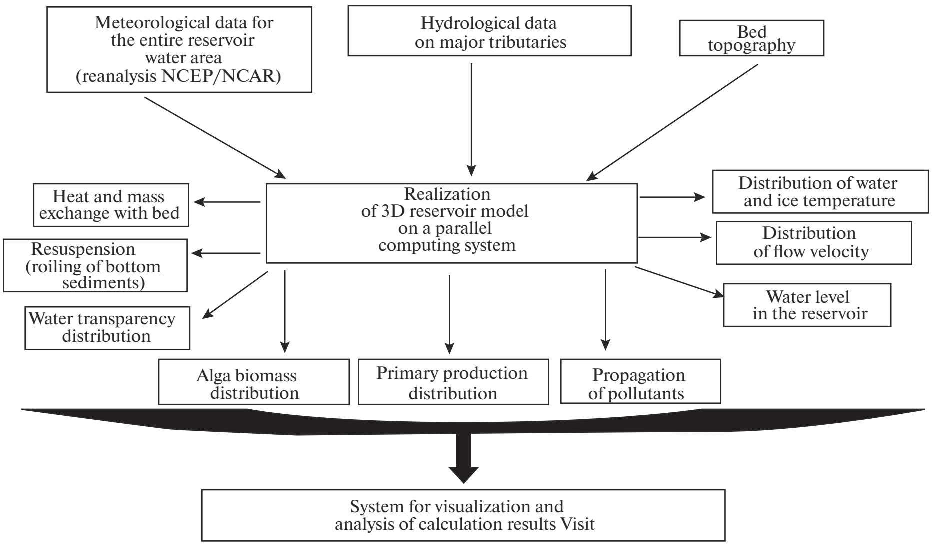

Fig. 5. Block scheme of the modified model.

thermodynamic and chemical–biological characteristics of the Kuibyshev Reservoir over 2012 to 2015.

The characteristic chosen to simulate a dissolved nonreactive matter was total dissolved solids. Water chemistry in the Kuibyshev Reservoir is mostly (by (90–95%) governed by the composition of its two major tributaries, the Volga and Kama rivers [7]. The total dissolved solids content of water in the tributaries differs almost twice: its mean value for the Kama is 0.42 kg/m^3, while that for the Volga is 0.24 kg/m^3. The specifics of the mixing of waters from these tributaries in different seasons of the year is the main governing factor for the total dissolved solids content in the entire reservoir.

Figure 6 gives the simulation results of the spatial distribution of the total mineralization in the Kuibyshev Reservoir in the freeze-up and open-water periods. As can be seen from the figures, the distributions of total dissolved solids over the reservoir in these periods are radically different; this is due to the factors that govern the processes of Volga and Kama water mixing in different seasons of the year. In winter, when there is no direct effect of atmospheric processes—mostly wind mixing of water masses—the propagation of waters from tributaries is mostly governed by baroclinic factors. In this case, water masses are mixing all along the Volga–Kama pool to reach values of 0.37–0.38 kg/m^3. The picture in summer is different. Under the effect of wind, Volga and Kama waters mix all over the depth to the values close to 0.35 kg/m^3. This value of total dissolved solids persists all along the reservoir down to the Priplotinnyi pool.

Figure 7 gives the results of simulating the spatial distribution of total phytoplankton biomass in the Kuibyshev Reservoir during the vegetation period of 2014. The distribution of alga concentrations in the beginning of the vegetation season is mostly governed by temperature differences between individual parts of reservoir water area. Thus, the maximal values of biomass are recorded at the mouths of tributaries and along coastal shallows, where water temperature is higher after freeze-up period. In the mid-summer, maximal values of alga biomass can be clearly seen in the well-heated shallow pools of the reservoir. This is due to the fact that the Kuibyshev Reservoir is a eutrophic water body; therefore, when phytoplankton development is not limited by nutrients, other factors gain in importance, including water temperature. This is true, in particular, for Cheremshanskii Bay, which is known as the most productive area in the reservoir [18].

CONCLUSIONS

An Information–Modeling Complex was developed for information support of decision making in the field of rational use, protection, and restoration of reservoir ecosystems. It incorporates the successive implementation of three mathematical models of the system The Drainage Basin of the Nizhnekamskoe Reservoir—the Nizhnekamskoe Reservoir—the Kuibyshev Reservoir. The calculation in the system is carried out successively, starting from the model of the drainage basin, which is the physically based ECOMAG runoff formation model. The input data for this model includes the characteristics of the drainage basin of the Nizhnekamskoe Reservoir, weather data, and the characteristics of anthropogenic load onto the drainage area. The results of model calculations of the hydrological and hydrochemical blocks of the model are hydrographs of water inflow and pollutant inputs from the drainage basin into the Nizhnekamskoe Reservoir with a daily time step.

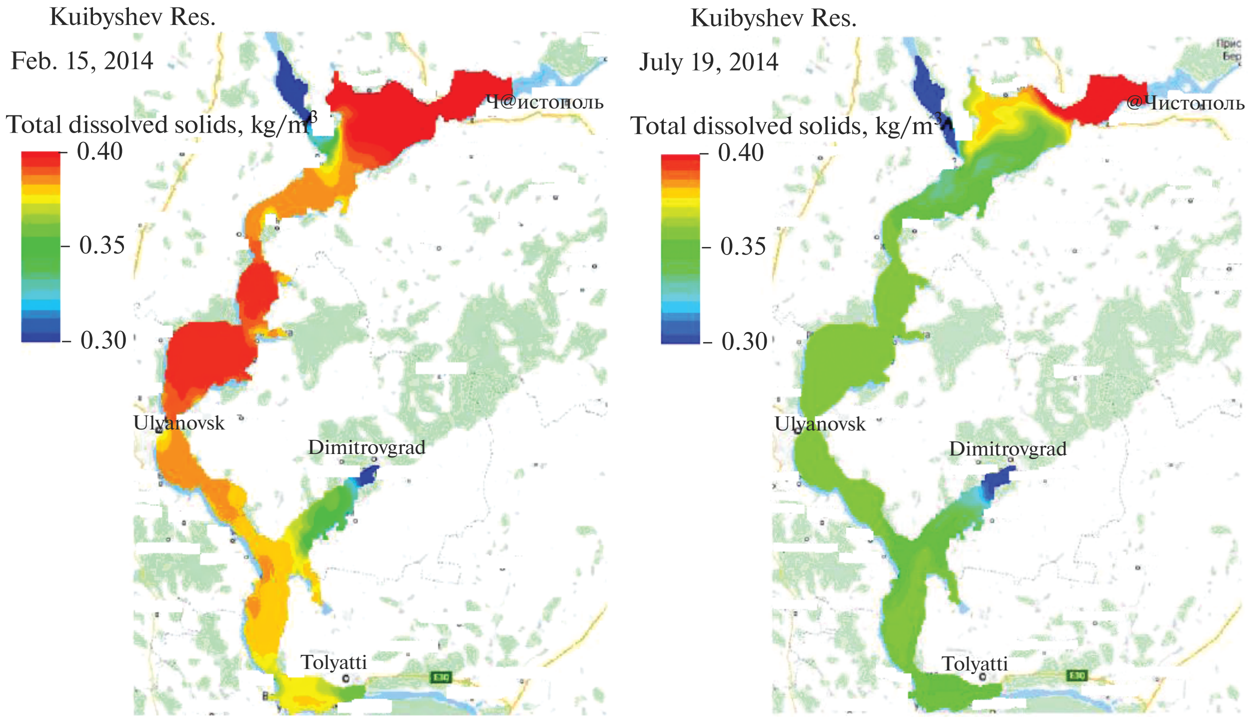

Fig. 6. Spatial distribution of the total mineralization in the Kuibyshev Reservoir (left) in winter and (right) in midsummer.

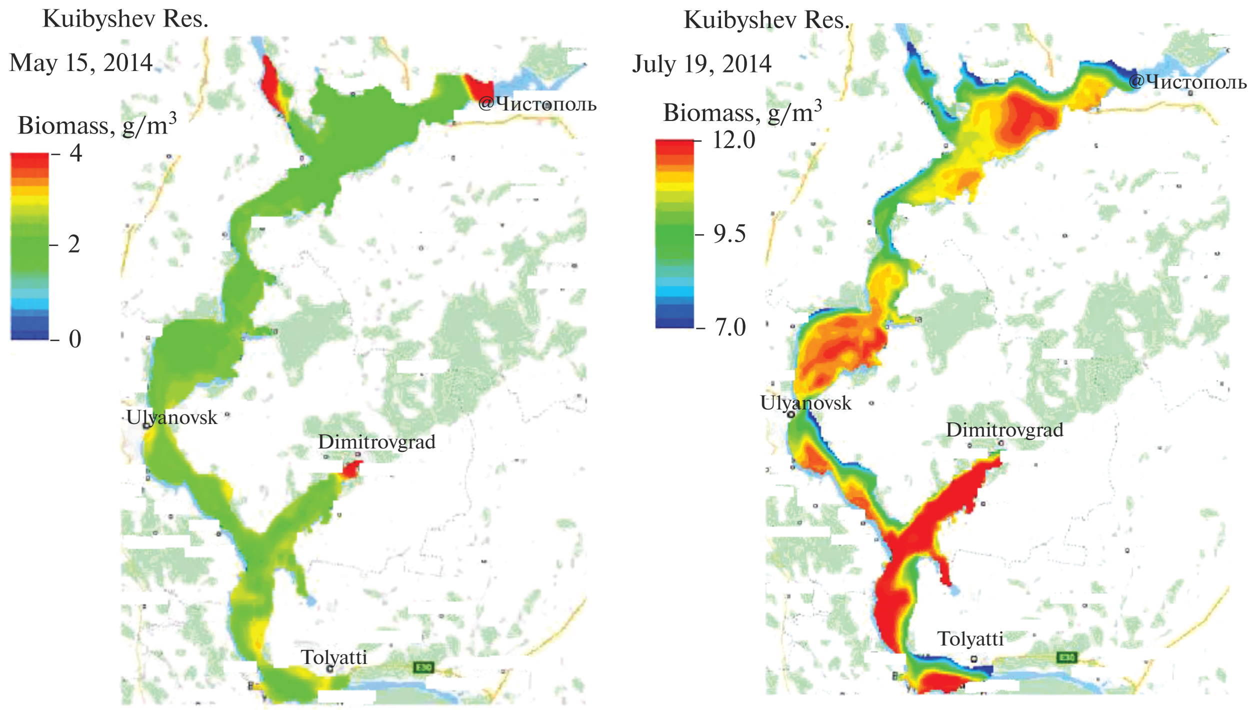

Fig. 7. Spatial distribution of total phytoplankton biomass in the Kuibyshev Reservoir in the beginning of vegetation period and in midsummer.

Calculations on the drainage basin provide input data for GMV-MGU model. This two-dimensional longitudinal vertical model can be used to calculate daily changes in various chemical and biological characteristics, which determine water quality and production characteristics of reservoir ecosystem depending on the hydrometeorological conditions of individual years. This model enables real-time calculation of the distribution of chemical concentrations and hydrobiont biomasses in the Nizhnekamskoe Reservoir and the daily variations of these characteristic in water discharge, i.e., in the lower pool of the reservoir.

The discharges from the Nizhnekamskoe Reservoir largely determine the ecological conditions of the downstream Kuibyshev Reservoir. Therefore, the calculated water quality in the discharge of the Nizhnekamskoe Reservoir forms important input information for calculations using the three-dimensional hydroecological model of the Kuibyshev Reservoir, developed in the Institute of Limnology, Russian Academy of Sciences, based on the model hydrodynamics of an inland sea. The latter model of the system describes the processes of water quality formation, migration of chemicals and phytoplankton biomass in the Kuibyshev Reservoir.

The presented system of three models can be promptly supplied with information about the hydrological regime and the dynamics of water quality and pollution characteristic in the drainage basin–reservoir system, considering their cascade position, i.e., considering water quality transformations at different stages of the chain.

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