Research report

2.Research

2.4 Modeling runoff series in light of CC

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Introduction

This report describes results of the research on runoff formation and evaluation in the Amudarya basin for 2016-2055 and the assessment of climate change impact on natural (non-regulated) river runoff. This work is a part of second stage of PEER Project research, Position 2.4 “Modeling runoff series in light of CC.”

The research was carried out according to the developed methodology (see PEER Project report, position 1.2 by A.G.Sorokin) and fitted the proposed scheme of scenarios on water formation and regulation in the Amudarya basin for 2016–2055. Task 1 in this scheme of scenarios is formulated as “Assessment of natural (non-regulated) water resources in the Amudarya basin”; it is proposed to study two cases for solution of this task. The first case (1.1) entails the assessment of runoff series constructed by method of historical cycle-series extrapolated to the future (SIC ICWC), with the assumption that there is no impact of climate change on river runoff. The second case (1.2) considers climate change based on the REMO-0406 scenario; an impact of climate change was taken into account through coefficients (adjustments) derived from the NIGMI’s data.

1. Constructing Amudarya basin runoff series for 2016-2055 for no climate change impact conditions

This Chapter describes the results of construction of Amudarya basin runoff series for 2015/2016 – 2054/2055. The runoff series were constructed by analyzing historical cycle-series and selecting an analog (1958/1959 – 1997/1998), which was extrapolated to the period after 2014/2015.
Chapter 3 of given report shows the results of correction of the selected runoff series in light of climate change. Such approach was applied for the first time in the scenarios played by the ASBmm set of models [www.asbmm.uz] and later adapted by the CAWa Project for the Syrdarya basin for the conditions of REMO 0406 climatic scenario; it is based on the concept of the cyclical nature of natural process variations. Such cyclical nature is viewed as progressive development on which climate-caused changes have an impact rather than as simple periodical repetition of observed phenomena.

Figure 1.1 shows the comparison of cycles of Amudarya River runoff (natural, non-regulated, no anthropogenic impact of water withdrawals and drainage discharge) for two periods of time: 1937/1938 – 1957/1958 and 1994/1995 – 2014/2015. It is clear that dynamics of annual river runoffs in these periods of time is comparable and close by cycles (n-year periods) of dry and wet years. With a certain probability, this allows expecting after the year 2014/2015 (its analog in historical series – the year 1957/1958) the series with characteristics similar to those of the period 1958/1959 – 1997/1998.

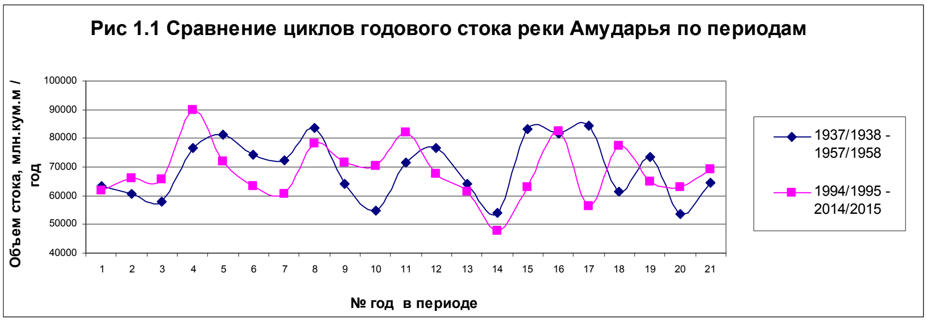

Fig.1.1. Comparison of annual runoff cycles of Amudary River by time periods

Figure 1.2 shows dynamics of annual river runoff in the Amudarya basin over 2015/2016 – 2054/2055 which is built without account of climate change, and Table 1.1 gives the values of average annual river runoff by period of time.

Table 1.1 River runoffs in Amudarya basin by period of time, cubic km/year

Time period	Pyandj	Vakhsh	Kafirnigan	Surkhandarya	Kunduz	Amudarya
2016-2025	33.87	19.3	5.27	3.19	4.3	65.93
2026-2035	36.73	20.35	5.22	3.27	4.44	70.01
2036-2045	32.63	19.34	5.42	3.43	4.44	65.26
2046-2055	38.2	19.87	6.13	3.94	4.46	72.6
2016-2055	35.36	19.72	5.51	3.45	4.41	68.45

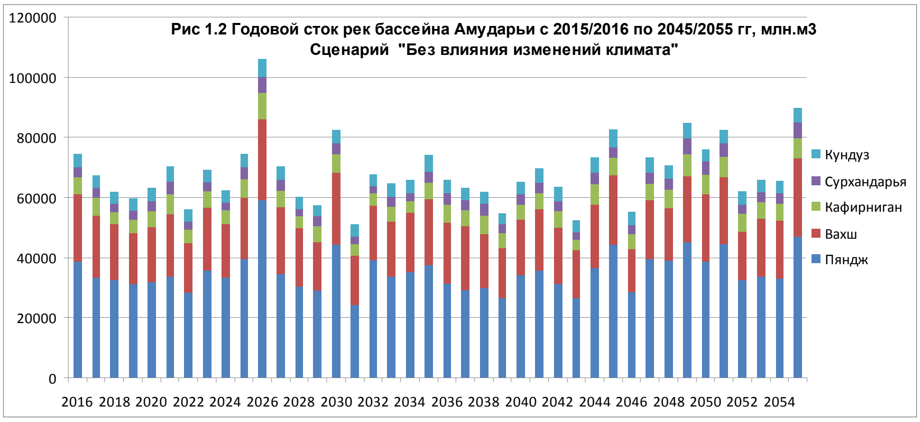

Fig.1.2. Annual river runoffs in Amudarya basin from 2015/2016 to 2045/2055, Mm3
"No climate change impact" scenario

If one compares the average annual runoffs of Amudarya basin's rivers for the two periods of time - 2015/2016–2045/2055 and 1932/1933–2014/2015 – the following observations can be made:

- average long-term runoff of Amudarya (as the sum of rivers) over 2015/2016–2045/2055 is 68.45 km^3/year, while that over 1932/1933–2014/2015 is 68.89 km^3/year; i.e. the decrease in runoff is as small as 0.6 %;
- the observed decrease is 0.2 % for the Pyandj river runoff and 2.5 % for of the Vakhsh river runoff;
- the first ten years (2015/2016–2024/2025) are characterized by the average annual Amudarya runoff of 65.93 km^3/year, i.e. it is the dry decade (95% of average runoff over 1932/1933–2014/2015), while next decade will see higher runoff of 70.01 km^3/year (102%), the third decade will have runoff lower than the norm – 65.26 km^3/year (95%), and the forth decade will have the runoff of 72.6 km^3/year (105 %);
- the average decade annual runoff of the Vakhsh River will be lower than the norm in all decades (95-98 %), except for the second decade (101 %).

2. Impact of climate change on river runoff

For the assessment of an impact of probable climate change on crop water requirements and water resources, the PEER project uses the output of REMO-0406 regional climate models with the spatial resolution of 0.5° and 0.16°. REMO-0406 plays the greenhouse gas concentration scenario CMIP3 SRES-A1B. As part of the CAWa Project, the University of Wurzburg carried out modeling of regional climate by the REMO-0406 for Central Asia, including the whole area of the Amudarya basin.

According to the World Meteorological Organization, the year 2015 was hottest in the history and characterized by exceptional rainfall, devastating droughts and unusually intensive tropical cyclones. Such tendency of record meteorological values is observed in 2016 as well. According to the REMO 0406 climatic scenario, the air temperature is expected to grow by 0.051°C a year on average. Rainfall will not change substantially; however, rainfall variability, i.e. natural variations between minimum and maximum will be stronger.

Most hydrological models that are based on moderate, 'soft' climatic scenarios do not produce noticeable lowering of runoff in major rivers of Amudarya basin until 2030. However, one estimation gives a decrease in water resources in Amudarya basin within 5-8% of the norm closer to 2030, and the impact of climate change (warming) on annual runoff will be more sensible – expected lowering of Amudarya water resources within 10-15% by 2050-2060 (EDB and EC IFAS, 2009).

Earlier research indicate to larger deviations of annual runoff from the average long-term values: the "depth" of dry years may exceed the earlier observed values, and the frequency of occurrence of dry years with probability of 75% and more may increase (Agaltseva N.A., Bolgov M.V. et al., 2011). Warming is expected to cause shifts in typical high water dates (beginning, peak, duration) in intra-annual river regime: peak of high water may occur (10-30 days) earlier; and, duration of high water can be longer (10 to 50 days) (EDB and EC IFAS, 2009).

When assessing potential impact of climate change on water resources in the PEER Project, we used the output of the REMO-0406 regional model, which is a projection for CA of average warming A1B simulated by the general circulation model ECAM 5. According to NIGMI's estimation (2014), for conditions of the REMO-0406 scenario one should expect reduced snow storage in different flow formation zones of Amudarya basin. As the methodological basis for such estimation a regional hydrological model implemented as an automated information system for hydrological forecasts (AISHF) is used in Uzbekistan. This model helps to solve a range of problems in applied hydrology, including calculation, forecast, and reconstruction of flow in unaccounted river section; calculation of inflow to reservoir, etc. AISHF is based on a mathematical model of flow formation in mountain river basin and allows estimating snow storage, glacial component of flow, and long-term river runoff.

This system is adapted to current conditions of hydrometeorological information provision and adjusted for the use of climatic scenarios, i.e. it can be used for assessment of current and future status of water resources in Amudarya basin.

This system was developed at SARNIGMI (currently NIGMI - Research Institute of the Center of Hydrometeorological Service at the Uzbek Cabinet of Ministers) and adapted, under the conditions of the lack of data, for future estimation of climate impact on water resources (Agaltseva N.A., Pak A.V., 2007).

The results of modeling of runoff series for Amudarya basin on monthly and ten-day scale based on the REMO 0406 scenario by the NIGMI's model showed that climate change will lead to reduction of available surface water resources during the growing season and to minor increase of water during non-growing season; by 2060, the estimated reduction of flow during the growing season (against the norm of flow, i.e. the average long-term flow) will be as follows: Pyandj River – 6 %; Vakhsh River – 5 %; Kafirnigan River – 8 %; and, Surkhandarya River– 6 %. Past research (EDB and EC IFAS, 2009) indicates to such reduction as early as by 2030.

The NIGMI/REMO 0406 modeling suggests the maximal reduction of flow (against the norm) in 2060 in July: 14 % for the Pyandj River; 19 % for the Vakhsh River; 25 % for the Kafirnigan River; and 10 % for the Surkhandarya River. At the same time, river flow is expected to increase during the non-growing season and by the beginning of the growing season in April: Pyandj River – 6 %; Vakhsh River – 6 %; Kafirnigan River – 18 %; and, Surkhandarya River – 8 %.

Thus, we can state that the REMO 0406-based assessments characterize this scenario (regarding an impact on river runoff) as a 'soft' scenario, which slightly changes the natural river regime in annual dimension but shows substantial reduction of runoff by 2060 in some months of the growing season (June and July).

While using these results in the PEER Project, we made calculations to build the matrix of correction coefficients (reducing or increasing the flow norm) for each river by month over 2015/2016 – 2054/2055. Figures 2.1 – 2.5 illustrate hydrographs that show transformation of river runoff (against the flow norm) in the basin by 2055. Tables in the Annex to this report provide the data on changes of basin's river runoff by 2020, 2040, and 2060.

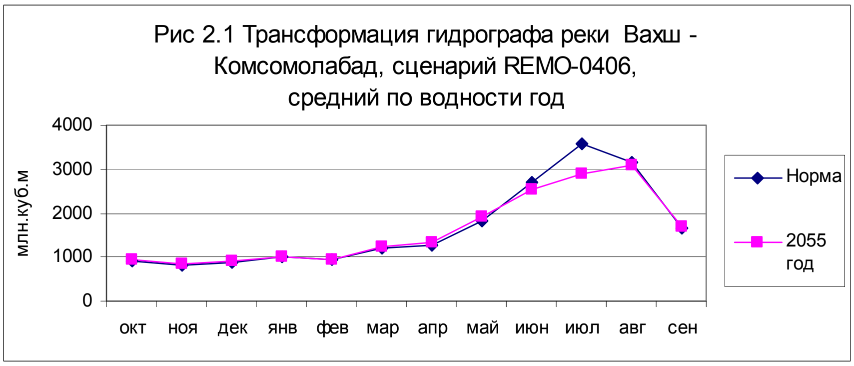

Fig.2.1. Transformation of Vakhsh River hydrograph – Komsomolabad, REMO-0406 scenario, average year

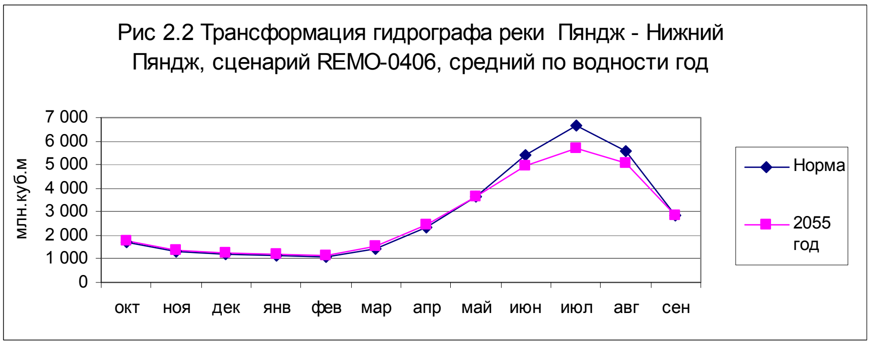

Fig.2.2. Transformation of Pyandj River hydrograph – Lower Pyandj, REMO-0406 scenario, average year

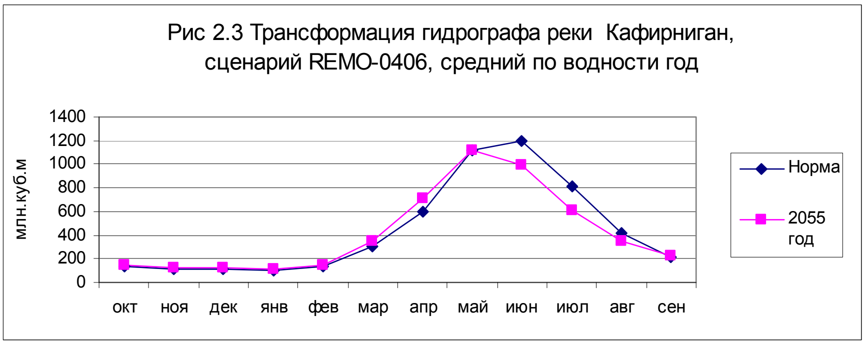

Fig.2.3. Transformation of Kafirnigan River hydrograph, REMO-0406 scenario, average year

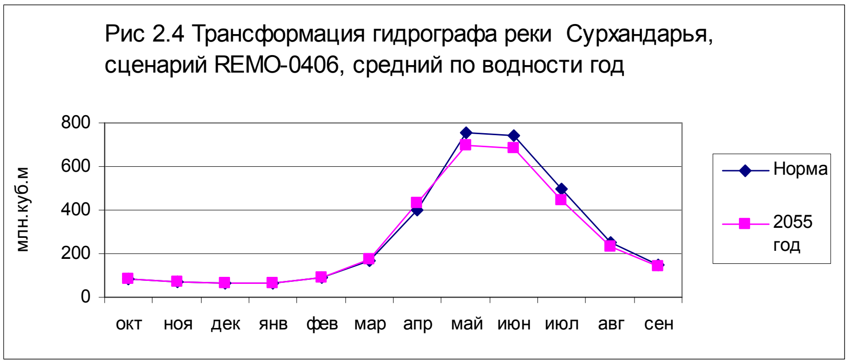

Fig.2.4. Transformation of Surkhandarya River hydrograph, REMO-0406 scenario, average year

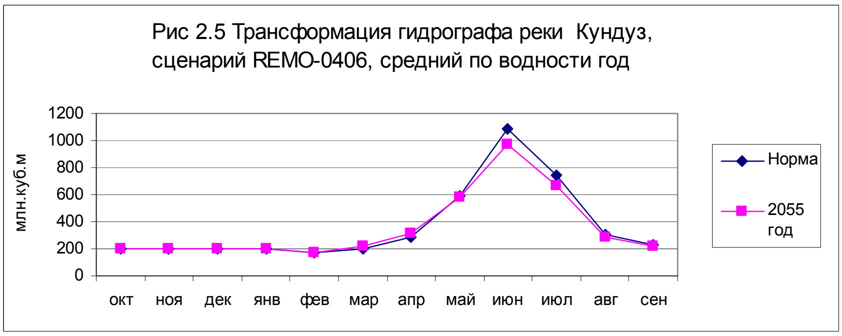

Fig.2.5. Transformation of Kunduz River hydrograph, REMO-0406 scenario, average year

3. Construction of river runoff series in Amudarya basin for 2016-2055 according to the REMO 0406 climate change scenario

River runoff series in Amudarya basin were constructed for 2015/2016 – 2054/2055 with account of climate change according to the REMO 0406 scenario and on the basis of river runoff series that were not affected by anthropogenic and climate impact.
The series were corrected by coefficients derived from the NIGMI model's assessments. Thus, the concept of cyclical nature (which takes into account all special characteristics of local flow generation) in given approach is enhanced by hydrological modeling, fitting climatic scenarios. By using this approach in the PEER Project, we project the NIGMI estimation (in form of a deviation from the flow norm by 2020–2060), which was made on the basis of REMO 0406 scenario, to natural cycles of flow hydrographs that continue and keep observed trends in the future.

Figure 3.1 shows dynamics of annual runoff of the Amudarya River for 2015/2016 – 2054/2055 as corrected by the coefficients of climate change; it indicates to slight upward trend of river runoff, which is lower than the average long-term one over 1932/1933 – 1998/1999.

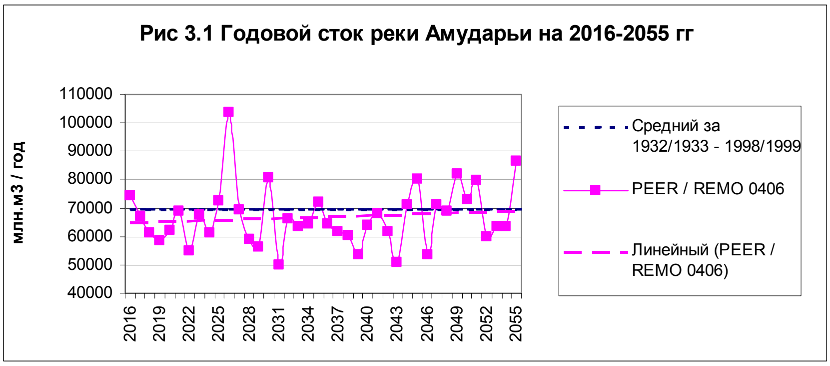

Fig.3.1. Annual runoff of Amudarya River over 2016-2055

Table 3.1 provides the average long-term flow in Amudarya basin's rivers derived for 2015/2016 – 2054/2055 by decade, with account of climate change, whereas Table 3.2 compares those data with the data on average long-term flow in Amudarya basin that do not account climate change.

Figure 3.2 below shows dynamics of Amudarya River runoff for October-March and April-September 2015/216 – 2054/2055, with account of climate change.

Table 3.1 River flow in Amudarya basin for different periods of time, with account of climate change (REMO 0406), km3/year

Period	Pyandj	Vakhsh	Kafirnigan	Surkhandarya	Kunduz	Amudarya
2016-2025	33.29	18.88	5.16	3.20	4.31	64.84
2026-2035	35.93	19.74	5.07	3.26	4.44	68.44
2036-2045	31.83	18.72	5.24	3.39	4.42	63.61
2046-2055	36.96	19.13	5.90	3.82	4.37	70.18
2016-2055	34.50	19.12	5.34	3.42	4.39	66.77

Table 3.2 River flow in Amudarya basin with no climate change and with account of climate change (REMO 0406), average over 2016-2055, km3/year

Period	Pyandj	Vakhsh	Kafirnigan	Surkhandarya	Kunduz	Amudarya
Account of climate change	34.50	19.12	5.34	3.42	4.39	66.77
No climate change	35.36	19.72	5.51	3.45	4.41	68.45
Difference	- 0.86	- 0.60	- 0.17	- 0.03	- 0.02	- 1.68

Fig.3.2. Amudarya water: PEER/REMO 0406 scenario

The strongest effect that climate will have on river runoff is expected in June-July, when by 2055 the runoff of Amudarya will decrease by 0.8 km^3 in August, by 1.3 km^3 in June, and by 2.7 km^3 in July. Figures 3.3 – 3.7 below show runoff dynamics of Amudarya River and its tributaries for some months, and Figure 3.8 demonstrates reduction of runoff in August, June, and July since 2016 to 2055.

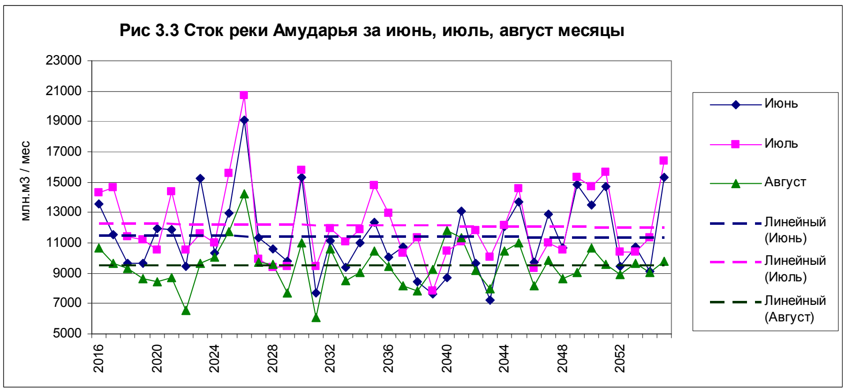

Fig.3.3. Amudarya River runoff in June, July, and August

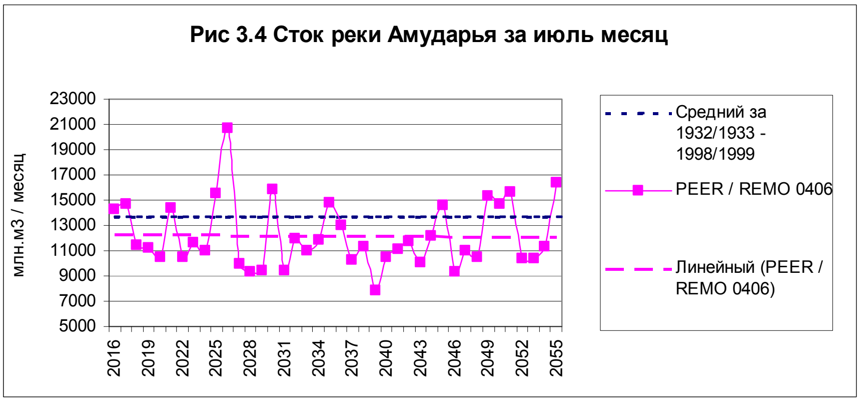

Fig.3.4. Amudarya River runoff in July

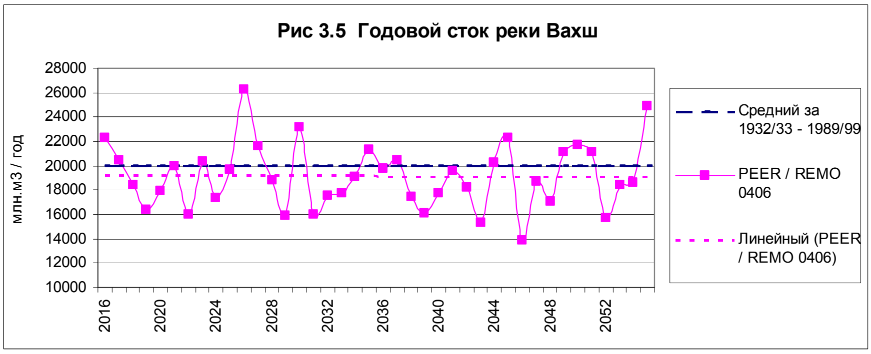

Fig.3.5. Annual runoff of Vakhsh River

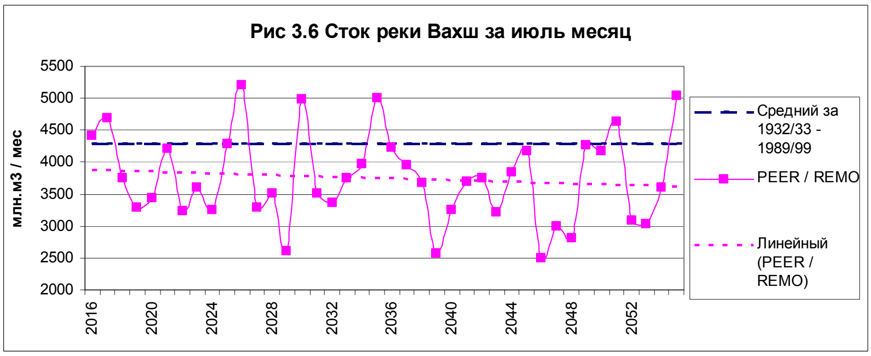

Fig.3.6. Vakhsh River runoff in July

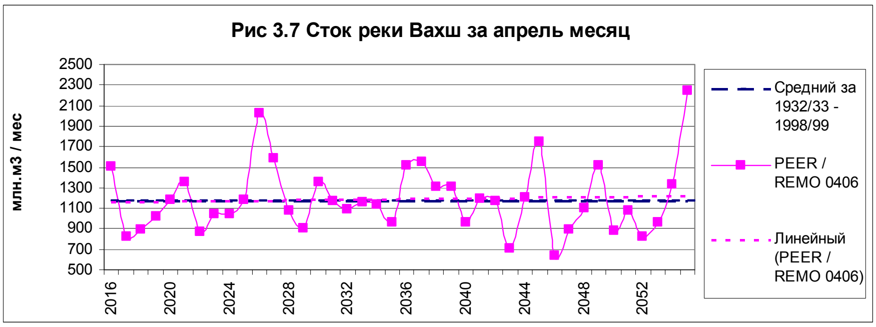

Fig.3.7. Vakhsh River runoff in April

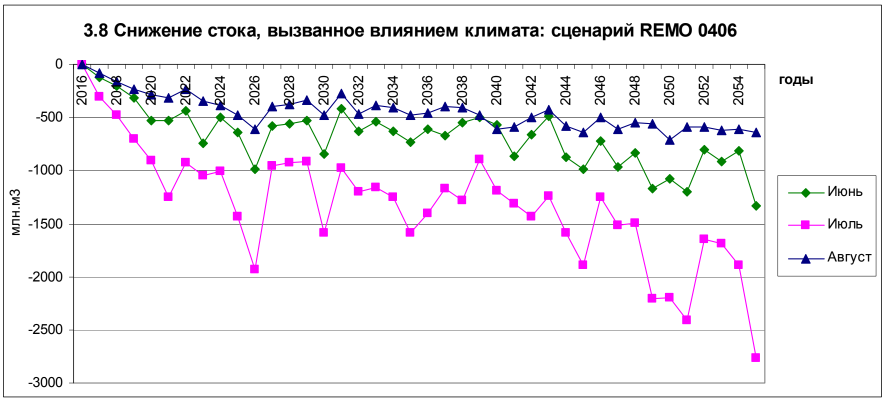

Fig.3.8. Reduction of runoff caused by climate change: REMO 0406 scenario

Conclusion

An impact of climate change on river runoff in the Amudarya basin, according to the REMO 0406 climate scenario, is mixed when considering seasons, particular months and rivers. REMO-0406 scenario should be treated as ‘soft’ scenario, which is feasible.

No significant impact is expected on annual river runoff: the average long-term annual runoff of Amudarya is expected to decrease by 1.68 km3/year for 2015/2016 – 2054/2055 as compared to 1932/1933 – 2014/2015; the same indicator will be 0.6 km3/year for the Vakhsh River and 0.86 km3/year for the Pyandj River. The impact becomes stronger over the period of time 2015/2016 – 2054/2055; in the last decade (2045/2046 –2054/2055), the reduction of runoff will be: 2.42 km^3/year for Amudarya; 0.75 km^3/year for Vakhsh, and 1.24 km^3/year for Pyandj.

An impact on monthly river runoff is more significant: river runoff is expected to decrease in June-August, and the runoff will increase in April and some months during the growing season. The maximum decrease in Amudarya runoff in July by 2050 may be 2.8 km3 a month (against the average flow for 1932/1933 – 2014/2015).

If one traces flow dynamics in the Amudarya basin over 2015/2016 – 2054/2055, a series of dry years can be highlighted: 2022– 54.98 km3/year (80% of norm), 2031 – 49.89 km3/year (73% of norm); 2039 – 53.67 km3/year (78% of norm); 2043 – 50.98 km3/year (74% of norm). The flow in July will decrease to: 9.9 km3 (74% of norm), 9.3 km3 (69 %) and 9.4 km3 (70 %) in 2027, 2028, and 2029, respectively; and, 7.8 km3 (58% of norm) in 2039.

In addition, this research allowed constructing water series for Amudarya basin that would serve as a basis of numerical experiments planned in the Project at the third stage (late 2016, early 2017).

Annex to Position 2.4 Modeling runoff series in light of CC

The Vakhsh: change in the flow norm according to REMO 0406 scenario

Month	Norm	2020		2040		2060	
	Mm3	%	Mm3	%	Mm3	%	Mm3
Oct	915.5	100	916	102	934	103	943
Nov	813.6	99	805	101	822	102	830
Dec	891.1	98	873	100	891	101	900
Jan	1012.3	98	992	100	1012	101	1022
Feb	932.9	99	924	101	942	102	952
Mar	1213.1	100	1213	102	1237	103	1249
Apr	1262.9	102	1288	105	1326	106	1339
May	1833.4	101	1852	101	1852	104	1907
Jun	2711.3	96	2603	94	2549	93	2522
Jul	3572.1	89	3179	88	3143	81	2893
Aug	3163.6	100	3164	98	3100	98	3100
Sep	1648	101	1664	102	1681	103	1697
Oct-Mar	5779	99	5723	101	5839	102	5896
Apr-Sep	14191	97	13750	96	13651	95	13458
Oct-Sep	19970	98	19473	100	19490	99	19354

The Pyandj: change in the flow norm according to REMO 0406 scenario

Month	Norm	2020		2040		2060	
	Mm3	%	Mm3	%	Mm3	%	Mm3
Oct	1 698	101	1715	103	1749	104	1766
Nov	1 300	101	1313	103	1339	104	1352
Dec	1 196	100	1196	102	1220	103	1232
Jan	1 136	100	1136	102	1159	103	1170
Feb	1 075	102	1096	104	1117	105	1128
Mar	1 445	102	1474	104	1503	105	1517
Apr	2 323	105	2439	105	2439	106	2462
May	3 623	102	3695	102	3695	101	3659
Jun	5 385	95	5116	94	5062	92	4954
Jul	6 637	93	6172	91	6039	86	5708
Aug	5 572	95	5293	94	5238	91	5071
Sep	2 868	101	2897	101	2897	100	2868
Oct-Mar	7849	101	7930	103	8087	104	8165
Apr-Sep	26407	97	25612	96	25370	94	24721
Oct-Sep	34256	98	33541	100	33456	98	32886

The Kafirnigan: change in the flow norm according to REMO 0406 scenario							
Month	Norm	2020		2040		2060	
	Mm3	%	Mm3	%	Mm3	%	Mm3
Oct	133	103	137	107	142	111	147
Nov	117	103	120	106	124	110	128
Dec	111	102	113	104	116	108	120
Jan	107	102	109	105	112	108	115
Feb	136	103	140	107	146	110	150
Mar	300	105	315	110	330	115	345
Apr	602	105	633	110	663	118	711
May	1115	100	1115	103	1148	100	1115
Jun	1201	94	1128	88	1056	83	996
Jul	811	90	730	81	657	75	608
Aug	423	88	373	85	360	84	356
Sep	213	103	220	105	224	107	228
Oct-Mar	904	103	935	107	969	111	1006
Apr-Sep	4365	96	4197	94	4107	92	4013
Oct-Sep	5268	97	5132	96	5077	95	5020

The Surkhandarya: change in the flow norm according to REMO 0406 scenario							
Month	Norm	2020		2040		2060	
	Mm3	%	Mm3	%	Mm3	%	Mm3
Oct	85	102	87	105	89	101	86
Nov	73	102	74	105	76	100	73
Dec	66	101	66	104	68	100	66
Jan	67	101	68	104	70	100	67
Feb	89	102	90	105	93	101	89
Mar	165	104	172	105	173	104	172
Apr	401	103	413	101	405	108	433
May	757	102	772	100	757	92	696
Jun	743	99	735	97	720	92	683
Jul	495	98	485	95	470	90	445
Aug	250	97	243	94	235	92	230
Sep	146	101	148	100	146	95	139
Oct-Mar	544	102	557	105	570	102	553
Apr-Sep	2791	100	2795	98	2733	94	2627
Oct-Sep	3336	100	3352	99	3303	95	3179

The Kunduz: change in the flow norm according to REMO 0406 scenario							
Month	Norm	2020		2040		2060	
	Mm3	%	Mm3	%	Mm3	%	Mm3
Oct	198	102	202	105	208	101	200
Nov	201	102	205	105	211	100	201
Dec	204	101	206	104	212	100	204
Jan	197	101	198	104	204	100	197
Feb	169	102	173	105	178	101	171
Mar	202	104	210	105	212	106	214
Apr	288	104	300	106	306	109	314
May	590	102	602	100	590	99	584
Jun	1081	99	1070	97	1049	90	973
Jul	739	99	732	95	702	90	665
Aug	309	97	300	95	294	92	285
Sep	229	101	231	100	229	97	222
Oct-Mar	1170	102	1194	105	1225	101	1186
Apr-Sep	3237	100	3235	98	3169	94	3043
Oct-Sep	4407	100	4429	100	4394	96	4229