PEER Project - "Transboundary Water Management Adaptation in the Amudarya Basin to Climate Change Uncertainties"

Approved by:

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REPORT

Developing recommendations for BWO Amu Darya territorial divisions (Tajikistan, Turkmenistan, Uzbekistan) on adaptation of water management (planning, analysis) in the context of climate change, potentially increased water consumption by Afghanistan and runoff regulation by HEPS

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Introduction

The work was done in line with the project work program and terms of reference. Given topic refers to Phase 3 “Numerical experiment”, task 3.2 “Development of recommendations on water management in the context of climate change”.

This work was completed by A.Nazariy under methodological guidance by A.Sorokin. The results of project phases 2 and 3 and the reports and data of BWO Amu Darya were used in the analysis of water-related situation.

Proceeding from the output of task 3.2 in the Project work program, ***the objective of work*** can be formulated as follows: develop recommendations for territorial divisions of BWO Amu Darya on water management adaptation to climate change, potentially increased water consumption by Afghanistan, and runoff regulation by HEPS.

To achieve this objective, the following **tasks** were set:

- Analyze current and future challenges of basin water management in terms of tasks set before the territorial divisions and BWO as a whole,
- Analyze project results (assessing scenarios of impact of climate change, growing water withdrawal by Afghanistan and runoff regulation by HEPS on water availability and water use) in terms of BWO’s mandate,
- Develop recommendations for BWO and its territorial divisions on adaptation of water management and water use in the basin (Amu Darya and its tributaries) in the context of climate change and other challenges.

Analysis

Mandate of BWO Amu Darya and water management challenges

The Basin Water Organization Amu Darya (BWO Amu Darya) is an executive and inter-departmental control body of the Interstate Commission for Water Coordination.

The key mandate of BWO is to ensure the guaranteed water supply to users according to ICWC-established limits of water withdrawal from interstate sources and the water releases into the Amu Darya delta and the Aral Sea based on annual planned volumes. It is also responsible for operational control over observance of the established limits and the operation regimes of reservoirs.

According to general agreement among the Central Asian states, stem streams of the following rivers fall in the sphere of interstate water management and distribution: Panj River, Vakhsh River, Kafirnigan River, and the Amu Darya River itself.

BWO must develop and agree with all concerned members of ICWC the operation regimes of reservoirs, hydroschemes, and intake structures and submit them for approval to ICWC meeting. Notably, the regime of Nurek Hydroscheme is developed jointly with representatives of the energy sector of Tajikistan, while that of Tuyamuyun Hydroscheme, together with the Operation office of this hydroscheme.

BWO Amu Darya is comprised of:

- Upper Darya Division (hereinafter, VDU), which delivers water to a part of Osh province in Kyrgyzstan, to Khatlon and Gorno-Badakhshan provinces and districts under direct Republican control in Tajikistan; the cascade of Vakhsh HEPS is located in the area of VDU; the stem stream of Amu Darya in the territory of Uzbekistan is controlled by VDU Termez branch;
- Middle Darya Division (SDU) controls water intakes in the river reach from Kelif to Birata hydroposts, including large main canals (Garagumdarya, Karshi, Amubukhara); the system of main canals includes intra-system reservoirs; intake to Amubukhara canal is controlled by SDU Amubukhara branch;
- Amu Darya Inter-republican Canals Division (UPRADIK) controls water withdrawal to irrigation systems of Turkmenistan and Uzbekistan from

Tuyamuyun hydropost (downstream of Tuyamuyun Hydroscheme – TMHS) to Kipchak hydropost;

- Lower Darya Division (NDU) operates Takhiatash Hydroscheme in Amu Darya River and controls water withdrawals from the river downstream of Kipchak hydropost;
- Dashoguz Direction of BWO Amu Darya provides financial and logistical support to divisions of BWO in the territory of Turkmenistan.

VDU controls water withdrawal (limit) to the Kyrgyz Republic in the amount of 0.45 km^3, to the Republic of Tajikistan in the amount of 9.5 km^3, and to Surkhandarya province, Republic of Uzbekistan in the amount of 1.57 km^3. SDU and NDU control water withdrawal (limit) of 22.0 km^3 to Turkmenistan and 22.0 km^3 to the Republic of Uzbekistan. Additionally, they control environmental releases of 0.8 km^3 to canals in the lower reaches.

The main challenge for all territorial divisions of BWO is the ***growing water shortage*** that must be ***minimized*** for each division, by ***agreeing upon on its distribution over the basin*** with the headquarters of BWO.

The general task of all territorial divisions of BWO Amu Darya in the context of climate change and other challenges (increased water withdrawal to Afghanistan, energy-oriented regulation of flow and reduction of discharge from hydroelectric power stations during growing season), especially in dry years, is to achieve ***lowering of water losses and uniform distribution of water shortage***. A number of questions are raised in this context: how this could be achieved; what are available reserves and unused opportunities; what should be changed to improve management.

Let us consider the *growing season 2000*. Over the period of time from 1.04.2000 to 1.10.2000, water shortage (i.e. when the established water withdrawal limit is higher than actual water use) in the Amu Darya Basin was 11.1 km^3 or approx. 30% of the limit. The actual distribution of water shortage among the state was as follows: Tajikistan – 0.7 km^3 (or 11% of the established limit); Turkmenistan – 4.6 km^3 (or 30% of the limit); Uzbekistan - 5.8 km^3 (or 37% of the limit). Such distribution has largely determined *non-uniform distribution in space*: upper reaches - 0.7 km^3 (or 11% of the limit); middle reaches - 2.7 km^3 (17% of the limit); lower reaches - 7.7 km^3 (30% of the limit).
The issue of non-uniform distribution of irrigation water *should not be treated as an interstate one only* as even within the territory of one state distribution of water shortage is not uniform (example, growing season 2000): (1) Turkmenistan: - middle reaches 1.8 km^3 (17% of the limit), lower reaches - 2.8 km^3 (55% of the

limit); (2) Uzbekistan: - middle reaches 0.8 km^3 (15% of the limit), - Khorezm 1.2 km^3 (36% of the limit), - Karakalpakstan 3.8 km^3 (59% of the limit).
While analyzing the actual situation with regard to the river during the growing season 2000, the following balance can be drawn, km^3:

1	Water content in the Amu Darya River	34.1
2	Filling of Nurek Reservoir	4.4
3	Water withdrawal in Amu Darya upper reaches	1.3
4=1-2-3	Flow upstream of point of water intake to Garagumdarya	28.4
5	Return water	1.4
6	Drawdown of Tuyamuyun Hydroscheme	1.8
7=4+5+6	Available resource	31.6
8	Water withdrawal in middle and lower reaches	20.4
9	Flow in Samanbay section	0.2
10=7-8-9	Balance discrepancy (losses, unrecorded water withdrawals)	11.0

It should be noted that water shortage in 2000 was partially the result of inefficient management in previous period. Resource capacities in the non-growing season 1999-2000 were used sub-optimally and, by the beginning of growing season, no necessary water storage was available in reservoirs. Water was under-accumulated by 0.2 km^3 (as compared to the plan) in the Nurek reservoir and by 0.5 km^3 in intra-system reservoirs, while water withdrawal was in excess by 1.2 km^3 during the non-growing season and water delivery from the river to the Aral Sea was above the limit by 1.6 km^3. In total, unused water reserves during the non-growing season are estimated at 3.5 km^3 and, if consider engineering limits of accumulation, at 2.5…3.0 km^3.

The analysis of non-growing season 1999-2000 shows that if strict control and efficient management of reservoirs had been ensured in that period of time, 2.5 ...3 km^3 of water could have been accumulated additionally. Moreover, operation of the Nurek Reservoir as a multiyear regulator could have released about 0.5 …1.0 km^3 additionally in the growing season 2000 (without damage to subsequent years).

Thus, 2000 water shortage could have been reduced by 3 … 4 km^3 down to 7…8 km^3. *Given the uniform distribution among users, water shortage would be about 20% of the established limit of water withdrawal*.

While analyzing dry growing seasons (2000, 2001, 2008), we find that despite taken measures, BWO and territorial divisions were ***not able to make use of their management capacity in full***.

The work of ***water allocation commission in Amudarya lower reaches*** can be considered effective. One may say that real joint water management takes place between Turkmenistan and Uzbekistan: the parties make decisions on water withdrawals, operation of TMHS, time of leaching irrigation, flood regulation, etc. The permanent members of the commission are comprised of managerial staff of BWO Amu Darya and its territorial divisions (UPRADIK, NDU).

However, existing *institutional and legal frameworks* of BWO's activity need to be improved. The current agreement between Turkmenistan and Republic of Uzbekistan sets water allocation as 50 to 50, but there are not *rules for water management* in the basin, including flow regulation by reservoirs, scientifically based *methodology for drawing up channel balances* (all elements, including water losses, changes in water volume in the river channel and floodplain) to help BWO Amu Darya to plan and operationally control water distribution in the basin on the basis of reliable forecasts and effective monitoring.

To ensure guaranteed water releases from the reservoir of Nurek HEPS by energy operators as agreed with BWO, a special legal document is needed to formalize liabilities (including economic ones) of the parties.

One of priority tasks is to ***improve reliability of water accounting***. This can be achieved through equipping of hydroposts with up-to-date water meters and implementation of SCADA system. Currently, regular monitoring in the Amu Darya is maintained only within the reach from the Aral Sea to Termez hydropost. No information is available on the Panj and Kafirnigan Rivers since the 90s. This affects reliability of water forecasting in flow formation zones.

It is necessary to strengthen BWO's territorial divisions by ***analytical tools*** that would help to make correct assessments of water losses and flow transformation in the river and floodplain. Such package of tools should be the same for all territorial divisions and operate in common information field formed by the network monitoring, DB and data transmission.

The current flow management practices in the Amu Darya show that the reach downstream of TMHS demonstrates high uncertainties in terms of water discharge and losses. Major complexities in water management by BWO Amu Darya are caused by the lack of scientifically-based information on forecast estimations of water balance of the Amu Darya River by river reach (channel balance is calculated by down-top approach) and changes in river flow hydrograph downstream. Increased variability of river flow transformation caused by climate and anthropogenic factors and consequent water shortage and its non-uniform distribution in time and space necessitates updating and improvement of management algorithms for lower reaches. Those updated algorithms should guide BWO's practical activity and *documentation for technical meetings of representatives from Turkmenistan and Uzbekistan.*

Finally, water management in the basin should be based on the following: account of interests of main water stakeholders, limit setting on water withdrawals from transboundary rivers, joint decisions on flow regulation and water distribution in emergency conditions (drought, flood), coordination of operation of hydropower reservoirs (interstate ones) between the countries.

Aggravation of water-related situation

At present, territorial divisions are mainly concerned by potential growth of water withdrawals by Afghanistan. This can cause reduction of flow by 3.0 km^3 in the Amu Darya.

Climate change will impact river flow, which with insignificant changes in annual volume will be substantially lower in summer.

As to the growing seasons, by 2050 (PEER Project data), the reduction of flow norm (average long-term annual values) according to REMO-0406 scenario will be: 5% for the Vakhsh River, 6% for the Panj River, 8% for the Kafirnigan River, and 6% for the Surkhandarya River. The flow norms in those rivers will be 12…25% lower in July.

Available water supply for riparian countries and their zones will decrease and depend on: flow probability in given year; water demands in this year and regime of flow regulation by reservoirs. Water shortage can amount to 12 km^3 maximally (provided that open channel losses do not exceed 8 km^3) over 2020-2050.

Inflow to Southern Prearalie will decrease. Moreover, flow variations will increase, i.e. periods of droughts lasting for a few years will be possible against discrete wet years. For maintenance of lake ecosystems in Southern Prearalie and the Aral Sea, up to 9 km3/year must flow on average for a long-term period from the Amu Darya River and through discharge of collector-drainage water. Water delivered to the Aral Sea should not be less than 4 km3 a year and delivery to lakes should amount to, at least, 3 km3 a year.

Impact of big reservoirs

Flow regulation capacities for transboundary rivers in small Amu Darya Basin are determined at present by usable storage capacity of the reservoirs of *Nurek and Tuyamuyun hydroschemes (TMHS)*. Given the siltation of reservoirs and usage of TMHS' Kaparas reservoir for drinking water supply, the total usable storage capacity of in-stream reservoirs is estimated at 7.3 km^3. This capacity plus intra-system capacities (about 7 km^3) is sufficient for regulation of Amu Darya flow in the amount of 2 km^3/year.

Current agreements cannot settle all emerging issues related to regulation of flow by reservoirs in the basin, first of all, operation regime of *Nurek HEPS*.

Since 1991, annually Nurek reservoir has been filled up to maximum level and discharged down to minimum level. Moreover, Nurek HEPS is operated in energy regime. This requires adjustment in dry years in order to prevent water shortage and undesirable conflicts between the countries.

The main functions of TMHS are meeting drinking water demands, prevention of water shortage in lower reaches during low-water period, and observance of environmental flow releases to Prearalie.

Operation regime of the TMHS reservoirs should possibly ensure minimal losses and siltation of in-stream storage capacity. The main principle of flow re-distribution between TMHS reservoirs is to drawdown in-stream reservoir mainly (as compared to off-stream reservoirs) and, at the same time, accumulate water in all other reservoirs (if accumulation is possible). This principle allows decreasing significantly flow losses in both in-stream reservoir and in lower reaches of the Amu Darya. Delivery of turbid water along the river channel and to lower reaches canals can decrease losses 1.2…1.4 times in tail-water of TMHS and canals.

The project research showed that for more guaranteed water yield in the basin, it is necessary to maintain ***multiyear regulation***. Only this way we can reach maximal effect from operation of reservoirs for both energy sector and irrigation after putting into operation of Roghun hydroproject.

Could the future situation be aggravated as a result of putting into operation of Roghun project? The estimations say yes if *Roghun and Nurek* will be operated in tandem only for energy needs of Tajikistan. Operation of those reservoirs in energy regime could virtually shift summer floods to winter and create artificial shortage of water in summer in middle and lower reaches of Amu Darya and drying up of river channel in summer, when the river loses its capacity as natural drain. In hot season this leads to critical epidemiological situation.

There is possibility of construction of *Dashtijum HEPS* along the Panj River for energy generation, while operation of this HEPS could be under supervision by Afghanistan. The hydroenergy power station (and the set of hydraulic structures including a reservoir with the useful capacity of 10.2 billion m^3) should be considered as a *potential first priority structure* for integrated energy-irrigation purposes as part of the cascade of hydroschemes planned along the Panj River. The hydroscheme is to be constructed in the territory of Tajikistan (Khatlon province, Shamsiddin Shokhin district) and Afghanistan (Badahshan province, Khavakhan district). It could be used for *multiyear* re-regulation of flow in Panj and Amu Darya and ensure water withdrawal from the Panj by Afghanistan (according to media, 1.5 Mha of Afghan land could be watered). It is planned that Dashtijum Reservoir will lower flood flow along the Panj and prevent flooding. As Tajik experts estimate [Source: G.N.Petrov, Kh.M.Akhmedov. Effectiveness of Dashtijum HEPS Reservoir at the Panj River for the Prevention of Flood Flows and Flooding. Izvestia Akademiyi Nauk Respubliki Tajikistan. No. 4(141), 2010], for wet year the reservoir could “level flow rates” to 912 m^3/s from January to May and 1136 m^3/s from June to December, thus reducing flood flows 2.18 times.

Options of operation regime of Dashtijum HEPS should be studied in combination with operation of *Roghun and Nurek HEPS* and re-regulating reservoir of *Upper Amudarya HEPS* located downstream and guaranteeing irrigation regime of operation that compensates energy-oriented regulation of flow (option – full reservoir volume 345 m, useful volume 11.4 billion m^3); if such re-regulator is not available, energy regime of Dashtijum hydroscheme would increase winter generation and significantly reduce summer flow in Amu Darya River. Therefore, the Upper Amudarya hydroscheme, according to master plans, should be viewed as a unit for multipurpose irrigation-energy use designed to re-regulate flow released by Vakhsh and Panj cascades. The Upper Amudarya hydroscheme is to be constructed in the territory of Tajikistan (Khatlon province, Kubadiya district) and the Islamic Republic of Afghanistan (Kunduz province, Kala-i-Zal district).
Guaranteed winter release of flow from Upper Amudarya HEPS is set in master plans at 900 m3/s [Source: Master plan for multipurpose water use in Amu Darya River, CAO Gidroproyekt], which amounts to 52% of average long-term annual discharge. We estimate that if guaranteed discharge is kept in winter, then in average year, 2500 m^3/s or 40 billion m^3 will flow downstream of Upper Amudarya HEPS during the growing season. For comparison: water quantity in the section upstream of intake to Garagumdarya was estimated at 50.3 billion m^3 during the growing season 2017.
Thus, in growing season, the estimated flow downstream of Upper Amudarya HEPS (which operates in energy-irrigation regime, i.e. energy-oriented, guaranteed winter flow rate is kept) will be 10 billion m^3 lower in an average year than the

flow in 2017 (average year). Under such circumstances, water withdrawal to canals and Prearalie is expected to decrease.
The reservoir of Upper Amudarya HEPS causes flooding in the valley of Panj (including within Afghanistan) and Vakhsh ("Tigrovaya balka" nature reserve) over 75 km along the Vakhsh River and over 115 km along the Pyanj River if the project is implemented according to option 1 (full-reservoir level 345 m). The flooding area is estimated to be 110,000 ha, including 42,000 ha in Afghanistan. As a consequence of such flooding, *hydrometric measurements in the mouths of the Vakhsh and Panj would not be correct*.

Intra-system reservoirs

It is characteristic for the Amu Darya Basin is that irrigated and irrigable land in some areas is located at a considerable distance from water sources (head intakes). This circumstance influenced on formation of water-management systems in the basin and on construction of intra-system off-stream seasonal reservoirs. Major, currently operating intra-system reservoirs are Zeid, Uchkyzyl, Talimarjan, Tudakul, and Kuyumazar, which regulate flow of the Amu Darya.

Operation of intra-system reservoirs shows that actual volumes of regulation are not constant and depend on flow probability and engineering constraints on accumulation and drawdown of the reservoirs. Wise seasonal regulation by intra-system reservoirs can increase guaranteed water yield and available water in summer.

Operation of intra-system reservoirs as compensators of energy-oriented regulation of flow depends on both their own regulating capacities (max and min water levels, accumulation and drawdown constraints) and operation regimes of main canals (Garagumdarya, Karshi, Amubukhara) through which the reservoirs accumulate water.

If ***dry years*** occur, operation of intra-system reservoirs should be aimed to compensate water shortage during growing season through maximum possible water withdrawal from the Amu Darya River during non-growing season and accumulation of water by the beginning of growing season.

Volumes of flow regulation by intra-system reservoirs (and respective water withdrawals to canals which fill reservoirs) can be planned based on the following conditions: 1) regulation of flow of the Vakhsh River according to demand in middle reaches of Amu Darya and possible Panj River (in case of its regulation for energy generation purposes by Dashtijum hydroscheme), 2) re-regulation of residual flow (inflow to Tuyamuyun hydroscheme) according to demand of lower reaches of Amu Darya (in particularly dry years).

Here, the *limitations* could be: water level in the Amu Darya River in low-water period, which may limit water withdrawals to canals; and, sanitary water releases in low-water period.

Changes in schemes of collector-drainage water disposal

Collector-drainage water formed in the Turkmen territory of the Amu Darya Basin (Lebap, Dashoguz, Mary, and Akhal provinces) is estimated at 4.5...7 billion m^3/year. Bulk of collector-drainage water in the amount of 2…2.5 billion m^3/year in Lebap province has been discharged into the Amu Darya River till present. Collector-drainage water in Dashoguz province (about 65%) is formed in the territory of Uzbekistan (in Ozerniy, Daryalyk, and Daudan collectors) and has been discharged into Sarykamysh Lake (upstream of inflow the Ozerniy and Daryalyk collectors are joined into one collector) till present. The project of Golden Age Lake has changed the existing scheme and parameters of collector-drainage water disposal.

First, it is planned to cut discharge of collector-drainage water into the Amu Daya from Turkmenistan territory by delivering it to Golden Age Lake. Disposal of collector-drainage water from Lebap province will lead to cutting of discharge of such water into the Amu Darya from the left bank and to lowering of river flow by 1.1…2.1 billion m^3/year, that is on average approx. 7% of water withdrawal limit allocated for Turkmenistan from the Amu Darya River.

Second, catch collector-drainage water formed in Khorezm province of Uzbekistan that till present have flown to Sarykamysh Lake and transport this water to Golden Age Lake. In such a case, Sarykamysh Lake will lose 3 billion m^3 of inflow annually, with consequences for its water balance.

In the context of the new scheme of water disposal, it is necessary to make corrections in the current water balances of the Amu Darya River, Garagumdarya River, and irrigated areas of Turkmenistan and Khorezm.

Water shortage and mitigation measures

According to the project data, by 2040, water shortage due to climate change and growing consumption (including by Afghanistan) in the basin is expected to be 8.0 km^3 for average year and 10-12 km^3 for dry year. In given situation, the territorial divisions of BWO must work ***jointly*** and aim to ***reduce water losses*** in the basin within their respective areas:

- Within river reaches and in reservoirs through optimization of regimes; for example, BWO's territorial divisions should contribute to wise operation of in-stream reservoir of the Tuyamuyun Hydroscheme, which ensures periodically flushing regime at lower levels. This contributes to reduction of losses in the in-stream reservoir (through inflow of groundwater) and in lower reaches canals receiving more turbid water from the Amu Darya during flushing,
- Along main canals and in irrigation systems through better control over water discharge.

The territorial divisions should *elaborate a common approach to water conservation and water saving in the basin* and to effective *monitoring* by engaging all stakeholders.

Additional important points

- Flow in the Panj and Amu Darya Rivers will decrease as far as water withdrawal by *Afghanistan* increases and discharge of collector-drainage water from the *left bank* (Turkmenistan) is cut,

- Flow in the Vakhsh, Panj and Amu Darya Rivers will increase in winter (and, consequently, decrease in summer) in case of putting into operation of *Roghun Project* in the Vakhsh River and construction of *Dashtijum HEPS* in the Panj River and *Upper Amudarya HEPS* in the Amu Darya River; autumn-winter water releases will increase even if those reservoirs are operated in *energy-irrigation and compensatory regimes* as for smooth operation of HEPS, at least, *guaranteed winter energy release* (e.g. 900 m^3/s for Upper Amudarya HEPS) is needed.

Recommendations

Aim: prepare recommendations to a program of ***actions for water management adaptation in the context of climate and other changes*** – a comprehensive program for conservation of water, improvement of water use monitoring and control, improvement of flow regulation by reservoirs and HEPS, and operational management of water supply and demand.

It is necessary to improve interactions between countries and BWO'S territorial divisions and organize permanent and consistent ***process of effective monitoring, management, and use of water resources***.

Along with improvement of monitoring, a ***program of water conservation*** should be initiated and considered as priority one. It should set ***obligations for reduction of water requirements*** (concrete figures), distribute responsibilities and authorities for water conservation measures between territorial divisions of BWO Amu Darya, provincial water management organizations, and basin irrigation system administrations (BISA).

It is proposed to *distribute the water shortage of 5.0 km^3* over the basin territory and the territorial divisions proportionally to allocated limits (see Table 1). Each territorial division should *take an obligation* to reduce water withdrawal by approx. 1.0–1.2 km^3 and prepare jointly with basin water management organizations and BISAs relevant plan of work.

VDU needs to establish effective interaction with the Land Reclamation and Water Management Authority of the Khatlon province, Republic of Tajikistan and the Amu-Surkhan BISA (Republic of Uzbekistan). SDU is to establish interactions with the "Garagumdarya" Authority, Lebapsuvkhojalik (Turimenistan), the Amu-Kashkadaryan and Amu-Bukhara BISAs (Republic of Uzbekistan). UPRADIK and NDU need to maintain effective relationships with Dashoguzsuvkhojalyk (Turkmenistan) and Lower-Amudarya BISA (Republic of Uzbekistan).

Table 1. Proposal on reduction of water withdrawal limits by 10% to canals by BWO Amu Darya territorial division

Water withdrawal	**Limit for growing season**	**Limit for non-growing season**	**Limit for hydrological year**	**Reduction of water withdrawal limit by 10%**
1.VDU BWO Amu Darya	**8,176.3**	**3,203.5**	**1,1379.8**	**1,138**
Tajikistan	6,976.3	2,833.5	9,809.8	**981**
Uzbekistan	1,200.0	370.0	1,570.0	**157**
Water withdrawal from Amu Darya to virtual Atamurat hydropost (Kerki)	**3,1520.0**	**1,2480.0**	**4,4000.0**	**4,400**
Turkmenistan	15,500.0	6,500.0	22,000.0	**2,200**
Uzbekistan	16,020.0	5,980.0	22,000.0	**2,200**
2.SDU BWO Amu Darya	**16,207.0**	**8,345.0**	**24,552.0**	**2,455**
Turkmenistan	10,472.0	5,100.0	15,572.0	**1,557**
Uzbekistan	5,735.0	3,245.0	8,980.0	**898**

3.UPRADIK	**8,022.9**	**2,526.8**	**10,549.7**	**1,055**
Uzbekistan	5,348.0	1,755.0	7,103.1	**710***
Turkmenistan	2,674.9	771.8	3,446.6	**345**
4.NDU BWO Amu Darya	**7,290.1**	**1,608.2**	**8,898.3**	**890**
Turkmenistan	2,353.1	628.2	2,981.3	**298**
Karakalpakstan	4,937.0	980.0	5,917.0	**592**
Total from Amu Darya Basin	**39,696.3**	**15,683.4**	**55,380**	**5,538**

For improvement of monitoring program:

- Improvement of measurement system along the rivers – automation of gauging stations (or hydroposts) measuring water level, discharge, and quality (hydrochemical composition and other water quality indicators),
- Improvement of monitoring over water distribution – automation of hydroschemes, intake structures,
- Improvement of measurement system along main canals (Garagumdarya, Karshi, Amubukhara); expected outcome: updated elements of water balance and performance coefficient,
- Improvement of the system of control over water disposal (of collector-drainage water), expected outcome: updated schemes of collector-drainage water distribution (re-use, discharge into river, discharge into lakes and reservoirs), updated volumes and hydrographs of collector-drainage water, assessment of collector-drainage water quality.

For water conservation program:

- *Reduction of limits* of water withdrawal to canals (see Table 1),
- *Lowering of losses* in irrigation systems by reconstructing water-management systems – this is the primary task in the Uzbek water economy (see Annex 3),
- Optimization of crop water requirements in the Amu Darya Basin in the context of climate change – agroclimatic parameters, *updating of irrigation norms and schedules*, development of practical recommendations for individual zones in the basin,
- Improvement of cost-effectiveness of water use and water and land productivity in individual zones in the Amu Darya Basin through a set of

measures: optimization of *cropping patterns and crop distribution,* improvement of current irrigation technique, *adoption of innovations* (drip irrigation, etc.), implementation of *IWRM*, *water charges, computer-aided management* of irrigation systems,

- Improvement of usage of local and unconventional water sources – groundwater, drainage water, creeks.

Roadmap for water conservation program

- Step 1 – initiate support to a water conservation program implemented by territorial divisions of BWO, from the side of IFAS, ICWC, riparian countries, donors,
- Step 2 – prepare a water conservation program,
- Step 3 – establish an institutional and legal framework of interaction between all organizations and stakeholders engaged in the program, a Basin Council,
- Step 4 – create the information field (network) in support of effective interaction and online data transmission,
- Step 5 – implement step-by-step the program, monitor achieved results.

For the program of improvement of water management by territorial divisions

- It is necessary to organize *on periodical basis,* jointly with Hydromet services, *check measurements* of water in boundary control stations of the territorial divisions to record river flow ("passed" from one territorial division to another one) by balance method and assess open-channel losses,
- In the context of climate change, VDU should *correct together with energy sector representatives the design water releases from* the Nurek Reservoir, taking into account the tendency towards lowering of inflow to the reservoir in June-August,
- The territorial divisions of lower reaches should plan water distribution, while bearing in mind the expected cutting of collector-drainage water

discharge from the left bank and the reduction of inflow to Tuyamuyun Reservoir by 1.0 – 1.5 km^3,

- The information system and dispatch system of BWO needs to be improved by unifying information flows by communication line: a) BWO headquarters with territorial divisions – ODC “Energy” – Hydromets – national Ministries of water management; b) territorial divisions of BWO – provincial water management organizations – BISAs – organizations which operated reservoirs, HEPS and large main canals; c) dispatch system – monitoring network. Real-time data showing the current status and functioning of BWO’s structures, monitoring parameters, the data on flow forecast (Hydromets), and analytical information of BWO, ODC “Energy”, etc. should be transmitted.

Based on this, it will be possible to have daily water balance for the basin as a whole – by territorial divisions – by BISAs.

For the program of improvement of BWO institutional structure

- Give proposal on the improvement of institutional structure of water management. Such structure should be based on interaction and responsibilities of individual levels: ICWC/BWO& ODC “Energy” and Ministries – territorial divisions of BWO & provincial water management organizations, BISAs & organizations which operate reservoirs, HEPS, large canals – Basin Councils & water consumers and users.
- Establish cooperation of VDU (Tajikistan) with energy agencies in the area of collection and transmission of real-time (energy-related) information on operation of hydropower reservoirs to BWO headquarters,
- Establish cooperation of VDU (Tajikistan) with the Tajik Hydromet in the area of collection and transmission of real-time (hydrological and climatic) information to BWO headquarters,
- Facilitate establishment of Basin Councils (stakeholder organizations) that mainly will help to settle controversial matters related to water distribution and flow regulation by reservoirs, as well as observance of environmental releases and implementation of water conservation and water saving measures.

For the research program

- Develop practical tools for operational management of the flow of the Amu Darya River in its upper, middle and lower reaches (with involvement of all territorial divisions of BWO; expected outcome: improved operational management of river flow, including: a) forecast of flow transformation in reaches of Kelif-Birata, Tuyamuyun-Samanbai, b) correction of water distribution plan against actual water content (see Annex 2),

- Carry out comprehensive research and develop recommendations for norm setting on open channel losses (with involvement of all territorial divisions of BWO) depending on river water content,

- Seek wise operation regimes for in-stream and intra-system reservoirs (as objects of irrigation-oriented re-regulation of energy-oriented regulated flow) in the Amu Darya Basin (with involvement of all territorial divisions of BWO); expected outcome: *lowering of water and energy losses* through coordination of actions, optimization and improvement of operation of reservoirs, liquidation of idle discharge,

- Develop measures for improvement of water-related and environmental situation in Southern Prearalie (with involvement of BWO's divisions for lower reaches); expected outcome: *planning and regular monitoring* of sanitary and environmental water releases to Amu Darya delta, Mezhdurechie reservoir, lake systems and wetlands.

Annex 1. Proposal for development of organizational and economic model for BWO Amu Darya operation

The development of an ***organizational and economic model for BWO Amu Darya operation*** *under the future* ***challenges*** is critical to solve the problems in the Amu Darya basin. This model would serve as a basis for efficient water resource management in the Amu Darya basin in the nearest future (10-20 years).
Such model is to ***coordinate the work of BWO territorial divisions with provincial water management departments and BISAs*** (in terms of legal, organizational, and information support).
The model can be represented as ***an objective tree***, where **an objective**, for instance, is ensuring water security in the basin, and sub-objectives include ensuring water availability, *equitable water distribution* , rational use, *water conservation*, *preventing water pollution*, etc.. The model should include the ***function of losses and algorithms of their minimization (optimization)***, algorithms of flow regulation by hydropower reservoirs, ***algorithms of economic incentives for water conservation, introduction of economic penalties for water withdrawals above-limit and unreasonable reduction of summer water releases from the reservoirs***.

The objective may be defined in other way – ensuring continuous and dynamic water balance in the territorial divisions and BISAs, including travel time.

Annex 2. Proposal for development of water distribution planning model for BWO Amu Darya

The task of distribution of Amu Darya river runoff during the fixed time intervals – season, water-management year, with decadal or monthly step can be formulated as follows. One need to choose such operation parameters of river system (reservoirs, water intakes, spills) that would meet demands of users (according to the limits of water withdrawals for canals and for Prearalie), ensure minimum losses of runoff, while keeping necessary volumes of water in reservoirs by the end of management period.

BWO Amu Darya fulfills this task for growing (April-September) and non-growing (October-March) seasons of water-management year. Here, first available water resources are estimated based on the forecast by UzHydromet on flow probability of Amu Darya at Kerki section, the forecast of lateral inflow to the river downstream of Kerki, and initial water storage in reservoirs. Then, BWO analyzes the ratio between available water and water demands and calculates regimes of runoff regulation by reservoirs and water supply to canals and Prearalie.

Flow forecasting is directly linked with the control over fulfillment of approved regimes and established limits and the adjustment of the regimes and limits depending on actual water-related situation.

The method of channel water balance (CWB) serves as a basis of calculation. The result is actual (for reporting period) and forecast (period of forecast) water balances, with average decade parameters of river runoff in representative sections, plus estimated losses, water shortage and balance discrepancies are indicated.

The river runoff is transformed through water withdrawal, regulation by reservoirs, discharge of return water into the river, and re-distribution, in time, of runoff in channel and floodplain, i.e. its accumulation during high-water and drawdown during low-water.

The dynamic factor in Amu Darya river water balance – channel regulation (accumulation of water in the channel and floodplain when water level rises and water discharge when water level is lowering) – plays the important role. Consideration of this factor along the Amu Darya during high-water in the middle reaches only helps to make corrections in balance calculations at approximately 2-3 km^3 seasonally and, thus, reduce the error of calculated inflow to Tuyamuyun hydroscheme (TMHS). With extension of the calculation period to year, when the cycle “accumulation-drawdown” usually finishes, the value of channel regulation approaches zero.

The balance calculations by BWO Amu Darya and SIC ICWC show that since 1992 discrepancies of channel balance in middle and lower reaches of Amu Darya has increased substantially. In order to find the losses component in those actual discrepancies of channel balance, special research is needed, including modeling of interaction between river channel and its flow (inflow in form of filtration, outflow, etc.) and numerical experiments that would produce results helping to "limit" the losses. Remote sensing may be used to study the changes in water surface of river channel in various periods – low-water period, water level raise and lowering for different water years. To consider dynamics of steady-state conditions for ten-day (daily), MODIS satellite images may be used.

The model is to construct hydrological series that change under influence of natural and anthropogenic factors (controls). The most difficult tasks here are: selection and programming of dynamic scheme that allows forecasting, on decade basis, transformation of flow hydrograph from the beginning of the reach under consideration to its end.

The computer-based modeling of runoff transformation can be done using various methods for calculation of unsteady water flow in open channels that are strict and simple and need minimum set of input data (that is often principal for selection of a method).

Hydrodynamic modeling for most methods is based on equations of mathematical physics, where initial system consists of the equations of mass conservation (2) and motion (dynamic equation) (1):

$$i_o - \frac{\partial h}{\partial S} = \frac{a}{g} V \frac{\partial V}{\partial S} + \frac{a}{g} \quad \frac{\partial V}{\partial t} + \frac{V|V|}{C^2 R} + \frac{qV}{q\omega} \qquad (1)$$

$$\frac{\partial \omega}{\partial t} + \frac{\partial Q}{\partial S} = q \qquad (2)$$

Where: the coordinate of distance (S) and time (t) are independent variables, the depth (h) and average velocity (V) are their functions, the cross-sectional area (ω) is the known function of depth; the water discharge (Q) is the multiplication of V and ω; C is Chezy's coefficient; R is hydraulic radius; g is the acceleration of gravity; q is lateral inflow per unit length; a is the coefficient of irregular cross sectional velocity distribution (a is usually equal to 1).

The dynamic equation (1) can be simplified or even replaced by another motion equation, usually by empirical one. The most well-known transformations are diffusion equation, kinematic wave, balance methods, including travel time.

The proposed modeling of water regime for the Amu Darya River is the schematization of river flow movement, where the river is divided into reaches (storages), parameters of which are estimated by using empirical patterns of flow formation and transformation (morphometric relationships) that are characteristic for middle and lower reaches. The model will include also relationships to calculate lateral inflow and water losses.

Such scheme will be implemented in the GAMS system that will help to calculate flow transformation along the river and solve the optimization control problem, i.e. distribute water between users and regulate flow by hydropower reservoirs.

Proposed structure of information-analytical tool that implements the model

- Web-interface, including user menu and control program, linking information blocks and computer programs,
- Information block with reference information (morphometry of rivers, reservoirs, parameters of HEPS, etc.),
- Information block with input data – initial and boundary conditions to solve the problem of regulation, transformation and distribution of flow (flow hydrographs in sections, initial accumulation in reservoirs, etc.),
- Computer program for calculation of final reservoir storage (simulation of possible scenarios for annual and long-term regulation),
- Computer program for calculation of water balances of the reservoirs,
- Computer program for calculation of lateral inflow,
- Computer program for calculation of channel losses,
- Computer program for calculation of operation regimes of HEPS, including electricity generation,
- Computer program for calculation of channel balance and distribution of water,
- Information block with calculation results,
- Data store.

Adaptation:

- Maximally close capacities of the model to the *practical tasks* of BWO; include BWO structures to calculation schemes (balancing sites, hydroschemes, and water intakes),
- Research and include in the model factors and linkages that improve *adapted capacity* of the model – calibration on data by BWO,

- Use only *actual data* available at BWO *that practically characterize water management process* (planning, control, analysis, and adjustment).

Users:

- BWO Amu Darya and its territorial divisions,
- SIC ICWC and other organizations responsible for water resource management in the Amu Darya basin.

Annex 3. Examples of ongoing projects

At the moment, 2 projects are implemented in the lower reaches of the Amu Darya River (territory of the Amu Darya Inter-republican Canals Division **(UPRADIK)**, **BWO Amu Darya**):

- Reconstruction of Main Irrigation Canals of Tashsaka Irrigation System in the Khorezm Region,
- South Karakalpakstan Water Resources Management Improvement.

Reconstruction of Main Irrigation Canals of Tashsaka Irrigation System in the Khorezm Region

The project aims at decreasing seepage losses in the main and inter-farm canals.
Project outcomes:

- Increased water availability over an area of 191.3 thousand ha in low water and average water years,
- Decreased seepage losses to 90 mcm. This will result in lowering of the groundwater table, i.e. in improved land conditions over an area of 100 thousand ha.
- Water resource saving in the amount of 700-860 mcm,
- Improved performance from 0.544 to 0.62 in the province.

South Karakalpakstan Water Resource Management Improvement

The project aims at decreasing seepage losses in the main and inter-farm canals.

Project outcomes:

- Improved water resource management over an area of 100 thousand ha
- Annual water resource saving in amount of 269 mcm,
- Improved performance from 0.49 to 0.6.

If those objectives are achieved, water saving is expected to reach ≈ 1.0 – 1.1 km3 in the reach under control of UPRADIK BWO Amu Darya.
In the reach under control of **VDU BWO Amu Darya, the Reconstruction of Khazarbag-Akkapchigay Canal System in the Surkhandarya province project** of the Republic of Uzbekistan is implemented.

The project aims at decreasing seepage losses in the main and inter-farm canals.

Project outcomes:

- Improved water availability in the project area; this will allow delivering by gravity 1,2 bcm per year, given 92% of estimated flow probability, and 1,5 bcm per year, given 72% of estimated flow probability.
- Improved operational conditions of main canals and safety of structures.
- Improved performance of canal system from 0.72 to 0.92, thus ensuring their safe and reliable operation.

Annex 4. Proposal for monitoring

To improve river monitoring within the boundaries of VDU BWO Amu Darya, gauging stations need to be reconstructed and improved on the Panj, Vakhsh, and Kafirnigan rivers which are on the balance of Tajik Hydromet of the Republic of Tajikistan. A new gauging station should be installed on the Amu Darya River in the border area of the Surkhandarya province (Uzbekistan) and Khatlon province (Tajikistan). This would allow controlling, how much water was supplied from Tajikistan and Afghanistan to the middle reaches of the Amu Darya River.

Kelif gauging station needs to be improved so that water discharge could be measured here. Kerki and Birata gauging stations also need to be improved.

To improve monitoring in the lower reaches, Tuyamuyun gauging station should be automated; measurement system should be calibrated. In this regard, a system should be developed to transfer data online from the automated station to BWO Amu Darya; data transfer protocols and interface should be developed; an access to measurement data should be ensured for territorial divisions of BWO Amu Darya, Hydromet services of Turkmenistan and Republic of Uzbekistan.