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INTEGRATED PROJECTION FOR RUNOFF CHANGES IN LARGE RUSSIAN RIVER BASINS IN THE XXI CENTURY

ABSTRACT. The paper discusses an approach to a long-term forecast of river runoff changes for Russian large river basins in the first third of the XXI century caused by climate warming and social-economic changes. The approach considers runoff changes under a range of possible climate warming effects. This range is chosen by generalizing the calculation results obtained by using an ensemble of global climate models within CMIP 3 and CMIP 5 experiments for two contrasting scenarios (A2/RCP 8.5 and B1/RCP 2.6) of globally averaged air temperature rises. The approach also utilizes a method for alternative scenario for water consumption related to socio-economic changes. The obtained scenario estimates show that expected changes in the Volga and Don annual river runoff and its intra-annual distribution in the first third of this century can be relatively small, while changes in water use characteristics may be extremely negative in some scenarios, especially in the Don River basin.

KEY WORDS: large river basins, scenarios of river runoff changes, global climate warming, socio-economic changes, water consumption

INTRODUCTION

Global climate warming and socio-economic changes are the leading factors in determining the future state of large river basin water systems that play an important role in the economic development of Russia. For this reason, it is necessary to generate integrated scenarios of river runoff changes within the large river basins, which would take into account the long-term potential changes in the two factors. Such scenarios should provide the basis for an ecologically safe management of water systems in the future.

Because the long-term trends and rate of changes in climate and social and economic development are rather uncertain, it is important to use their alternative scenarios in the forecast. Thus a great deal of attention is given to the development of long-term scenario forecasting the hydrological effects of global climate change and the water management system transformation in large Russian river basins.

In recent years, the authors have developed a methodology for long-term scenario projections of river runoff changes, which includes a water balance model and methods for utilization of global climate warming scenarios, methods for the scenario estimates of the water management system transformation, and GIS technologies [Georgiadi et al., 2011; Georgiadi et al., 2014].

RESEARCH METHODOLOGY

The approach taken to create a long-term scenario projection of river runoff changes in large Russian river basins in the

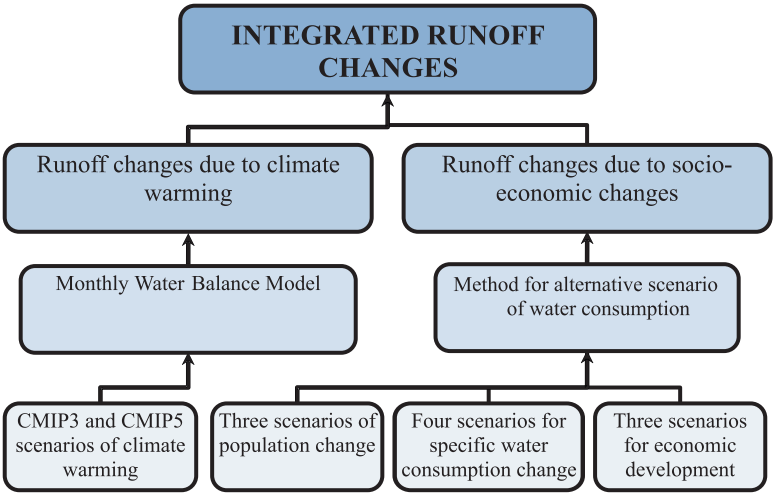

Fig. 1. Flowchart of the estimation.

first third of the XXI century includes two methods: (1) a method generating scenario estimations of runoff changes for a range of potential climate warming scenarios based on the generalization of calculated results obtained by using an ensemble of global climate models and (2) a method for alternative scenario estimations for the water management system transformation caused by socio-economic changes and their impact on the river runoff. The estimation flowchart is shown in Fig. 1.

Monthly water budget model

The model and its application to the largest river basins of the Russian Plain are considered in detail in the following publications: Georgiadi & Milyukova [2002] and Georgiadi et al. [2010, 2011]. This model can be categorized as one of a number of macro-scale hydrological models that have been developed in recent years [Willmott et al., 1985; WATCH, 2008]. The model is based on the conservation equation for the long-term monthly average water balance of river watersheds. It simulates the following processes: infiltration and moisture accumulation in the soil; evaporation (based on a modified Thornthwaite's method [Willmott et al., 1985]); water accumulation in the snow cover and snow melting (based on V.D. Komarov's method 'Manual on Hydrological Forecasts,' 1989); movement of the freezing front calculated from a simplified solution for classical single-front Stefan problem [Bel'chikov & Koren', 1979; Pavlov, 1979]; formation of surface, subsurface, and groundwater flow in the rivers and full river runoff. In the monthly water balance model, the changes in the river runoff and other water balance elements are estimated in the cells of a regular grid, which facilitates the coupling of the model and climate model simulations.

The range of probable climatic changes, which is estimated by calculating mean annual deviations of climatic elements for the 2010–2039 (conventionally referred to as 2025) from their recent values, is used as a climatic scenario. The calculations in water balance model are made for the two scenarios using the most (A2 and RCP 8.5) and the least (B1 and RCP 2.6) intensive rises of globally averaged air temperatures. Calculation results obtained by using ten global climate models for CMIP3 scenarios [Meehl et al., 2007] and about 30 global climate models for CMIP5 scenarios (http://cmip-pcmdi.llnl.gov/cmip5/) were incorporated. The ten "best" climate models, which were chosen by A.V. Kislov with co-authors [Kislov et al., 2008] from 23 climate models by comparing the present-day observed climatic conditions with the simulated ones in case of CMIP 3, while to estimate the runoff changes by the CMIP 5 scenarios, the results obtained from all climate models included in this program are used. The range of scenario deviations of mean monthly air temperatures and precipitation totals is determined for each of the scenario ensemble mentioned by averaging the calculated results obtained from each of the climate model chosen.

Method for alternative scenario estimations for water management system transformation

The methodology of estimating the impact of socio-economic changes on river runoff [Koronkevich, 1990; Georgiadi et al., 2008, 2011] is based on the assumptions of different rates of socio-economic development of a country and its regions and on the scenarios built around using different levels of water consumption and the water system protection technologies in place.

Major water consumers (household and industrial water use, irrigation, and rural water supply) are taken into account. Scenarios of household water use changes are recognized with regard to urban and rural population dynamics.

Scenarios of accelerated, moderate, and minimum socio-economic development are considered. The scenarios are based on the current specific level of water consumption and its maximum, average, and minimum decrease. Changes in storage evaporation rates and land use effects are also taken into account.

It is essential to understand that in the past decades, the water consumption dynamics in the Volga and Don river basins are in many respects close to that which was typical for Russia as a whole (Fig. 2a, b). This makes it possible to use economic and water consumption changes recorded/predicted for the whole of Russia when working out basin scenarios. Along with this, the natural and economic features of individual basins should be taken into account in forecast scenarios as well. The general algorithm for the method behind alternative scenario estimations for the water management system transformation takes place in two stages: pre-projection and projection.

The pre-projection stage includes the following steps: general orientation of the method development; analysis of natural conditions and space-time patterns of water resources distribution and water resources quality; analysis of economic activity and its impact on water systems; analysis of water system state dynamics; and selection of operating units.

The projection stage consists of the following steps: consideration of the expected natural hydrological and climatic situation; consideration of predicted population and economic development; estimation of probable changes in water use technology; consideration of the aggregate of anthropogenic and natural climatic factors; and scenario verification from water economy balances.

Estimates of future anthropogenic impacts on water resources for the years 2025–2030 are based on three scenarios for population change (average, maximum, and minimum), three options for economic development (inertia, energy and resource-based, and innovative) and four scenarios of specific water consumption change (the basic levels in 2000–2005, average, maximum, and minimum reduction). According to the official statistical forecast, the 1.05–1.15 times population decline is expected by 2025–2030. The Ministry of Economic Development of The Russian Federation gives the following economic growth rates of economic development for the same period – in industry 3–5 % per year increase, 2–4 % in the sectors of agriculture, and 1–3 % in other industries [The concept of long-term socio-economic development…, 2008; Kuzyk & Yakovets, 2006, etc.].

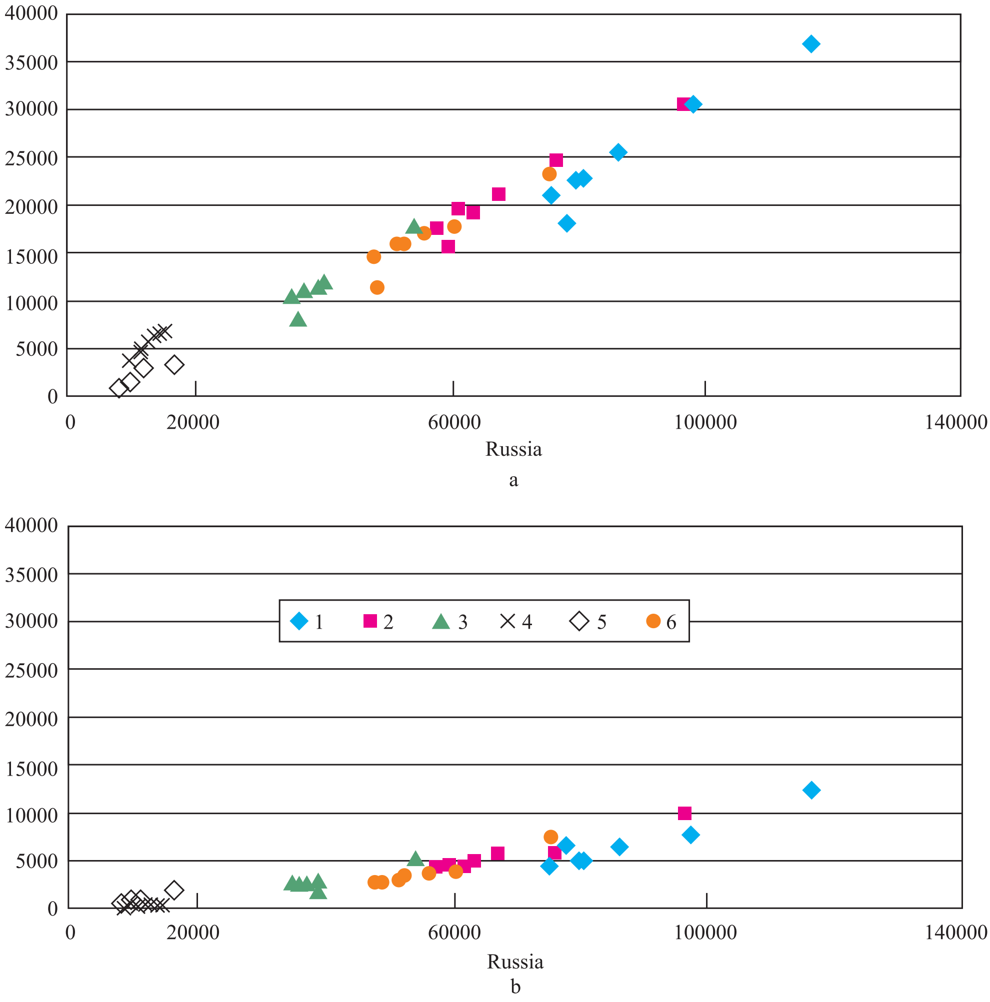

Fig. 2. Water consumption indices in Russia as related to those in the Volga (a) and Don (b) river basins (in mln m^3/yr) in 1990, 1995, 2000, and 2005. 1 – the total water volume abstracted; 2 – the total water volume used; 3 – the water volume used to meet production needs; 4 – the water volume used for domestic water supply; 5 – the water volume used for irrigation; and 6 – the total sewage volume discharged.

Possible improvement in the water use technology provides the opportunity to plan for a 1.2–5 times reduction in delivery waste [Water Resources of Russia..., 2008; Demin, 2005; Laskorin et al, 1981]. There is a 10 % per capita decline expected in domestic water use according to the scenario of the average specific water consumption changes, 20 % – according to the maximum changes, and 5 % – according to the minimum changes. Industrial water use in the Volga and Don basins is projected to decline by 1.7 times according to the scenario of maximum specific water consumption changes; in the medium and minimum scenarios, it is 1.5 and 1.2 times, respectively, which is slightly lower than the average reduction for Russia as a whole, taking into account possible water-intensive industry distribution in the areas rich in water resources. In agriculture, the consumption of water for irrigation will decrease by 1.1–1.5 times. This reduction is less than the average for Russia currently where, for example, in the Volga and Don basins, sprinkling irrigation is used for large areas as a more economical form as opposed to contour ditch irrigation, prevailing in regions like Northern Caucasus.

HYDROCLIMATIC CHANGES IN THE FIRST THREE DECADES OF THE XXIST CENTURY

Specific features of air temperature and atmospheric precipitation changes

In the first three decades of the XXI century, the mean annual air temperature in the Volga and Don river basins is expected to rise by 1.4–2.1 °C and 1.3–2 °C, respectively. Air temperature changes according to CMIP 5 scenario are slightly more notable (by 0.1–0.2). According to the scenarios, the mean annual atmospheric precipitation will increase in the Volga basin by 32–46 mm (the A2 and RCP 8.5 scenarios) and by 24–42 mm (the B1 and RCP 2.6 scenarios) and in the Don basin by 10–31 and 13–26 mm, respectively, which is within the limits of 5–8 % for the Volga and 2–5 % for the Don as it relates to its recent values. Intra-annual distributions of air temperature and atmospheric precipitation scenario changes in the Don basin were quite similar for each scenario; however, the figures for the Volga basin were substantially different.

Main trends for river runoff changes

Relatively close scenario changes of air temperature and atmospheric precipitation in the first third of the XXI century may result in varying character of hydrological consequences in the Volga and Don basins. Annual runoff in the Don basin may be expected to have small changes under the conditions of all considered scenarios. Whereas the Volga runoff most possibly would increase in A2, RCP8.5, and RCP2.6 climatic conditions scenarios by approximately 10 %, but in the B1 scenario changes may be less notable (Fig. 3).

The response of the intra-annual runoff structure to scenario climate changes is also quite different for the Volga and Don basins. A flattening-out of the flood wave can be expected for the Don River, while on the Volga River, on the contrary, in the month of the highest runoff during flood there may be a runoff increase, whereas the runoff of the next month can decrease. The winter runoff

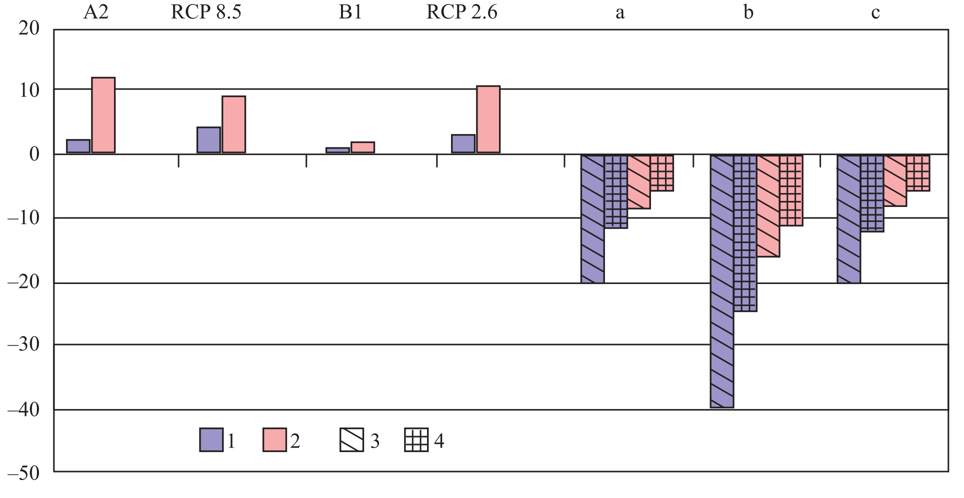

Fig. 3. Observed and expected in future (2025–2030) water abstraction in the Don (1) and Volga (2) river basins, and the projected change in their mean annual river runoff in the third three decades of the XXI century with contrasting scenarios of global climate warming A2/RCP8.5 and B1/RCP2.6 (as a percentage of the mean annual runoff).

__a__ – the existing situation; __b__ – the most favorable scenario of economic development and the current specific water consumption; __c__ – moderate rates of economic development and reduced specific water consumption; 3 – total water withdrawal; 4 – consumptive water use.

can increase both on the Volga and on the Don; however, the summer-autumn runoff on the Volga may be lower than the recent runoff; and on the Don it may be higher.

PROJECTED CHANGES IN THE CHARACTERISTICS OF WATER MANAGEMENT SYSTEMS

The long-term forecast for anthropogenic changes in the Volga and Don runoff has been significantly refined compared to the previous one [Georgiadi at al., 2014a, 2014b]. This is due to a number of circumstances that have arisen in the last few years. Among them, the economic crisis, intensive water resources management restructuring associated with the wet industries replacement, and water saving measures. As a result the previously presented indices of economic development and water protection measures are adjusted to fit the almost double-term reduction forecast, and attributed to the modern period (2010–2013).

Refined results of the calculations have shown that keeping the existing specific water consumption rates in the Volga and, in particularly, the Don basins is unacceptable since under any scenario, this imposes an excessive load on the water elements of the environment, mainly on the river runoff.

With the most favorable scenario of economic development and the current specific water consumption, water abstraction, compared to the existing situation, can increase twice on average and reach 17 % of the mean annual runoff in the Volga basin and almost 40 % in the Don basin, which is unacceptable in respect to water economy and ecology. However, a close to the current level water abstraction can be maintained with specific water consumption reduced by a factor of 1.2–1.3 and moderate rates of economic development (Fig. 3).

Reduction in specific water consumption based on the known technological solutions, primarily those intended to avoid non-productive water losses, would result in a substantial decrease in major water consumption indices. Moreover, under one of the scenarios of economic development and the greatest level of introduction of new technology, a decrease in the anthropogenic load on water resources can be achieved to be lower than or approximately equal to the current levels, with a significantly higher standard of living attained.

CONCLUSION

The proposed ensemble approach to the long-term forecast scenario of runoff changes in large river basins, related to the socio-economic transformation and global climate warming, allows for the estimation of a range of runoff changes in the Volga and Don basins that can be expected in the first three decades of the XXI century.

Under the most favorable scenario of economic development and the current specific water consumption, water abstraction can increase by as much as three times compared to the current situation and reach a critical level, which would have an adverse effect on the water management system and the environment. However, the current water abstraction levels can be maintained with specific water consumption reduced by a factor of 1.5 and with moderate rates of economic development. Under global climate warming scenarios, the mean annual Volga river runoff can increase, which, to a certain extent, offsets the negative impacts of water abstraction growth. However, this compensation to the negative impacts would not occur in the Don river basin, where negative effects are expected to take toll on the regional environment.

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