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Climate Change

Estimate of possible hydrological regime change of Tsimlyansk reservoir in conditions of the climate warming

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ABSTRACT
Results of calculation of hydrological characteristics changes of the Tsimlyansk Reservoir in case of predicted warming (water exchange, ice covered period, a mineralization of water, stratification of water body) are given at realization of the most adverse for water supply and water use scenario at reduction of an annual drain layer and a drain layer for flood period.

Keywords: Reservoir; management, climate changes, model

Abbreviations: DMC – Don main canal, ETR - European territory of Russia, IPCC - Intergovernmental Panel on Climate Change

1. INTRODUCTION

According to numerous forecasts warming of the climate observed at the end of the XX century, will increase during this century. In this connection predictive estimates of the effect of warming on water ecosystems of some lakes were madeby the stuff of some institutes (Ruhovec et al., 2005; Filatov et al. 2007; Golosov et al. 2012). Doubts in the probability of essential global warming are put forward in (Dobrovolskiy, 2002). In (Monin and Sonechkin, 2005) it is affirmed that cooling in the Holocene glacial period caused the increase of CO_2 in the atmosphere four times, and not the reverse. The reason of the increase of the global temperature by 1990 is considered to be the growth of solar activity which will decrease by 2020 just as it was observed in the 1940-1970. However these hypotheses have not yet received quantitative estimates in the form of climatic models, which could serve as the base of predictive calculations of the changes of the river flow and respectively the changes of hydrological and ecological conditions of reservoirs. Besides cooling won't, probably, lead to the unexpected change of river flow regime and its regulation on European territory of Russia (ETR). The probability of changes of considerable climatic warming in case of realization of predictive calculations are considered in this work since the reduction of the flow for the south of ETR connected with it is adverse for many branches of economy.

Hydrological regime:
Natural changes in the status of the water body in time and space, caused mainly by climatic conditions of the basin.

The work purpose is to estimate probable changes of the hydrological regime of the Tsimlyansk Reservoir – first in their Don cascade. The aim of the first part of work is to conduct predictive calculations of the annual regime of level and water exchange, ice thermal regime and mineralization of water using hydrometeorological observation data. The aim of second part is to make predictive calculations of the same characteristics of a hydrological regime of the reservoir taking into account the change in flow formation conditions in the catchment areas of Don river and other tributaries of the reservoir to reveal the possible adverse effects of warming for the largest water management complex of the southwest of Russia.

2. MATERIALS AND METHODS

The number of predictive studies of climatic, hydrothermal and water resource changes is the basis of our study at the Geographical Faculty of Moscow State University in case of further warming on the East European Plain in the XXI century (Kislov et al., 2011). Data results of climate modeling for the scenario IPCC A2 (the most "rigid" option) served as basic for the assessment of the possible change of river flow (Evstigneev et al., 2010). The universal two-dimensional box hydrological model of a reservoir is developed and verified (HRM-MSU) (Puklakov, 2011). It has been used by us many times for diagnostic calculations of water, thermal and salt balance as well as for the mode of technogenic reservoirs of different size and water regime. Predictive calculations of the possible change of the characteristics of the some reservoirs regime were made using this model in case of climatic weather change (Grechushnikova et al., 2013). Quantitative evaluation of some water and thermal balance constituents as well as level and flowage fluctuations temperature regime characteristics in hot and low water years are needed for the subsequent calculations of chemical and biotic indicators of water quality at expected climatic changes.

HRM-MSU: model
Mathematical model of thermal and hydrodynamic processes, which describes the dynamics in time of the vertical distribution of temperature, the conductivity of the water and any dissolved conservative substance in separate compartments of valley reservoir, located along its axis. It is designed to examine internal and external problems of heat and mass transfer in the reservoir in the stages of its project and operation; to evaluate the efficiency of influence operations on the thermohydrodynamic processess; diagnostic and simulation components of the water and heat balances, balance of dissolved conservative substances, medium water levels, discharges and velocities, density, compensation and stock movements, the vertical distribution of the simulated parameters in the water column of different parts of the reservoir and their values in water discharges into the downstream, regime of snow-ice cover of the reservoir in winter.

Morphologically complicated Tsimlyansk valley reservoir (fig. 1) is located in the lower part of the Don River basin. It was filled with water in 1952-1953 and was constructed as a component of the Volga-Don water way. Now the reservoir has a universal function: it realizes the long-term regulation of the Don river flow, provides spring fishery and navigation releases for the creation of necessary ecological and navigation conditions in the downstream part of the river, it is used for the production of electric power at the dam hydroelectric power station and Rostov nuclear power plant. The Don Main Channel (DMC) originates in Volgodonsk which was built at the same time as the Tsimlyansk hydroelectric power station, its annual water intake exeeds 1500 million m^3. The water drifts into the Valley of Sal River along the DMC, where it is distributed among the secondary channels and then it is used for irrigation. The reservoir water volume is used also by other smaller irrigation systems such as Generalovskaya since 1959 (50–60 million m^3 during a season) and Khoroshevskaya since 1963 (3 million m^3 during a season). The reservoir is connected with the Volga River by the Volga-Don Channel. Its compensation water is taken from the Tsimlyansk reservoir.

The Tsimlyansk Reservoir makes long-term regulation with water exchange mean annual coefficient of 0,8 year^{-1}. The relevance of the study of the possible change of the reservoir regime is that the catchment area of Don River is poorly provided with water resources. The river flow is mainly formed due to spring snow melting and the possesses great variability of usually short and high water, from which considerable interannual fluctuations of flood volume depend. Such hydrological features of the flow need its deep long-term and seasonal regulation since water supply of populated and irrigated areas by DMC is of the most priority in the water management complex. Hydroelectric power is of subordinat importance: water expenses only hydropower purposes are not envisaged. The minimum sanitary release downstreams is accepted equal 100 m^3/s.

Water exchange mean annual coefficient:
It is the ratio of annual runoff from the reservoir to its volume. This characteristic of the aquatic environment is of great ecological value.

Average daily water discharge, its temperature and mineralization are necessary to calculate the inflow of water from tributaries. Expenses of water dumping downstream and water fence from the reservoir to channels are necessary as well. In the HRM-MSU model which has a daily calculation step, the Tsimlyansk Reservoir is presented by 8 sections, 5 of which – in the main valley (fig. 1) and 3 – in the mouth gulfs of tributaries. Each section consists of boxes – layers of a meter thickness, water mass in each of them is accepted homogeneous. Computation is based on the calculation of daily water balance of the reservoir, and then on the consecutive calculation of water, salt and thermal balance of each box in all sequence of the sections with the account of the processes of external and internal heat and salt exchange, as well as density stability of water thickness if it is stratified. For test calculations the years of 1972 and 1973 with total necessary hydrometeorological information are chosen. For the statistical assessment of the results of test model calculations (their validation) the surface temperature published in year-books is used. Initial day of these calculations is accepted as January 1. Model calculation reproduces the annual thermodynamic cycle well in all sections of the reservoir. Some overestimation of water surface temperature values in the compartments I-1, I-3 and I-4, is possible, caused by the fact that meteorological stations in Volgograd and Kotelnikovo are situated at the distance of 60 and 25 km from a reservoir respectively.

For predictive calculation of the supposed climatic change of water balance structure and inter annual fluctuations of water level estimates of probable water flow change published in MSU are used (Ecological and geographical consequences…, 2011) . According to this forecast based on a row of models of the atmosphere general circulation for the central part of the European plain, essential decrease of river flow to the south from 54-55º NL is expected, and the tendency of the decrease of the river flow to the south of the plain at the end of the XXI century will exceed.

For calculation of the possible change of Tsimlyansk Reservoir hydrological regime the low water year of 1973 is chosen as a base year. The ratio of flow from the watershed, according to the hydrological forecast will make up in the winter – 0.9; 0.5 - in the spring; 0.8 - in the summer; 0.6 - in the autumn; 0.7 - in the year in the relation to the average long-term volumes of inflow for the same seasons. As the Tsimlyansk reservoir is of multi-purpose appointment, in predictive calculations the expenses of water dumped through hydroelectric power station and pumped water to channels of Volga-Don and DMC proportional to the reduction of inflow of water from a the reservoir watershed are reduced. Water intakes of other consumers and other irrigating systems weren't considered since the volume of their transfer is much less than in DMC. Filtration losses of water are included in dumping and reduced in proportion to the average annual reducing coefficient of K_r (tab. 1). When predictive calculations are made the observance of the requirements to the guaranteed water discharge and to the sanitary release is impossible because at essential reduction of water inflow to the reservoir, the revision of existing water management standards is undoubtedly required. Predictive data obtained on the INMCM4 model (Institute of Numerical Mathematics Climate Model version 4), developed at Institute of Computing Mathematics of the Russian Academy of Sciences (Volodin et al., 2010) were used as the meteorological forcing factor. These are data from numerical experiments of the climate forecast for 2006-2100, prepared according to IPCC scenario within the CMIP5 project (http://83.149.207.89/GCM_DATA_PLOTTING/documents/climate.pdf (25.04.2013)) For hydrological modeling we used the data for the scenario RCP8.5 (the greatest warming of climate by the end of the XXI century): average daily values of the ground velocity of the wind (model level – 2 m), temperature, air pressure, humidity, value of coming and leaving long-wave radiation, a stream of short-wave solar radiation, the daily sums of a precipitation during 2045-2075. In predictive calculation to introduce weather conditions for the Tsimlyansk Reservoir results of the climatic INM RAS model for the closest knot of a grid (47°n.l. 42°e.l in 60 km to the South from the water-engineering system) are used.

Model calculation has to reproduce not the average seasonal fluctuations, but the annual variability of hydrological characteristics corresponding to the synoptic conditions in this or that year usual for the region. Therefore the file of initial meteorological data is prepared as follows. According to the observation data in 1973 the freezing-over and open water periods are outlined. For each of them average values of meteorological characteristics are defined. Then for a number of air temperature T, for example, and the model average climatic range T^* daily mean reduced coefficients of k_i for corrective action to observed average daily values are calculated: $T_i^*=k_i{\cdot}T_i$. In the same way rows are reduced as well as precipitation, wind velocity, temperature and air humidity and atmospheric pressure. As a result the received sum of precipitation and average indexes of other values are specified to characteristic of predicted values which are calculated using the climatic INM RAS model.

3. RESULTS

The multiple calculations of water balance components of the Tsimlyansk Reservoir executed on the HRM-MSU model give an idea of the possible variability of a hydrological mode in low water years of the middle and the end of the current century (fig. 2, tab. 2).

Probable values of the major characteristics are shown in the table according to scenario of model calculations with optimistic B1 and C1 and adverse B2 and C2 forecasts of inflow reduction in reservoir and with inevitable deficiency of water resources for the water management of Lower Don.

In case of water inflow and its reduction approximately by two times, the reservoir flowage will decrease by 1,5 times (B2 and C1 options). If the inflow decreases by 4 times, the flowage will be slowed down by 3,5 times (B2 option). In case of adverse warming of the climate (scenario B2) water expenses downstream, which take place from April till the end of June for the flooding of the spawning areas of Don mouth, should be reduced by two times (fig. 2.2) that will lead to the decrease in water level in the reservoir by 0,5-1 m lower than the mark of the level of the minimum volume (31 m). It is adverse for the hydroelectric power station work during the whole autumn and winter (fig. 2.3). These problems will become more acute in case of the continuing warming of climate before the end of the century (scenario B2).

For the observation period with available data , the most low water period was 1972 with the capacity of inflow of 7,99 км^3, total dumping of hydroelectric power station 7,2 км^3, water intake to canals Volga-Don and Don main about 0,5 and 1,5 км^3 respectively. Comparing these values to those at tab. 2, it is seen that the flow reduction as in scenario B1 was already observed in the XX century. However such years are dangerous, from the point of view of water supply if they form a row so low water years when water level at the beginning of the year becomes lower relatively the minimum admitted level (31 m).

Table 1

Expected relative change of a drain from the Tsimlyansk reservoir basin in the XXI century and reducing coefficient (*Kr*) at an assessment of the most probable change of the main account water balance components

Time	Lower-top limits 90% confidential interval of coefficients		
	***Kr* annual water flow**	***Kr* flood flow**	***Kr* annual water discharge**
Middle XXI в.	0,56–0,74	0,3–0,67	0,43–0,72
End XXI в.	0,29–0,63	0,18–0,46	0,25–0,56

Table 2

Change of the main components of the Tsimlyansk reservoir annual water balance and its level characteristics by scenario calculations (A – using hydrometeorological supervision data of 1973, B1 and B2-in the middle of the XXI century, according to the forecast of the reduction of inflow for the upper and low limits of 90% of a confident interval, C1 and C2 - for the similar limits of a probable interval of inflow at the end of the XXI century.

Components of water balance and intensity of water exchange	Options diagnostic and predictive calculations				
	A (1973 г.)	**B1–B2**		**C1–C2**	
Inflow, km^3	11,79	8,55–5,11		6,67–2,91	
Dumping of water of hydroelectric power station, km^3	7,45	5,36	3,20	4,32	1,86
Water intake in the Volga-Don channel, km^3	0,36	0,26	0,15	0,20	0,09
Water intake in the Don main channel, км^3	1,49	1,07	0,64	0,85	0,37
Water exchange coefficient Kv, year^{-1}	0,86	0,62	0,37	0,54	0,25
Level, m abs.					
01/01	30,81	30,81	30,81	30,81	30,81
31/12	31,74	30,63	30,22	30,39	29,92
Minimal annual	31,64	30,51	30,04	30,24	29,83
Maximal annual	32,97	32,19	31,37	31,71	31,12

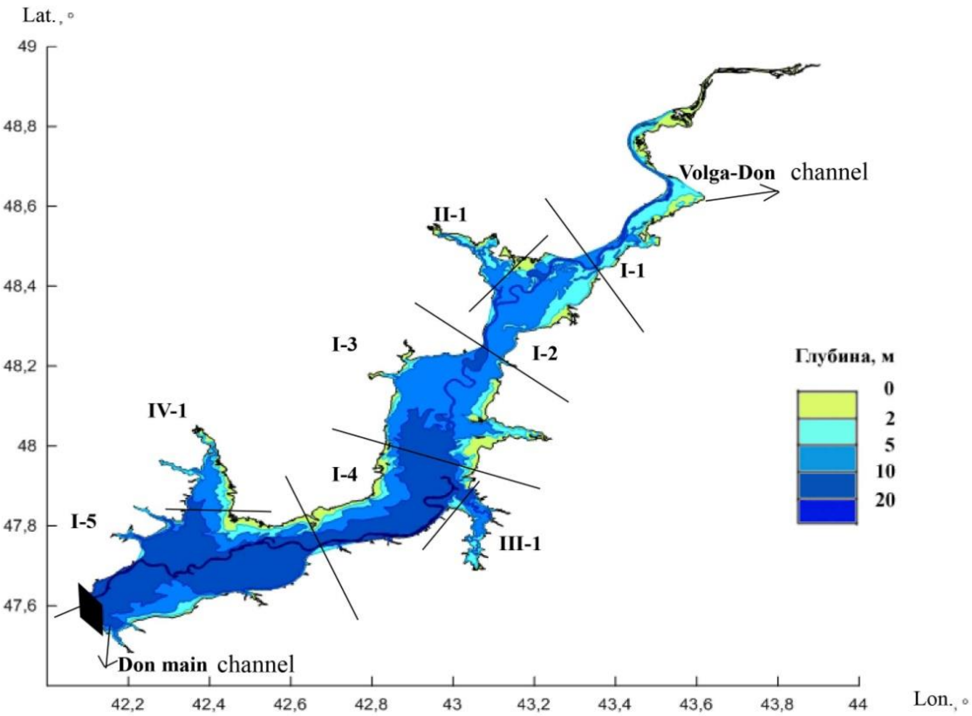

Figure 1
Compartments of the Tsimlyansk Reservoir

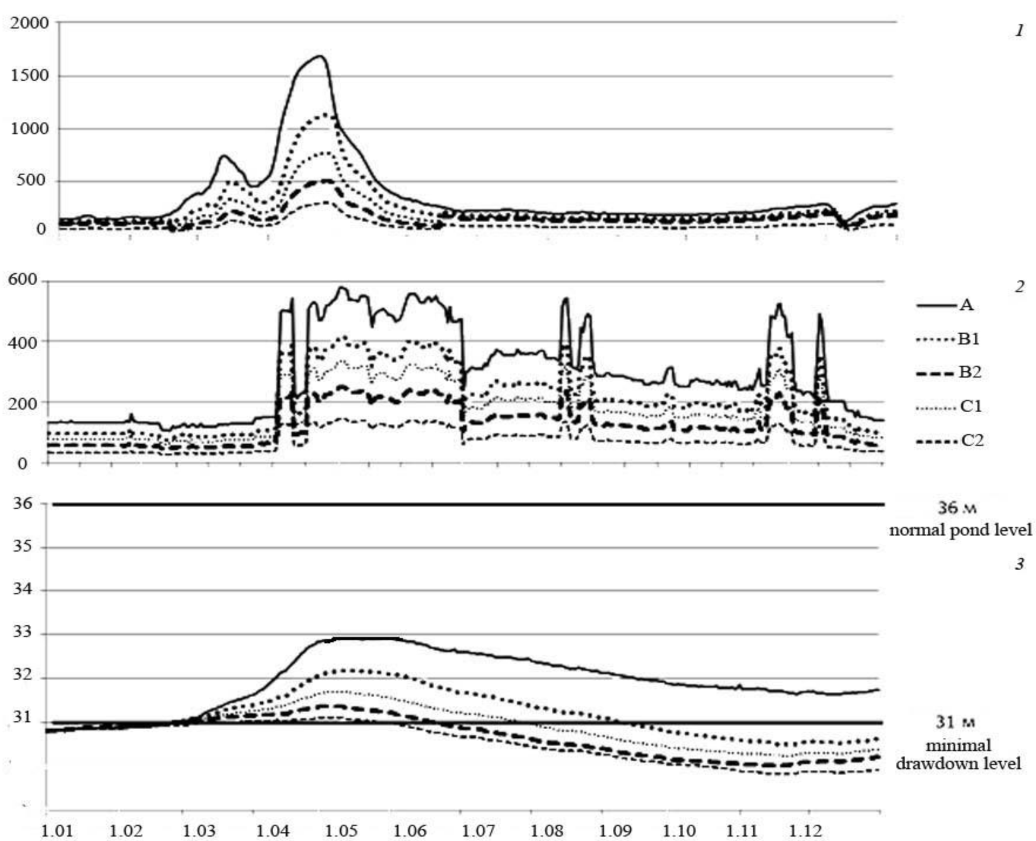

Figure 2
Change of total inflow (1) and total dumping of water, including water intake (2) and a water level (3) in various options of model calculations.

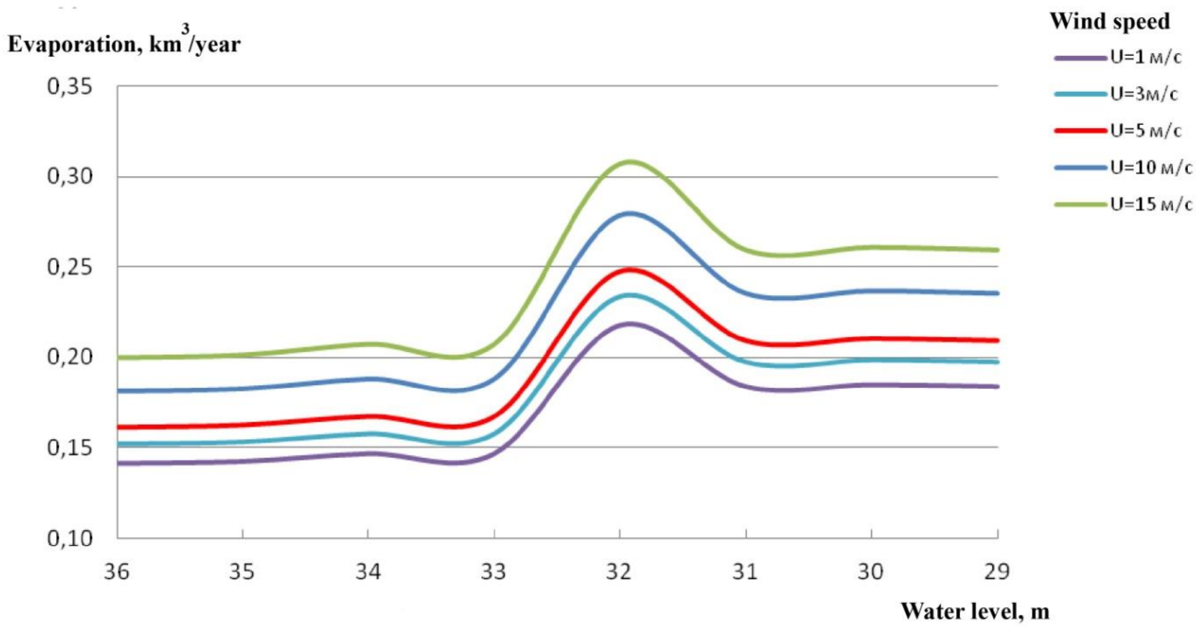

Figure 3
Change of evaporated water volumes by shoals of the Tsimlyansk reservoir (with a depth of 1 m) at different marks of level and wind speeds.

4. DISCUSSION

Under identical initial conditions the results of calculations show essential distinctions in the hydrological mode of the reservoir since February. In scenarios of calculation of B and C the ice cover melts by the end of the first decade of February (a month earlier than in scenario A). During the period of open water in these variants water body accumulates more heat and cools down more slowly. As a result, it leads to the fact that the ice cover isn't formed at all though in basic A (1973) variant it is formed in upper courses at the beginning of December, and near dam – at the end of its first decade (diagnostic calculation will be well coordinated with data of water-measuring supervision). Thus, in all predictive scenarios ice cover duration reduction is possible up to its absence.

Early ice melting (or almost full absence of ice) causes uniform distribution of water temperature and mineralization from the middle of February, and now inverse stratification remains under ice to the middle of March in the upper courses and until the end of March near the dam. By the beginning of February distinctions in water mineralization are already noticeable in results of diagnostic and scenario calculations in upper courses (to 20 mg/l for B1, B2 and C1 and up to 40 mg/l in C2) because of the increase in a share of underground food of inflows.

To the middle of March in options B and C water is already heated-up to 4–7°C, and in the upstream temperature is lower because of Don river water influence flowing from the North to the South. The increase in mineralization, in comparison with the calculations using the 1973 data, in the upstream reaches 50 mg/l in B1, 100 mg/l in B2 and C1, and in C2 – more than 150 mg/l. Therefore in the bottom horizons of the sections I-4 and I-5 ground water mass begins to be formed.

Since the end of March and to the beginning of September surface temperature during the period of direct stratification in predictive calculations by 1,5–3°C exceeds To values in 1973. The same excess of temperature during this period is possible in the bottom layer (fig. 3b) because of greater warming of water in predictive scenarios during the isothermal period in March. In the middle of September water mass starts being cooled, and the distinctions of water temperature in a dam section in diagnostic variant of calculations and in predictive one practically disappear (taking into account posible model mistakes). According to diagnostic calculation the inverse stratification is formed before winter with surface temperature near 0°C. Whereas in predictive scenarios isothermal period lasts until the end of the year with temperature from 5 to 2-3°C .

Model calculations of thermal balance components showed that the greater increase of heat loss for evaporation (up to 1,5 times) in predictive scenarios will occur during summer and autumn, and also in March because of early cleaning of the reservoir from the ice cover. At the same time heat loss with an effective radiation will increase by 2-3 times during the spring and summer period and in autumn by 1,5 times. Such a big increase in heat losses during the period of open water prevents the overheat of water mass in the conditions of expected warming of the climate. In water equivalent the increase in losses with evaporation will make up in average from 10% (B1 option) to 20% in a year (C2 option). At the lower level of water (32 m and below) and the reduced water surface the additional decrease of level owing to the increase of evaporation will make up from only 20 (B1 option) to 30 cm (C2 option).

Additional studies showed that at the interaction of the Tsimlyansk reservoir with the atmosphere there can appear a certain critical condition in the change of the intensification of this interaction, namely the increase of evaporation at water level in the vicinity of 32 m that is connected with the features of a bathymetry (at water level change from 33 m to 31 m, at different velocity of wind volume of evaporated water considerably increases at first to the level of 32 m, and then decreases, fig. 3). The decrease of the intensity of evaporation at the decrease in level of a reservoir from 32 m to 31 m can cause the corresponding decrease in gas exchange that can worsen the ecological condition of a water body. The standing of the level near at mark of 32 m is unprofitable because of the increase of water losses at future inflow reduction from the point of view of water consumption. The decrease of the intensification of evaporation can really lead to warming up of the top layer and, in particular, its near-surface layer. In these conditions the warm blanket with steady temperature stratification in it will limit a gas exchange that can negatively influence a shallow zone of the reservoir, a zone of spawning areas (Panin et al., 2007).

Shallow zone:
A plot with small depth of water up to 2 m.

The increase in losses of evaporated water is one of the factors of mineralization increase in a reservoir in a steppe zone, along with the increase in a share of feeding of tributaries by ground waters at the reduction of flood volume (The prognosis of salinity..., 1965). Calculation by HRM-MSU model for option A (with the greatest flow intensity from all options) shows the increase of water mineralization for the period of open water by 15% that coordinates quiet well with the balance assessment executed by a technique of N. M. Bochkov (Krivencov, 1967). Predictive calculation for B1 scenario showed probable increase in the sum of ions in water mass by 18%, by C2 option – by 20%. Mineralization increase by autumn from 420 to 470 mg/l (and consequently hardness of water) in the dam area is adverse for water management of the Rostov nuclear power plant.

5. CONCLUSION

Due to the possible adverse reduction of water flow in the south of the European territory of Russia it is necessary to begin the development of new dispatching service regulations of the Tsimlyansk water-engineering system in advance and to estimate the consequences of possible reduction of water supply at irrigating and transport systems. Probably, it will appear ecologically and economically more expedient to carry out feeding of the Volga-Don Canal not by Don, but by the Volga water.

SUMMARY OF RESEARCH

Multiple predictive model calculations show that at possible warming of the climate in the second half of the XXI century and the reduction of inflow of water to the Tsimlyansk Reservoir changes will be mostly observed in the reduction of its net volume and water cycle. Duration of ice period will be reduced. Since March the vegetative and navigation season in some years can last till January. The considerable increase in water temperature during the summer period shouldn't be expected. It will be within limits of 2-3ºC and not more because of significant increase in heat losses at evaporation and the increasing effective water radiation. Water mineralization during the spring period will increase in the upper courses, and in summer-autumn low inflow period in the dam area as well.

FUTURE ISSUES

An important task for the future is to evaluate the changes in water regime of large reservoirs, which are sources of water supply for many sectors of the economy.

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