Research report

2. Research

2.1 ASBmm adjustment

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Introduction

Given report describes the research results on assessment of water resources and river flow regulation by reservoirs and HEPS in the Amudarya Basin. It provides also information on the changes made in the ASBmm software. This work was done as part of PEER Project Research Stage Two, Position 2.1 “ASBmm adjustment”.

1.Water Resources

Water resources in the Amudarya Basin are formed in the territories of Tajikistan, Uzbekistan, Kyrgyzstan, Afghanistan, Turkmenistan, and Iran and comprised of surface river flow, lakes, reservoirs, return water (collector-drainage flow from irrigated fields, wastewater from industry and municipal sector), and groundwater. All these components are considered in the modeling exercise.

Transboundary and local river water

For the PEER Project, the scheme of water regulation and distribution includes: transboundary Amudarya River and its main tributaries (Vakhsh, Pyandj, Kafirnigan), Surkhandarya River (discharge from Surkhandarya planning zone), Kunduz River (discharge from Afghan planning zone); lateral inflow to the Vakhsh River through discharge from Vakhsh planning zone, and to the Pyandj River through discharge from Pyandj and Afghan (along the Kokcha River) planning zones.

Local river flows (along with transboundary water resources) are accounted in water balances of planning zones. For example, the water balance of Karshi planning zone includes a minor part of water resources in the Kashkadarya River and a part of the Zaravshan River (which is transboundary one) as 'local' river water. The water balance of Navoiy planning zone as a 'local' river water considers the Zaravshan river, while that of Turkmenistan's planning zones includes transboundary rivers, such as Tedzhen (called Herirud in Afghanistan) and Murghab as 'local' ones. In Surkhandarya planning zone, the transboundary flow of the Amudarya River, which is supplied by Amu-Zang pumping cascade to the zone, and the 'local' flow of Surkhandarya and Sherabad basin are accounted. The planning zones in Amudarya lower reaches (Dashouz, Khorezm, two zones in Karakalpakstan) and Lebap planning zone (Turkmenistan) do not have local river component.

Water resources modeling

The transboundary network of the rivers Vakhsh, Pyandj (together with the Kokcha River), Kafirnigan, Kunduz, and Amudarya and the reservoirs of the Vakhsh HEPS cascade and TMHS are included into the model of flow regulation and distribution (WAm) in ASBmm software, while the rest of river flow consisting of transboundary and local sources, as well as the water resources of reservoirs at rivers and canals are included into the Planning zone model (PZm) of ASBmm. It is meant that besides in-stream reservoirs, seasonal regulation of flow is provided through a number of intra-system reservoirs at Karshi and Amu-Bukhara canals and at Garagumdarya (Karakum canal). Surface water resources of planning zones include a part of Amudarya River flow and its tributaries Vakhsh, Pyanj, Kafirnigan (intake into canals), Surkhandarya River flow, a part of flow in Kashkadarya and Zaravshan Rivers, and flow of Tedzhen and Murghab Rivers.

Groundwater is accounted for each planning zone in PZm ASBmm. CDF is formed in a planning zone and then distributed as follows: partly re-used for irrigation in this planning zone; partly discharged into rivers and lakes in this planning zone; partly transferred to neighboring planning zone; and, partly discharged into the transboundary network. The river flow, which is not used in given planning zone is discharged into the transboundary network or to neighboring planning zone (if the river network is common for the both zones).

Assessment of water resources in Tajikistan

Hydrographically, the small Amudarya basin bounded by Tajikistan is comprised of the basins of Pyandj, Vakhsh, and Kafirnigan Rivers and the Karatag-Shirkent and Kyzylsu-Yakhsu basins. There are different assessments of the renewable surface flow in Tajikistan in these basins. For instance, the Diagnostic report "Rational and Efficient Use of Water Resources in Central Asia" prepared by the Special Programme for the Economies of Central Asia (SPECA) estimates the total average annual flow of Tajikistan's rivers in the Amudarya Basin at 55.26 km^3/year. SIC

ICWC gives comparable assessment, which is based on the analysis of historical river flow series for the Aral Sea basin over 1911-1999. In this period of time, the total average flow of Pyandj, Vakhsh, Kafirnigan, and Surkhandarya is estimated at 63.3 km^3/year, of which 55.49 km^3/year for Tajikistan.

The SPECA Report (UN, 2000) estimates the river flow of Tajikistan as an average long-term flow for three cycles of water availability over 1943-1992: Pyandj River flow at 34.289 km^3/year, of which Tajikistan - 31.089 km^3/year; Vakhsh River flow at 20.004 km^3/year, of which Tajikistan - 18.4 km^3/year and the Kyrgyz Republic – 1.604 km^3/year; Kafirnigan River flow at 5.452 km^3/year and Surkhandarya River flow at 3.324 km^3/year, of which Tajikistan - 0.32 km^3/year and Uzbekistan – 3.004 km^3/year. The SPECA's assessment shows a flow volume of 79.28 km^3/year for the Big Amudarya Basin (which includes Zarafshan) that is comparable with the figures indicated in the Master Plan of Multipurpose Water Use and Conservation in the Amudarya Basin of 1984 (79.4 km^3/year).

The "Water Sector Strategy of the Republic of Tajikistan" (2008) estimates the average annual river flow of Tajikistan in the Amudarya Basin at 62.9 km^3/year, i.e. 7.64 km^3/year more than in the SPECA assessment. One of the reasons of this difference is that the SPECA assessment does not account all water resources. Whereas the river flow in the Kafirnigan Basin is accounted in this assessment by the sum of flow in watercourses in the catchment area measured at gauging stations located close to mountain outlet, the river flow in the Pyandj River is accounted only by the Lower Pyandj section (estuary), and the flow of the Vakhsh River is accounted by the Nurek HEPS point only. For estimation of the natural flow of the Pyandj River, one needs to add to this flow at the key section (the Lower Pyandj section in our case) the consumptive water use (i.e. water withdrawal minus discharge) upstream of this section in irrigated fields of the Kuzylsu-Yakhsu Basin and GBAR river basins. Similarly, for the Vakhsh River basin the water use by Garm irrigation system located upstream of the Nurek HEPS and the water use in the Kyzylsu River basin (Kyrgyzstan) is not counted; also, lateral inflow to the Vakhsh River downstream of Nurek reservoir is not counted. On the contrary, all these specificities of flow formation in the Amudarya Basin are considered in modeling the river network and in calculation of the water balance of transboundary rivers and local sources (Kyzylsu-Yakhsu rivers, GBAR, Garm district group, Kyzylsu river basin, etc.).

<u>Assessment of water resources in the Kyrgyz Republic</u>

In the Amudarya Basin the Kyrgyz Republic occupies a part of basin of the Pyandj River – its tributary Kyzyl-Su. The river flow is estimated at 1.604 km^3/year (UN, 2000).

<u>Assessment of water resources in Afghanistan</u>

In the water management scheme of the Amudarya Basin the Kunduz River, left tributary of Amudarya, is considered separately. The Kokcha River is accounted as one of components of the Pyandj River. The Afghanistan's rivers, Murghab and Herirud (Tedzhen) are accounted in the water balance of planning zones located in Turkmenistan.

Kokcha and Kunduz refer to the rivers that flow through northeast Afghanistan. Observations until 1985 (Garbovskiy E.A., 1989) indicated to the average flow of the Kokcha River at estuary section Khodzhagar of 199 m^3/s or 6.28 km^3/year and to the average flow of the Kunduz River at estuary section Kulukh-Tepa of 111 m^3/s or 3.5 km^3/year. The weighted average elevations of the river basins in relation to these sections are 2,730 m and 2,400 m for Kokcha and Kunduz, respectively. V.A.Shultz (1968) estimated flow of the Kunduz River at 3.62 km^3/year and that of the Kokcha River at 5.4 km^3/year.

Irrigation water withdrawal in 1985 was estimated at 54 m^3/s or 1.7 km^3/year in the Kunduz Basin (Garbovskiy E.A., 1989) and at 12 m^3/s or 0.38 km^3/year in the Kokcha Basin. Total water withdrawal from the two rivers is: 1.7 + 0.38 = 2.08 km^3/year. By knowing the volume of water withdrawal and the river flow in estuaries, one may calculate the natural river flow: 111 + 54 =

165 m^3/s or 5.2 km^3/year for the Kunduz River and 199 + 12 = 211 m^3/s or 6.65 km^3/year for the Kokcha River.

The weighted average elevation of the Murghab Basin up to the boundary with Turkmenistan is 1,760 m, while that of the Herirud Basin is 1,870 m, i.e. lower than Kokcha and Kunduz. The flow of the Murghab River is measured in several sections; Balamurgan section is closest one to Turkmenistan. The flow of Murghab in this section was estimated (Garbovskiy E.A., 1989) at 53.7 m^3/s or 1.69 km^3/year. Taking into account irrigation withdrawal (5.4 m^3/s), the natural flow of Murghab is 59.1 m^3/s or 1.86 km^3/year. The flow of the Herirud (Tedzhen) River up to the boundary with Iran is estimated at 30.7 m^3/s or 0.97 km^3/year at Tirpul' section. The same figure is indicated in V.L.Shultz (1968) and E.A.Garbovskiy (1989). With allowance for irrigation, the natural flow of Herirud (Tedzhen) is estimated at 69 m^3/s or 2.17 km^3/year, i.e. water content in the river in its natural status exceeds that of the Murghab River. The total natural flow of Murghab and Tedzhen is estimated at 1.86 + 2.17 = 4.03 km^3/year.

The publication "Afghanistan: back to peaceful life. Development trends and regional cooperation areas. Glance from Central Asia" (SIC ICWC, 2007) provides the data from various sources on the flow of Afghanistan's rivers for Amudarya and Preturkmen zones: Kunduz River - 3.6 km^3/year; Kokcha River - 5.4…5.7 km^3/year; Murghab River - 1.6 km^3/year; Herirud River - 0.97 km^3/year. The data characterizes the flow of Afghanistan's rivers as disturbed by anthropogenic impacts.

Assessment of water resources in Turkmenistan

In the PEER research the Murghab and Tedzhen rivers are considered in the assessment of planning zones' water balances. The Atrek River and small, in terms of water availability, rivers in northeastern slope of Kopet-Dag mountain range are not included in calculations as the former refers to the Caspian basin.

Within the boundaries of Turkmenistan the flow in the Murghab River is measured in several sections, the closest one to Afghanistan being the Sein-Aly section; the flow in this section is estimated (Garbovskiy E.A., 1989) at 47.9 m^3/s or 1.51 km^3/year, and, with allowance for irrigation, at 50 m^3/s or 1.58 km^3/year. Rivers of Kushk (4.5 m^3/s) and Kashan (6.5 m^3/s) join the Murghab River downstream the Sein-Aly section in Turkmenistan. Thus, natural water resources in the Murghab Basin in Turkmenistan (with account of water withdrawal by Afghanistan in 1985) can be equal to 50 + 4.5 + 6.5 = 61 m^3/s or 1.91 km^3/year. Flow in the Herirud (Tedzhen) River is estimated at the section, which is downstream of Pulikhatum bridge; based on the data over 1914-1959, the average annual river flow amounts to 32.3 m^3/s or 1.02 km^3/year (V.A.Shultz, 1968). The total flow of Murghab and Tedzhen is 1.91 + 1.02 = 2.93 km^3/year.

Assessment of water resources in the Republic of Uzbekistan

In the scheme of flow regulation and distribution water resources in the Republic of Uzbekistan include the flow in transboundary Amudarya River in its upper (up to section upstream of Garagumdarya), middle (to TMHS) and lower reaches. Water balances of planning zones count: water resources of Surkhandarya and Sherabad basins; and, part of flow in Kashkadarya (Karshi zone) and Zarafshan (Karshi and Navoiy planning zones) rivers. The Diagnostic report "Rational and Efficient Use of Water Resources in Central Asia" prepared by the Special Programme for the Economies of Central Asia (UN, 2000) estimates the total flow of Surkhandarya and Sherabad rivers at 3.32 km^3/year, of which: Tajikistan - 0.32 km^3/year; Uzbekistan - 3.00 km^3/year. The flow of the Kashkadarya River is estimated at 1.23 km^3/year, while that of the Zarafshan River at 5.14 km^3/year (of which Uzbekistan has 4.64 km^3/year). This SPECA assessment is comparable with SIC's assessment, which is based on the analysis of historical river flow series for the Aral Sea basin until 1999: water resources equal 3.4 km^3/year in Surkhandarya basin, 1.3 km^3/year in Kashkadarya basin, and 5.2 km^3/year in Zarafshan basin.

Reconstruction of river flow series

SIC's database collects the data on water resources for all major rivers in Amudarya Basin over the hydrological years 1932/1933-1998/1999 (that start since October 1 and end by September 30). Besides, as part of the PEER Project, the data was collected on the rivers of the Republic of Uzbekistan, Vakhsh River flow at Darbanbeh gauging station (previously named as Komsomolabad) and Amudarya River flow from 1999/2000 to 2014/2015. For the users in Turkmenistan and Uzbekistan who receive Amudarya water the major monitoring points are the gauging stations of Termez and Atamyrat (previously named as Kerki) in the river middle reaches and those of Darganata, Tuyamuyun, and Samanbai in the lower reaches.
As assigned by ICWC, for planning and analysis of water distribution along the Amudarya River, BWO Amudarya and SIC ICWC make assessment of the river's natural flow at Atamyrat gauging station upstream of Garagumdarya. Based on the value of flow at this station, one may judge about water resources in Amudarya in the location, which is upstream of water intake to Garagumdarya (previously named as Karakum canal). The value of flow at this station is calculated from the flow measured at Atamyrat gauging station plus measured water intake to Garagumdarya (Turkmenistan) and Karshi main canal (Uzbekistan).
If one adds to the river flow at Atamyrat upstream of Garagumdarya the consumptive water use, which takes place upstream of this station, including basins of Surkhandarya, Kafirnigan, Vakhsh, Pyandj and (if possible) Kunduz, we will get the flow for small Amudarya basin; if one adjusts this flow for regulation by the Nurek reservoir (i.e. subtract the regulation effect of the reservoir), we may get the natural flow of the Amudarya River. This is the procedure followed by BWO Amudarya and SIC ICWC in their estimations of rivers' water availability.
For the PEER project purposes, the natural flow of Amudarya Rivers estimated at Atamyrat upstream of Garagumdarya is considered as the base one for reconstruction of flow series for Pyandj, Kafirnigan, Surkhandarya, and Kunduz rivers for the time period 1999/2000–2014/2015. The reconstruction procedure is as follows: relationships between the annual flows of river basins and the natural flow of Amudarya are plotted based on historical data (see Figures 1.1 – 1.4); then, using these relationships, annual river flows are calculated for 1999/2000 – 2014/2015; the annual river flows are converted into average monthly flow rates to which end the typical hydrographs of annual distribution plotted for various flow conditions are used.
The annual flow of Kafirnigan River over 1999/2000 – 2014/2015 was reconstructed proceeding from its relationship with the annual flow of Vakhsh River; the annual flows of Surkhandarya and Kunduz rivers were reconstructed proceeding from their relationships with that of Kafirnigan River; the annual natural flow of Amudarya River over 1999/2000–2014/2015 was calculated through the balance method by using the data on measured river flow rates at Kerki gauging station, statistics on water withdrawals upstream of Kerki, flow regulation by the Nurek reservoir, return flow, and water losses (expert estimates); the annual flow of Pyandj River was calculated through the balance method as the difference between the natural flow of Amudarya and the sum of flows of Vakhsh, Kafirnigan, Surkhandarya, and Kunduz rivers.

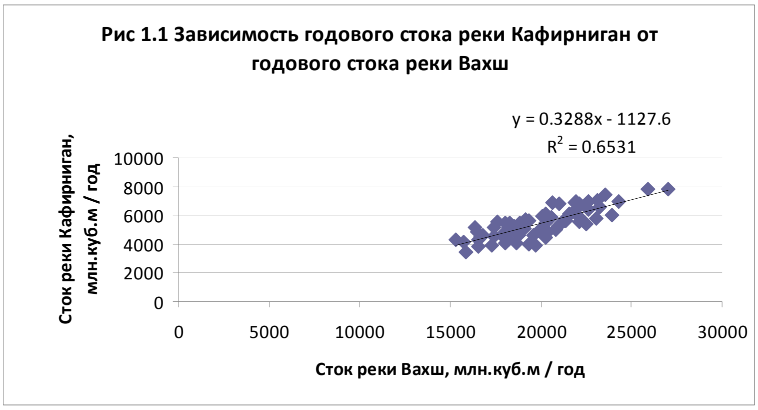

Fig.1.1. Relationship between the annual flow of Kafirnigan River and the annual flow of Vakhsh River

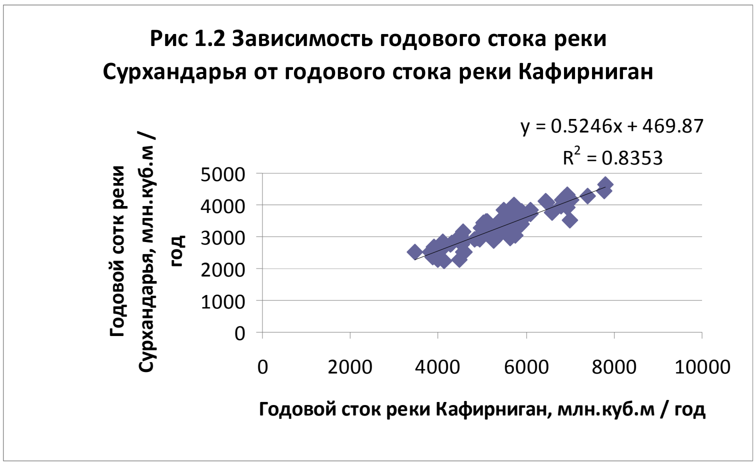

Fig.1.2. Relationship between the annual flow of Surkhandarya River and the annual flow of Kafirnigan River

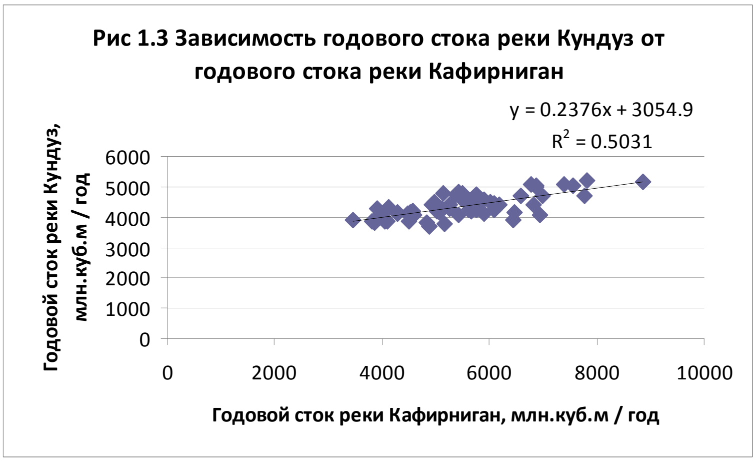

Fig.1.3. Relationship between the annual flow of Kunduz River and the annual flow of Kafirnigan River

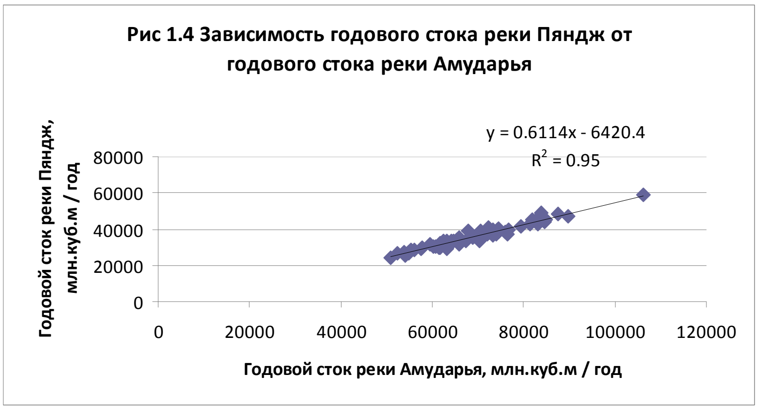

Fig.1.4. Relationship between the annual flow of Pyandj River and the annual flow of Amudarya River

Assessment of Amudarya water resources

The Amudarya is the largest river in Central Asia. The river flows along the northern part of Afghanistan, Tajikistan, and Turkmenistan, through a large part of Uzbekistan and small area in the upstream in Kyrgyzstan; its catchment area is 309,000 km^2 and the length from the Pyandj headstream is more than 2,540 km. The main tributaries are Vakhsh and Pyandj, and further down the river is joined by right tributaries, the Kafirnigan, the Surkhandarya, and the Sherabad, and one left tributary, Kunduz, from Afghanistan. Downstream of Atamyrat gauging station the river is not joined by a single tributary, except for collector-drainage water discharged into the river.

Melting snow and glaciers are the source of water for the Amudarya. Therefore, its natural hydrograph coincides in time with irrigation needs, i.e. the strongest flow is in April-September (up to 80%). From Atamyrat to the delta, the Amudarya loses a large part of its flow (including through evaporation and filtration), although there is inflow in some sections (Il'chik-Darganata), i.e. interaction of the river channel with groundwater and resulting water exchange depending on water availability and site hydrology.

First comprehensive water assessments of Small Amudarya Basin (SAB), i.e. of the Amudarya as the sum of its tributaries, Vakhsh, Pyandj, Kafirnigan, Surkhandarya, and Kunduz, given no significant anthropogenic impact (i.e. natural condition), were made by the Central Asian branch of the Hydroproject Institute in 1971 during development of the Comprehensive Master Plan for the Amudarya River basin (SAOhydroproject, 1971) and by the Sredazgiprovodkhlopok Institute while developing the Master Plan for multipurpose water use in the Aral Sea Basin (Sredazgiprovodkhlopok, 1973). The results of assessments virtually were the same. The average annual flow of the Amudarya (as the sum of its tributaries in their natural condition) was 67.94 km^3/year in the first work and 68.2 km^3/year in the second work.

Re-assessments of water resources were undertaken by SAOhydroproject in 1983 and Sredazgiprovodkhlopok in 1984 during refinement of the Master Plan for the Amudarya River basin (Sredazgiprovodkhlopok, 1984). According to SAOhydroproject's estimations (SAOhydroproject, 1983), water resources in SAB were equal to 68.6 km^3/year, while Sredazgiprovodkhlopok estimated water resources at 66.32 km^3/year (Sredazgiprovodkhlopok, 1984), i.e. 2.28 km^3/year lower. This difference is caused by the methods used in the assessments: in the first case water resources were estimated through key river sections in the main channel plus water use, while in the second case the estimation was based on the sum of flows measured at gauging stations located close to mountain outlet. It seems that the first method is more reliable as the second one does not count inflow to the river from the territories located further down from the gauging stations.

These official assessments characterize the natural flow for the time period till the mid 80-ies. Research work by SANIIRI (Sorokin A.G., 1994) and SIC ICWC allows making assessment of the river flow until 2000. According to SANIIRI's data (Sorokin A.G., 1994), the average annual flow of the Amudarya River for 1911-1993 is estimated at 69.7 km^3/year, while from the SIC's data (selection from SIC's DB for 1932 - 2000) it is 69.23 km^3/year. Further research made as part of the PEER Project allows making assessments until 2016.

The reconstructed flow series for Amudarya basin over 1999/2000–2014/2015 are shown in Figures 1.5, 1.6, and 1.7. Figure 1.8 shows dynamics of annual natural flow of the Amudarya River over 1932/1933 – 2014/2015, while Figure 1.9 shows the flow of rivers that form the cumulative flow of the Amudarya.

Analysis of these data indicates to somewhat downward trend of annual Amudarya flow over 1932/1933 – 2014/2015; the annual flow decreased by 0.8 % in this period of time.

The comparison of the data on annual river flow in Amudarya basin for different periods of time and data sources is given in Table 1.1.

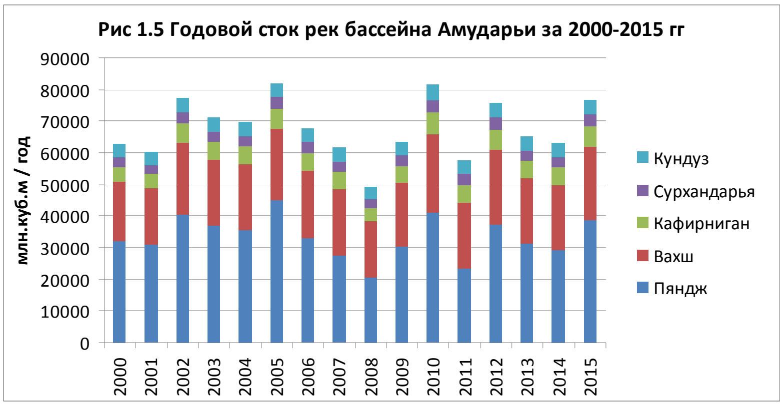

Fig. 1.5. Annual river flow in Amudarya basin over 2000-2015

Fig. 1.6. Annual flow of Amudarya River over 2000-2015

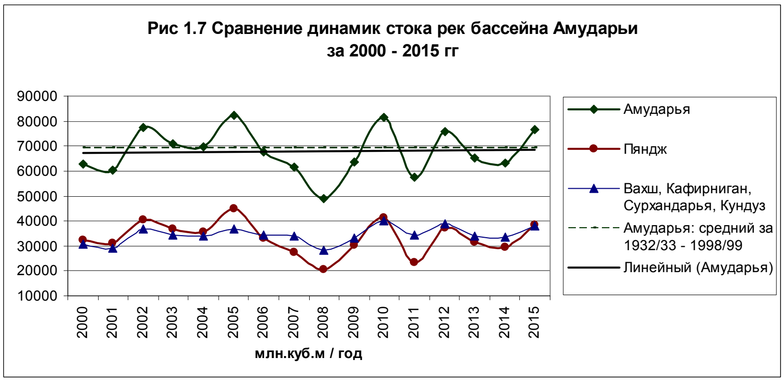

Fig. 1.7. Comparison of river flow dynamics in Amudarya basin, 2000-2015

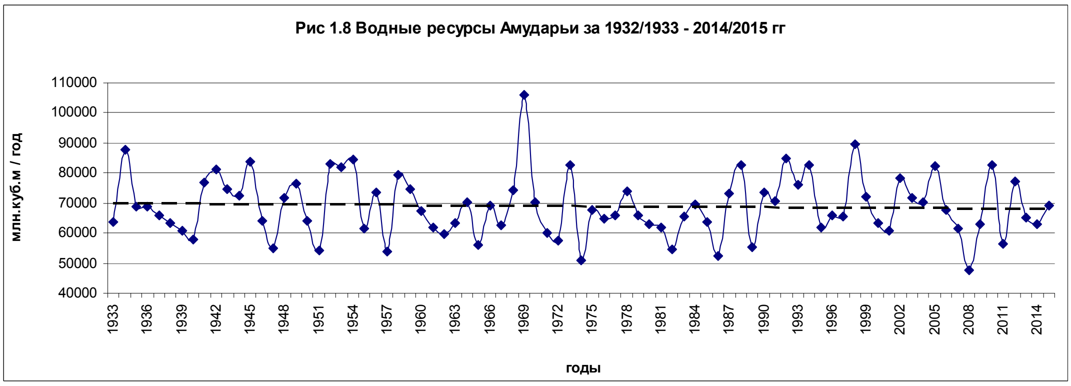

Fig. 1.8. Water resources of Amudarya over 1932/1933-2014/2015

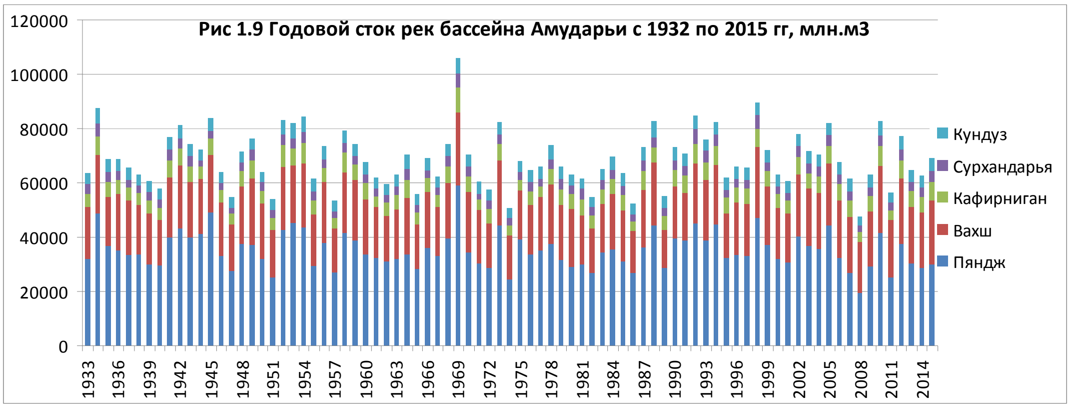

Fig.1.9. Annual river flow in Amudarya basin from 1932 to 2015, million m^3

Table 1.1 Comparison of data on annual river flow in Amudarya basin for different periods of time and data sources

Parameter	Period	Data source	Unit	Pyandj	Vakhsh	Kafir-nigan	Surkhan-darya	Kunduz	Amudarya (sum of rivers)
Average long-term river flow	1932/1933 - 1998/1999	SIC's DB	km^3/year	35.91	19.99	5.51	3.38	4.44	69.23
	1999/2000 - 2014/2015	PEER	km^3/year	33.39	21.12	5.61	3.38	4.34	67.84
	1932/1933 - 2014/2016	SIC ICWC / PEER	km^3/year	35.43	20.21	5.53	3.38	4.42	68.97
	data until 1970	SAO Hydroproject, 1972	km^3/year	34.9	20	5.56	3.82	3.66	67.94
Changes in annual flow for periods of time	1999-2016 against 1932-1999		km^3/year	-2.52	1.13	0.1	0	-0.1	-1.39
			%	-7.0	5.7	1.8	0.0	-2.3	-2.0
	1999-2016 against 1932-2016		km^3/year	-2.04	0.91	0.08	0	-0.08	-1.13
			%	-5.8	4.5	1.4	0.0	-1.8	-1.6

Table 1.1 shows that the average long-term flow of Amudarya River (the sum of rivers, Vakhsh, Pyandj, Kafirnigan, Surkhandarya & Sherabad, and Kunduz) over 1999/2000 - 2014/2015 was lower by 1.39 km3 or 2% than the average long-term flow over 1932/1933 – 1998/1999; the Pyandj, which flow decreased by 2.52 km3 (7%) contributed largely to the lowering of Amudarya flow, whereas the flow of Vakhsh increased by 1.13 km3 (5.7%). The largest 'drop' in Pyandj's water availability was observed in 2008 – down to 20 km3/year, and this was the lowest recorded flow that led to reduction of Amudarya flow (see Figures 1.6, 1.7).
The analysis of Amudarya River flow indicates that the natural (non-regulated) flow of major tributaries, the Pyandj and the Vakhsh, meets very well the irrigation needs. It is characteristic for the Amudarya basin that irrigated and irrigable land in some planning zones is far distant from water sources (head water intakes). This circumstance determines specific formation of water management systems in the basin and construction of seasonal off-stream reservoirs, as well as generation and distribution of collector-drainage water discharged into the Amudarya and lakes through main collecting drains (collectors).

Collector-drainage flow in Amudarya basin

The collector-drainage flow in Amudarya basin is measured mainly in the mouth sections of main collectors (collecting drain). This does not allow counting the whole generated drainage flow; for simulation of drainage flow and all its components, it is necessary: to take into account the time lag, i.e. lagging (if exists) of major phases of CDF increase and decrease from the phases of hydrographs of water intake into canals; separate out an amount of CDF discharged into lakes and depressions and into the river network (Amudarya basin is characterized by 'regulation' of CDF in lakes). In terms of source of generation, CDF should be divided into two components: CDF generated in irrigated fields; and, wastewater from industries, municipal sector, and farms. Such division will help to model correctly CDF generation and distribution in the future, depending on trends in irrigated fields, cropping patterns, industrial growth, population growth, etc. CDF (or its portion) is considered as one of elements of return water, the other elements being sterile spills from canals and residual river flow (lateral inflow).

Most intensive generation of CDF in the Amudarya basin was observed in the 1970s-1980s, i.e. during development of irrigation and construction of drainage systems. In 1980s-1990s, CDF varied depending on water availability. Figures 1.10-1.11 show dynamics of disposal of collector-drainage and wastewater in Amudarya basin, including discharge into the Amudarya River itself. It is clear from the Figures that maximum disposal of CDF is in lower reaches, while the minimum one is in upper reaches. As to dynamics of CDF discharge into the Amudarya River, the picture is different: maximum amount of CDF is discharged in middle reaches, whiles the minimum one is discharged in lower reaches.

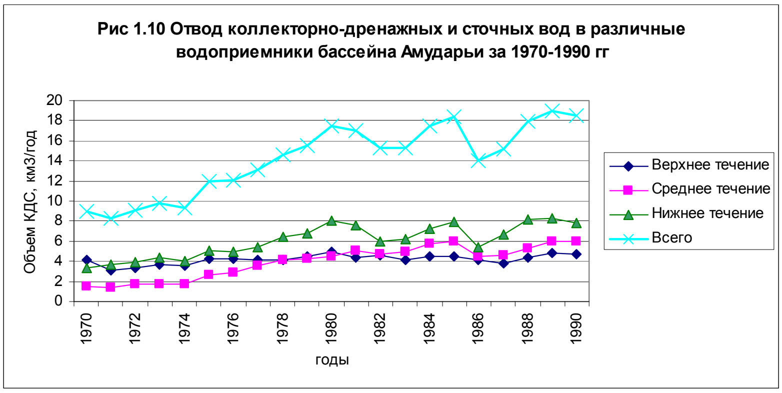

Fig.1.10. Disposal of collector-drainage water and wastewater in Amudarya basin, 1970-1990

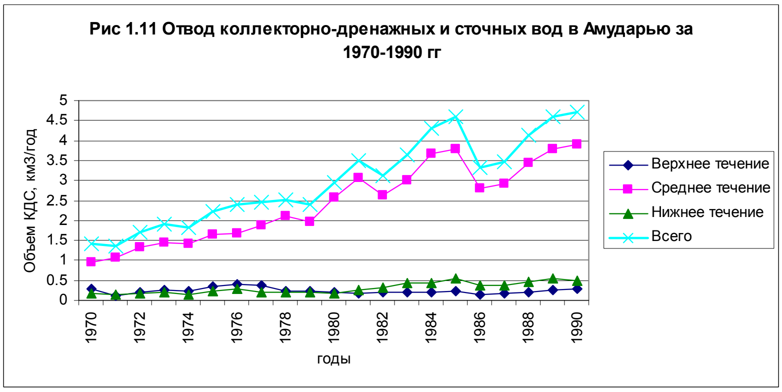

Fig.1.11. Discharge of collector-drainage water and wastewater into the Amudarya, 1970-1990

CDF stopped increasing since 1990 to 2000. By the late 90s the total amount of collector-drainage water and wastewater discharged into the basin's water bodies was 19 km^3/year, and the average CDF was 18.2 km^3/year over 1990-2000, varying from 16 to 19 km^3/year and even decreasing as a whole (main cause – reduced water withdrawal into canals). Table 1.2 gives averaged data over 1990-2000, characterizing formation and disposal of return water in the Amudarya basin (source: Diagnostic report "Rational and efficient use of water resources in Central Asia", SPECA, UN, 2000).

Table 1.2 Formation and disposal of return water in Amudarya basin: average over 1990-2000, km^3/year

Indicator	Tajikistan	Turkmenistan	Uzbekistan	Total, basin
1.Total return flow	2.55	4.05	11.6	18.2
including:				
- CDF from irrigation	2.4	3.8	10.8	17.0
- Sewage water	0.15	0.25	0.8	1.2
2. Re-use	0.07	0.04	2.0	2.11
3. Total discharge	2.48	4.01	9.6	16.09
including:				
- into rivers	2.48	0.91	3.37	8.5
- into depressions	0	3.1	6.23	7.59

There was no such intensive increase in CDF in the basins of Pyandj, Vakhsh, and Kafirnigan over 1970-1990 (see Fig. 1.12). By the late 90s, the total volume of disposal of collector-drainage water and wastewater in Amudarya basin in Tajikistan was 3.35 km^3/year. The volume of return water decreased on average to 2.55 km^3/year over 1990-2000. The current volume of return water in Tajikistan is about 3.5…4.0 km^3/year, including 3.0 km^3 of drainage water from irrigated fields and 0.50 km^3 of municipal and industrial sewage. In Pyandj and Vakhsh basins, CDF is formed through wastewater from irrigated fields (10…20 %) and drainage water. The distribution of return water throughout the territory is as follows: RRS - 19 % of total CDF volume; Khatlon province - 80 %; GBAR - 1 %.

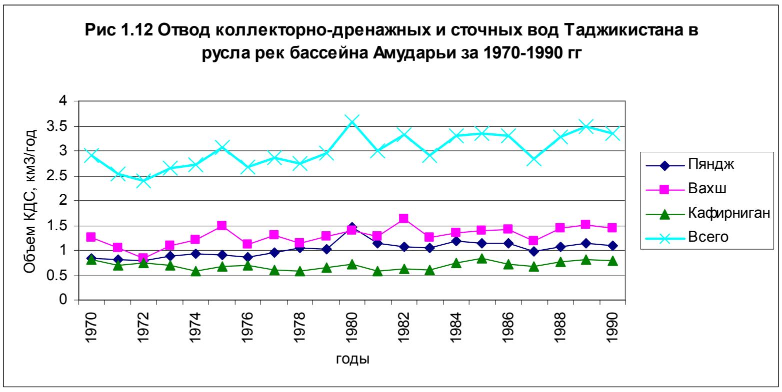

Fig.1.12. Discharge of collector-drainage water and wastewater in Tajikistan into the rivers of Amudarya basin, 1970-1990

Over 2010–2015, return flow in Surkhandarya basin averaged 0.96 km3/year (according to the data collected by the PEER Project); distribution of this flow by year is quite uneven (see Figure below) and depends on basin's water availability. Here, one should separate out: discharge of CDF into the Surkhandarya and its tributaries; discharge of CDF into the Karasu (extension of Sherabad River); and, direct discharge into the Amudarya.

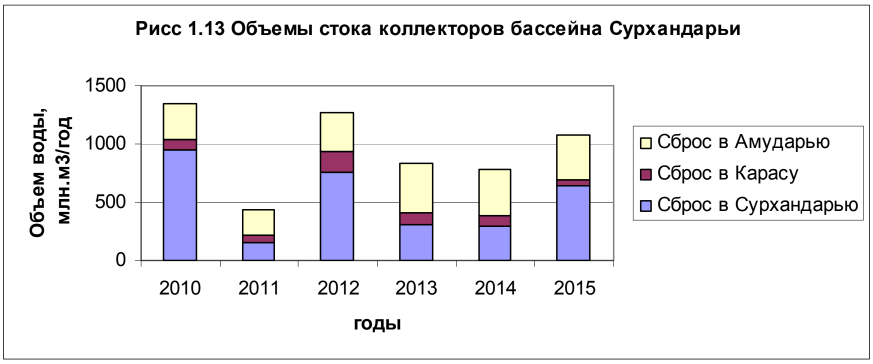

Fig.1.13. Volume of flow from collectors in Surkhandarya basin

In its middle reaches, the Amudarya receives CDF from Karshi PZ through South collector, from Bukhara PZ through Parsankul spillway (from Solenoye lake) and through collectors of Lebap PZ (Turkmenistan). Figures 1.14, 1.15 show dynamics of volume of CDF discharged from the collectors of Karshi, Bukhara, and Lebap into the Amudarya over 2010-2015 (data from the PEER Project DB).

The collector system of Bukhara PZ includes, besides Parsankul spillway (Main Bukhara collector):

- North Bukhara collector – brings water to natural depression, Karakyr,
- Central Bukhara collector – drains into the Zarafshan River (Karakuldarya),
- Makhankul' spillway – continued Central Bukhara collector – drains into Solenoye lake,
- West Romitan collector – discharges water into Solenoye lake,
- Parallelniy and Dengizkul' – drain into Dengizkul depression,
- Main Karakul' collector – brings CDF to Solenoye lake.

Thus, only a portion of CDF formed in Bukhara PZ is discharged into the Amudarya River. This complicates forecasting of CDF discharge into the Amudarya since it depends on water withdrawal to PZ, water availability of rivers in PZ, and engineering aspects of CDF transportation (length, flow rate, regulation in lakes) by spillway channels.

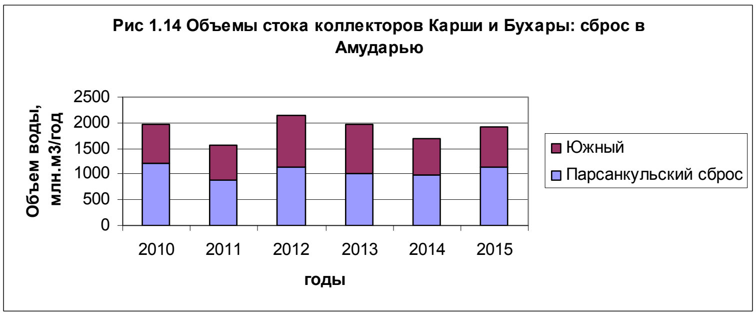

Fig.1.14. Volume of flow in collectors of Karshi and Bukhara: discharge into Amudarya

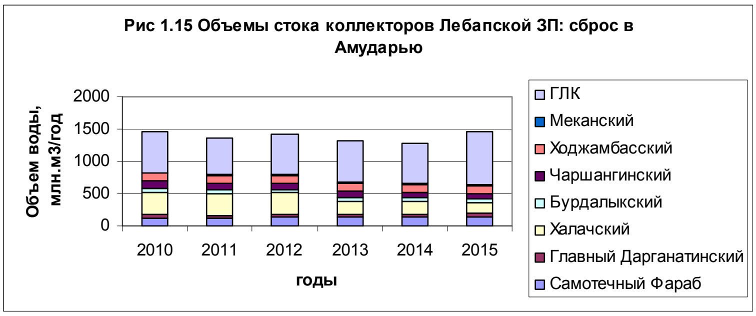

Fig.1.15. Volume of flow in collectors of Lebap PZ: discharge into Amudarya

Major collectors in Khorezm are transboundary collectors Daryalyk and Ozerniy. Daryalyk collector passes through an old channel of Daryalyk and collects water from Divankul', Shavat-Andreyev, Chagat-Ataba and other collectors up to the boundary with Turkmenistan. Ozerniy collector also collects CDF up to the boundary with Turkmenistan and integrates a range of lakes into a single network. Irrigation wastewater from the fields makes significant contribution to these collectors. The junction point of Daryalyk and Ozernie collectors is in the territory of Turkmenistan (Dashoguz PZ). The collectors also receive CDF from Dashoguz PZ and drain into Sarykamysh lake (as one Daryalyk collector after junction).

Collectors in the Republic of Karakalpakstan can be classified into right and left bank collectors. The right-bank collectors include, among others, Main South collector of Karakalpakstan (GUKK), KC-1, and KC-3. Among the left-bank collectors is KKC (Kungrad collector). This collector brings water to Sudochye lake. KKC is comprised of right branch and Main left-bank collector.

Figures 1.16-1.17 show dynamics of CDF in collectors of Khorezm and Republic of Karakalpakstan over 2010-2015 (data from PEER Project DB).

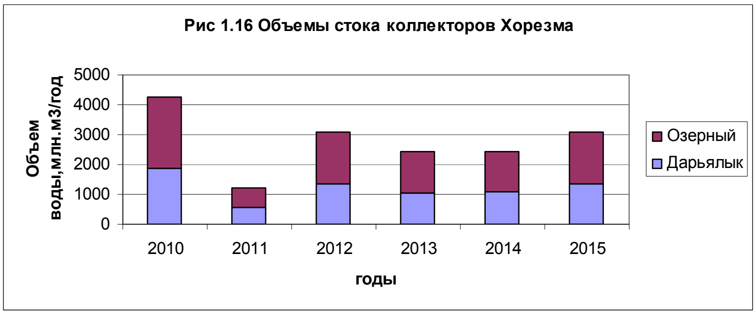

Fig. 1.16. Volume of flow in collectors of Khorezm

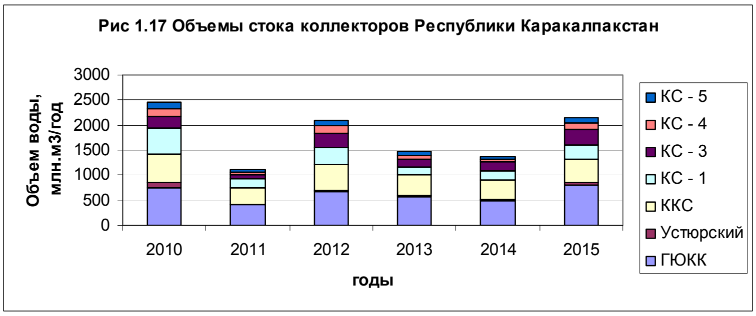

Fig.1.17. Volume of flow in collectors of the Republic of Karakalpakstan

Return water of Turkmenistan (collector-drainage water from irrigated fields and wastewater) can be broken down into planning zones, Lebap, Dashoguz, and Garagumdarya command area (Akhal and Mary PZs). In the PEER Project we do not study the water balance of Balkan PZ (as it refers to the Caspian Sea basin), which includes also return water, but in the water balance of Garagumdarya (former Karakum canal) we must count water supply to Balkan PZ (which may increase in the future).

About 74% of CDF formed in Lebap PZ is discharged into the Amudarya, while the rest of CDF is transported to depressions. Over 2010-2015, about 1.4 km^3/year, on average, of CDF formed in this planning zone was discharged into the Amudarya River and 0.4 km^3/year of this CDF were brought to depressions. CDF is estimated at 0.5 km^3/year in Akhal PZ, 1.3 km^3/year in Mary PZ, 2.2 km^3/year in Dashoguz PZ, and in total at 5.8 km^3/year in Turkmenistan in general, including 1.8 km^3/year in Garagumdarya area. Major collectors include: GKS 1, …, 5, GVSK, K 1, K 5, K 6, and TCK in Akhal PZ; ТЦК; GMK and Djar in Mary PZ; and Daryalyk (about 60 % of CDF in PZ) and Ozerniy in Dashoguz PZ.

<u>Groundwater</u>

Proven groundwater reserves in small Amudarya basin (SAB) were estimated by Sredazgiprovodkhlopok in 1984 at 11.5 km^3 a year, including 0.01 km^3 in Kyrgyzstan, 1.68 km^3 in Tajikistan, 4.08 km^3 in Turkmenistan, and 5.73 km^3 in Uzbekistan.

Groundwater resources can be divided into those naturally formed through rainfall, filtration from water bodies and river channels and those formed by filtration in irrigated land and artificial canals. Groundwater aquifers can be hydraulically connected with the surface water bodies; the surface flow levels drop in case of excessive withdrawal of groundwater. Therefore, limits on the withdrawal of groundwater are imposed for each aquifer. For SAB this limit is estimated (Sredazgiprovodkhlopok, 1984) approximately at 2 km^3, including: Amudarya upper reaches – 0.97 km^3; Lebap zone of Turkmenistan and Garagumdarya area – 0.36 km^3; Karshi and Bukhara zone – 0.39 km^3; and, Amudarya lower reaches – 0.28 km^3. Groundwater is used for drinking and household needs, industry, pasture watering, and irrigation.

Subsequently these limits were revised. The SPECA Diagnostic report (UN, 2000) shows the estimated groundwater reserves approved for use of 2.2 km^3/year for Tajikistan, whereas the Water Sector Strategy of the Republic of Tajikistan (2008) indicates 2.8 km^3/year, of which about 2.0 km^3/year is for the small Amudarya basin (SIC' estimates). The actual groundwater withdrawal by Tajikistan is less than the volume approved for use. For instance, in 1999, Tajikistan used only 45 % of the limit, of which about 55 % for irrigation, 34 % for drinking water supply, and 9 % for industry. Groundwater distribution in Tajikistan is as follows: regions of republican subordination (RRS) - 65 % of total withdrawal by Tajikistan in small Amudarya basin; Khatlon province – 34 %; and, GBAR – 1 %.

Turkmenistan has about 190 freshwater aquifers, of which 75 account for proven groundwater reserves. Present groundwater reserves approved for use are estimated (UN, 2000) at 1.22 km^3/year, of which actual withdrawal (data of 1999) is 37 %, including about 46 % used for irrigation (plus vertical drainage), 45% for drinking water supply, and 8% for industry. Dashoguz PZ uses about 9 % of the total groundwater used in Turkmenistan, and this share of groundwater use out of total withdrawal is 28 % for Mary PZ and 55 % for Akhal PZ.

According to Uzbekgidroingeo's data (as of 2001), proven groundwater reserves in the Amudarya basin in Uzbekistan amount to 9.93 km^3/year, of which freshwater (less than 1 g/l salinity) accounts for 3.11 km^3/year; the groundwater reserves approved for use are estimated approximately at 1 km^3/year. Groundwater distribution in the Uzbek part of Amudarya basin is as follows: Surkhandarya province – 0.2 km^3/year; Kashkadarya province - 0.25 km^3/year; Bukhara and Navoiy provinces - 0.2 km^3/year; Khorezm province and Republic of Karakalpakstan – 0.05 km^3/year. Household and drinking water supply sectors use 56 % of the total groundwater in Surkhandarya and Kashkadarya provinces, 66 % in Bukhara and Navoiy provinces, and 54 % in Khorezm and Republic of Karakalpakstan. Other users are agricultural water supply (20…40 %) and industry.

Withdrawal of groundwater in Amudarya basin is kept within the limits approved for use. Groundwater use also will be within the approved reserves in the future.

Table 1.3 shows dynamics of groundwater withdrawal in the countries of Amudarya basin at present level and for the future, in % of available water resources (analysis of data provided in national report of the Republic of Uzbekistan. Aral Sea Basin Program, Water resources and environment management project, Sub-component A-1. Tashkent, 2001).

Table 1.3 Use of groundwater and collector-drainage water in Amudarya basin, % of available water resources: present level and future (tentatively by 2025)

Republic	**Groundwater use, %**		**CDF use, %**	
	Present level	**Future**	**Present level**	**Future**
Kyrgyzstan	8	10	0	0
Tajikistan	5	7	0	0
Turkmenistan	2	2	10	17
Uzbekistan	3	3	7	13

2. Flow regulation by water reservoirs and HEPS

Flow in Amudarya basin is regulated by river (in-stream and off-stream) and intrasystem (inside irrigation systems) reservoirs. Flow regulation is provided by Vakhsh HEPS cascade on the Vakhsh river and the TMHS reservoirs on the Amudarya. Regulation of Vakhsh and Pyandj rivers is considered in the ASBmm WAm model, while regulation of other rivers is accounted in the ASBmm PZm. Short description of reservoirs in Amudarya basin is given in Annex to this report.

Tajikistan HEPS'

At present, the only reservoir system with hydropower, which significantly affects the intra-annual distribution of flow along the Vakhsh river (and hence that of Amudarya) is the Nurek hydrosystem. Other HEPS of Tajikistan have useful capacities that provide daily and weekly regulation.

Dynamics of cumulative capacity of all HEPS in Tajik part of Amudarya basin is shown in Figure 2.1 over 2010-2015. Energy facilities of Tajikistan in this basin include (as of 2015): Nurek HEPS; Vakhsh HEPS cascade (Baypasin, Golovnaya, Sangtuda 1 and 2); Vakhsh canal HEPS (Perepadnaya, Centralnaya); Varzob HEPS cascade; and, Gunt River HEPS (Pamir, Khorog). These do not include Kairakkum HEPS as it belongs to Syrdarya basin. The total installed capacity of all Tajik HEPS (in Amudarya basin) is estimated at 4.81 GW for 2015. Brief description of all major HEPS in Tajikistan is given in Annex to this report.

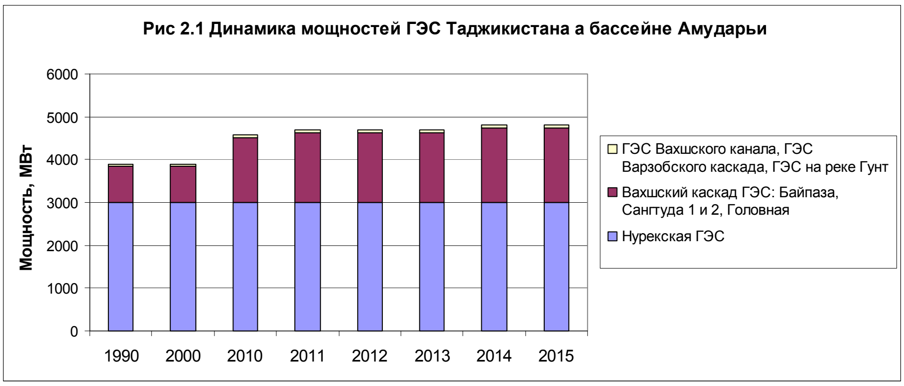

Fig.2.1. Dynamics of HEPS capacities in Tajikistan in Amudarya basin

The capacity of thermal power stations in Tajikistan is estimated at 0.67 GW; this is the total actual capacity of rayon heating systems that generate electricity, including Dushanbe TPS-1 and Yavan TPS. Thus, the total capacity of all electric power stations in the Tajik part of Amudarya basin can be estimated as 5.48 GW for 2015.

Sangtuda HEPS 1 and 2

Sangtuda-1 is located in Khatlon province of Tajikistan, 110 km to the south from the capital of Tajikistan, Dushanbe, and is the largest investment project implemented by the Russian Federation. Construction of Sangtuda-1 lasted four years from 2005 till 2009. First hydroelectric generator started to work in January 2008; the station was put into operation by late July 2009. An open joint stock company "Barki Tojik" ensures transmission, distribution and trade of electric energy generated by HEPS to end users (local population and industries).

Sangtuda-2 is located 120 km southeastward of Dushanbe, has design capacity of 220 MW and is the joint Tajik-Iranian project. Construction of HEPS was started in February 2006. First generator (110 MW) was put into operation in September 2011, and second generator (110 MW) started its operation in September 2013. During 14.5 years since the set-up Sangtuda-2 will be under ownership of Iran, and then it will be transferred to Tajikistan.

Nurek hydrosystem

Nurek hydrosystem for irrigation and energy generation purposes has been operating since 1972. Its major characteristics are: full reservoir level - 910 m; dead storage elevation - 857 m; full volume – 10.5 km^3; useful volume – 4.5 km^3; installed capacity of HEPS – 3,000 thousand KW; head - 223 m. Sedimentation (survey 1990) is estimated at 1.8 km^3, including about 700 Mm^3 within dead storage (below the level of 857 m) and 1.1 km^3 of useful volume (Sredazgiprovodkhlopok's data). The guaranteed average daily winter water releases to tail-water of Nurek hydrosystem are set at 300 m3/s. The allowable rates of drawdown and filling of the reservoir are 0.5 m (900-910 m) and 1.0 (below 900m), respectively. Maximum water releases are 3000 m3/s.

Evaporation from the water surface of Nurek hydrosystem is 1050 mm/year, and the evaporation volume given the average surface area of 98 km^2 is 90 Mm^3/year. This hydrosystem is operated by the company "Barki Tojik".

As designed, the Nurek reservoir is to regulate flow of the Vakhsh River during growing season under compensation (relative to Pyandj) regime for irrigation purposes. The present purposes of this hydrosystem (in order of priority) are: seasonal regulation for Tajikistan's hydropower; water releases for irrigated agriculture during growing season in upper and lower reaches of Amudarya based on ICWC/BWO Amudarya schedule.

Efficiency of flow regulation by Nurek hydrosystem can be assessed by:

- Quantity of generated hydropower in autumn and winter and the electric energy deficit in this period of time,
- Quantity of generated hydropower in growing season and the excess (losses) of electric energy,
- Volume of water releases from the Nurek reservoir during growing season and in autumn-winter and by sterile spills from HEPS.

Efficiency of water management by Nurek hydrosystem can be judged from:

- Comparison of forecast and actual inflow to Nurek reservoir,
- Comparison of planned (BWO Amudarya schedule) and actual water releases from Nurek reservoir.

Figures 2.2 – 2.8 show:

- Hydrographs of inflow to and releases from the Nurek reservoir for 2009-2010; these hydrographs indicate to monthly volume fluctuations, with maximum fluctuations of water releases in growing season (Fig. 2.2, 2.3),
- Dynamics of water releases from the Nurek reservoir over 1987-2014 for July and December; here downward trend of July flow and minor upward trend of December flow can be tracked (Fig. 2.4),
- Comparison by ten-day of forecast (Uzhydromet) and actual inflow to the Nurek reservoir since October 2009 till September 2015; one may note here that forecast inflow exceeds actual one (Fig. 2.5); the average ten-day inflow was 561 Mm3 by forecast, with the forecast error of 54 Mm3/ten-day (or approx.10 %),
- Comparison by ten-day of planned (BWO Amudarya schedule) and actual water releases from the Nurek reservoir since October 2009 till September 2015 (Fig. 2.6); here also one may observe that planned volume of releases is higher than actual one; so, the forecast error is 53 Mm3/ten-day (or approx. 9 %),
- Cumulative curves (cumulative summation) of ten-day difference between actual and planned water releases by season (Fig. 2.7, 2.8); by the end of October-March the cumulative curve takes negative values that indicates to over-planning errors (i.e. plan higher than actual), while in April-September the cumulative curve is going up and takes

positive values by the end of this period, i.e. indicates to under-planning errors (i.e. plan lower than actual); such planning errors is largely the result of inappropriate forecast of water inflow to the Nurek reservoir.

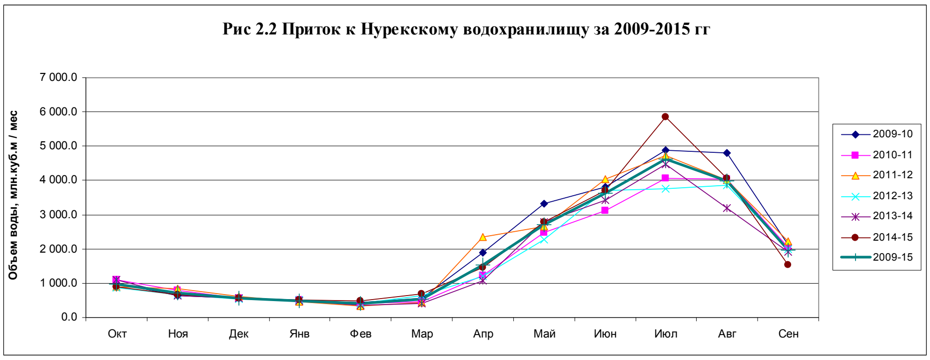

Fig.2.2. Inflow to Nurek reservoir, 2009-2015

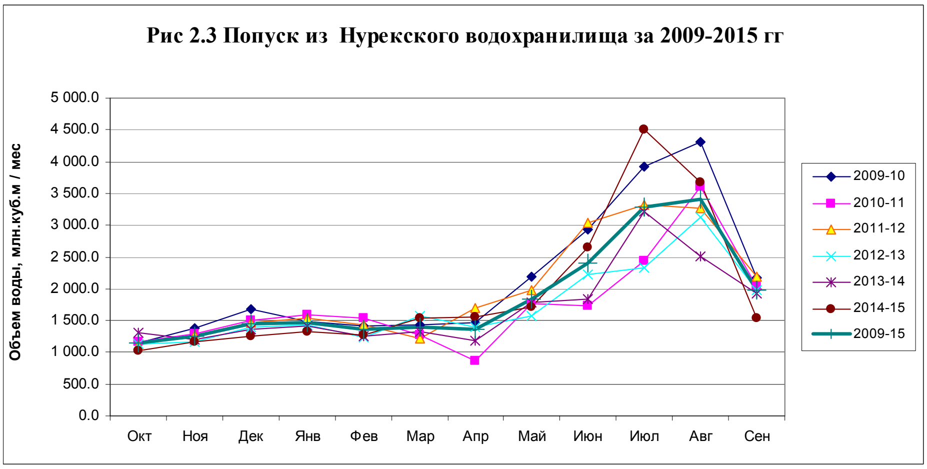

Fig.2.3. Water releases from Nurek reservoir, 2009-2015

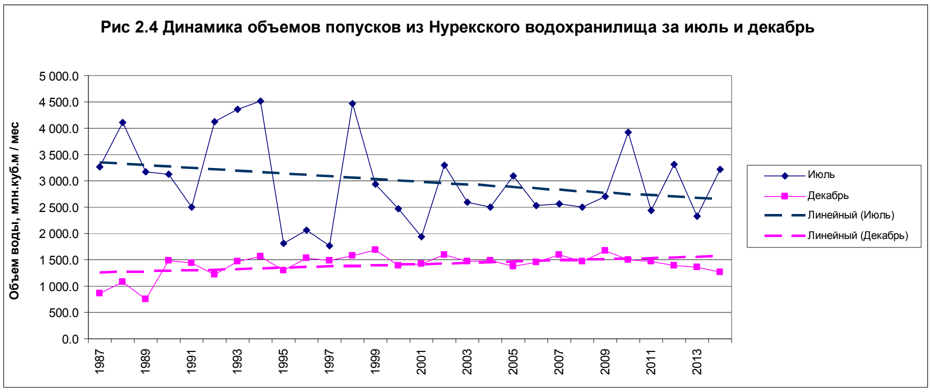

Fig. 2.4. Dynamics of water releases from Nurek reservoir for July and December

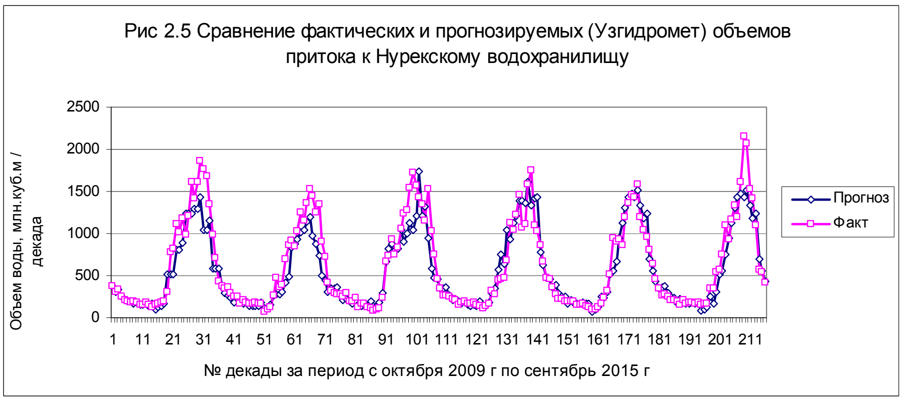

Fig. 2.5. Comparison of actual and forecast volumes of inflow to Nurek reservoir

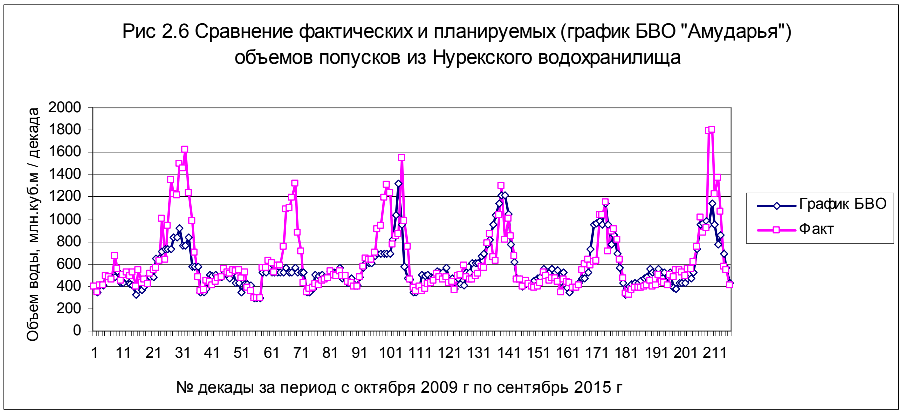

Fig.2.6. Comparison of actual and planned volumes of water releases from Nurek reservoir

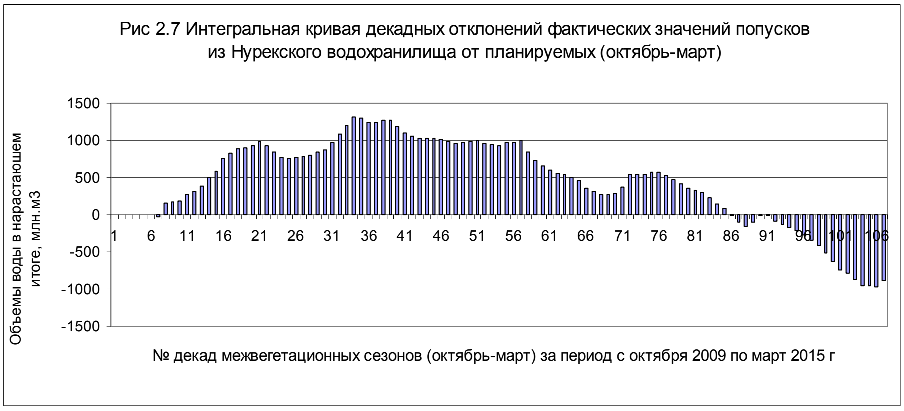

Fig.2.7. Cumulative curve of ten-day differences between actual and planned water releases from Nurek reservoir (October-March)

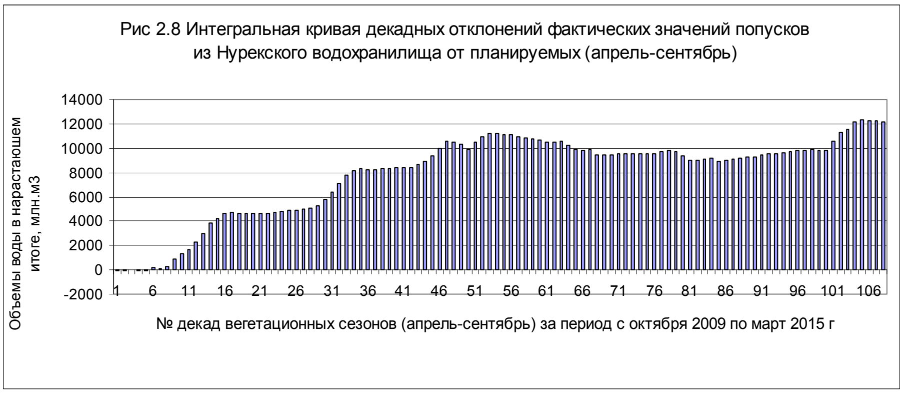

Fig.2.7. Cumulative curve of ten-day differences between actual and planned water releases from Nurek reservoir (April-September)

<u>Multi-year flow regulation by the Nurek reservoir</u>

If we trace dynamics of accumulation in Nurek reservoir from 1992 to 2015 (Fig. 2.9), the following can be noted. Almost every year the reservoir accumulates water to its maximum volume (10.5 km^3) and decreases its storage by early April. Thus, by 1st of August the reservoir performs seasonal regulation, while by 1st of April it provides seasonal (annual) and partially multiyear regulation. The Figure below shows annual volumes of flow regulation, i.e. years of water accumulation (from the Vakhsh River) and years of drawdown (adding of water to the river).

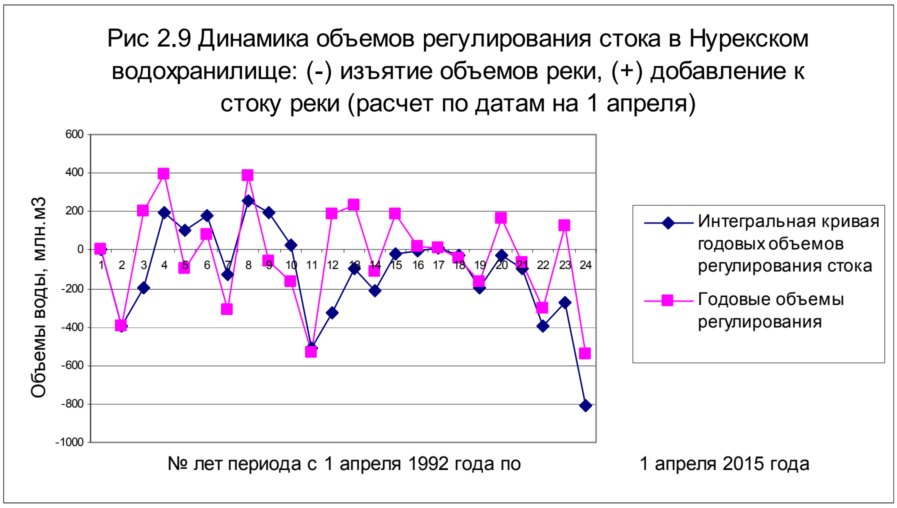

Fig.2.9. Dynamics of flow regulation by Nurek reservoir: (-) intake from the river, (+) adding to river flow (by April 1)

By comparing volumes of multi-year flow regulation with inflow to the reservoir (water availability in the Vahksh River), one may observe: the reservoir can decrease its storage in wet year and accumulate water in dry year, i.e. there is inefficient management in terms of irrigation and hydropower. Moreover, the following pattern is found (see Fig. 2.10): the higher is inflow to the Nurek reservoir, the larger is the decrease of multi-year storage of the reservoir, and the lower is inflow (and accordingly water availability of Vakhsh), the larger is the accumulation in the reservoir and additional intake of water from the Vakhsh River.

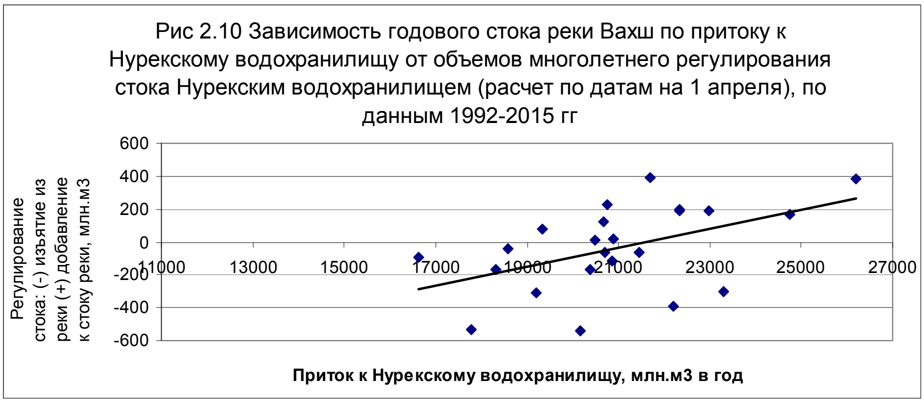

Fig. 2.10. Dependence of annual flow in Vakhsh River on volumes of multi-year flow regulation, 1992-2015

Fig. 2.11 shows dynamics of water abstraction from the Vakhsh River by Nurek reservoir for accumulation of water. There is an upward trend of water abstraction that distorted the natural flow of the Vakhsh River over 1991–2015. The maximum monthly volume of abstraction during growing season reaches 2.5 km^3.

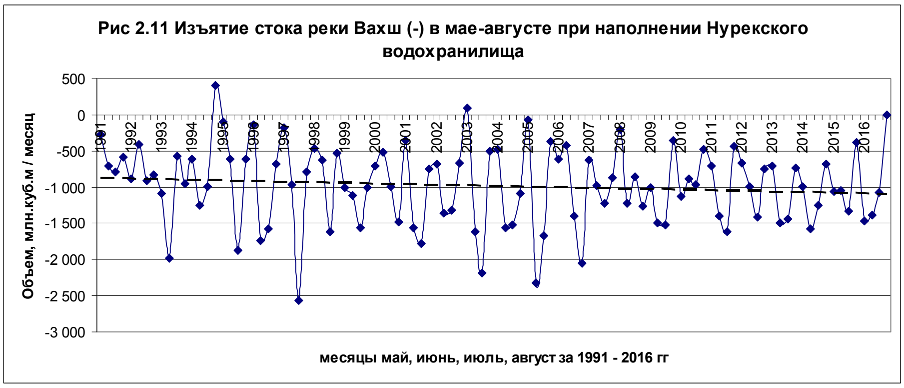

Fig.2.11. Abstraction of water from Vakhsh River (-) in May-August during accumulation in Nurek reservoir

<u>Sterile spills</u>

The analysis of Nurek HEPS operation made by G.N.Petrov (2009) in his monograph "Optimizing operation of hydropower reservoir units" shows that sterile spills from Nurek hydrosystem over 1991 - 2005 were as follows: 2.74 km3 (1992), 1.95 km3 (1993), 4.07 km3 (1994), 0.5 km3 (1995), 1.89 km3 (1996), 1.74 km3 (1997), 2.57 km3 (1999), 0.3 km (2000), 3.26 km3 (2002), 0.9 km3 (2003), 0.2 km3 (2004), and 1.3 km3 (2005). The author shows that sterile spills can be excluded when annual inflow to Nurek is below 21 km3 a year.

The conclusions made by G.N.Petrov are proven by our calculations. Moreover, we can outline several elements of sterile spills:

- Sterile spills caused by engineering limitations (carrying capacity of units, installed capacity) – in our estimations, over 2010 – 2019 the sterile spills at Nurek HEPS reached: 530 m^3/s (third ten-day of September 2010), 283 m^3/s (second ten-day of August 2012), 725 m^3/s (second ten-day of July 2015).
- Sterile spills depending on excess capacity of HEPS (such excess is determined from the difference between design potential generation and demand for electric energy).

Figures 2.12 – 2.14 show examples of daily operation regimes of Nurek HEPS for August and September 2014 (processed CDC "Energy"data): HEPS discharge, sterile spills and energy losses through sterile spills.

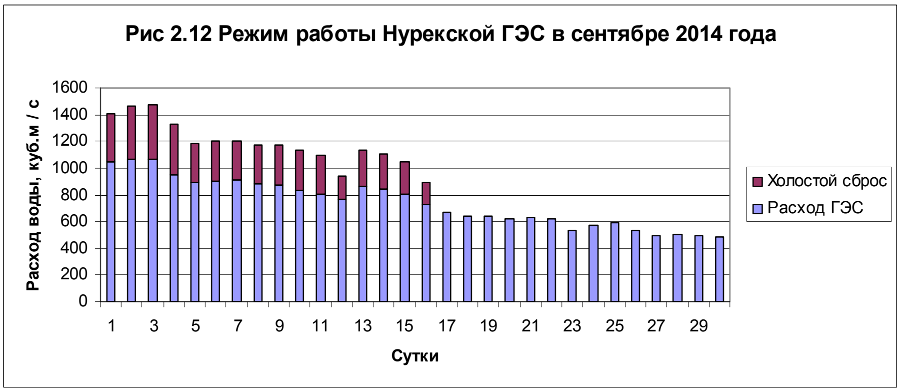

Fig.2.12. Operation regime of Nurek HEPS in September 2014

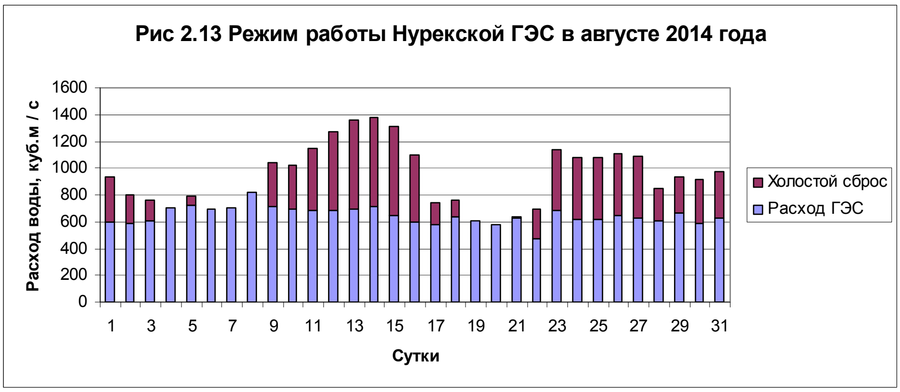

Fig.2.13. Operation regime of Nurek HEPS in August 2014

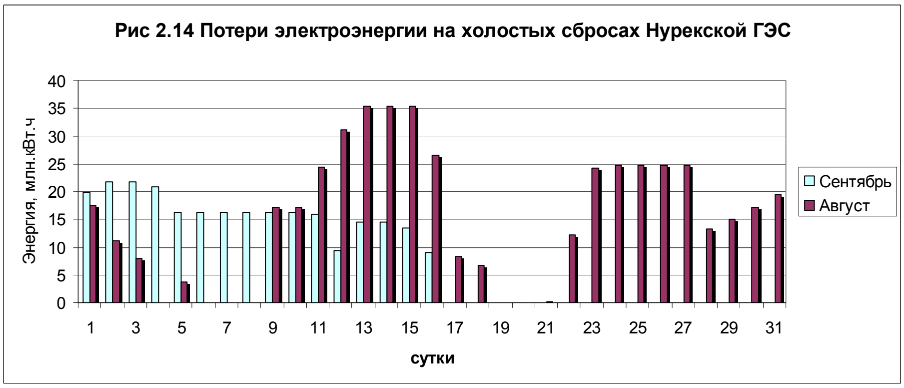

Fig.2.14. Energy losses through sterile spills of Nurek HEPS

<u>Tuyamuyun hydrosystem</u>

The importance of Tuyamuyun hydrosystem (TMHS) as a regulating unit has increased in 20 years in light of growing water deficit and poor capacity of the Nurek reservoir to mitigate summer water deficit in middle and lower reaches.

TMHS is located at the tail of the Vakhsh-Amudarya cascade; it is comprised of in-stream and three off-stream reservoirs, and HEPS.

Sedimentation of in-stream reservoir (1992 survey) is estimated at 0.7 km^3, including within the dead storage volume (i.e. below 120 m) at 0.2 km3. The present level of sedimentation is estimated at 1…1.2 km^3 and depends on operation regime, which implies accumulation, intensive drawdown, and flushing.

In engineering terms, the real potential for regulation of Amudarya flow is currently determined mainly by volumes of Nurek and TMHS reservoirs. The total regulation capacity of those reservoirs is estimated at 7.5 km^3 only.

Main functions of TMHS are:

- intra-annual (seasonal) transformation of inflow (to facility) hydrograph to the benefit of irrigation, based on demand of irrigation systems in lower reaches – Khorezm, Karakalpakstan (Uzbekistan), and Dashovuz (Turkmenistan);
- accumulation of slightly saline water in Kaparas reservoir for its use for drinking water supply in the lower reaches;
- control of floods.

Many years of TMHS operation set a number of restrictions to be kept: it is prohibited to drawdown reservoirs with a rate of more than 1 m per day; intensity of changes in discharge must be within admissible limits, especially during freezing-over; storage of off-stream reservoirs should not be decreased lower than 126 m as otherwise this will cause mixing of water masses and lift of salt water to upper horizons.

As designed, drawdown of TMHS starts during spring leaching irrigation. Water is accumulated in autumn and winter through guaranteed water releases from Vakhsh reservoirs and excess of river flow. According to operational rules of TMHS, its reservoirs are filled in September-my and decrease their storage in June-August.

Figures 2.15 – 2.18 show:

- Dynamics of water volume, inflow, and releases of TMHS since October 2009 till September 2015,
- Dynamics of water volume, inflow, and releases of TMHS in dry periods (October 1999 – September 2001; October 2007 – September 2008).

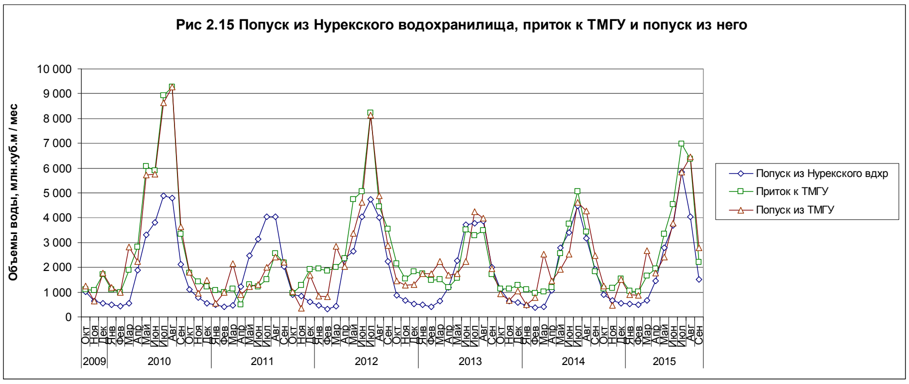

Fig.2.15. Water releases from Nurek reservoir, inflow to and releases from TMHS

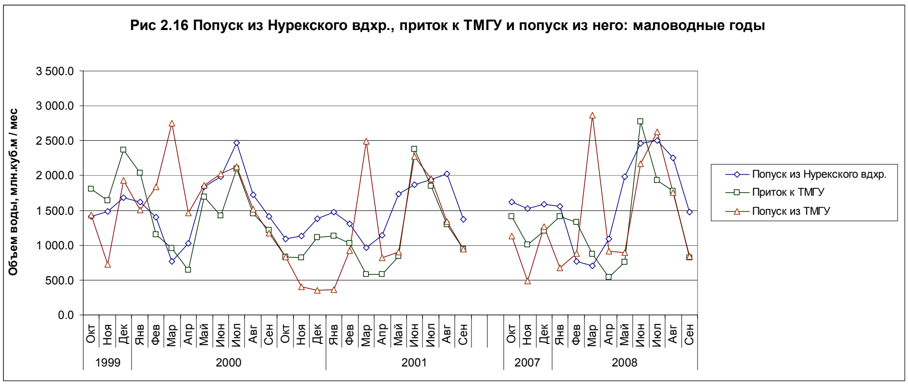

Fig.2.16. Water releases from Nurek reservoir, inflow to and releases from TMHS: dry years

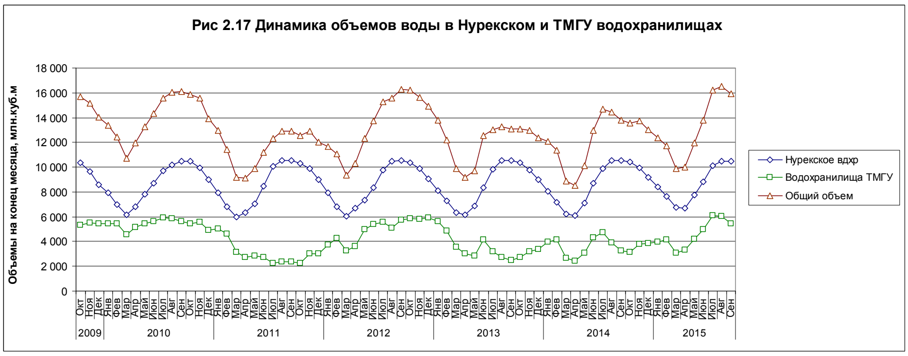

Fig.2.17. Dynamics of water volume in Nurek and TMHS reservoirs

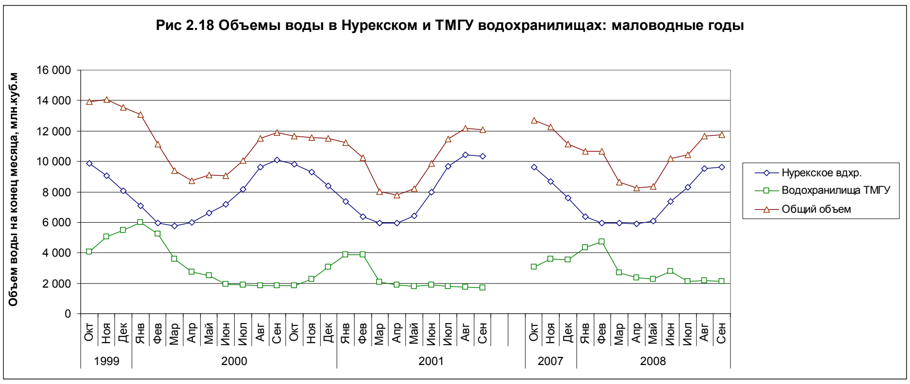

Fig.2.18. Water volumes in Nurek and TMHS reservoirs: dry years

There are the following specifics of flow regulation during dry periods:

- Lowest inflow to TMHS is observed in March-April; Nurek reservoir discharges lowest water volume in the same period;
- Since late May, inflow to TMHS increases and reaches its maximum in June; since July, inflow to TMW TMHS F and water releases from Nurek reservoir decrease;
- Maximum water releases from TMHS reservoirs are in April (inflow to TMHS and water releases from Nurek reservoir are minimal), and next peak of water releases (somewhat lower) from TMHS is in June-July.

Intrasystem reservoirs

As part of the PEER Project, intrasystem reservoirs located along the canals of planning zones were studied. The following reservoirs were considered: intrasystem reservoirs in Amudarya lower reaches – in Tajikistan and Surkhandarya basin (Uzbekistan); those in Amudarya middle reaches – Garagumdarya command area, Lebap, Mary, and Akhal planning zones (Zeid, Khauzkhan, Kopetdag, Madlus, and other reservoirs), reservoirs of Karshi canal and Karshi planning zone (Talimarjan, Shorsai), and reservoirs of Amu-Bukhara main canal (Uchkyzyl).

Reservoirs located along the rivers of planning zones are in water balances of planning zones. Those include reservoirs along the Surkhandarya (Tupalang, Yuzhnosurkhan), the Tedzhen (Tedzhen 1,2, and Dostlun), and the Murghab (Tashkepri, Saryzain).

Zeid reservoir is located at the head of Garagumdarya (Karakum canal), has useful capacity of 2 km^3, the surface area at full reservoir level of 465 km^2. It is designed to compensate deficit of flow in the area of Karakum canal, mainly during autumn and winter leaching irrigation. Besides, it was supposed that conveyance of flow through the reservoir would clarify water in the Karakum canal, with consequent saving of operational costs of pump cleaning. Evaporation rate in the area of reservoir is 2,155 mm of water column per year, while the total sedimentation is 205 mm only. Evaporation losses under full sedimentation are 800 Mm^3.

Uchkyzyl reservoir is located in Surkhandarya lower reaches. It is designed as off-stream reservoir for seasonal flow regulation for irrigation, with the full volume of 160 Mm^3 and the useful volume of 80 Mm^3. The reservoir accumulates autumn-winter flow of the Surkhandarya River in order to improve water supply of lands in the south zone. After construction of Amu-Zang pump canal the Uchkyzyl reservoir started to receive water from the Amudarya.

Talimarjan reservoir is off-stream one for seasonal flow regulation, with the full volume of 1.53 km^3 and useful volume of 1.4 km^3. It is located at junction of head (pump canal) and working (gravity canal) parts of the Karshi main canal (KMC). The reservoir accumulates water delivered from the head part and feeds the working part of KMC. As designed, the reservoir is to accumulate Amudarya water delivered through the cascade of pumping stations in autumn and winter and feeds the working part of KMC during growing season. Evaporation rate from the surface of reservoir is 1300 mm/year and the volume of evaporation is 68 Mm3/year. Actual operation of Talimarjan reservoir slightly differs from the design one. The minimum water volume in the reservoir is observed in late August. Filling starts since September and lasts till early or mid-March, when water volume in the reservoir reaches its maximum. The reservoir decreases its storage in March-April and June-August.

Kuyumazar reservoir is off-stream one for seasonal flow regulation in lower reaches of the Zerafshan River; full volume - 350 Mm^3, useful volume - 300 Mm^3; evaporation is 24 Mm^3/year. It was put into operation in 1958. The reservoir is filled with water from the Zaravshan through feeding canal and with water from the Amudarya through the Amu-Bukhara main canal. The reservoir accumulates water since September till May and decreases its storage since December till March and in April-September.

Reservoirs of Kulyab irrigation system: Serbul reservoir located along Kzylsu River, with the useful volume of 16 Mm^3; and, Muminabad reservoir located along the Obi-Shur River, with the useful volume of 26 Mm^3. These reservoirs regulate flow for irrigation purposes.

Figures 2.19 – 2.25 show filling and drawdown of the intrasystem reservoirs in Amudarya basin, with focus on the area of Garagumdarya, Amu-Bukhara main canal, Karshi main canal, and Amuzang.

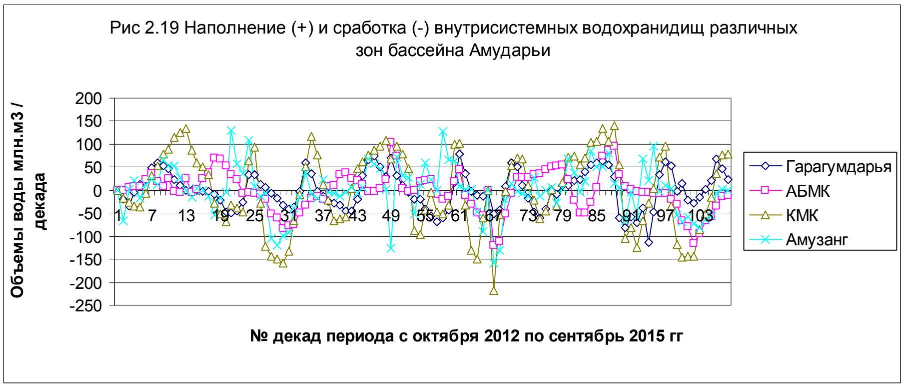

Fig.2.19. Filling (+) and drawdown (-) of intrasystem reservoirs in the zones of Amudarya basin

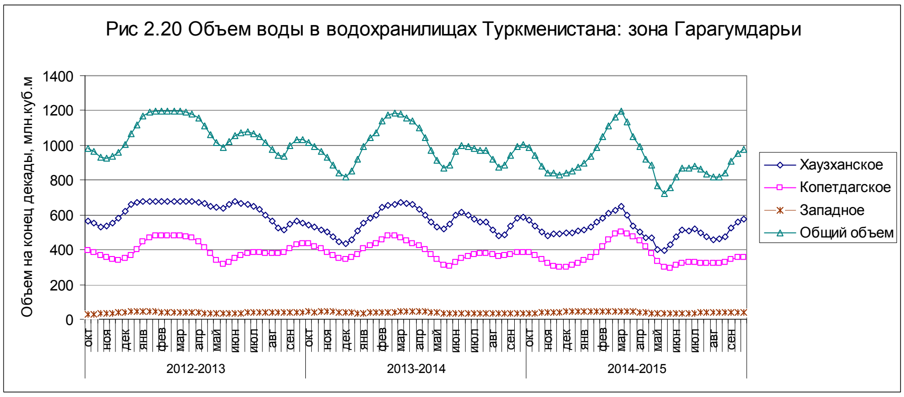

Fig.2.20. Water volume in reservoirs of Turkmenistan: Garagumdarya zone

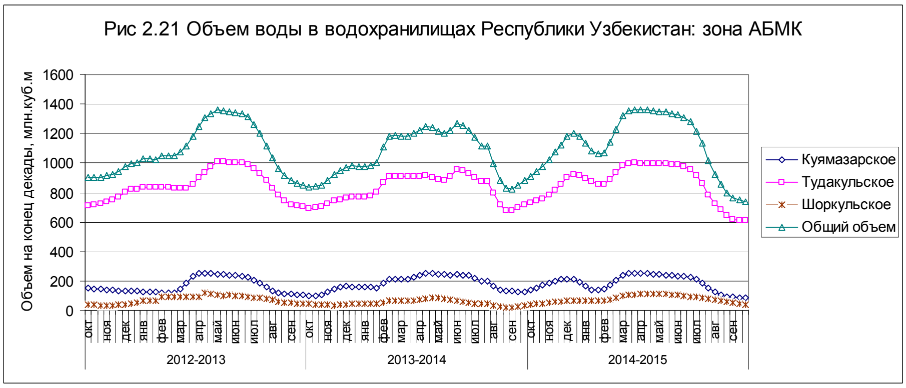

Fig.2.21. Water volume in reservoirs of Uzbekistan: ABMC zone

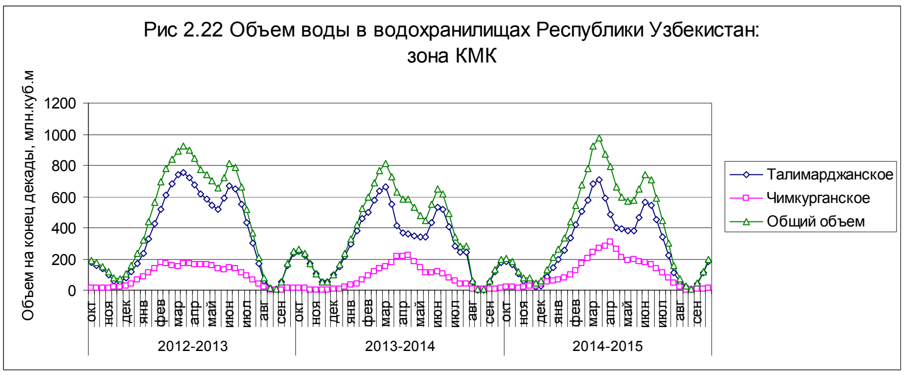

Fig.2.22. Water volume in reservoirs of Uzbekistan: KMC zone

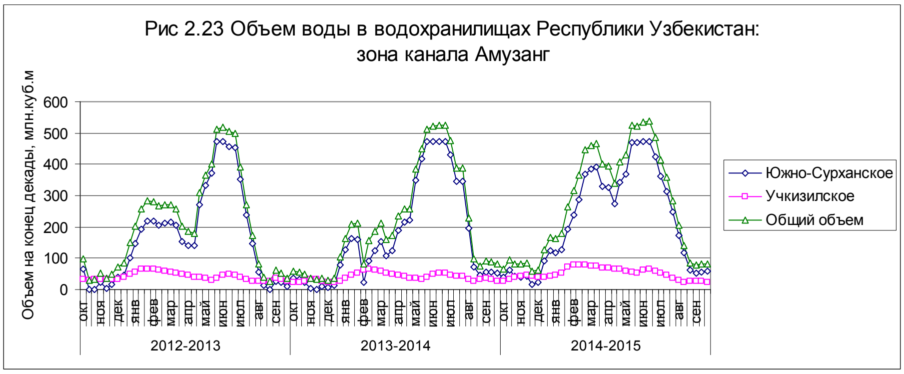

Fig.2.23. Water volume in reservoirs of Uzbekistan: Amuzang canal zone

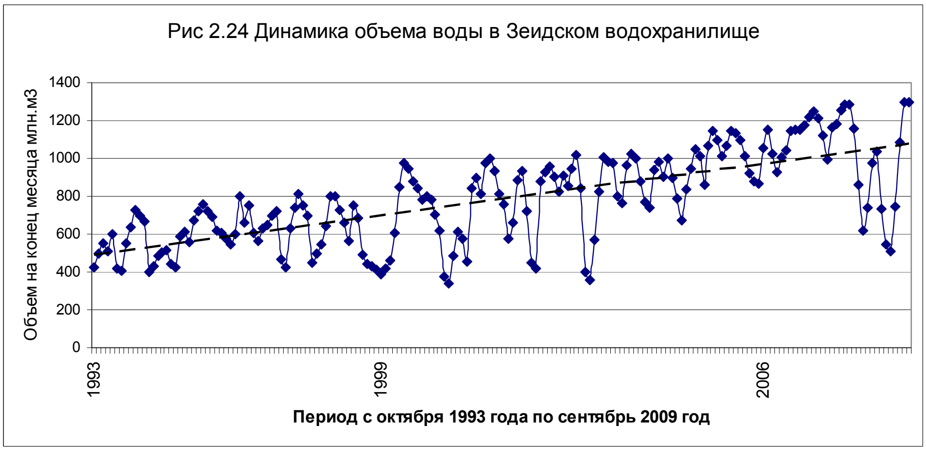

Fig.2.24. Dynamics of water volume in Zeid reservoir

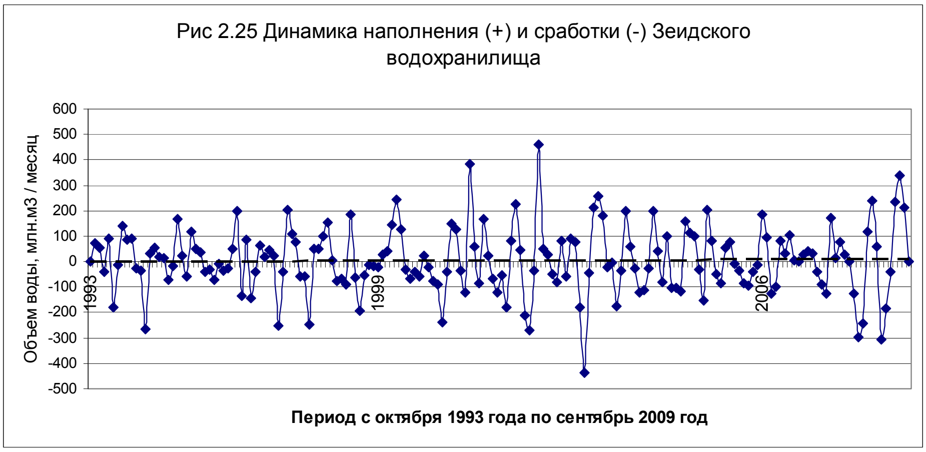

Fig.2.25. Filling (+) and drawdown (-) of Zeid reservoir

3. Modification of ASBmm software

The task of adaptation of ASBmm as set by the PEER Project consists of:

- Research – rethinking of functioning of individual objects and the system as a whole, refinement of some functions, and introduction of new factors and variables,
- Improvement of algorithms – water balance of PZ, hydropower model**,**
- Improvement of Web-interface – user menu, DB structure and filling.

All modifications and additions made in ASBmm by PEER Project fit the requirements of the American methodology for modeling complex systems (Function Modeling) and information flows (Information Modeling).

Improvement of hydropower model

Analysis of operation of the Vakhsh HEPS cascade shows that for better management of the cascade it is necessary to define more exactly the following indicators:

- inflow to Nurek hydrosystem,
- useful volume of Nurek reservoir,
- performance of HEPS cascade,
- sterile spills (caused by engineering characteristics) of Nurek, Baipaza, and head HEPS,
- sterile spills of the cascade caused by absence of energy consumer.

The following changes and additions were made in the model:

- calculation of maximum admissible discharge of Nurek HEPS for given flow capacity for small heads and cavitation for high heads (G.N.Petrov, 2009),
- calculation of sterile (engineering) spills from Nurek HEPS that are determined as the difference between design discharge of HEPS and maximum admissible discharge,
- environmental boundary conditions for Nurek hydrosystem – discharge through turbines and sterile spills in total must not be lower than sanitary releases,
- checking if design HEPS capacity of the whole cascade is lower than the established (available) capacity,
- more precise definition of bathymetric relationships ‘water level – water volume in reservoir’, ‘water level – water surface area’ for Nurek reservoir (G.N.Petrov, 2009),
- calculation of lateral inflow in the reach from Komsomolabad station to Nurek reservoir (G.N.Petrov, 2009),,
- calculation of water level in the Vakhsh River downstream of Nurek HEPS and of head at HEPS ((G.N.Petrov, 2009),),
- calculation of sterile spills and capacity (generation) losses of HEPS cascade caused by absence of energy demand.

Conclusion

Reconstruction of flow of Pyandj and Kunduz rivers and of Turkmenistan’s rivers helped to assess dynamics of surface water in the Amudarya basin for 2010-2015 (base period) and prepare basis (long-term historical series) for forecast assessment of water resources for 2015-2055.

The current water-related situation in the Amudarya river basin is characterized by re-distribution of flow by Nurek reservoir to the benefit of hydropower. This requires compensatory regulation downstream for irrigation purposes. Analysis of operation of Nurek reservoir over 1990-2015 showed that the reservoir has small volumes of multiyear regulation (as clearly seen from dynamics of filling of the reservoir as of April 1). The reservoir decreases its storage in wet year and accumulates water in dry year, i.e. there is inefficient management in terms of irrigation and hydropower.

Energy and irrigation sector conflict is not so acute in Amudarya basin as in Syrdarya since insufficient useful volume of Nurek reservoir limits its energy- generation oriented operation. However, the role of Tuyamuyun hydrosystem and intrasystem reservoirs as compensatory regulators undoubtedly has increased recently.

Practices of operation of intrasystem reservoirs show that actual volumes of flow regulation by reservoirs are not constant and depend on water availability. In case of higher water availability, there is advance in filling of reservoirs as compared to established regime, while during dry period the volume of filling decreases.