5. Assessment of water resources changes under probable climatic change

Water resources play very important role in development of arid and semi-arid zones and their socio-economic well-being. Uzbekistan is major water consumer in Central-Asian region. Agrarian sector development on base of irrigated farming and other water uses have decisive meaning for Uzbekistan economy development.

Under uneven water resources distribution and their scarcity assessment of water resources and their changes under climatic factors is very topical.

Impact of probable climate changes on region's river mode can be evaluated using flow formation rather complete and reliable models of certain frequency and accuracy.

Flow formation model for mountainous rivers developed by SANIGMI allows to take into account main flow formation regularities and evaluate climatic changes impact on river flow, snow cover, glaciers within separate river basins [1, 2/.

Set of models includes model of snow cover formation in the mountains, model of glacier flow and model of snow, glacier and rain transformation into flow. It takes into account major regional peculiarities of flow formation zone located in high mountains of Tyan-Shan' and Pamir-Alai.

For set of models practical use automated information system has been created. Numerical experiments are carried out with series of meteorological scenarios to assess model response to meteorological elements impact (their values and temporal distribution). To evaluate climatic impact on water resources flow formation zones of large and small rivers were selected having different types of recharge within Amudarya and Syrdarya basin: Pskem, Chatkal, Ahangaran, inflow to Charvak reservoir, Kurshab, Tar, Yassy, Karakulja in Syrdarya basin and Vakhsh and Zerafshan in Amudarya basin. Vahsh river has glacier-snow recharge and Ahangaran river has snow-rain recharge.

As to climatic scenarios, documents of Interstate Expert Group (IEG) show that methods of reliable forecast of troposphere and climate as a whole temperature change are not yet available. All proposed assessments present options of climatic system response to green house effect, which are called "climatic scenarios".

Prediction of future earth climate change as a whole and for separate regions is not a goal of climatic scenarios. Climatic scenarios are developed for evaluation of potential vulnerability of regional ecosystems and socio-economic sectors and reaction strategy development. Because climatic scenarios are accompanied by high uncertainty, it is expedient to use several climate change scenarios for vulnerability assessment.

For physical processes modeling determining global climate, three-dimensional numerical models of general atmosphere circulation (MGAC) are considered as the most reliable tool. Presently, there are at least 20 MGAC, which can potentially provide agreed and physically plausible assessments of global climate changes [7, 9, 13, 14].

Recent combined climatic models "atmosphere-ocean" development permits use them for evaluation of future climate and quantitatively evaluate impact of green house gases concentration increase in the atmosphere. Such models are being developed in leading climatic centers and IEG recommends use these results for the regional climatic scenarios building.

In 1992 IEG suggested 6 scenarios of green house gases emission (iIS92a, ... IS92f) [11] and, as a consequence, global air temperature change. Scenario IS92a assumes population growth up to 11,3 bln. at 2100 (doubling), economic growth is assumed as 2,3-2,9% per year and no measures would be taken to prevent gases emission. This is scenario "business as usual". Scenario IS92b assumes the same but foresees measures on gases emission reduction.

Scenarios IS92c and IS92d suppose less emission compared with scenarios IS92a and IS92b, as well as scenarios IS92e and IS92f – more emission due to difference in population and economic growth, various types of fuel and energy sources use [14].

In accordance with these scenarios, there is the same number of global air temperature increase options. Each option has own uncertainty limits.

In conditions of Uzbekistan for each scenario of emission and each season set of values has been obtained determining model forecast of temperature changes since 2000 till 2030. Because of small difference in effect on temperature scenarios 'a' and 'b', 'c' and 'd', 'e' and 'f' were united in pairs. As to probable precipitation change, only annual sum of precipitation for different scenarios in mountainous territories at 2030 were obtained.

Results of calculations presented in table 2.26 permit suppose that in case of considered scenarios realization at 2030, significant changes of water resources are not expected. In Amudarya basin their reduction by 2-4% and in Syrdarya basin their increase by 3-4% are probable.

Table 26 | Norms and probable river flow changes in Central-Asian region by 2030 under various climatic scenarios

River	Q	Q_{norm}	Q % of norm for various climatic scenarios		
			IS92ab	IS92cd	IS92ef
Akhangaran	$Q_{вег.}$ $Q_{год.}$	33,8 20,9	103 106	102 103	106 109
Chatkal	$Q_{вег.}$ $Q_{год.}$	179 112	103 105	102 103	105 106
Pskem	$Q_{вег.}$ $Q_{год.}$	118 73,5	98 99	98 99	95 98
Inflow to Charvak reservoir	$Q_{вег.}$ $Q_{год.}$	297 185	98 100	98 99	93 97
Vakhsh	$Q_{вег.}$ $Q_{год.}$	944 547	97 97	94 94	98 98

Taking into account high scenarios uncertainty in precipitation (annual sum of precipitation without distribution between the seasons is given in scenario), it is expedient to make calculations without regard for precipitation. Results of such calculations are presented in Table 27. They show trend of flow maintenance at existing level and even its small reduction.

Table 27 | Norms and probable river vegetation flow changes in Central-Asian region by 2030 under various climatic scenarios

River	Q	Q_{norm}	Q % of norm for various climatic scenarios		
			IS92ab(t)	IS92cd(t)	IS92ef(t)
Akhangaran	$Q_{вег.}$ $Q_{год.}$	33,8 20,9	96 99	97 99	94 98
Chatkal	$Q_{вег.}$ $Q_{год.}$	179 112	97 99	98 99	92 97
Pskem	$Q_{вег.}$ $Q_{год.}$	118 73,5	98 99	98 99	95 98
Inflow to Charvak reservoir	$Q_{вег.}$ $Q_{год.}$	297 185	98 100	98 99	93 97
Vakhsh	$Q_{вег.}$ $Q_{год.}$	944 547	97 97	94 94	98 98

5.1 Climatic scenarios use based on models of general atmosphere circulation

Anthropogenic climate changes can be accepted as scenarios obtained through equilibrium models of general atmosphere circulation under CO_2 concentration doubling.

Model GFDL is developed in Geophysical Laboratory of Fluid Dynamics (USA), model GISS – in Goddard Institute of Space Research (USA), model UKMO – In Meteorological Agency in UK, model CCCM – in Canadian Climatic Center.

Results of air temperature near the earth, precipitation and radiation computation corresponding to current CO_2 concentration are control running and show model capability to produce real climate. Under CO_2 concentration doubling computations relate to state of equilibrium and assess climate changes occurring under CO_2 concentration doubling (it is possible by 2050-2075) [10].

Model scenarios of seasonal precipitation changes in percent of 1951-1980 basic norm for Uzbekistan and adjacent mountainous territory under CO_2 concentration doubling are shown on Fig. 25.

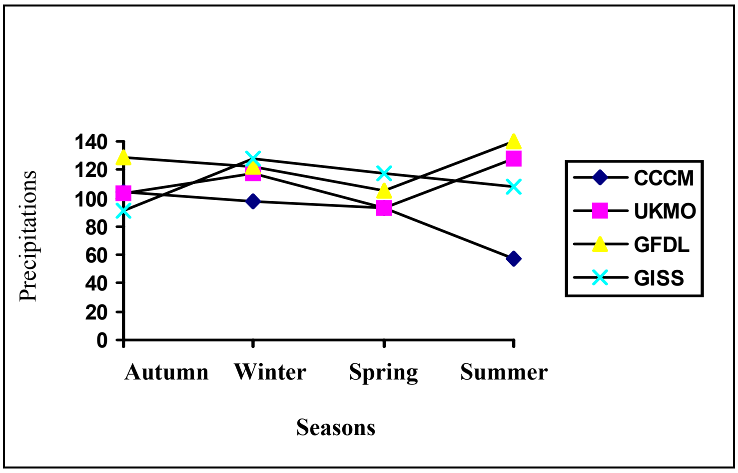


Fig. 25 | Model scenarios of probable precipitation changes in percent of 1951-1980 basic norm for Uzbekistan and adjacent mountainous territory CO_2 concentration doubling

In Table 28 results of surface water resources changes under various climatic scenarios are given. Model CCCM gives maximum discrepancies with real climate in control running and presents the strictest scenario giving maximum climate aridization.

According to this model, under CO_2 concentration doubling significant average annual temperature increase is probable; precipitation in mountain and foothills will be 95-98%. Vegetation flow will reduce by 40-50% on small rivers and by 15-20% on large ones.

Unfavorable situation can occur in case of climate changes development in accordance with model UKMO. In this case surface resources can reduce by 15-20%.

According to scenario GFDL average annual precipitation will increase by 24% and water resources can increase by 5-10% that coincides with scenario GISS.

Analysis showed that under climatic scenarios CCCM and UKMO evaporation from basin surface can increase by 20-22% as well as under scenarios GFDL and GISS - by 10 -15% of norm. Spring flood will be shifted by one month. For rivers of snow-rain recharge peak flow can occur in April. In result of warming share of rain will increase.

On Fig. 26, 27 Akhangaran and Kugart rivers' hydrographs are presented as an example. Peak flow shift is evident on these hydrographs. It should be taken into account that modeling results are not predictive. These are computations of river low under different climatic scenarios, which are being further developed.

Table 28 | Surface water resources changes in river basins of Central Asia under anthropogenic climate changes within the model of general atmosphere circulation

River	Q	Q norm	Surface water resources change, %			
			GFDL	GISS	UKMO	CCCM
Akhangaran	$Q_{\text{вег.}}$	33,8	+1	-4	+8	-41
	$Q_{\text{год.}}$	20,9	+12	+12	+20	-16
Chatcal	$Q_{\text{вег.}}$	179	+8	-3	-4	-27
	$Q_{\text{год.}}$	112	+11	+7	+3	-11
Pskem	$Q_{\text{вег.}}$	118	+18	+13	-3	-9
	$Q_{\text{год.}}$	73,5	+13	+12	+2	-4
Inflow to Charvak reservoir	$Q_{\text{вег.}}$	297	+11	+3	-2	-17
	$Q_{\text{год.}}$	185	+12	+9	+3	-7
Vakhsh	$Q_{\text{вег.}}$	944	+16	0	-11	-27
	$Q_{\text{год.}}$	547	+12	+1	-7	-12
Kugart	$Q_{\text{вегю}}$	28,6	-7	-12	-29	-48
	$Q_{\text{год,}}$	18,4.	+2	+4	-11	-27
Zerafshan	$Q_{\text{вег.}}$	257	+6	-4	-19	-30
	$Q_{\text{год.}}$	158	+10	+5	-3	-15

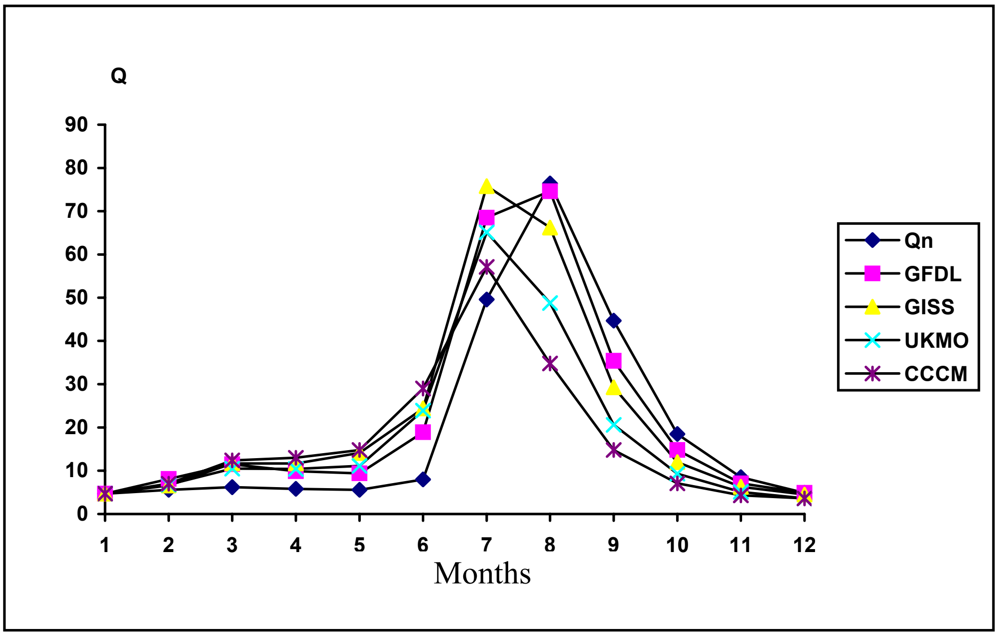


Fig. 26 | Hydrographs of Akhangaran river flow under climatic scenarios based on general atmosphere circulation

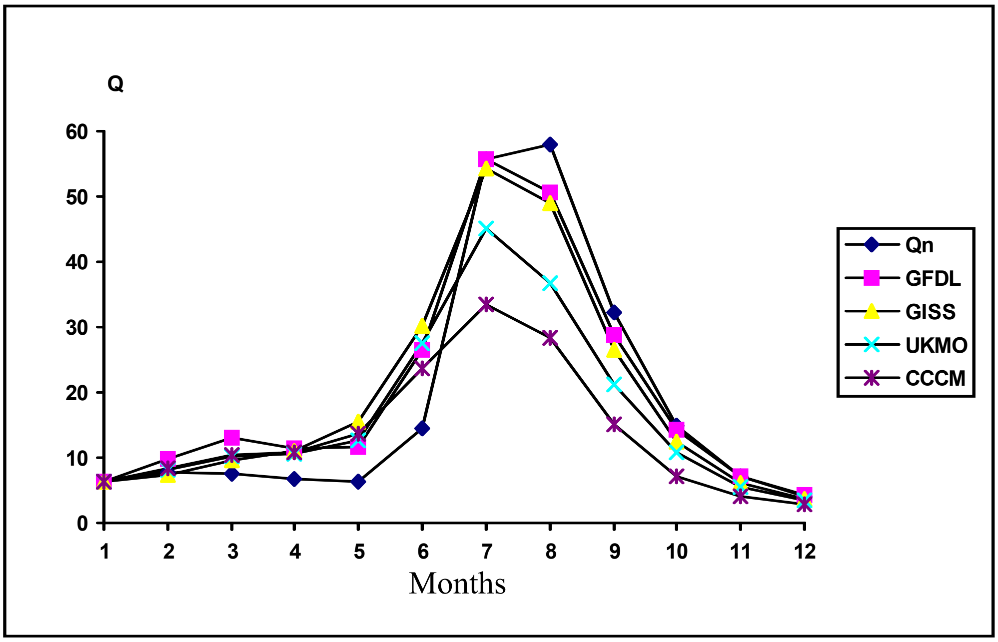


Fig. 27| Hydrographs of Kugart river flow under climatic scenarios based on general atmosphere circulation

Since goal is to build regional climatic scenarios for the nearest future, transition models ECHAM4 and HadCM2 described in second section were used.

In table 29 vegetation flow changes computed under transition and regional scenarios realization are presented.

Computations on mathematical model of mountainous rivers flow formation under above scenarios realization allow suppose that within range of climatic parameters under consideration during 20-30 years water resources change will not be significant. But under climate warming average vegetation water discharge reduction will be observed. Probable flow changes will be within +3 to – 2…7%.

Table 29 | Norms and probable vegetation flow changes in the rivers of Central-Asian region by 2025 under various climatic scenarios

River	Q	Q_{norm}	Q % of norm for different climatic scenarios		
			ECHAM4	**HadCM2**	**IS92ab(t)**
Chatkal	$Q_{\text{вег.}}$	212	92	97	88
Pskem	$Q_{\text{вег.}}$	126	99	103	105
Inflow to Charvak reservoir	$Q_{\text{вег.}}$	338	94	99	94
Vahsh Inflow to Nurek reservoir	$Q_{\text{вег.}}$	984	93	95	93
Zerafshan	$Q_{\text{вег.}}$	258	99	97	93
Karakulja	$Q_{\text{вег.}}$	39,1	97	97	99
Yassy	$Q_{\text{вег.}}$	39,8	96	96	99
Kurshab	$Q_{\text{вег.}}$	26,7	96	98	99
Tar	$Q_{\text{вег.}}$	76,9	96	99	101
Inflow to Andizhan reservoir (sum of 4)	$Q_{\text{вег.}}$	182,5	96	98	100
Inflow to Toktogul reservoir	$Q_{\text{вег.}}$	595	590	586	581

5.2. Evaluation of river watershed sensitivity to natural and anthropogenic changes of climatic parameters

Region rivers differently response to climate warming because of their different sources of recharge. Snow rivers flow quicker decreases with temperature increase. Rivers with glacier recharge are more inert. At the same time, along with glaciers degradation more active flow reduction will occur.

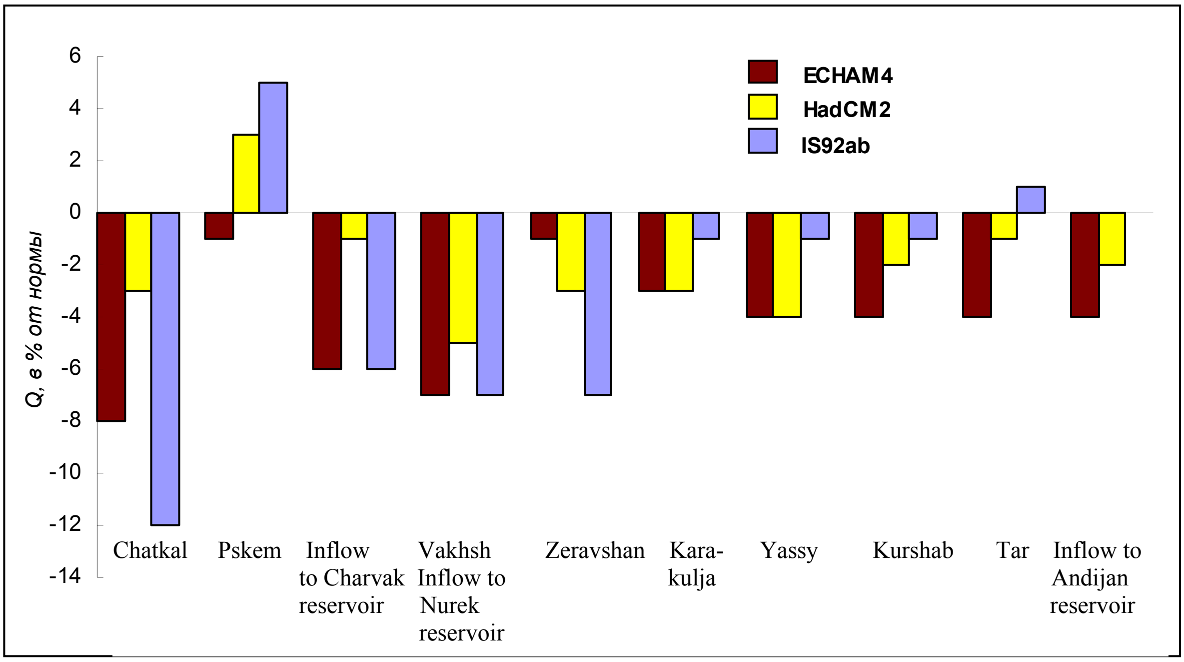


Fig. 28 | Evaluation of river watersheds sensitivity under various climatic scenarios

On Fig. 28 some rivers-indicators' flow changes under "transition" and regional climatic scenarios are presented. Inflow to Charvak reservoir (Syrdarya basin) and Nurek reservoir (Amudarya basin) is presented on Fig. 29 as an example of integral characteristic.

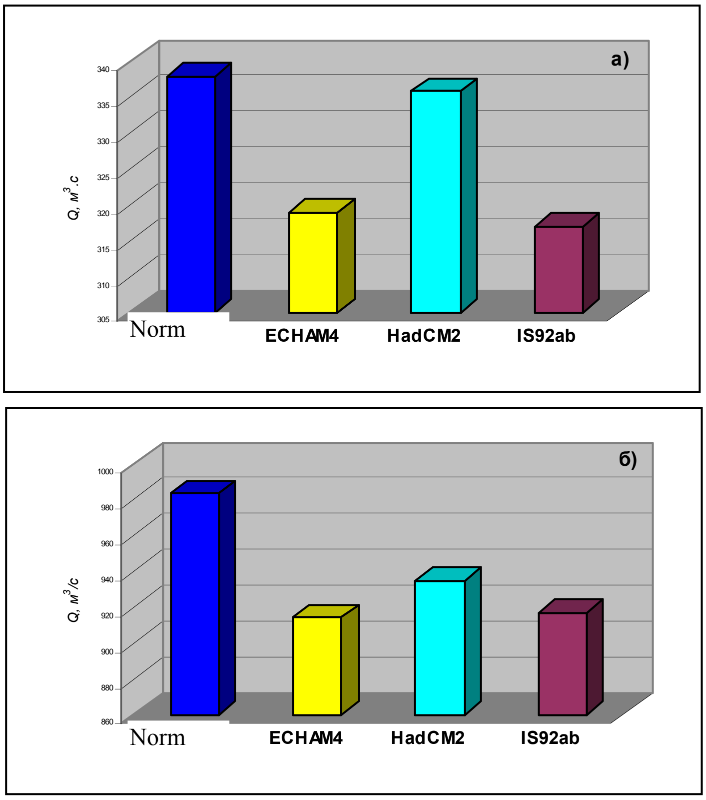


Fig. 29 | Changes of inflow to Charvak (a) and Nurek (b) reservoirs under various climatic scenarios

In Table 30 Amudarya and Syrdarya flow integral assessment based on numerical experiments with basins-indicators under "transition" and regional climatic scenarios is given.

Results show that significant river flow reduction will not occur. Flow fluctuation increase between different years can be expected.

It can be supposed that period up to 2025 will be interrupted by dry years similarly to last decade. Complex hydrometeorological situation of 2000 can serve as analogue. Dryness of this year is caused by low precipitation in flow formation period and high air temperature. To verify models basing on precipitation and air temperature, Chatkal and Pskem rivers hydrograph for 2000 has been compute.

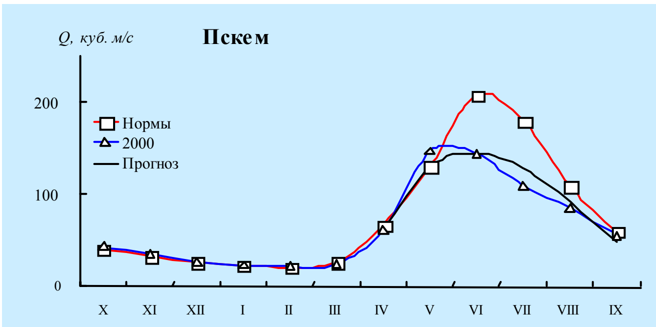
Table 30 | Expected water resources change in main rivers of the Aral sea basin under various climatic scenarios (% of basic norm)

River	Basic nom (km^3/year)	Climatic scenarios		
		ECHAM4	HadCM2	IS92ab
Syrdarya	37,9	-2	-1	-2
Amudarya	78,5	-3	-3	-4

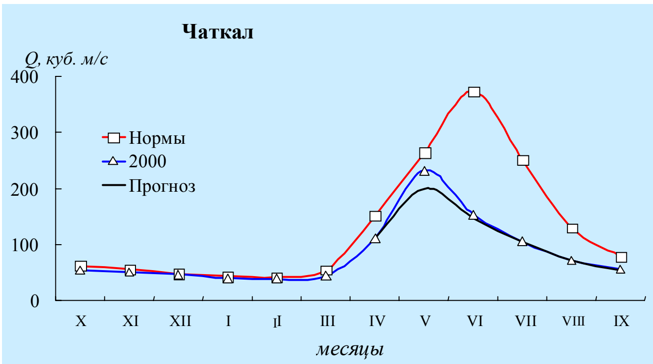
On Fig. 30 actual and computed hydrographs are presented compared with average annual values.

According to Glavgidromet data, average annual air temperature in Uzbekistan in 2000 was higher compared with climatic norm. This year like 1941 was warmest for all observation period. Analysis of annual precipitation changes shows that 2000 was very dry.

Similar situation can lead to extremely dry years when significant flow reduction is possible.



1)



2)

Fig. 30 | Actual and predicted hydrographs compared with average annual values

1 - Pskem; 2 - Chatkal

5.3 Glaciers and climatic changes

Presently, glaciers shrinking are under consideration. What is the cause: green house effect or climatic cycles?

According to V.M. Kotlyakov, during last 420 thousand years there were 4 climatic cycles. Cold periods were longer than warm ones. Because of different causes temperature sharply reduced and fell with difference up to 10C^o. Even during last millennium temperature fluctuations amounted for 1.5-1.0 C^o. YII, XVI, XX centuries were warm as well as XIII-XY and XYII-XIX centuries were cold. Present warming does not come beyond natural fluctuations in spite of higher green house concentration [15].

Glaciers located in the mountains are main source and long-term reserve of fresh water. But ice stock is not stable. Presently, glaciers retirement is observed: small glaciers disappear and large ones are being broken. Glacier shrinking leads to snow melt flow reduction.

Observations in various glacier regions showed that flow reduces slower than glacier area. Actual area of glacier grows due to its separation.

Different researches note incompliance between snow melt increase and glacier area reduction. Scientists have found that "long-term flow changes linked with glaciers degradation are shadowed by snow melt increase in dry years: glacier area decreases and flow increases".

Glaciers differently response to air temperature increase. Calculations performed for summer temperature change by 0.5 C^o and 1C^o and annual precipitation by 20% showed that temperature change by 1C^o leads to change of firn ice border change on 120–140 m. The same effect gives precipitation reduction by 20%.

These characteristics effect on glacier area is more complicated. Maybe it depends on precipitation distribution and relief structure. These factors change much for various basins and lead to different results.

For instance, temperature increase by 0.5C^o leads to glacier area in Sokh and Isfara basin reduction by 8%, in Margilandaya, Kashkadarya and Oihangs basin by 30%. Temperature increase by 1C^o reduces glacier area twice. It worth to remind that long-term temperature change influence is difficult to find.

If to consider glacier evolution during last 50 years and compare data on glacier morphometry in USSR Catalogue (1965-1982) with ground observations and aerospace images, some glaciers show stationary state and even increase (liner size increase, "dead tongue" animation). For main mass of glaciers signs of reduction are typical: glaciers with area less than 1 km^2 disappear, large glaciers are broken into small ones, morena area glacier and pollution increase.

Glacier response to climatic parameters (temperature, precipitation) changes has inert character: lag depends on area (0-10 years).

It is necessary to note following peculiarities of glacier flow:

Firstly, its share depends on snow amount during preceding winter and winter ablation. In low snow years glaciers are spent for flow compensating lack of snow melt and rain.

Secondly, glacier flow reaches maximum in July-August when other water sources (seasonal snow and rain) are exhausted.

If big glaciers are located in flow formation zone and glacier recharge exceeds 5-10% of total annual inflow, calculation without regard for glacier flow leads to big discrepancies in mountainous river flow modeling. For that model of glacier flow formation is included in a set of models because it computers total flow from glaciers including snow melt, ice and firn.

For description and calculation of total melt water all glaciers within region under consideration are considered as single ice area. Dependant of basin size within this area several rayons are excreted uniting multitude of similar glaciers. Mathematical and physical-statistical models of snow and ice accumulation and melting within annual cycle are taken as a methodological base.

It is evident that river basin frozenness depends on relief and climatic conditions. It is known that for high mountains firn line is integral climatic indicator. Accuracy of frozenness assessment is determined by climatic scenarios reliability.

Frozenness response to climatic changes assessment was performed for Ghissar-Alai based on methodology described in [15]. Since in all scenarios temperature increase is assumed, all combinations of temperature (0, 1, 2, 3 C^o.) and precipitation (–50%, 0%, 50%, 100%) changes were taken. Results showed that option is optimal when temperature is unchanged and precipitation is doubled. In this case firn line height reduces by 0.5km that will lead to sharp increase of glacier area and flow.

Option is the most unfavorable when precipitation decreases twice and temperature increases by 3C^{o}: firn line goes up by 700 m, frozenness area reduces by 86%, glacier flow – by 96%.

Obtained results show that climatic conditions change under temperature increase by 1-2°C will lead to river flow reduction of both types of recharge.

Temperature increase by 1-2°C will foster glacier degradation process. For 1957-1980 glaciers within the Aral Sea basin lost 115.5 km^3 of ice (near 104 km^3 of water) that constitutes almost 20% of ice stock by 1957. By 2000 losses amounted for 14% of 1957 stock. By 2020-2025 glaciers will loose 10% more from initial volume.

Calculations of glacier flow done under "transition" scenarios (ICHAM, HADSM) showed that under those scenarios glacier flow reduction (3-5%) will occur by 2025 because under frozenness area reduction melting will occur at expense of melting layer increase.