Research report

2.Research

2.1 ASBmm adjustment

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Introduction

The report describes the results of the second research stage concerning: assessment of water balance of planning zones (PZ); assessment of water losses in the Amudarya River channel; and adjustment of ASBmm model.

1. Water Balance of Planning Zones

The main objectives of drawing water balances in the Amudarya Basin for the base period (2010-2015) consist in identification of characteristics of water formation and distribution in space and time, assessment of return flow, and determination of losses and discrepancies (unrecorded inflow or losses). The discrepancy of water balance in planning zones (PZ) indicates to losses of water in PZ and to inaccurate estimation of balance's elements, such as local water use, collector-drainage water (CDW), and flow regulation. The discrepancies of the water balance of rivers and their reaches, including reservoirs, characterize: inaccuracies in computation of lateral inflow and channel losses; unrecorded inflow to river channel in some reaches; and, losses in reservoirs through evaporation and percolation. In case of the Amudarya River, discrepancy in ten-day periods or days may characterize inaccurate computation of changes in water volume in the river channel and floodplain – 'flow regulation by river' (dynamic factor). Analysis of water balance for the basin as a whole and for its reaches, planning zones for the base period (2010-2015) makes it possible to identify balance discrepancies and calibrate the PZ model. One needs to incorporate into the water balance elements the functions of losses reflecting the characteristics of generation of losses in PZs and river reaches and the impact - on losses - of water availability in particular seasons of a hydrological year to minimize balance discrepancies for PZs and river reaches (see section 2 of given report, and PZ model testing report by R.Khafazov). By present, the PZ model has been calibrated by using the data on the Lower Amudarya PZ and will be continued in 2017. The calibrated PZ model will help to minimize errors in drawing water balances for PZs for 2016-2055 and accurately estimate "water supply – water demand" balance for various PZ development scenarios in CC context.

Water balances were drawn up for separate PZs within water districts (WD) of the Amudarya basin, for the Amudarya River sections and its tributaries (Vakhsh, Pyandj, Kafirnigan, and Surkhandarya). Rivers, such as Zeravshan, Kashkadarya, Murghab and Tedjen that do not flow to the Amudarya River but supply water to PZs were considered in the water balance of PZs as "local rivers". Afghanistan's rivers, Kokcha (left tributary of the Pyandj) and Kunduz (left tributary of the Amudarya), were considered in the Afghan PZ. To draw up water balance (within the PEER Project scope), the Amudarya River basin was divided into: i) upper reaches, ii) middle reaches, and iii) lower reaches. Water is transported from the upper reaches to the middle reaches through the intake upstream of Garagumdarya (former Karakum canal) and from the middle reaches to the lower reaches through the gauging station (GS) Birata (Darganata), on the basis of which the inflow to TMHS is determined. In the upper reaches, the following PZs are located: 1) Alay PZ in Osh province (Kyrgyzstan); 2) Vakhsh, Pyadnj, and Lower Kafirnigan PZs in Khatlon province (Tajikistan); 3) Upper Kafirnigan, Karatag-Shirkent, and Garm PZs in the Districts of Republican Subordination (DRS) (Tajikistan); 4) Gorno-Badakhshan PZ (Tajikistan); and 5) Surkhandarya PZ in Surkhandarya province (Uzbekistan). In the middle reaches, the following PZs are located: 1) Karshi, Bukhara, and Navoi PZs (Uzbekistan); 2) Lebap, Mary, and Akhal PZs (Turkmenistan). The Balkan PZ is not located in

the Amudarya River basin; it is located in the Caspian Sea basin. But its demand for the Garagumdarya flow (Karakum canal) is considered in the water balance. The Karshi PZ is located in the newly irrigated zone of Kashkadarya province (Uzbekistan). Water is mainly supplied here from the Amudarya River through the Karshi Main Canal (KMC). Mubarek, Mirishkor, Kasansay, Kasb, Karshi, Bakhristan and Nishan districts are located in the Karshi PZ. In the Bukhara PZ, water is mainly supplied from the Amudarya River through the Amu Bukhara Main Canal (ABMC) and partly from the Zeravshan River. In the Navoi PZ, the main source of water is the Zeravshan River; only small volume of water is supplied from ABMC. In the lower reaches, the following PZs are located: 1) Dashoguz PZ (Turkmenistan); 2) Khorezm PZ (Uzbekistan); and 3) Karakalpakstan's PZs – Northern Karakalpakstan PZ and Southern Karakalpakstan PZ (Uzbekistan). Ellikkala, Beruniy, Amudarya, and Turtkul districts make up Southern Karakalpakstan PZ; the rest of districts make up the Northern Karakalpakstan PZ (Uzbekistan).

Large main transfer canals (Garagumdarya, KMC, ABMC) taking water directly from the river and transporting water to larger distances serve as an important feature of the Amudarya middle reaches. The network of these canals includes system reservoirs operating as irrigation regulators. Such system diverts part of water from the Amudarya for irrigation during non-growing season (October-March), accumulates water in system reservoirs and, then, discharges water into an irrigation network in addition to water flowing from Amudarya along local rivers during growing season (April-September). Water balances of KMC and ABMC are shown in Tables 1.8-1.10.

Channel balance

The water balance of the Amudarya River for the base period (2010-2015) is shown in Table 1.1. Tables 1.2-1.6 provide annual water balances of the Amudarya and its main tributaries for average year and dry year (90% flow probability). The functions of return flow (position 2.1, Report "Assessment of channel losses and return flow by Amudarya River reach" by A.Nazariy) are determined for river reaches from the flow from collectors (or collecting drains), depending on water withdrawal from the river; flow from collectors and water withdrawals were summed up by planning zone. The functions of water losses in river channel were determined on the basis of dependences of channel balance discrepancies on river runoff at the beginning of balancing site under consideration; channel balances for 1991-2016 were used (Section 2, Figures 2.3, 2.3a, 2.4, 2.4a). The functions of water losses in the reservoirs of Tuyamuyun Hydroscheme (TMHS) – total losses through evaporation and percolation – were determined on the basis of volume of water in the reservoirs (average for given period). (See Section 2, Figures 2.6-2.6a).

Table 1.1 Channel balance of the Amudarya River for the base period

Channel balance components, mcm	2010-2011			2011-2012			2012-2013			2013-2014			2014-2015		
	Oct-Mar	Apr-Sep	year	Oct-Mar	Apr-Sep	year	Oct-Marc	Apr-Sep	year	Oct-Mar	Apr-Sep	year	Oct-Marc	Apr-Sep	year
UPPER REACHES															
1.Available water resources *	17,773	33,570	51,344	17,694	53,215	70,909	21,589	39,354	60,943	16,486	42,406	58,892	19,607	52,205	71,812
2.Water intake from	2,281	6,082	8,364	1,975	5,817	7,791	2,135	5,572	7,707	2,101	5,679	7,780	2,088	5,925	8,013
2.1. Vakhsh River	2,059	4,334	6,393	1,797	4,143	5,940	1,819	3,923	5,742	1,866	4,100	5,966	1,787	4,312	6,098
2.2. Pyandj River	150	1,238	1,388	118	1,218	1,336	247	1,171	1,419	191	1,196	1,387	236	1,254	1,491
2.3. Kafirnigan River	72	511	583	60	456	516	69	478	547	44	383	427	65	359	424
2.4. Amudarya River	322	861	1,182	234	692	926	371	696	1,068	381	936	1,317	338	828	1,166
3.CDW discharge into Amudarya River	226	234	460	372	1,407	1,779	283	493	776	266	448	714	291	821	1,112
4. Amudarya: upstream of intake to Garagumdarya	15,718	27,722	43,440	16,092	48,805	64,897	19,736	34,275	54,011	14,651	37,175	51,826	17,810	47,101	64,911
MIDDLE REACHES															
8. Water intake from Amudarya to Turkmenistan	4,703	7,814	12,517	4776	9,370	14,146	5,023	9,241	14,265	4,811	9,395	14,207	5,055	10,085	15,140
8.1.Garagumdarya	3,399	5,566	8,964	3,620	6,913	10,533	3,807	6,695	10,502	3,582	6,726	10,308	3,777	7,366	11,143

8.2. Lebap PZ	1,304	2,248	3,552	1,156	2,457	3,613	1,216	2,547	3,763	1,229	2,670	3,899	1,278	2,720	3,998
9. Water intake from Amudarya to Uzbekistan - total	3,346	5,129	8,476	3,186	5,775	8,961	3,128	5,483	8,611	3,108	5,476	8,584	3,228	5,713	8,942
9.1.Karshi Main Canal	1,501	2,214	3,715	1,661	2,401	4,063	1,497	2,306	3,803	1,402	2,297	3,700	1,340	2,308	3,648
9.2.Amu Bukhara Main Canal	1,845	2,915	4,760	1,524	3,374	4,898	1,632	3,177	4,808	1,705	3,179	4,884	1,889	3,405	5,294
10. CDW discharge into Amudarya – total	1,333	1,438	2,771	1,349	1,536	2,885	1,275	1,555	2,831	1,028	1,763	2,790	1,236	1,984	3,220
10.1.from Karshi PZ (South Karshi)	57	448	505	39	279	317	41	419	461	10	550	560	55	570	625
10.2. from Bukhara PZ (Parsangkul)	642	282	925	647	494	1,142	607	420	1,026	441	501	942	573	615	1,188
10.3.from Lebap PZ	634	708	1,341	663	763	1,426	627	717	1,343	578	711	1,289	609	799	1,408
11. Water losses in river channel	494	461	955	518	1,429	1,947	779	705	1,484	429	829	1,258	634	1,331	1,966
Estimation by functions, %	3	2		3	3		4	2		3	2		4	3	
12.Amudarya: Birata GS (Darganata)	7,622	12,094	19,717	7,622	30,304	37,926	10,407	15,471	25,878	6,878	20,644	27,523	9,192	29,777	38,969
13.Balance discrepancy: (-) unrecorded losses	-885	-3,662	-4,547	-1,339	-3,464	-4,802	-1,674	-4,931	-6,604	-452	-2,593	-3,045	-937	-2,178	-3,115
% of river flow	-6	-13	-10	-8	-7	-7	-8	-14	-12	-3	-7	-6	-5	-5	-5

LOWER REACHES															
14. Amudarya: release from TMHS (to river and canals)	7,926	10,046	17,972	7,572	25,921	33,493	9,793	15,834	25,626	6,483	17,239	23,722	7,696	23,044	30,740
15.Water intake to Turkmenistan (Dashoguz)	1,470	2,738	4,208	1,525	5,115	6,639	1,551	4,233	5,783	1,188	4,427	5,615	1,430	4,472	5,902
16.Water intake to Uzbekistan	2,615	5,279	7,894	2,667	1,0061	12,727	2,791	8,046	10,837	2,321	8,806	11,127	2,685	10,228	12,913
16.1.Khorezm PZ	1,090	1,746	2,836	1,096	3,424	4,520	1,256	2,723	3,979	1,013	3,161	4,173	1,177	3,673	4,850
16.2.Karakalpakstan	1,525	3,533	5,058	1,570	6,637	8,208	1,535	5,323	6,858	1,309	5,645	6,954	1,508	6,555	8,063
17. Water losses in river channel	1,564	487	2,051	1,462	7,047	8,508	1,962	2,012	3,974	1,119	2,534	3,654	1,498	5,311	6,809
Estimation by functions, %, %	24	9		24	33		24	18		22	20		24	29	
18.Amudarya: Samanbay GS (inflow to Aral)	1,866	207	2,073	624	5,446	6,070	2,014	470	2,484	610	443	1,053	499	4,357	4,856
19.Balance discrepancy: (-) unrecorded losses	-411	-1,335	-1,746	-1,295	1,747	453	-1,475	-1,073	-2,548	-1,244	-1,029	-2,272	-1,584	1,323	-261
% of river flow	-5	-13	-10	-17	7	1	-15	-7	-10	-19	-6	-10	-21	6	-1
TOTAL DISCREPANCY FOR RIVER	-1,296	-4,997	-6,293	-2,634	-1,716	-4,350	-3,148	-6,004	-9,152	-1,695	-3,621	-5,317	-2,521	-855	-3,376
% of river flow	-7	-15	-12	-15	-3	-6	-15	-15	-15	-10	-9	-9	-13	-2	-5

***** Regulated flow (minus losses) of Amudarya controlled at transboundary level	

Table 1.2 Current channel balance of the Vakhsh River

№	Item	Units	Low water year, p=90%	Average year, p=50%
	VAKHSH RIVER BASIN			
1	Inflow to Nurek hydroscheme	km3/year	16.84	20.09
2	Flow regulation by Nurek reservoir: (+) accumulation, (-) drawdown	km3/year	0.3	0
3	Water losses in Nurek reservoir	km3/year	0.1	0.1
4	Lateral inflow	km3/year	0.25	0.30
5	Water losses in river channel	km3/year	0.08	0.10
6	Water intake from Vakhsh at Nurek-Tigrovaya Balka section: 90 % of limit for low water year and limit for average year (Tajikistan)	km3/year	6.44	7.15
7	Water intake downstream of Tigrovaya Balka (Tajikistan)	km3/year	0.15	0.15
6	Return flow	km3/year	3.54	3.93
8	Vakhsh River flow: mouth	km3/year	13.56	16.82

Table 1.3 Current channel balance of the Pyandj River

№	Item	Units	Low water year, p=90%	Average year, p=50%
	PYANDJ RIVER BASIN			
1	Pyandj River: Khirmanjoy	km3/year	22.34	29.3
2	Kokcha River flow (natural inflow)	km3/year	5.35	6.65
3	Water intake from the Kokcja River (Afghanistan)	km3/year	0.4	0.4
4	Kokcha River: discharge to Pyandj River	km3/year	4.95	6.25
5	Kyzylsu and Yakhsu Rivers (natural inflow)	km3/year	1.2	2.1
6	Water intake from Pyandj River: 90 % of limit for low water year and limit for average year (Tajikistan)	km3/year	1.53	1.7
7	Water use of Kyzylsu and Yakhsu River basins (Tajikistan)	km3/year	0.30	0.30
8	Return flow	km3/year	0.84	0.94
9	Water losses in river channel	km3/year	0.00	0.00
10	Pyandj River flow: Lower Pyandj	km3/year	27.50	36.59

Table 1.4 Current channel balance of the Kafirnigan River

№	Item	Units	Low water year, p=90%	Average year, p=50%
	KAFIRNIGAN RIVER BASIN			
1	Kafirnigan River basin: recorded flow	km3/year	4.2	5.6
2	Water supply to Surkhandarya basin (Karatag, Shirkent) through Large Hissar Canal (LHC)	km3/year	0.3	0.3
3	Water intake of Upper Kafirnigan PZ (Tajikistan)	km3/year	1.5	1.5
4	Water intake of Lower Kafirnigan PZ: 90 % of limit for low water year and limit for average year (Tajikistan)	km3/year	0.9	1
5	Return flow	km3/year	1.08	1.13
6	Water losses in river channel	km3/year	0.00	0.00
7	Kafirnigan River flow: mouth	km3/year	2.58	3.93

Table 1.5 Current channel balance of the Surkhandarya River

№	Item	Units	Low water year, p=90%	Average year, p=50%
	SURKHANDARYA RIVER BASIN			
1	Surkhandarya River basin: recorded inflow	km3/year	2.78	3.4
2	Lateral inflow	km3/year	0.28	0.34
3	Water supply from Kafirnigan River basin (Varzob River) through LHC	km3/year	0.2	0.2
4	Water supply from Amudarya: 90 % of limit for low water year and limit for average year (Uzbekistan)	km3/year	1.413	1.57
5	Water intake of Karatag-Shirkent PZ (Tajikistan)	km3/year	0.4	0.4
6	Water intake of Surkhandarya PZ (Uzbekistan)	km3/year	4.043	4.2
	Including from Amudarya	km3/year	1.413	1.57
7	CDW: generation	km3/year	1.21	1.26
8	Return water	km3/year	0.97	1.01
7	Water losses in reservoirs	km3/year	0.1	0.1
8	Surkhandarya River flow: mouth	km3/year	1.10	1.82

Table 1.6 Current channel balance of the Amudarya River

№	Item	Units	Low water year, p=90%	Average year, p=50%
	AMUDARYA RIVER			
1	Vakhsh River flow: mouth	km3/year	13.56	16.82
2	Pyandj River flow: Lower Pyandj	km3/year	27.50	36.59
3	Kunduz River flow (natural inflow)	km3/year	5.2	6.2
4	Water intake from Kunduz River (Afghanistan)	km3/year	1.7	1.7
5	Kunduz River: discharge to Amudarya		3.5	4.5
6	Kafirnigan River flow: mouth	km3/year	2.58	3.93
7	Surkhandarya River flow: mouth	km3/year	1.10	1.82
8	Water intake from Amudarya to Surkhandarya PZ: 90 % of limit for low water year and limit for average year (Uzbekistan)	km3/year	1.41	1.57
9	Return flow to Amudarya	km3/year	0.24	0.25
10	Amudarya River flow: inflow to middle reaches	km3/year	47.07	62.33
11	Water intake to Garagumdarya – Mary, Akhal and Balkan PZs (Turkmenistan): 90 % of limit for low water year and limit for average year	km3/year	10.377	11.53
12	Water intake to Karshi Main Canal – Karshi PZ (Uzbekistan): 90 % of limit for low water year and limit for average year	km3/year	3.357	3.73
13	Water intake to Amu Bukhara Canal – Bukhara and Navoi PZs (Uzbekistan): 90 % of limit for low water year and limit for average year	km3/year	4.734	5.26

14	Water intake to Lebap PZ(Turkmenistan): 90% of limit for low water year and limit for average year	km3/year	3.636	4.04
15	Total water intake in middle reaches of Amudarya	km3/year	22.10	24.56
16	Return flow from Lepab PZ(Turkmenistan)	km3/year	2.55	2.83
17	Return flow from Karshi PZ (Uzbekistan)	km3/year	0.74	0.45
18	Return flow from Bukhara PZ (Uzbekistan)	км3/год	1.28	1.42
19	Water losses in river channel	km3/year	2.33	2.35
20	Amudarya River flow: inflow to TMHS	km3/year	27.19	40.12
21	Flow regulation by TMHS reservoirs: (+) accumulation, (-) drawdown	km3/year	-1	0
22	Water losses in TMHS reservoirs	km3/year	0.3	0.8
23	Water releases from TMHS	km3/year	27.89	39.32
	Including water intake from TMHS	km3/year	5.6	5.6
	release to river	km3/year	22.29	33.72
24	Water intake to Dashoguz PZ: 90 % of limit for low water year and limit for average year (Turkmenistan)	km3/year	5.79	6.43
25	Water intake to Khorezm PZ: 90 % of limit for low water year and limit for average year (Uzbekistan)	km3/year	4.42	4.91
26	Water intake in Karakalpakstan's PZs: 90 % of limit for low water year and limit for average year (Uzbekistan)	km3/year	7.30	8.11
27	Total water intake to lower reaches of Amudarya	km3/year	17.51	19.45

28	Discharge of emergency environmental flow into canals	km3/year	1.6	1.6
	Including to Dashoguz PZ	km3/year	0.4	0.4
	Khorezm PZ	km3/year	0.8	0.8
	Karakalpakstan's PZs	km3/year	0.4	0.4
29	Collector-drainage flow	km3/year	8.24	9.16
	Including Dashoguz PZ	km3/year	2.89	3.22
	Khorezm PZ	km3/year	2.43	2.70
	Karakalpakstan's PZs	km3/year	2.92	3.24
30	CDW reuse for irrigation	km3/year	1.59	1.77
	Including Dashoguz PZ	km3/year	0.41	0.45
	Khorezm PZ	km3/year	0.31	0.34
	Karakalpakstan's PZ	km3/year	0.88	0.97
31	CDF discharge into lakes	km3/year	6.65	7.39
	Including Dashoguz PZ	km3/year	2.49	2.76
	Khorezm PZ	km3/year	2.12	2.36
	Karakalpakstan's PZs	km3/year	2.04	2.27
32	Return flow: discharge into Amudarya	km3/year	0	0
33	Water losses in river channel	km3/year	4.01	5.06
34	Amudarya River flow: inflow to Prearalie	km3/year	4.77	13.21
35	Water supply to lakes in Prearalie	km3/year	2.5	5
36	Losses in Prearalie	km3/year	0.34	0.82
37	Amudarya River flow: discharge into Large Aral Sea (Eastern part)	km3/year	1.93	7.39
38	CDW discharge into Prearalie	km3/year	1.63	1.82
	TOTAL WATER INTAKE		41.02	45.58

	TOTAL SUPPLY FOR ENVIRONMENTAL NEEDS	km3/year	4.1	6.6
	TOTAL CDW	km3/year	13.05	14.11
	% of water intake	%	32	31
	TOTAL WATER LOSSES	km3/year	6.99	9.03
	% of Amudarya's flow (total of 5 rivers)	%	15	14

Table 7.1 Water balance of planning zones in the Republic of Uzbekistan

Parameters, mcm	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Average
Surkhandarya PZ						
1. Total water resources	4742	4950	4570	4806	5132	4840
1.1 Amudarya	1182	926	1068	1317	1166	1132
1.2 Local rivers	3380	3844	3322	3309	3785	3528
1.3 CDW reuse	80	80	80	80	80	80
1.4 Groundwater use	100	100	100	100	100	100
2. Total water intake for	3910	3964	4190	3931	4270	4053
2.1 Irrigation	3745	3792	4018	3767	4105	3885
2.2 Domestic use	125	124	124	124	125	124
2.3 Industry	17	17	18	17	18	17
2.5 Other consumers	40	48	48	40	40	43
3. Regulation by reservoirs	0	0	0	0	0	0
4.Return flow: 4.1 Actual	946	2705	827	778	1380	1327
4.2. Calculated	1408	1427	1508	1415	1537	1459
4.3. Deviation (actual-calculated)	-462	1278	-681	-637	-157	-132
discrepancy, %	-49	47	-82	-82	-11	-10
5. Water transfer – calculation	2239	2413	1889	2291	2399	2246

6. Water transfer – calculated by actual return	1778	3691	1208	1653	2242	2114
7. Discharge through river into Amudarya	1519	3155	1032	1413	1916	1807
8.CDW discharge into Amudarya	258	536	175	240	326	307
Karshi PZ						
1. Total water resources	3969	4320	4046	3960	3896	4038
1.1 Amudarya	3715	4063	3803	3700	3648	3786
1.2 Local rivers	50	50	50	50	50	50
1.3 CDW reuse	68	69	65	70	66	68
1.4 Groundwater use	136	138	129	141	132	135
2. Total water intake for	4526	4596	4301	4689	4400	4502
2.1 Irrigation	4028	4090	3828	4173	3916	4007
2.2 Domestic use	158	161	151	150	141	152
2.3 Industry	317	322	301	328	308	315
2.5 Other consumers	23	23	22	38	35	28
3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow to river:						
4.1. Actual	921	1136	1026	936	959	996
4.2. Calculated	996	995	1001	993	999	997
4.3. Deviation (actual-calculated)	-76	141	25	-57	-40	-1
%	-8	12	2	-6	-4	0
5. Water transfer	0	0	0	0	0	0
6. Discrepancy (5-1+2+3)	557	277	255	728	504	464
%	12	6	6	16	11	10

Bukhara PZ						
1. Total water resources	5066	5186	5109	5165	5583	5222
1.1 Amudarya	4760	4898	4808	4884	5294	4929
1.2 Local rivers	0	0	0	0	0	0
1.3 CDW reuse	225	208	221	201	209	213
1.4 Groundwater use	80	80	80	80	80	80
2. Total water intake for	4681	4358	4628	4213	4373	4451
2.1 Irrigation	4503	4157	4425	4018	4182	4257
2.2 Domestic use	41	52	46	46	46	46
2.3 Industry	37	40	38	37	37	38
2.5 Other consumers	100	109	119	112	108	110
3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow to river:						
4.1. Actual	1205	1136	1210	1178	1148	1176
4.2. Calculated	1203	1165	1196	1148	1167	1176
4.3. Deviation (actual-calculated)	2	-29	14	30	-19	0
%	0	-3	1	3	-2	0
5. Water transfer	0	0	0	0	0	0
6. Discrepancy (5-1+2+3), losses (-)	-384	-828	-481	-952	-1210	-771
%	-8	-19	-10	-23	-28	-17
Khorezm PZ						
1. Total water resources	2941	4649	4112	4291	4990	4197
1.1 Amudarya	2836	4520	3979	4173	4850	4072
1.2 Local rivers	0	0	0	0	0	0

1.3 CDW reuse	80	104	108	93	115	100
1.4 Groundwater use	25	25	25	25	25	25
2. Total water intake for	3289	4253	4410	3802	4685	4088
2.1 Irrigation	3200	4162	4320	3719	4596	3999
2.2 Domestic use	86	88	86	80	85	85
2.3 Industry	3	3	3	3	3	3
2.5 Other consumers	0	0	1	0	1	0
3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow to river:						
4.1. Actual	2704	3099	2654	2657	3105	2844
4.2. Calculated	2681	2881	2914	2787	2971	2847
4.3. Deviation (actual-calculated)	23	218	-260	-130	134	-3
%	1	7	-10	-5	4	0
5. Water transfer	0	0	0	0	0	0
6. Discrepancy (5-1+2+3)	348	-396	297	-489	-305	-109
%	11	-9	7	-13	-7	-3
Karakalpakstan's PZs						
1. Total water resources	5106	8265	6912	7004	8121	7081
1.1 Amudarya	5058	8208	6858	6954	8063	7028
1.2 Local rivers	0	0	0	0	0	0
1.3 CDW reuse	28	37	34	30	39	33
1.4 Groundwater use	20	20	20	20	20	20
2. Total water intake for	5935	7788	7249	6285	8135	7078
2.1 Irrigation	5554	7399	6851	5910	7720	6687

2.2 Domestic use	49	52	55	50	59	53
2.3 Industry	325	329	335	320	340	330
2.5 Other consumers	7	8	8	5	16	9
3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow:						
4.1. Actual	2139	2185	2170	2086	2200	2156
4.2. Calculated	2110	2185	2163	2124	2199	2156
4.3. Deviation (actual-calculated)	29	0	7	-38	1	0
%	1	0	0	-2	0	0
5. Water transfer	0	0	0	0	0	0
6. Discrepancy (5-1+2+3)	829	-476	337	-719	14	-3
%	14	-6	5	-11	0	0

Table 7.2 Water balance of planning zones in Turkmenistan

Parameters, mcm	**2010-2011**	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**Average**
Mary PZ						
1. Total water resources	10654	12620	12438	12188	13310	12242
1.1 Amudarya(Garagumdarya)	8964	10533	10502	10308	11143	10290
1.2 Local rivers	1363	1790	1611	1550	1835	1629
1.3 CDW reuse	126	114	125	127	128	124
1.4Groundwater use	202	183	200	203	205	199
2. Total water intake for	5184	4705	5154	5233	5263	5108
2.1 Irrigation	4272	3818	4251	4306	4327	4195

2.2 Domestic use	60	62	75	85	96	76
2.3 Industry	820	820	820	820	820	820
2.5 Other consumers	32	5	8	22	20	18
3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow:						
4.1. Actual	1319	1197	1312	1332	1339	1300
4.2. Calculated	1175	1117	1173	1180	1182	1165
4.3. Deviation (actual-calculated)	144	80	139	152	157	135
%	11	7	11	11	12	10
5. Overflow to neighboring PZ along the canal	3606	5706	5107	4822	5718	4992
6. Discrepancy, losses (-)	-1864	-2208	-2177	-2133	-2329	-2142
% of water intake	-35,97	-46,94	-42,23	-40,76	-44,26	-42
Akhal PZ						
1. Total water resources	4531	7145	6343	5987	7232	6247
1.1 Amudarya(Garagumdarya)	3606	5706	5107	4822	5718	4992
1.2 Local rivers	689	1196	983	911	1249	1005
1.3 CDW reuse	91	93	97	97	102	96
1.4Groundwater use	145	149	155	156	164	154
2. Total water intake for	3733	3840	3993	4012	4210	3958
2.1 Irrigation	3440	3522	3640	3654	3806	3613
2.2 Domestic use	249	279	290	320	360	300
2.3 Industry	36	36	36	36	36	36
2.5 Other consumers	8	3	27	2	8	10

3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow:						
4.1. Actual	472	485	504	507	532	500
4.2. Calculated	479	482	485	486	490	484
4.3. Deviation (actual-calculated)	-8	3	19	21	42	16
%	-2	1	4	4	8	3
5. Overflow to neighboring PZ along the canal	448	527	525	515	557	514
6. Discrepancy, losses (-)	-349	-2778	-1824	-1459	-2465	-1775
% of water intake	-9	-72	-46	-36	-59	-44
Lebap PZ						
1. Total water resources	3597	3663	3813	3950	4049	3814
1.1 Amudarya(Garagumdarya)	3552	3613	3763	3899	3998	3765
1.2 Local rivers	0	0	0	0	0	0
1.3 CDW reuse	45	49	50	51	52	49
1.4Groundwater use	0	0	0	0	0	0
2. Total water intake for	3000	3287	3332	3420	3456	3299
2.1 Irrigation	2937	3214	3258	3335	3362	3221
2.2 Domestic use	40	45	50	54	59	50
2.3 Industry	20	20	20	20	20	20
2.5 Other consumers	3	8	4	11	15	8
3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow:						
4.1. Actual	1724	1833	1725	1655	1808	1749
4.2. Calculated	1539	1647	1664	1697	1711	1651
4.3. Deviation (actual-	185	186	61	-42	97	98

calculated)						
%	11	10	4	-3	5	5
5. Overflow to neighboring PZ along the canal	0	0	0	0	0	0
6. Discrepancy (5-1+2+3)	-597	-376	-481	-530	-593	-516
% of water intake	-20	-11	-14	-16	-17	-16
Dashoguz PZ						
1. Total water resources	4208	6639	5783	5615	5902	5629
1.1 Amudarya (Garagumdarya)	4208	6639	5783	5615	5902	5629
1.2 Local rivers	0	0	0	0	0	0
1.3 CDW reuse	0	0	0	0	0	0
1.4Groundwater use	0	0	0	0	0	0
2. Total water intake for	4160	4845	4150	3986	4140	4256
2.1 Irrigation	4140	4834	4125	3959	4114	4235
2.2 Domestic use	18	21	23	23	24	22
2.3 Industry	2	2	2	2	2	2
2.5 Other consumers	0	-12	0	2	0	-2
3. Regulation by reservoirs	0	0	0	0	0	0
4. Return flow:						
4.1. Actual	2150	2504	2145	2060	2140	2200
4.2. Calculated	2021	2061	2021	2011	2020	2027
4.3. Deviation (actual-calculated)	129	443	125	49	120	173
%	6	18	6	2	6	8
5. Overflow to neighboring PZ along the canal	0	0	0	0	0	0

6. Discrepancy (5-1+2+3)	-48	-1794	-1633	-1629	-1762	-1373
% of water intake	-1	-37	-39	-41	-43	-32

Table 7.3 Water balance of planning zones in Tajikistan

Parameters, mcm	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Average
1.Water resources of Tajikistan	50635	68175	58219	56147	69159	60467
1.1 River flow	49915	67455	57499	55427	68439	59747
1.1.1 Vakhsh	21015	23804	20668	20591	23452	21906
1.1.2 Pyandj	23303	37160	31344	29375	38609	31958
1.1.3 Kafirnigan	5598	6490	5487	5462	6378	5883
1.2. Groundwater use	720	720	720	720	720	720
1.3. CDW reuse	0	0	0	0	0	0
2. Water intake at the borders of PZs	8186	7763	7331	7589	8013	7776
2.1 Khatlon province	6274	5966	5656	5865	6208	5994
2.1.1 Vakhsh PZ	4015	3818	3620	3754	3973	3836
2.1.2 Pyandj PZ	1380	1312	1244	1290	1366	1319
2.1.3 Lower Kafirnigan PZ	878	835	792	821	869	839
2.2 DRS	1284	1187	1081	1104	1146	1161
2.2.1 Upper Kafirnigan PZ	886	819	746	762	791	801
2.2.2 Karatag-Shirkent PZ	283	261	238	243	252	255
2.2.3 Garm PZ	116	107	97	99	103	104
2.3 Gorno-Badakhshan PZ	628	610	593	620	659	622

3. Water intake for						
3.1 Irrigation	6958	6599	6231	6451	6811	6610
3.2 Domestic use	470	479	487	496	508	488
3.3 Industry	252	239	219	221	217	230
3.5 Other consumers	506	446	394	421	477	449
4. Return flow	3111	2950	2786	2884	3045	2955
4.1. Khatlon province	2489	2360	2229	2307	2436	2364
4.2.DRS	591	560	529	548	579	563
4.3. Gorno-Badakhshan PZ	31	29	28	29	30	30
5. Amudarya						
5.1 BP: Kunduz, Surkhandarya	4378	7572	4781	5219	6088	5608
5.2 Water intake at Kafirnigan-Garagumdarya section	1182	926	1068	1317	1166	1132
5.3 Flow of Amudarya upstream of intake to Garagumdarya – calculated	48756	70007	57387	55345	69112	60121
5.4 Flow of Amudarya upstream of intake to Garagumdarya – actual	43440	64877	54011	51826	64911	55813
5.5. Discrepancy (actual-calculated), losses	-5316	-5130	-3376	-3519	-4201	-4308
% of river flow	-12	-8	-6	-7	-6	-5

Table 1.8 Water balance of the Karshi Main Canal (KMC) for average year over 2010-2015

Indicator	Unit	Oct-Mar	Apr-Sep	Year
1.Water intake from Amudarya to KMC (Uzbekistan)	mcm	1,700	2,700	4,400
2.Supply from KMC to Talimardjan reservoir	mcm	700	0	700
3.Release from Talimardjan reservoir to irrigation network	mcm	200	450	650
4.Accumulation (+), drawdown (-) of Talimardjan reservoir	mcm	500	-450	50
5.Regulated flow in Amudarya River (Uzbekistan)	mcm	1,200	3,150	4,350
6. Performance efficiency of the main network	mcm	0.72	0.72	0.72
7.Losses in main network	mcm	336	567	783
8.Regulated available water of Amudarya (Uzbekistan)	mcm	864	2,583	3,567
9.Water intake of Karshi PZ at the border of districts	mcm	860	2,630	3,490
11.Balance discrepancy	mcm	-4	47	-77
% of water intake	%	0	2	-2

Table 1.9 Water balance of the Amu Bukhara Main Canal (ABMC) for average year over 2010-2015

Indicator	Unit	Oct-Mar	Apr-Sep	Year
1.Water intake from Amudarya to ABMC (Uzbekistan)	mcm	1,800	3,350	5,150
Including: Bukhara PZ	mcm	1,500	2,920	4,420
Navoi PZ	mcm	300	430	730
2.Accumulation (+), drawdown (-) of Tudakul and Kuyumazar reservoirs	mcm	180	-150	30
3.Regulated flow of Amudarya River (Uzbekistan)	mcm	1,620	3,500	5,120
4. Performance efficiency of the main network	mcm	0.91	0.91	0.91
5.Losses in main network	mcm	145.8	315	460.8
6.Regulated available water of Amudarya (Uzbekistan)	mcm	1,474.2	3,185	4,659.2
7.Water intake from irrigation network, fed with water from Amudarya, at the borders of Navoi and Bukhara PZs	mcm	1,550	3,030	4,580
Including: Bukhara PZ	mcm	1,350	2,610	3,960
Navoi PZ	mcm	200	420	620
8.Balance discrepancy	mcm	-75.8	155	79.2
% of water intake	%	-5	5	2

Table 1.10 Water balance of Garagumdarya/Karakum Canal (KC) for average year over 2010-2015

Indicator	Unit	Oct-Mar	Apr-Sep	Year
1.Water intake from Amudarya to KC	mcm	3,640	6,650	10,290
2.Murghab River flow (Turkmenistan)	mcm	240	1,670	1,910
3.Tedjen River flow (Turkmenistan)	mcm	260	760	1,020
4.Groundwater in KC zone (water intake)	mcm	80	320	400
5.Return water use	mcm	0	250	250
6. Total water resources(1+2+3+4+5)	mcm	4,220	9,650	13,870
7.Flow regulation by reservoirs: accumulation (+), drawdown (-)	mcm	-600	600	0
8.Losses in KC	mcm	1,055	2,413	3,468
9.Losses in reservoirs of Murghab and Tedjen Rivers	mcm	90	140	230
10.Losses in reservoirs of KC	mcm	120	280	400
11.Available water resources regulated by reservoirs (6-7-8-9-10)	mcm	3,555	6,218	9,773
12.Water intake of Mary PZ (at the border)	mcm	1,955	3,155	5,110
13.Water intake of Akhal PZ(at the border)	mcm	1,420	2,540	3,960
14.Water supply to Balkan PZ through KC	mcm	182	333	515
15.Total water intake (12+13+14)	mcm	3,557	6,028	9,585
16.Balance discrepancy (11-15)	mcm	-2	190	188
% of flow	%	0	3	2

Table 1.11 Comparison of calculated and actual return (collector) flow discharged into the Amudarya from the Karshi PZ

Indicator	Average	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Average
Karshi Canal flow, mcm	Oct-Mar	1,501	1,661	1,497	1,402	1,340	1,480
	Apr-Sep	2,214	2,401	2,306	2,297	2,308	2,305
	Oct-Sep	3,715	4,063	3,803	3,700	3,648	3,786
Return flow to Amudarya from Karshi PZ – calculated, mcm	Oct-Mar	55	114	53	34	8	53
	Apr-Sep	427	439	433	432	433	433
	Oct-Sep	482	553	486	466	441	486
Return flow to Amudarya from Karshi PZ – actual, mcm	Oct-Mar	57	102	50	30	10	50
	Apr-Sep	448	479	419	391	369	421
	Oct-Sep	505	581	469	421	379	471
Deviation: actual-calculated, mcm	Oct-Mar	2	-12	-3	-4	2	-3
	Apr-Sep	22	39	-13	-41	-64	-11
	Oct-Sep	24	28	-17	-45	-62	-15
Deviation: actual-calculated, %	Oct-Mar	3	-12	-7	-14	16	-3
	Apr-Sep	5	8	-3	-11	-17	-4
	Oct-Sep	5	5	-4	-11	-16	-4

Table 1.12 Comparison of calculated and actual return (collector) flow discharged into the Amudarya River from the Bukhara PZ

Indicator	Period	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	Average
Flow of Amu Bukhara Canal, mcm	Oct-Mar	1,845	1,524	1,632	1,705	1,889	1,719
	Apr-Sep	2,915	3,374	3,177	3,179	3,405	3,210
	Oct-Sep	4,760	4,898	4,808	4,884	5,294	4,929
Return flow to Amudarya from Bukhara PZ - calculated, mcm	Oct-Mar	711	606	641	666	726	670
	Apr-Sep	484	558	527	527	564	532
	Oct-Sep	1,196	1,165	1,168	1,192	1,289	1,202
Return flow to Amudarya from Bukhara PZ – actual, mcm	Oct-Mar	679	647	607	657	772	672
	Apr-Sep	428	549	516	501	615	522
	Oct-Sep	1,107	1,196	1,123	1,158	1,387	1,194
Deviation: actual-calculated, mcm	Oct-Mar	-32	41	-34	-9	46	2
	Apr-Sep	-56	-9	-11	-26	51	-10
	Oct-Sep	-89	32	-45	-34	97	-8
Deviation: actual-calculated, %	Oct-Mar	-5	6	-6	-1	6	0
	Apr-Sep	-13	-2	-2	-5	8	-3
	Oct-Sep	-8	3	-4	-3	7	-1

Water balance of planning zones and large canals

The water balance of planning zones for the base period (2010-2015) is shown in Tables 1.7.1, 1.7.2, 1.7.3. Particular characteristics of PZ's water balances are described below. We also provide the data on system reservoirs and on the structure of water management. Tables 1.8-1.10 show water balances of large main canals, such as KMC, ABMC, and Garagumdarya (former Karakum canal).

Planning zones in the Republic of Tajikistan

Planning zones (PZ) in Tajikistan are located in the upper reaches of the Amudarya River and grouped into large water districts (WD) as stipulated by the Revised Master Plan for Multipurpose Water Use and Protection in the Amudarya River (Sredazgiprovodkhoz, 1984). In the upper reaches of the Amudarya River, the Pyandj and Gorno-Badakhshan PZs are located in the Pyandj WD and Vakhsh and Garm PZs - in the Vakhsh WD. The Alay PZ (Kyrgyzstan) is also located in the Vakhsh WD. Upper and lower Kafirnigan PZs are located in the Kafirnigan WD. Tajik Karatag-Shirkent PZ is located in the Surkhandarya WD. The largest irrigated area of Tajikistan is located in the Vakhsh Valley; it includes Vakhsh and Garm PZs. Kulyab, Parkhar-Chubek and Gorno-Badakhshan irrigated systems are located in the Pyandj irrigated area. Kafirnigan irrigated area is located in the Kafirnigan River basin (upper and lower PZ). Here, irrigated agriculture is more developed in the Hissar and Lower Kafirnigan Valleys. The flow is diverted from the Kafirnigan River basin to the Tajik zone of the Surkhandarya basin through the Large Hissar Canal (Karatag-Shirkent PZ).

On average, over 2010-2015 water resources available for Tajik PZs are estimated at 60 bcm, water diversion is7.8 bcm, and return flow is3 bcm. Water balance is achieved with substantial discrepancy (water losses) which is 4.2 bcm or 5% of the Amudarya's flow upstream of the intake to Garagumdarya (Karakum canal).

Planning zones in the Republic of Uzbekistan

Planning zones in Uzbekistan are located in the upper, middle and lower reaches. The Surkhandarya PZ is located in the Surkhandarya WD, Karshi PZ in the Karshi WD, Bukhara and partly Navoi PZs in the Bukhara WD, and Khorezm PZ and Karakalpakstan PZs in the Lower reaches WD.

Surkhandarya planning zone

The Surkhandarya PZ is an Uzbek part of the Surkhan-Sherabad WD. The land is irrigated from the Surkhandarya River and its tributaries, Sherabad River, and Amudarya River. Irrigated lands are located in the Surkhandarya and Sherabad River Valleys. The following Irrigation System Administrations (ISA) are responsible for water distribution in the Surkhandarya PZ: Tupalang-Koratog, Surkhon-Sherabad, and Amu-Zang. ISA Amu Zang is responsible for water diversion from the Amudarya River. ISAs Surkhon-Sherabad and Amu-Zang distribute water of the Surkhandarya and Sherabad Rivers; ISA Tupalang-Koratog distributes the flow of the Tupalong River. In the PEER Project models, the flow of the Tupalang, Surkhandarya and Sherabad Rivers is accounted as a "local" resource, whereas the flow of the Amudarya – as a transboundary resource, on which the limit of 1,200 mcm is imposed. In the Surkhandarya PZ, Yujnosurkhan, Tupalang, Degrez, Uchkyzyl, and Aktepe reservoirs are located, with the total active capacity of 1.4 bcm. In the Surkhandarya PZ, the Surkhandarya artesian basin is located, with groundwater storage in the amount of 1 bcm, of which 1/10 is used.

In the Surkhandarya planning zone, water resources are estimated at 4.8 bcm, water diversion – at 4.1 bcm, and return flow – at 1.5 bcm for 2010-2015. The outflow from the Surkhadnarya PZ to the Amudarya River is estimated at 2.1 bcm.

Karshi planning zone

The Karshi PZ is a newly irrigated zone in the Kashkadarya province (Karshi steppe, Uzbekistan); water is supplied from the Amudarya River through the Kashri Main Canal. Flow in the canal flow is regulated by the Talimardjan reservoir, with the active capacity of 1.4 bcm. The reservoir is filled from October to March in the amount of 500 mcm and drawn down to the irrigation network during the growing season in the amount of 450 mcm. In the Karshi PZ, the following ISAs are responsible for distribution of water from the Amudarya River: KMK, Mirishkor, and Yakkabog-Guzor.

In the Karshi PZ, water resources are estimated at 4 bcm, water diversion – at 4.5 bcm, and return flow – at 1 bcm for 2010-2015. Water balance is achieved with positive discrepancy which is 0.5 bcm (unrecorded inflow).

Bukhara and Navoyi planning zones

In the Bukhara PZ, water is supplied from the Amudarya River through the Amu-Bukhara Main Canal (ABMC). In the Navoi PZ, water is supplied from the Zeravshan River and partly from ABMC. In the Bukhara PZ, water is distributed by the Amu-Bukhara Basin Irrigation System Administration (BISA) and the following ISAs: Amu-Karakul, Shakhrud-Dustlik, Kharkhur-Dooba, and Toshrabad-Jivlon. In the Navoyi planning zone, water is distributed by BISA Amu-Bukhara and ISA Toshrabad-Urtachul, which is an integral part of the BISA.

The current water diversion from the Amudarya River through ABMC is estimated at 5 bcm, of which 4.5 bcm is supplied to the Bukhara PZ and the rest to the Navoi PZ. In the Bukhara PZ, the flow is regulated by the Tudakul and Kuyumazar reservoirs, with the total active capacity of 850 mcm. In the Bukhara PZ, water resources are estimated at 5.2 bcm and water diversion at 4.4 on average over 2010-2015. Water losses (calculated on the basis of balance discrepancy) were estimated at about 800 mcm.

Khorezm PZ and Karakalpakstan PZs

Khorezm PZ (Khorezm oasis) is located on the left bank of the Amudarya River in its lower reaches; it is irrigated by the Tuyamuyun hydroscheme (TMHS) reservoirs and the river mainstream. Water is distributed through interstate and national canals by the following ISAs: Tashsaka, Polvan-Gazavat, Shavat-Kulavat, and Karamazi-Klychbay. In the Khorezm province, water resources are estimated at 4.2 bcm, and the return flow-at 2.8 bcm on average over 2010-2015.

In the PZs of Karakalpakstan (Karakalpak oasis), water is supplied from TMHS (Southern PZ) and the Amudarya River (Northern PZ). Nizhneamudarya BISA and 6 ISAs are responsible for water distribution in the Southern and Northern PZ of Karakalpakstan. The flow is regulated by the TMHS reservoirs (designed active capacity of 5.2 bcm) and Mejdurechenskoye reservoir (400 mcm). In the PZs of Karakalpakstan, water resources are estimated at 7.1 bcm and the return flow – at 2.2 bcm over 2010-2015. Water availability in the PZs depends on water supply from the Amudarya River to TMHS and its effective operation. In the PZs, a lake system of Prearalie is located. It is represented by aquatic ecosystems maintained by water discharged from the irrigation and collector network. Water is discharged from the Northern PZ to the Eastern part of the Aral Sea through the Amudarya River and collectors.

Planning zones in Turkmenistan

Under the PEER project, water balance is calculated for the following planning zones in Turkmenistan: in the middle reaches of the Amudarya – Lebap, Mary and Akhal (the Balkan PZ was considered in the balance for the Garagumdarya) and in the lower reaches – Dashoguz. Lebap PZ is located in the Turkmenistan's coastal WD, Mary and Akhal PZ –Karakum WD, and Dashoguz–Lower Amudarya PZ. In the PZs of Turkmenistan, water is managed at the velayat (provincial) level: "Akhalsuvkhodjalygy" in the Akhal PZ, "Murgapsuvkhodjalygy" in the Mary PZ (Mary city), "Lebapsuvkhodjalygy" in the Lebap PZ (Turkmenabad city), and "Dashoguzsuvkhodjalygy" in the Dashoguz PZ (Dashoguz city).

Garagumdarya planning zones

In the Garagumdarya PZ (up to the border with the Balkan PZ), the main source of irrigation is the Amudarya River and local rivers, Tedjen and Murghab. The Garagumdarya and a number of reservoirs sustainably supply water to the Mary and Akhal PZs. In the Mary PZ, the Khauzkhan reservoir (active capacity of 0.5 bcm) is located on Garagumdarya. In the Mary PZ, the Saryyazin (active capacity of 0.25 bcm), Tashkeprin (0.15 bcm) reservoirs and other reservoirs (0.46 bcm) are located on the Murghab River. In the Lebap PZ, the largest reservoir "15 Years of Turkmenistan's Independence" (former Zeid reservoir) is located on Garagumdarya, with active capacity of 1.1 bcm. In the Akhal PZ, Kopetdag (0.52 bcm), Danatin (0.39 bcm), and Madluss (0.65 bcm) reservoirs are located on Garagumdarya. In the Akhal PZ, Dostluk reservoir (1 bcm) and other reservoirs with lower capacity are located along the Tedjen River. In general, the regulating capacity of all reservoirs in the Garagumdarya PZ (up to the border with the Balkan PZ) is estimated at 4.9 bcm, which is enough to redistribute water resources from non-growing season to growing season for irrigation purposes.

Murghab and Tedjen oases, the largest ones in the Garagumdarya PZ, are located in the Murghab and Tedjen River basins. Oases are separated by the Karakum desert; larger part of Garagumdarya PZ is covered by sand that resulted in substantial water losses. According to the balance, 2.1 bcm and 1.8 bcm is lost in the Mary PZ and Akhal PZ, respectively.

Lebap and Dashoguz planning zones

Lebap PZ is located in the valley of the middle reaches of the Amudarya River and Turkmenistan's coastal WD. The only source of irrigation is the Amudarya River. For 2010-2015, water resources are estimated at 3.8 bcm and return flow – at 1.7 bcm in the planning zone. Collector flow in the Lebap PZ is now discharged mainly into the Amudarya River; however, in the future it will be discharged into Lake Altyn Asyr. Dashoguz PZ, the northernmost oasis in Turkmenistan, is located in the lower reaches of the Amudarya River and supplied with water from TMHS and river mainstream through a number of interstate canals.

Planning zone is represented by a flat relief crossed by a network of canals and collectors that extend from Uzbekistan. The largest collectors, Ozerniy and Daryalyk, discharge collector water from Khorezm province (Uzbeksitan) and Dashoguz to Sarykamysh Lake. In the Dashoguz PZ, water resources are estimated at 5.6 bcm for 2010-2015. Water balance is achieved with substantial water losses in the volume of 1.4 bcm (32% of water diversion).

The detailed water balance of planning zones (by economic sector and water source) is shown for 2010-2015 in the report on planning zone model testing by R.Khafazov. This report also gives the comparison between the estimated water requirements (based on crop water use norms and irrigated crop areas) and the actual water use.

For drawing the future channel balance of the Amudarya River (2016-2055) it is necessary to calculate return flow from collectors into the river. According to scenarios, discharge from collectors in lower Amudarya and from the left bank of middle reaches will be discontinued,

while on the right bank of middle reaches collector water will flow out of Karshi PZ and Bukhara PZ. Tables 1.11 and 1.12 show the testing results of linear functions that allowed calculating the return flow from Karshi PZ and Bukhara PZ, depending on water withdrawal from the Amudaray River through Karshi main canal and Amu-Bukhara main canal.

For example, we will show relationships between the return flow (Y) and the water withdrawal (X) for Bukhara PZ (see the report by A.Nazariy):

- from April to September $Y = 0.162*X + 11.96$, $R2 = 0.62$

- from October to March $Y = 0.328*X + 106.21$, $R2=0.61$

The comparison of calculated and measured values of return flow discharged into the Amudarya River from Karshi and Bukhara planning zones demonstrates that calculation by linear relationships produces acceptable results: for 2010-2015 the average deviation of measured values from calculated ones is 3…4% for growing season and 0…3% for non-growing season. The comparison of calculated and actual values of return flow generated in planning zones showed the following. On the average over 2010-2015 the annual volume of return flow differs from calculated one by 1…10% in PZs of Uzbekistan and by 3…10% in PZs of Turkmenistan.

Conclusions

1.The channel balance of the Amudarya River drawn by using the data over 2010-2015 was achieved with the annual discrepancy of 5…15% of the river runoff. This indicates to unrecorded losses in the river. The annual balance discrepancy varied within 1…10% in the lower reaches.

2.Water balance of Karshi main canal drawn by using the data over 2010-2015 was achieved with the negative annual discrepancy of 2%. This indicates to minor unrecorded losses in the canal; the Karakum canal (now Garagumdarya) and Amu-Bukhara main canal showed positive discrepancy of 2% (unrecorded inflow). The balance discrepancy is positive for all canals - 2…5% - during the growing season.

3.The lowest negative discrepancies of water balance (on average over 2010-2015) indicating to flow losses are observed in PZs of Uzbekistan in the lower reaches of Amudarya (- 3% of water withdrawal) – Khorezm, Karakalpakstan. The balance discrepancy is -10% for Surkhandarya and Karshi PZs (Uzbekistan) and -16% for Lebap PZ (Turkmenistan). The highest negative discrepancies are observed in Dashoguz (Turkmenistan) – 32% and in the zone of Garagumdarya (former Karakum canal): Mary – 42% of water withdrawal and Akhal PZ – 44%. The total losses (calculated from discrepancies) in the Garagumdarya irrigation network to the border with Balkan are estimated approx. at 4 billion cubic km.

4.This research allowed drawing the present channel balance of the Amudarya River which is linked with channel balances of Vakhsh, Pyandj, Kafirnigan, and Surkhandarya rivers. The balance shows that the current demands for water intake into canals can be met for average year. Furthermore, water supply to the Aral Sea amounts to 7.4 bcm. For dry year, it is necessary to cut intake into canals by 10%, and water supply to the Aral Sea will diminish to 1.9 bcm. The losses in the channel balance are estimated at 14% for average year and 15% for dry year.

2. Assessment of water losses in river channel

Calculation methods

Many authors made assessments of water losses in the Amudarya River channel by using various methods and on the basis of actual (measured) elements of channel balance (CB). We can identify two main approaches to calculation of losses. The first approach refers to constructing of a dynamic model of channel balance, where water losses in river channel (evaporation from the water surface and seepage) are considered as individual elements; such model, as a rule, calculates changes in water volume in the river channel within balancing sites (dynamic factor), and therefore, dynamic factor is not accounted in the calculated values of losses. As the examples of such models we cite the computer models developed at the Central Asian Irrigation Research Institute, SPA SANIIRI (Sorokin A.G., 2002) and SIC ICWC (Sorokin A.G., 2014). The models are used for various tasks related to planning of water distribution along Amudarya as the tools for scientific assessments; however, formally those were not adopted as a common tool for calculation of losses in the region and did not receive due consideration by the riparian countries. The second approach refers to assessment of losses by the CB method for river reaches; in this case, losses are estimated cumulatively, without separation of percolation and evaporation elements, as an identified discrepancy of CB. In such approach, losses, usually, include also dynamic factor (the values of change in water volumes in the river channel); the quality of assessments of flow losses based on CB depends on calculation scheme – selection of representative time periods (rise and recession of flood, low-water level) and of representative river reaches that are close in terms of flow transformation conditions and data reliability (if the data is not reliable, losses may include unrecorded water withdrawal or (with negative sign) unrecorded lateral inflow).

An impact of dynamic factor (changes in water volume in the river channel) on water losses can be shown by the actual CB for July 2015. Relative water losses in the river reach Kelif g/s – Birata g/s (Darganata) in % of river flow at Kelif g/s were about 20% in the first and second ten-days of July 2015 and decreased to 3% in the third ten-days. The abrupt decrease in related losses in the third ten-days can be explained as follows: in the first and second ten-days the water level in the river reach increased because of growth of flow rate at Kelif g/s, and a share of flow was accumulated in the river channel (that was reflected in losses); in the third ten-days the flood got stabilized and the flow rates slightly decreased even – this was reflected in losses via some compensation through discharge of water accumulated in the river channel in the previous ten-day period.

Since commissioning of the Tuyamuyun Hydroscheme (TMHS), in the mid 80-s, when TMHS reservoirs had got filled and regime of the Amudarya River in the lower reaches had changed, there arose a task to draw river's CB and calculate water losses in the reservoirs and in the river downstream of TMHS. Relevant research, supported by strong expeditions, was carried out since the mid 80-s to the mid 90-s by SANIIRI Institute; the research comprised field observations, their processing and computer modeling of generation of losses (Sorokin A.G., 2002). The use in the SANIIRI's models of seepage-based relationships and morphometric relationships allowed calculating water losses in the river for any flow conditions in year, season, and month. The hypothesis about presence of seepage component in water losses is proven in many research work, including Proskuryakov A.K. (1953), Svetitskiy V.P. (1985), and Al'tshul A.kh. (1989).

The CB modeling exercises were continued by SIC ICWC. It was demonstrated that the bulk of seepage losses is observed in the reaches, such as Kerki-Il'chik and Tuyamuyun-

Kipchak; continuous inflow of seepage water to the river channel was identified in the Il'chik-Birata (Darganata) reach.

Assessment of losses based on the past research results

In the sixties of the last century V.Shultz (1965) assessed annual water losses in the Amudarya River as 7.6 km^3. In the design studies by the Central Asian division of Gidroproyekt Institution (1971) carried out for the Master Plan of multipurpose water use of the Amudarya River the water losses in the river (for conditions of the average long-term flow) were estimated at 7.8 km^3, including 6.6 km^3 in the Kerki-Chatly reach (4.7 km^3 are lost through evaporation). In the early eighties during revision of the Master Plan this assessment of losses was reduced (Sredazgiprovodkhlopok, 1984) – for a dry year only 2.9 km^3, including 1.96 km^3 (or 7% of river flow at Tuyamuyun g/s) in the lower reaches.

The calculations made by SIC ICWC on the basis of the data for a period of time until 1990 show that in the middle reaches of the Amudarya River, particularly in Kelif-Birata (Darganata) reach the average monthly losses do not exceed 2..6% if the flow rate in Amudarya is less than 500 m3/s and vary within 1..4% if the flow rate is more than 500 m3/s. The estimated losses are higher in the lower reaches: can amount to 12…17 % if the flow rate is less than 500 m3/s and vary within 6…14 % if the flow rate is more than 500 m3/s.

ADB's assessment

The assessment of losses under the Asian Development Bank's Project "RETA 6163 – Improved Management of Shared Water Resources in Central Asia" is the product of joint work of the basin's countries (**www.cawater-info.net/reta**/).

As part of the RETA 6163 Project the ten-day channel balances were drawn for Kelif-Darganata, Tuyamuyun-Kipchak and Kipchak-Samanbay reaches for 1989 - 2006. Water losses are expressed in % of flow at the beginning of the reach under consideration, and their expected range is given (Max, Min) for dry, wet, and average years during two temporal periods, such as April-September and October-March.

According to the project's estimations, for CB calculations and water distribution at the Tuyamuyun-Samanbay reach the channel losses are recommended for accounting as: 16…20% over October-March; and, 14…17% over April-September. For Kelif-Darganata reach the recommended maximum losses are determined as 1.5…2%.

Analysis of BWO Amudarya's data

For implementation of the protocol decision of the 54th ICWC meeting (January 14-15, 2010, Shymkent) SIC ICWC organized a Commission to analyze the BWO Amudarya's data in February 2011. The Commission was comprised of leading experts from BWO Amudarya, SIC ICWC and its national branches. Based on provided data by BWO Amudarya, the Commission has analyzed water losses within the river's balancing sites, such as Kelif-Darganata, Darganata-Tuyamuyun, Tuyamuyun-Kipchak, and Kipchak-Samanbey for various flow conditions, with division into non-growing and growing seasons over 1989/1990–2009/2010. The values of water withdrawal by states were proven by Verification acts stored at BWO.

The Commission drew a summary channel balance for Amudarya River over 2007/2008 – 2009/2010 and identified discrepancies of the channel balance. Table 2.1 shows those discrepancies that can be considered as water losses (with "-" sign) or unrecorded inflow within reaches (with "+" sign).

Table 2.1.Discrepancy of channel balance of the Amudarya River for 2007/2008-2009/2010

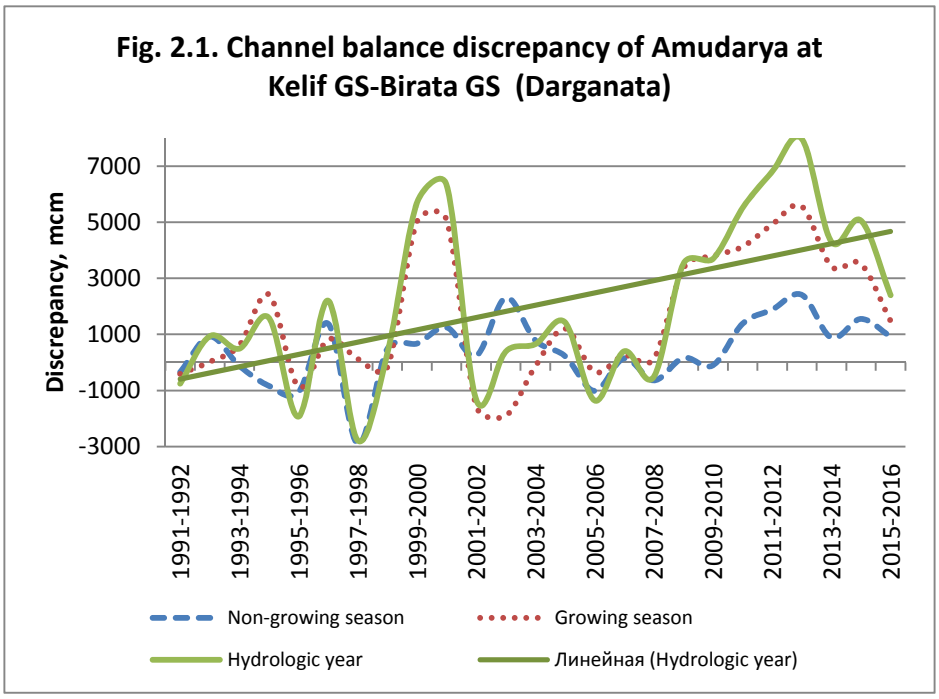
Section	Balance item	2007-2008	2008-2009	2009-2010
1. Kelif GS – Darganata GS, L = 552 km	Amudarya River flow - Kelif GS, mcm	36,209	52,245	71,359
	Amudarya River flow – Darganata GS, mcm	17,919	26,634	47,219
	Average flow at section, mcm	27,064	39,440	59,289
	Channel balance **discrepancy,** mcm	**+ 404**	**- 4,737**	**- 4,509**
	% of Amudarya flow at Kelif GS	**+ 1.1**	**- 9.1**	**- 6.3**
	mcm/km of river	**+ 0.73**	**- 8.6**	**- 8.2**
2. Darganata GS - Tuyamuyun GS, L = 161 km	Amudarya River flow - Darganata GS, mcm	17,919	26,634	47,219
	Amudarya River flow- Tuyamuyun GS, mcm	12,261	18,396	37,304
	Average flow at section, mcm	15,090	22,515	42,262
	Channel balance **discrepancy,** mcm	**- 845**	**- 1,822**	**- 3,121**
	% of Amudarya flow at Darganata GS	**- 4.7**	**- 6.8**	**- 6.6**
	mcm/km of river	**- 5.2**	**- 11.3**	**- 19.4**
3. Tuyamuyun GS - Kipchak GS, L = 167 km	Amudarya River flow - Tuyamuyun GS, mcm	12,261	18,396	37,304
	Amudarya River flow - Kipchak GS, mcm	6,573	11,570	28,658
	Average flow at section, mcm	9,417	14,983	32,981
	Channel balance **discrepancy,** mcm	**- 3,835**	**- 3,603**	**- 4,685**
	% of Amudarya flow at Tuyamuyun GS	**- 31.3**	**- 19.6**	**- 12.6**
	mcm/km of river	**- 23**	**- 21.6**	**- 28.1**
4. Kipchak GS - Samanbay GS, L = 68 km	Amudarya River flow – Kipchak GS, mcm	6,573	11,570	28,658
	Amudarya River flow – Samanbay GS, mcm	651	1,973	16,152
	Average flow at section, mcm	3,612	6,772	22,405
	Channel balance **discrepancy,** mcm	**- 1,480**	**- 1,743**	**- 2,143**
	% of Amudarya flow at Kipchak GS	**- 22.5**	**- 15.1**	**- 7.5**
	mcm/km of river	**- 21.8**	**- 25.6**	**- 31.5**

The analysis of discrepancies of Amudarya channel balance over 2007/2008 – 2009/2010 shows the following:

- In the first reach (Kelif-Darganata), Amudarya midstream, the relative discrepancy of channel balance was within + 1.1 … - 9.1%, the minimum value of negative discrepancy (losses) was observed in the wet year 2009–2010, while unrecorded inflow was fixed in the dry year 2007 – 2008; on the average over 2007/2008 – 2009/2010, the discrepancy (losses) was – 4.8 % or 2.4 higher than the maximum losses estimated by the RETA 6163 Project,
- In the second reach (Darganata-Tuyamuyun), in the area of Tuyamuyun Hydroscheme, the relative discrepancy of channel balance was within - 4.7 … - 6.8 %, the minimum value of negative discrepancy (losses) was observed in the wet year 2009 – 2010 and in the dry year 2007 – 2008,
- In the third reach (Tuyamuyun-Kipchak), Amudarya downstream, the relative discrepancy of channel balance was highest and amounted to 31.3 % in dry year, 19.6 % in average year, and 12.6 % in wet year. In the fourth reach (Kipchak-Samanbay), the losses were slightly lower (-7.5 % … -22.5 %); according to RETA 6163 Project, maximum discrepancy (losses) in lower reaches is estimated at 20%,
- Unit (per 1 km) discrepancies (water losses in river channel) increase further downstream as flow rates grow along the river; discrepancies vary within + 0.73 … - 8.2 mcm per 1 km of river in the middle reaches (Kelif-Samanbay), while they amount to - 21.8 … - 31.5 mcm per 1 km in the lower reaches (Kipchak-Samanbay).

Assessment of discrepancies of Amudarya River flow over the last years

To update water losses in Amudarya river channel over the last year, we drew channel balances by river reach, with division into seasons (October-March, April-September) of a hydrological year over 1991 – 2016 and estimated discrepancies that were regarded as flow losses. Consequently, we derived relationships between the water losses in river channel and the river flow at the beginning of reaches under consideration. The results are shown in Figures 2.1 – 2.4.



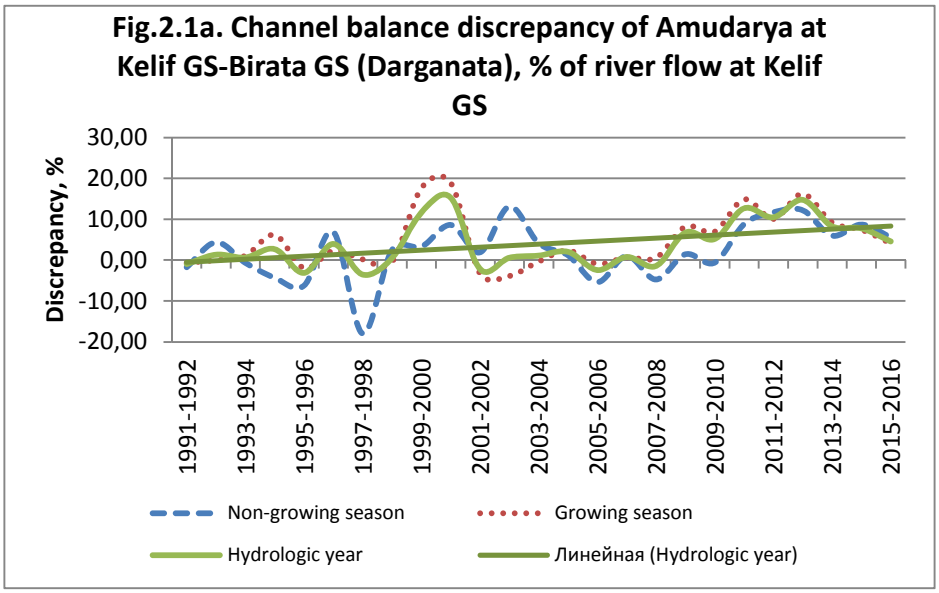


Fig. 2.2. Channel balance discrepancy of Amudarya at Tuyamuyun GS-Samanbay GS

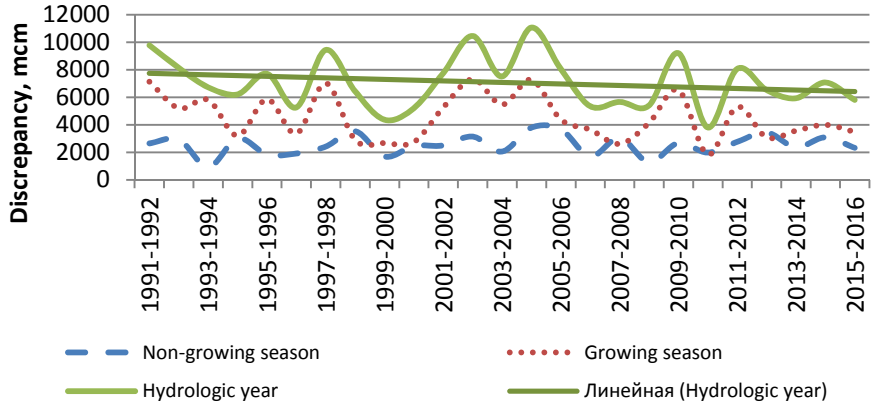


Fig.2.2a. Channel balance discrepancy of Amudarya at Tuyamuyun GS-Samanbay GS, % of release from TMHS

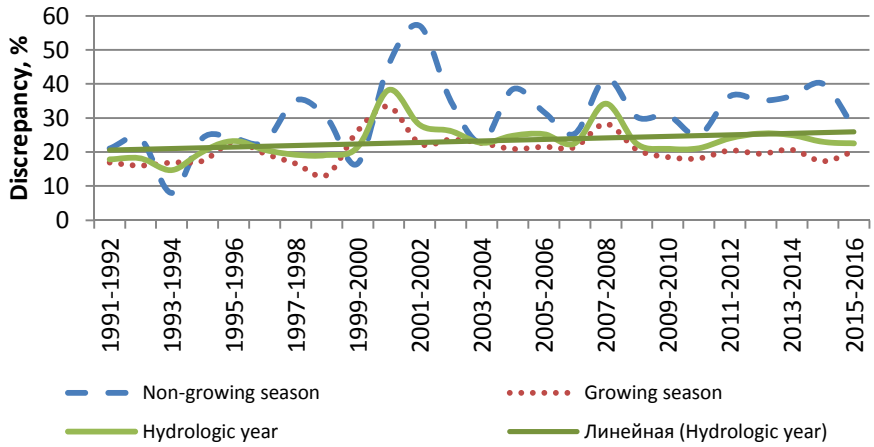


Fig. 2.3. Relationship between channel water balance at Kelif -Birata section (Y, %) and Amudarya flow at Kelif section(X, mcm) for October-March (data for 1991-2016)

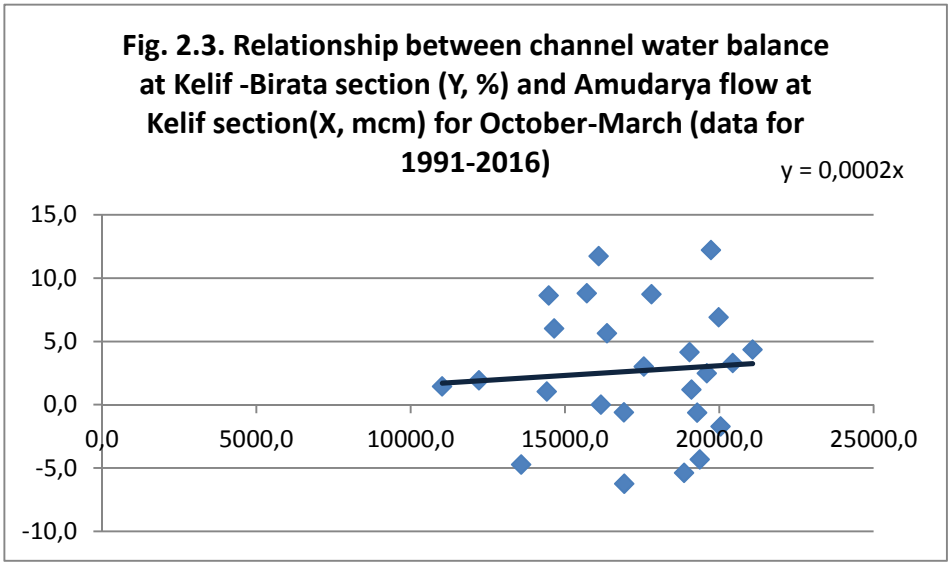


Fig.2.3a. Relationship between channel balance discrepancy at Kelif-Birata section (Y, %) and Amudarya flow at Kelif section (X, mcm) for April-September (data for 1991-2016)

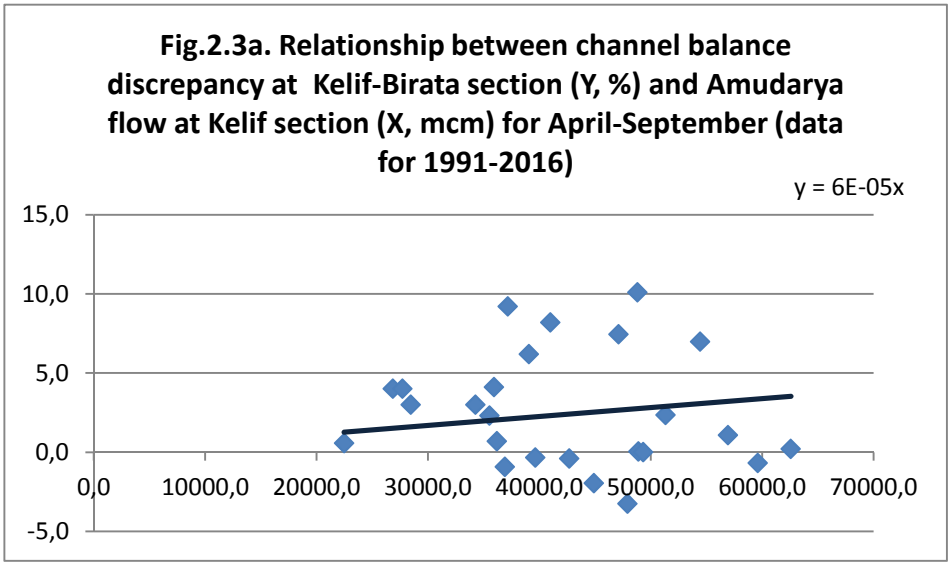


Fig.2.4. Relationship between channel balance discrepancy at Tuyamuyun-Samanbat section(Y, %) and Amudarya flow at TMHS tailwater (X, mcm) for October-March (data for 1991-2016)

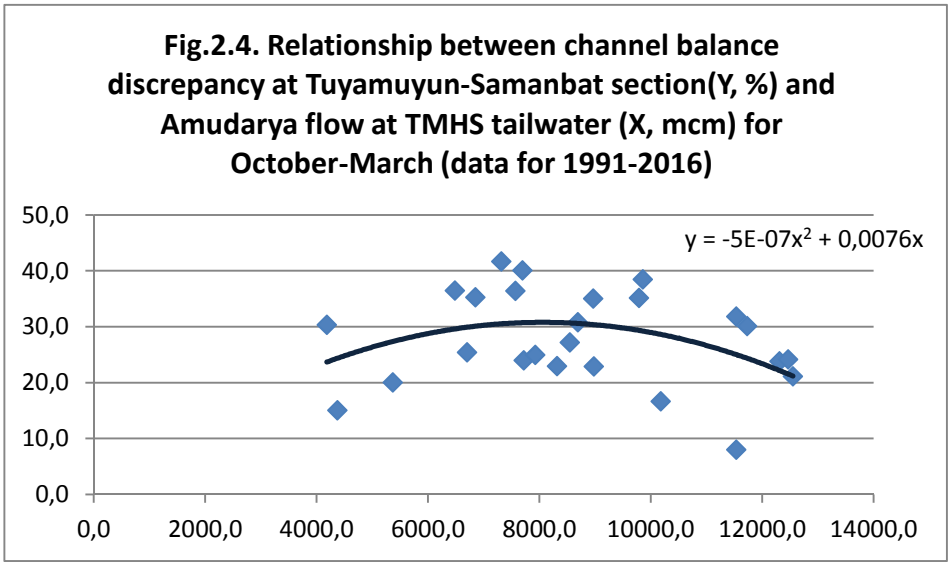


Fig.2.4a. Relationship between channel balance at Tuyamuyun-Samanbay section (Y, %) and Amudarya flow at TMHS tailwater (X, mcm) for April-September (data for 1991-2016)

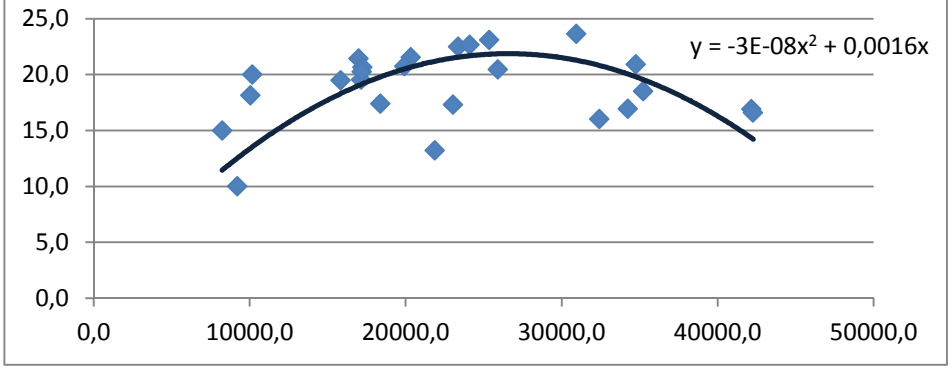


Fig.2.5 Water balance discrepancy at Birata - Tuyamuyun section

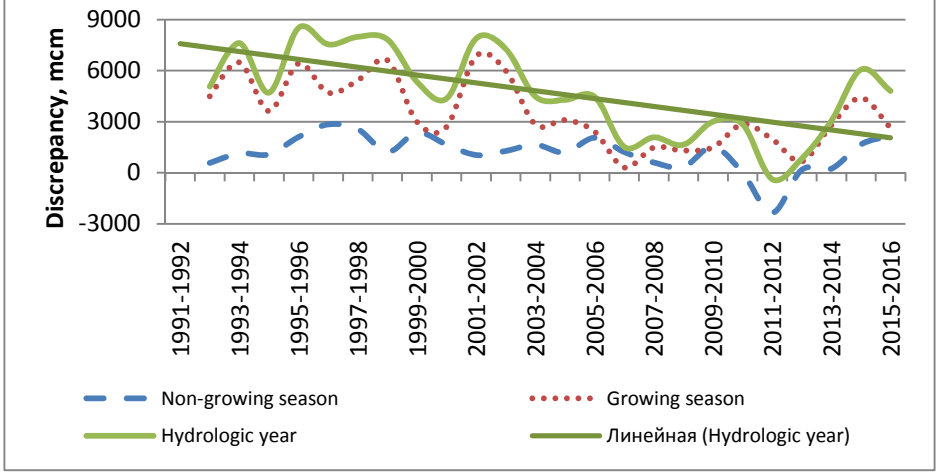
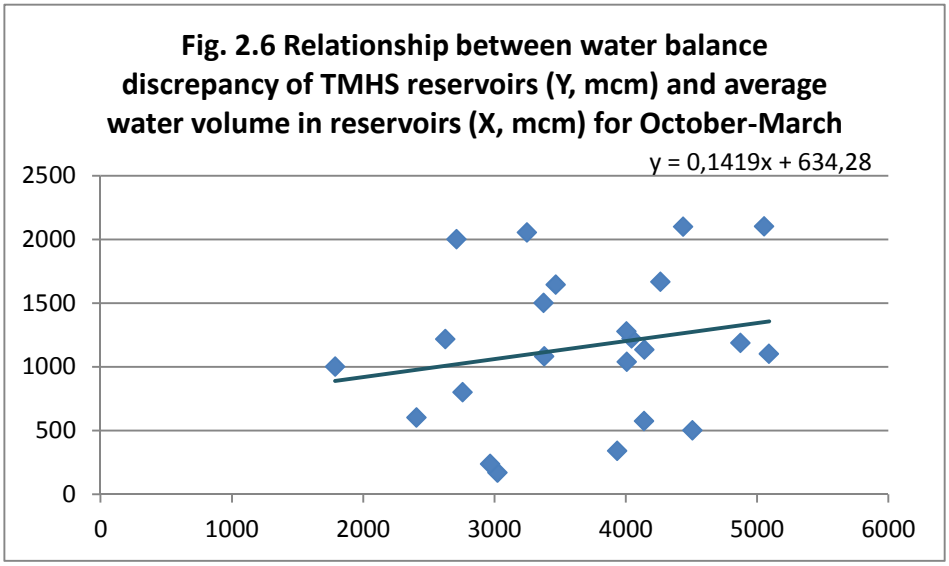
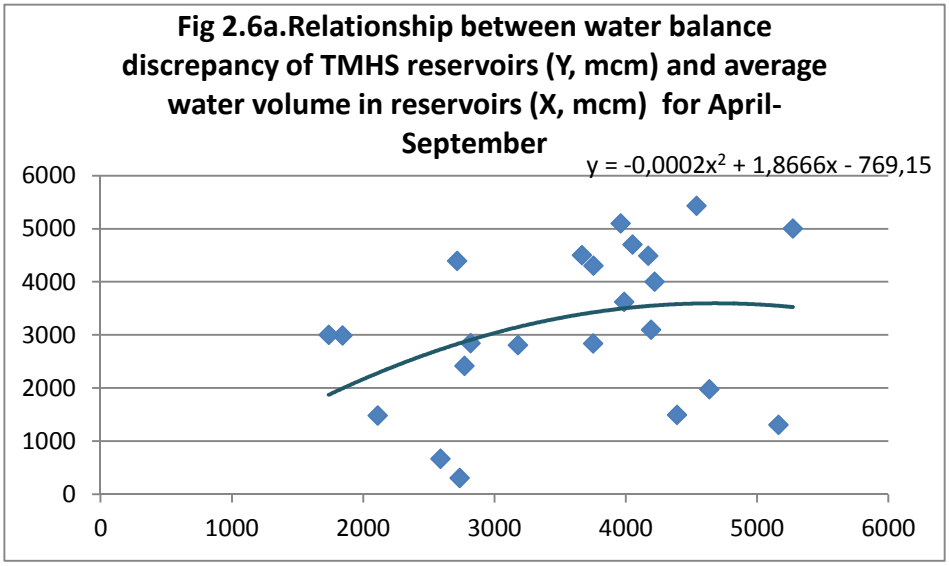


Fig. 2.6 Relationship between water balance discrepancy of TMHS reservoirs (Y, mcm) and average water volume in reservoirs (X, mcm) for October-March





The dependence of water balance discrepancy (losses) on the flow in Amudarya was not found in the river reach of Bir-Ata g/s-Tuyamuyun g/s, where reservoirs of Tuyamuyun Hydroscheme were located. Water losses in off-channel reservoirs of TMHS (such as Kaparas, Sultansanjar, Koshbulak) depend on season and evaporation from reservoir's water surfaces, while for in-stream reservoir those depend on water accumulation: if the reservoir is full (water level 128…130 m), there are seepage losses from the reservoir (with partial discharge into the river in the tail-water of dam); and, in case of empty reservoir (water level 116…120 m), there is seepage from groundwater. Discrepancy of water balance in this section depends on both the water losses through evaporation and the seepage and accuracy (reliability) of flow recording based on inflow to in-stream reservoir (Bir-Ata g/s and intake at Bir-Ata – inflow to TMHS). Figure 2.5 shows dynamics of discrepancies of water balance in TMHS site with its significant downward trend over 1991/1992 – 2015/2016.

Conclusions and recommendations

1. In the Amudarya midstream (Kelif g/s – Bir-Ata g/s) there was an upward trend of channel balance discrepancies during both growing season and non-growing season over 1991/1992 – 2015/2016. This trend is illustrated in Figures 2.1, 2.1a (positive signs of discrepancy mean losses of flow, while negative signs mean unrecorded inflow). On average for this period, the positive discrepancies were 2.4 % of river flow at Kelif section during growing season and 4.6 % during non-growing season. However, in some years the balance discrepancy amounted to: 14.9% (2010 – 2011); 16.2% (2012 – 2013). The increase in discrepancies in the middle reaches cannot be explained only by growth of water losses in river channel, and another cause could be the lower reliability of the data on river flow at the boundary between middle and lower reaches, at Bir-Ata section (Darganata). As the past research shows, channel losses in this section vary within no more than 2…9 %.

2. Over 1991/1992 – 2015/2016, the average flow discrepancy in the lower reaches of Amudarya (Tuyamuyun g/s – Samanbay g/s) was: 30.6% of volume of water releases from TMHS during non-growing season and 20.6% during growing season. There is a downward trend of annual discrepancies in the absolute values from 8 to 6.5 km3 (see Figures 2.2, 2.2a). This indicates to improvement of flow recording in the lower reaches as a result of effective operation of the Commission for lower reaches (which is responsible for routine tasks of flow distribution in TMHS and the river) rather than to decrease of water losses. As recommended by the RETA

6163 Project, flow losses should not exceed 17 % during growing season and 20 % during non-growing season. This is close to actual discrepancies of channel balance over the last 5 years.

3. When calculating water balances of the Amudarya River under the PEER Project, it is recommended to use the derived relationships between the discrepancies (losses) in the reach under consideration and the river flow at the beginning of the reach: for middle reaches (Kelif g/s – Bir-Ata g/s) - liner relationships showing slight growth of losses during growing and non-growing seasons (within 1…4 %) as flow rates increase along the river (Figures 2.3, 2.3a); and, for lower reaches (Tuyamuyun g/s – Samanbay g/s) – polynomial relationships of second degree producing reduction of losses (in %) in dry and wet periods (Figures 2.4, 2.4a): within 20…30 % during non-growing season and 10…22 % during growing season.

4. In Bir-Ata g/s – Tuyamuyun g/s the average discrepancies are estimated at 1.2 km3 during non-growing season and 3.5 km3 during growing season over 1991/1992 – 2015/2016. This is approximately twice as high as estimated losses. The annual discrepancy is 3…2 km3 over the last 5 years and this is close to estimated one. When drawing channel balances, it is recommended to calculate water losses within Bir-Ata – Tuyamuyun g/s reach by using the relationships shown in Figures 2.6 and 2.6a, excluding water withdrawal within Bir-Ata g/s – inflow to in-stream reservoir. These are linear relationship between TMHS reservoirs' water balance discrepancies and average water volume in reservoirs for the non-growing season and polynomial relationship of second degree for the growing season. The losses estimated this way amount to 1.5…2.5 km3 for dry years and 3.0…3.5 km3 for wet years.

5. As part of the PEER Project, BWO Amudarya experts (A.Nazariy, report for position 2.1) made an assessment of water losses in the Amudarya River channel over 1989/1990 – 2015/2016 (see Table 2.2). This assessment fits the range of values of unit loss functions Y(X) recommended for calculation of channel balances in the lower reaches (Figures 2.4, 2.4a). However, BWO overestimates the average values by 20 % as compared to the recommended function Y(X) for the growing season (Figures 2.3, 2.3a).

Table 2.2 Average values of water losses in the Amudarya River channel over 1989/90… 2015/16

River section	Average losses for October-March, %	Average losses for April-September, %	Average losses for October-September, %
Kelif GS – Birata GS (Darganata)	3.1	5.5	4.6
Tuyamuyun GS – Kipchak GS	13.3	18.1	16.2
Kipchak GS – Samanbay GS	20.2	12.3	14.1

Adjustment of ASBmm

Adjustments of ASBmm as planned in the PEER Project include:

- Improvement of planning zone model – rethinking of functioning of facilities and the system as a whole; refinement of some functions; inputting new factors and variables; improvement of water balance algorithms (A.Sorokin, R.Khafazov),
- Improvement of hydropower model (D.Sorokin)**,**
- Adaptation of WEB-Interface – separating base period and scenario assessment period (2016-2055); adjustment of user menu; improvement of DB structure (R.Toshpulatov).

All changes and additions to ASBmm by the PEER Project are in line with the requirements of the methodology for modeling complex systems (Function Modeling) and information flows (Information Modeling) as developed in the United States.

This section describes the planning zone model. Description of the hydropower model and the interface is given in other reports.

Modules and blocks of the Planning zone model

The improved planning zone model includes the following modules:

- Water balance calculation (B1),
- Irrigated agriculture production calculation (B2),
- Socio-economic assessment (B3)

The 'Water balance calculation" module (B1) consists of the following blocks:

B1.1 "Processing of input data"

B1.2 "Calculation of water requirements"

B1.3 "Calculation of usable water resources"

B1.4 "Drawing of water balance and estimation of water use"

B1.5 "Processing and presentation of output data"

The "Irrigated agriculture production calculation" (B2) consists of the following blocks:

B2.1 "Processing of input data"

B2.2 "Calculation of potential irrigated agriculture production"

B2.3 "Calculation of irrigated agriculture production and of production losses"

B2.4 "Processing and presentation of output data"

The "Socio-economic assessment" module (B3) consists of the following blocks:

B3.1 "Processing of input data"

B3.2 "Calculation of revenues from selling of irrigated agriculture products"

B3.3 "Calculation of value added"

B3.4 "Calculation of socio-economic indicators"

B3.5 "Processing and presentation of output data"

Variables

- Endogenous variables – determined by the model
- Exogenous variables - input data of the user (inputted via the Interface), data from DB – scenarios, outputs from other models, reference information, "parameters" in GAMS terms

Indexes and arrays describe: period of time, planning zones, water sources, water users, crops. Indexes are indicated in brackets after variables.

The index of month in a hydrological year (which starts since 1st of October) is ***m***, while the index of month in a calendar year is ***n***; the index of hydrological year is ***y***, while that of calendar year is **t**; the index of planning zone is ***z***, that of crop is ***c***; water users (sectors) are designated as ***j***, and water sources are marked as ***i***.

Accordingly, the arrays are indicated as: ***M, N, Y, T, Z, J, I, C.*** In the arrays **Y** and **T** there is division between: base periods (comparison) - ***Yb, Tb*** and "forecasts" - ***Yf, Tf.***
where: ***M*** = {Oct,..Sep}, ***N*** = {Jan,…Dec}, ***Y*** = {2010/2011,..2049/50},
Yb = {2010/2011,..2014/15}, ***Yf*** = {2015/2016,..2049/50}, ***T*** = {2011,..2050},
Tb = {2011,..2016}, ***Tf*** = {2016,..2050},
Z = {planning zones of Amudarya basin},
J = {irr, ind, dom, fis}, ***I*** = {tra, loc, und, dra}, ***C*** = {cot, whe, ric, mai, veg, orc, for, oth, hom}.

Types of data:

The input data (D1) include:

D1.1 Control actions (user's data)

D1.2 Scenarios, trends and reference data from DB

D1.3 Work parameters of the model that are a part of code only

D1.4 Output data (calculations) imported from other PZm modules

D1.5 Output data imported from other models

The output data (D2) include:

D2.1 Results of calculations used in this module

D2.2 Results of calculations exported to other PZm modules

D2.3 Results of calculations exported to other models

D2.4 Results of calculations available for the user (via Interface)

D2.5 Results of calculations not available for the user

Water intake to planning zone (water balance module) is calculated through the following two schemes:

Scheme # 1 – primary meeting of demands through transboundary water sources

Scheme # 2 - primary meeting of demands through local water sources

Table 3.1 shows the array elements of planning zone model. The list of variables and algorithms is given in the Annex.

Table 3.1 Elements of arrays in the planning zone model

Symbol	Name	Description
C = { }	**Crops**	**Crops**
cot	Cotton	Cotton
whe	Wheat	Wheat
ric	Rice	Rice
mai	Maize	Maize for grain
veg	Vegetables	Vegetables:potato, tomato, root crops, legumes, and cucurbits
orc	Orchards	Orchards and grapes
for	Forage	Forage crops: maize for silage, alfalfa
oth	Other	Other: grain and industrial crop – oil crops, sugar beet, tobacco, etc.
hom	Homestead	Crops grown in homestead plots
	Double crops	Double-season crops; not included in the array but considered through multiplying factors for: a) vegetables (carrot, mung bean, legumes, radish, etc.), b) fodder crops and c) rice. They are sown after wheat harvesting.

I = { }	Water sources	Water resources
tra	Transboundary	Transboundary water resources
loc	Local	Local water resources
und	Underground	Groundwater sources
dra	Drainage	Collector-drainage water
J = { }	**Sectors**	**Water users**
irr	Irrigation	Irrigation
ind	Industry	Industry
dom	Domestic	Domestic
fis	Fisheries	Fisheries and other users
Z = { }		**Planning zone (PZ)**
gar	Garm	**Garm PZ**, Tajikistan -K_1 element in WAm ASBmm
vah	**Vakhsh**	**Vakhsh PZ,** Tajikistan - K_2 element in WAm ASBmm
pya	**Pyandj**	**Pyandj PZ,** Tajikistan - K_3 element in WAm ASBmm
gba	Gorno-Badahshan	**Gorno-Badakhshan PZ**, Tajikistan - K_4 element in WAm ASBmm
uka	**Upper Kafirnigan**	**Upper Kafirnigan PZ**, Tajikistan - K_5 element in WAm ASBmm
dka	**Lower Kafirnigan**	**Lower Kafirnigan PZ**, Tajikistan, - K_6 element in WAm ASBmm
ksh	Karatag-Shirkent	**Karatag-Shirkent PZ**, Tajikistan, - K_7 element in WAm ASBmm
sur	**Surkhandarya**	**Surkhandarya PZ**, Uzbekistan, - K_8 element in WAm ASBmm
mar	**Mary**	**Mary PZ,** Mary province, Turkmenistan -K_9 element in WAm ASBmm
aha	**Akhal**	**Akhal PZ**, Akhal PZ, Turkmenistan - K_10 element in WAm ASBmm. Assumption: water flowing to Balkan province (the Caspian Sea basin) through Karakum Canal is considered in the Akhal PZ (as well as agricultural land irrigated with this water).
leb	**Lebap**	**Lebap PZ**, Turkmenistan - K_11 element in WAm ASBmm
kas	Kashkadarya	**Kashkadarya PZ**, Uzbekistan - K_12 element in WAm ASBmm
kar	**Karshi**	**Karshi PZ,** Uzbekistan - K_13 element in WAm ASBmm

zar	Zarafshan	**Zeravshan PZ**, Tajikistan - K_14 element in WAm ASBmm
sam	Samarkand	**Samarkand PZ**, Uzbekistan - K_15 element in WAm ASBmm
nav	Navoi	**Navoi PZ**, Uzbekistan - K_16 element in WAm ASBmm
buh	**Bukhara**	**Bukhara PZ**, Uzbekistan - K_17 element in WAm ASBmm
hor	**Khorezm**	**Khorezm PZ**, Uzbekistan -K_18 element in WAm ASBmm
skk	Southern Karakalpakstan	**Southern Karakalpakstan PZ**, Uzbekistan -K_19 element in WAm ASBmm
nkk	**Northern Karakalpakstan**	**Northern Karakalpakstan PZ**, Uzbekistan - K_20 element in WAm ASBmm
tas	**Tashauz**	Dashoguz PZ, Turkmenistan - K_21 element in WAm ASBmm
ala	Alay	Alay PZ, Kyrgyzstan, - K_22 element in WAm ASBmm
afg	Afghan	Afghan PZ, Afghanistan, - K_22 element in WAm ASBmm

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