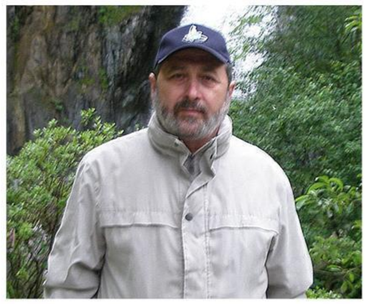
Long-term changes of runoff for the large rivers of Russian plain and Siberia



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The characteristics of long-term phases of multi-year changes for naturalized and observed annual and seasonal (snow flood, winter) for Volga (Volgograd), Don (Razdorskaya), Dnepr (Dneproges), Ob' (Salekhard), Enisey (Igarka) and Lena (Kyusyur) and for rivers of Russian plain additionally summer-autumn runoff for the period of instrumental observations are analyzed.

Key Words: climate changes, large rivers, river long-term phase, anthropogenic impact

METHODS

Curves of cumulative sum of normalized annual values of runoff are used for analysis of long-term phases of river runoff changes (Andreyanov, 1959; Kuzin, 1979). Their values are calculated by the following formula:

$$\tilde{N}s_i = \sum (K_i - 1)/C_v \qquad K_i = E_i / E_m$$

where *Csi* is the cumulative sum of the normalized values of the hydrological/climatic element; *Ki* is the modulus coefficient of the element *Wi*; *Cv* is the coefficient of variation, *Ei* is the value of the element for the i-year; *Em* is the mean value of the element.

Methods for river runoff naturalization. To study the long-term phase changes conditionally natural (naturalized) annual and seasonal runoff is used long-term series of these characteristics. The first part of the data sets includes long-term data for the period prior to the significant anthropogenic impact (primarily water reservoirs). The second part – consists of a multi-year data sets of naturalized runoff values, i.e., "purified" from the influence of anthropogenic factors.

The naturalization of the runoff is based on two methods. On the basis of rivers-indicators of climatic changes is naturalized annual and seasonal runoff (Georgiadi et al. 2014). This method is based on the regression relationships between the runoff of the main river and runoff of rivers-indicators (tributaries), with relatively little disruption of water regime.

Long-term series of average daily water consumption, recovered by the method of runoff hydrograph transformation (A.Shiklomanov et al. 2011), based on the Duamel influence function suggested by G.P. Kalinin and P.I. Milyukov (1958), were used as well.

LONG-TERM PHASES OF RIVER RUNOFF CHANGES

I - phase of runoff increase D - phase of runoff decrease		Duration of long-term phases (in years) Ro/Rn (MRI)/Rn (MNT)					
		Volga, Volgograd	Don, Razdorskaya	Dnieper, DneproGES	Ob', Salekhard	Enisey, Igarka	Lena, Kyusyur
Annual runoff	I	28/26/-	56/*/-	50/24/-	39/24/39	33/28/32	21/20/20
	D	48/48/-	53/31/-	68/30/-	39/33/39	31/43/29	49/49/49
Snow flood runoff	I	57/38/-	57/79/-	57/57/-	*	28/36/31	50/33/50
	D	59/60/-	57/35/-	51/38/-	*	43/35/32	22/28/20
Winter runoff	I	51/30/-	53/29/-	50/41/-	40/46/38	37/20/21	30/17/25
	D	66/47/-	63/87/-	70/79/-	40/32/40	34/45/43	46/51/46
Summer-Autumn runoff	I	30/30/-	54/29/-	43/32/-	-	-	-
	D	82/47/-	62/81/-	71/58/-	-	-	-

Table 1. Long-term phase change of conditionally natural annual and seasonal runoff

*It was not determined.

Ro-observed runoff, Rn (MRI)-naturalized runoff based on rivers-indicators method (Georgiadi et al, 2014), Rn (MNT)-naturalized runoff based on multi-year data series for daily water discharges naturalized by hydrograph transformation method (A. Shiklomanov et al, 2011)

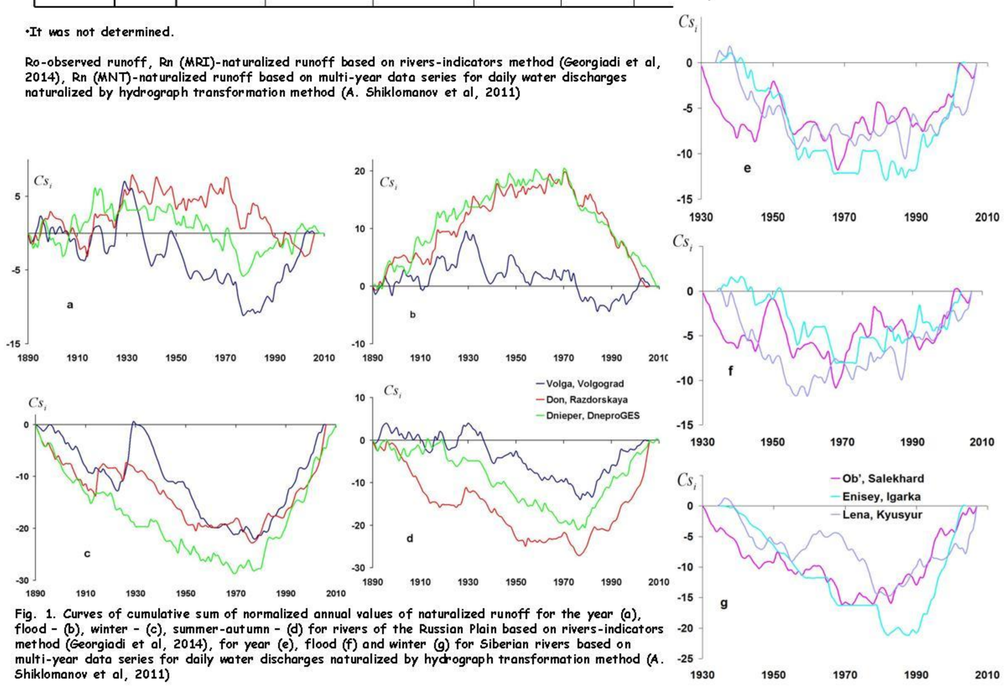
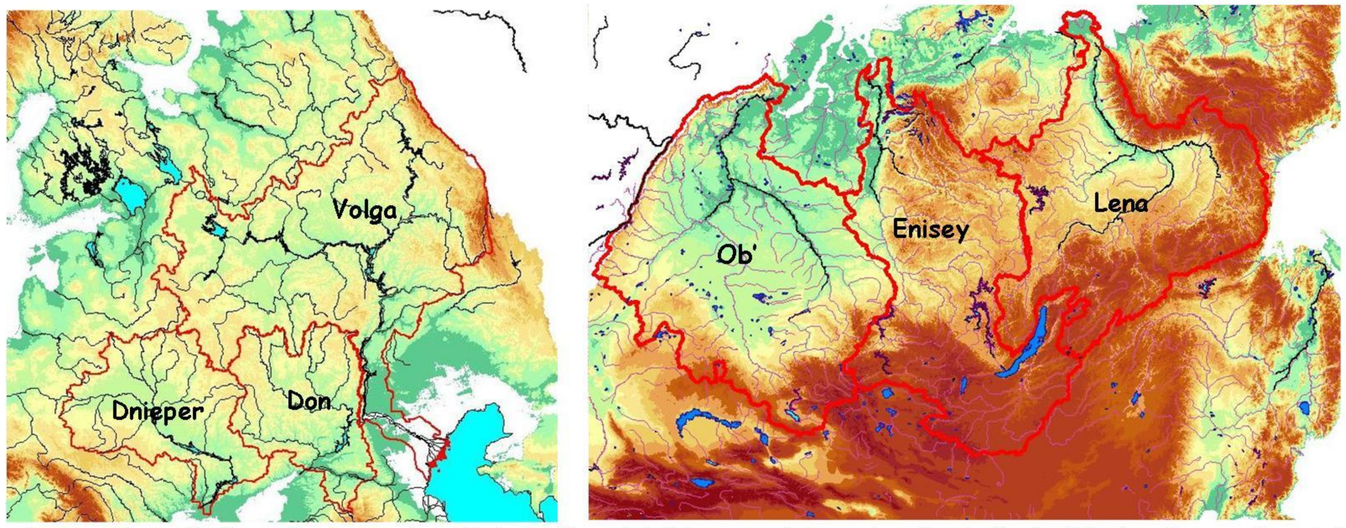


Fig. 1. Curves of cumulative sum of normalized annual values of naturalized runoff for the year (a), flood – (b), winter – (c), summer-autumn – (d) for rivers of the Russian Plain based on rivers-indicators method (Georgiadi et al, 2014), for year (e), flood (f) and winter (g) for Siberian rivers based on multi-year data series for daily water discharges naturalized by hydrograph transformation method (A. Shiklomanov et al, 2011)

Table 2. Mean runoff for the long-term phase of increasing and decreasing conditionally natural and anthropogenic-changed runoff

Long-term phase	Volga, Volgograd		Don, Razdorskaya		Dnieper, DneproGES		Ob', Salekhard			Enisey, Igarka			Lena, Kyusyur		
	Ro	Rn (MRI)	Ro	Rn (MRI)	Ro	Rn (MRI)	Ro	Rn (MRI)	Rn (MNT)	Ro	Rn (MRI)	Rn (MNT)	Ro	Rn (MRI)	Rn (MNT)
Annual runoff															
I	264	274	27	*	53	55	412	426	419	606	600	615	572	561	568
D	228	241	21	23	46	48	385	361	382	560	578	571	517	514	517
Snow flood runoff															
I	170	177	18	18	26	26	294	-	-	416	433	433	399	408	412
D	123	163	8	12	16	20	259	-	-	382	411	412	369	378	375
Winter runoff															
I	64	40	4	4	11	10	80	75	76	133	83	101	52	41	39
D	31	27	2	2	6	7	66	65	64	76	75	71	34	33	32
Summer-Autumn runoff															
I	66	59	10	9	19	17	-	-	-	-	-	-	-	-	-
D	52	49	6	6	13	13	-	-	-	-	-	-	-	-	-



Conditionally-natural (naturalized) annual and seasonal runoff. During the period of instrumental observations (for the Russian Plain rivers between the end of the XIX century and the beginning of the XXI century, and for the Siberian rivers – from 1930-1940 till the beginning of the XXI century) winter runoff (for all the considered rivers), summer – autumn runoff (for European rivers), flood and whole year runoff (for the Siberian rivers) are characterized by the two long-term phases. Decrease phase of the above runoff types starts in the beginning of the observation period, and begins to change in to increase runoff phase in 1970-1980 (which is close to the beginning of the recent global warming). This continues till the first decade of the 2000s.The flood runoff for Russian plain rivers are also characterized by two long-term phases. Only as the first phase was observed phase of runoff increase, changed by phase its decrease. Phases of changes for the Russian Plain rivers year runoff (including runoff of genetically heterogeneous hydrological seasons) are "noisy" short-period changes and so much less pronounced.

The duration of the long-term phases is a few decades, reaching nearly 90 years on the Dnieper.

The differences between mean multi-year averaged natural runoff for Volga and the Don and long-term phases of its increase and decrease, respectively, for annual runoff are more than 10 % for both rivers, runoff during floods – 10 and 50 %; for winter runoff – about 50 % and 100 %, and for summer-autumn – 25 and 50 % (Table 2).

Effects of anthropogenic impact. Anthropogenic impact shifted the boundary time of transition between winter runoff decrease and increase to the earlier years (Fig. 2). This is especially noticeable on the rivers of the Russian Plain (where phase change for summer-autumn runoff is also very significant), and on the Enisey (offset more than a decade). It is weakly manifested on the Lena and Ob' (3 year displacement). A strong human impact due to water reservoirs on the long-term phase changes showing up in asynchrony changes of conditionally natural and anthropogenic changed runoff are also observed and becomes noticeable in the flood runoff of the Russian plain rivers and Yenisei in the last few decades.

Anthropogenic factors significantly alter runoff differences between increase and decrease phases characteristic for conditionally natural runoff. (Table 2).

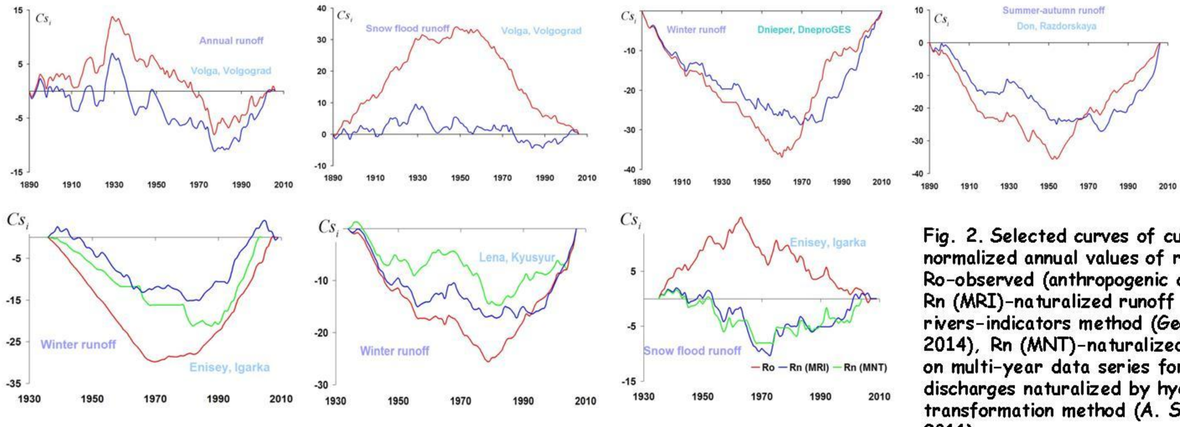


Fig. 2. Selected curves of cumulative sum of normalized annual values of runoff for Ro-observed (anthropogenic changed) runoff, Rn (MRI)-naturalized runoff based on rivers-indicators method (Georgiadi et al, 2014), Rn (MNT)-naturalized runoff based on multi-year data series for daily water discharges naturalized by hydrograph transformation method (A. Shiklomanov et al, 2011)

The presented results show that during the period of instrumental observations for conditionally natural (naturalized) annual and seasonal runoff long-term (few decades) phases of their decrease and increase are typical for rivers of the Russian Plain and Siberia. Runoff for these phases is characterized by significant differences, especially for the Russian Plain rivers, for winter, summer-autumn and flood runoff. Anthropogenic factors significantly change the long-term phase characteristics, especially winter runoff. They also transform the differences between runoff for phase of its decrease and increase characteristic for conditionally natural runoff.

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