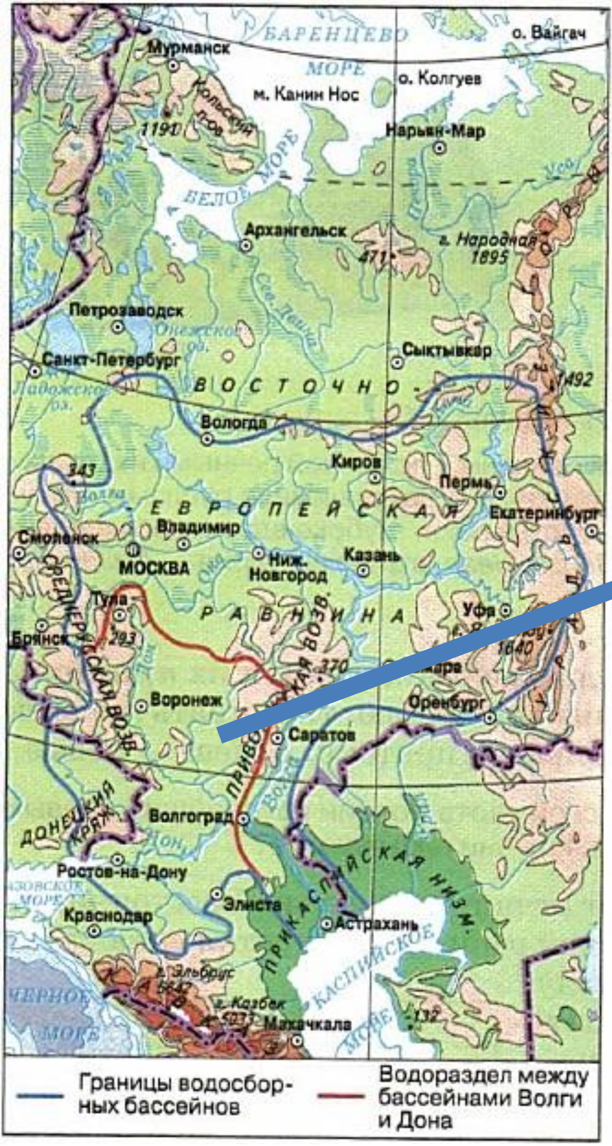
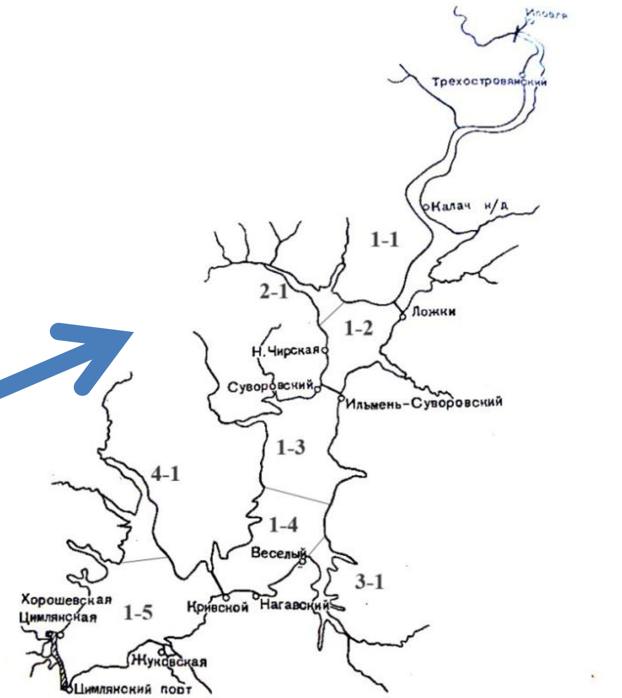
Гидрология суши

Estimation of probable changes of the hydrological regime of the Tsimlyansk Reservoir

Grechushnikova Maria
MSU
Faculty of geography
allavis@mail.ru



Object: **Tsimlyansk Reservoir**



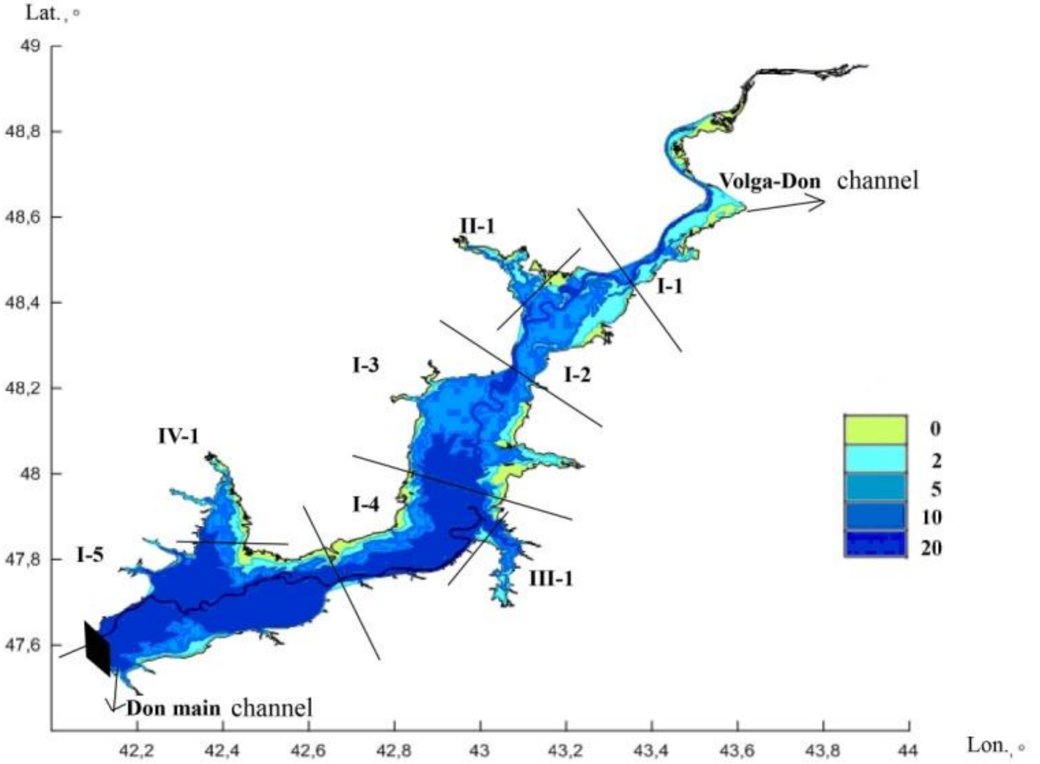
Aim: Predictive calculations of the annual regime of level and water exchange, ice-thermal regime and salinity of water taking into account the change in flow formation conditions in the catchment areas of the river Don and other tributaries of this reservoir reveal the possible adverse effects of warming for the largest water management complex of the southwest of Russia.

Technique and used data

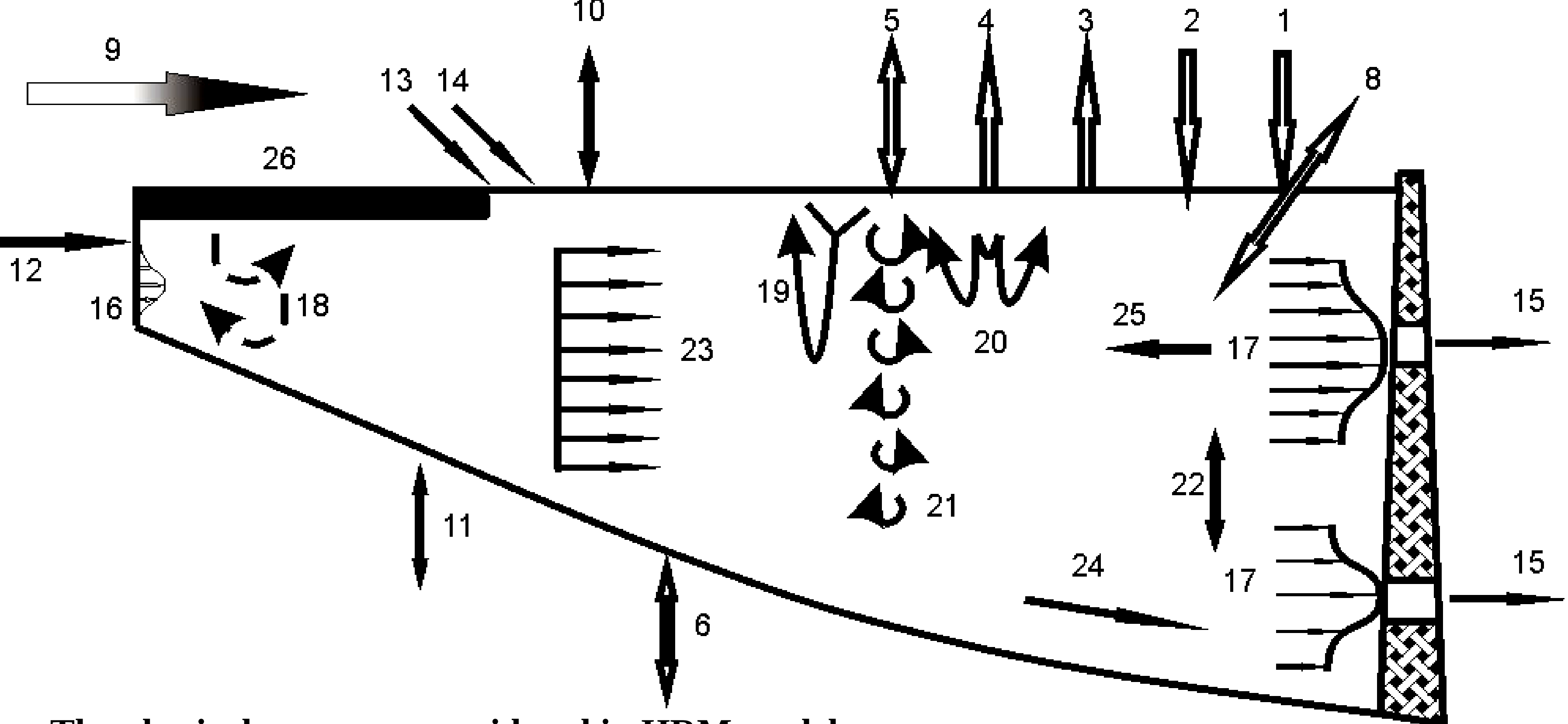
The relevance of the study of the reservoir regime possible change is that the catchment area of river Don is poorly provided with water resources.

The high river flow is mainly formed due to spring snow melting with a great variability which is the reason of considerable annual fluctuations of the flood volume.

Such hydrological features of the flow need its deep long-term and seasonal regulation since water supply of populated and irrigated areas by Don Main Canal has the most priority in the water management complex. Hydroelectric power has less importance. The minimum sanitary release downstream is accepted equal to 100 m^3/s.



Compartments and the depth of the Tsimlyansk reservoir.

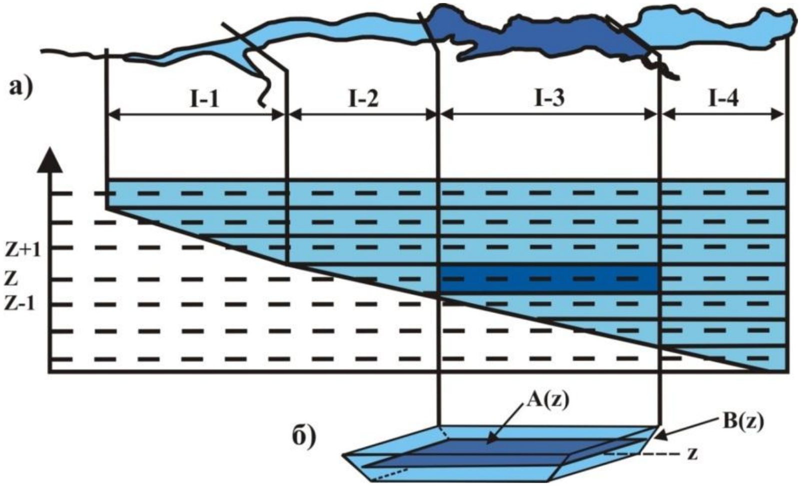


The physical processes considered in HRM model:

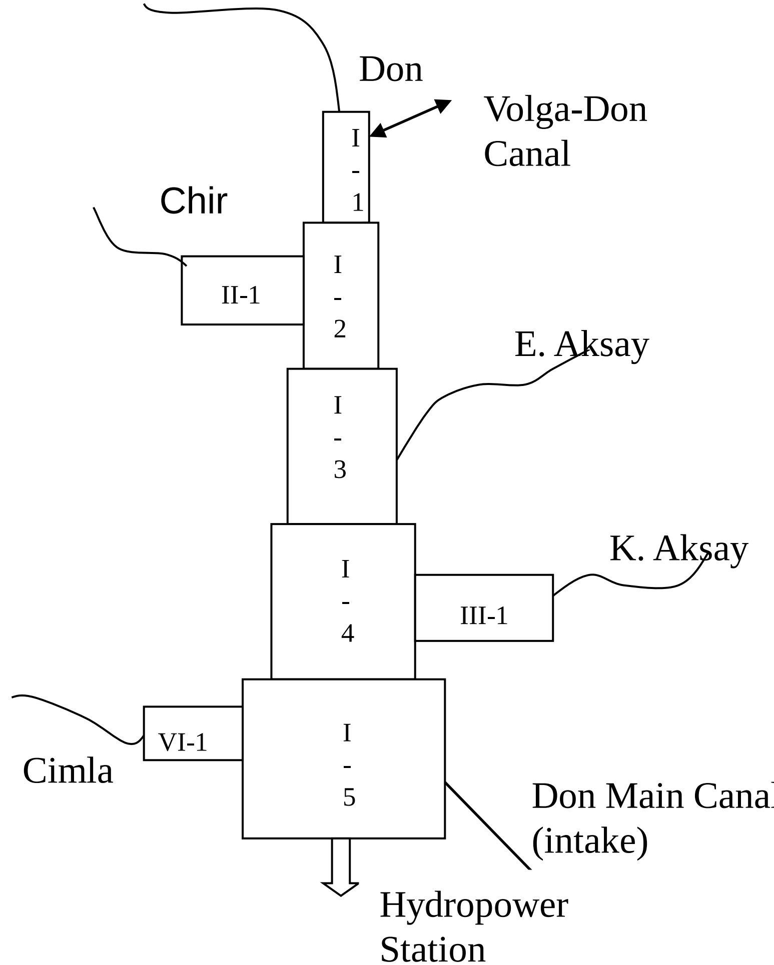
1 – the solar radiation, 2 – the long-wave radiation of atmosphere, 3 – the long-wave radiation of water, 4 – losses of heat on evaporation, 5 – turbulent heat exchange with the atmosphere, 6 – heat exchange with a bottom, 7 – absorption of short-wave radiation, 8 – reflection of solar radiation,

9 – transformation of air over a reservoir, 10 – precipitation and evaporation,

11 – water exchange in a coastal zone, 12 – inflow on the main river, 13 – inflow on the side rivers, 14 – the dispersed inflow, 15 – dumping, 16 – density distribution of the flowing stream, 17 – a selective water intake, 18 – dynamic hashing in a stock current, 19 – free convection, 20 – the compelled convection, 21 – vertical kinetic transfer, 22 – vertical advection, 23 – flow current, 24 – density currents, 25 – a compensation current, 26 – formation of a snow-ice cover.



Scheme of a simple valley reservoir



- In the hydrological reservoir model (HRM) with a **daily calculation step**, the Tsimlyansk Reservoir is presented by 8 sections, 5 of which – in the main valley and 3 – in the mouth gulfs of its tributaries.

- Each section consists of boxes – layers of a 1 m thickness.

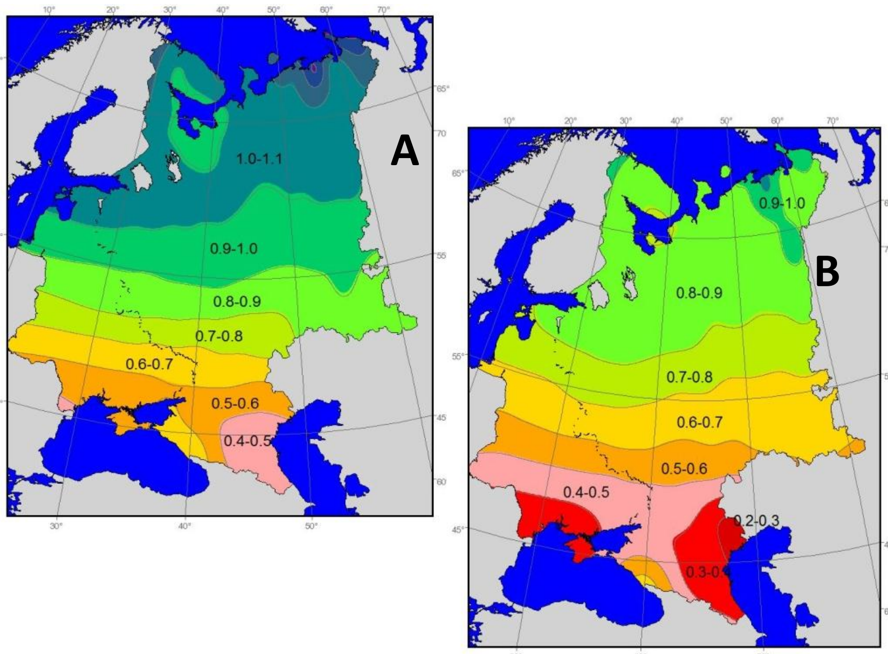
- Water mass in each of them is accepted homogeneous.

- 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.

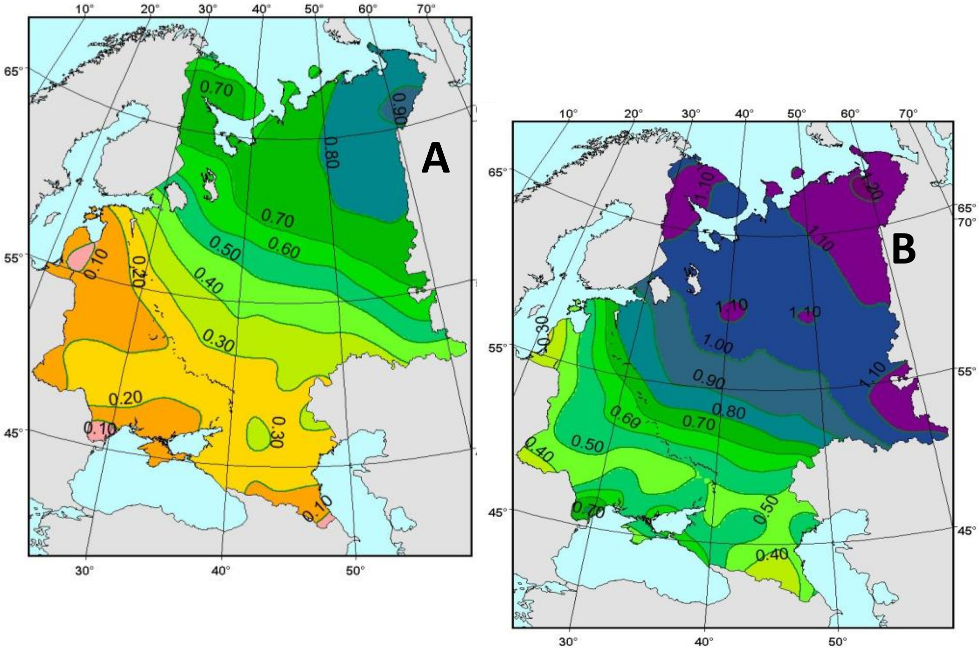
- Years of 1972 and 1973 with total necessary hydrological and meteorological information and observations are chosen for test calculations. Model calculation reproduces the annual thermal cycle well in all sections of the reservoir.

Technique and used data

The number of predictive studies of climatic, hydrothermal and water resource changes (Kislov et al., 2009) is the basis of the present study in case of further warming on the East European Plain in the 21st century. 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 54-55° NL is expected.



The relative changes in annual runoff in ETR over the ensemble of 12 models in the middle of the XXI century: (A) the upper limit of the confidence interval, (B) the lower limit of the confidence interval

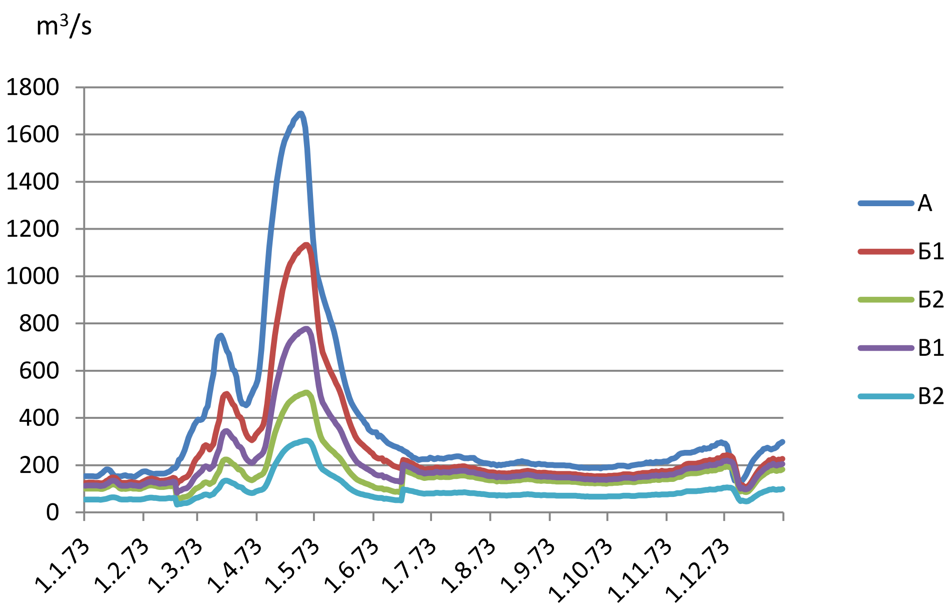


The relative changes of flood runoff over the ensemble 7 models in the middle of the XXI century: (A) the upper limit of the confidence interval, (b) the lower limit of the confidence interval

Expected relative change of drain from the Tsimlyansk reservoir basin in the 21st century and reducing coefficient (*Kr*) at the 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	0,56–0,74	0,3–0,67	0,43–0,72
End	0,29–0,63	0,18–0,46	0,25–0,56

Predictive data obtained from INMCM4 model, developed at Institute of Computing Mathematics of the Russian Academy of Sciences (Volodin, 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. The used data included average daily values of the ground velocity of the wind (model level – 2 m), temperature, air pressure, humidity, values of atmospheric long-wave radiation and stream of short-wave solar radiation, the daily sums of a precipitation during 2045-2075.



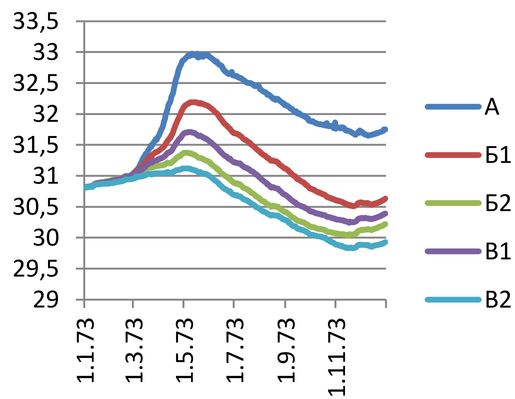
A –observation data of 1973,
B1 and B2 – in the middle of the 21st century, according to the forecast of the inflow reduction for the upper and low limits of 90% confident interval,
C1 and C2 – for the similar limits of a probable interval of inflow at the end of the 21st century.

The multiple calculations of water balance components of the Tsimlyansk Reservoir executed on the GRM model give an idea of the possible variability of a hydrological regime in low water years of the middle (B) and the end of the current century (C).

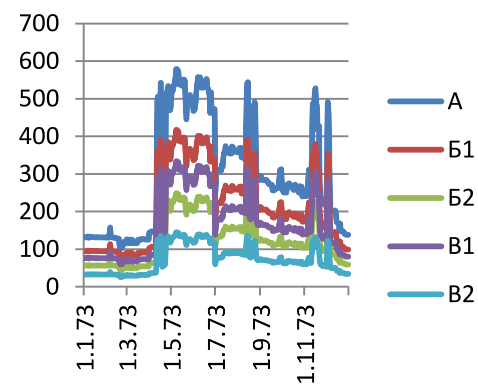
Probable values of the major characteristics are shown in the table according to scenario of model calculations with optimistic (B1 and C1) and adverse (B2 and C2) forecasts of inflow reduction in reservoir and with inevitable deficiency of water resources for the water management of river Don.

- In case of water inflow and its reduction approximately by two times, the reservoir flowage will decrease by 1,5 times
- If the inflow decrease by 4 times, the flowage will be slowed down by 3.5 times
- 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 in the river Don mouth, should be reduced by two times.
- That will lead to the decrease in water level in the reservoir by 0.5–1 m lower than the mark of the minimum volume level (31 m).
- It is adversely for the hydropower station work during autumn and winter.
- Decreasing of flowage intensifies the processes of self-purification, but the decrease of river flow will reduce dilution of contaminants above the reservoir and below it and will cause the increase of salinity in Azov sea with the following consequences for its ecosystem.

Components of water balance and intensity of water exchange	Options diagnostic and predictive calculations				
	A	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					
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



Level, m

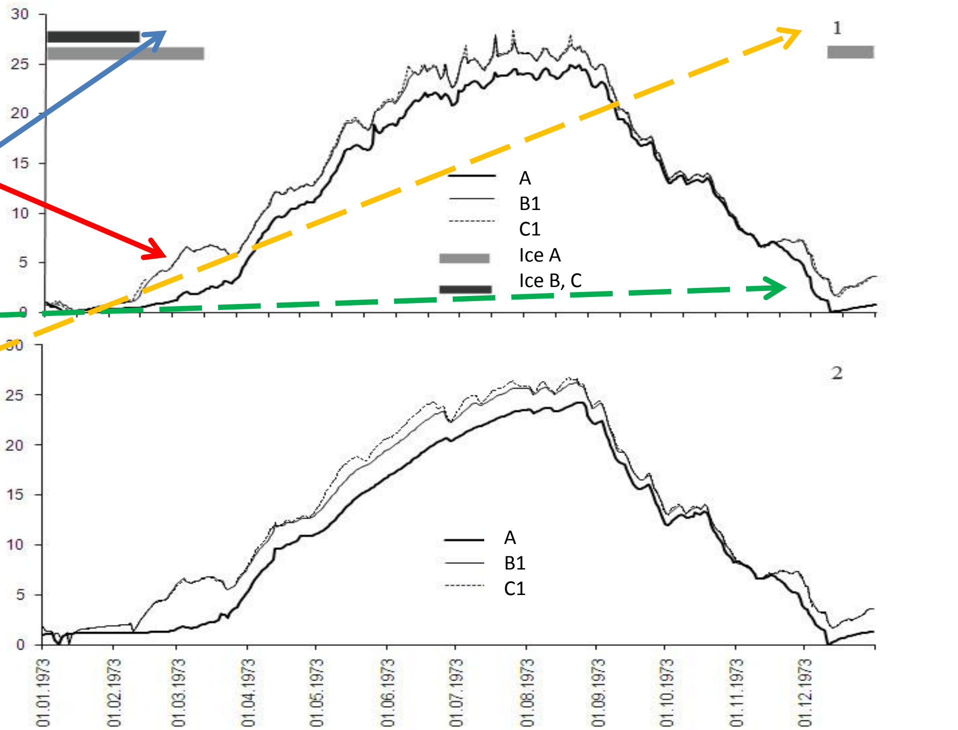


Discharge m^3/s

For the observation period with available data, the most low water period was 1972 with the capacity of inflow equal to 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 table, it is seen that the flow reduction as in scenario B1 was already observed in the 20th century. However such years are dangerous from the position of water supply if they follow one by one, and water level at the beginning of the year becomes lower relatively to the minimum admitted level (31 m).

Under identical initial conditions the results of calculations show essential distinctions in the hydrological mode of the reservoir since February:

- In scenarios B and C the ice cover melts by the end of the first decade of February (one month earlier than in A).
- In these variants water body accumulates more heat and cools down slowly during the period of open water.
- It leads to the fact that the ice cover isn't formed at all though in basic variant (1973) it is formed in upper courses at the beginning of December, and near the dam – at the end of its first decade.
- It is positive for aeration of water body and river transport.
- Early ice melting (or almost full absence of ice) causes equal distribution of water temperature and salinity from the middle of February, and in A (1973) the inverse stratification remains under the ice up to the middle of March in the upper courses (I-1) and until the end of March near the dam (I-5).



Surface (1) and bottom (2) temperature of water and duration of ice period

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.

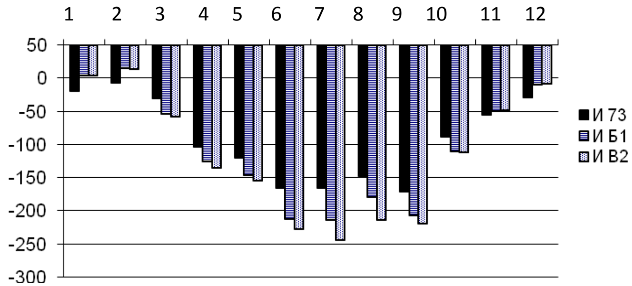
At the same time heat loss with an effective radiation will increase by 2-3 times during the spring and summer period and in autumn by 1,5 times.

The significant increase of turbulent heat transfer in spring and late autumn in experiments B an C is die to absence of ice cover.

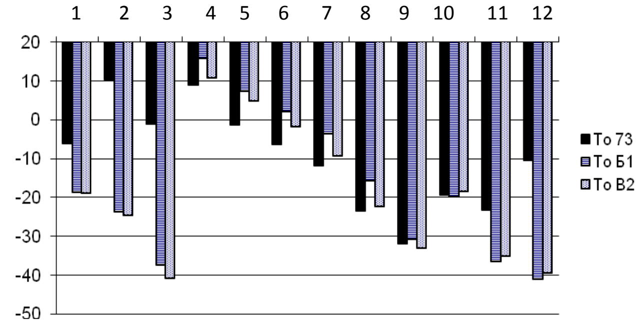
Such a big increase in heat losses during the period of open water prevents the overheat of water mass in the conditions of expected warming of climate.

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 at the reduced water surface the additional decrease of level owing to the increase of evaporation will make up from **20 cm** (B1 option) to **30 cm** (C2 option).

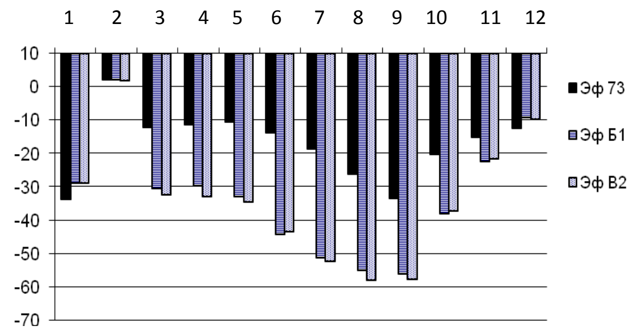
Evaporation



Turbulent heat transfer



Effective radiation



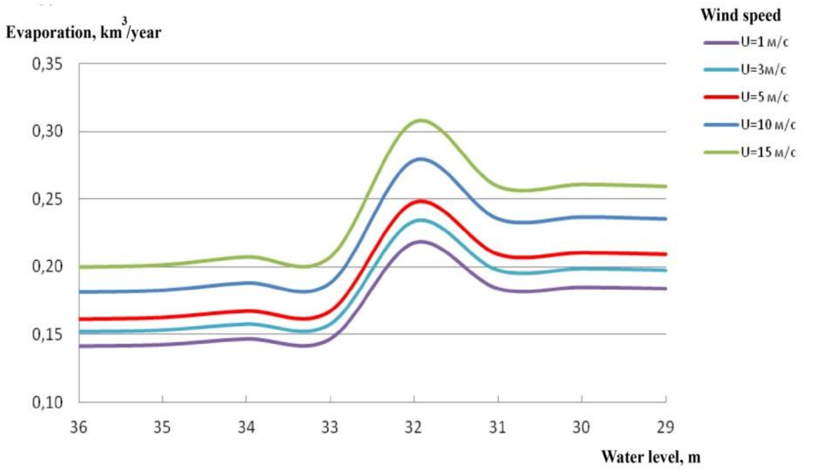
Mean month values of heat balance components (Wt/m^2) .

$$U_*^{SW} = U_* + U_* k_U^{SW} \frac{h^{sw}}{H} \approx U_*(1 + 1.6 h^{sw} / H)$$

$$Q_T^{SW} = Q_T + Q_T k_T^{SW} \frac{h^{sw}}{H} \approx Q_T(1 + 2 h^{sw} / H)$$

$$E^{SW} = E + E k_E^{SW} \frac{h^{sw}}{H} \approx E(1 + 2 h^{sw} / H)$$

h – wave height, H – depth, E, Q – latent and turbulent heat on deep water, U_* – dynamic wind speed,
$k_T^{SW} \approx k_E^{SW} \approx 2.0$, $k_U^{SW} \approx 1.6$ – empiric koefficients
«*sw*» means shallow water.



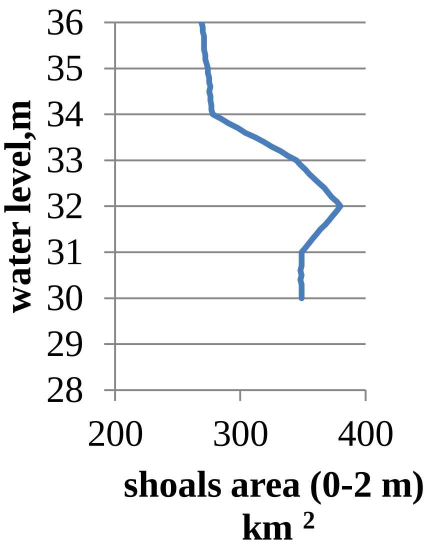
Change of evaporated water volumes by shoals of the Tsimlyansk reservoir (with a depth of 1 m) at different marks of level and wind speed.

Additional studies showed that there can appear a certain critical condition at the interaction of the Tsimlyansk reservoir with the atmosphere.

• It is found an increase of evaporation at water level in the vicinity of 32 m that is connected with the features of the shape of reservoir bed (at water level change from 34 m to 31 m at different velocity of wind the volume of evaporated water considerably increases at first to the level of 32 m and then decreases).

•This decrease of the intensity of evaporation can cause the corresponding decrease in gas exchange that can worsen the ecological condition of a water body (Panin et al., 2007).

• !!! The standing of the level near the 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 increase in losses of evaporated water is one of the factors of salinity increase in a reservoir in a steppe zone, along with the increase in a share of ground waters at the reduction of flood volume.

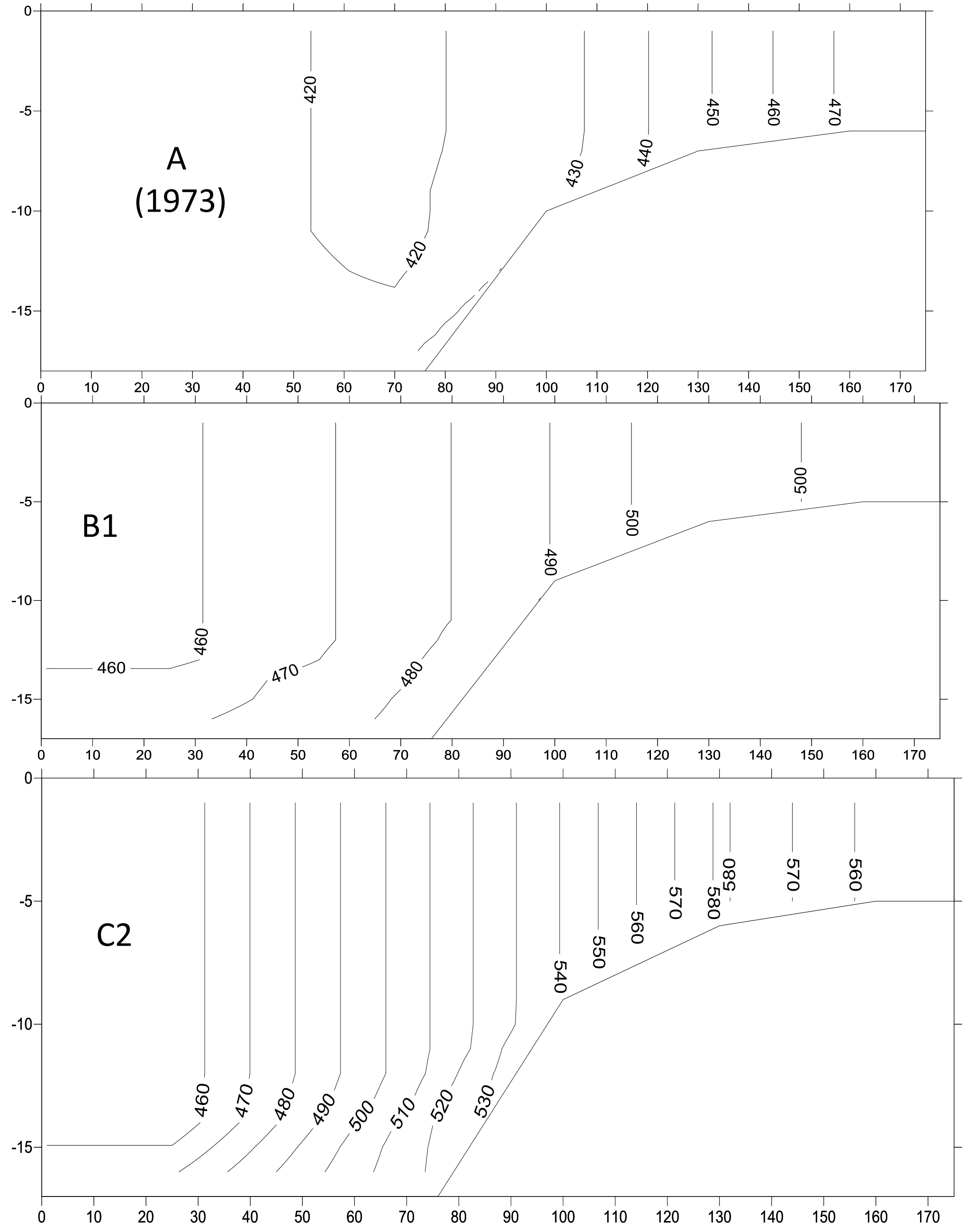
Calculation by HRM model for option A shows the increase of water mineralization for the period of open water by 15% that coordinates quiet well with the balance assessment.

Predictive calculation for B1 scenario showed probable increase in the sum of ions in water mass by 18%,

by C2 option – by 20%.

Salinity increase by autumn from 420 to 470 mg/l (and consequently the hardness of water) in the dam area is adversely for water management of the Rostov nuclear power plant.

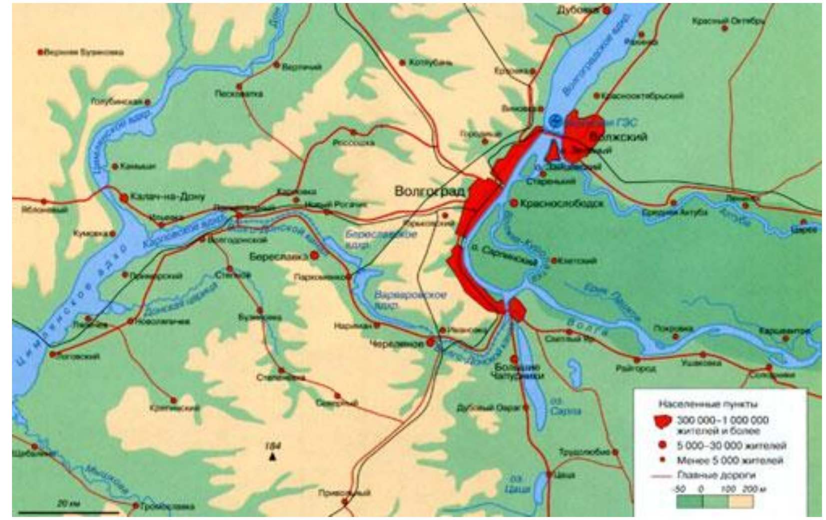
october



CONCLUSION

Multiple predictive model calculations show that at possible warming of climate in the second half of the 21st century and the reduction of water inflow to the Tsimlyansk Reservoir changes in its regime 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 2-3^{o}C and no more because of significant increase in heat losses by evaporation and effective radiation.
- Water salinity during the spring period will increase in the top area, and in summer-autumn low inflow period in the dam area as well.
- The decrease of fresh water inflow will have negative concequences for Azov sea (decrease in productivity while reducing the inflow of nutrients, decrease in the number of valuable fish species, increase of stratification and as a result growth of anoxia duration in the sea and etc.).



Due to the possible 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.