FORECAST CHANGES IN RUNOFF FOR THE NEMAN RIVER BASIN

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INTRODUCTION

The main hydrological parameters of the river runoff are not stable. These parameters change constantly under the influence of the complex variety of factors. The combination of these factors can be divided into climatic and anthropogenic those differ by the nature and consequences of impact on water resources (Water Resources, 2012).

Natural causes determine spatial-temporal variations of water resources under the influence of the annual and secular climatic conditions. Intra-annual fluctuations occur constantly and consistently. Secular variations occur slowly and cover quite extensive areas. These variations are typically quasi-periodic and tend to some constant value. Studies show that in historical time these deviations were not progressive. Periods of cooling and warming, dry and wet alternating in time and the general condition of water resources and their quality does not change significantly. The main feature of the natural reasons is that the changes have not unilateral tendencies (The Blue Book, 1994).

Anthropogenic causes are the result of various human activities. They affect water resources and water quality relatively quickly and unilaterally, and this is their main difference from natural causes. The economic activities causing changes in quantitative and qualitative parameters of water resources are diverse and depend on the physiographic conditions of the territory, the characteristics of its water regime and the nature of the use (Water Resources, 2012).

The climate change and the increasing of anthropogenous effect on the river runoff during the last 20-30 years are observed. Hydrological regime for the Neman River basin is determined by the natural fluctuations of meteorological elements and anthropogenic factors. In this case the role of the anthropogenic factors increases every year despite the economic downturn, and inadequate attention to these factors may lead to significant errors in the determination of estimated parameters (Ikonnikov et al., 2003; Volchak, Kirvel, 2013).

The aim of our research is the forecasting changes in river runoff for the Neman River basin using two scenarios of economic development and climate change (A1B and B1).

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DATA SOURCES

The Neman River basin is shown in Figure 1 (Korneev et al., 2014).

Figure 1. The Neman River basin

The data sources are based on the materials for the 24 hydrological stations at the Neman River in Belarus and Lithuania since 1961 till 2009 (Table 1).

Table 1 – Hydrological stations

River	Station	Coordinates		Basin area, km^2
		Longitude	Latitude	
Neman	Stolbtsy	26° 42' 56" E	53° 28' 43" N	3070
Neman	Mosty	24° 32' 10" E	53° 24' 11" N	25600
Neman	Grodno	23° 48' 23" E	53° 40' 43" N	33600
Isloch	Borovikovshina	26° 44' 16" E	53° 57' 26" N	624
Gavya	Lubiniata	25° 38' 40" E	53° 59' 26" N	920
Schara	Slonim	25° 19' 37" E	53° 04' 56" N	4860
Svisloch	Sukhaya Dolina	24° 01' 33" E	53° 28' 04" N	1720
Vilija	Steshytsy	27° 23' 39" E	54° 33' 50" N	1200
Vilija	Mikhalishki	26° 09' 59" E	54° 48' 50" N	10300
Naroch	Naroch	26° 43' 33" E	54° 33' 24" N	1480

Oshmyanka	Bolshiye Yatsiny	26° 12' 57" E	54° 44' 27" N	1480
Dubysa	Lyduvenai	23° 5' 14.1" E	55° 30' 23.1" N	1134
Jūra	Taurage	22° 16' 45.0" E	55° 15' 4.0" N	1664
Merkys	Puvociai	24° 18' 12.0" E	54° 7' 4.3" N	4300
Šešupė	K. Naujamestis	22° 51' 49.2" E	54° 46' 37.5" N	3179
Minija	Kartena	21° 28' 48.2" E	55° 54' 59.2" N	1230
Šventoji	Anykščiai	25° 5' 52.7" E	55° 31' 29.9" N	3600
Šventoji	Ukmerge	24° 46' 8.0" E	55° 14' 48.0" N	5440
Žeimena	Pabrade	25° 46' 21.0" E	54° 59' 1.7" N	2580
Nemunas	Druskininkai	23° 58' 48.7" E	54° 1' 9.4" N	37100
Nemunas	Nemajūnai	24° 4' 26.3" E	54° 33' 14.8" N	42800
Nemunas	Smalininkai	22° 35' 15.6" E	55° 4' 22.3" N	81200
Neris	Vilnius	25° 16' 36.5" E	54° 41' 31.1" N	15200
Neris	Jonava	24° 16' 54.9" E	55° 4' 10.2" N	24600

The climatic information consisted of the air temperature, precipitation and deficits of air humidity since 1961 till 2010 for 23 meteorological stations were used (Table 2).

Table 2 – Meteorological stations

Station	Coordinates		
	Latitude	Longitude	Altitude, m
Baranovichi	53° 07' 54"	25° 58' 16"	193
Grodno	53° 36' 13"	24° 02' 39"	148
Volkovyssk	53° 08' 05"	24° 27' 34"	193
Lida	53° 54' 25"	25° 19' 24"	157
Novogrudok	53° 35' 48"	25° 51' 04"	280
Vileika	54° 30' 25"	26° 59' 23"	165
Volozhin	54° 05' 42"	26° 30' 56"	228
Naroch	54° 53' 52"	26° 40' 56"	171
Kaunas	54°53'	23°50'	76
Kybartai	54°38'	22°47'	58
Laukuva	55°37'	22°14'	165
Lazdijai	54°14'	23°31'	133
Panevėžys	55°45'	24°23'	57
Raseiniai	55°23'	23°07'	111
Šilutė	55°21'	21°28'	4
Ukmergė	55°15'	24°46'	72
Utena	55°32'	25°36'	105
Varėna	54°15'	24°33'	109
Vilnius	54°38'	25°06'	162
Biržai	56°12'	24°46'	60
Klaipėda	55°44'	21°04'	6
Šiauliai	55°56'	23°19'	106
Telšiai	55°58'	22°15'	153

RESEARCH METHODS

For the research purposes Mezentsev's method of the hydrological-climatic calculations was adapted. The method is based on joint solution of the equations for water and thermal balances (Mezentsev, 1995). During the research we devised a multi-factor model that includes the standard equation of water balance. The developed model is used to assess the possible changes in runoff according to the various hypotheses of climate fluctuations and anthropogenic impacts on water resources.

The equation of water balance is following:

$$H(I) = E(I) + Y_K(I) \pm \Delta W(I), \tag{1}$$

where $H(I)$ – total humidity, mm; $E(I)$ – total evaporation, mm; $Y_K(I)$ – total calculated runoff, mm; $\Delta W(I)$ – changes of humidity reserves of the active soil layer, mm; I – interval of averaging.

The total evaporation is given by:

$$E(I) = E_m(I)\left[1 + \left(\frac{\dfrac{E_m(I)}{W_{HB}} + V(I)^{1-r(I)}}{\dfrac{KX(I)+g(I)}{W_{HB}} + V(I)}\right)^{n(I)}\right]^{-\frac{1}{n(I)}}, \tag{2}$$

where $E_m(I)$ – maximum total evaporation, mm; W_{HB} – minimum humidity ratio of the soil, mm; $V(I) = W(I)/W_{HB}$ – relative index of the humidity of soils at the beginning of calculating; $KX(I)$ – sum of precipitation, mm; $g(I)$ – soil-water balance component, mm; $r(I)$ – parameter depending on water-physical properties and mechanical composition of soils; $n(I)$ – parameter depending on physical-geographical conditions of runoff.

Relative index of the soil humidity at the end of calculation period is determined from the following relations

$$V(I+1) = V(I) \cdot \left(\frac{V_{av}(I)}{V(I)}\right)^{r(I)}; \tag{3}$$

$$V_{av}(I) = \left(\frac{\dfrac{KX(I)+g(I)}{W_{HB}} + V(I)}{\dfrac{E_m(I)}{W_{HB}} + V(I)^{1-r(I)}}\right)^{\frac{1}{r(I)}}. \tag{4}$$

The values $V_{av}(I)$ are compared with the relative index of the total humidity V_{TH}. If $V_{av}(I) \le V_{TH}$ then must be taken the calculated value of the relative average humidity, otherwise, when $V_{av}(I) \ge V_{TH}$ then taken $V_{av}(I) = V_{TH}$ and the value $(V_{av}(I) - V_{TH}) \cdot W_{HB}$ refers to surface runoff.

The maximum total evaporation is according to the method described in (Volchak, 1986).

The thermal resources of the evaporation process for any calculation period are defined as:

$$LE_{mi} = R_i^+ + P_i^+ \pm \Delta B_i - \Delta E_{0i}, \tag{5}$$

where E_{mi} – the equivalent of the thermal resources by the maximum possible evaporation, m;

L – the latent warmth of evaporation, j/m^3; R_i^+ – the positive component of the radiation balance, j/m^2; P_i^+ – the positive component of turbulent warmth transfer, j/m^2; ΔB_i – changes of the warmth stocks of the active layer of soil, j/m^2; ΔE_{0i} – warmth consumption for melting of snow, ice, the warming of the soil, j/m^2.

Due to the limitations of the initial data for the radiation regime and turbulent warmth transfer it is difficult to use the equation (5) in practical calculations. Studies have shown that the optimal distance between actinometric stations should be no more than 100 km. In the existing network of actinometric stations this condition is not satisfied. Therefore, one needs to find the connection elements of the radiation balance with the climatic parameters.

Currently there are a lot of dependencies to determine the annual standards of E_0 in the case of Belarus by the sum of temperatures above 10°C. We have found the approximate solution of equation (5) for the monthly time intervals (Volchak, 1986). Based on the modal analysis of the available initial data from the actinometrical stations the quantitative relation of the monthly values of the positive component of the radiation balance with the air humidity deficit was calculated. It is noteworthy that for all geographical areas the type of relation is constant in general. The reasons for nonlinearity and hysteresis in this context is that the positive component of the radiation balance is one of the components of equation (5), which has warmth expenditure on evaporation, turbulent warmth exchange with the atmosphere and change the warmth content of the soil. The deficit of air humidity only characterizes the intensity of turbulent exchange with the atmosphere. In accordance with the sign of warmth transfer in soils and the intensity of warmth spent for evaporation changes of air humidity deficit in the first half of the year occurs on the convex curve and in the second – on the line. The effect of hysteresis increases with the continentality increasing, i.e. for the Neman River basin it means moving from North to South and from West to East.

The dependences are corrected according to the available initial data for the conditions of the Neman River basin. An analytical approximation of the ascending and descending branches of the hysteresis was found.

The ascending branch for the period of growth of the air humidity deficits is as following

$$R_{Mi}^+ = 2.26 + 6.77 \cdot lg\, d_{Mi} \quad if \;\; d_{Mi} \le d_{Mi+1}. \tag{6}$$

The descending branch for period of decreasing of the air humidity deficits is as following

$$R_{Mi}^+ = 1.06 d_{Mi} \quad if \;\; d_{Mi} > d_{Mi+1}, \tag{7}$$

where d_{Mi} – the mean monthly values of the air humidity deficits, millibar.

Equations (6) and (7) are characterized by the correlation coefficients respectively r=0.965±0.006; r=0.945±0.010 and values of the Fisher test respectively F=14.31; F=9.45, which are much more acceptable at the 1% level of significance $F^T_{(107,106,1\%)} = 1.643$. Therefore, the obtained equations are statistically significant.

Without taking into account the phenomenon of hysteresis the averaged equation is:

$$R_{Mi}^+ = 1.79 + 6.59 \cdot lg\, d_{Mi}\ , \tag{8}$$

$$r{=}0.937 \pm 0.007;\ F{=}8.29 > F^T_{(215,214,1\%)} = 1.533$$

The annual value of adventive warmth is determined by the ratio (Mezentsev, Karnatsevich, 1969):

$$P_\Gamma^+ = 6.8 - 0.082 \cdot R_\Gamma, \tag{9}$$

where R_Γ – concentrated radiation balance, kcal/cm^2.

The positive radiation balance R^+ for the territory of Eastern Europe can be fairly accurately calculated using the dependence:

$$R_{\text{Г}}^{+} = 1.17 \cdot R_{\text{Г}} + 2.10, \ (r = 0.995 \pm 0.002) \qquad (10)$$

For the months a similar dependence is offered:

$$R_{Mi}^{+} = 1.0 \cdot R_{M} + 0.77, \qquad (11)$$

$$(r = 0.985 \pm 0.002;\ F = 45.67 > F^{T}_{(215,214,1\%)} = 1.533).$$

Taking into account formula (10) the equation (9) takes the form:

$$P_{\text{Г}}^{+} = 6.65 - 0.07 \cdot R_{\text{Г}}^{+}\ . \qquad (12)$$

The annual distribution of the positive component of turbulent warmth transfer (P) is as following (Belonenko, Valuev, 1974):

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
12	12	9	7	6.5	5.5	6.5	6.5	6.5	7.5	10	11	100%

The changes of the warmth stocks of the active layer of soil *ΔB* is significantly less than the values of radiation balance. For this calculation there are not always available data, so the calculation is made approximately using the data tables of the annual warmth exchange in the soil depending on annual amplitudes of air temperature and warmth transfer in the soil (Budyko, 1971).

The winter climate in Belarus has a substantial impact of the Atlantic Ocean, causing frequent and prolonged thaws throughout the winter. In this regard, the correction to the melting of snow and frozen ground were distributed for the colder months and is equally determined by following equation (Marchuk, 1982):

$$\Delta E_m = \frac{L_1}{L} \cdot \left(1.4 \cdot W_{\text{СН}} + W_{\text{ГР}}\right), \qquad (13)$$

where $W_{\text{СН}}$, $W_{\text{ГР}}$ – the water reserves in snow and frozen soil layer; *L* – latent warmth of melting water.

The parameter *n* was determined using the value of the maximum total evaporation under optimal moistening of the active layer of soil. Expressing the conditions of runoff formation using the average slope of the basin area and the coefficient of roughness, which in turn depends on the hydraulic radius or average depth of runoff, one can determine the parameter *n* (Mezentsev, 1982).

The parameter *n* adopted differentiated both within the territory and years, and varied in the range of 2.5 to 3.4. Analysis of data on runoff, precipitation and maximum total evaporation for the Neman River basin have shown the correctness of chosen parameter *n*.

The total humidity is defined as follows:

$$H(I) = KX(I) + W_{HB}(V(I) - V(I+1))\,. \qquad (14)$$

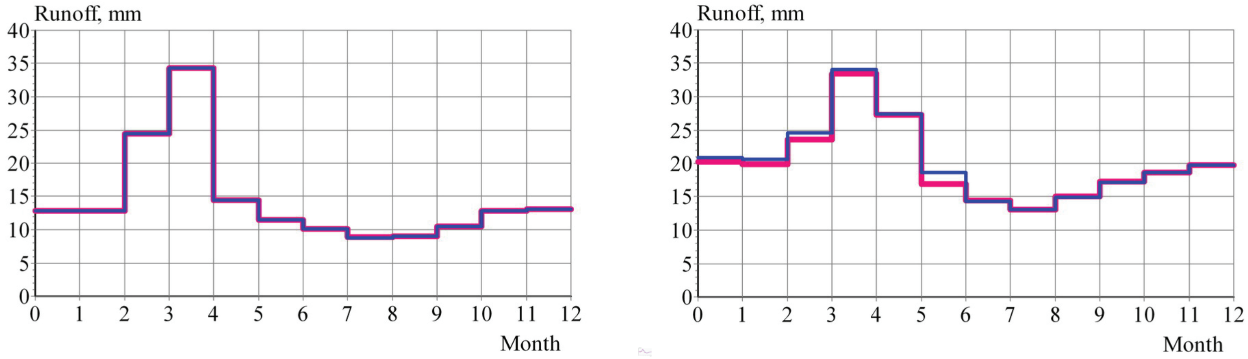
The solution of the equations system (1) – (4) is carried out iteratively. During calculating the initial value of the humidity is taken equal to the value of the minimum humidity ratio of the soil, i.e. $W(1) = W_{HB}$, where $V(1) = 1$. The convergence of the solution method is achieved for the fourth step of the calculation.

Adjustment of the calculated runoff is carried out using coefficients that take into account the influence of various factors on the formation of the measured runoff, i.e.

$$Y_P(I) = k(I) \cdot Y_K(I)\,, \tag{15}$$

where $Y_P(I)$ – total measured runoff, mm; $k(I)$ – coefficient taking into account the hydrographic parameters of the basin.

Modeling the water balance of the river is realized in a computer program and is performed in two stages. The first step is to configure the model for known components of water and thermal balances of the studied river. The first stage ends with plotting the calculated and measured runoff figures and outputting the modeling error. The example of modeling average annual runoff and its intra-annual distribution is shown in Figure 2.



a b

── measured runoff, ▬ calculated runoff

Figure 2 – Measured and calculated runoff (a – for the Neman River at the Stolbtsy Station; b – for the Žeimena River at the Pabrade Station)

The measured and calculated runoffs are very close; therefore the model is correct. The obtained model parameters were used for the numerical experiment.

The second stage is a direct modeling the water balance of the river using the parameters obtained during model calibration. The calculation of the water balance is tailored to the specific characteristics of the studied river. The simulation results indicate high accuracy of the calculation of the water balance for both practical applications and theoretical studies that tested for a lot of rivers in Belarus with basin area of about 1000 km^2 (Volchak, Parfamuk, 2007).

Thus, the developed computer program with available data on precipitation, air temperature, air humidity deficits and modern values of the water runoff, as well as hydrographic parameters of the basin provides forecast values of the water balance of rivers.

The technique of simulation has been tested on almost all climatic parameters that gave the opportunity to attract additional large amount of hydrometeorological information that are included in the balance equations.

When setting up models by the proposed method have problems with the definition of parameters for the winter months. The fact that the model did not accurately included the thaw for the recent years. Therefore, we conducted an adjustment model taking into account the thaw. The obtained difference between measured and calculated runoff treated runoff formed during thaws, which were recorded in the settings of the model. When forecasting runoff this component was added directly to the runoff and its value was subtracted from precipitation. The values of runoff during thaws were adjusted for the predicted temperature of the corresponding month. In the first approximation the value of runoff can be taken from the ratio of monthly air temperatures and runoff during the period of thaw.

Forecasting changes of river runoff for the Neman River basin was carried out by the following scheme. The model was adjusted for average long-term data on river runoff, atmosphere precipitation, air temperature and deficits of air humidity, obtained parameters remained in computer. Then entered forecast value for those weather stations that were used in the setting model. The last stage was reading the settings of the model and carrying out the runoff forecast.

DISCUSSION OF THE RESULTS

Runoff forecasts for 24 rivers in the Neman River basin for two scenarios of A1B and B1 climate change were done in two options. The first option is forecasting without considering the thaw and the second option with regard to thaw. The results consist of the model configuration as well as modern and forecast calculated values of the river runoff. Based on the analysis of the obtained forecasts the changes in river runoff for the Neman River basin preference should be given to the second option.

In tables 3 and 4 shows the forecasted values of runoff changes for the two scenarios of climate change in percent to the modern level.

Table 3 – Forecast changes in runoff for the A1B scenario in 2035, % to 2009

River	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Neman	Stolbtsy	117.1	119.2	111.8	112.5	130.6	197.4	61.4	67.6	130.0	89.4	102.3	114.5	114.3
Neman	Mosty	118.8	124.8	126.2	111.8	153.6	178.3	98.2	99.1	102.5	66.2	110.9	116.5	119.0
Neman	Grodno	123.3	124.6	102.9	129.0	173.0	134.4	95.3	100.6	105.9	84.6	109.3	123.6	120.3
Isloch	Borovikovshina	123.5	123.1	113.5	114.5	145.1	207.6	82.0	90.6	102.3	90.8	103.9	118.9	118.1
Gavya	Lubiniata	123.5	120.5	101.1	121.1	186.9	173.3	96.3	81.1	102.4	83.8	118.4	123.9	119.8
Schara	Slonim	115.9	116.5	115.1	115.9	160.0	178.3	85.8	77.2	143.7	93.9	106.7	114.8	120.8
Svisloch	Sukhaya Dolina	118.8	127.1	94.3	121.6	177.3	115.7	79.4	97.0	104.3	81.9	108.5	121.9	113.0
Vilija	Steshytsy	119.9	116.9	116.5	109.2	137.5	143.2	82.0	72.3	71.7	94.2	98.7	114.7	108.6
Vilija	Mikhalishki	119.1	111.9	99.0	112.9	176.0	109.8	109.2	67.0	69.8	100.0	105.0	114.9	110.3
Naroch	Naroch	118.5	113.0	107.8	108.4	140.4	146.2	151.7	95.2	72.8	95.7	98.8	114.6	113.8
Oshmyanka	Bolshiye Yatsiny	121.3	119.5	116.4	118.6	133.9	228.3	78.8	88.1	102.2	91.0	103.4	117.7	118.9
Dubysa	Lyduvenai	128.6	125.3	109.2	130.9	48.6	93.3	150.9	66.8	128.1	116.2	116.9	124.9	115.7
Jūra	Taurage	134.0	126.7	143.5	107.7	276.2	159.2	168.3	133.8	128.6	118.7	114.8	130.1	133.9
Merkys	Puvociai	131.0	127.6	107.3	127.7	152.3	74.5	100.0	94.6	104.5	93.0	113.7	128.5	112.8
Šešupė	K. Naujamestis	129.9	134.6	116.0	129.0	201.7	106.5	108.8	228.0	147.0	104.4	111.3	125.0	132.3
Minija	Kartena	152.6	132.9	98.9	129.8	81.8	74.8	140.7	144.1	142.3	133.4	119.0	151.2	126.4
Šventoji	Anykščiai	129.9	123.7	106.8	114.0	198.0	119.1	170.1	119.0	131.5	114.8	112.3	126.2	127.8
Šventoji	Ukmerge	144.3	132.2	103.3	122.7	53.9	61.5	79.9	132.1	112.6	128.2	118.2	127.9	107.4
Žeimena	Pabrade	133.2	124.6	95.9	134.3	188.9	147.3	138.9	44.4	106.0	86.6	114.4	127.3	124.8
Nemunas	Druskininkai	118.9	123.9	112.2	114.0	135.2	99.2	70.1	106.9	107.9	82.9	109.6	118.9	111.1
Nemunas	Nemajūnai	117.4	118.1	144.6	115.4	142.4	160.0	113.0	126.2	117.5	86.0	110.3	119.2	123.8
Nemunas	Smalininkai	128.8	131.4	105.5	130.7	164.2	132.5	106.3	119.2	112.4	82.6	111.2	125.7	122.6
Neris	Vilnius	136.6	132.2	107.7	138.6	138.5	60.9	102.4	104.9	101.5	91.1	114.0	129.3	114.4
Neris	Jonava	128.7	126.8	155.1	117.9	154.4	161.9	135.0	142.2	122.9	92.0	111.0	123.6	131.4

Table 4 – Forecast changes in runoff for the B1 scenario in 2035, % to 2009

River	Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Neman	Stolbtsy	106.2	111.5	112.2	90.7	110.4	187.8	25.5	64.5	133.3	109.5	110.2	114.5	105.7
Neman	Mosty	105.3	113.1	112.1	100.0	142.9	172.9	65.9	82.5	144.7	94.0	105.8	116.5	112.8

Neman	Grodno	102.3	114.9	101.9	111.4	138.0	134.4	77.5	78.2	157.8	104.4	103.1	121.1	112.8
Isloch	Borovikovshina	113.6	116.3	116.7	90.8	126.8	195.9	106.0	92.9	120.0	103.5	108.4	125.2	115.3
Gavya	Lubiniata	100.0	110.0	111.7	91.4	151.9	153.3	128.1	38.7	136.0	109.4	115.7	122.8	113.8
Schara	Slonim	101.8	107.8	108.6	97.1	134.4	172.6	61.2	76.3	153.3	113.5	115.0	113.0	112.3
Svisloch	Sukhaya Dolina	93.2	113.9	100.0	102.2	142.2	114.7	58.8	84.6	161.1	105.4	102.3	118.2	107.4
Vilija	Steshytsy	102.0	105.4	111.2	87.5	107.6	147.7	110.1	107.3	104.0	110.8	98.7	118.6	107.1
Vilija	Mikhalishki	98.5	100.0	102.9	90.6	137.7	128.8	139.5	90.4	106.1	118.1	104.3	117.9	109.2
Naroch	Naroch	101.3	103.9	119.8	84.4	107.9	151.7	85.1	84.2	100.9	111.6	98.8	119.5	105.2
Oshmyanka	Bolshiye Yatsiny	114.0	112.8	107.1	92.9	124.7	208.3	110.9	103.0	122.6	102.6	108.0	124.6	117.0
Dubysa	Lyduvenai	116.1	113.4	106.7	110.5	58.8	111.3	79.6	68.9	169.4	143.1	114.6	128.4	111.6
Jūra	Taurage	112.1	112.4	118.6	98.9	181.1	197.1	114.6	89.2	144.4	132.8	110.7	129.7	120.7
Merkys	Puvociai	103.8	117.8	109.7	109.1	128.6	56.4	77.8	98.6	144.2	111.0	108.2	125.8	106.6
Šešupė	K. Naujamestis	111.5	117.6	107.3	113.4	181.5	153.5	80.4	144.9	127.8	114.5	94.8	125.7	119.9
Minija	Kartena	105.0	113.9	103.5	100.5	67.3	77.9	84.7	107.9	134.5	169.2	116.2	142.0	114.5
Šventoji	Anykščiai	113.7	110.0	113.6	100.2	146.5	128.2	110.0	102.8	134.3	133.8	106.4	126.2	116.6
Šventoji	Ukmerge	119.8	118.8	104.7	108.1	66.4	78.8	61.3	101.3	74.0	156.5	122.0	129.1	101.9
Žeimena	Pabrade	102.4	114.3	99.6	108.7	169.3	149.5	133.3	61.8	120.0	120.3	108.6	124.2	119.4
Nemunas	Druskininkai	100.0	112.3	114.6	95.0	110.9	92.7	52.5	95.2	139.7	105.5	110.4	118.0	102.3
Nemunas	Nemajūnai	100.7	110.4	115.5	102.0	119.2	157.7	140.0	140.8	166.0	107.4	108.1	118.5	119.9
Nemunas	Smalininkai	103.9	117.0	103.0	112.9	140.3	158.7	79.5	81.5	141.9	105.8	100.0	125.0	114.2
Neris	Vilnius	108.5	119.1	114.0	111.6	110.9	47.6	83.5	99.2	122.1	119.2	107.0	127.3	105.0
Neris	Jonava	111.4	116.5	127.5	106.3	135.8	173.1	116.2	99.1	124.6	115.2	111.0	126.1	121.6

CONCLUSION

As a result of research we developed a mathematical model to forecast runoff for the Neman River basin. Modeling of runoff changes for the two scenarios of climate change A1B and B1 taking into account the thaw was carried out. The results for the A1B scenario indicate the increasing of runoff from 7.4% for the Šventoji River to 33.9% for the Jūra River. Scenario B1 has shown a minor change in runoff from 1.9% for the Šventoji River up to 21.6 % for the Neris River.

Development of compensation measures to reduce impacts from increased runoff of the Neman River is the subject of further research.

REFERENCES

1. Belonenko G., Valuev V. (1974). The annual distribution of warmth and power resources and the maximum total evaporation. Hydraulic engineering and land reclamation in Western Siberia. – Omsk. – T. 118. – pp. 58-64.
2. Budyko M. (1971). Climate and life. – Leningrad. – 472 p.
3. Ikonnikov V.F, Lishtvan I.I., Loginov V.F. (2003). Use of Nature: Collection of Scientific Works. Minsk – Is.9.-p.25-33.
4. Korneev V., Volchak A., Gertman L., Bulak I. (2014). Forecasting river runoff in the Western Dvina and the Western Bug River basins in the current climatic changes. Natural resources. – No. 2. – pp. 72-85.
5. Loginov V.F. (2007). Spectral-time Analysis of the Level Mode of the Lakes and Fluctuations of Consumption of Large Rivers in Belarus, Minsk-480 p.
6. Marchuk V. (1982). Calculations of warmth power resources of process warmth and wet

interface conditions in the wetlands (by the example of Belarus). Hydrology and hydraulic engineering of land reclamation. – Omsk. – pp. 74-76.

7. Mezentsev V., Karnatsevich I. (1969). Hydration of the West Siberian plain. – Leningrad. – 168 p.

8. Mezentsev V. (1982). Hydrological calculations for melioration. – Omsk. – 84 p.

9. Mezentsev V. (1995). Hydrological-climatic hypothesis and examples. – Water resources. – Vol. 22, No. 3. – pp. 299-301.

10. The Blue Book of Belarus: Encyclopaedia. (1994). Belarus, Minsk – 415 p.

11. Volchak A. (1986). Method of determining the maximum possible evaporation for mass meteogram (by example of Belarus). – Scientific and technical information on reclamation and water management. – No. 12. – pp. 17-21.

12. Volchak A., Parfamuk S. (2007). Assessment of the transformation of the water regime of small rivers of the Belarusian Polesie under the influence of natural and anthropogenic factors (for example, the Yaselda River). – Water sector of Russia: problems, technologies, management. – Ekaterinburg. – No. 1. – pp.50-62.

13. Volchak A., Kirvel I. (2013). Lake water level variations in Belarus. Limnological Review 13, 2. – p. 115-126.

14. Water Resources of the National Park «Narochansky»: Reference Book. (2012) – Minsk: RIFTUR PRINT, -128 p.