Experience in controlling structures of Volzhski-Kamsk cascade of reservoirs and issues of socio-economic and environmental stability in the Volga region

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The Volga basin, with the catchment area of more than 1.35 million square kilometers, is the largest river basin in Europe and among the biggest basins in the world. The mean annual flow of the Volga River is about 260 cubic kilometers. More than 60 million people live in basin area. As a result of construction of 11 hydroschemes with reservoirs in the 30-70-ties of XX century on the Volga River and its main tributary Kama, one of the world's largest water-management systems was formed, with the total reservoir volume of about 190 cubic kilometers and the net storage capacity of 80 cubic kilometers. The established system has a number of functions, including electricity generation, large-capacity navigation, water supply to population, irrigation, etc.

Construction of hydroschemes and reservoirs, especially in Lower Volga (Kuibyshev and Volgogradsky) allowed radically changing the hydrological regime of the Volga River by redistributing its streamflow from high-water spring to low-water summer and winter. Besides, the hydroschemes blocked passage of valuable fish species (first, unique Caspian sturgeon) to spawning places. By the time of putting into operation of tail Volgogradski hydroscheme within the cascade (late 50-ties), it became evident that without special measures the natural and economic systems in Lower Volga, that depend completely on spring flooding of Volgo-Akhtubinskaya floodplain and Volga delta, are doomed to degradation and disappearance. In order to conserve natural ecosystems and traditional living conditions for residents of Lower Volga, the Government of USSR decided to make every year, since 1959, specific spring water releases through Volgogradski hydroscheme into lower reaches of the Volga River to the benefit of fisheries and agriculture, as a "temporal measure to finish fishery and agricultural reconstruction in Lower Volga". Since measures planned for Lower Volga were not implemented, those specific spring releases have been kept until now.

Great changes took place in economic activities in the basin over the last 50 years.

The state cascade management system was established and still functions with involvement of multiple concerned departments and organizations.

In spring period, hydroschemes are operated in special environment-oriented mode.

There is a number of different problems affecting management decision-making, including development of land in downstream and upstream sides of reservoirs, poor conditions

of engineering infrastructure at public utility companies and agricultural objects, incompleteness of the cascade, respective navigation problems, etc.

Inspection of the cascade operation was made in 2005-2007, during which period a number of extreme events or close to such conditions occurred in water system:

2005 – high water – problems related to water pass through cascade's hydroschemes and to flood prevention;

2006 – extremely low spring tide and summer drought – problems related to special spring pass in Lower Volga, very tense environmental situation, social tension growth;

winter 2006-2007– historical maximum inflow to reservoirs of the cascade; problems related to high-water by-pass in winter period;

spring 2007– fulfilling of optimal environmental releases to the lower reaches of Volga under low spring tide.

Recently, despite the smoothly running cascade management system, contradictions rise primarily between territorial interests (and respective entities of the Russian Federation) connected with both the socio-political and economic changes in the country and the hydrological changes over the last 15 years.

Description of current cascade management system is given below.

Figure 1 shows the general pattern of Volzhski-Kamsk reservoir cascade management system.

The management objects are the largest hydroschemes in the Volga basin as shown in the Figure in the left upper corner.

The management system consists of the following blocks:

- receiving and processing of on-line information;
- drawing up of proposals on hydroscheme operation regimes (information-analytical center, which is FSUE "Registry and Cadastre Center");
- representatives of concerned departments and organizations related to the water use through the cascade of reservoirs and the protection from negative water effect in the reservoirs' affected zone;
- management decision-making (inter-departmental task force (ITF) and decision makers).


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Текущие проблемы водопользователей
ЦДУ ЕЭС
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ПРОГРАММНЫЙ КОМПЛЕКС МОДЕЛИРОВАНИЯ РЕЧНЫХ БАССЕЙНОВ
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Fig. 1.

In the block for receiving and processing of on-line information, the main information providers are:

- public corporation “System operation “ Central Dispatch Administration of the Unified Energy System of Russia (UES CDA) - data on operation modes of hydropower stations’ hydroschemes (excluding such HEPS hydroschemes as Sheksninsky and Ivankovsky hydroschemes belonged to non-energy organizations);

- Hydrometeorological center of the Russian Federation (Institute of Rosgidromet) - data on: water levels in reservoirs and rivers; inflow to reservoirs, water temperature in certain gauging stations; weather data, including air temperature and humidity, rainfall, atmospheric pressure from all weather stations of the Volga basin and adjacent areas (in total, more than 700 stations); soil moisture and frost zone from basin’s agrometeostations; water storage in snow; monthly and quaterly forecasts of inflow to reservoirs; forecasts of ice development on basin’s rivers and reservoirs;

- Federal state unitary enterprise "Moscow Canal" at Rosmorrechflot of Russia’s Ministry of Transport - data on operation modes of Ivankovskoye and Verkhnevolzhsky reservoirs on the Volga River;

- Basin water authorities at Federal Agency for Water Resources (Moscowsko-Oksky, Verkhnevolzhsky, Kamsky and Nizhnevolzhsky) in their jurisdiction areas - data on technical and environmental conditions of reservoirs and river reaches; current problems and requirements of water users, executive agencies and local authorities.

Every day, data from UES CDA are transmitted through e-mail to Rosvodresursy (Federal agency for water resources) in form of DBF-file and stored on a network drive of local computer network of FSUE "Registry and Cadastre Center", to which one of computers from the on-line regulation division is connected. The data are used for keeping on-line e-journal on operation modes of Russia’s reservoirs, which is a database on large reservoir’s hydroscheme performance measures.

Data from Hydrometeorological center of the Russian Federation are transmitted through INTERNET-based connection between local computer networks of the Center and the FSUE "Registry and Cadastre Center" immediately after their acquisition from territorial branches of Rosgidromet, in coded data formats established by the latter. After decoding, these data are placed in respective databases of FSUE "Registry and Cadastre Center" for further use, including for information support of water management in Volzhsky-Kamsk cascade of reservoirs. Besides, data on water levels over recent 10 days from all gauging stations in Russia are posted on FSUE’s web-site (www.waterinfo.ru) under the project “Russia’s rivers".

Every day, data from FSUE "Moscow Canal" are transmitted through phone to on-line regulation division of Rosvodresursy and then to FSUE "Registry and Cadastre Center" and inputted manually into e-journal on operation regimes of Russia's reservoirs.

Data from basin water authorities are transmitted through various communication facilities (phone, fax, e-mail, cable, ordinary mail) to on-line regulation division of Rosvodresursy and, if necessary, to "Registry and Cadastre Center" for reservoir operation variants calculation as additional limitations.

All received data are used in FSUE "Registry and Cadastre Center", which acts as an information-computer center for calculations and development of proposals on reservoir operation modes.

Schematically, the process of the long-term planning of Volzhsky-Kamsk hydroscheme operation modes and the development of proposals on hydroscheme regulation consists of the two main stages:

1. Based on scenario calculations by flow formation model, dynamics of lateral inflow to Volzhsky-Kamsk cascade's reservoirs is estimated;
2. Based on scenario simulations of lateral inflow by simulation model of reservoir cascade functioning, operation modes of Volzhsky-Kamsk cascade's hydroschemes are calculated.

The information-modeling system (IMS) ECOMAG (ECOlogical Model for Applied Geophysics) is used as a platform for calculations of flow formation and lateral inflow to reservoirs in the "Registry and Cadastre Center". The system includes: mathematical model ECOMAG, specialized geographical information system (GIS), database on terrain characteristics and control frame. The ECOMAG system allows calculating hydrological characteristics (including inflow reservoirs) from weather data and creating an information hydrological picture (mapping description) of terrain, including diagnostic, prognostic and simulation hydrological maps and river basin pollution maps under different hydrometeorological conditions and anthropogenic pressure. The general structure of IMS ECOMAG is shown in the Figure 2.

Fig. 2. The general structure of modeling system ECOMAG

Schematization of catchment area and river network in the Volga basin is made on the basis of thematic maps 1:1000000, using special GIS-based software ArcView. To this end, GIS database contains a number of layers of basin's thematic e-maps (digital elevation models - DEM, hydrographic, soil, landscape and other maps, Fig. 3). These layers were rastered on square net (2km x 2km), and each cell was attributed respective value of elevation, number of soil type and landscape. Using special GIS software, the model tree-like structure of river network was constructed and watershed lines - boundaries of individual inflow catchments were identified. At the next stage, relief's work grid was corrected to define more exactly the model river network in those places where it does not correspond to actual (vector) one. Then, information on characteristics of slope elements and river network structure is transmitted to IMS «ECOMAG», where from respective databases each element is attributed model parameters (soil, vegetation, etc.).

An example of model Volga river network is shown in the Figure 4. The Figure 5 shows catchment areas of the reservoirs of Volzhsky-Kamsk cascade and simulation elements of catchment areas received by special DEM-based GIS system.

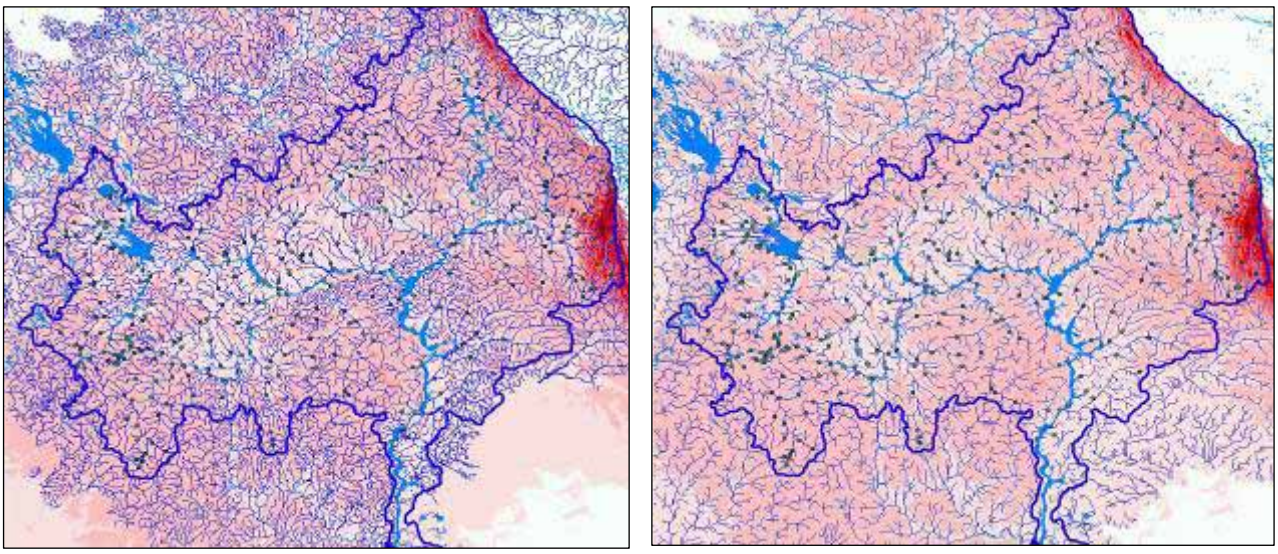
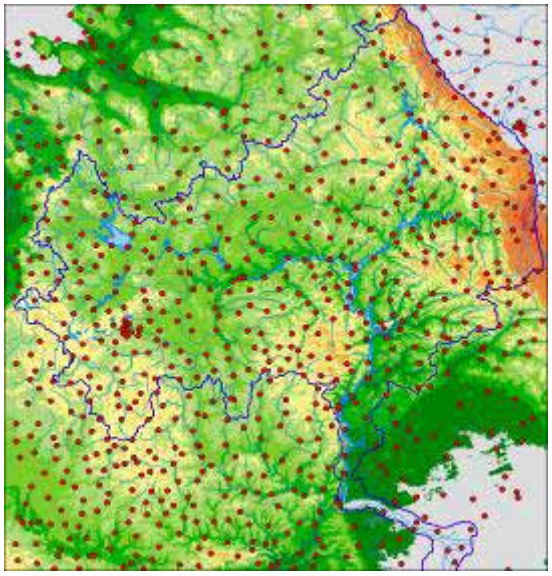


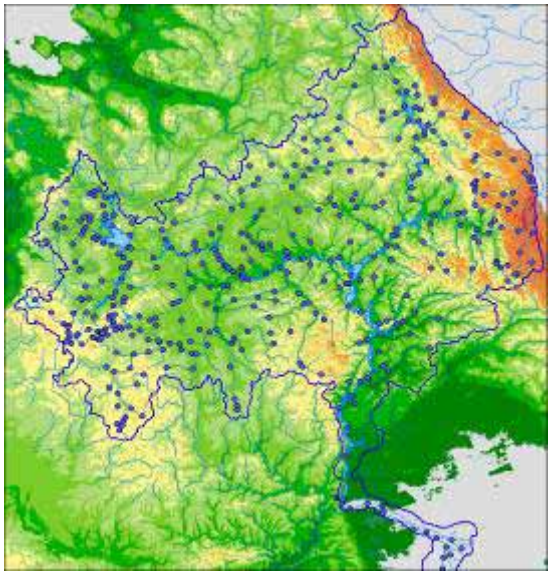
Fig.4 Structure of actual (scale 1:1000000) and model (DEM-based) river network in the Volga basin

Digital elevation model

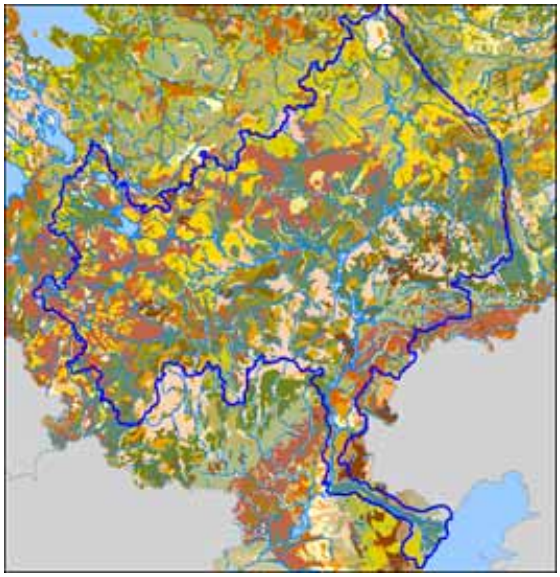
Landscape map



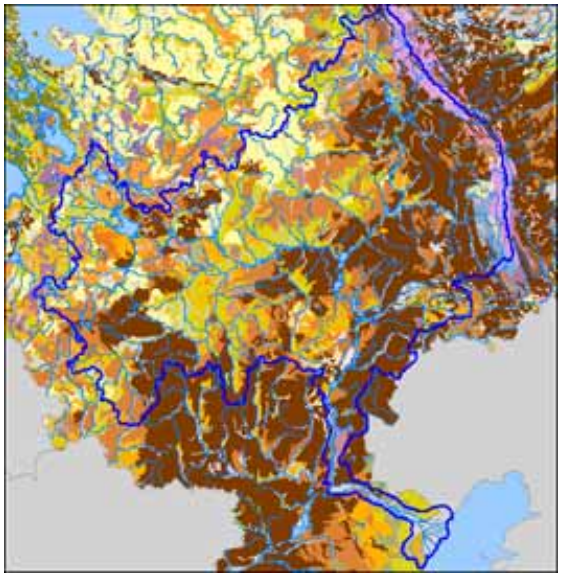
Weather stations



Gauging stations



Soil types



Soil texture

Fig.3 Basic GIS-information

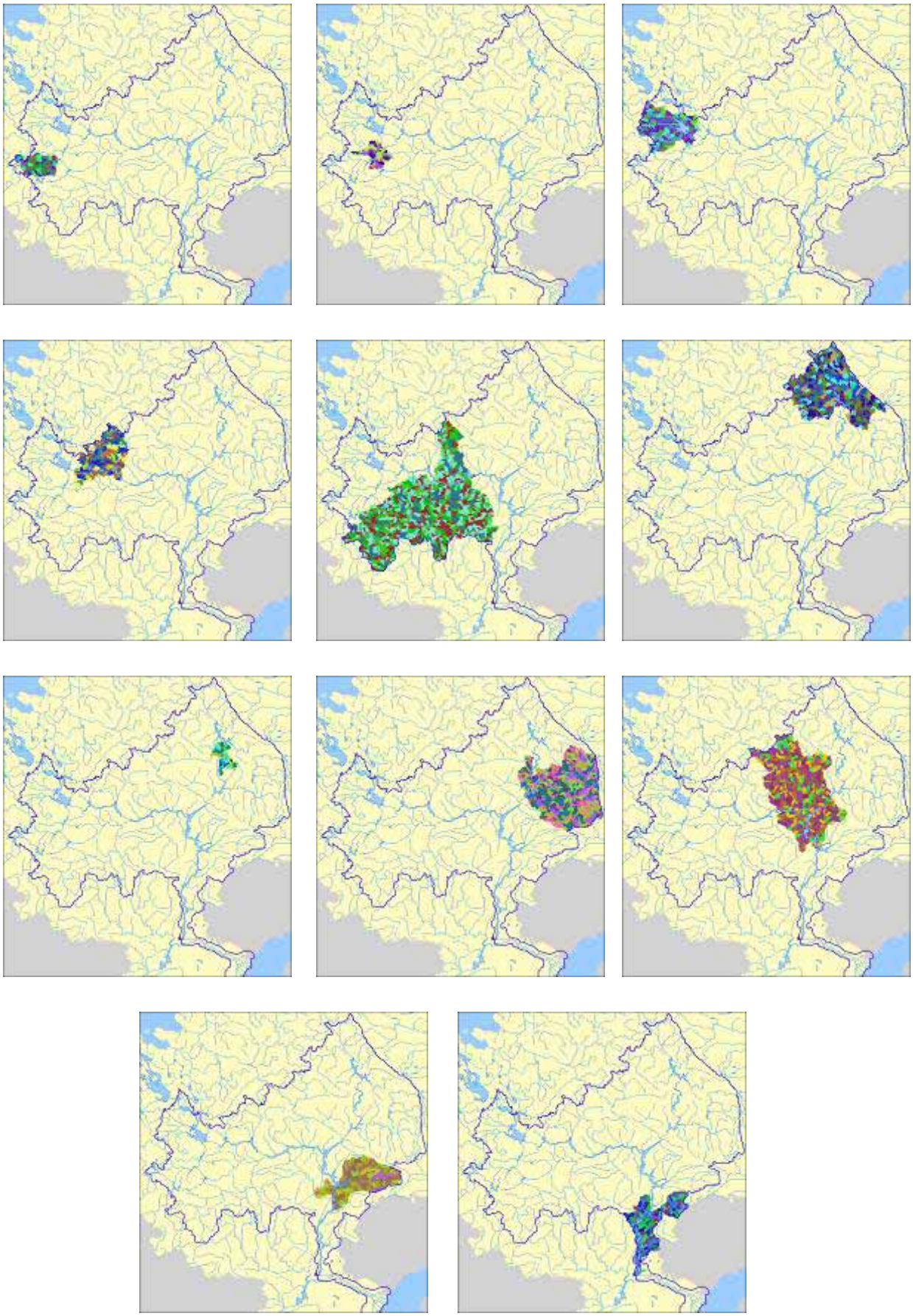


Fig.5 Catchment areas of Ivankovsky, Uglichsky, Rybinsky, Gorkovsky, Cheboksarsky, Kamsky, Votkinsky, Nizhnekamsky, Kuibyshev, Saratov and Volgogradsky reservoirs (with selection of elementary catchments)

Scenario computations of inflow to the reservoirs of Volzhsky-Kamsk cascade using the ECOMAG model consist of the following stages:

1. The model makes computations using weather information for current date of scenario generation for no later than previous yearly period.
2. In order to estimate the processes of hydrological cycle and lateral inflow to reservoirs to the next period (for example, the second half of the year 2007), scenarios of meteorological process development are set for this period. Since weather forecasts with daily resolution are not available for such periods, the model sets the following meteorological scenarios for the second quarter: it is assumed that weather since June 30 till December 31 in 2007 would be the same as during the same dates in 2005 or in 2006 - according to another scenario, or the same as in 2003, etc., using historical weather information for the previous years. Besides, for the nearest 10 days since the date of the beginning of scenario computations (i.e. since July 1 to July 10), the model considers the weather forecast of Rosgidromet for largest settlements located close to the reservoirs, which is taken from Internet. For this period of time, a synthetical weather scenario is built by choosing similar to forecast days from the previous period. In addition to the above-mentioned meteorological scenarios of weather development, we use a synthetic weather scenario, which is generated by averaging weather characteristics by days in long-term dimension, using archive weather base.

Then, the hydrological model ECOMAG computes, for the period of meteorological scenarios, the flow formation processes in reservoirs' catchment areas and the scenarios of lateral inflow to them. The output of ECOMAG are scenario hydrographs of lateral inflow to the reservoirs of Volzhsky-Kamsk cascade for calculation period. Besides, a synthetic inflow hydrograph is built by averaging all scenario hydrographs by date. Those scenario computations are used for the development of operation modes of hydroschemes when regulating the reservoirs of Volzhsky-Kamsk cascade.

Planning of operation modes of hydroschemes located in Volzhsky-Kamsk cascade, including by-puss of spring floods, is made on the basis of multi-variant calculations of the operation modes for the whole range of probable hydrological conditions (as predicted by Rosgidromet and scenario ones by ECOMAG), using the simulation model VOLPOW.

Implementation of the mathematical simulation model VOLPOW connects the hydraulic calculations of water flow in reservoirs with the water balance calculations for the cascade of hydroschemes and, hence, with the water use management. The hydrological block of the model is based on unsteady flow equations. The water-management block includes requirements and limitations contained in dispatch rules of hydroscheme operation, that are the relationships between the required (and allowable) releases of water through a hydroscheme and the water level in upstream pool and the time of year. Connection of hydraulic calculations with the water-

management block is made by imposing for the unsteady flow equations of boundary conditions resulted from dispatch regulation rules for hydroscheme operation and from structures' flow capacities.

Generally, in order to solve given problem, detailed information about width of control stations, slopes, roughness coefficients, etc. is needed. Usually, such detailed information is not available in engineering practice. Often there is some integrated information in form of curves of reservoir volumes, relationships between discharge and level in control stations, nomograms of flow capacity, etc. Therefore, finite-difference algorithms are modified in the VOLPOW model by integrating some terms into certain functional relations that allow using detailed and integrated input morphometrical and hydraulic information.

In schematization of reservoirs of Volzhsky-Kamsk cascade, each reservoir is divided into a few calculation sections (from 1 to 4). Available integrated and point morphometric and hydraulic characteristics are used for each section. Boundary conditions are formulated in section lines of hydroschemes. These conditions are determined by flow capacities of the structures and dispatch rules of hydroscheme operation.

Input hydrological information is calendar series of lateral water inflow to calculation sections (in particular, calculated by ECOMAG). Simulation calculations can be made with the time resolution from 1 day to 1 month (experience showed that for the Volzhsky-Kamsk cascade the following calculation time steps are enough: flood period - 1 day to 10 days; low-flow period - 10 days to 1 month).

The output of the simulation model VOLPOW are water balances for each reservoirs in the cascade and calculated regimes of discharge and level in section line for lateral inflow scenarios.

The long-term planning of operation modes of hydroschemes in Volzhsky-Kamsk cascade is made on the basis of the lateral inflow scenarios and the calculated scenarios of hydroscheme operation modes.

Among the set of calculated scenarios, the most plausible scenario of lateral inflow to reservoirs is selected, as well as schedules of hydroscheme operation within with cascade, with account of optimal regime of reservoirs, their complete filling and provision of effective annual special spring by-pass though Volgogradsky hydroscheme to Volga downstream to the benefit of fisheries and agriculture. Selection of the most plausible scenario of lateral inflow is made on the basis of current hydrometeorological situation in Volga basin and Rosgidromet's forecasts, using total volumes of lateral inflow to reservoirs over the current quarter and its first month. Moreover, calculations on meteorological scenarios that on the date of calculation do not correspond to current weather are rejected at once.

Besides, from the set of lateral inflow scenarios calculated by ECOMAG, the more negative maximum and minimum inflow scenarios are selected and scenarios of optimal hydroscheme operation modes calculated by the simulation model VOLPOW on the basis of selected inflow scenarios are chosen then.

The results of lateral inflow scenarios and of the consequent scenarios of optimal hydroscheme operation modes for the most plausible maximum and minimum inflow scenarios are disseminated among concerned departments of Rosvodresursy and presented at meetings of Inter-departmental task-force for regulation of Volzhsky-Kamsk cascade reservoirs in form of proposals for decision-making by the authorized federal executive agency (Rosvodresursy).

During the low-flow period, the calculations are made once in 10 days, while in spring tides, scenario calculations by the simulation models are made once in 5 days, taking into account current hydrometeorological and water-management conditions and weather forecasts for nearest 10 days.

Besides, actual useful inflow is calculated for previous period at each stage (the so called “inverse problem”). Based on calculation results, the expected design hydrographs of inflow to reservoirs are changed for next period.

At the end of each calendar quarter, by comparing scenario calculations with actual data on inflows to and releases from the reservoirs, an analysis of the efficiency of the long-term hydroscheme operation planning is made, causes of deviations are identified, and proposals for the improvement of Volzhsky-Kamsk cascade situation management system are formulated.

An important element of the described management system is the Inter-departmental task-force group (ITG), which is formed among the representatives of concerned Federal Ministries and Departments, major water users, executive agencies, research and production organizations. ITG is established according to an Order of Rosvodresurcy and acts on the basis of regulations approved by Rosvodresurcy as well.

The main objective of ITG is to create conditions for on-the-fly provision of demands of all actors interested in hydroscheme operation modes under current hydrological and water-management conditions. ITG includes representatives of Rosvodresursy, Ministry of Environment, Ministry of Agriculture, the Russian Emergencies Ministry, Rosgidromet, the Russian Marine and Inland Water Transport (Rosmorrechflot), Rosstroy, Rospotrebnadzor, Rosselphoznadzor, Administrations of Astrakhan and Volgograd provinces, Public Corporation “RAO Unified Energy System of Russia”, Public Corporation “GidroOGK”, Public Corporation "RAO CDA UES", FSUE "Caspian fisheries research institute”, FSUE “Registry and Cadastre Center”. Besides, members of Federation Council or delegates of the State Duma, representatives of legislative and executive agencies, local authorities, basin water administrations at

Rosvodresursy, basin waterway administrations of Rosmorrechflot, shipping, building and other companies, and research and community organizations take part in the meetings of the Task Force by invitation or on their own initiative.

Based on the developed proposals on operation modes of hydroschemes (prepared by FSUE "Registry and Cadastre Center") and the current hydrological conditions (reported by representative of Rosgidromet), ITG meetings discuss and develop recommendations regarding operation of cascade's hydroschemes for the next period. The recommendations are documented in the minutes of Task-force meeting, where major points of speeches and opinions of ITG members and participants are fixed as well.

It should be noted that the ITG recommendations form the basis for decision making but are not obligatory for implementation since authority to make decisions on regimes of reservoir filling and drawdown is given to the Federal Agency for Water Resources (Rosvodresursy). Thus, responsibility for decisions made is fixed clearly. Within Rosvodresursy, regulations set decision makers, including Director of Agency, one of his deputies and the chief of real-time regulation. Moreover, lower-level DM can make decision only if the upper-level DM is absent. Though in most cases, DM follows the recommendations of ITG, and in few cases, decisions were in contradiction with the recommendations. This is the case, when momentary interests of the most bodies and organizations are the same but contradict to the goals of guaranteed water supply and security as specified in the effective regulatory legal acts. Thus, this causes a risk of breaking guaranteed water supply or emergencies as a result of water-logging or flooding of land and settlements.

Decisions made by DM are documented in form of directions signed by DM, sealed by Rosvodresursy and submitted immediately by fax to System operator of CDA UES. On the basis of the decisions received, the operator develops hourly operation mode of the cascade's hydroschemes and submits it to HEPS management for implementation. Thus, this closes the control cycle of the cascade's hydroschemes.