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PEER project report for 2017

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

Stage 3 "Numerical experiments"
Positions 3.1 and 3.2

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Tashkent, July 2017

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List of abbreviations

W – Watt
GW – gigawatt, 1 GW = 1,000,000 kW
HS – Hydroscheme
HEPS – Hydro-electric power station
PZ – Planning zone is a baseline territorial unit of modeling, which is located within the boundaries of administrative province or in its part (for instance, South Karakalpakstan PZ and North Karakalpakstan PZ)
kW – kilowatt, 1 kW = 1,000 W
KWh – kilowatt-hour
MW – Megawatt, 1 MW = 1,000 kilowatts
TW – terawatt, 1 TW = 1,000,000,000 kW

ASBmm –The Aral Sea Basin Management Model (UNESCO-IHE & SIC ICWC)
BAU –Business as usual scenario – one of socio-economic development scenarios used in the PEER project to allocate irrigated areas and introduce innovations in irrigated agriculture
ESA – Export-oriented sustainable adaptation – one of alternatives of socio-economic development aimed at increased agricultural production for export plus cropping pattern scenario (simulated in the PEER Project)
FSA – Food security and diet change – one of alternatives of socio-economic development aimed at food security and import substitution plus cropping pattern scenario (simulated in the PEER Project)
GAMS – General Algebraic Modeling System used in the PEER project when developing hydroenergy model (D.Sorokin) and cropping pattern optimization model (T.Kadyrov)

Introduction

The report is based on the results of work implemented according to Terms of Reference (ToR) under the PEER project on the following positions:

Position 3.1. Conducting series of calculations for different scenarios:

- Testing hydroenergy model on the data over 2010-2015, item 3.1.2.9 of ToR (D.Sorokin),
- Calculation of alternative operation modes of HEPS for 2016-2055, item 3.1.2.9 of ToR (D.Sorokin),
- Assessment of water resources and river channel balance for 2016-2055 in the context of climate change under alternative operation modes of HEPS; calculation of return flow and open channel losses, item 3.1.1.1 of ToR (A.Sorokin)
- Assessment of influence of Afghanistan and HEPS modes on available water for Prearalie and withdrawals, item 3.1.1.2 (A.Sorokin, D.Sorokin).
- Comprehensive computer-based assessment of prospective development in country provinces and the Amudarya basin as a whole under climate change, regulated flow and water shortage; water balance of PZs for 2016-2055, item 3.1.2.1 of ToR (A.Sorokin)

Position 3.2. Drawing proposals on water management in the context of climate change:

- River flow regulation by reservoirs and HEPS, item 3.2.1. of ToR (D.Sorokin),
- Search for consensus between resources and demands in the context of climate change, influence of HEPS and increased demand of Afghanistan, item 3.2.1.1 of ToR (A.Sorokin, D.Sorokin)

The report consists of Introduction, 6 sections (where research results and recommendations are stated), Conclusion, References, and 6 Annexes.

1. Developing and testing the hydroenergy model (2010-2017)

Operation modes of the Vakhsh hydropower cascade were calculated using two computer programs that realized the hydroenergy model (developed by D.Sorokin).This model was developed and tested on actual data for 2010-2017 under the PEER project.

The hydroenergy model consists of the following computer programs:

1. Program for optimization of the Nurek HEPS operation, realized in GAMS (see Annex 5);
2. Program for calculation of the Nurek HEPS operation and energy generation by the Vakhsh hydropower cascade in MS Excel.

Besides the Nurek HEPS, the model also includes Baypaza HEPS (with installed capacity of 600 MW), Sangtuda-1 HEPS (670 MW), Sangtuda-2 HEPS (220 MW), Sarbada HEPS (Golovnaya, 240 MW), Perepadnaya and Central HEPS (with total capacity of 45 MW).

Table 1.1 Variables in the hydroenergy model

Parameter	Symbol	Unit	Note
Inflow to the Nurek HS	Inflow	Mm3	Input data
Water volume in the reservoir	Res.vol	Mm3	Variable determined by the optimization program
Maximum water level in the reservoir	Hmax	m	Corresponding to normal water level
Minimum water level in the reservoir	Hmin	m	Corresponding to dead storage level
Water level in the reservoir	H	m	Calculated by bathymetric curve (1), Hmax > H > Hmin
Water level in the tailwater	Hout	m	Calculated as a function of water discharge in tailwater (2), R^2=0.997
Water discharge in the tailwater of HS (hydroscheme)	Outflow	Mm3	Variable determined by the optimization program Outflow.max > Outflow > Outflow.min
Water discharge at HEPS	Qhps	Mm3	Qhps.max > Qhps = Outflow
Head at HEPS	dH	m	dH = H – Hout
Coefficient (9.81*efficiency factor)	K		Calculated using formula (3)
HEPS design capacity	N	MW	N = K* Qhps* dH / 1000
Electricity generated by the Nurek HEPS	Enur	GW/h	Enur = n*24*N/1000, where n-number of days in a month
Electricity generated by the Vakhsh hydropower cascade	Evahsh	GW/h	Calculated as a function of energy generation by the Nurek HEPS (4)
Total energy generation	E	GW/h	E = Enur + Evahsh
Unit water discharge by the Nurek HEPS per kilowatt-hour of generated energy	q	m^3/kW/h	q = Qhps*n*24*3600/(Enur*10^6)

Main variables of the model are shown in Table 1.1 with explanation.

Relationship between the water volume and the water surface level of the reservoir [Petrov G.N., 2009]:

$H = 12.12*Res.vol + 781.83$ … (1)

Relationship between the water level and the water discharge in the tailwater of the Nurek HS [Petrov G.N., 2009]:

$Hout = 0.0000000005* Outflow^3 – 0.000003266** Outflow^2 +0.007169* Outflow +642.8469$ …(2)

The formula to calculate "K" coefficient [Petrov G.N., 2009] is as follows:

$K = - 0.00672*dH + 10.379$ … (3)

The formula to calculate energy generation by the Vakhsh hydropower cascade (excluding Nurek HEPS) [Petrov G.N., 2009]:

$Evahsh = 0.386*Enur + 67.251$ … (4)

Target functions (Y1 and Y2) included in the model are the sum of energy generated by the Nurek HEPS annually (October-September) and in non-growing season (October-March).

$Y1 = sum (t, Enur(t))$ …. (5)

$Y2 = sum (tn, Enur(t))$ …. (6)

Where: Y1 – target function used for optimization of the energy-irrigation mode of operation of the Nurek reservoir, Y2 - target function used for optimization of the energy mode of operation of the Nurek reservoir, t – month index in N calculation series, t = 1,…N, tn – month indexes in non-growing seasons (October-March) of N calculation series. One GAMS program suggests N = 60 month or 5 years. Calculations are made by 7 linked programs for 35 years (7 five-years) or 7*60 = 350 months.

Annual energy generation is maximized by non-linear programming method while meeting the following criterion:

$Y1 \rightarrow max$ … (7)

energy generation during the non-growing season is maximized by non-linear programming method while meeting the following criterion:

$Y2 \rightarrow max$ … (8)

Operation mode of the Nurek HEPS and estimated energy generation by the Nurek HEPS and Vakhsh hydropower cascade for 2010-2017 are given in Annex 1.

Figure 1.1 illustrates the results of calculation by the model of indicator "energy generation by the Nurek HEPS" for 2010-2016; Figure 1.12 illustrates comparison of actual values (data processed by ODC "Energy") with simulated ones, on average over 2010-2016.

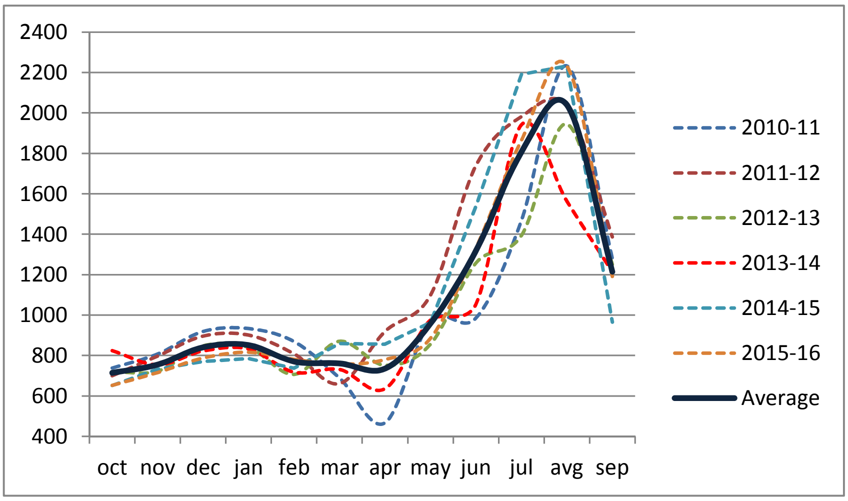

Figure 1.1 Energy generation by the Nurek HEPS for 2010-2016: results of model calculation.

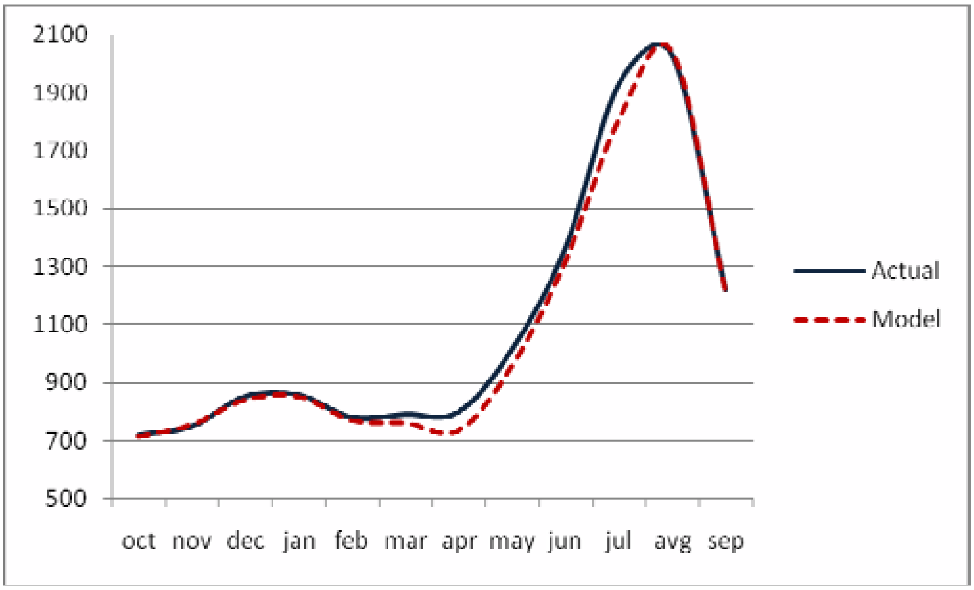

Figure 1.2 Energy generation by the Nurek HEPS average for 2010-2016: comparison of actual values with simulated values.

On the average, deviation of simulated values (model data) of energy generation from actual ones is 2%, with deviations by month varying from 1 to 8% (see Figure 1.3). The link between simulated and actual values is characterized by the coefficient $R^2 = 0.984$ (Figure 1.4).

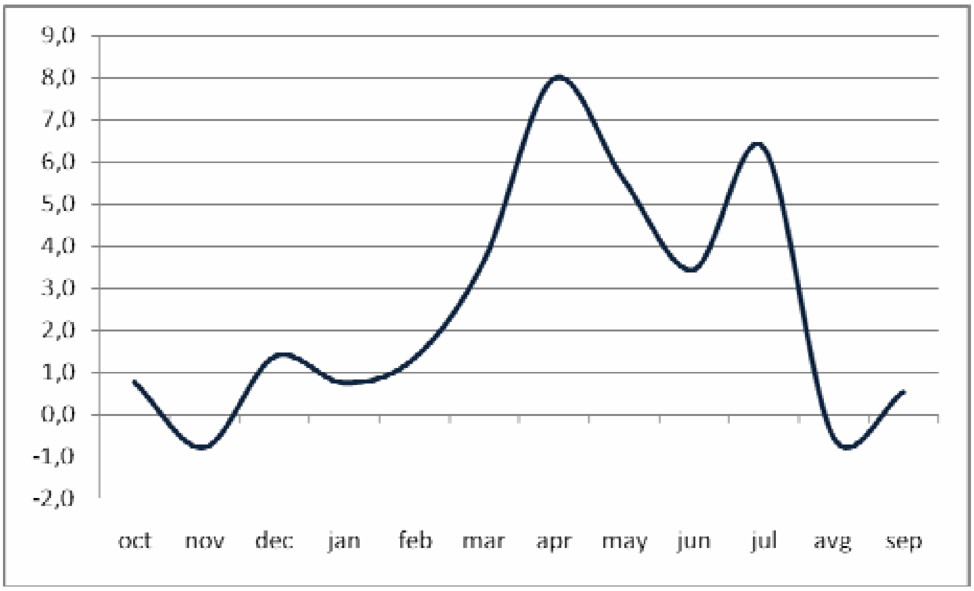

Figure1.3 Deviation of simulated values of energy generation from actual values, % of actual ones: average for 2010-2016.

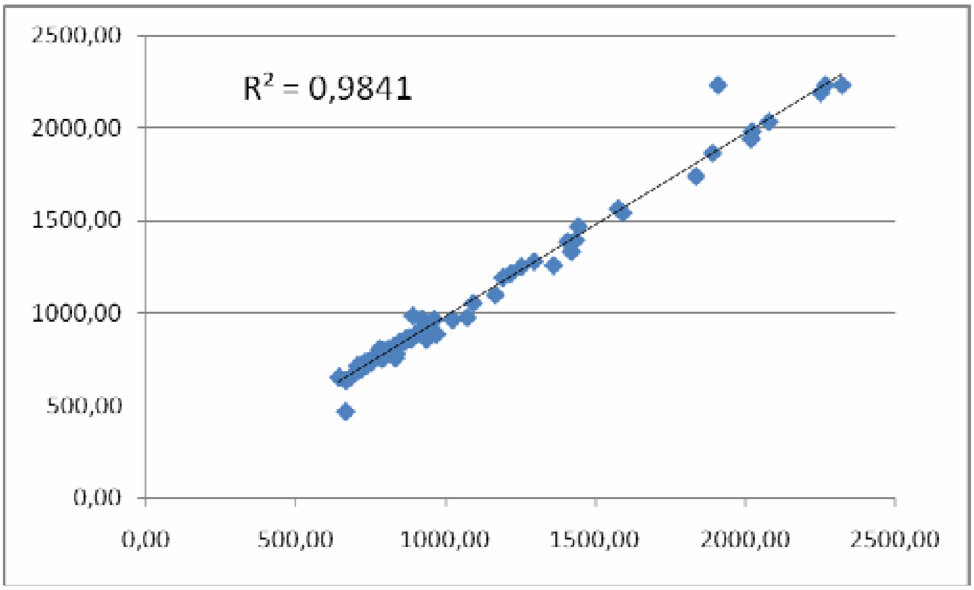

Figure 1.4 Relationship between actual (X-axis, million kWh/month) and simulated (Y-axis, million kWh/month) values of energy generation by the Nurek HEPS

The current mode of operation of the Nurek HEPS is characterized by idle discharges and consequent energy losses (see Figures 1.5 and 1.6).

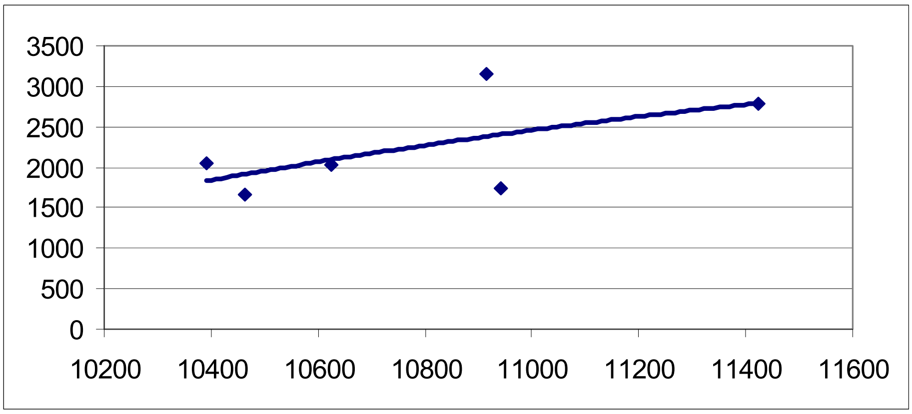

Figure 1.5. Empirical relationship between the annual energy losses through idle discharge (Y-axis) and the consumption of electricity generated by the Nurek HEPS (X-axis)

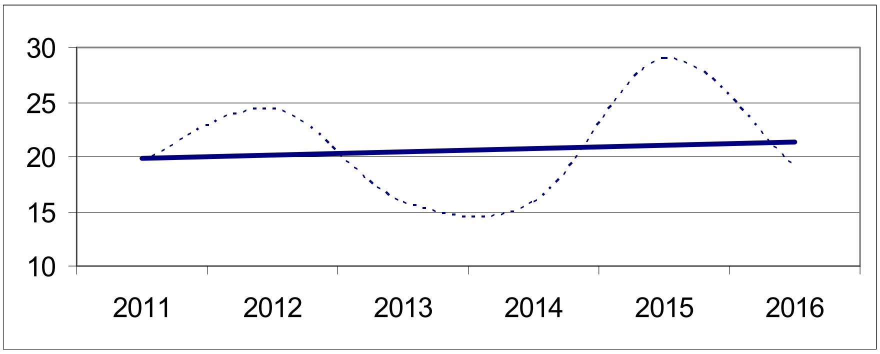

Figure 1.6 Dynamics of energy losses at the Nurek HEPS through idle discharge for 2011-2016, % of consumed energy

When optimizing the operation mode of the Nurek HEPS for the future, idle discharges will be reduced to zero through limitation put in the model on maximum allowable discharge by HEPS, as well as through an option in the model to create additional capacity before flood flows.

Charts 1.7-1.10 provided below show water releases from the Nurek HEPS from 1980 to 2017. They are grouped by year: 1980-1991, 1991-2002, 2002-2013, and 2013-2017, of which 1991-2002 and 2002-2013 with energy mode, 2013-2017 with energy-irrigation mode, and 1980-1991 with irrigation mode.

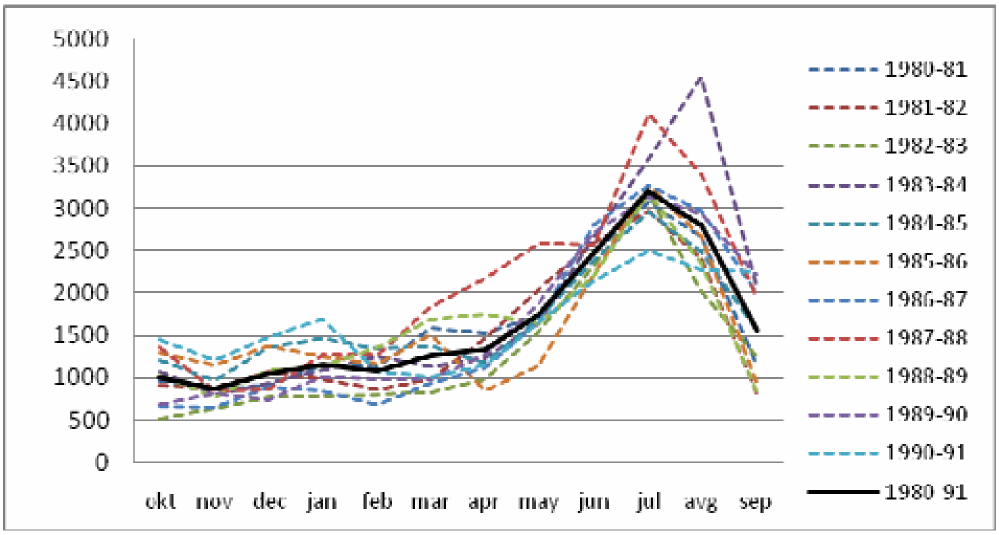

Figure 1.7 Water releases from the Nurek HS for 1980-1991, Mm3/month

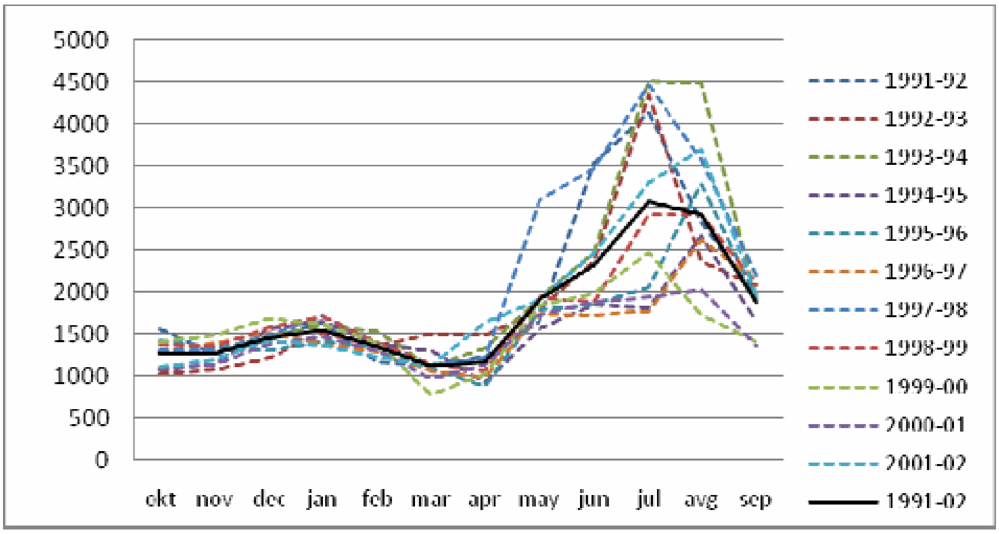

Figure 1.8 Water releases from the Nurek HS for 1991 – 2002, Mm3/month

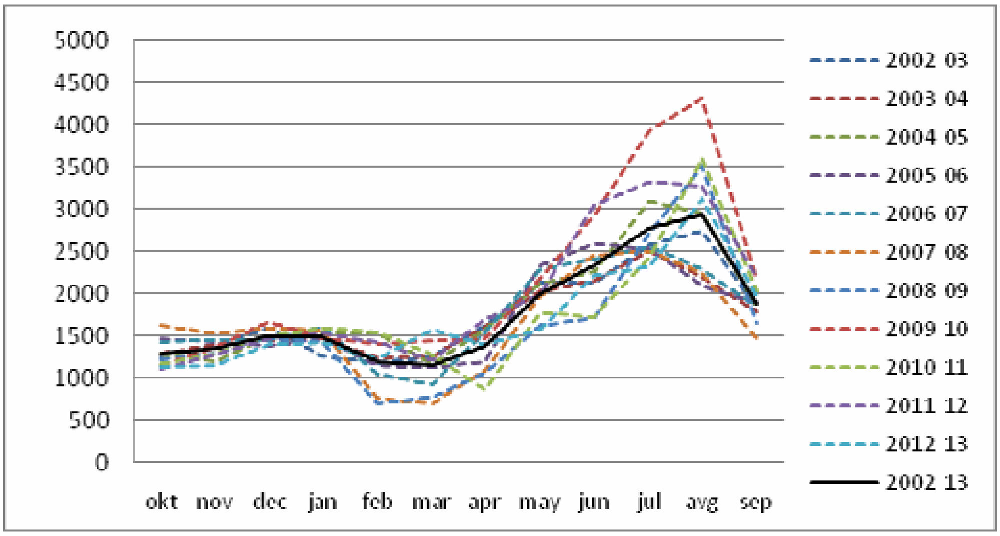

Figure 1.9 Water releases from the Nurek HS for 2002 – 2013, Mm3/month

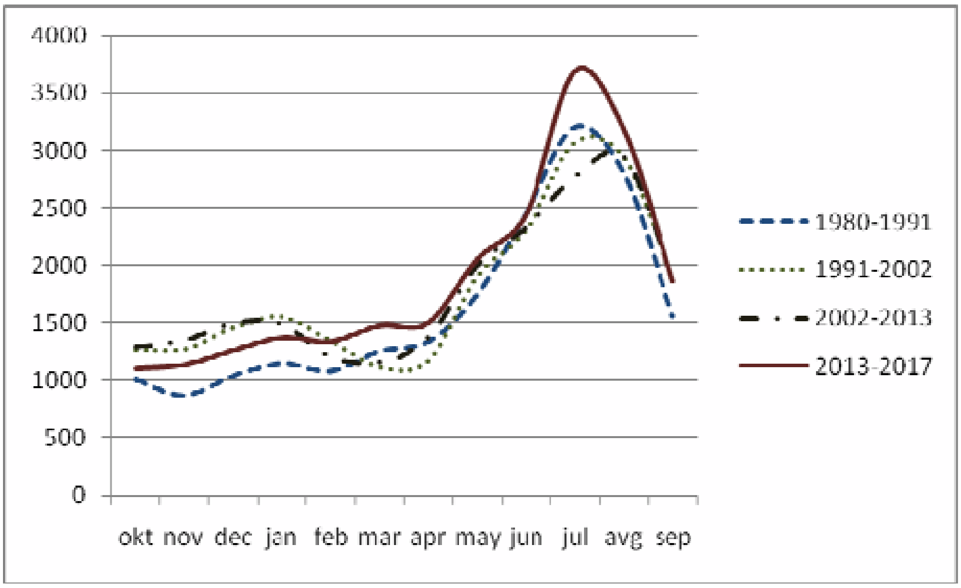

Figure 1.10 Comparison of graphs of water delivery in the tailwater of the Nurek HS for individual periods of its operation, Mm3/month

Analysis of graphs of water releases from the Nurek HS for individual periods of its operation allows determining maximum and minimum values of releases corresponding to alternative operation modes of hydroscheme (HS), i.e. energy and energy-irrigation modes, which are the most likely in the future (Figure 1.11).

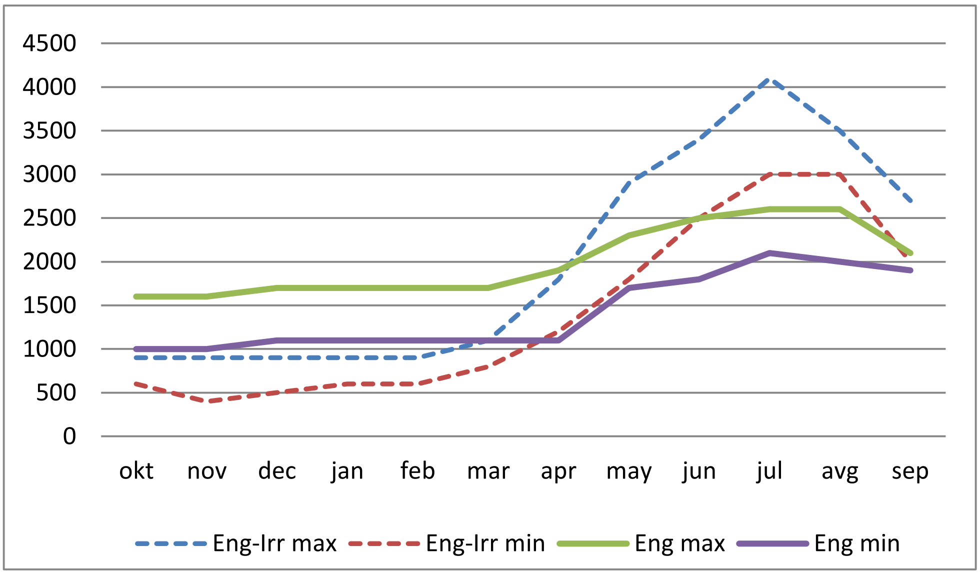

Figure 1.11 Range of water releases from the Nurek HS under energy and energy-irrigation operation modes of HEPS, Mm3/month

The curves in Figure 1.11 are incorporated into the hydroenergy model. If appropriate, they may be activated as limitations. Then optimization by criteria (7) and (8) will be realized within these limitations, i.e. within existing (earlier estimated) values.

2. Calculation of operation modes of the Nurek HEPS for 2020-2055, assessment of regulated runoff of the Vakhsh River in the context of climate change, and recommendations

Tajikistan has set three main goals in energy development (CAREC, 2015): i) availability of electricity (regular energy supply to the population); ii) energy efficiency (reduced energy losses); and iii) renewable energy (its increased generation).

The Water Sector Strategy of the Republic of Tajikistan (2006) mentions regular energy excess of 1.5 billion kilowatt-hours formed in summer. However, currently this excess has been lacking demand on both internal and external markets. At the same time, due to energy shortage in winter (at about 3 billion kilowatt-hours), restrictions on energy consumption are introduced in Tajikistan in winter time. In this context, the objective is set that the domestic energy needs should be met in full and the potential of energy export should be increased up to 12 billion kilowatt-hours in 2015-2020, including 2-2.5 billion kilowatt-hours in summer, through the development of hydropower.

A long-term regional water development strategy (according to the PEER project) should determine mechanisms and criteria for water allocation in alignment with national hydropower and agrarian development strategies. In this context, it is important to study scenarios of operation of the Nurek HEPS.

In the future, there could be changes in the current mode of operation of the Nurek HEPS as undertaken for: i) optimization of winter energy demand in Tajikistan – this may result in reduction of water releases from the reservoir in summer, ii) minimization of idle discharges – this will result in re-allocation of water releases in summer, and iii) generation of additional summer energy for export – this will result in an increase of water releases in summer.

> The option of Nurek HEPS operation that suggests growth of water releases in summer is acceptable for Turkmenistan. This option will be acceptable for Uzbekistan only provided that this summer energy is not supplied to Kyrgyzstan in exchange (return to Tajikistan) for winter energy; such energy exchange will worsen the situation in the Syrdarya basin – summer releases from the Toktogul HEPS will decrease and winter releases will increase, leading to more critical summer water shortage in the Fergana Valley and the middle reaches of the Syrdarya River and to floods in autumn and winter.

Taking into account future energy needs in Tajikistan, including potential energy export, the following modes of the Nurek HEPS were determined for numerical experiments: i) actual mode typical for 2010-2015, given potential options of water content; ii) simulated energy mode – maximization of autumn and winter generation; iii) simulated energy-irrigation mode – maximization of annual generation, with additional generation in summer (export of summer energy).

In numerical experiments, energy and energy-irrigation modes of operation of the Nurek HEPS are combined with two scenarios of water content in the Naryn River, with and without account of climate change impact (by REMO 0406 scenario).

In the PEER project, we follow the concept of the cyclical nature of natural process variations when constructing Amudarya basin flow series (including the inflow to the Nurek HS). Such cyclical nature is viewed as progressive development on which climate-caused changes have an impact rather than as simple periodical repetition of observed phenomena.

$$Wt = kc \times WNt, \qquad t = 1,(1+dt) \tag{1}$$

Где: Wt - forecast flow series considering climate change impact, WNt - natural flow series selected from retrospective data, dt - forecast period, kc – coefficient considering climate change impact (as deviation from the norm).

Thus, four combinations of scenarios (cases) were modelled and constructed:

Case 1. Energy mode of operation of the Nurek HEPS: inflow to the reservoir is based on the scenario of continued cycling for no climate change impact conditions,
Case 2. Energy-irrigation mode of operation of the Nurek HEPS: inflow to the reservoir is based on the scenario of continued cycling for no climate change impact conditions,
Case 3. Energy mode of operation of the Nurek HEPS: inflow to the reservoir is based on the scenario of continued cycling for climate change impact conditions,
Case 4. Energy-irrigation mode of operation of the Nurek HEPS: inflow to the reservoir is based on the scenario of continued cycling for climate change impact conditions.

Climate change impact was assessed by comparing Case 1 and Case 3 with regard to the inflow to the Nurek HEPS. Flow regulation was assessed by comparing Case 1 and Case 2 (under natural cycling) and Case 3 and Case 4 (under climate change impact) with regard to the outflow from the Nurek HEPS.

Construction of operation modes of the reservoirs consists in selection of the mode,

$$U_{k,t} \qquad k = 1, R \qquad t = 1, T \quad \dots (2)$$

which meets the objective of planning

$$F \rightarrow \max \dots (3)$$

and system of limitations

$G_{i,t} = 0, \quad i = 1, n$ - balance equations determining interaction of water volume, inflow, and outflow in the reservoirs

$P_{j,t} > 0, \quad j = 1, m$ - allowable reservoir volume, allowable discharge from the reservoirs, HEPS,

where: k, R – reservoir index and quantity,

i, j, n, m – limitations indexes and quantity,

t, T – time step and calculation period,

U – regulated flow,

F – target functions depending on the scenario selected (HEPS regime)

Figure 2.1 shows the curves of water volume in the Nurek reservoir under various operation modes of HEPS. The first two are energy and energy-irrigation modes with estimated and average data for 2020-2055 as a result of optimization in GAMS model (see section 1 of the report) by criterion (target function): maximization of autumn and winter generation (Energy) and of annual generation. The rest two modes are averaging of actual data for 1980-1991 and 1991-2017.

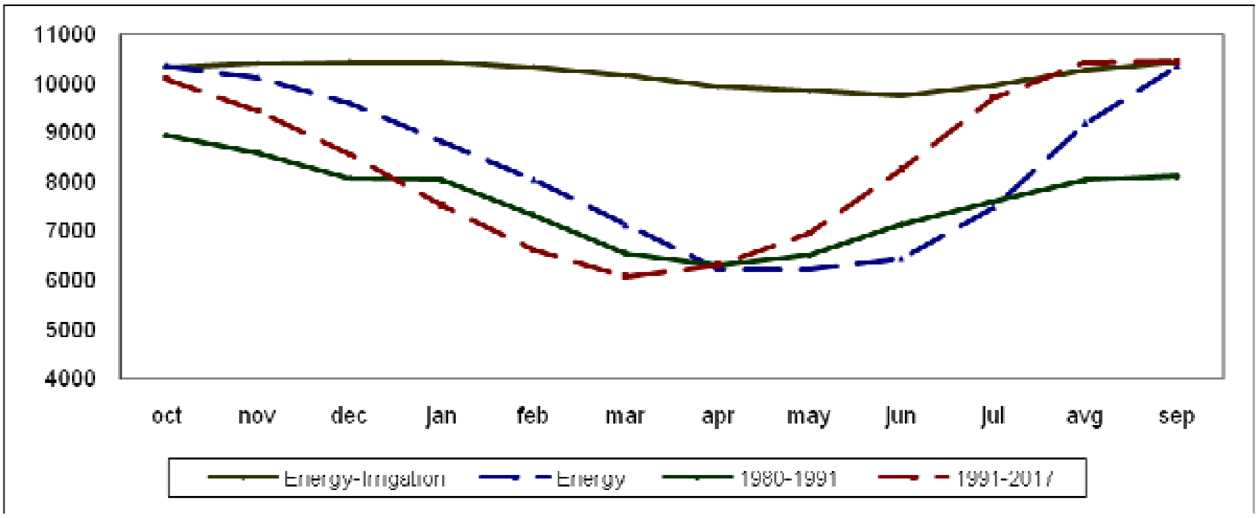

Figure 2.1. Water volume in the Nurek reservoir under various modes of operation of the hydroscheme: i) alternative scenarios – energy and energy-irrigation modes – average data for 2020-2055, ii) actual average data for 1980-1991 and 1991-2017

The analysis of curves shows that water accumulation in the reservoir is later in time under energy mode than under the actual mode of 1991-2017. Optimization shows that beginning of accumulation is shifted from May to July. Consequently, idle discharges are liquidated and more energy is produced. In case of energy-irrigation mode, the head of the hydropower station is maintained at maximum level.

Nurek hydroscheme operation under preserved current climate conditions

Figure. 2.2 shows graphs of water releases from the Nurek HS for two alternatives: energy mode (Case 1) and energy- irrigation mode (Case 2). To compare, curves with average values for 1980-1991 and 1991-2017 are provided.

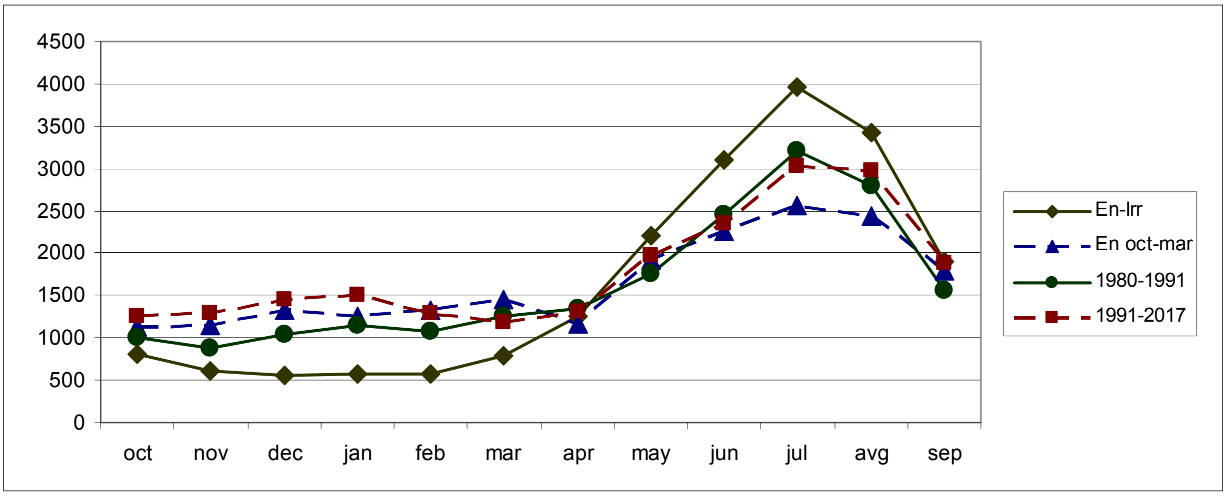

Figure. 2.2 Graphs of water releases from the Nurek HS: energy-irrigation mode, energy mode (average for 2020-2055), average values for 1980-1991 and 1991-2017. Inflow to HS based on the scenario of continued existing cycles, excluding climate change impact.

The analysis of curves shows that the calculated curve of energy mode (derived from averaged optimization results in GAMS-based hydroenergy model) in September-April is close to actual releases of 1991-2017; in May-August, the calculated curve is below actual values of 1991-2017. This indicates to increased deficit in case of shift to energy operation mode of HEPS, when maximum electricity is generated from October to March.

Figures 2.3-2.6 illustrate the curves of seasonal water releases from the Nurek HS as a result of calculation in GAMS model for alternative operation modes of HEPS over 2020-2055 (Case 1 and Case 2).

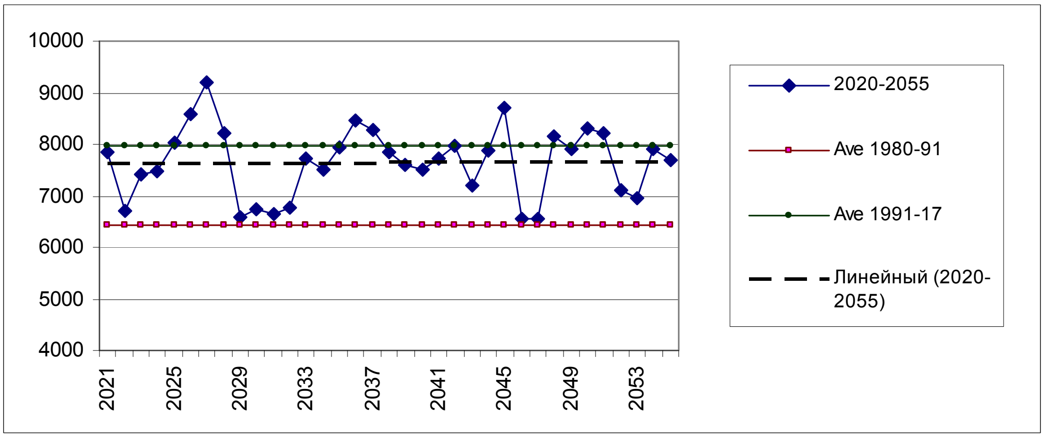

Figure 2.3 Water releases from the Nurek HS in the non-growing season (October-March), Mm3: results derived in GAMS-based model (2020-2055) against average water releases for 1980-1991 and 1991-2017. Case 1. Energy mode

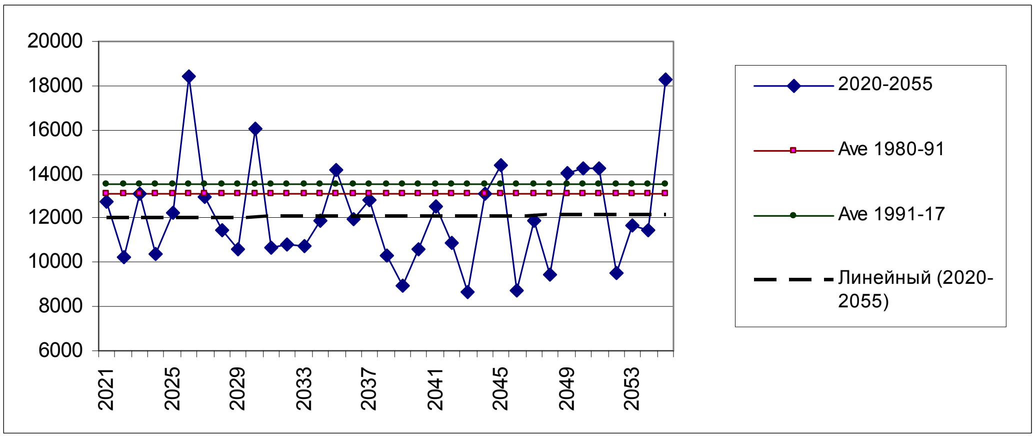

Figure 2.4 Water releases from the Nurek HS during the growing season (April-September), Mm3: results by the GAMS-based model (2020-2055) against average water releases over 1980-1991 and 1991-2017. Case 1. Energy mode

For Case 1 (energy mode), the average water releases from the Nurek HS for 2020-2055 are estimated at 12.12 bcm over the growing season, with sharp reductions is some seasons to 8,940 Mm3 (2039), 8,650 Mm3 (2043), and 8,700 Mm3 (2046) or 34-36% less than average water releases in 1991-2017. In the non-growing season, average water releases for Case 1 (energy mode) are estimated at 7.65 bcm or 4% less than in 1991-2017.

Table 2.1 compares the data on Case 1 and Case 2. The difference between the cases (operation modes of HEPS) in terms of water releases from the Nurek HS is estimated at 3.73 bcm for the season: water releases in Case 2 are higher than in Case 1 during the growing season, whereas water releases in Case 1 are 3.73 bcm more than in Case 2 during the non-growing season.

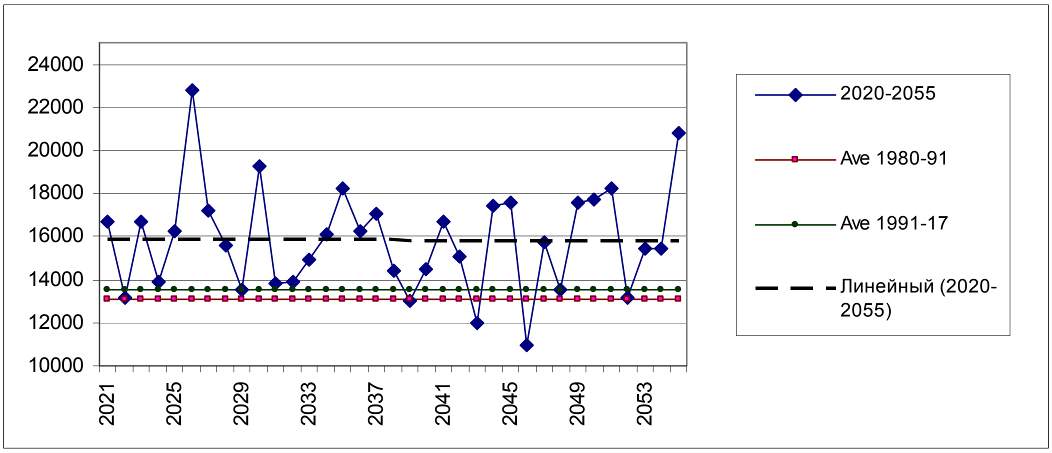

Figure 2.5 Water releases from the Nurek HS during the growing season (April-September), Mm3: results of the GAMS-based model (2020-2055) against average water releases for 1980-1991 and 1991-2017. Case 2 (Energy-irrigation mode)

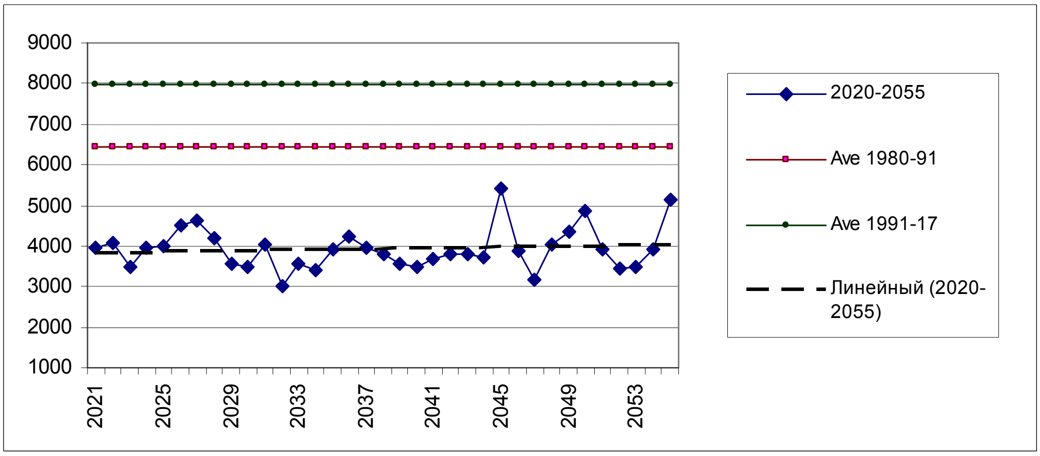

Figure 2.6 Water releases from the Nurek HS during the non-growing season (October-March), Mm3: results of the GAMS-based model (2020-2055) against average water releases for 1980-1991 and 1991-2017. Case 2 (Energy-irrigation mode)

Table 2.1 Comparison of parameters of the Nurek HS by case – results of the hydroenergy mode, averaging over 2020-2055

Case #, operation mode	Parameter and unit	April-September	October-March	Annual
1 and 2	Inflow to HS	16,250	3,520	19,770
1.Energy	Water releases from HS, Mm3	12,120	7,650	19,770
2.Energy-irrigation	Water releases from HS, Mm3	15,850	3,920	19,770
Difference between 1 and 2	Changed water releases, Mm3	- 3,730	3,730	0
	% of inflow	- 23	106	
1.Energy	Regulation of flow in the Vakhsh River (inflow – outflow), Mm3	4,130	-4,130	0
2.Energy-irrigation	Regulation of flow in the Vakhsh River (inflow – outflow), Mm3	400	-400	0

Operation of the Nurek HS in the context of climate change

The data in Table 2.2 allows assessing climate change impact on annual and season flows of the Vakhsh River in the reach of inflow to the Nurek HS. The table gives average data for 2020-2055. This is the result of processing of river flow series modeled with one month increment for 2020-2055 by two scenarios: i) natural flow based on the scenario of continued cycling, ii) natural flow adjusted by coefficients considering climate changes.

For the assessment of an impact of probable climate change on water resources, the PEER project uses the output of regional climate models REMO-0406 with the spatial resolution of 0.5° and 0.16° and the greenhouse gas concentration scenario CMIP3 SRES-A1B.

Operation of the Nurek HS under climate change was assessed in Case 3 and Case 4. Table 2.3 provides comparison of the data on water releases and flow regulation in these cases.

Table 2.2 Climate change impact on long-time annual average flow of the Vakhsh River (2020-2055) in the reach of inflow to the Nurek HS

Case #, climate change impact	Parameter and unit	April-September	October-March	Annual
1 and 2, excluding impact	Inflow to HS, Mm3	16,250	3,520	19,770
3 and 4, including impact	Inflow to HS, Mm3	15,570	3,550	19,120
Difference between 1 and 3 (2 and 4)	Changed inflow to HS, Mm3	680	- 30	650
	% of inflow	4	- 0.8	3

Table 2.3 Comparison of parameters of the Nurek HS by case – results of the hydroenergy model, averaging over 2020-2055

Case #, HEPS operation modes	Parameter and unit	April-September	October – March	Annual
3 and 4	Inflow to HS	15,570	3,550	19,120
3.Energy	Water releases from HS, Mm3	11,440	7,680	19,120
4. Energy-irrigation	Water releases from HS, Mm3	15,170	3,950	19,120
Difference between 3 and 4	Changed water releases, Mm3	- 3,730	3,730	0
	% of flow	- 24	105	
3.Energy	Regulation of flow in the Vakhsh River (inflow – outflow), Mm3	4,130	- 4,130	0
4. Energy-irrigation	Regulation of flow in the Vakhsh River (inflow – outflow), Mm3	400	- 400	0

Climate change mostly influences the formation of water resources in summer, particularly in June and July (see report by Sorokin D. on the PEER project results, position 2.4 “Modeling river flow series in light of CC”, September 2016).

As to the inflow to the Nurek HS, the Vakhsh River loses 6% of its flow in June (average for 2020-2025) and 13% in July under climate change impact. The maximum lowering is observed in 2050 – 7% in June and 17% in July.

The reservoir of the Nurek HS modifies this flow as follows: losses of 5% of flow in June and 11% in July under climate change. Thus, the reservoir to some extent compensates the negative effect of climate change in these months

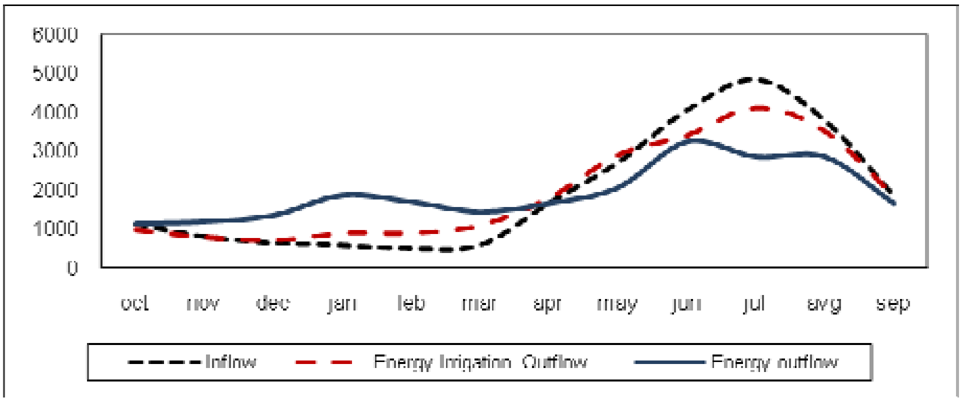

Figure 2.6 Dynamics of inflow in and outflow from the Nurek HS under alternative operation modes for wet year (2044-2045)

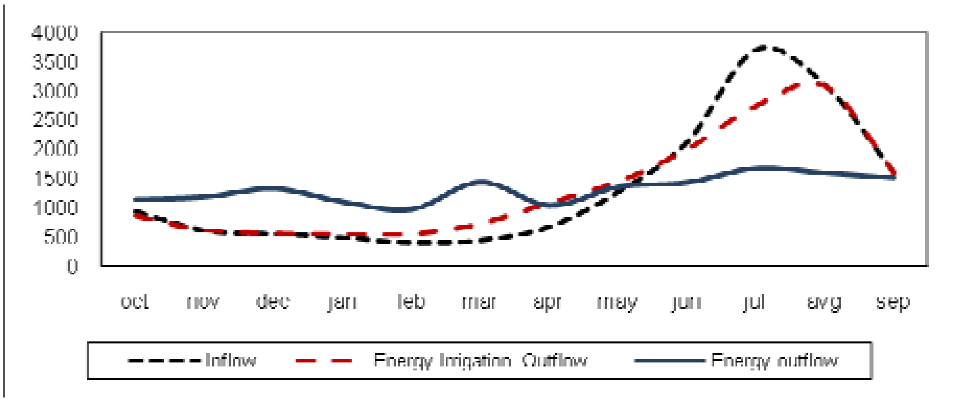

Figure 2.7 Dynamics of inflow in and outflow from the Nurek HS under alternative operation modes for dry year (2042-2043)

Figures 2.6 and 2.7 show hydrographs of Nurek HEPS inflow and outflow under its alternative operation modes (energy and energy-irrigation) for two options of water content in the Vakhsh River – dry year (corresponds to 2042-2043) and wet year (2044-2045).

All calculation results for the operation mode of the Nurek HEPS over 2010-2020 and 2020-2055 are inputted into DB of the PEER project.

Recommendations

1. The current operation mode of the Nurek HS is characterized by idle discharges at HEPS and consequent energy losses through such discharges. Idle discharges depend on water content in the Vakhsh River (the higher is inflow to the hydroscheme, the larger are idle discharges), as well as management efficiency (forecast accuracy). On the average for 2010-2016, losses through idle discharges are estimated at aprox.20% of consumed energy, which was generated by the Nurek HEPS (see Section 1, Figures 1.5 and 1.6). To solve this problem, control of the Nurek HS should become better, particularly by improving the forecast of inflow to HS. According to our estimations, the time of water accumulation in the Nurek reservoir should be shifted forward 1-2 months (Sea Figure 2.1). Such mode will be more comfortable for irrigation schedule as well (water intake from the Vakhsh-Amudarya River).

2. Modification of flow in the Vakhsh River (in the reach of inflow to the Nurek HS) due to climate change over 2020-2055 will not have great influence on the operation mode of the Nurek

HEPS. Nevertheless, one should expect a decrease in inflow to the Nurek HS in some summer months (June-July, August). This should be taken into account when regulating flow in the growing season and minimizing idle discharges.

3. Assessment of alternative scenarios of operation of the Vakhsh hydropower cascade (mode, energy generation) for 2020-2055 and of energy balance “demand-generation”

The analysis of available national documents, reviews and studies by international organizations reveals that by 2020 the current energy shortage in Tajikistan is to be reduced by better balancing of demand and supply through the following measures: i) reduce electricity demand through investments in energy efficiency, tariff policy; ii) increase electricity generation by modernizing existing hydropower schemes, improving HEPS performance; and iii) increase energy import and export (in summer as well), mainly, through export opportunities of Tajikistan (CASA-1000 project, etc.).

The PEER project assumes that energy demand in the residential sector is expected to depend mainly on demographic load in the future. Moreover, the rates of energy consumption growth in the residential sector will correspond to rates of population growth. Estimations of electricity demand in other sectors, including industry, are based on the World Bank’s studies (2013).

According to our estimations (D. Sorokin, PEER project report, positions 2.2, 2.5), by 2030 the domestic annual demand in Tajikistan within the small Amudarya basin (excluding Sogd province) will be 14,490 gigawatt-hours (no measures for energy saving and energy shortage reduction) and 11,240 gigawatt-hours or 22% lower if the above measures are implemented. By 2055, the domestic demand may increase up to 17,376 gigawatt-hours (without measures) or 14,126 gigawatt-hours (after implementation of these measures) in Tajikistan (small Amudarya basin).

On the average for 2020-2055, the domestic annual demand for electricity in Tajikistan within the small Amudarya basin (excluding Sogd province) is estimated to be 12.07 billion kilowatt-hours, including 5.75 billion kilowatt-hours during the growing season (April-September) and 6.32 billion kilowatt-hours in October-March (Tables 3.3-3.5). On the average for 2020-2055, the domestic annual demand for electricity in Tajikistan as a whole is estimated to be 15.9 billion kilowatt-hours. The demand for electricity within the small Amudarya basin is 76% of the total demand.

A part of this demand is supposed to be covered through thermal energy production, including by Dushanbe-2 TPP, Shurob-1 TPP, and Shurob-2 TPP. On the average for 2020-2055, generation by TPPs is estimated to be 3.5 billion kilowatt-hours (D. Sorokin, PEER project report, positions 2.2, 2.5). Consequently, the part of energy demand to be covered through hydropower production is estimated at 12.4 billion kilowatt-hours on the average for 2020-2055 (Tables 3.6 and 3.7).

Currently the main generators of energy in Tajikistan are the Nurek HEPS and the downstream Vakhsh hydropower cascade (see Section 1 of the report).

The PEER research does not include in its analysis the Rogun Hydroproject as it is currently analyzed in detail by a number of relevant experts and decision makers, including design parameters, operation mode of Rogun in the Vakhsh cascade, cost-efficiency, technical safety, economic and social risks for all riparian states.

Energy generation by the Nurek HEPS and the Vakhsh cascade as a whole from 2017 to 2020 is given in Table 3.1. The operation of the Nurek HEPS over this period of time is taken close to the actual operation mode of the Nurek Hydroscheme (HS), with exclusion of idle discharges.

On the average for 2017-2020, energy generation by the Vakhsh cascade is to be 13.95 billion kilowatt-hours.

Energy generation in the long-term future (2020-2055) is calculated in scenarios with account of climate change impact and given in Table 3.2. For Case 3 (energy regime), annual generation by the Vakhsh cascade (including Nurek HEPS) is estimated at 14.74 billion kilowatt-hours on the average for 2020-2055, including 6.07 billion kilowatt-hours (41%) in October-March and 8.67 billion kilowatt-hours (59%) in April-September. For Case 4 (energy-irrigation mode), annual generation is estimated at 15.50 billion kilowatt-hours or 0.74 billion kilowatt-hours more than in Case 3. In October-March, 3.48 billion kilowatt-hours is generated in Case 4 or 2.59 billion kilowatt-hours less than in Case 3. In April-September, 12.02 billion kilowatt-hours is generated in Case 4 or 3.35 billion kilowatt-hours more than in Case 3. Consequently, when shifting from Case 3 (energy mode) to Case 4 (energy-irrigation mode), one can see:

- Increased annual generation by 5 %,
- Decreased generation by 54 % in October-March,
- Increased generation by 39 % in April-September.

Table 3.1 Electricity generation by the Vakhsh hydropower cascade for 2017-2020

Year	Generation by the Vakhsh hydropower cascade, million kilowatt-hours			Including generation by the Nurek HEPS, million kilowatt-hours		
	Oct-Mar	Apr-Sep	Oct-Sep	Oct-Mar	Apr-Sep	Oct-Sep
2017-18	6,389	8,099	14,488	4,792	6,149	10,941
2018-19	6,215	6,841	13,056	4,644	5,149	9,793
2019-20	6,062	8,245	14,307	4,529	6,248	10,777
Total	18,666	23,185	41,851	13,965	17,546	31,511
Average for 2017-2020	6,222	7,728	13,950	4,655	5,849	10,504

Table 3.2 Electricity generation by the Vakhsh hydropower cascade for 2020-2055 under alternative operation modes of the Nurek HEPS and climate change

Year	Generation by the Vakhsh hydropower cascade, Case 3 (energy mode), million kilowatt-hours			Generation by the Vakhsh hydropower cascade, Case 4 (energy-irrigation mode), million kilowatt-hours		
	Oct-Mar	Apr-Sep	Oct-Sep	Oct-Mar	Apr-Sep	Oct-Sep
2020-2030	6,054	9,241	15,295	3,493	12,597	16,090
2030-2040	6,042	8,153	14,195	3,297	11,634	14,931
2040-2050	6,130	8,386	14,517	3,605	11,633	15,238
2050-2055	6,041	9,147	15,188	3,542	12,471	16,014
2020-2055	6,071	8,672	14,743	3,476	12,028	15,504

Figures 3.1-3.4 illustrate graphs of electricity generation by the Vakhsh hydropower cascade under energy (Case 3) and energy-irrigation (Case 4) operation modes of the Nurek HEPS by month, year, and on the average for 2020-2055.

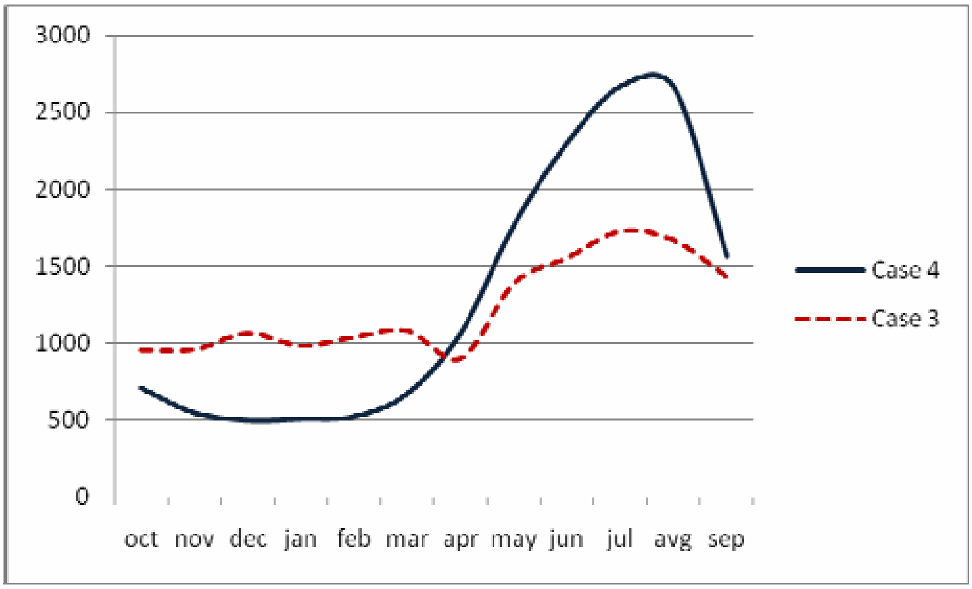

Figure 3.1 Within-year electricity generation by the Vakhsh hydropower cascade (including Nurek HEPS); average for 2020-2055 under energy (Case 3) and energy-irrigation (Case 4) operation modes of the Nurek HEPS, million kilowatt-hours

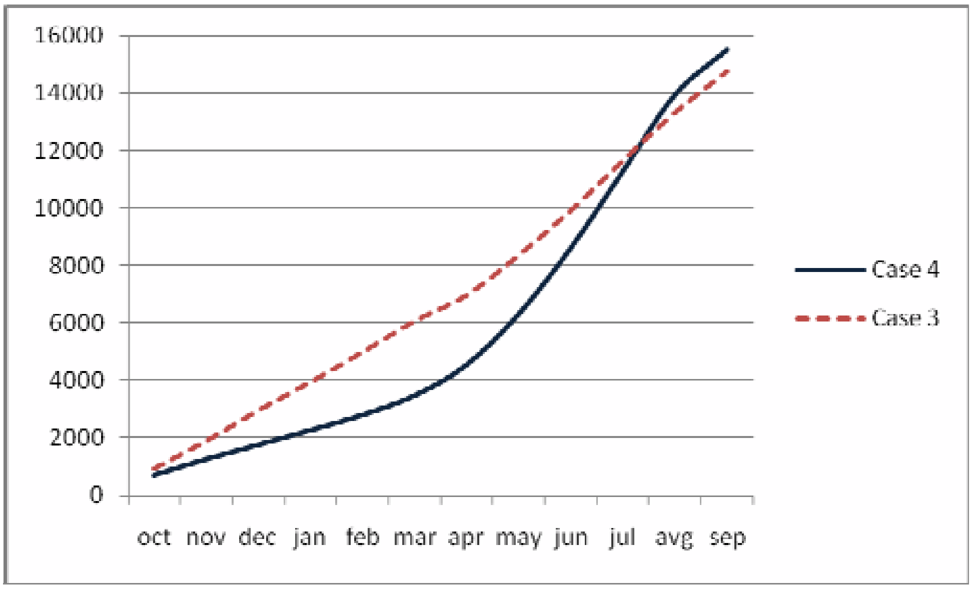

Figure 3.2 Integral curve of monthly electricity generation by the Vakhsh hydropower cascade (including Nurek HEPS): average for 2020-2055 under energy (Case 3) and energy-irrigation (Case 4) operation modes of the Nurek HEPS, million kilowatt-hours

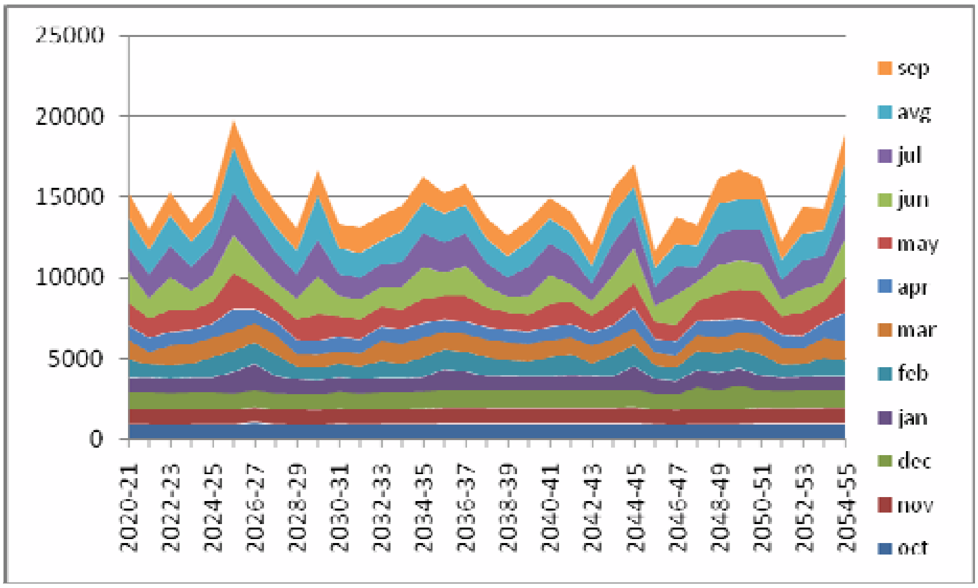

Figure 3.3 Electricity generation by the Vakhsh hydropower cascade (including Nurek HEPS) for 2020-2055 under energy operation mode (Case 3) of the Nurek HEPS, million kilowatt-hours

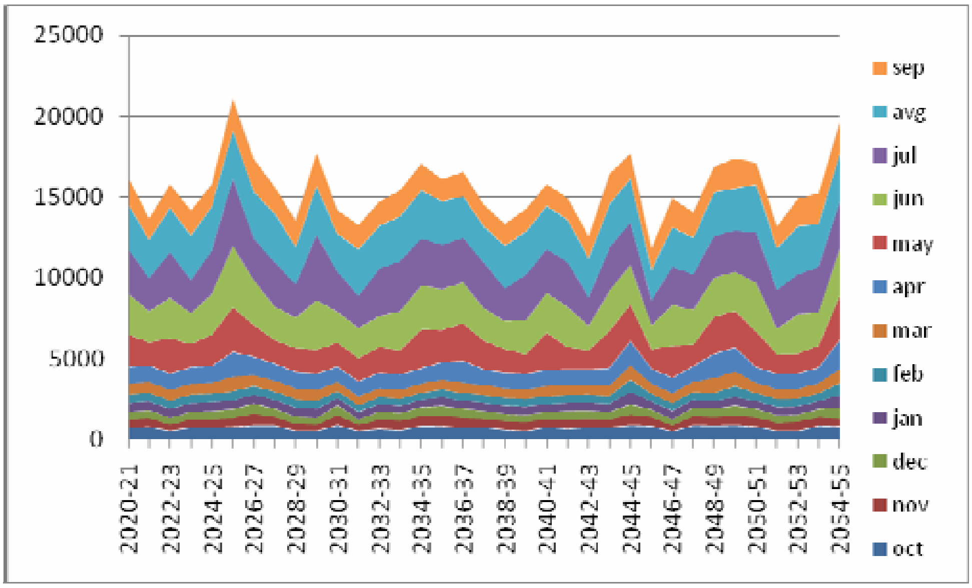

Figure 3.4 Electricity generation by the Vakhsh hydropower cascade (including Nurek HEPS for 2020-205 under energy-irrigation operation mode (Case 4) of the Nurek HEPS, million kilowatt hours

Tables 3.3 – 3.5 give the data on electricity demand in Tajikistan (excluding Sogd province) and energy generation by the Vakhsh cascade over 2020-2055 under alternative operation modes of the Nurek HEPS in the context of climate change. Energy balance (generation-demand) is given by season and per year.

Table 3.3 Comparison of electricity demand in Tajikistan (excluding Sogd province) and energy generation by the Vakhsh cascade in October-March over 2020-2055 under alternative operation modes of the Nurek HEPS in the context of climate change

Period	Electricity demand, million kWh/ Oct-Mar	Electricity generation by the Vakhsh cascade, million kWh / Oct-Mar		Energy balance, million kWh / Oct-Mar	
		Case 3	Case 4	Case 3-demand	Case 4-demand
2020-2030	5,640	6,054	3,493	414	-2,147
2030-2040	6,119	6,042	3,297	-77	-2,822
2040-2050	6,690	6,130	3,605	-560	-3,085
2050-2055	7,219	6,041	3,542	-1,178	-3,677
2020-2055	6,322	6,071	3476	-251	-2,846

Table 3.4 Comparison of electricity demand in Tajikistan (excluding Sogd province) and energy generation by the Vakhsh cascade in April-September over 2020-2055 under alternative operation modes of the Nurek HEPS in the context of climate change

Period	Electricity demand, million kWh / Apr-Sep	Electricity generation by the Vakhsh cascade, million kWh / Apr-Sep		Energy balance, million kWh Apr-Sep	
		Case 3	Case 4	Case 3-demand	Case 4-demand
2020-2030	5,132	9,241	12,597	4,109	7,465
2030-2040	5,568	8,153	11,634	2,585	6,065
2040-2050	6,088	8,386	11,633	2,298	5,545
2050-2055	6,570	9,147	12,471	2,577	5,902
2020-2055	5,753	8,672	12,028	2,920	6,276

Table 3.5 Comparison of electricity demand in Tajikistan (excluding Sogd province) and energy generation by the Vakhsh cascade in October-September over 2020-2055 under alternative operation modes of the Nurek HEPS in the context of climate change

Period	Electricity demand, million kWh / Oct-Sep	Electricity generation by the Vakhsh cascade, million kWh / Oct-Sep		Energy balance, million kWh / Oct-Sep	
		Case 3	Case 4	Case 3-demand	Case 4-demand
2020-2030	10,772	15,295	16,090	4,523	5,318
2030-2040	11,687	14,195	14,931	2,508	3,244
2040-2050	12,778	14,517	15,238	1,739	2,460
2050-2055	13,789	15,188	16,014	1,399	2,225
2020-2055	12,075	14,743	15,504	2,668	3,429

Table 3.6 Comparison of electricity demand in Tajikistan and energy generation by the Vakhsh cascade in October-September over 2020-2055 under alternative operation modes of the Nurek HEPS in the context of climate change

Period	Electricity demand in Tajikistan, million kWh / Oct-Sep	Electricity generation by the Vakhsh cascade, million kWh / Oct-Sep		Energy balance, million kWh / Oct-Sep	
		Case 3	Case 4	Case 3-demand	Case 4-demand
2020-2030	14,017	15,295	16,090	1,278	2,073
2030-2040	15,346	14,195	14,931	-1,151	-415
2040-2050	16,908	14,517	15,238	-2,392	-1,670
2050-2055	18,349	15,188	16,014	-3,160	-2,335
2020-2055	15,900	14,743	15,504	-1,157	-396

Table 3.7 Comparison of electricity demand in Tajikistan (excluding thermal power generation) and energy generation by the Vakhsh cascade in October-September over 2020-2055 under alternative operation modes of the Nurek HEPS in the context of climate change

Period	Electricity demand in Tajikistan, excluding thermal power generation, million kWh / Oct-Sep	Electricity generation by the Vakhsh cascade, million kWh / Oct-Sep		Energy balance, million kWh / Oct-Sep	
		Case 3	Case 4	Case 3-demand	Case 4-demand
2020-2030	10,517	15,295	16,090	4,778	5,573
2030-2040	11,846	14,195	14,931	2,349	3,085
2040-2050	13,408	14,517	15,238	1,108	1,830
2050-2055	14,849	15,188	16,014	340	1,165
2020-2055	12,400	14,743	15,504	2,343	3,104

Table 3.8 Comparison of electricity demand and energy generation by the Vakhsh cascade in dry year (2042-2043) under alternative operation modes of the Nurek HEPS in the context of climate change

Dry year 2042-2043	Demand for electricity, million kWh per year	Electricity generation by the Vakhsh cascade, million kWh /year		Energy balance, million kWh /year	
		Case 3	Case 4	Case 3-demand	Case 4-demand
Tajikistan	12,557 *	12,028	12,536	-529	-21
Excluding Sogd province	9,105	12,028	12,536	2,923	3,431

*) Excluding energy generation by TPPs and HEPS of the Bakhri Tojik reservoir

The analysis of data on within-year electricity demand and generation allows assessing seasonal demands and potential of energy sector in Tajikistan (see Tables 3.6 – 3.8). The tables give the comparison of data on electricity demand in Tajikistan and energy generation by the Vakhsh cascade over 2020-2055 under alternative operation modes of the Nurek HEPS in the context of climate change. The balance is assessed for Tajikistan as a whole, excluding thermal power generation; assessment for dry year (2042-2043) is also provided.

The analysis of energy balances of Tajikistan for 2020-2055 shows that:

- By 2050-2055, annual energy balance (generation minus demand) is positive for the small Amudarya basin. Moreover, HEPS capacity is enough to meet domestic annual demand in Tajikistan (excluding Sogd province): energy generation exceeds demand by 1.4 billion kilowatt-hours in Case 3 and by 2.2 billion kilowatt-hours in Case 4. Thus, the Vakhsh hydropower cascade has capacities to consider demand of Tajikistan for electricity within the small Amudarya basin, excluding thermal power generation,
- By 2050-2055, annual energy balance in Tajikistan shows deficit in the amount of 3.2 billion kilowatt-hours in Case 3 and 2.3 billion kilowatt-hours in Case 4 (this Case does not consider energy generation by the HEPS of the Bakhri Tochik reservoir located on the Syrdarya River and thermal power generation),
- By 2050-2055, annual energy balance in Tajikistan (minus thermal power generation) is positive, with energy surplus in the amount of 0.34 billion kilowatt-hours in Case 3 and 1.67 billion kilowatt-hours in Case 4.

In general by 2050-2055, the Vakhsh hydropower cascade (including the Nurek HEPS) will be capable to produce annually the energy to meet not only domestic demand of Tajikistan within the small Amudarya basin (zone under the PEER project review), but also to partially meet demand of Tajikistan as a whole (with 12%deficit in Case 4). Given that the electricity demand is partially met by TPPs, there would be even energy surplus in the amount of 1.7 billion kilowatt-hours in Case 4, which can be exported.

The analysis of seasonal energy balances indicates to energy deficit from October to March and its surplus from April to September. By 2050-2055, energy deficit in October is estimated at 1.18 billion kilowatt-hours in Case 3 and 3.68 billion kilowatt-hours in Case 4 for Tajikistan, excluding Sogd province. In general, energy deficit is lower over 2020-2055: 0.25 billion of kilowatt-hours in Case 3 and 2.85 billion kilowatt-hours in Case 4, respectively.

The problem of seasonal energy deficit may be solved by:

- Increasing capacities of energy generation (not considered under the PEER project),
- Regulating seasonal flows of energy (export-import).

Section 5 (Sorokin A.G.) of the report provides a comprehensive analysis of development in the Amudarya River basin, with quantitative assessment of scenarios that reduce the risks of water and energy deficit in the countries.

4. Assessment of water resources and river channel balance for 2020-2055, influence of hydropower stations and Afghanistan on availability of water for Prearalie

The river channel balance of the Amudarya River and its tributaries was assessed for the period of time 2020-2055 according to the rules below:

- The river channel balance is drawn up for the Amudarya River and its tributaries (Vakhsh, Pyanj, Kafirnigan, Surkhandarya) in their ensemble,
- Surface waters in the flow formation zone are estimated by modeling river runoff series, with account of cyclical nature and climate impact through scenarios,
- The required water withdrawal from transboundary sources, i.e. from the rivers Vakhsh, Pyanj, Kafirnigan, and Amudarya, within the jurisdiction of BWO Amudarya is set through the limits of water withdrawal into canals (based on water allocation practices of 1991-2017); thus, restrictions are set on above-limit water withdrawals from transboundary sources since basin's water resources would not increase in the long-term,
- Water withdrawal from transboundary sources into canals and lakes in the basin are calculated based on available usable surface waters that include return flow (collector-drainage water and surface water runoff into canals) minus water losses in the river and reservoirs and taking into account flow regulation by reservoirs,
- Water withdrawal, which is not controlled by BWO Amudarya (e.g. from the Surkhandarya River) is considered in the river channel balance of Amudarya River's tributaries,
- Occurring water shortage (discrepancy of channel balance) is distributed among countries and river reaches proportionally to the established water limits (country quotas) that results in reduction of water withdrawals by an amount, which is the difference between limit and shortage,

  Regulation of flow in the Vakhsh River is governed by operation modes of the Nurek HEPS; those modes are modeled under different scenarios (optimization),
- Operation modes of TMHS reservoirs (viewed as a single structure) are determined proceeding from conditions of water shortage in middle and lower reaches: first, water shortage is minimized in the lower reaches, then this shortage is distributed all over the basin; inflow to TMHS is corrected and water scarcity is again minimized in the lower reaches (1-2 iterations),
- Flow regulation by intra-system reservoirs (Zeid, Talimarjan, etc.) is taken into account in the water balance of planning zones (PZ) and not included in the river channel balance of Amudarya,
- Losses and return flow (collector-drainage water discharged into rivers and lakes) are calculated by formulas derived in the course of project research (A.Nazariy's report).

Assessment of river channel balance over 2020-2055 was made against four options representing combinations of scenarios (named as Cases), see Table 4.1.

All cases include an influence of Afghanistan on the flow in the Pyanj and the Vakhsh rivers that is shown in increased water withdrawal from the rivers, as well as the lowering of Amudarya River flow caused by cutting of discharge of drainage water into the middle reaches of Amudarya (Table 4.2).

Table 4.1 Scenario combinations

Operation mode of Nurek HEPS:	Climate impact scenarios:	
	No impact	Impact as modeled by REMO 04-06
Energy generation	Case 1	Case 3
Energy-irrigation	Case 2	Case 4

Table 4.2 Factors affecting the river flow of Amudarya, Mm^3

	2020	2025	2035	2045	2050
1.Increased water withdrawal by Afghanistan	0	500	1000	2000	3000
2.Water withdrawal of Afghanistan	3000	3500	4000	5000	6000
3.Reduced discharge of collector-drainage water into the river from Turkmenistan	200	790	1970	1970	1970
4.Lowering of water content in Amudarya (1+3)	200	1290	2970	3970	4970

Table 4.3 shows the results of calculation of river channel balance for the Amudarya River in its middle (from the section upstream of intake to Garagumdarya) and lower reaches – average over 2020-2055, max and min in these series; the data are provided for 4 cases (Case 1...4) for the whole year (October-September) and for the growing season (April-September). Annex 4 includes the Table comparing 4 cases of annual river channel balance of the Amudarya River from 2020 to 2055.

Table 4.3 Components of criver hannel balance of the Amudarya river by case: water volume annual and seasonal, km^3

Annual volume	Case	Average over 2020-2055	MAX	MIN
Flow of Amudarya River in the section upstream of intake to Garagumdarya, km3	1	54.85	91.66	38.90
	2	54.66	92.21	39.03
	3	53.58	89.24	37.80
	4	53.39	89.79	37.78
Flow of Amudarya River at Birata gauging station (inflow to TMHS), km3	1	32.36	66.73	19.48
	2	31.58	67.10	18.54
	3	31.29	64.45	18.79
	4	30.53	64.81	18.10
Water supply to lakes of South Prearalie, km3	1	3.49	5.00	0.00
	2	2.57	5.00	0.00
	3	3.46	5.00	0.00
	4	2.26	5.00	0.00
Water supply to the Aral Sea from the Amudarya and collectors, km3	1	5.41	32.26	2.12
	2	5.08	29.08	1.98
	3	4.79	30.51	1.96

	4	4.76	27.42	2.53
Water withdrawal, km3	1	51.57	55.24	45.37
	2	52.97	55.24	46.95
	3	51.23	55.24	43.39
	4	52.58	55.24	44.98
Open channel losses, km3	1	8.23	16.50	5.13
	2	8.18	18.23	4.82
	3	7.84	15.83	4.97
	4	7.84	17.47	4.65
Water shortage, km3	1	3.67	9.87	0.00
	2	2.27	8.29	0.00
	3	4.01	11.85	0.00
	4	2.66	10.26	0.00

Volume in April-September				
Flow of Amudarya River in the section upstream of intake to Garagumdarya, km3	1	40.14	72.85	25.77
	2	43.55	77.30	28.39
	3	38.49	70.11	24.40
	4	41.91	74.56	27.26
Flow of Amudarya River at Birata gauging station (inflow to TMHS), km3	1	25.28	55.41	14.14
	2	27.88	59.64	15.25
	3	23.84	52.82	12.84
	4	26.47	57.04	14.86
Water supply to lakes of South Prearalie, km3	1	2.14	3.00	0.00
	2	1.70	3.00	0.00
	3	1.94	3.00	0.00
	4	1.41	3.00	0.00
Water supply to the Aral Sea from the Amudarya and collectors, km3	1	4.27	28.62	1.68
	2	4.05	25.21	1.62
	3	3.59	26.63	1.51
	4	3.61	23.29	1.55
Water withdrawal, km3	1	35.82	39.49	29.62
	2	37.63	39.49	33.57
	3	35.48	39.49	27.64
	4	37.23	39.49	31.59
Open channel losses, km3	1	7.08	14.46	4.27
	2	7.30	16.33	4.25
	3	6.64	13.72	4.10
	4	6.93	15.50	4.05
Water shortage, km3	1	3.67	9.87	0.00
	2	1.86	5.92	0.00
	3	4.01	11.85	0.00
	4	2.26	7.90	0.00

Water resources in the section upstream of intake to Garagumdarya are estimated on average over 2020-2055 at 53.4…54.9 km^3 a year, depending on case (87% of average flow over 1980-1999, 106 % of average flow over 2010-2015). At the same time, climate impact in general over a year (difference between cases 1 and 3, 2 and 4) will be manifested only in 1.27 km^3 or 2% of annual river flow. Maximum river flow in this section is estimated at 89.8…92.2 km^3, while minimum one, at 37.8…39.0 km^3.

In the growing season (April-September), river flow is expected to be 38.5…43.6 km^3 in the section upstream of intake to Garagumdarya. In this period of time, an impact of operation mode of the Nurek HEPS is visual: under energy-irrigation mode (cases 2 and 4) the flow is higher along the Amudarya River as compared to energy mode (cases 1 and 3). If operation of the Nurek HEPS is changed from energy mode to energy-irrigation one, the river flow would increase during the growing season by approximately 3.4 km^3 or 8...9 % of the flow in April-September.

Average, over 1980-1999, annual flow of the Amudarya River in the section upstream of intake to Garagumdarya is 62.2 km^3 (according to data from SIC's DB), including 45.8 km^3 during the growing season (April-September). Over 2010-2015 (base period in the PEER Project), the average annual flow was 51.2 km^3, including 34.0 km^3 during the growing season.

At the section of Birata gauging station (inflow to TMHS), the annual flow of the Amudarya River is estimated on average (over 2020-2055) at 30.5…32.4 km^3 a year depending on the case. Maximum river flow in this section is estimated at 64.4…67.1 km^3, while minimum one, at 18.1…19.5 km^3 only.

Water shortage in the basin (against the water limit) is estimated on average over 2020-2055 at 2.3…4.01 km^3, depending on the case, and can be 8…12 km^3 in some years. Operation of the Nurek HEPS in energy mode can increase annual shortage (as compared to energy-irrigation mode) in the basin by 1.3…1.4 km^3 on average over 2020-2055 and by 1.8 km^3 in the growing season. In dry years, water shortage caused by energy mode of Nurek operation can be about 4 km^3.

Open channel losses in the Amudarya River are estimated on average over 2020-2055 at approximately 8 km^3 that is about 15% of Amudarya flow in the section upstream of intake to Garagumdarya. Water losses may increase to 16…18 km^3 in some particularly wet years and decrease to 5 km^3 in particularly dry years.

In calculation of open channel losses in the PEER Project we used the derived relationships between losses and flow in river reaches: for middle reaches – linear relationships showing losses in the amount of 1...4% of river flow; for lower reaches – polynomial 2nd order relationships showing losses of 20...30% during growing season and 10...22% from October to March (see assessment of channel losses in the report by A.Sorokin, section 2.1, August 2016).

Water supply to the lakes of Southern Prearalie and to the Aral Sea from the river and collecting drains (collectors) averages 7.02…8.9 km^3, depending on the case, over 2020-2055 (Figure 4.3). As a whole over 2020-2055, available water supply for Southern Prearalie is estimated at 78…100 % (against the demand of 9 km^3).

Southern Prearalie (hereinafter Prearalie) considered as the ecosystem of "Delta-Sea" is a single system of lakes and wetlands located in the Amudarya River delta and has some demand for annual water resources. Prearalie comprises the Mejdurechenskoye reservoir along the Amudarya River, a range of lakes and water bodies (Sudochie Lake, Djiltyrbas Bay, etc.), as well as Eastern and Western parts of the Large Aral Sea. Water in Prearalie is needed to maintain its sustainability at a certain level in order to replenish the lakes in the delta, ensure water flowage, supply water to the Aral Sea, as well as maintain sanitary water releases along the Amudarya River. This does not include sanitary-environmental water releases into lower basin canals allocated by ICWC annually in the amount of 800 mcm. The total demand of Southern Prearalie is estimated at 8..9 km^3 a year (report by A.Sorokin, section 2.6).

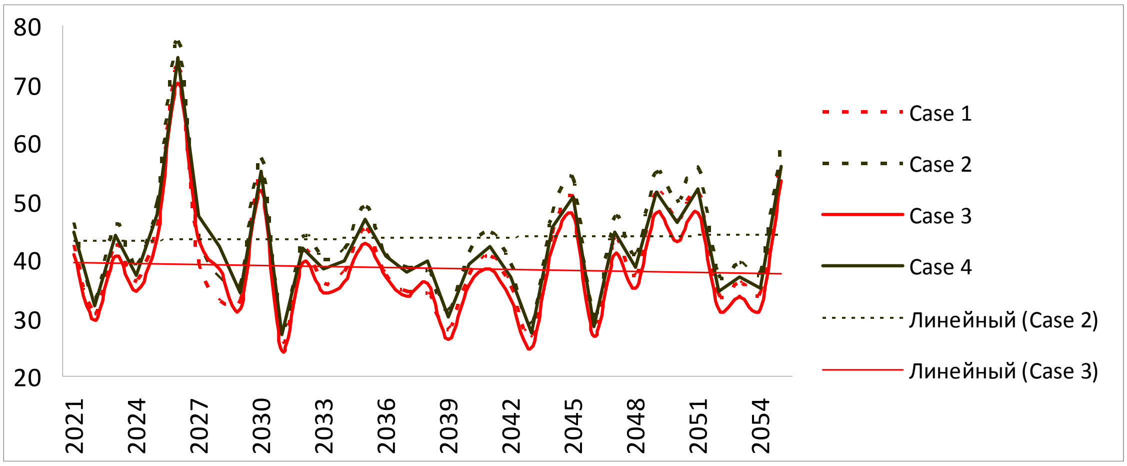

Fig. 4.1 Dynamics of annual flow of the Amudarya River in the section upstream of intake to Garagumdarya, 2020-2055, by case, km3

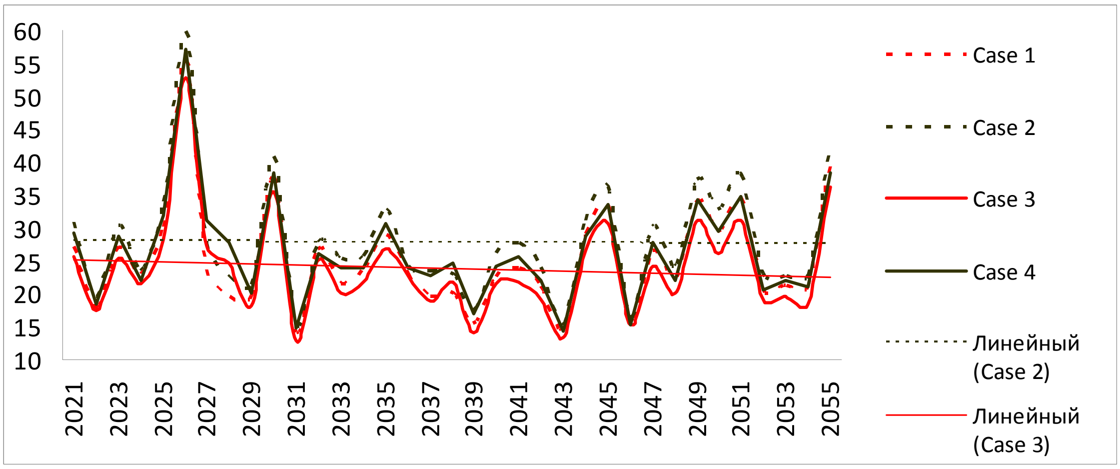

Fig. 4.2 Dynamics of annual flow of the Amudarya River during growing season (April-September) at Birata gauging station (inflow to TMHS), 2020-2055, by case, km3.

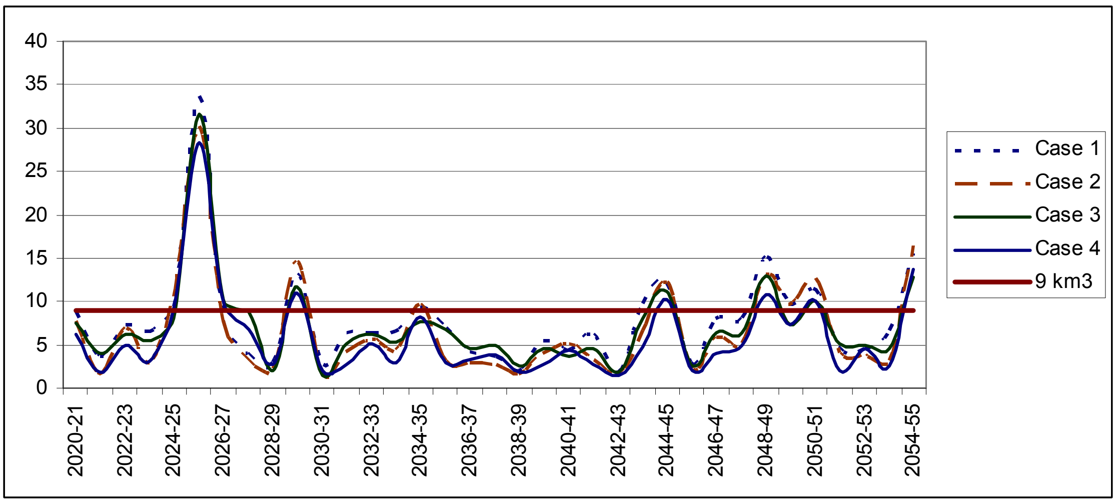

Fig. 4.3 Dynamics of annual volume of water delivered to Southern Prearalie – lakes and the Aral Sea, by case, km3.

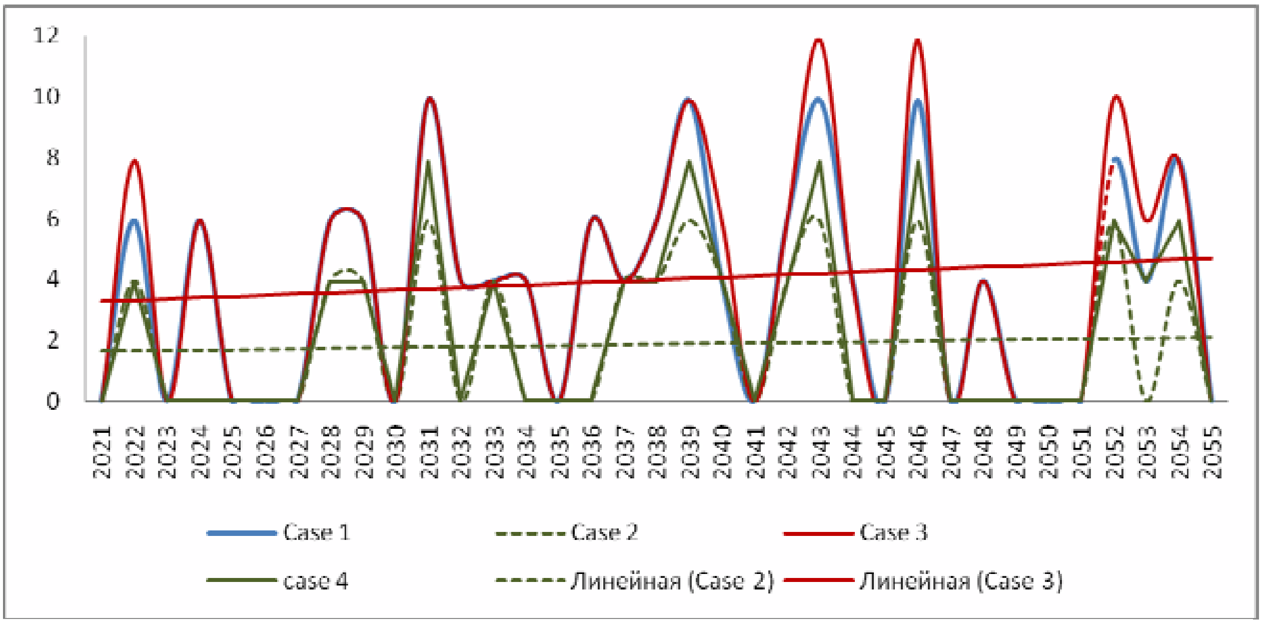

Fig. 4.4 Dynamics of water shortage in the Amudarya basin during growing season (April-September), 2020-2055, by case, km3.

The difference in river channel balance's elements in different cases (case 1,2,3,4) can be observed from dynamics of flow transformation in the Amudarya River during growing seasons caused by climate impact and operation of HEPS (Figures 4.1-4.2, Table 4.4).

Table 4 shows <u>the results of river channel balances for the whole Amudarya basin</u>, i.e. for the Amudarya River (including upper, middle, and lower reaches) and its tributaries, the Vakhsh, Pyanj, Kafirnigan, and Surkhandarya Rivers (averaging over 2020-2055). The data is shown for two cases of scenario combinations, such as case 3 and case 4.

Table 4.4 River channel balance of small Amudarya basin (year, growing season), average over 2020-2055 for energy (Case 3) and energy-irrigation (Case 4) operation modes of Nurek HEPS in the context of climate change

№	Balance item (km3)	Case 3		Case 4	
		Oct-Sep	Apr-Mar	Oct-Sep	Apr-Mar
	VAKHSH RIVER BASIN				
1	Inflow to Nurek hydroscheme	19.66	16.11	19.66	16.11
3	Water releases from Nurek hydroscheme	19.66	11.98	19.63	15.71
6	Water withdrawal from the Vakhsh River	6.62	4.16	6.76	4.37
8	Shortage	0.47	0.47	0.33	0.26
10	Flow of the Vakhsh River: mouth	14.58	8.81	14.45	12.32
	PYANJ RIVER BASIN				
1	Pyanj (Khirmanjoy) + Kokcha	34.68	26.49	34.68	26.49

3	Water withdrawal by Afghanistan	1.57	1.25	1.57	1.25
6	Water withdrawal from the Pyanj River	1.55	1.28	1.60	1.34
7	Water shortage	0.14	0.14	0.09	0.08
11	Flow of the Pyanj River: Lower Pyanj	32.70	24.83	32.65	24.78
	KAFIRNIGAN RIVER BASIN				
1	Recorded inflow	5.38	4.39	5.38	4.39
2	Delivery to Surkhandarya Basin	0.30	0.25	0.30	0.25
3	Water withdrawal of Upper Kafirnigan PZ	2.00	1.75	2.00	1.75
4	Water withdrawal of Lower Kafirnigan PZ	0.83	0.66	0.85	0.69
5	Water shortage	0.07	0.07	0.05	0.04
9	Flow of the Kafirnigan River: mouth	2.71	2.21	2.70	2.19
	SURKHANDARYA RIVER BASIN				
1	Recorded inflow	3.46	2.84	3.46	2.84
2	Delivery from the Kafirnigan River Basin	0.30	0.25	0.30	0.25
3	Delivery from the Amudarya River	1.45	1.08	1.49	1.13
4	Water withdrawal of Karatag-Shirkent PZ	0.40	0.32	0.40	0.32
5	Water withdrawal of Surkhandarya PZ	4.20	3.40	4.20	3.40
	including: from Amudarya	1.45	1.08	1.49	1.13
6	Water shortage (based on delivery from Amudarya)	0.12	0.12	0.08	0.07
11	Flow of the Surkhandarya River: mouth	1.54	1.27	1.59	1.32
	AMUDARYA RIVER				
1	Flow of the Vakhsh River: mouth	14.58	8.81	14.45	12.32
2	Flow of the Pyanj River: Lower Pyanj	32.70	24.83	32.65	24.78
5	Kunduz River: discharge into Amudarya River	3.51	2.45	3.51	2.45
6	Flow of the Kafirnigan River: mouth	2.71	2.21	2.70	2.19
7	Flow of the Surkhandarya River: mouth	1.54	1.27	1.59	1.32
8	Water withdrawal from Amudarya into Surkhandarya PZ	1.45	1.08	1.49	1.13
9	Water shortage in Surkhandarya PZ	0.12	0.12	0.08	0.07
10	Return flow into Amudarya	0.25	0.20	0.25	0.20
11	Open channel losses	0.28	0.20	0.27	0.22
12	Amudarya River flow: inflow to middle reaches	53.58	38.49	53.39	41.91
13	Intake to Garagumdarya – Mary, Akhal, and Balkan PZs	10.84	7.03	11.09	7.37
14	Water shortage	0.79	0.79	0.54	0.45
15	Intake to KMC (Karshi PZ)	4.13	2.43	4.20	2.55
16	Water shortage	0.27	0.27	0.20	0.15
17	Intake to ABMC (Bukhara and Navoyi PZs)	4.26	2.72	4.36	2.86
18	Water shortage	0.31	0.31	0.21	0.17
19	Water withdrawal of Lebap PZ	3.66	2.37	3.75	2.49
20	Water shortage	0.27	0.27	0.18	0.15
21	Total water withdrawal in middle reaches of Amudarya	22.89	14.55	23.39	15.26
22	Return flow from Lebap PZ	0.59	0.38	0.60	0.40

	(Turkmenistan)				
23	Return flow from Karshi PZ (Uzbekistan)	0.50	0.29	0.50	0.31
24	Return flow from Bukhara PZ (Uzbekistan)	1.07	0.68	1.09	0.71
25	Open channel losses	1.55	1.45	1.66	1.60
26	Flow of the Amudarya River at Birata gauging station (inflow to TMHS)	31.29	23.84	30.53	26.47
29	Water releases from TMHS (discharge into river + water withdrawal)	30.13	22.85	29.34	22.97
30	Water withdrawal of Doshoguz PZ	5.93	4.53	6.12	4.75
31	Water shortage of Doshoguz PZ	0.51	0.51	0.32	0.29
32	Water withdrawal of Khorezm PZ	4.34	3.10	4.46	3.25
33	Water shortage of Khorezm PZ	0.35	0.35	0.23	0.20
34	Water withdrawal of Republic of Karakalpakstan	7.64	6.14	7.90	6.44
35	Water shortage of Republic of Karakalpakstan	0.69	0.69	0.43	0.39
36	Total water withdrawal in Amudarya lower reaches	17.91	13.77	18.48	14.44
37	Water shortage in lower reaches	1.55	1.55	0.98	0.88
38	Emergency-environmental water releases into canals	0.80	0.80	0.80	0.80
	including: Doshoguz PZ	0.15	0.15	0.15	0.15
	Khorezm PZ	0.15	0.15	0.15	0.15
	Republic of Karakalpakstan	0.50	0.50	0.50	0.50
43	Open channel losses	4.74	4.02	4.71	4.07
44	Amudarya River flow at Samanbay gauging station	6.69	4.26	5.36	3.65
45	River water delivery to Prearalie lakes	3.46	1.94	2.26	1.41
46	Water shortage in lake system	1.54	1.06	2.74	1.59
50	Water supply to the Aral Sea from the river and collecting drains	4.79	3.59	4.76	3.61
51	TOTAL WATER WITHDRAWAL	51.23	35.48	52.58	37.23
54	TOTAL WATER LOSSES	7.84	6.64	7.84	6.93
56	TOTAL WATER SHORTAGE	4.01	4.01	2.66	2.26

River channel balance for dry year

Annex 4 shows monthly river channel balance for particularly dry year (2042-2043), which can occur in the future under combination of cases 3 and 4, i.e. under energy and energy-irrigation modes of operation of the Nurek HEPS in the context of climate change, increased water use by Afghanistan and discontinued discharge of collector-drainage water into Amudarya from the territory of Turkmenistan. Some components of that balance are shown in Figures 4.5-4.9 in form of diagram schedule (since October till September) and integral curves (cumulative total).

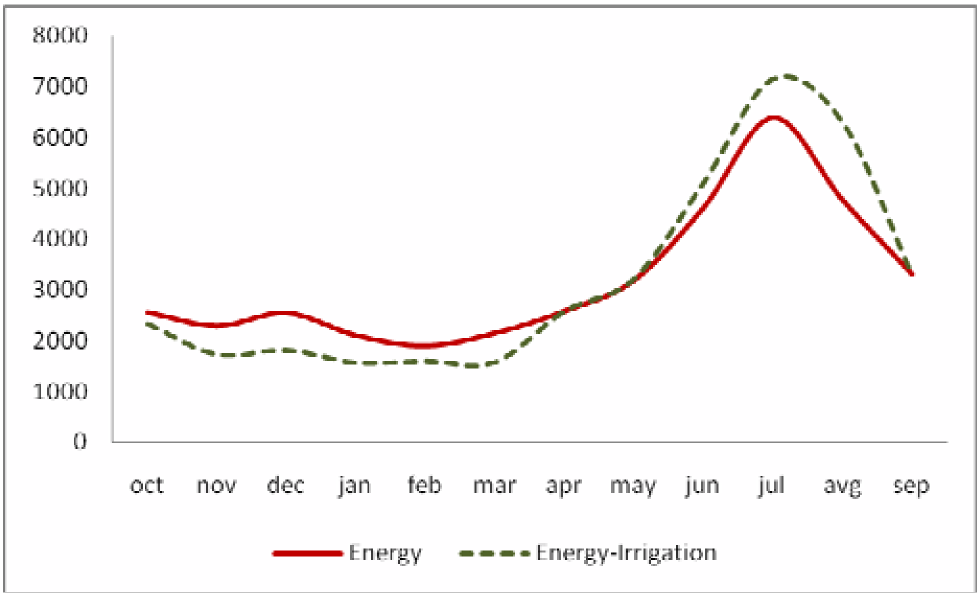

Figure. 4.5 Flow hydrograph of the Amudarya River in the section upstream of intake to Garagumdarya (Kelif g/s) for particularly dry year (2042-2043 г): case 1(energy) and case 2 (energy-irrigation), Mm3 / month

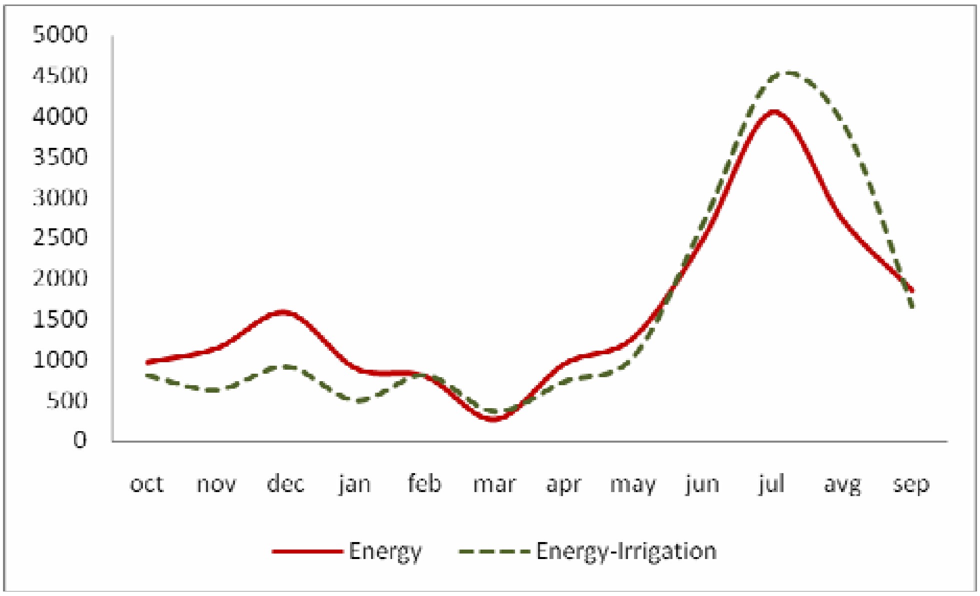

Figure. 4.6 Flow hydrograph of the Amudarya River at Birata g/s for particularly dry year (2042-2043 г): case 1(energy) and case 2 (energy-irrigation), Mm3 / month

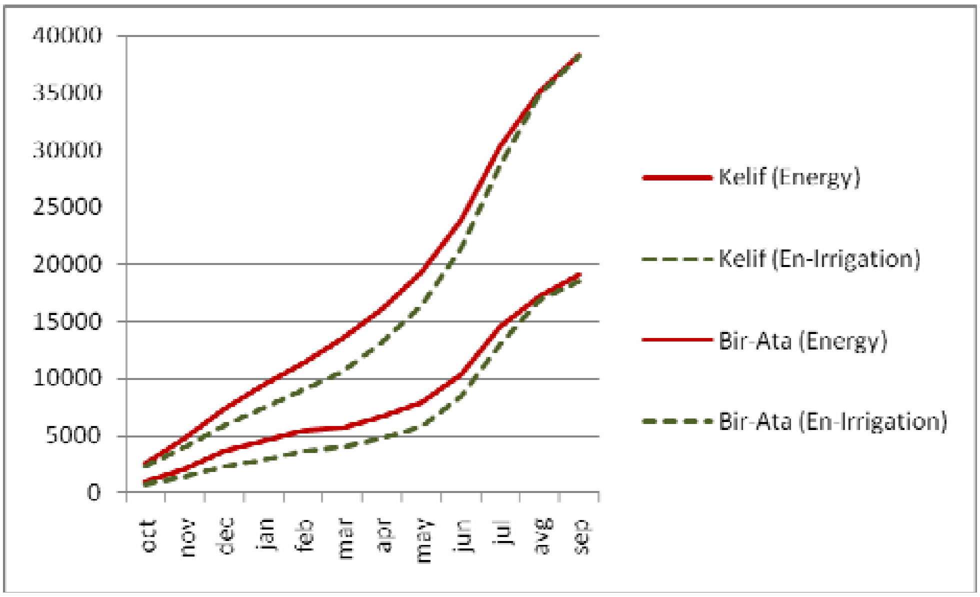

Figure 4.7 Integral curves of Amudarya River flow at Kelif g/s and Birata g/s for particularly dry year (2042-2043 г): case 1(energy) and case 2 (energy-irrigation), Mm3

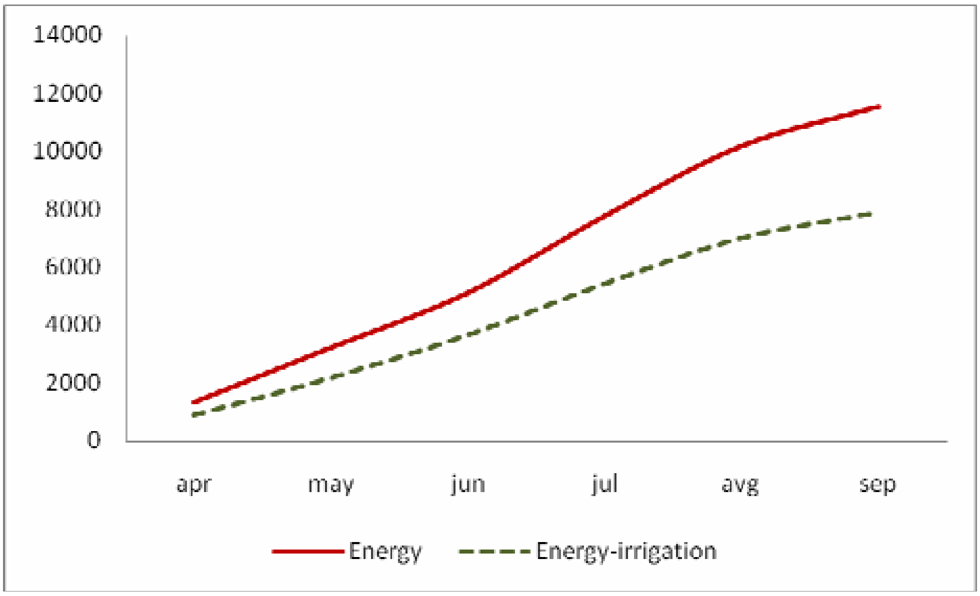

Figure 4.8 Integral curve of water shortage in the Amudarya River Basin in particularly dry year (2042-2043 г): case 1(energy) and case 2 (energy-irrigation), Mm3

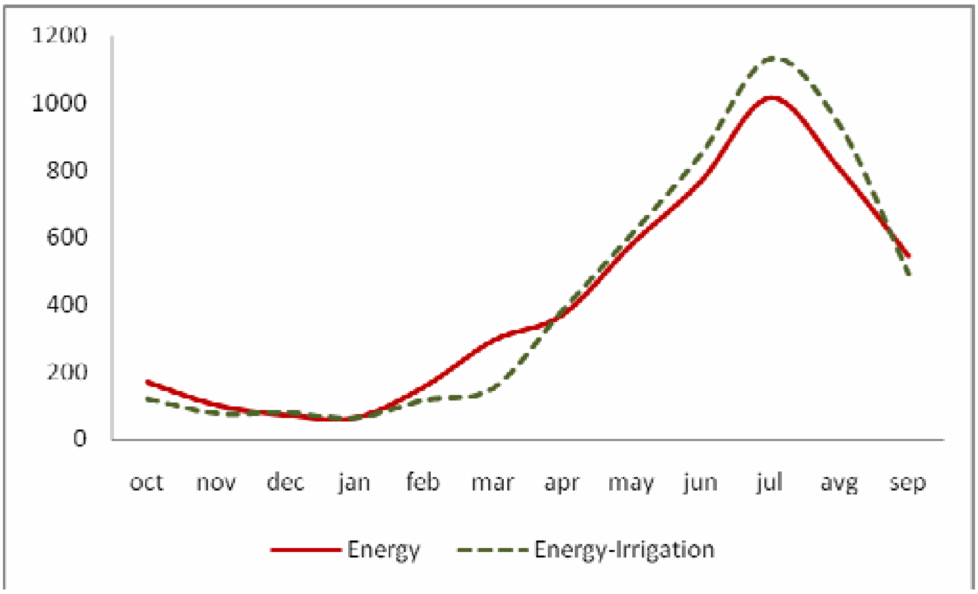

Figure 4.9 Dynamics of open-channel losses in the Amudarya River for particularly dry year (2042-2043 г): case 1(energy) and case 2 (energy-irrigation), Mm3 / month

The river channel balance of dry year is shown for 2042-2043. This year, water releases from the Nurek HEPS during the growing season are expected to be 8.1 km^3 in case 3 (energy mode of operation) and 11.4 km^3 in case 4 (energy-irrigation mode of operation), i.e. 3.3 km^3 higher.

The river flow is estimated at 15.3 km^3 in the Vakhsh River (based on inflow to the Nurek HEPS), 24.4 km^3 in the Pyanj River (Lower Pyanj section), 0.8 km^3 in the Kafarnigan River (mouth), 0.4 km3 in the Surkhandarya River (mouth), 3.0 km^3 in the Kunduz River (mouth), and 38.3 km^3 in the Amudarya River (in the section upstream of intake to Garagumdarya), including during the growing season: 24.8 km^3 in case 3; and, 27.6 km^3 in case 4.

In hydrological series 2020-2055, Amudarya flow of 2042-2043 in the section upstream of Garagumdarya corresponds to flow probability (exceedance probability, Pm) of 95% (see Figure 4.10). This means that only in 5 instances out of 100 such flow would pass the Amudarya River in the section upstream of intake to Garagumdarya.

In retrospective series 1980-2017, an amount of flow in the Amudarya River that was close to that of 2042-2043 was observed only in 2 instances: in 2000-2001 - 41.3 km^3, including 26.8 km^3 in growing season; and, in 2007-2008 - 36 km^3, including 22.5 km^3 in growing season.

In 2042-2043, inflow to TMHS is expected to be 18.5…19 km^3, and delivery to South Prearalie (including collector-drainage water) is expected to be 2.6…3 km^3, that is 29…33% of the desired volume.

That year, the cumulative water scarcity (derived from the difference between limits and estimated water delivery to canals) in the growing season is expected to be 11.9 km^3 in case 3 (energy mode of operation of the Nurek HEPS) and 7.9 km^3 in case 4 (energy-irrigation mode of operation); thus, when changing from energy to energy-irrigation mode (under which more electricity is generated annually and lower in winter period), water shortage is reduced by 4 km^3, that is 10% of the established limit. During growing season, water shortage (for all countries and river reaches) will be 30% of the limit in case 3 and 20% of the limit in case 4.

Distribution of water shortage among countries and river reaches in shown in Table 4.5. Table 4.6 provides the data on water withdrawal, limits and shortage.

Table 4.5 Distribution of shortage of water flowing to canals of the Amudarya basin, dry year 2042-2043, km^3

Basin countries, reaches	Case 3. Energy operation mode of Nurek HEPS + climate impact			Case 4. Energy-irrigation operation mode of Nurek HEPS + climate impact		
	October-March	April-September	Year	October-March	April-September	Year
1.Upper reaches	0.00	2.39	2.39	0.49	1.60	2.09
1.1.Tajikistan	0.00	2.03	2.03	0.44	1.36	1.79
1.2 Uzbekistan	0.00	0.36	0.36	0.06	0.24	0.30
2.Middle reaches	0.00	4.86	4.86	1.25	3.24	4.49
2.1.Turkmenistan	0.00	3.14	3.14	0.77	2.09	2.86
2.2 Uzbekistan	0.00	1.72	1.72	0.49	1.15	1.63
3.Lower reaches	0.00	4.60	4.60	0.62	3.06	3.69
3.1.Turkmenistan	0.00	1.51	1.51	0.21	1.01	1.22
3.2 Uzbekistan	0.00	3.08	3.08	0.41	2.06	2.47
TOTAL	0.00	11.85	11.85	2.36	7.90	10.26
Tajikistan	0.00	2.03	2.03	0.44	1.36	1.79
Turkmenistan	0.00	4.65	4.65	0.98	3.10	4.08
Uzbekistan	0.00	5.16	5.16	0.95	3.44	4.39

Table 4.6 Water withdrawal and water shortage during the dry year 2042-2043

Channel balance item	Case 3. Energy operation mode of Nurek HEPS + climate impact			Case 4. Energy-irrigation operation mode of Nurek HEPS + climate impact		
	October-March	April-September	Year	October-March	April-September	Year
Limits, km3	15.75	39.49	55.24	15.75	39.49	55.24
Water withdrawal	15.75	27.64	43.39	13.39	31.59	44.98
% of limit	100	70	79	85	80	81
Shortage, km3	0.00	11.85	11.85	2.36	7.90	10.26
% of limit	0	30	21	15	20	19

Statistical analysis

Figures 4.10 - 4.12 show probability curves that characterize empirical probability of exceedance of amounts of flow in the Amudarya River in the section upstream of intake to Garagumdarya and in Birata section (inflow to TMHS). The exceedance probability Pm was calculated by formula:

$$Pm = [\ m / (\ n + 1)\ ] * 100\ \% \qquad \ldots.\ (1)$$

where: m is the index number of members in hydrological series arranged in descending order, n is the total quantity of members in the series, n = 35 (2020/21 -2054/55).

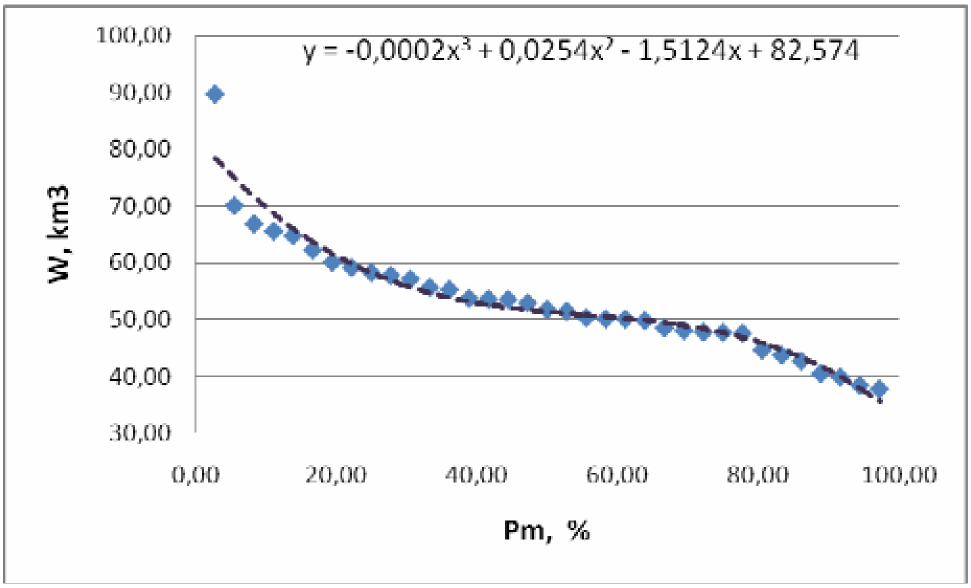

Figure 4.10 Annual flow probability curve Pm (W) for Amudarya River in the section upstream of intake to Garagumdarya, case 4 (processing of the data of Amudarya river channel balance over 2020-2055)

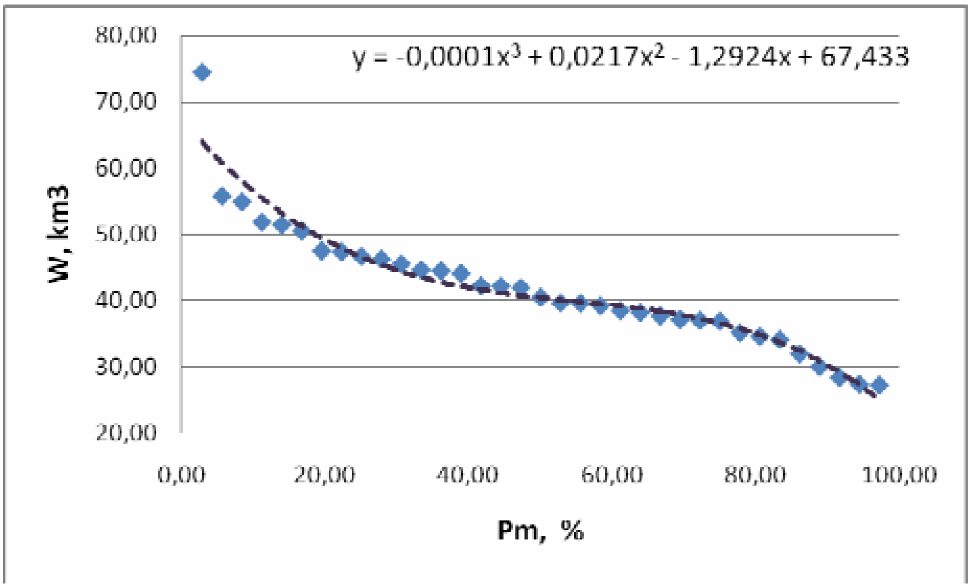

Figure 4.11 Flow probability curve Pm (W) for the Amudarya River for the growing season (April-September) in the section upstream of intake to Garagumdarya, case 4 (processing of the data of Amudarya river channel balance over 2020-2055)

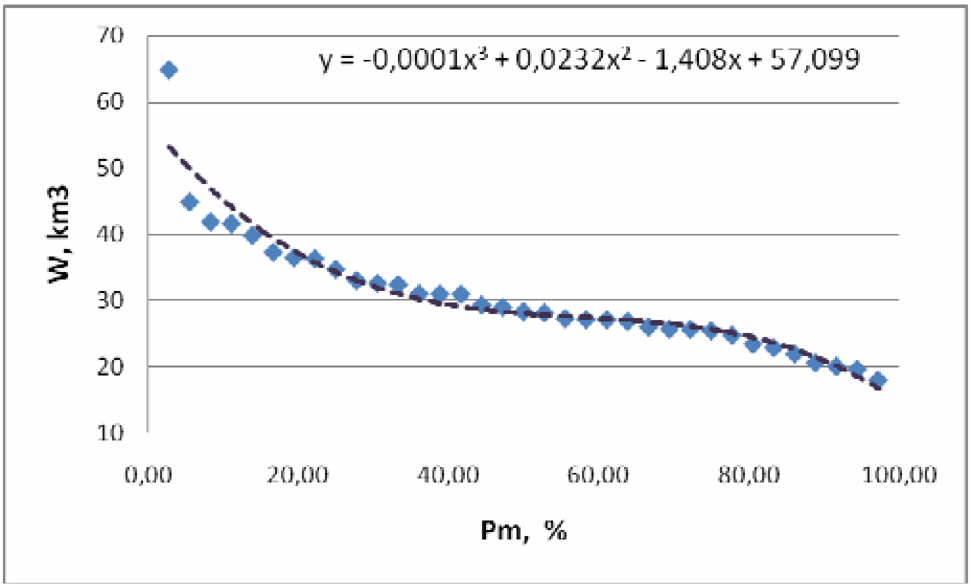

Figure 4.12 Annual flow probability curve Pm (W) for the Amudarya River at Birata section, case 4 (processing of the data of Amudarya river channel balance over 2020-2055)

Table 4.7 shows how many instances of water shortage occur out of 100 in different scenario combinations of Nurek HEPS operation (1, 3 – energy mode, 2,4 – energy-irrigation) and climate impact (1, 2 – no impact, 2,3 – impact according REMO 0406 climate scenario) – the results of numerical experiment statistics on river channel balances of the Amudarya River over 2020-2055.

Under energy mode of operation of the Nurek HEPS and given the climate impact according to REMO 0406 scenario, water shortage is expected to be within 30% of the water limit in 6 instances out of 100. When changing to energy-irrigation mode of operation, water shortage with such values is absent but instances of shortage of 20% increases to 11 out of 100.

Table 4.7 Number of instances (K) out of 100 of occurrence of water shortage (D, %) for different cases

Case	Water shortage D, % of water withdrawal limit				
	10%	15%	20%	25%	30%
Case 1	23	20	6	11	0
Case 2	26	14	0	0	0
Case 3	17	23	6	9	6
Case 4	26	6	11	0	0

Figures 4.13-4.14 show the curves indicating graphically to the ratio of intensity of shortage (D, %) and number of instances of its occurrence (K) out of 100 under four scenario combinations (Case).

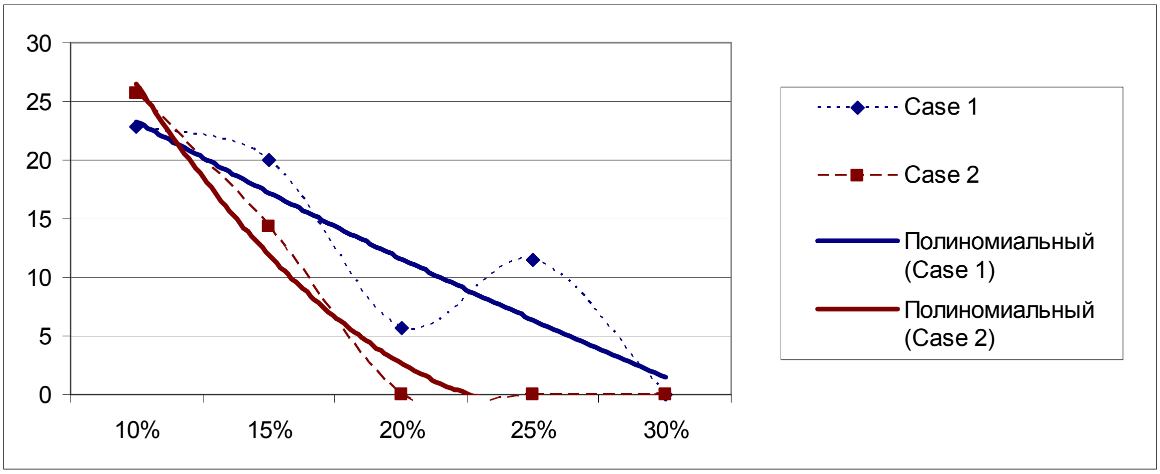

Figure 4.13 Relationship between the degree of water shortage (D, %) and number of instances of its occurrence (K) out of 100: case 1 – energy mode of operation of the Nurek HEPS, case 2 – energy-irrigation mode of operation of the Nurek HEPS, climate impact is not considered

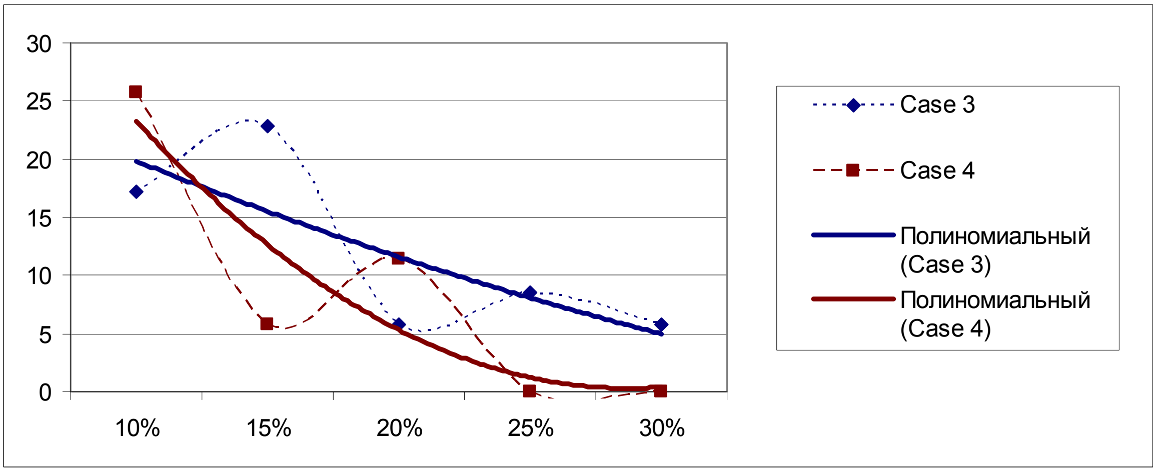

Figure 4.14 Relationship between the degree of water shortage (D, %) and number of instances of its occurrence (K) out of 100: case 3 – energy mode of operation of the Nurek HEPS, case 4 – energy-irrigation mode of operation of the Nurek HEPS, climate impact is considered by REMO 0406

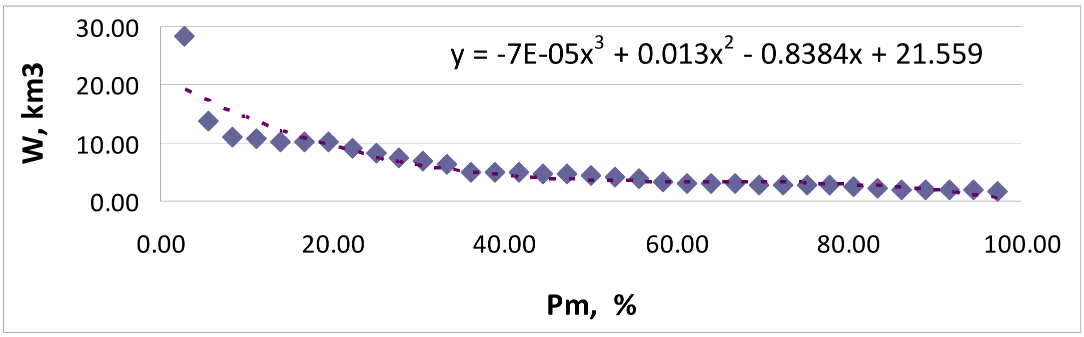

Figure 4.15 Probability curves Pm (W) of the Amudarya flow delivered to Southern Prearalie (processing of the data of Amudarya river channel balance over 2020-2055)

As calculated, in 2020-2055, depending on the case, 5.9…7.8 km^3 of water on average will be supplied to Southern Prearalie, including 3.6..4.3 km^3 a year to the Aral Sea, i.e. about 58% of total supply to lakes and Aral. The amount of flow of 9 km^3 and larger is possible in 23 instances out of 100, the flow of 9 - 4 km^3 is probable in 37 instances out of 100 and that lower than 4 km^3 is probable in 40 instances out of 100. The probability curve Pm (W) of Amudarya river flow supplied to Southern Prearalie is demonstrated in Figure 4.15.

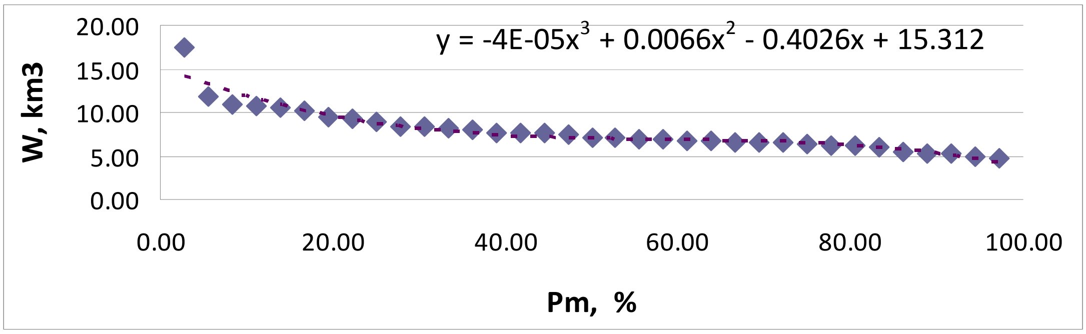

Figure 4.16 Probability curve Pm (W) of open channel losses in Amudarya, case 4 (processing of the data of Amudarya river channel balance over 2020-2055)

Open channel losses are estimated at 7.8…8.2 km^3 a year on average over 2020-2055. Herewith, losses of more than 10 km^3 are expected in 14 instances out of 100, losses within 7…10 km^3 are expected in 40 instances out of 100, and losses within 5…7 km^3 can occur in 44 instances out of 100. The probability curve Pm (W) of open channel losses in Amudarya River for case 4 is shown in Figure 4.16.

5. Comprehensive assessment of prospective development in country provinces and the basin as a whole: accounting of water shortage and irrigated agriculture production losses, search for consensus between hydropower, irrigation, and natural environment

Comprehensive assessment methodology

- This assessment was made for water and hydropower sectors within small Amudarya Basin, excluding Sogh province (Tajikistan), Samarkand, Navoyi provinces and a part of Kashkadarya province (Uzbekistan). PZs were assessed in linkage with river balancing sites (i.e. upper, middle, and lower reaches),
- Water withdrawal from transboundary sources (derived from river channel balance) is compared with the limits of water withdrawal into canals, as well as with estimated water demand of PZs (simulated by the Planning zone model by summing up the estimated needs for irrigation, household sector, industry, etc.) under scenarios BAU, FSD, and ESA, combined with climate impact,
- Water shortage by reaches of transboundary sources is estimated from river channel balance, while water shortage of planning zones (PZs) is estimated by comparing transboundary water withdrawals with water demands of PZs,
- For linkage of PZs with river reaches, the estimated water withdrawal in reaches is distributed among PZs with some adjustment for some main canals and PZs: it is considered for Garagumdarya that a portion of its flow is delivered to Balkan PZ and another portion is delivered through the Amu-Bukhara Canal to Navoyi PZ that are out of project area; it is considered also that PZs' demand can be met partially through local sources (those PZs include Surkhandarya, Akhal, Mary, and, to lesser degree, Karshi and Bukhara),
- Available water supply for environmental needs is assessed from shortage of water delivered to Southern Prearalie and the Aral Sea, based on the total needs of 9 km^3; water delivery to canals in lower reaches for environmental needs is obligatory and fully fulfilled,
- Assessment of electricity generation by the Vakhsh cascade (which includes the Nurek HEPS) is made by comparing with the trend of growing demand for electricity of Tajikistan within the small Amudarya Basin and with demands of Tajikistan as a whole; in this comparison, we determine a possibility to transfer electricity to Sogd province in Tajikistan and the export potential; losses of hydropower are estimated from electricity deficit and prices,
- Assessment of irrigated agriculture development is made using the scenarios BAU, FSD, and ESA (different cropping patterns, volumes, agricultural areas under innovations and rates of their introduction), with the assumption that the total irrigated area is kept the same in each state; productivities of land ($/ha) and water ($/m^3) are estimated by numerical experiments – simulations of the PZ model; damage for irrigated agriculture (output losses in money terms) is estimated, based on water shortage and productivity data,
- Consensus in the basin is sought through such an option that ensures maximal productivity of water and hydropower, by country sector and in the basin as a whole, on the basis of collaboration and cooperation,
- The consensus option should ensure: i) maximal annual generation of electricity by the Vakhsh HEPS cascade (here, export-import of seasonal energy should be possible), ii)

maximal productivity of irrigated agriculture for the countries and the basin as a whole (here, export-import of agricultural output should be possible), iii) minimal guaranteed supply to Southern Prearalie (85% of water to be delivered),
- Benefits and losses (damage) are assessed by country, sector and the basin as a whole (summing up by sector), including per capita (population trends derived from the PEER Project research).

Formation of water resources under climate impact

An impact of the observed climate change on formation of river flow in the Amudarya Basin is recognized to be more serious than in the Syrdarya Basin. Most models of flow formation that use "soft" climate scenarios do not assume substantial reduction of flow in major rivers of the Amudarya Basin until 2030. However, water resources in the Amudarya Basin could decrease by 2050. Deviation of annual flow from average long-term values is to increase. It is expected that warming would cause shifts, in intra-annual dimension, of typical flood time, i.e. flood peak could occur earlier.

In assessing the impact of possible climate changes on water resources, adjustments were made to natural, cyclical series of flow in the PEER Project. Additionally, coefficients were used from open sources, showing deviations of flow by month from its norms, which was derived by hydrological modeling using REMO-0406 climate data – projection for Central Asia of average warming scenario based on A1B and calculated by the general circulation model ECHAM 5.

For growing season, by 2055, the reduction of flow norm (average long-term values) according to REMO-0406 will be: 5% for the Vakhsh River; 6% for the Pyanj River; 8% for the Kafirnigan River; and, 6% for the Surkhandarya River. The reduction of the norms of flow in these rivers will be 12…25 % in July.

Hydropower

The current electricity shortage in Tajikistan is caused by high energy demands in winter (due to consumption patterns and electricity tariffs) and the lack of energy supply (largely, depends on operational efficiency of the Nurek HEPS and energy losses). In the future, electricity shortage in Tajikistan will depend on a possibility to account regional benefits from energy generation, as well as on Tajikistan's policy on export-import of seasonally generated energy. The important factor will be tariffs for residential sector, industry, and export tariffs.

When assessing scenarios of operation of the Vakhsh HEPS cascade, the PEER Project calculated indicators expressing electricity generation and deficit in absolute and money values derived from the assessment of resource balances through the "demand and supply" analysis.

The estimation of electricity cost (the product of tariff and generation) was made on the basis of export electricity price at 6.2 cent/kWh (calculated in the CASA Project, stage 2) that was taken as constant for 2020-2055; this allows assessing hydropower efficiency in dynamics for the long-term, without accounting the factor of price growth (by analogy with irrigated agriculture output prices taken as constant for 2020-2055). The calculation results of electricity cost are shown in Tables 5.1 - 5.3.

Table 5.1 Annual electricity generation by the Vakhsh cascade and electricity cost

Period of time	Generation by the cascade, MkWh/year		Electricity cost, M$/year		
	Case 3	Case 4	Case 3	Case 4	Case 4 - Case 3
2020-2030	15295	16090	948	998	49
2030-2040	14195	14931	880	926	46
2040-2050	14517	15238	900	945	45
2050-2055	15188	16014	942	993	51
2020-2055	14743	15504	914	961	47

Table 5.2 Electricity generation by the Vakhsh cascade during growing season and electricity cost

Period of time	Generation by the cascade, MkWh/growing season		Electricity cost, M$		
	Case 3	Case 4	Case 3	Case 4	Case 4 - Case 3
2020-2030	9241	12597	573	781	208
2030-2040	8153	11634	505	721	216
2040-2050	8386	11633	520	721	201
2050-2055	9147	12471	567	773	206
2020-2055	8672	12028	538	746	208

Table 5.3 Electricity generation by the Vakhsh cascade during non-growing season and electricity cost

Period of time	Generation by the cascade, MkWh/ non-growing season		Electricity cost, M$		
	Case 3	Case 4	Case 3	Case 4	Case 4 - Case 3
2020-2030	6054	3493	375	217	-159
2030-2040	6042	3297	375	204	-170
2040-2050	6130	3605	380	224	-157
2050-2055	6041	3542	375	220	-155
2020-2055	6071	3476	376	216	-161

Table 5.4 Excess of generation by the Vakhsh HEPS cascade and its cost (electricity demand in Tajikistan does not include that of the Sogd province)

Period of time	Excess electricity (+) at the cascade, MkWh/year		Cost of excess electricity, M$/year	
	Case 3	Case 4	Case 3	Case 4
2020-2030	4523	5318	280	330
2030-2040	2508	3244	155	201

2040-2050	1739	2460	108	153
2050-2055	1399	2225	87	138
2020-2055	2668	3429	165	213

Table 5.5 Excess of generation by the Vakhsh cascade during growing season (April-May) and its cost (electricity demand in Tajikistan does not include that of the Sogd province)

Period of time	Excess electricity (+) at the cascade during growing season, MkWh		Cost of excess electricity, M$	
	Case 3	Case 4	Case 3	Case 4
2020-2030	4109	7465	255	463
2030-2040	2585	6065	160	376
2040-2050	2298	5545	143	344
2050-2055	2577	5902	160	366
2020-2055	2920	6276	181	389

Table 5.6 Excess (+) and deficit (-) of electricity generated by the Vakhsh HEPS cascade in October-March and electricity cost (electricity demand in Tajikistan does not include that of the Sogd province)

Period of time	Excess (+) and deficit (-) of electricity in October-March, MkWh		Electricity cost, M$	
	Case 3	Case 4	Case 3	Case 4
2020-2030	414	-2147	26	-133
2030-2040	-77	-2822	-5	-175
2040-2050	-560	-3085	-35	-191
2050-2055	-1178	-3677	-73	-228
2020-2055	-251	-2846	-16	-176

In case 4 (energy-irrigation mode), on average over 2020-2055 the cascade generates 761 MkWh more electricity than in case 3 (energy mode) that is estimated at 47 M$.

Afghanistan

In the PEER project we consider water resources of Afghanistan comprised of the Murghab, Tedjen, Kokcha and Kunduz rivers. The Murgab and Tedjen rivers (namely their runoff at the border with Turkmenistan) are accounted as “local” resources in Mary and Akhal planning zones, the Kokcha River - as one of components of the Pyanj River, and the Kunduz River is included into the scheme of transboundary watercourses in the Amudarya basin.

According to SIC ICWC, in 1965, the total water use in the Pyanj and Amudarya River basins was 2.11 km^3/year, including 1.81 km^3/year in the Kunduz River basin and 0.03 km^3/year in the Kokcha River basin. The current total use of water resources by Afghanistan in catchments of the Pyanj and the Amudarya rivers is estimated at approximately 3 km^3 a year. It also provides calculation of the options of water demand in the Northern Afghanistan in the future. The more realistic option is that water use by Afghanistan will increase up to 6 km^3, i.e. by 2050 by 3 km^3 as compared to the current water withdrawal. This water use is accounted in balance calculations made in the PEER Project.

Regulation of collector-drainage water flowing from Turkmenistan

The prerequisite condition for implementation of the Turkmen lake XXI project (Altyn Asr or Golden Age) should be an Agreement between Turkmenistan and Uzbekistan, which will assess the risks of reduction of Amudarya water flowing to the lower reaches and set the terms to minimize these risks. Major channels of the Golden Age lake project are suggested to get the status of interstate ones as the former use collector-drainage water formed from the flow of the transboundary Amudarya River.

In the future, it is planned to deliver annually up to 10 bcm of water to Altyn Asr Lake. Additionally, diversion of collector-drainage water from the Lebap PZ will lead to cutting of discharge of collector-drainage water into the Amudarya from the left bank and to the reduction of river flow in the amount of 1.0…1.6 bcm a year that is on average about 6% of the water withdrawal limit allocated for Turkmenistan from the Amudarya River. Consequently, inflow to Prearalie will decrease by 0.8…1.3 bcm.

In case of capture of collector-drainage water formed in Khorezm province of Uzbekistan that currently flows into Sarykamysh Lake and their transportation to Altyn Asr Lake, Sarykamysh Lake may lose annually up to 3 bcm of inflow. The new Agreement needs to set minimum water releases for environmental needs into Sarykamysh Lake that would ensure its conservation as an interstate aquatic ecosystem, with the established shares from Turkmenistan and Uzbekistan at 20 each.

Available water supply for Prearalie and the Aral Sea

To maintain lake ecosystems in Southern Prearalie and the Aral Sea, the inflow from the Amudarya River and through collector-drainage water should be up to 9 km3/year on average over the long-term period. Inflow to the Aral Sea should not be less than 4 km3/year, while that to lakes should be higher than 3 km3/year (see PEER Project report 2.6 by A.Sorokin).

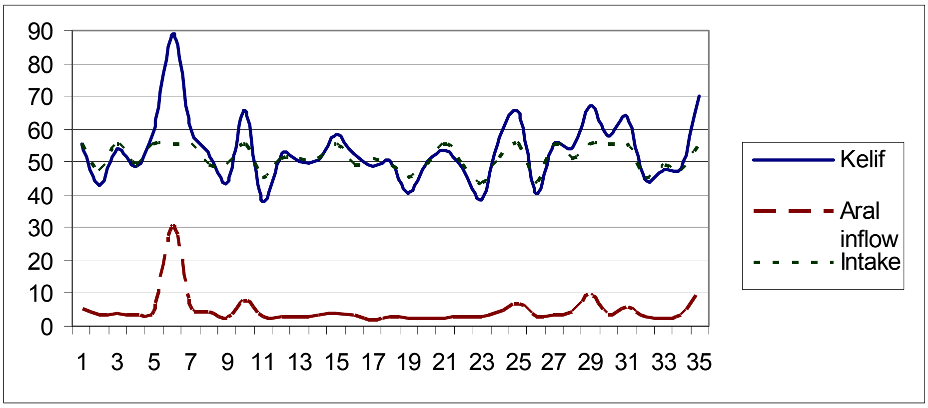

Figure 5.1 Dynamics of flow transformation in the Amudarya River from the section upstream of intake to Garagumdarya (Kelif) to the Aral Sea, for 35-year series (2020 – 2055)

Available water supply for planning zones

On average over 2020-2050, the annual water shortage (as the difference between the established water limits and actual water withdrawal from transboundary sources) within small Amudarya basin (Amudarya River and its tributaries) under energy mode of operation of the Nurek HEPS (which is close to the current one, where max energy is generated in autumn and winter) and in the context of climate change, increased water use by Afghanistan (3 km^3 higher as compared to the current water withdrawal), and cut discharge of collector-drainage water from Turkmenistan into the Amudarya River is estimated at 4 km^3. Moreover, open channel losses are not higher than 8 km^3. Maximum water shortage could be 12 km^3 (2043, 2046). The probability of occurrence of water shortage at 25 – 30 % of water withdrawal is 15 instances out of 100.

If the Nurek HEPS is operated under energy-irrigation mode (which is comfortable for irrigation water withdrawal schedules, where max energy is generated during a year), the average water shortage may decrease from 4 to 2.5 km^3, while reaching maximally 8 km^3 (2043). Moreover, water shortage will not be more than 20 % of water withdrawal and the number of such instances (years) will drop to 11 out of 100.

Table 5.7 shows the data on estimated water withdrawal from transboundary sources and the average, over 2020-2055, water shortage for different cases of operation of the Nurek HEPS: energy mode (case 3) and energy-irrigation mode (case 4), with climate impact simulated by the REMO 0406 scenario.

One of the tasks in the PEER Project was to define more precisely water requirements of PZs in the context of climate change under different irrigated agriculture development strategies that were viewed as scenarios BAU, FSD and ESA.

This precise definition was done using two models: i) the model, which calculates elements of water requirements – crop evapotranspiration, recharge from groundwater, active precipitation derived from climate data of the REMO 0406 scenario (F.Solodkiy), ii) PZ model (A.Sorokin, R.Toshpulatov), which calculates water balance based on G.Solodkiy's data and BAU, FSD and ESA scenarios that provide trends by 2055 of population, cropping patterns, introduced innovations to increase yields and reduce irrigation depths.

Table 5.8 shows averaged for 2020-2055 data on desirabe water supply for PZs from transboundary sources (Amudarya, Vakhsh, Pyanj, Kafirnigan models) under BAU, FSD, and ESA scenarios (PZ modeling results). Comparison of water requirements shows that, on average, water requirements under the ESA scenario are 0.96 km^3/year lower than those under the FSD scenario (in the basin as a whole).

Water requirements calculated under the ESA scenario in the basin as a whole are 5 m^3/year lower than water withdrawal limits set in the years of average or higher water availability but 0.44 km^3/year smaller than reduced limit for dry year (2007-2008). Water requirements calculated under the FSD scenario are higher than limit by 4 km^3/year and, in dry year, water requirements exceed the reduced limit by 1.4 km^3/year. Thus, values of desirable water withdrawal from transboundary sources derived from modeling are within the water limits established for average and dry years.

Comparison of water requirements (under ESA scenario) with average values of water withdrawal shows (Table 5.9) that in the basin as a whole estimated water withdrawal exceeds water requirements: by 1.02 km^3/year (2% of water withdrawal) in case 3 (energy mode); and, by 2.37 km^3/year (5% of water withdrawal) in case 4 (energy-irrigation mode).

In dry year, the estimated water withdrawal will be lower than desirable one (ESA): by 6.8 km^3/year (water shortage of 14%) in case 3; and, by 5.2 km^3/year (water shortage of 10%) in case 4. Thus, when shifting from energy mode of operation to energy-irrigation mode under the ESA strategy (orientation to export of irrigation agriculture output), water shortage will be within 10% during dry year in the basin as a whole.

Under the FSD scenario (food security) and energy mode of operation of the Nurek HEPS, water shortage increases to 7.8 km^3/year (15 %) during dry year, that is 2.6 km^3/year more than in combination of FSD + Case 3.

Table 5.7 Water withdrawal from transboundary sources and water shortage in the Amudarya Basin, average over 2020-2055, case 3 and 4 (results of river channel balance)

Water users	Water withdrawal, km3		Water shortage as compared to limit, km3	
	Case 3	Case 4	Case 3	Case 4
Vakhsh PZ (TJ)	6.62	6.76	0.47	0.33
Pyanj PZ (TJ)	1.55	1.60	0.14	0.09
Lower Kafirnigan PZ (TJ)	0.83	0.85	0.07	0.04
Surkhandarya PZ (UZ)	1.45	1.49	0.12	0.08
TOTAL UPPER REACHES	10.44	10.71	0.81	0.54
Mary, Akhal, Balkan PZs (TU)	10.84	11.09	0.79	0.54
Karshi PZ (UZ)	4.13	4.20	0.27	0.20
Bukhara and Navoyi PZ (UZ)	4.26	4.36	0.31	0.21
Lebap PZ (TU)	3.66	3.75	0.27	0.18
TOTAL MIDDLE REACHES	22.89	23.39	1.64	1.14
Dashoguz PZ (TU)	5.93	6.12	0.51	0.32
Khorezm PZ (TU)	4.34	4.46	0.35	0.23
Republic of Karakalpakstan PZ (UZ)	7.64	7.90	0.69	0.43
TOTAL LOWER REACHES	17.91	18.48	1.55	0.98
GRAND TOTAL	51.23	52.58	4.01	2.66
TAJIKISTAN	8.99	9.22	0.69	0.46
TURKMENISTAN	20.43	20.95	1.57	1.05
UZBEKISTAN	21.81	22.41	1.75	1.15

Table 5.8 Desirable water supply for PZs from transboundary sources under different scenarios (results of PZ modeling), average over 2020-2055, Mm^3/year

	BAU	FSD	ESA	ESA-FSD
Upper reaches	8401	9612	9041	-571
Middle reaches	22591	24426	24383	-43
Lower reaches	16074	17137	16788	-349
TOTAL	47066	51175	50212	-963
Tajikistan	7046	8269	7712	-557
Turkmenistan	18817	21725	21586	-139
Uzbekistan	21203	21181	20913	-267

Table 5.9 Desirable water supply for PZs from transboundary sources under the ESA scenario as compared to estimated water withdrawal in cases 3 and 4, average over 2020-2055, km^3/year

	ESA 2020-2055	Case 3 2020-2055	Case 4 2020-2055	Case 3 - ESA	Case 4 - ESA
Upper reaches	9.04	10.44	10.71	1.40	1.67
Middle reaches	24.38	22.89	23.39	-1.49	-0.99
Lower reaches	16.79	17.91	18.48	1.12	1.69
TOTAL	50.21	51.23	52.58	1.02	2.37

Tajikistan	7.71	8.99	9.22	1.28	1.51
Turkmenistan	21.59	20.43	20.95	-1.16	-0.64
Uzbekistan	20.93	21.81	22.41	0.88	1.48

Figures 5.1-5.2 show dynamics of water requirements and water withdrawal in the Amudarya Basin over 2020-2055 under two combinations of scenarios, with account of climate impact (REMO 0406):

- ESA + Case 3 - Export orientation + Energy mode
- ESA + Case 4 - Export orientation + Energy-irrigation mode

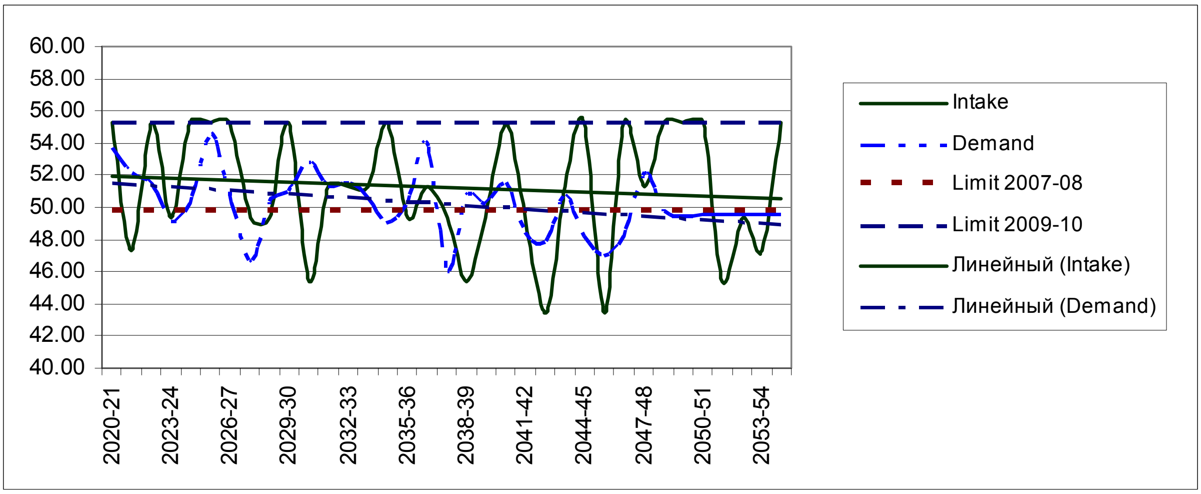

Figure 5.2 Dynamics of water requirements and water withdrawal in the Amudarya Basin over 2020-2055; combination of scenarios: ESA + Case 3

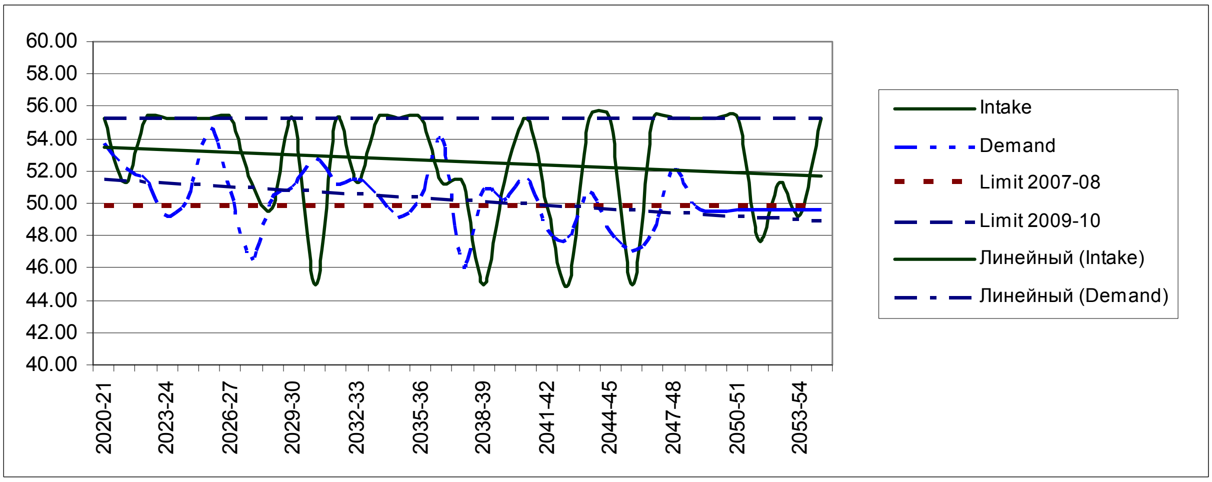

Figure 5.3 Dynamics of water requirements and water withdrawal in the Amudarya Basin over 2020-2055; combination of scenarios: ESA + Case 4

Effectiveness of flow management and regulation

The difficulties BWO Amudarya encounters when planning and implementing the plan of river flow distribution is, first of all, the absence of data on flow forecast for all tributaries of the Amudarya (including the Pyanj River) and the lack of routine mechanism for receipt and transmission of the data on flow rates at border stations, upstream and downstream of large hydraulic structures; better organization of this data transmission at all key river sections of the

Amudarya river channel (Termez, Kelif, Kerki, Turkenabad, Ilchik, Bir-Ata, Tuyamuyun, Kipchak, Samanbay and Kyzyldjar) would undoubtedly result in improvement of water management and control over water losses and water allocation.

The analysis of operation of the Nurek reservoir reveals that when natural water deficit occurs during low-water years, the energy generation mode leads to well lower water supply of irrigated lands in Turkmenistan and Uzbekistan. At the same time, operation of the Nurek HEPS is not always effective in terms of electricity losses. Sterile spills that could be avoided under reliable forecast of flow in the Naryn River, are observed. Simulated modes of operation of the Nurek HEPS for the long-run (cases 3 and 4 with account of climate impact) exclude sterile spills and energy losses through such spills.

The main task of TMHS (Tuyamuyun Hydroscheme) is to put the system of management in lower Amudarya Basin in order and thus: i) ensure guaranteed drinking water supply to population through Kaparas reservoir; ii) minimize negative consequences of extreme water conditions (drought, floods) and create favorable conditions for maintenance of uniform water delivery at transboundary level, including delivery to Prearalie.

Operation of the Nurek hydroscheme and TMHS should be aligned with regulation of flow in intra-system reservoirs that depends on dry or wet year (season) conditions. In case of occurrence of dry years, operation of intra-system reservoirs should ensure, first of all, mitigation of water shortage during growing season that is achieved mainly through maximum possible water withdrawal from the Amudarya River during non-growing season and formation of water storage in reservoirs by the beginning of growing season. In particularly wet years, intra-system reservoirs (and associated canals) should be operated in such a way so that to maximally cut flood peaks along the Amudarya River.

Water and land productivity and assessment of output losses

One of the factors that is not accounted in water distribution and irrigation management in the Amudarya Basin is the productivity of water and land resources. It is evident that water users that have more productive land suffer higher damage in case of water shortage than water users with less productive land.

Consideration of this factor in water distribution will be practiced only when damage compensation in low productivity zones becomes a national policy. Otherwise, as the result of disproportionate water allocation, social and economic losses related to human resources (employment of the population) and production will exceed potential benefits from the use of higher productive lands

According to SIC's data, in the early days of independence (since 1992 till 2000), water productivity in irrigated agriculture in the Central Asian countries decreased to 0.01…0.05 $/m3, with the following increase to 0.8…0.16 $/m3 by 2010. The same can be said about productivity of an irrigated hectare: that was estimated at 120…530 $/ha in 2000 and at 1000…1300 $/ha by 2010.

The estimation by SIC ICWC of water and land productivity in planning zones in 2015 is given in Tables 5.10-5.11. The same Tables show the data on productivity of irrigation water and irrigated land in PZs derived from the PZ model for the period of time 2020-2055 as the cost of irrigated agriculture output divided by water withdrawal and irrigated area.

Table 5.10 Productivity of irrigation water delivered to PZs in the Amudarya Basin under different scenarios (based on results of the PZ model)

PZ	Water productivity, $/m3		
	BAU	FSD	ESA

	2015	2020	2055	2020	2055	2020	2055
Bukhara	0.40	0.38	0.39	0.41	0.76	0.43	0.94
Karshi	0.22	0.15	0.17	0.18	0.42	0.20	0.57
Surkhandarya	0.32	0.22	0.24	0.24	0.62	0.26	0.80
Khorezm	0.13	0.19	0.19	0.21	0.39	0.21	0.55
South Karakalpakstan	0.09	0.12	0.14	0.14	0.30	0.15	0.40
North Karakalpakstan	0.09	0.13	0.18	0.16	0.28	0.16	0.37
Vakhsh	0.12	0.12	0.17	0.15	0.27	0.17	0.41
Pyanj	0.09	0.16	0.18	0.16	0.30	0.17	0.45
Lower Kafirnigan	0.09	0.15	0.15	0.17	0.25	0.19	0.35
Akhal	0.23	0.17	0.23	0.20	0.60	0.21	0.78
Mary	0.19	0.14	0.19	0.16	0.41	0.16	0.49
Lebap	0.18	0.14	0.19	0.16	0.45	0.16	0.53
Dashauz	0.12	0.10	0.10	0.12	0.26	0.13	0.41

Table 5.11 Productivity of irrigated land in PZs of the Amudarya Basin under different scenarios (based on results of the PZ model)

PZ	Land productivity, $/ha						
	BAU			FSD		ESA	
	2015	2020	2055	2020	2055	2020	2055
Bukhara	1851	2729	2959	3104	6306	3218	7777
Karshi	1335	1054	1205	1310	3106	1402	4208
Surkhandarya	2451	1850	1687	2088	4409	2231	5701
Khorezm	1398	1952	2165	2172	4502	2202	6238
South Karakalpakstan	1036	1366	1631	1542	3579	1608	4533
North Karakalpakstan	990	1502	2266	1825	3587	1907	4679
Vakhsh	291	2170	2731	2545	4572	2808	6308
Pyanj	1071	1279	1458	1310	2469	1404	3608
Lower Kafirnigan	1044	2214	2421	2672	4344	2940	5673
Akhal	705	955	1161	1076	2949	1131	3845
Mary	1125	1150	1362	1274	3470	1307	4191
Lebap	1114	860	1090	951	2594	977	3169
Dashauz	1110	774	776	974	2559	1003	3875

Table 5.12 Productivity of irrigation water and losses of irrigated agriculture output in Amudarya Basin under the ESA scenario and flow regulation cases 3 and 4

Water users	Water productivity (ESA), $/m^3	Output losses, M$/year	
		Case 3	Case 4
Vakhsh PZ (TJ)	0.29	136	95
Pyanj PZ (TJ)	0.31	45	27
Lower Kafirnigan PZ (TJ)	0.27	20	11
Surkhandarya PZ (UZ)	0.53	65	41
TOTAL UPPER REACHES	0.32	265	175
Mary, Akhal and Balkan PZs (TU)	0.41	325	223

Karshi PZ (UZ)	0.39	105	76
Bukhara and Navoyi PZ (UZ)	0.69	211	146
Lebap PZ (TU)	0.35	92	63
TOTAL MIDDLE REACHES	0.45	734	509
Dashoguz PZ (TU)	0.27	138	87
Khorezm PZ (TU)	0.38	133	87
Republic of Karakalpakstan PZ (UZ)	0.27	187	116
TOTAL LOWER REACHES	0.30	458	290
GRAND TOTAL	0.37	1457	974
TAJIKISTAN	0.29	201	134
TURKMENISTAN	0.36	556	374
UZBEKISTAN	0.41	700	466

Table 5.13 Productivity of irrigation water and losses of irrigated agriculture output in Amudarya Basin under the FSD scenario and flow regulation cases 3 and 4

Water users	Water productivity (FSD), \$/m^3	Output losses, M\$/year	
		Case 3	Case 4
Vakhsh PZ (TJ)	0.21	99	69
Pyanj PZ (TJ)	0.23	33	20
Lower Kafirnigan PZ (TJ)	0.21	16	9
Surkhandarya PZ (UZ)	0.43	52	34
TOTAL UPPER REACHES	0.24	200	131
Mary, Akhal and Balkan PZs (TU)	0.34	270	185
Karshi PZ (UZ)	0.30	82	59
Bukhara and Navoyi PZ (UZ)	0.59	180	124
Lebap PZ (TU)	0.31	82	56
TOTAL MIDDLE REACHES	0.37	613	425
Dashoguz PZ (TU)	0.19	97	62
Khorezm PZ (TU)	0.29	100	65
Republic of Karakalpakstan PZ (UZ)	0.22	152	94
TOTAL LOWER REACHES	0.23	349	221
GRAND TOTAL	0.29	1162	778
TAJIKISTAN	0.21	147	98
TURKMENISTAN	0.29	448	303
UZBEKISTAN	0.33	566	377

Table 5.14 Productivity of irrigation water and the cost of irrigated agriculture output in Amudarya Basin under the FSD and ESA scenarios and the flow regulation case 4 (energy-irrigation mode), with account of climate impact

Water user	Productivity (FSA), \$/m3	Productivity (ESA), \$/m3	Agricultural output, billion \$	
			FSD	ESA
Vakhsh PZ (TJ)	0.21	0.29	1.42	1.96
Pyanj PZ (TJ)	0.23	0.31	0.37	0.50
Lower Kafirnigan PZ (TJ)	0.21	0.27	0.18	0.23
Surkhandarya PZ (UZ)	0.43	0.53	0.64	0.79
TOTAL UPPER REACHES	0.24	0.32	2.61	3.48
Mary, Akhal and Balkan PZs (TU)	0.34	0.41	3.77	4.54
Karshi PZ (UZ)	0.30	0.39	1.26	1.62
Bukhara and Navoyi PZ (UZ)	0.59	0.69	2.55	2.98
Lebap PZ (TU)	0.31	0.35	1.14	1.29

TOTAL MIDDLE REACHES	0.37	0.45	8.72	10.44
Dashoguz PZ (TU)	0.19	0.27	1.16	1.65
Khorezm PZ (TU)	0.29	0.38	1.27	1.70
Republic of Karakalpakstan PZ (UZ)	0.22	0.27	1.74	2.13
TOTAL LOWER REACHES	0.23	0.30	4.17	5.48
GRAND TOTAL	0.29	0.37	15.50	19.40
TAJIKISTAN	0.21	0.29	1.97	2.69
TURKMENISTAN	0.29	0.36	6.07	7.49
UZBEKISTAN	0.33	0.41	7.46	9.22

Tables 5.12 - 5.13 show the data on irrigation water productivity and output losses in irrigated agriculture in the Amudarya Basin under scenarios ESA and FSD and flow regulation cases 3 (energy mode) and 4 (energy-irrigation mode), with account of climate impact by REMO 0406 scenario. Table 5.14 shows the data on the cost of agricultural output for case 4 (energy-irrigation mode).

As calculated, agricultural output losses (in money terms) on average over 2020-2055 are estimated (given the productivity corresponds to PZ development under the ESA scenario) at 1.46 billion $ a year under operation of the Nurek HEPS in energy mode. Those losses are caused by cumulative effect of a number of factors, the major being: lowering of Amudarya River flow because of increased water use by Afghanistan, cutting of discharge of collector-drainage water into the Amudarya River from Turkmenistan, re-regulation of natural regime of the Vakhsh River by the Nurek HEPS operating under energy mode. In the case of shift to energy-irrigation mode of operation, the losses can be reduced to 0.97 billion $ in the basin.

Cooperation and consensus searching

During low-water years, the situation is rather complicated in the Amudarya Basin; it demands certain decisions on strengthening cooperation, first of all, by means of institutional and legal measures.

The existing agreements do no cover all issues related to transboundary water sharing in the basin. Inflow to the Aral Sea is not guaranteed. It is important to pave the way for future agreement on water allocation with Afghanistan, rates of allowable channel losses, regulation of collector-drainage flow, and maintenance of lake ecosystems in the basin.

It will be important for implementation of the cooperation concept to shape public opinion in the countries and adopt democratic water governance principles through participatory water management and gradual transfer of some authority to the lower level of water hierarchy.

The riparian countries seeking consensus in water management in the Amudarya Basin should agree with the following points:

- no development in the riparian countries is possible without innovations and measures aimed at reduction of unit (per capita) water demand,
- it is necessary to ensure observance of proportional water limits set for the countries from transboundary rivers and of a share of flow for maintenance of aquatic ecosystems in the basin,
- one should acknowledge that contradictions between hydropower and irrigation demands for river flow exist and will remain in the future. These contradictions can be solved through efficient operation of large reservoirs and cascades of HEPS according to the

rules (restrictions) and in line with resource conservation based principles as agreed by the states.

The following approach is proposed to consensus searching in the Amudarya Basin: all countries tend to maximize regional revenue from the use of basin's resources (water, land, energy), without detriment to countries and sectors. The PEER Project results indicate to possibility of generating such revenue by:

- increasing energy generation when shifting from energy mode to energy-irrigation mode of operation of the Nurek HEPS,
- increasing irrigated agriculture production when shifting from energy mode to energy-irrigation mode of operation of the Nurek HEPS through reduced water shortage,
- raising the cost of irrigated agriculture output when changing from the FSD scenario (food security) to the ESA scenario (export orientation),
- introducing innovations to improve yields and reduce irrigation depths.

Below we show the methodology and example of calculation of regional (basin) revenue - cumulative for hydropower and irrigated agriculture in the Aral Sea Basin:

- regional benefit (dC) is calculated by the sum of values added in hydropower (dCH) and irrigated agriculture (dCI),
- value added of electricity (dCH_{IRR-EN}) is determined by difference between the cost of energy generation at the Vakhsh cascade under energy-irrigation mode (max generation throughout the year) and that under energy mode (max generation in October-March) of operation of the Nurek HEPS within this cascade,
- value added from the effect of flow regulation in irrigated agriculture (dCI_{IRR-EN}) in all riparian countries is derived from the amount of reduction of water shortage when shifting from energy mode to energy-irrigation mode of operation of the Nurek HEPS,
- value added from the effect of implementation of national agrarian policies in irrigated agriculture ($dCI_{ESA-FSD}$) is calculated by the difference of output (in money terms) produced under ESA and FSD scenarios; export products are sold at the Central Asian market and outside,
- probable deficits and losses of output (in money terms) occurring during generation of regional revenue should be compensated,
- seasonal energy deficit/excess is mitigated through buying and selling at Central Asian energy market,
- excess electricity can be delivered outside Central Asia.

$$dC = dCH + dCI \quad \dots (1)$$

$$dCH = dCH_{IRR-EN} = CH_{IRR} - CH_{EN} \quad \dots (2)$$

$$dCI = dCI_{IRR-EN} + dCI_{ESA-FSD} = CI_{IRR} - CI_{EN} + CI_{ESA} - CI_{FSD} \quad \dots (3)$$

Here: CH_{IRR} , CH_{EN} are the costs of energy generated at the Vakhsh cascade under energy-irrigation and energy modes of operation of the Nurek HEPS; CI_{IRR},CI_{EN} is irrigated agriculture output, in money terms, produced under regulation of flow in the Vakhsh River under energy-irrigation and energy modes of operation of the Nurek HEPS; CI_{ESA}, CI_{FSD} is irrigated agriculture output, in money terms, produced under ESA and FSD scenarios.

When replacing energy mode of operation of the Nurek HEPS by energy-irrigation mode, additional energy deficit occurs in October-March ($D_{IRR-EN(OCT-MAR)}$) that should be compensated through a part of additional regional revenue. The additional deficit is derived from the difference between deficits (if any) occurring in October-March under energy-irrigation and energy modes of operation of the Nurek HEPS. Energy deficit associated with one or another operation mode is determined by the difference between energy demand and generation at the Vakhsh cascade.

Cooperation between the countries in the region implies organization of energy and agricultural product markets. The energy market should facilitate (given the state guarantees) formation of necessary export-import flows to eliminate energy deficit in Tajikistan in winter. Assessment of export-import flows should be made in money terms.

We may propose the following calculation scheme of compensation of energy deficit in Tajikistan (Ind) through a portional; of additional regional revenue (dC):

- determine additional energy deficit in October-March - $D_{IRR-EN(OCT-MAR)}$,
- determine a portion of additional regional revenue that would compensate energy deficit - dCI_{IRR-EN} ($dCI_{ESA-FSD}$ revenue is not included in compensation as it is generated from implementation of national irrigated agriculture policies rather than from flow regulation),
- the size of compensation Ind should not exceed a portion of revenue in irrigation - $k*dCI_{IRR-EN}$ and deficit $D_{IRR-EN(OCT-MAR)}$; the "k" coefficient is the subject of negotiations, $0<k<1$.

Energy excess in April-September - $S_{IRR(APR-SEP)}$ – occurring when energy mode is replaced by energy-irrigation mode can be used: for transmission to the Sogd province in Tajikistan; within Central Asia; and, for export outside Central Asia.

Table 5.15 shows the results of calculation of regional revenue (dC) and its components, as well as the volume and value of compensation, Ind, and energy excess, $S_{IRR(APR-SEP)}$. The coefficient "k" can be taken tentatively equal to 0.5 in the calculations of compensation.

Table 5.15 Example of calculation of regional revenue (dC) and its components
in the Amudarya Basin in case of replacement of energy mode by energy-irrigation mode
and of FSD by ESA (results of hydropower model and PZ model for 2020-2055)

Indicator	Symbol	Q-ty	Cost, billion $
1.Energy generation under energy-irrigation mode	CH_{IRR}	15.5 billion kWh	0.96
2.Energy generation under energy mode	CH_{EN}	14.74 billion kWh	0.91
3.Difference 1- 2	dCH	0.76 billion kWh	0.05
4.Energy deficit in October-March	$D_{IRR(OCT-MAR)}$	2.6 billion kWh	0.16
5.Energy excess in April-September	$S_{IRR(APR-SEP)}$	6.28 billion kWh	0.39
6.Water withdrawal and agricultural output under energy-irrigation mode	CI_{IRR}	52.58 billion m3	19.4

Indicator	Symbol	Q-ty	Cost, billion $
7. Water withdrawal and agricultural output under energy mode	CI_{EN}	51.23 billion m3	18.9
8.Difference 6 - 7	dCI_{IR-EN}	1.35 billion m3	0.5
9.Agricultural output under ESA	CI_{ECA}		19.4
10. Agricultural output under FSD	CI_{FSD}		15.5
11.Difference 9- 10	$dCI_{ESA-FSD}$		3.9
12.Sum 8 +11	dCI		4.4
13.Sum 3 +12 (regional revenue in hydropower and irrigated agriculture)	dC		4.45
14.Compensation	Ind		0.16
15.Energy excess in April-September	E	6.28 billion kWh	0.39

Figure 5.3 shows the average, over 2020-2055, data on revenues in hydropower (CH) and irrigated agriculture (CI) given the alternative operation modes of the Nurek HEPS.

Table 5.16 gives unit indicators of development in the Amudarya Basin, on average over 2020-2055, under alternative operation modes of the Nurek HEPS and the irrigated agriculture development scenario of ESA.

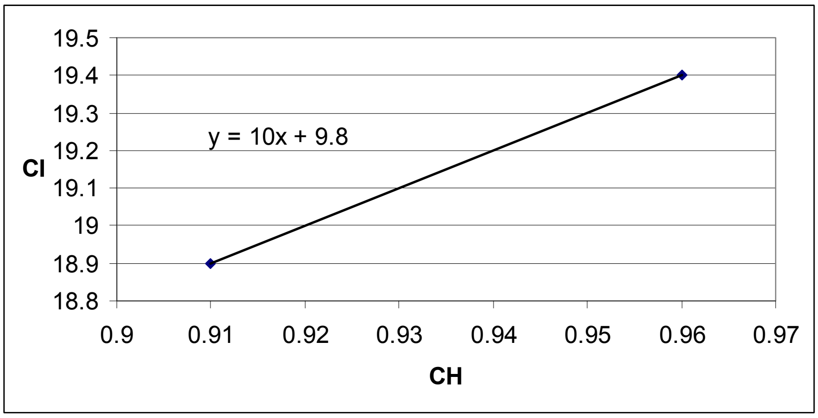

Figure 5.3 Revenues in hydropower (CH) and irrigated agriculture (CI) under alternative operation modes of the Nurek HEPS, billion $

Table 5.16 Unit indicators of development in the Amudarya Basin, average over 2020-2055

Operation mode of Nurek HEPS	Generation, billion $/year	Energy cost, thousand $ per capita	Agricultural output, ESA billion$/year	Agricultural output, ESA thousand $ per capita
1.Energy-irrigation	15.5	3.78	19.40	0.92
2.Energy	14.74	3.59	18.90	0.89
Difference 1 - 2	0.76	0.19	0.50	0.02

The unit irrigation area (ha per capita) will change from 2020 to 2055 as follows: from 0.14 to 0.09 ha/person (average 0.11 ha/person) in Tajikistan; from 0.2 to 0.14 ha/person (average 0.16 ha/person) in Turkmenistan; and, from 0.16 to 0.10 ha/person (average 0.13 ha/person) in Uzbekistan.

6. Proposals on adaptation to climate change

The adaptation measures to potential climate change must be proactive, rather than passive. Whereas passive adaptation implies measures that mitigate potential negative consequences of climate change, proactive adaptation is to create the effective warning system, which is an integral part of national development strategies of the riparian countries that seek for improvement of water management and prevention of potential conflicts related to regulation of river flow.

Given the periodical droughts in the future, effective water demand management, involving water saving and innovations should be among major means of adaptation to climate change. It is necessary to start redefining water use limits and update the hydromodule zoning in the irrigation sector.

Perhaps, we have to return to the idea of gradual reduction of the limits of water withdrawal from transboundary rivers within the quotas (%) allocated to the countries. Thus, with water made available, sustainability of aquatic ecosystems can be achieved in Prearalie.

Among opportunities for mitigation of water scarcity are the joint regulation of in-stream (Vakhsh-Amudarya cascade) and in-system (Zeid, Talimarjan, etc.) reservoirs.

The expected reduction of water resources in summer months dictates specific requirements for regulation of summer flow by reservoirs. Currently, the Nurek reservoir is operated in such a mode, under which the largest amount of flow is diverted in summer to ensure annual maximal accumulation by September. This leads to substantial sterile spills from the hydropower station in August-September and consequent electricity losses. Optimization of the operation mode of the Nurek HEPS could minimize sterile spills, on the one hand, and allow for additional water releases in summer needed (especially in dry years) for riparian countries, on the other hand.

Within the framework of development and implementation of basin strategies, as important adaptation measure for the reduction of a negative impact of climate change and future challenges, it is necessary to organize comprehensive research for revision of “Master Plans for comprehensive (integrated) use of water resources in the river basins” and development of “Rules of control of reservoir and HEPS cascades in river basins” that are to set guaranteed water releases from HEPS and flows of hydroenergy.

The effectiveness of adaptation measures will depend on:

- Governance policy – activities of governments in internal and external arenas that determine interests and priorities of development in economic sectors, including hydropower, irrigated agriculture and aquatic ecosystems,
- Cooperation between the countries,
- Investments in national water sectors.

Investment policies should be aimed at implementing projects for technological reconstruction of hydraulic structures and irrigation systems and at energy and water saving and agroindustry and small businesses support to produce “deficit” and competitive (at internal and external markets) foodstuffs, at creating optimal conditions for innovation-driven growth of agriculture, i.e. provision of technical base, reduction of costs, etc. Development of innovations should be one of priorities. The main targets of agrarian policies should be orientation to import substitution and export of agricultural products.

The riparian countries of the Amu Darya Basin should maintain interstate cooperation and, based on this, organize joint work for coordination of their actions in economic sectors. The countries should make progress in the following directions that are important for the Amudarya River basin:

- improvement of transboundary water management and prevention of conflicts between riparian countries,
- reduction of the risk of lower water availability in some zones (parts) of the basin,
- lowering of open channel losses,
- improvement of flow regulation, which combines operation of in-stream and in-system reservoirs,
- prevention of growth of adverse environmental damage, ensuring of environmental flows,
- organization of joint water monitoring.

The combination of energy-operation mode of operation of the Nurek HEPS with PZ development strategy (scenario) of ESA (orientation to export of irrigated agriculture products) should be recognized as the best combination of scenarios for the basin.

Conclusion

The implemented research allows formulating a range of tasks for the future in the Amudarya River Basin:

- Ensure legal guarantees that exclude (reduce) the risks of an adverse impact of flow regulation by large reservoirs with hydropower on available water supply of irrigated areas; develop rules of flow regulation in the Amudarya River Basin that reduce shortage and losses of energy and water in the basin,
- Shift in emphasis to active development scenario that suggests accelerated modernization of country agrarian sectors, including processing and export potential (ESA scenario); creation of specialized economic development zones where the concept of innovation-based agricultural development and water saving concept will be tested with the aim to achieve food security, productivity growth and expand export potential; first of all, low productive cotton land can be allocated for such zones,
- Introduction of advanced information technologies and application of modeling in routine water management to optimize water distribution, reduce losses in the context of growing water shortage and abrupt flow variations caused by natural factors,
- Modernization of water accounting system and development of monitoring, use of RS technology and modeling for better hydrological forecasting for short- and mid-term.

National water policies and strategic development strategies address regional (basin) advantages of water management to insufficient degree since the former proceed mainly from self-sufficiency of the countries with agricultural products and energy that is the basis of food and energy security.

The Central Asia has not yet developed common approaches to efficient water management and sustainable development in Amudarya Basin that are based on recognition of the regional value of water, partnership, mutual respect of the interests of riparian countries and search for regional benefits that could be sought in implementing an integrated approach that smooths over intersectoral contradictions and in shifting to interstate and intersectoral levels of information, mutual approval and (perhaps) management.

National strategy documents should lay down responsibilities of the countries for soonest development of comprehensive joint decisions in the fields, where the interests of national economic sectors intersect. First step in development of such decisions was made by the PEER Project in form of a comprehensive analysis of the region. As a result of this analysis, all stakeholders may have precise information (in form of figures, trends) about the current problems of interstate water use and prospective country development until 2030, 2050.

The project results show potential options for reconciliation of national priorities in water management at the basin level in the context of climate change.

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Annex 1. Operation mode of the Nurek HEPS and electricity generation by the Vakhsh cascade for 2010-2020

2010-2011	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,095	785	566	507	400	472	1,231	2,474	3,127	4,051	4,041	2,047	3,824	16,972	20,796
Rule Curve	0.99	0.94	0.85	0.75	0.64	0.57	0.60	0.67	0.80	0.95	0.99	1.00	0.79	0.84	0.81
Res.vol. 1, Mm3	10,507	10,469	9,965	9,025	7,945	6,800	6,000	6,364	7,066	8,469	10,088	10,517	9,119	8,084	8,601
Res.vol. 2, Mm3	10,469	9,965	9,025	7,945	6,800	6,000	6,364	7,066	8,469	10,088	10,517	10,537	8,367	8,840	8,604
Avg.Res.vol, Mm3	10,488	10,217	9,495	8,485	7,373	6,400	6,182	6,715	7,767	9,278	10,302	10,527	8,743	8,462	8,602
Avg.Res. H, m	910	907	899	888	875	864	862	868	880	897	908	911	891	888	889
Outflow, Mm3	1,166	1,289	1,506	1,587	1,544	1,271	868	1,772	1,724	2,432	3,612	2,027	8,363	12,435	20,799
Outflow, m3/s	435	497	562	593	638	474	335	662	665	908	1,348	782	533	783	658
dH = H-Hout-Hlos, m	265	262	253	242	229	219	217	222	233	250	260	264	245	241	243
K	8.60	8.62	8.68	8.75	8.84	8.91	8.92	8.89	8.81	8.70	8.63	8.60	9	9	9
Qhps_, m3/s	435	497	562	593	638	474	335	662	665	908	1,348	782	533	783	658
N, MWh	992	1,121	1,235	1,254	1,293	925	649	1,304	1,368	1,973	3,000	1,776	1,137	1,678	1,408
Enurek, mkwth	738	807	919	933	869	688	467	970	985	1,468	2,232	1,279	4,955	7,401	12,356
Evahsh, mkwth	235	259	284	296	314	250	197	323	324	418	588	369	1,639	2,218	3,857
E, mkwth	973	1,067	1,203	1,229	1,182	939	664	1,293	1,309	1,885	2,820	1,648	6,594	9,619	16,213
q = Out / Enur, m3/kwth	1.58	1.60	1.64	1.70	1.78	1.85	1.86	1.83	1.75	1.66	1.62	1.58	1.69	1.68	1.68

2011-2012	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	895	830	623	452	323	444	2,341	2,644	4,038	4,724	4,018	2,232	3,567	19,999	23,565
Rule Curve	0.98	0.93	0.85	0.75	0.65	0.57	0.63	0.70	0.79	0.92	0.99	1.00	0.79	0.84	0.81
Res.vol. 1, Mm3	10,537	10,324	9,877	9,029	7,950	6,838	6,064	6,703	7,366	8,358	9,765	10,509	9,092	8,128	8,610
Res.vol. 2, Mm3	10,324	9,877	9,029	7,950	6,838	6,064	6,703	7,366	8,358	9,765	10,509	10,543	8,347	8,874	8,610
Avg.Res.vol, Mm3	10,430	10,100	9,453	8,489	7,394	6,451	6,384	7,034	7,862	9,062	10,137	10,526	8,720	8,501	8,610
Avg.Res. H, m	910	906	899	888	876	865	864	872	881	894	906	911	890	888	889
Outflow, Mm3	1,108	1,278	1,470	1,532	1,434	1,217	1,703	1,981	3,046	3,317	3,274	2,198	8,039	15,520	23,559
Outflow, m3/s	414	493	549	572	593	454	657	740	1,175	1,238	1,222	848	512	980	746
dH = H-Hout-Hlos, m	264	260	253	242	230	220	218	225	233	247	259	264	245	241	243
K	8.60	8.63	8.68	8.75	8.84	8.90	8.91	8.87	8.81	8.72	8.64	8.61	9	9	9

Qhps_, m3/s	414	493	549	572	593	454	657	740	1,175	1,238	1,222	848	512	980	746
N, MWh	941	1,107	1,205	1,211	1,203	888	1,277	1,476	2,416	2,664	2,732	1,926	1,092	2,082	1,587
Enurek, mkwth	700	797	896	901	808	661	919	1,098	1,739	1,982	2,033	1,386	4,763	9,158	13,921
Evahsh, mkwth	227	258	279	288	296	243	321	353	521	545	539	395	1,590	2,674	4,264
E, mkwth	927	1,055	1,175	1,189	1,104	904	1,240	1,451	2,260	2,527	2,572	1,781	6,354	11,831	18,185
q = Out / Enur, m/kwth	1.58	1.60	1.64	1.70	1.77	1.84	1.85	1.80	1.75	1.67	1.61	1.59	1.69	1.69	1.69

2012-2013	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	881	675	525	504	408	628	1,193	2,282	3,712	3,765	3,865	2,002	3,620	16,819	20,439
Rule Curve	0.98	0.93	0.86	0.77	0.69	0.60	0.58	0.65	0.79	0.93	1.00	1.00	0.80	0.82	0.81
Res.vol. 1, Mm3	10,543	10,352	9,865	9,039	8,121	7,292	6,365	6,161	6,868	8,360	9,801	10,539	9,202	8,016	8,609
Res.vol. 2, Mm3	10,352	9,865	9,039	8,121	7,292	6,365	6,161	6,868	8,360	9,801	10,539	10,561	8,506	8,715	8,610
Avg.Res.vol, Mm3	10,447	10,109	9,452	8,580	7,707	6,829	6,263	6,514	7,614	9,081	10,170	10,550	8,854	8,365	8,610
Avg.Res. H, m	910	906	899	889	879	869	863	866	878	895	907	911	892	886	889
Outflow, Mm3	1,139	1,157	1,390	1,423	1,237	1,581	1,397	1,575	2,219	2,325	3,127	1,980	7,927	12,624	20,551
Outflow, m3/s	425	447	519	531	511	590	539	588	856	868	1,168	764	504	797	651
dH = H-Hout-Hlos, m	264	261	253	243	233	223	217	220	231	248	259	264	246	240	243
K	8.60	8.63	8.68	8.75	8.81	8.88	8.92	8.90	8.83	8.72	8.64	8.60	9	9	9
Qhps_, m3/s	425	447	519	531	511	590	539	588	856	868	1,168	764	504	797	651
N, MWh	967	1,004	1,140	1,129	1,052	1,170	1,044	1,151	1,747	1,873	2,613	1,737	1,077	1,694	1,385
Enurek, mkwth	720	723	848	840	707	870	751	856	1,258	1,394	1,944	1,251	4,707	7,454	12,161
Evahsh, mkwth	231	240	268	272	265	295	275	294	398	402	518	362	1,571	2,250	3,820
E, mkwth	951	962	1,115	1,112	971	1,166	1,027	1,150	1,655	1,796	2,462	1,613	6,278	9,703	15,981
q = Out / Enur, m/kwth	1.58	1.60	1.64	1.69	1.75	1.82	1.86	1.84	1.76	1.67	1.61	1.58	1.68	1.69	1.69

2013-2014	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,095	641	574	477	364	398	1,064	2,777	3,412	4,464	3,182	1,909	3,549	16,808	20,357
Rule Curve	0.98	0.93	0.85	0.76	0.68	0.59	0.58	0.67	0.82	0.94	1.00	1.00	0.80	0.83	0.82
Res.vol. 1, Mm3	10,561	10,351	9,783	9,005	8,070	7,175	6,240	6,121	7,100	8,683	9,917	10,554	9,157	8,103	8,630
Res.vol. 2, Mm3	10,351	9,783	9,005	8,070	7,175	6,240	6,121	7,100	8,683	9,917	10,554	10,541	8,437	8,819	8,628
Avg.Res.vol, Mm3	10,456	10,067	9,394	8,538	7,623	6,708	6,181	6,611	7,892	9,300	10,235	10,548	8,797	8,461	8,629
Avg.Res. H, m	910	906	898	888	878	868	862	867	881	897	907	911	891	888	889

Outflow, Mm3	1,305	1,209	1,352	1,412	1,260	1,333	1,184	1,791	1,837	3,220	2,505	1,921	7,870	12,459	20,328
Outflow, m3/s	487	467	505	527	521	498	457	669	709	1,202	935	741	501	785	643
dH = H-Hout-Hlos, m	264	260	252	243	232	222	217	221	235	249	260	264	246	241	243
K	8.60	8.63	8.68	8.75	8.82	8.89	8.92	8.90	8.80	8.70	8.63	8.60	9	9	9
N, MWh	1,108	1,047	1,106	1,119	1,067	983	883	1,312	1,464	2,609	2,101	1,686	1,071	1,676	1,374
Enurek, mkwth	824	754	823	832	717	731	636	976	1,054	1,941	1,563	1,214	4,681	7,384	12,065
Evahsh, mkwth	255	247	262	271	268	259	244	325	341	531	428	353	1,563	2,223	37,86
E, mkwth	1,079	1,001	1,085	1,103	985	990	879	1,301	1,395	2,472	1,992	1,567	6,244	9,607	15,851
q = Out / Enur, m/kwth	1.58	1.60	1.64	1.70	1.76	1.82	1.86	1.83	1.74	1.66	1.60	1.58	1.68	1.69	1.68

2014-2015	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	905	662	556	522	496	679	1,458	2,783	3,692	5,839	4,049	1,522	3,820	19,343	23,163
Rule Curve	0.99	0.94	0.87	0.80	0.72	0.64	0.63	0.73	0.83	0.96	0.99	0.99	0.83	0.86	0.84
Res.vol. 2, Mm3	10,419	9,929	9,205	8,411	7,633	6,779	6,700	7,761	8,810	10,145	10,500	10,500	8,729	9,069	8,899
Avg.Res.vol, Mm3	10,480	10,174	9,567	8,808	8,022	7,206	6,740	7,231	8,286	9,478	10,323	10,500	9,043	8,759	8,901
Avg.Res. H, m	910	907	900	891	883	874	868	874	886	899	908	910	894	891	892
Outflow, Mm3	1,029	1,170	1,259	1,317	1,275	1,535	1,562	1,722	2,651	4,508	3,668	1,528	7,585	15,640	23,225
Outflow, m3/s	384	451	470	492	527	573	603	643	1,023	1,683	1,370	590	483	985	734
dH = H-Hout-Hlos, m	265	261	254	246	237	228	222	228	238	251	261	264	248	244	246
K	8.60	8.62	8.67	8.73	8.79	8.85	8.89	8.85	8.78	8.69	8.63	8.60	9	9	9
Qhps, m3/s	384	451	470	492	527	573	603	643	1,023	1,350	1,350	590	483	926	705
Qlos, m3/s	0	0	0	0	0	0	0	0	0	333	20	0	0	59	29
N, MWh	875	1,017	1,037	1,055	1,097	1,154	1,190	1,294	2,140	2,944	3,000	1,341	1,039	1,985	1,512
Enurek, mkwth	651	732	771	785	737	859	857	963	1,541	2,191	2,232	965	4,536	8,748	13,284
Evahsh, mkwth	216	242	249	257	271	289	300	315	462	717	596	295	1,522	2,685	4,207
E, mkwth	867	974	1,020	1,042	1,008	1,147	1,157	1,278	2,003	2,908	2,828	1,260	6,058	11,433	17,491
q = Out / Enur, m/kwth	1.58	1.60	1.63	1.68	1.73	1.79	1.82	1.79	1.72	2.06	1.64	1.58	1.67	1.79	1.75

2015-2016	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	955	754	578	551	431	591	1,079	3,087	3,727	4,162	3,198	1,977	3,860	17,230	21,090
Rule Curve	0.99	0.94	0.85	0.75	0.64	0.57	0.60	0.67	0.80	0.95	0.99	1.00	0.79	0.84	0.81
Rule Curve	0.99	0.94	0.85	0.75	0.64	0.57	0.60	0.67	0.80	0.95	0.99	1.00	0.79	0.84	0.81

Res.vol. 2, Mm3	10,469	9,965	9,025	7,945	6,800	6,000	6,364	7,066	8,469	10,088	10,517	10,537	8,367	8,840	8,604
Avg.Res.vol, Mm3	10,488	10,217	9,495	8,485	7,373	6,400	6,182	6,715	7,767	9,278	10,302	10,527	8,743	8,462	8,602
Avg.Res. H, m	910	907	899	888	875	864	862	868	880	897	908	911	891	888	889
Outflow, Mm3	1,030	1,142	1,289	1,387	1,387	1,399	1,455	1,615	2,335	3,094	3,026	1,887	7,634	13,412	21,047
Outflow, m3/s	385	441	481	518	573	522	562	603	901	1,155	1,130	728	487	846	667
dH = H-Hout-Hlos, m	265	262	254	242	229	219	216	222	233	249	261	264	245	241	243
K	8.60	8.62	8.68	8.75	8.84	8.91	8.93	8.89	8.81	8.70	8.63	8.60	9	9	9
Qhps_, m3/s	385	441	481	518	573	522	562	603	901	1,155	1,130	728	487	846	667
N, MWh	877	994	1,059	1,097	1,163	1,018	1,083	1,190	1,848	2,506	3,000	1,654	1,034	1,880	1,457
Enurek, mkwth	652	716	788	816	781	757	780	885	1,331	1,864	2,232	1,191	4,510	8,283	12,794
Evahsh, mkwth	216	237	253	267	289	269	284	300	415	513	503	348	1,531	2,364	3,894
E, mkwth	868	953	1,041	1,083	1,070	1,026	1,064	1,185	1,746	2,378	2,735	1,539	6,041	10,647	16,688
q = Out / Enur, m/kwth	1.58	1.60	1.64	1.70	1.78	1.85	1.87	1.83	1.75	1.66	1.36	1.58	1.69	1.62	1.65

2016-2017	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	942	634	606	523	476	608	1,946	3,796	3,995	5,268	4,285	2,160	3,790	21,451	25,241
Rule Curve	0.98	0.93	0.85	0.75	0.65	0.57	0.63	0.70	0.79	0.92	0.99	1.00	0.79	0.84	0.81
Res.vol. 1, Mm3	10,537	10,324	9,877	9,029	7,950	6,838	6,064	6,703	7,366	8,358	9,765	10,509	9,092	8,128	8,610
Res.vol. 2, Mm3	10,324	9,877	9,029	7,950	6,838	6,064	6,703	7,366	8,358	9,765	10,509	10,543	8,347	8,874	8,610
Avg.Res.vol, Mm3	10,430	10,100	9,453	8,489	7,394	6,451	6,384	7,034	7,862	9,062	10,137	10,526	8,720	8,501	8,610
Avg.Res. H, m	910	906	899	888	876	865	864	872	881	894	906	911	890	888	889
Outflow, Mm3	1,059	1,019	1,145	1,370	1,427	1,642	1,801	3,098	2,980	3,928	3,482	2,117	7,662	17,406	25,068
Outflow, m3/s	395	393	428	512	590	613	695	1,157	1,150	1,467	1,300	817	488	1,097	793
dH = H-Hout-Hlos, m	264	261	253	242	230	219	218	224	233	246	259	264	245	241	243
K	8.60	8.63	8.68	8.75	8.84	8.91	8.91	8.87	8.81	8.72	8.64	8.61	9	9	9
Qhps, m3/s	395	393	428	512	590	613	695	1,157	1,150	1,350	1,300	817	488	1,078	783
Qlos, m3/s	0	0	0	0	0	0	0	0	0	117	0	0	0	19	10
N, MWh	899	884	940	1,084	1,197	1,195	1,350	2,300	2,364	2,901	2,905	1,855	1,033	2,279	1,656
Enurek, mkwth	669	636	699	807	804	889	972	1,711	1,702	2,159	2,161	1,335	4,505	10,040	14,544
Evahsh, mkwth	220	219	232	265	295	304	335	514	511	633	569	382	1,535	2,945	4,480
E, mkwth	889	855	931	1,072	1,099	1,193	1,307	2,225	2,213	2,792	2,730	1,718	6,039	12,985	19,024
q = Out / Enur, m/kwth	1.58	1.60	1.64	1.70	1.77	1.85	1.85	1.81	1.75	1.82	1.61	1.59	1.70	1.73	1.72

2017-2018	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	905	669	565	479	399	552	879	1,958	2,579	3,964	3,375	2,309	3,569	15,064	18633
Rule Curve	0.99	0.95	0.86	0.73	0.65	0.57	0.57	0.62	0.73	0.82	0.95	0.99	0.79	0.78	0.79
Res.vol. 1, Mm3	10,543	10,469	10,042	9,090	7,716	6,871	6,000	6,025	6,553	7,716	8,667	10,042	9,122	7,501	8,311
Res.vol. 2, Mm3	10,469	10,042	9,090	7,716	6,871	6,000	6,025	6,553	7,716	8,667	10,042	10,469	8,365	8,245	8,305
Avg.Res.vol, Mm3	10,506	10,255	9,566	8,403	7,293	6,435	6,012	6,289	7,135	8,192	9,354	10,255	8,743	7,873	8,308
Avg.Res. H, m	910	908	900	887	874	865	860	863	873	885	898	908	891	881	886
Outflow, Mm3	979	1,096	1,516	1,854	1,245	1,422	854	1,429	1,416	3,013	2,001	1,882	8,112	10,595	18,707
Outflow, m3/s	366	423	566	692	515	531	329	534	546	1,125	747	726	515	668	592
dH = H-Hout-Hlos, m	265	262	254	241	229	219	215	217	227	237	251	261	245	235	240
K	8.60	8.62	8.67	8.76	8.84	8.91	8.93	8.92	8.85	8.79	8.69	8.62	9	9	9
Qhps_, m3/s	366	423	566	692	515	531	329	534	546	1,125	747	726	515	668	592
N, MWh	834	956	1,247	1,458	1,041	1,036	633	1,035	1,098	2,343	1,630	1,635	1,095	1,396	1,245
Tmax, h	744	720	744	744	672	744	720	744	720	744	744	720	4,368	4,392	8,760
Enurek, mkwth	621	688	928	1,085	699	771	456	770	790	1,743	1,212	1,177	4,792	6,149	10,941
Evahsh, mkwth	208	230	286	334	266	272	194	273	278	501	356	348	1,597	1,950	3,547
E, mkwth	829	919	1,214	1,419	965	1,043	650	1,043	1,068	2,244	1,568	1,525	6,389	8,099	14,488
q = Out / Enur, m/kwth	1.58	1.59	1.63	1.71	1.78	1.85	1.87	1.86	1.79	1.73	1.65	1.60	1.69	1.72	1.71

2018-2019	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	884	594	504	455	411	562	1,003	1,543	2,468	3,589	3,134	1,638	3,410	13,374	16,784
Rule Curve	0.99	0.94	0.83	0.77	0.65	0.57	0.57	0.62	0.75	0.85	0.95	1.00	0.79	0.79	0.79
Res.vol. 1, Mm3	10,469	10,469	9,936	8,773	8,139	6,871	6,000	6,025	6,553	7,928	8,985	10,042	9,109	7,589	8,349
Res.vol. 2, Mm3	10,469	9,936	8,773	8,139	6,871	6,000	6,025	6,553	7,928	8,985	10,042	10,537	8,365	8,345	8,355
Avg.Res.vol, Mm3	10,469	10,202	9,354	8,456	7,505	6,435	6,012	6,289	7,240	8,456	9,513	10,289	8,737	7,967	8,352
Avg.Res. H, m	910	907	898	888	877	865	860	863	874	888	899	908	891	882	886
Outflow, Mm3	884	1,127	1,666	1,090	1,680	1,433	978	1,014	1,093	2,532	2,077	1,143	7,879	8,837	16,716
Outflow, m3/s	330	435	622	407	694	535	377	379	422	945	775	441	504	557	530
dH = H-Hout-Hlos, m	265	262	251	242	230	219	215	218	229	240	253	263	245	236	241
K	8.60	8.62	8.69	8.75	8.83	8.91	8.93	8.91	8.84	8.76	8.68	8.61	9	9	9
Qhps_, m3/s	330	435	622	407	694	535	377	379	422	945	775	441	504	557	530

N, MWh	752	980	1,359	862	1,413	1,044	725	736	853	1,991	1,701	997	1,068	1,167	1,118
Enurek, mkwth	560	706	1,011	642	949	777	522	548	614	1,482	1,265	718	4,644	5,149	9,793
Evahsh, mkwth	195	235	307	224	335	274	213	213	230	432	367	237	1,570	1,693	3,263
E, mkwth	754	941	1,319	866	1,285	1,050	735	761	844	1,914	1,632	955	6,215	6,841	13,056
q = Out / Enur, m/kwth	1.58	1.60	1.65	1.70	1.77	1.85	1.87	1.85	1.78	1.71	1.64	1.59	1.70	1.72	1.71

2019-2020	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	763	578	498	437	409	579	1,161	1,829	3,344	3,857	3,321	1,729	3,263	15,241	18,505
Rule Curve	0.99	0.96	0.87	0.73	0.65	0.58	0.57	0.61	0.72	0.82	0.94	0.99	0.80	0.78	0.79
Res.vol. 1, Mm3	10,537	10,485	10,094	9,175	7,716	6,871	6,131	6,025	6,448	7,610	8,667	9,936	9,146	7,469	8,308
Res.vol. 2, Mm3	10,485	10,094	9,175	7,716	6,871	6,131	6,025	6,448	7,610	8,667	9,936	10,469	8,412	8,193	8,302
Avg.Res.vol, Mm3	10,511	10,290	9,635	8,445	7,293	6,501	6,078	6,236	7,029	8,139	9,302	10,202	8,779	7,831	8,305
Avg.Res. H, m	911	908	901	887	874	866	861	863	872	884	897	907	891	881	886
Outflow, Mm3	815	969	1,418	1,895	1,254	1,318	1,267	1,407	2,181	2,800	2,053	1196	7,670	10,903	18,573
Outflow, m3/s	304	374	529	708	519	492	489	525	841	1,045	766	461	488	688	588
dH = H-Hout-Hlos, m	266	263	255	241	229	220	215	217	225	237	250	262	246	234	240
K	8.59	8.61	8.67	8.76	8.84	8.90	8.93	8.92	8.87	8.79	8.70	8.62	9	9	9
Qhps_, m3/s	304	374	529	708	519	492	489	525	841	1,045	766	461	488	688	588
N, MWh	695	847	1,169	1,493	1,049	964	940	1,016	1,677	2,174	1,669	1,040	1,036	1,419	1,228
Enurek, mkwth	517	610	870	1,111	705	717	677	756	1,207	1,617	1,241	749	4,529	6,248	10,777
Evahsh, mkwth	185	212	272	340	267	257	256	270	392	471	363	245	1,533	1,997	3,530
E, mkwth	702	821	1,142	1,451	972	974	933	1,026	1,599	2,088	1,605	994	6,062	8,245	14,307
q = Out / Enur, m/kwth	1.58	1.59	1.63	1.71	1.78	1.84	1.87	1.86	1.81	1.73	1.65	1.60	1.69	1.75	1.72

Annex 2.Alternative operation modes of the Nurek HEPS and calculation of electricity generation by the Vakhsh hydropower cascade for 2020-2055 (Case 1 and Case 2): 2025, 2030, 2035, 2040, 2045, 2050, and 2055

Case 1. Energy mode (maximum energy generation in autumn and winter): inflow to the Nurek HS based on the scenario of continued cycling, excluding climate change impact

2024-2025	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	838	617	554	474	402	640	1,148	1,832	3,209	4,818	4,122	1,630	3,525	16,760	20,285
Rule Curve	0.97	0.92	0.85	0.78	0.67	0.57	0.57	0.57	0.63	0.84	0.99	0.99			
Res.vol. 1, Mm3	10,497	10,235	9,702	8,937	8,256	7,057	6,000	6,037	6,000	6,700	8,918	10,440	9,114	7,349	8,232
Res.vol. 2, Mm3	10,235	9,702	8,937	8,256	7,057	6,000	6,037	6,000	6,700	8,918	10,440	10,501	8,365	8,099	8,232
Avg.Res.vol, Mm3	10,366	9,969	9,320	8,596	7,657	6,528	6,018	6,018	6,350	7,809	9,679	10,470	8,739	7,724	8,232
Avg.Res. H, m	909	904	897	889	879	866	860	860	864	880	901	910	891	879	885
Outflow, Mm3	1,100	1,150	1,320	1,155	1,600	1,698	1,111	1,869	2,509	2,600	2,600	1,570	8,023	12,259	20,282
Outflow, m3/s	411	444	493	431	661	634	429	698	968	971	971	606	512	774	643
dH = H-Hout-Hlos, m	264	259	252	244	232	220	215	214	217	233	254	264	245	233	239
K	8.61	8.64	8.69	8.74	8.82	8.90	8.94	8.94	8.92	8.81	8.67	8.61	9	9	9
Qhps_, m3/s	411	444	493	431	661	634	429	698	968	971	971	606	512	774	643
N, MWh	932	993	1,077	919	1,355	1,240	823	1,334	1,872	1,994	2,138	1,376	1,086	1,589	1,338
Enurek, mkwth	693	715	801	683	910	923	592	992	1,348	1,483	1,591	991	4,726	6,998	11,723
Evahsh, mkwth	226	239	257	234	323	312	233	337	441	442	442	301	1,590	2,195	3,785
E, mkwth	919	953	1,059	917	1,233	1,235	825	1,329	1,789	1,925	2,033	1,292	6,316	9,193	15,509
q = Out / Enur, m/kwth	1.59	1.61	1.65	1.69	1.76	1.84	1.88	1.88	1.86	1.75	1.63	1.58	1.70	1.75	1.73

2029-2030	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	876	555	493	463	409	581	1,312	2,590	4,386	5,638	4,087	2,522	3,377	20,535	23,911
Rule Curve	0.88	0.86	0.81	0.74	0.68	0.62	0.57	0.59	0.62	0.70	0.92	0.93			
Res.vol. 1, Mm3	9,352	9,128	8,573	7,801	7,142	6,561	6,000	6,190	6,559	7,444	9,690	9,877	8,093	7,627	7,860
Res.vol. 2, Mm3	9,128	8,573	7,801	7,142	6,561	6,000	6,190	6,559	7,444	9,690	9,877	10,499	7,534	8,377	7,955

Avg.Res.vol, Mm3	9,240	8,850	8,187	7,471	6,851	6,280	6,095	6,374	7,001	8,567	9,784	10,188	7,813	8,002	7,907
Avg.Res. H, m	896	892	884	876	870	863	861	864	871	889	902	907	880	882	881
Outflow, Mm3	1,100	1,110	1,265	1,122	990	1,142	1,122	2,221	3,500	3,392	3,900	1,900	6,729	16,035	22,764
Outflow, m3/s	411	428	472	419	409	426	433	829	1,350	1,266	1,456	733	428	1,011	719
dH = H-Hout-Hlos, m	251	247	239	231	224	218	216	217	223	241	254	260	235	235	235
K	8.69	8.72	8.77	8.83	8.87	8.92	8.93	8.92	8.88	8.76	8.67	8.63	9	9	9
Qhps_, m3/s	411	428	472	419	409	426	433	829	1,350	1,266	1,456	733	428	1,011	719
N, MWh	896	921	990	855	814	828	834	1,607	2,678	2,674	3,212	1,647	884	2,109	1,496
Enurek, mkwth	667	663	737	636	547	616	600	1,196	1,928	1,989	2,390	1,186	3,865	9,290	13,155
Evahsh, mkwth	226	233	250	229	225	232	234	387	588	556	629	350	1,394	2,746	4,140
E, mkwth	892	896	986	865	772	848	835	1,583	2,517	2,545	3,019	1,536	5,259	12,035	17,294
q = Out / Enur, m/kwth	1.65	1.67	1.72	1.76	1.81	1.85	1.87	1.86	1.82	1.71	1.63	1.60	1.74	1.73	1.73

2034-2035	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	964	716	627	466	374	506	918	2,150	3,466	5,667	4,281	1,975	3,653	18,458	22,111
Rule Curve	0.98	0.94	0.87	0.81	0.70	0.59	0.57	0.57	0.61	0.86	0.99	0.99			
Res.vol. 1, Mm3	10,499	10,333	9,909	9,238	8571	7,419	6,224	5,999	6,033	6,499	9,046	10,467	9,328	7,378	8,353
Res.vol. 2, Mm3	10,333	9,909	9,238	8,571	7,419	6,224	5,999	6,033	6,499	9,046	10,467	10,500	8,615	8,090	8,353
Avg.Res.vol, Mm3	10,416	10,121	9,573	8,904	7,995	6,821	6,112	6,016	6,266	7,772	9,757	10,483	8,972	7,734	8,353
Avg.Res. H, m	909	906	900	893	882	869	861	860	863	880	902	910	893	879	886
Outflow, Mm3	1,130	1,140	1,298	1,133	1,526	1,700	1,144	2,116	3,000	3,120	2,860	1,943	7,927	14,183	22,110
Outflow, m3/s	422	440	485	423	631	635	441	790	1,157	1,165	1,068	750	506	895	700
dH = H-Hout-Hlos, m	264	261	254	247	236	223	216	213	215	232	255	264	248	233	240
K	8.60	8.63	8.67	8.72	8.79	8.88	8.93	8.94	8.93	8.82	8.67	8.61	9	9	9
Qhps_, m3/s	422	440	485	423	631	635	441	790	1,157	1,165	1,068	750	506	895	700
N, MWh	959	989	1,069	912	1,310	1,257	851	1,508	2,227	2,386	2,357	1,701	1,083	1,838	1,460
Enurek, mkwth	713	712	795	678	880	935	612	1,122	1,603	1,775	1,754	1,225	4,714	8,092	12,806
Evahsh, mkwth	230	237	254	231	311	312	238	372	514	517	479	357	1,575	2,477	4,052
E, mkwth	943	949	1,050	909	1,191	1,247	850	1,494	2,117	2,292	2,233	1,581	6,289	10,568	16,858
q = Out / Enur, m/kwth	1.58	1.60	1.63	1.67	1.73	1.82	1.87	1.89	1.87	1.76	1.63	1.59	1.68	1.75	1.73

2039-2040	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	806	627	496	445	373	434	912	2,017	2,501	3,696	4,285	1,656	3,180	15,068	18,248
Rule Curve	0.95	0.89	0.81	0.75	0.67	0.57	0.57	0.63	0.73	0.82	0.98	0.99			
Res.vol. 1, Mm3	10,339	9,995	9,423	8,609	7,899	7,119	6,023	6,001	6,657	7,719	8,680	10,365	8,897	7,574	8,236
Res.vol. 2, Mm3	9,995	9,423	8,609	7,899	7,119	6,023	6,001	6,657	7,719	8,680	10,365	10,502	8,178	8,321	8,249
Avg.Res.vol, Mm3	10,167	9,709	9,016	8,254	7,509	6,571	6,012	6,329	7,188	8,199	9,523	10,434	8,538	7,947	8,243
Avg.Res. H, m	907	902	894	885	877	866	860	864	873	885	899	910	888	882	885
Outflow, Mm3	1,150	1,200	1,309	1,155	1,152	1,530	935	1,360	1,440	2,735	2,600	1,520	7,496	10,590	18,086
Outflow, m3/s	429	463	489	431	476	571	361	508	556	1,021	971	586	477	667	572
dH = H-Hout-Hlos, m	261	256	248	240	231	220	215	218	227	237	252	264	243	236	239
K	8.62	8.66	8.71	8.77	8.82	8.90	8.93	8.91	8.85	8.78	8.68	8.61	9	9	9
Qhps_, m3/s	429	463	489	431	476	571	361	508	556	1,021	971	586	477	667	572
N, MWh	967	1,026	1,056	907	972	1,120	693	987	1,118	2,129	2,127	1,331	1,008	1,397	1,203
Enurek, mkwth	720	739	786	675	653	834	499	734	805	1,584	1,582	958	4,406	6,162	10,569
Evahsh, mkwth	233	246	256	234	251	288	206	263	282	461	442	294	1,507	1,948	3,456
E, mkwth	953	985	1,042	908	904	1,121	706	997	1,087	2,045	2,024	1,252	5,914	8,111	14,024
q = Out / Enur, m/kwth	1.60	1.62	1.67	1.71	1.76	1.84	1.87	1.85	1.79	1.73	1.64	1.59	1.70	1.72	1.71

2044-2045	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,119	798	638	578	494	584	1,666	2,705	4,044	4,829	3,776	1,850	4,211	18,869	23,080
Rule Curve	0.99	0.95	0.89	0.76	0.65	0.57	0.57	0.63	0.70	0.89	0.98	0.99	0.80	0.79	0.80
Res.vol. 1, Mm3	10,500	10,468	10,077	9,359	8,067	6,861	6,000	6,000	6,634	7,428	9,397	10,313	9,222	7,629	8,425
Res.vol. 2, Mm3	10,468	10,077	9,359	8,067	6,861	6,000	6,000	6,634	7,428	9,397	10,313	10,500	8,472	8,379	8,425
Avg.Res.vol, Mm3	10,484	10,272	9,718	8,713	7,464	6,430	6,000	6,317	7,031	8,413	9,855	10,407	8,847	8,004	8,425
Avg.Res. H, m	910	908	902	890	876	865	860	864	872	887	903	909	892	882	887
Outflow, Mm3	1,150	1,190	1,356	1,870	1,700	1,445	1,666	2,070	3,250	2,860	2,860	1,663	8,711	14,369	23,080
Outflow, m3/s	429	459	506	698	703	540	643	773	1,254	1,068	1,068	642	556	908	732
dH = H-Hout-Hlos, m	265	262	256	244	230	219	214	217	224	240	256	263	246	236	241
K	8.60	8.62	8.66	8.74	8.83	8.91	8.94	8.92	8.87	8.77	8.66	8.61	9	9	9
Qhps_, m3/s	429	459	506	698	703	540	643	773	1,254	1,068	1,068	642	556	908	732
N, MWh	978	1,038	1,122	1,489	1,427	1,052	1,229	1,495	2,491	2,244	2,365	1,454	1,184	1,880	1,532
Enurek, mkwth	728	747	835	1,107	959	783	885	1,113	1,794	1,669	1,760	1,047	5,159	8,267	13,426

Evahsh, mkwth	233	244	263	337	338	275	315	366	551	479	479	315	1,691	2,506	4,197
E, mkwth	961	992	1,097	1,444	1,298	1,058	1,200	1,478	2,345	2,149	2,239	1,362	6,850	10,772	17,622
q = Out / Enur, m/kwth	1.58	1.59	1.62	1.69	1.77	1.85	1.88	1.86	1.81	1.71	1.63	1.59	1.69	1.74	1.72

2049-2050	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,003	712	687	555	463	660	833	2,873	4,343	4,933	3,324	2,216	4,080	18,522	22,602
Rule Curve	0.98	0.95	0.84	0.76	0.66	0.59	0.57	0.60	0.75	0.95	0.99	0.99	0.80	0.81	0.80
Res.vol. 1, Mm3	10,499	10,402	10,014	8,838	8,033	6,966	6,266	5,999	6,342	7,962	10,035	10,499	9,125	7,850	8,488
Res.vol. 2, Mm3	10,402	10,014	8,838	8,033	6,966	6,266	5,999	6,342	7,962	10,035	10,499	10,500	8,420	8,556	8,488
Avg.Res.vol, Mm3	10,450	10,208	9,426	8,435	7,500	6,616	6,132	6,170	7,152	8,998	10,267	10,500	8,773	8,203	8,488
Avg.Res. H, m	910	907	898	887	877	867	861	862	873	894	908	910	891	885	888
Outflow, Mm3	1,100	1,100	1,863	1,360	1,530	1,360	1,100	2,530	2,723	2,860	2,860	2,214	8,313	14,287	22,600
Outflow, m3/s	411	424	696	508	632	508	424	945	1,051	1,068	1,068	854	530	902	716
dH = H-Hout-Hlos, m	265	262	252	242	231	221	216	215	226	246	260	263	245	238	242
K	8.60	8.62	8.69	8.76	8.83	8.89	8.93	8.94	8.86	8.72	8.63	8.61	9	9	9
Qhps_, m3/s	411	424	696	508	632	508	424	945	1,051	1,068	1,068	854	530	902	716
N, MWh	935	958	1,522	1,074	1,288	999	819	1,813	2,100	2,294	2,399	1,937	1,129	1,894	1,511
Enurek, mkwth	695	690	1,132	799	865	743	590	1,349	1,512	1,706	1,785	1,395	4,925	8,337	13,262
Evahsh, mkwth	226	231	336	263	311	263	231	432	473	479	479	397	1,630	2,491	4,122
E, mkwth	921	921	1,468	1,062	1,177	1,006	821	1,781	1,985	2,186	2,265	1,792	6,555	10,828	17,384
q = Out / Enur, m/kwth	1.58	1.60	1.65	1.70	1.77	1.83	1.87	1.88	1.80	1.68	1.60	1.59	1.69	1.71	1.70

2054-2055	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	922	544	505	320	394	494	2,594	3,560	4,087	6,095	4,114	2,292	3,179	22,742	25,921
Rule Curve	0.97	0.91	0.84	0.76	0.68	0.57	0.60	0.65	0.71	0.94	0.98	0.99	0.79	0.81	0.80
Res.vol. 1, Mm3	10,500	10,272	9,636	8,832	8,052	7,206	6,000	6,313	6,883	7,470	9,925	10,400	9,083	7,832	8,457
Res.vol. 2, Mm3	10,272	9,636	8,832	8,052	7,206	6,000	6,313	6,883	7,470	9,925	10,400	10,500	8,333	8,582	8,457
Avg.Res.vol, Mm3	10,386	9,954	9,234	8,442	7,629	6,603	6,156	6,598	7,176	8,697	10,162	10,450	8,708	8,207	8,457
Avg.Res. H, m	909	904	896	887	878	867	862	867	873	890	907	910	890	885	888
Outflow, Mm3	1,150	1,180	1,309	1,100	1,240	1,700	2,280	2,990	3,500	3,640	3,640	2,191	7,679	18,241	25,920
Outflow, m3/s	429	455	489	411	513	635	880	1,116	1,350	1,359	1,359	845	489	1,152	820

dH = H-Hout-Hlos, m	264	259	251	242	233	221	215	219	225	242	259	263	245	237	241
K	8.61	8.64	8.70	8.75	8.82	8.90	8.94	8.91	8.86	8.75	8.64	8.61	9	9	9
Qhps, m3/s	429	455	489	411	513	635	880	1,116	1,350	1,359	1359	845	489	1,152	820
N, MWh	975	1,018	1,065	870	1,051	1,245	1,688	2,179	2,698	2,882	3,039	1,914	1,037	2,400	1,719
Enurek, mkwth	725	733	792	647	706	927	1,216	1,622	1,942	2,145	2,261	1,378	4,530	10,563	15,093
Evahsh, mkwth	233	243	256	226	265	312	407	498	588	592	592	394	1,535	3,071	4,606
E, mkwth	958	976	1,048	873	971	1,239	1,622	2,120	2,531	2,736	2,853	1,772	6,065	13,634	19,699
q = Out / Enur, m/kwth	1.59	1.61	1.65	1.70	1.76	1.83	1.88	1.84	1.80	1.70	1.61	1.59	1.70	1.73	1.72

Case 2. Energy-irrigation mode (maximum electricity generation per year): inflow to the Nurek HS based on the scenario of continued cycling, excluding climate change impact

2024-2025	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	838	617	554	474	402	640	1,148	1,832	3,209	4,818	4,122	1,630	3,525	16,760	20,285
Rule Curve	0.99	0.99	0.99	0.98	0.96	0.95	0.94	0.88	0.87	0.93	0.99	0.99			
Res.vol. 1, Mm3	10,498	10,498	10,498	10,499	10,373	10,174	10,015	9,963	9,350	9,159	9,877	10,499	10,424	9,810	10,117
Res.vol. 2, Mm3	10,498	10,498	10,499	10,373	10,174	10,015	9,963	9,350	9,159	9,877	10,499	10,500	10,343	9,891	10,117
Avg.Res.vol, Mm3	10,498	10,498	10,499	10,436	10,274	10,094	9,989	9,656	9,254	9,518	10,188	10,499	10,383	9,851	10,117
Avg.Res. H, m	910	910	910	910	908	906	905	901	896	899	907	910	909	903	906
Outflow, Mm3	838	617	554	600	600	800	1,200	2,445	3,400	4,100	3,500	1,630	4,009	16,275	20,284
Outflow, m3/s	313	238	207	224	248	299	463	913	1,312	1,531	1,307	629	255	1,026	640
dH = H-Hout-Hlos, m	266	266	266	265	263	261	259	254	249	251	259	264	265	256	260
K	8.59	8.59	8.59	8.60	8.61	8.62	8.64	8.67	8.71	8.69	8.64	8.60	9	9	9
Qhps_, m3/s	313	238	207	224	248	299	463	913	1,312	1,531	1,307	629	255	1,026	640
N, MWh	714	544	473	511	562	673	1,036	2,010	2,841	3,344	2,925	1,429	580	2,264	1,422
Enurek, mkwth	531	392	352	380	378	500	746	1,496	2,045	2,488	2,176	1,029	2,534	9,981	12,514
Evahsh, mkwth	188	159	147	154	163	183	246	420	574	658	572	310	993	2,779	3,772
E, mkwth	719	551	499	534	541	683	992	1,915	2,619	3,146	2,748	1,339	3,527	12,760	16,287
q = Out / Enur, m/kwth	1.58	1.58	1.57	1.58	1.59	1.60	1.61	1.63	1.66	1.65	1.61	1.58	1.58	1.63	1.62

2029-2030	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	876	555	493	463	409	581	1,312	2,590	4,386	5,638	4,087	2,522	3,377	20,535	23,911
Rule Curve	0.88	0.86	0.81	0.74	0.68	0.62	0.57	0.59	0.62	0.70	0.92	0.93			
Res.vol. 1, Mm3	9,373	9,649	9,804	9,797	9,660	9,469	9,250	9,362	10,152	10,496	10,259	10,496	9,625	10,002	9,814
Res.vol. 2, Mm3	9,649	9,804	9,797	9,660	9,469	9,250	9,362	10,152	10,496	10,259	10,496	10,496	9,605	10,210	9,907
Avg.Res.vol, Mm3	9,511	9,726	9,800	9,728	9,564	9,359	9,306	9,757	10,324	10,378	10,378	10,496	9,615	10,106	9,861
Avg.Res. H, m	899	902	903	902	900	898	897	902	908	909	909	910	900	906	903
Outflow, Mm3	600	400	500	600	600	800	1,200	1,800	4,041	5,875	3,850	2,522	3,500	19,288	22,788
Outflow, m3/s	224	154	187	224	248	299	463	672	1,559	2,193	1,437	973	223	1,216	719
dH = H-Hout-Hlos, m	255	258	258	257	255	253	252	256	260	261	261	263	256	259	258
K	8.67	8.65	8.64	8.65	8.66	8.68	8.69	8.66	8.63	8.63	8.62	8.61	9	9	9
Qhps, m3/s	224	154	187	224	248	299	463	672	1,559	2,193	1,437	973	223	1,216	719
N, MWh	495	344	417	499	549	656	1,012	1,488	3,504	4,936	3,237	2,205	493	2,730	1,612
Enurek, mkwth	368	248	310	371	369	488	728	1,107	2,523	3,673	2,409	1,587	2,154	12,027	14,181
Evahsh, mkwth	154	127	139	154	163	183	246	327	669	914	622	443	919	3,221	4,140
E, mkwth	522	375	450	525	532	670	974	1,434	3,192	4,586	3,031	2,030	3,073	15,248	18,321
q = Out / Enur, m/kwth	1.63	1.61	1.61	1.62	1.63	1.64	1.65	1.63	1.60	1.60	1.60	1.59	1.62	1.60	1.61

2034-2035	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	964	716	627	466	374	506	918	2,150	3,466	5,667	4,281	1,975	3,653	18,458	22,111
Rule Curve	0.99	0.99	0.99	0.99	0.98	0.97	0.95	0.87	0.84	0.95	0.99	0.99			
Res.vol. 1, Mm3	10,499	10,499	10,499	10,499	10,485	10,379	10,244	10,083	9,185	8,911	10,068	10,499	10,476	9,832	10,154
Res.vol. 2, Mm3	10,499	10,499	10,499	10,485	10,379	10,244	10,083	9,185	8,911	10,068	10,499	10,500	10,434	9,874	10,154
Avg.Res.vol, Mm3	10,499	10,499	10,499	10,492	10,432	10,311	10,164	9,634	9,048	9,489	10,284	10,499	10,455	9,853	10,154
Avg.Res. H, m	910	910	910	910	910	908	907	901	894	899	908	910	910	903	907
Outflow, Mm3	964	716	627	480	480	640	1,080	3,048	3,740	4,510	3,850	1,975	3,907	18,203	22,110
Outflow, m3/s	360	276	234	179	198	239	417	1,138	1,443	1,684	1,437	762	248	1,147	697
dH = H-Hout-Hlos, m	265	266	266	266	265	264	261	253	246	251	260	264	265	256	261
K	8.60	8.59	8.59	8.59	8.59	8.61	8.62	8.68	8.72	8.69	8.63	8.61	9	9	9
Qhps, m3/s	360	276	234	179	198	239	417	1,138	1,443	1,684	1,437	762	248	1,147	697

N, MWh	821	631	535	410	453	543	939	2,500	3,100	3,674	3,227	1,730	565	2,528	1,547
Enurek, mkwth	611	454	398	305	304	404	676	1,860	2,232	2,734	2,401	1,245	2,476	11,148	13,624
Evahsh, mkwth	206	174	158	136	144	159	228	507	624	717	622	361	977	3,059	4,037
E, mkwth	817	628	556	441	448	563	904	2,367	2,856	3,451	3,023	1,607	3,453	14,207	17,661
q = Out / Enur, m/kwth	1.58	1.58	1.58	1.57	1.58	1.59	1.60	1.64	1.68	1.65	1.60	1.59	1.58	1.63	1.62

2039-2040	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	806	627	496	445	373	434	912	2,017	2,501	3,696	4,285	1,656	3,180	15,068	18,248
Rule Curve	0.99	0.99	0.99	0.98	0.97	0.94	0.93	0.98	0.96	0.92	0.99	0.99			
Res.vol. 1, Mm3	10,259	10,501	10,502	10,501	10,406	10,238	9,952	9,785	10,361	10,120	9,716	10,501	10,401	10,073	10,237
Res.vol. 2, Mm3	10,501	10,502	10,501	10,406	10,238	9,952	9,785	10,361	10,120	9,716	10,501	10,502	10,350	10,164	10,257
Avg.Res.vol, Mm3	10,380	10,502	10,501	10,454	10,322	10,095	9,868	10,073	10,241	9,918	10,109	10,502	10,376	10,118	10,247
Avg.Res. H, m	909	910	910	910	908	906	903	906	907	904	906	910	909	906	908
Outflow, Mm3	564	627	496	540	540	720	1,080	1,440	2,743	4,100	3,500	1,656	3,487	14,519	18,006
Outflow, m3/s	211	242	185	202	223	269	417	538	1,058	1,531	1,307	639	222	915	568
dH = H-Hout-Hlos, m	265	266	266	266	264	261	258	260	260	256	258	264	265	259	262
K	8.60	8.59	8.59	8.59	8.60	8.62	8.65	8.63	8.63	8.66	8.64	8.60	9	9	9
Qhps, m3/s	211	242	185	202	223	269	417	538	1,058	1,531	1,307	639	222	915	568
N, MWh	480	553	424	460	507	606	929	1,206	2,376	3,392	2,917	1,452	505	2,045	1,275
Enurek, mkwth	357	398	315	343	341	451	669	897	1,711	2,524	2,170	1,046	2,204	9,017	11,221
Evahsh, mkwth	149	161	139	145	153	171	228	275	476	658	572	314	917	2,522	3,440
E, mkwth	505	559	454	488	494	622	897	1,172	2,186	3,182	2,742	1,359	3,121	11,539	14,660
q = Out / Enur, m/kwth	1.58	1.58	1.57	1.58	1.58	1.60	1.61	1.61	1.60	1.62	1.61	1.58	1.58	1.61	1.60

2044-2045	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,119	798	638	578	494	584	1,666	2,705	4,044	4,829	3,776	1,850	4,211	18,869	23,080
Rule Curve	0.99	0.99	0.99	0.96	0.92	0.87	0.86	0.84	0.90	0.97	0.99	0.99	0.95	0.92	0.94
Res.vol. 1, Mm3	10,372	10,500	10,501	10,425	10,103	9,697	9,181	9,047	8,851	9,495	10,224	10,500	10,266	9,550	9,908
Res.vol. 2, Mm3	10,500	10,501	10,425	10,103	9,697	9,181	9,047	8,851	9,495	10,224	10,500	10,500	10,068	9,770	9,919
Avg.Res.vol, Mm3	10,436	10,500	10,463	10,264	9,900	9,439	9,114	8,949	9,173	9,860	10,362	10,500	10,167	9,660	9,913
Avg.Res. H, m	910	910	910	908	904	899	895	893	896	903	909	910	907	901	904

Outflow, Mm3	990	798	714	900	900	1,100	1,800	2,900	3,400	4,100	3,500	1,850	5,402	17,550	22,952
Outflow, m3/s	370	308	267	336	372	411	694	1,083	1,312	1,531	1,307	714	344	1,107	725
dH = H-Hout-Hlos, m	265	266	265	263	259	253	248	246	248	255	261	264	262	254	258
K	8.60	8.59	8.60	8.61	8.64	8.68	8.71	8.73	8.71	8.66	8.62	8.61	9	9	9
Qhps, m3/s	370	308	267	336	372	411	694	1,083	1,312	1,531	1,307	714	344	1,107	725
N, MWh	841	703	608	761	831	902	1,503	2,321	2,832	3,385	2,943	1,621	774	2,434	1,604
Enurek, mkwth	626	506	453	566	559	671	1,082	1,727	2,039	2,519	2,189	1,167	3,380	10,723	14,104
Evahsh, mkwth	210	186	170	197	211	226	335	485	574	658	572	343	1,200	2,967	4,166
E, mkwth	836	692	623	763	769	897	1,417	2,212	2,613	3,177	2,761	1,510	4,580	13,690	18,270
q = Out / Enur, m/kwth	1.58	1.58	1.58	1.59	1.61	1.64	1.66	1.68	1.67	1.63	1.60	1.59	1.60	1.64	1.63

2049-2050	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,003	712	687	555	463	660	833	2,873	4,343	4,933	3,324	2,216	4,080	18,522	22,602
Rule Curve	0.99	0.99	0.99	0.99	0.96	0.92	0.83	0.83	0.91	0.99	0.99	0.99	0.98	0.92	0.95
Res.vol. 1, Mm3	10,487	10,500	10,500	10,500	10,500	10,158	9718	8,751	8,724	9,667	10,500	10,500	10,441	9,643	10,042
Res.vol. 2, Mm3	10,500	10,500	10,500	10,500	10,158	9,718	8,751	8,724	9,667	10,500	10,500	10,500	10,313	9,774	10,043
Avg.Res.vol, Mm3	10,493	10,500	10,500	10,500	10,329	9,938	9,234	8,737	9,195	10,083	10,500	10,500	10,377	9,708	10,043
Avg.Res. H, m	910	910	910	910	908	904	896	891	896	906	910	910	909	902	905
Outflow, Mm3	990	712	687	555	805	1,100	1,800	2,900	3,400	4,100	3,324	2,215	4,849	17,739	22,588
Outflow, m3/s	370	275	256	207	333	411	694	1,083	1,312	1,531	1,241	855	309	1,119	714
dH = H-Hout-Hlos, m	265	266	266	266	264	259	250	243	248	258	263	264	264	254	259
K	8.60	8.59	8.59	8.59	8.61	8.64	8.70	8.74	8.71	8.65	8.61	8.61	9	9	9
Qhps_, m3/s	370	275	256	207	333	411	694	1,083	1,312	1,531	1,241	855	309	1,119	714
N, MWh	843	627	586	474	755	918	1,509	2,303	2,834	3,412	2,808	1,938	701	2,468	1,584
Enurek, mkwth	627	452	436	353	507	683	1,087	1,713	2,041	2,538	2,089	1,396	3,058	10,865	13,923
Evahsh, mkwth	210	173	166	147	196	226	335	485	574	658	546	397	1,118	2,996	4,114
E, mkwth	837	625	602	500	703	909	1,422	2,199	2,614	3,197	2,636	1,793	4,176	13,860	18,036
q = Out / Enur, m/kwth	1.58	1.58	1.58	1.57	1.59	1.61	1.66	1.69	1.67	1.62	1.59	1.59	1.59	1.63	1.62

2054-2055	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	922	544	505	320	394	494	2,594	3,560	4,087	6,095	4,114	2,292	3,179	22,742	25,921
Rule Curve	0.99	0.99	0.97	0.91	0.87	0.81	0.85	0.86	0.86	0.97	0.99	0.99	0.92	0.92	0.92
Res.vol. 1, Mm3	10,500	10,500	10,500	10,232	9,652	9,146	8,540	8,973	9,053	9,060	10,235	10,500	10,088	9,393	9,741
Res.vol. 2, Mm3	10,500	10,500	10,232	9,652	9,146	8,540	8,973	9,053	9,060	10,235	10,500	10,500	9,762	9,720	9,741
Avg.Res.vol, Mm3	10,500	10,500	10,366	9,942	9,399	8,843	8,756	9,013	9,056	9,647	10,367	10,500	9,925	9,557	9,741
Avg.Res. H, m	910	910	909	904	898	892	891	894	894	901	909	910	904	900	902
Outflow, Mm3	922	544	773	900	900	1,100	2,160	3,480	4,080	4,920	3,850	2,291	5,139	20,781	25,920
Outflow, m3/s	344	210	289	336	372	411	833	1,299	1,574	1,837	1,437	884	327	1,311	819
dH = H-Hout-Hlos, m	265	266	264	259	253	247	244	246	246	253	261	263	259	252	256
K	8.60	8.59	8.60	8.64	8.68	8.72	8.74	8.73	8.72	8.68	8.62	8.61	9	9	9
Qhps, m3/s	344	210	289	336	372	411	833	1,299	1,574	1,837	1,437	884	327	1,311	819
N, MWh	785	480	656	752	817	883	1,777	2,789	3,382	4,030	3,236	2,004	729	2,870	1,799
Enurek, mkwth	584	346	488	560	549	657	1,280	2,075	2,435	2,999	2,408	1,443	3,184	12,639	15,822
Evahsh, mkwth	200	148	179	197	211	226	389	569	675	776	622	408	1,161	3,439	4,600
E, mkwth	784	494	667	757	760	883	1,668	2,644	3,110	3,775	3,030	1,852	4,344	16,078	20,422
q = Out / Enur, m/kwth	1.58	1.57	1.58	1.61	1.64	1.67	1.69	1.68	1.68	1.64	1.60	1.59	1.61	1.64	1.64

Annex 3. Alternative operation modes of the Nurek HEPS and calculation of electricity generation by the Vakhsh hydropower cascade for 2020-2055 (Case 3 and Case 4): 2025, 2030, 2035, 2040, 2045, 2050, and 2055

Case 3. Energy mode (maximum energy generation in autumn and winter): inflow to the Nurek HS based on the scenario of continued cycling, including climate change impact (REMO 04-06)

2024-2025	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	843	614	546	467	400	643	1,180	1,850	3,064	4,276	4,101	1,651	3,512	16,123	19,636
Rule Curve	0.97	0.92	0.85	0.78	0.67	0.57	0.57	0.57	0.63	0.81	0.99	0.99			
Res.vol. 1, Mm3	10,497	10,235	9,702	8,937	8,256	7,057	6,000	6,037	6,000	6,700	8,518	10,440	9,114	7,282	8,198
Res.vol. 2, Mm3	10,235	9,702	8,937	8,256	7,057	6,000	6,037	6,000	6,700	8,518	10,440	10,501	8,365	8,033	8,199
Avg.Res.vol, Mm3	10,366	9,969	9,320	8,596	7,657	6,528	6,018	6,018	6,350	7,609	9,479	10,470	8,739	7,657	8,198
Avg.Res. H, m	909	904	897	889	879	866	860	860	864	878	899	910	891	879	885
Outflow, Mm3	1,104	1,147	1,312	1,148	1,598	1,701	1,143	1,887	2,365	2,458	2,179	1,590	8,010	11,622	19,632
Outflow, m3/s	412	442	490	429	661	635	441	705	912	918	814	614	511	734	623
dH = H-Hout-Hlos, m	264	259	252	244	232	220	215	214	217	231	252	264	245	232	239
K	8.61	8.64	8.69	8.74	8.82	8.90	8.94	8.94	8.92	8.83	8.68	8.61	9	9	9
Qhps, m3/s	412	442	490	429	661	635	441	705	912	918	814	614	511	734	623
N, MWh	935	990	1,070	913	1,353	1,242	846	1,347	1,765	1,871	1,782	1,394	1,084	1,501	1,292
Enurek, mkwth	696	713	796	679	909	924	609	1,002	1,271	1,392	1,326	1,003	4,718	6,603	11,321
Evahsh, mkwth	226	238	256	233	322	312	237	339	419	421	381	304	1,588	2,103	3,691
E, mkwth	922	951	1,053	912	1,231	1,237	847	1,341	1,690	1,813	1,707	1,307	6,306	8,706	15,012
q = Out / Enur, m/kwth	1.59	1.61	1.65	1.69	1.76	1.84	1.88	1.88	1.86	1.77	1.64	1.59	1.70	1.76	1.73

2029-2030	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	885	555	488	459	409	587	1,357	2,616	4,166	4,990	4,046	2,560	3,382	19,736	23,117
Rule Curve	0.88	0.86	0.81	0.74	0.68	0.62	0.57	0.59	0.62	0.70	0.92	0.93			
Res.vol. 1, Mm3	9,351	9,127	8,572	7,800	7,141	6,560	5,999	6,189	6,558	7,443	9,389	9,876	8,092	7,576	7,834
Res.vol. 2, Mm3	9,127	8,572	7,800	7,141	6,560	5,999	6,189	6,558	7,443	9,389	9,876	10,500	7,533	8,326	7,929
Avg.Res.vol, Mm3	9,239	8,849	8,186	7,470	6,850	6,279	6,094	6,373	7,000	8,416	9,633	10,188	7,812	7,951	7,882
Avg.Res. H, m	896	892	884	876	870	863	861	864	871	887	901	907	880	882	881

Outflow, Mm3	1,109	1,110	1,260	1,117	990	1,148	1,168	2,247	3,281	3,044	3,559	1,936	6,734	15,234	21,968
Outflow, m3/s	414	428	470	417	409	429	451	839	1,266	1,136	1,329	747	428	961	695
dH = H-Hout-Hlos, m	251	247	239	231	224	218	216	217	224	240	253	260	235	235	235
K	8.69	8.72	8.77	8.83	8.87	8.92	8.93	8.92	8.88	8.77	8.68	8.63	9	9	9
Qhps, m3/s	414	428	470	417	409	429	451	839	1,266	1,136	1,329	747	428	961	695
N, MWh	903	921	986	851	814	832	867	1,626	2,511	2,387	2,917	1,678	885	1,998	1,441
Enurek, mkwth	672	663	734	633	547	619	625	1,210	1,808	1,776	2,170	1,208	3,868	8,797	12,665
Evahsh, mkwth	227	233	249	228	225	233	241	391	556	506	580	356	1,395	2,630	4,024
E, mkwth	899	896	983	861	772	852	866	1,601	2,364	2,282	2,750	1,564	5,263	11,426	16,689
q = Out / Enur, m/kwth	1.65	1.67	1.72	1.76	1.81	1.85	1.87	1.86	1.81	1.71	1.64	1.60	1.74	1.73	1.73

2034-2035	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	978	720	624	464	376	514	957	2,172	3,275	5,002	4,217	2,010	3,675	17,632	21,307
Rule Curve	0.98	0.94	0.87	0.81	0.70	0.59	0.57	0.57	0.61	0.82	0.99	0.99			
Res.vol. 1, Mm3	10,500	10,334	9,910	9,239	8,572	7,420	6,225	6,000	6,034	6,500	8,647	10,468	9,329	7,312	8,321
Res.vol. 2, Mm3	10,334	9,910	9,239	8,572	7,420	6,225	6,000	6,034	6,500	8,647	10,468	10,500	8,616	8,025	8,321
Avg.Res.vol, Mm3	10,417	10,122	9,574	8,905	7,996	6,822	6,113	6,017	6,267	7,573	9,558	10,484	8,973	7,668	8,321
Avg.Res. H, m	909	906	900	893	882	869	861	860	863	878	900	910	893	879	886
Outflow, Mm3	1,144	1,144	1,295	1,131	1,528	1,708	1,183	2,138	2,809	2,854	2,396	1,979	7,949	13,358	21,307
Outflow, m3/s	427	441	483	422	632	638	456	798	1,084	1,066	894	763	507	844	675
dH = H-Hout-Hlos, m	264	261	254	247	236	223	216	213	216	230	253	264	248	232	240
K	8.60	8.63	8.67	8.72	8.79	8.88	8.93	8.94	8.93	8.83	8.68	8.61	9	9	9
Qhps, m3/s	427	441	483	422	632	638	456	798	1,084	1,066	894	763	507	844	675
N, MWh	971	992	1,066	910	1,311	1,263	879	1,524	2,087	2,167	1,963	1,732	1,086	1,725	1,405
Enurek, mkwth	722	715	793	677	881	939	633	1,134	1,502	1,612	1,461	1,247	4,728	7,589	12,316
Evahsh, mkwth	232	238	254	230	311	313	243	375	486	479	413	362	1,578	2,357	3,936
E, mkwth	955	952	1,047	907	1,192	1,253	877	1,509	1,988	2,091	1,873	1,609	6,306	9,946	16,252
q = Out / Enur, m/kwth	1.58	1.60	1.63	1.67	1.73	1.82	1.87	1.89	1.87	1.77	1.64	1.59	1.68	1.76	1.73

2039-2040	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	822	634	496	445	376	443	958	2,037	2,351	3,253	4,200	1,689	3,215	14,488	17,703
Rule Curve	0.95	0.89	0.81	0.75	0.67	0.57	0.57	0.63	0.70	0.77	0.98	0.99			
Res.vol. 1, Mm3	10,338	9,994	9,422	8,608	7,898	7,118	6,022	6,000	6,656	7,418	8,179	10,364	8,896	7,440	8,168

Res.vol. 2, Mm3	9,994	9,422	8,608	7,898	7,118	6,022	6,000	6,656	7,418	8,179	10,364	10,500	8,177	8,186	8,182
Avg.Res.vol, Mm3	10,166	9,708	9,015	8,253	7,508	6,570	6,011	6,328	7,037	7,798	9,272	10,432	8,537	7,813	8,175
Avg.Res. H, m	907	902	894	885	877	866	860	864	872	880	897	910	888	880	884
Outflow, Mm3	1,166	1,206	1,309	1,155	1,156	1,539	981	1,380	1,590	2,491	2,014	1,554	7,531	10,011	17,541
Outflow, m3/s	435	465	489	431	478	574	378	515	613	930	752	600	479	631	555
dH = H-Hout-Hlos, m	261	256	248	240	231	220	215	218	225	233	250	264	243	234	239
K	8.62	8.66	8.71	8.77	8.82	8.90	8.93	8.91	8.86	8.81	8.70	8.61	9	9	9
Qhps, m3/s	435	465	489	431	478	574	378	515	613	930	752	600	479	631	555
N, MWh	981	1,032	1,056	907	975	1,127	727	1,001	1,226	1,910	1,636	1,360	1,013	1,310	1,161
Enurek, mkwth	730	743	786	675	655	838	523	745	883	1,421	1,217	979	4,427	5,769	10,195
Evahsh, mkwth	235	247	256	234	252	289	213	266	304	426	358	299	1,512	1,866	3,378
E, mkwth	965	990	1,042	908	907	1,127	737	1,011	1,187	1,848	1,575	1,278	5,939	7,635	13,574
q = Out / Enur, m/kwth	1.60	1.62	1.67	1.71	1.76	1.84	1.87	1.85	1.80	1.75	1.66	1.59	1.70	1.74	1.72

2044-2045	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,144	808	640	580	500	597	1,753	2,752	3,791	4,165	3,700	1,892	4,269	18,053	22,322
Rule Curve	0.99	0.95	0.89	0.76	0.65	0.57	0.57	0.63	0.70	0.84	0.98	0.99	0.80	0.78	0.79
Res.vol. 1, Mm3	10,500	10,468	10,077	9,359	8,067	6,861	6,000	6,000	6,634	7,428	8,897	10,313	9,222	7,545	8,384
Res.vol. 2, Mm3	10,468	10,077	9,359	8,067	6,861	6,000	6,000	6,634	7,428	8,897	10,313	10,500	8,472	8,295	8,384
Avg.Res.vol, Mm3	10,484	10,272	9,718	8,713	7,464	6,430	6,000	6,317	7,031	8,163	9,605	10,407	8,847	7,920	8,384
Avg.Res. H, m	910	908	902	890	876	865	860	864	872	884	900	909	892	882	887
Outflow, Mm3	1,175	1,200	1,358	1,871	1,706	1,458	1,753	2,117	2,997	2,696	2,284	1,705	8,768	13,553	22,322
Outflow, m3/s	439	463	507	699	705	544	676	791	1,156	1,007	853	658	559	857	708
dH = H-Hout-Hlos, m	265	262	256	244	230	219	214	217	224	237	253	263	246	235	240
K	8.60	8.62	8.66	8.74	8.83	8.91	8.94	8.92	8.87	8.79	8.68	8.61	9	9	9
Qhps, m3/s	439	463	507	699	705	544	676	791	1,156	1,007	853	658	559	857	708
N, MWh	999	1,046	1,123	1,490	1,433	1,062	1,293	1,529	2,299	2,096	1,876	1,490	1,192	1,764	1,478
Enurek, mkwth	743	753	836	1,108	963	790	931	1,138	1,655	1,559	1,396	1,073	5,194	7,751	12,944
Evahsh, mkwth	237	246	263	337	339	277	328	372	514	456	396	321	1,699	2,388	4,087
E, mkwth	980	999	1,099	1,445	1,302	1,067	1,259	1,510	2,169	2,015	1,792	1,394	6,893	10,138	17,031
q = Out / Enur, m/kwth	1.58	1.59	1.62	1.69	1.77	1.85	1.88	1.86	1.81	1.73	1.64	1.59	1.69	1.75	1.72

2049-2050	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,028	723	690	558	470	676	879	2,944	4,061	4,168	3,258	2,271	4,145	17,581	21,727
Rule Curve	0.98	0.95	0.84	0.76	0.66	0.59	0.57	0.60	0.75	0.90	0.99	0.99	0.80	0.80	0.80
Res.vol. 1, Mm3	10,499	10,402	10,014	8,838	8,033	6,966	6,266	5,999	6,342	7,962	9,535	10,499	9,125	7,767	8,446
Res.vol. 2, Mm3	10,402	10,014	8,838	8,033	6,966	6,266	5,999	6,342	7,962	9,535	10,499	10,500	8,420	8,473	8,446
Avg.Res. H, m	910	907	898	887	877	867	861	862	873	891	905	910	891	884	887
Outflow, Mm3	1,125	1,111	1,866	1,363	1,537	1,376	1,146	2,602	2,441	2,595	2,294	2,269	8,378	13,347	21,725
Outflow, m3/s	420	429	697	509	635	514	442	971	942	969	856	876	534	843	688
dH = H-Hout-Hlos, m	265	262	252	242	231	221	216	215	226	244	258	263	245	237	241
K	8.60	8.62	8.69	8.76	8.83	8.89	8.93	8.94	8.86	8.74	8.64	8.61	9	9	9
Qhps, m3/s	420	429	697	509	635	514	442	971	942	969	856	876	534	843	688
N, MWh	956	967	1,525	1,076	1,293	1,011	853	1,864	1,884	2,064	1,910	1,986	1,138	1,760	1,449
Enurek, mkwth	711	696	1,135	801	869	752	614	1,387	1,356	1,535	1,421	1,430	4,964	7,743	12,707
Evahsh, mkwth	229	233	336	264	312	266	238	442	431	441	398	405	1,640	2,355	3,995
E, mkwth	940	929	1,471	1,064	1,182	1,018	852	1,829	1,787	1,977	1,819	1,835	6,604	10,099	16,702
q = Out / Enur, m/kwth	1.58	1.60	1.65	1.70	1.77	1.83	1.87	1.88	1.80	1.69	1.61	1.59	1.69	1.72	1.71

2054-2055	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	948	553	509	322	401	507	2,743	3,676	3,811	5,044	4,032	2,355	3,240	21,660	24,900
Rule Curve	0.97	0.91	0.84	0.76	0.68	0.57	0.60	0.65	0.71	0.89	0.98	0.99	0.79	0.80	0.80
Res.vol. 1, Mm3	10,500	10,272	9,636	8,832	8,052	7,206	6,000	6,313	6,883	7,470	9,425	10,400	9,083	7,748	8,416
Res.vol. 2, Mm3	10,272	9,636	8,832	8,052	7,206	6,000	6,313	6,883	7,470	9,425	10,400	10,500	8,333	8,498	8,416
Avg.Res. H, m	909	904	896	887	878	867	862	867	873	887	904	910	890	884	887
Outflow, Mm3	1,175	1,190	1,313	1,102	1,247	1,714	2,429	3,106	3,224	3,089	3,058	2,254	7,741	17,159	24,900
Outflow, m3/s	439	459	490	412	515	640	937	1,160	1,244	1,153	1,142	870	492	1,084	788
dH = H-Hout-Hlos, m	264	259	251	242	233	221	215	219	226	240	256	263	245	236	241
K	8.61	8.64	8.70	8.75	8.82	8.90	8.94	8.91	8.86	8.77	8.66	8.61	9	9	9
Qhps, m3/s	439	459	490	412	515	640	937	1,160	1,244	1,153	1,142	870	492	1,084	788
N, MWh	996	1026	1,068	872	1,057	1,255	1,798	2,263	2,486	2,425	2,533	1,969	1,046	2,246	1,646
Enurek, mkwth	741	739	795	649	710	934	1,294	1,684	1,790	1,804	1,884	1,418	4,567	9,875	14,442
Evahsh, mkwth	237	244	256	226	266	314	429	515	547	512	508	403	1,544	2,914	4,458
E, mkwth	978	983	1,051	875	976	1,248	1,723	2,199	2,337	2,317	2,392	1,821	6,111	12,789	18,900
q = Out / Enur, m/kwth	1.59	1.61	1.65	1.70	1.76	1.83	1.88	1.84	1.80	1.71	1.62	1.59	1.69	1.74	1.72

Case 4. Energy-irrigation mode (maximum energy generation per year): inflow to the Nurek HS based on the scenario of continued cycling, including climate change impact (REMO 04-06)

2024-2025	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	843	614	546	467	400	643	1,180	1,850	3,064	4,276	4,101	1,651	3,512	16,123	19,636
Rule Curve	0.99	0.99	0.99	0.98	0.96	0.95	0.94	0.88	0.87	0.93	0.99	0.99			
Res.vol. 1, Mm3	10,498	10,498	10,498	10,499	10,373	10,174	10,015	9,963	9,350	9,159	9,877	10,499	10,424	9,810	10,117
Res.vol. 2, Mm3	10,498	10,498	10,499	10,373	10,174	10,015	9,963	9,350	9,159	9,877	10,499	10,500	10,343	9,891	10,117
Avg.Res. H, m	910	910	910	910	908	906	905	901	896	899	907	910	909	903	906
Outflow, Mm3	842	614	546	593	598	803	1,232	2,463	3,256	3,558	3,479	1,650	3,996	15,638	19,634
Outflow, m3/s	314	237	204	221	247	300	475	920	1,256	1,328	1,299	637	254	986	620
dH = H-Hout-Hlos, m	266	266	266	265	263	261	259	254	249	252	259	264	265	256	260
K	8.59	8.59	8.59	8.60	8.61	8.62	8.64	8.67	8.71	8.69	8.64	8.60	9	9	9
Qhps, m3/s	314	237	204	221	247	300	475	920	1,256	1,328	1,299	637	254	986	620
N, MWh	718	541	466	505	561	675	1,063	2,025	2,721	2,904	2,908	1,447	578	2,178	1,378
Enurek, mkwth	534	390	347	376	377	502	766	1,507	1,959	2,161	2,164	1,042	2,525	9,597	12,122
Evahsh, mkwth	189	159	146	153	163	183	251	422	552	580	569	313	992	2,687	3,678
E, mkwth	723	548	493	528	539	685	1,016	1,929	2,511	2,741	2,732	1,355	3,517	12,284	15,801
q = Out / Enur, m/kwth	1.58	1.58	1.57	1.58	1.59	1.60	1.61	1.63	1.66	1.65	1.61	1.58	1.58	1.63	1.62

2029-2030	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	885	555	488	459	409	587	1,357	2,616	4,166	4,990	4,046	2,560	3,382	19,736	23,117
Rule Curve	0.88	0.86	0.81	0.74	0.68	0.62	0.57	0.59	0.62	0.70	0.92	0.93			
Res.vol. 1, Mm3	9,375	9,651	9,806	9,799	9,662	9,471	9,252	9,364	10,154	10,498	10,261	10,498	9,627	10,004	9,816
Res.vol. 2, Mm3	9,651	9,806	9,799	9,662	9,471	9,252	9,364	10,154	10,498	10,261	10,498	10,500	9,607	10,213	9,910
Avg.Res. H, m	899	902	903	902	900	898	897	902	908	909	909	910	901	906	903
Outflow, Mm3	609	400	495	595	600	806	1,246	1,826	3,822	5,227	3,809	2,558	3,505	18,487	21,992
Outflow, m3/s	227	154	185	222	248	301	481	682	1,474	1,951	1,422	987	223	1,166	695
dH = H-Hout-Hlos, m	255	258	259	257	256	253	251	256	261	261	261	263	256	259	258
K	8.67	8.65	8.64	8.65	8.66	8.68	8.69	8.66	8.63	8.63	8.62	8.61	9	9	9

Qhps, m3/s	227	154	185	222	248	301	481	682	1,474	1,951	1,422	987	223	1,166	695
N, MWh	502	344	413	495	549	660	1,050	1,510	3,314	4,392	3,203	2,236	494	2,618	1,556
Enurek, mkwth	374	248	307	368	369	491	756	1,123	2,386	3,268	2,383	1,610	2,157	11,527	13,684
Evahsh, mkwth	155	127	139	153	163	183	253	330	636	820	616	448	920	3,104	4,024
E, mkwth	529	375	446	521	532	675	1,009	1,454	3,023	4,088	2,999	2,058	3,077	14,631	17,708
q = Out / Enur, m/kwth	1.63	1.61	1.61	1.62	1.63	1.64	1.65	1.63	1.60	1.60	1.60	1.59	1.62	1.60	1.61

2034-2035	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	978	720	624	464	376	514	957	2,172	3,275	5,002	4,217	2,010	3,675	17,632	21,307
Rule Curve	0.99	0.99	0.99	0.99	0.98	0.97	0.95	0.87	0.84	0.95	0.99	0.99			
Res.vol. 1, Mm3	10,499	10,499	10,499	10,499	10,485	10,379	10,244	10,083	9,185	8,911	10,068	10,499	10,476	9,832	10,154
Res.vol. 2, Mm3	10,499	10,499	10,499	10,485	10,379	10,244	10,083	9,185	8,911	10,068	10,499	10,500	10,434	9,874	10,154
Avg.Res. H, m	910	910	910	910	910	908	907	901	894	899	908	910	910	903	907
Outflow, Mm3	978	720	624	478	482	648	1,119	3,070	3,549	3,844	3,786	2,010	3,929	17,377	21,306
Outflow, m3/s	365	278	233	178	199	242	432	1,146	1,369	1,435	1,413	775	249	1,095	672
dH = H-Hout-Hlos, m	265	266	266	266	265	264	261	253	246	251	260	264	265	256	261
K	8.60	8.59	8.59	8.59	8.59	8.61	8.62	8.68	8.72	8.69	8.63	8.61	9	9	9
Qhps, m3/s	365	278	233	178	199	242	432	1,146	1,369	1,435	1,413	775	249	1,095	672
N, MWh	833	634	532	408	455	549	973	2,518	2,942	3,133	3,173	1,760	569	2,417	1,493
Enurek, mkwth	620	457	396	303	305	409	700	1,873	2,119	2,331	2,361	1,267	2,490	10,651	13,141
Evahsh, mkwth	208	174	157	136	144	161	234	510	596	621	613	367	981	2,940	3,921
E, mkwth	828	631	553	440	450	569	934	2,383	2,714	2,952	2,974	1,634	3,471	13,591	17,062
q = Out / Enur, m/kwth	1.58	1.58	1.58	1.57	1.58	1.59	1.60	1.64	1.68	1.65	1.60	1.59	1.58	1.63	1.62

2039-2040	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	822	634	496	445	376	443	958	2,037	2,351	3,253	4,200	1,689	3,215	14,488	17,703
Rule Curve	0.99	0.99	0.99	0.98	0.97	0.94	0.93	0.98	0.96	0.92	0.99	0.99			
Res.vol. 1, Mm3	10,257	10,499	10,500	10,499	10,404	10,236	9,950	9,783	10,359	10,118	9,714	10,499	10,399	10,071	10,235
Res.vol. 2, Mm3	10,499	10,500	10,499	10,404	10,236	9,950	9,783	10,359	10,118	9,714	10,499	10,500	10,348	10,162	10,255
Avg.Res. H, m	909	910	910	910	908	906	903	906	907	904	906	910	909	906	908
Outflow, Mm3	580	633	496	540	544	729	1,126	1,460	2,593	3,656	3,414	1,689	3,522	13,939	17,460
Outflow, m3/s	217	244	185	202	225	272	434	545	1,000	1,365	1,275	652	224	879	551

dH = H-Hout-Hlos, m	265	266	266	266	264	261	258	260	260	256	258	264	265	259	262
K	8.60	8.59	8.59	8.59	8.60	8.62	8.65	8.63	8.63	8.66	8.64	8.60	9	9	9
Qhps, m3/s	217	244	185	202	225	272	434	545	1,000	1,365	1,275	652	224	879	551
N, MWh	493	558	424	460	511	613	968	1,222	2,247	3,026	2,846	1,481	510	1,965	1,237
Enurek, mkwth	367	402	315	342	343	456	697	910	1,618	2,252	2,117	1,066	2,226	8,659	10,885
Evahsh, mkwth	151	162	139	145	154	172	235	278	453	594	559	319	922	2,438	3,361
E, mkwth	518	564	454	488	497	628	932	1,187	2,071	2,846	2,677	1,385	3,148	11,098	14,246
q = Out / Enur, m/kwth	1.58	1.58	1.57	1.58	1.58	1.60	1.61	1.61	1.60	1.62	1.61	1.58	1.58	1.61	1.60

2044-2045	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,144	808	640	580	500	597	1,753	2,752	3,791	4,165	3,700	1,892	4,269	18,053	22,322
Rule Curve	0.99	0.99	0.99	0.96	0.92	0.87	0.86	0.84	0.90	0.97	0.99	0.99	0.95	0.92	0.94
Res.vol. 1, Mm3	10,372	10,500	10,500	10,424	10,102	9,696	9,180	9,046	8,850	9,494	10,223	10,500	10,266	9,549	9,907
Res.vol. 2, Mm3	10,500	10,500	10,424	10,102	9,696	9,180	9,046	8,850	9,494	10,223	10,500	10,500	10,067	9,769	9,918
Avg.Res. H, m	910	910	910	908	904	899	895	893	896	903	909	910	907	901	904
Outflow, Mm3	1015	809	716	901	906	1,113	1,887	2,947	3,147	3,436	3,423	1,892	5,460	16,733	22,194
Outflow, m3/s	379	312	267	337	375	416	728	1,100	1,214	1,283	1,278	730	348	1,056	702
dH = H-Hout-Hlos, m	265	266	265	263	259	253	248	246	248	255	261	264	262	254	258
K	8.60	8.59	8.60	8.61	8.64	8.68	8.71	8.73	8.71	8.66	8.62	8.61	9	9	9
Qhps_, m3/s	379	312	267	337	375	416	728	1,100	1,214	1,283	1,278	730	348	1,056	702
N, MWh	862	712	610	762	837	913	1,575	2,359	2,623	2,839	2,879	1,657	783	2,322	1,552
Enurek, mkwth	642	513	454	567	562	679	1,134	1,755	1,888	2,112	2,142	1,193	3,417	10,224	13,641
Evahsh, mkwth	214	188	170	197	212	228	348	492	536	562	561	349	1,208	2,848	4,057
E, mkwth	855	701	624	764	774	907	1,482	2,247	2,424	2,675	2,702	1,542	4,625	13,073	17,698
q = Out / Enur, m/kwth	1.58	1.58	1.58	1.59	1.61	1.64	1.66	1.68	1.67	1.63	1.60	1.59	1.60	1.64	1.63

2049-2050	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	1,028	723	690	558	470	676	879	2,944	4,061	4,168	3,258	2,271	4,145	17,581	21,727
Rule Curve	0.99	0.99	0.99	0.99	0.96	0.92	0.83	0.83	0.91	0.99	0.99	0.99	0.98	0.92	0.95
Res.vol. 1, Mm3	10,488	10,500	10,500	10,500	10,500	10,158	9,718	8,751	8,724	9,667	10,500	10,500	10,441	9,643	10,042
Res.vol. 2, Mm3	10,500	10,500	10,500	10,500	10,158	9,718	8,751	8,724	9,667	10,500	10,500	10,500	10,313	9,774	10,043
Avg.Res. H, m	910	910	910	910	908	904	896	891	896	906	910	910	909	902	905
Outflow, Mm3	1,016	723	690	558	812	1,116	1,846	2,972	3,118	3,335	3,258	2,270	4,915	16,799	21,714

Outflow, m3/s	379	279	258	208	336	417	712	1,110	1,203	1,245	1,216	876	313	1,060	687
dH = H-Hout-Hlos, m	265	266	266	266	264	259	250	243	248	258	263	263	264	254	259
K	8.60	8.59	8.59	8.59	8.61	8.64	8.70	8.74	8.71	8.64	8.61	8.61	9	9	9
Qhps, m3/s	379	279	258	208	336	417	712	1,110	1,203	1,245	1,216	876	313	1,060	687
N, MWh	865	637	589	476	761	932	1,547	2,360	2,600	2,778	2,753	1,987	710	2,337	1,524
Enurek, mkwth	643	458	438	354	512	693	1,114	1,756	1,872	2,067	2,048	1,430	3,100	10,287	13,387
Evahsh, mkwth	214	175	167	148	197	228	342	496	532	548	537	405	1,128	2,859	3,987
E, mkwth	857	633	605	502	709	922	1,456	2,251	2,404	2,615	2,585	1,836	4,228	13,146	17,374
q = Out / Enur, m/kwth	1.58	1.58	1.58	1.57	1.59	1.61	1.66	1.69	1.67	1.61	1.59	1.59	1.59	1.63	1.62

2054-2055	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct-Mar	Apr-Sep	Oct-Sep
Inflow, Mm3	948	553	509	322	401	507	2,743	3,676	3,811	5,044	4,032	2,355	3,240	21,660	24,900
Rule Curve	0.99	0.99	0.97	0.91	0.87	0.81	0.85	0.86	0.86	0.97	0.99	0.99	0.92	0.92	0.92
Res.vol. 1, Mm3	10,500	10,500	10,500	10,232	9,652	9,146	8,540	8,973	9,053	9,060	10,235	10,500	10,088	9,393	9,741
Res.vol. 2, Mm3	10,500	10,500	10,232	9,652	9,146	8,540	8,973	9,053	9,060	10,235	10,500	10,500	9,762	9,720	9,741
Avg.Res. H, m	910	910	909	904	898	892	891	894	894	901	909	910	904	900	902
Outflow, Mm3	947	554	777	902	907	1,114	2,309	3,596	3,804	3,869	3,768	2,354	5,201	19,699	24,900
Outflow, m3/s	354	214	290	337	375	416	891	1,342	1,468	1,444	1,407	908	331	1,243	787
dH = H-Hout-Hlos, m	265	266	264	259	253	247	244	246	246	253	261	263	259	252	256
K	8.60	8.59	8.60	8.64	8.68	8.72	8.74	8.73	8.72	8.68	8.62	8.61	9	9	9
Qhps, m3/s	354	214	290	337	375	416	891	1,342	1,468	1,444	1,407	908	331	1,243	787
N, MWh	807	488	659	754	823	894	1,899	2,881	3,154	3,171	3,167	2,059	738	2,722	1,730
Enurek, mkwth	600	352	491	561	553	665	1,367	2,144	2,271	2,359	2,356	1,483	3,222	11,980	15,202
Evahsh, mkwth	204	150	179	197	212	228	411	585	634	625	610	418	1,170	3,283	4,453
E, mkwth	804	501	670	759	765	893	1,778	2,729	2,904	2,984	2,967	1,900	4,392	15,263	19,654
q = Out / Enur, m/kwth	1.58	1.57	1.58	1.61	1.64	1.67	1.69	1.68	1.68	1.64	1.60	1.59	1.61	1.64	1.64

Annex 4. River channel balance of the Amudarya River basin: dry year (2042-2043), comparison of cases

Case 3.

Water resources: based on the scenario of continued cycling, including climate change impact (REMO 04-06)
HEPS operation mode: energy-irrigation (maximum electricity generation throughout a year)
Afghanistan: increased water consumption (reduced flow in the Amudarya River) from 3 cubic km to 6 cubic km by 2050
Turkmenistan: cut of CDW discharge into Amudarya

№	Balance item	Unit	Dry year (2042 - 2043). Case 3.														
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	October-March	April-September	annual
	VAKH RIVER BASIN																
1	Inflow to the Nurek HS	Mm3	949	614	553	487	399	447	706	1,283	1,986	3,213	3,033	1,632	3,448	11,853	15,301
2	Flow regulation by the reservoir: (+) accumulation, (-) drawdown	Mm3	-221	-583	-779	-622	-582	-1,008	-374	-95	676	1,816	1,695	77	-3,795	3,795	0
3	Water releases from the Nurek HS	Mm3	1,170	1,197	1,332	1,110	981	1,454	1,080	1,378	1,310	1,398	1,338	1,554	7,243	8,058	15,301
4	Lateral inflow	Mm3	5	3	3	2	2	2	4	6	10	16	15	8	17	59	77
5	Open river channel losses	Mm3	23	24	27	22	20	29	22	28	26	28	27	31	145	162	308
6	Water intake from Vakhsh at Nurek-Tigrovaya Balka section: limit cuts for dry year and limit for average year (Tajikistan)	Mm3	470	428	350	329	353	528	331	543	617	651	636	466	2,458	3,244	5,702
7	Water intake downstream of Tigrovaya balka GS (Tajikistan)	Mm3	15	8	5	5	6	10	8	14	20	23	21	13	50	100	150
8	Deficit	Mm3	0	0	0	0	0	0	142	233	264	279	273	200	0	1,390	1,390
9	Return flow	Mm3	131	108	105	99	156	158	99	163	185	195	191	140	757	973	1,730
10	Vakhsh River's flow: mouth	Mm3	797	848	1,058	854	760	1,048	822	963	842	907	860	1,192	5,365	5,584	10,949
	PYANJ RIVER BASIN	Mm3															
1	Pyandj River (Khirmanjoy) +	Mm3	1,818	1,275	1,152	1,040	904	1,027	1,431	2,043	3,254	5,463	4,260	2,300	7,216	18,752	25,967

	Kokcha River (discharge intoto Pyandj River)															
3	Water intake from the Kokcha River (Afghanistan)	Mm3	82	45	28	30	35	58	86	162	227	259	237	147	280	1,120	1,399
5	Kyzylsu and Yakhsu Rivers (natural inflow)	Mm3	100	70	63	57	50	56	79	112	179	300	234	127	397	1,031	1,428
6	Water intake from Pyandj River: limit cuts for dry year and limit for average year (Tajikistan)	Mm3	78	43	27	29	34	55	77	144	201	230	210	131	266	992	1,257
7	Water deficit	Mm3	0	0	0	0	0	0	33	62	86	98	90	56	0	425	425
8	Water use of Kyzylsu and Yakhsu River basins (Tajikistan)	Mm3	29	16	10	11	13	21	31	58	81	93	85	53	100	400	500
9	Return flow	Mm3	23	13	8	9	10	17	23	33	60	69	73	39	80	297	377
10	Open river channel losses	Mm3	9	6	6	5	5	5	14	20	33	55	43	23	36	188	224
11	Pyandj River flow: Lower Pyandj	Mm3	1,742	1,247	1,152	1,031	878	960	1,324	1,804	2,953	5,196	3,992	2,112	7,011	17,381	24,392
	KAFIRNIGAN RIVER BASIN	Mm3															
1	Kafirnigan River basin: recorded flow	Mm3	162	137	126	70	75	193	476	710	595	420	244	152	763	2,596	3,359
2	Water supply to Surkhandarya basin (Karatag, Shirkent) through Large Hissar Canal (LHC)	Mm3	18	12	0	0	5	15	23	53	57	52	40	26	50	251	301
3	Water intake of Upper Kafirnigan PZ (Tajikistan)	Mm3	91	61	0	0	25	74	158	401	437	355	247	152	250	1,750	2,000
4	Water intake of Lower Kafirnigan PZ: limit cuts for dry year and limit for average year (Tajikistan)	Mm3	61	41	0	0	17	50	59	125	135	108	51	33	169	511	680
5	Water deficit	Mm3	0	0	0	0	0	0	6	0	1	43	93	71	0	215	215
6	Return flow	Mm3	53	36	0	0	15	43	65	68	172	139	139	96	147	678	825
7	Accumulation (+) and drawdown (-) of the reservoirs, losses	Mm3	30	20	10	10	10	20	60	60	60	20	0	0	100	200	300
8	Open river channel losses	Mm3	3	3	3	1	1	4	10	14	12	8	5	3	15	52	67
9	Kafirnigan River flow: mouth	Mm3	12	36	114	58	31	73	232	125	66	15	41	33	325	512	836
	SURKHANDARYA RIVER BASIN	Mm3															
1	Surkhandarya River basin: recorded inflow	Mm3	95	74	67	63	60	101	311	508	506	396	194	110	460	2,026	2,485

2	Water supply from Kafirnigan River basin (Varzob River) through LHC	Mm3	18	12	0	0	5	15	23	53	57	52	40	26	50	251	301
3	Water supply from Amudarya: limit cuts for dry year and limit for average year (Uzbekistan)	Mm3	134	52	0	0	50	134	109	131	151	184	174	90	370	840	1,210
4	Water intake of Karatag-Shirkent PZ (Tajikistan)	Mm3	29	11	0	0	11	29	41	50	58	70	66	34	80	320	400
5	Water intake of Surkhandarya PZ (Uzbekistan)	Mm3	290	112	0	0	109	290	441	531	612	747	705	364	800	3,400	4,200
	Including from Amudarya by limit	Mm3	134	52	0	0	50	134	109	131	151	184	174	90	370	840	1,210
6	Water deficit (by supply from Amudarya)	Mm3	0	0	0	0	0	0	47	56	65	79	75	39	0	360	360
7	CDF: formation	Mm3	87	34	0	0	33	87	132	79	124	224	272	189	240	1,020	1,260
8	Return water	Mm3	79	17	0	0	16	80	56	55	57	195	269	177	192	809	1,001
9	Accumulation (+) and drawdown (-) of the reservoirs, losses	Mm3	0	20	50	40	-30	-80	0	100	50	-50	-100	0	0	0	0
10	Open river channel losses	Mm3	2	1	1	1	1	2	6	10	10	8	4	2	9	41	50
11	Surkhandarya River flow: mouth	Mm3	6	10	16	21	40	89	10	56	41	53	2	2	182	165	347
	AMUDARYA RIVER BASIN	Mm3															
1	Vakhsh River flow: mouth	Mm3	797	848	1,058	854	760	1,048	822	963	842	907	860	1,192	5,365	5,584	10,949
2	Pyandj River flow: Lower Pyandj	Mm3	1,742	1,247	1,152	1,031	878	960	1,324	1,804	2,953	5,196	3,992	2,112	7,011	17,381	24,392
3	Natural flow of Kunduz is rehabilitated in the form of discharge to Amudarya + water intake (1.7 km3) at the level of 2000	Mm3	252	254	256	187	276	195	404	776	1,367	918	385	300	1,420	4,151	5,571
4	Water intake from Kunduz River (Afghanistan)	Mm3	118	65	40	43	50	83	170	419	545	509	316	240	400	2,199	2,598
5	Kunduz River: discharge to Amudarya	Mm3	134	190	216	143	226	112	235	357	822	409	69	60	1,021	1,952	2,973
6	Kafirnigan River flow: mouth	Mm3	12	36	114	58	31	73	232	125	66	15	41	33	325	512	836
7	Surkhandarya River flow: mouth	Mm3	6	10	16	21	40	89	10	56	41	53	2	2	182	165	347
8	Water intake from Amudarya to Surkhandarya PZ: limit cuts for dry year and limit for average year (Uzbekistan)	Mm3	134	52	0	0	50	134	109	131	151	184	174	90	370	840	1,210
9	Water deficit in Surkhandarya PZ	Mm3	0	0	0	0	0	0	47	56	65	79	75	39	0	360	360
10	Return flow to Amudarya	Mm3	8	17	0	0	17	7	76	24	67	29	3	12	48	211	259

11	Pen river channel losses	Mm3	13	12	13	11	10	11	13	17	24	33	25	17	70	128	197
12	Amudarya River flow: inflow to middle reaches	Mm3	2,553	2,285	2,543	2,097	1,891	2,144	2,577	3,181	4,615	6,391	4,767	3,305	13,512	24,837	38,350
13	Water intake to Garagumdarya – Mary, Akhal and Balkan PZs (Turkmenistan): limit cuts for dry year and limit for average year	Mm3	804	544	482	482	560	938	823	976	998	1,031	948	697	3,810	5473	9,283
14	Water deficit	Mm3	0	0	0	0	0	0	353	418	428	442	406	299	0	2,345	2,345
15	Water intake to Karshi Main Canal – Karshi PZ (Uzbekistan): limit cuts for dry year and limit for average year	Mm3	348	285	268	268	173	358	298	319	333	356	331	254	1,700	1,890	3,590
16	Water deficit	Mm3	0	0	0	0	0	0	128	137	143	153	142	109	0	810	810
17	Water intake to Amu Bukhara Canal – Bukhara and Navoi PZs (Uzbekistan): limit cuts for dry year and limit for average year	Mm3	223	202	184	464	228	243	266	326	415	513	426	178	1,545	2,124	3,669
18	Water deficit	Mm3	0	0	0	0	0	0	114	140	178	220	183	76	0	910	910
19	Water intake to Lebap PZ(Turkmenistan): limit cuts for dry year and limit for average year	Mm3	267	156	70	99	268	430	275	323	349	358	305	240	1,290	1,851	3,141
20	Water deficit	Mm3	0	0	0	0	0	0	118	138	150	154	131	103	0	793	793
21	Total water intake in middle reaches of Amudarya	Mm3	1,642	1,188	1,004	1,314	1,229	1,969	1,661	1,944	2,095	2,259	2,010	1,369	8,345	11,338	19,683
22	Return flow from Lepab PZ(Turkmenistan)	Mm3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	Return flow from Karshi PZ (Uzbekistan)	Mm3	32	24	31	32	42	43	36	48	40	43	40	20	204	226	430
24	Return flow from Bukhara PZ (Uzbekistan)	Mm3	46	41	36	95	107	61	76	92	104	128	107	24	386	531	917
25	Open river channel losses	Mm3	14	15	18	13	12	8	73	94	164	250	174	118	80	874	954
26	Amudarya River flow: inflow to TMHS	Mm3	975	1,147	1,588	897	800	271	955	1,283	2,500	4,053	2,729	1,862	5,677	13,383	19,060
27	Flow regulation by TMHS reservoirs: (+) accumulation, (-) drawdown	Mm3	150	700	1,150	500	-550	-1,950	-400	-1,050	-350	300	-500	0	0	-2,000	-2,000
28	Water losses in TMHS reservoirs	Mm3	80	46	10	10	10	70	65	80	110	110	60	110	226	535	761
	Water volume in the reservoir by the beginning of season	Mm3	4,000	4,150	4,850	6,000	6,500	5,950	4,000	3,600	2,550	2,200	2,500	2,000			

	Water volume in the reservoir by the end of season	Mm3	4,150	4,850	6,000	6,500	5,950	4000	3,600	2,550	2,200	2,500	2,000	2,000			
29	Water releases from TMHS (discharge to river + water intake)	Mm3	745	401	428	387	1,340	2,151	1,290	2,253	2,740	3,643	3,169	1,752	5,451	14,848	20,299
30	Water intake to Dashoguz PZ: limit cuts for dry year and limit for average year (Turkmenistan)	Mm3	111	0	0	90	523	675	511	506	534	738	788	449	1,400	3,527	4,927
31	Water deficit in Dashoguz PZ	Mm3	0	0	0	0	0	0	219	217	229	316	338	193	0	1,511	1,511
32	Water intake to Khorezm PZ: 90 % of limit for dry year and limit for average year (Uzbekistan)	Mm3	144	0	0	0	375	716	181	289	514	631	547	252	1,235	2,415	3,650
33	Water deficit in Khorezm PZ	Mm3	0	0	0	0	0	0	78	124	220	271	235	108	0	1,035	1,035
34	Water intake in Karakalpakstan’s PZs: 90 % of limit for dry year and limit for average year (Uzbekistan)	Mm3	301	324	154	3	278	439	201	859	986	1,406	1,072	260	1,500	4,784	6,284
35	Water deficit in Karakalpakstan	Mm3	0	0	0	0	0	0	86	368	422	603	459	111	0	2,050	2,050
36	Total water intake to lower reaches of Amudarya	Mm3	556	324	154	93	1,177	1,830	894	1,655	2,034	2,776	2,407	961	4,135	10,726	14,861
37	Water deficit in the lower reaches	Mm3	0	0	0	0	0	0	383	709	872	1,190	1,032	412	0	4,597	4,597
38	Discharge of emergency environmental flow into canals	Mm3	0	0	0	0	0	0	133	133	133	133	133	133	0	800	800
	Including to Dashoguz PZ	Mm3	0	0	0	0	0	0	25	25	25	25	25	25	0	150	150
	Khorezm PZ	Mm3	0	0	0	0	0	0	25	25	25	25	25	25	0	150	150
	Karakalpakstan’s PZs	Mm3	0	0	0	0	0	0	83	83	83	83	83	83	0	500	500
39	Collector-drainage flow	Mm3	222	130	62	37	471	732	358	662	814	1,110	963	384	1,654	4,290	5,944
	Including Dashoguz PZ	Mm3	44	0	0	36	209	270	204	202	214	295	315	180	560	1,411	1,971
	Khorezm PZ	Mm3	58	0	0	0	150	286	73	116	206	253	219	101	494	966	1,460
	Karakalpakstan’s PZs	Mm3	121	130	62	1	111	176	81	344	394	562	429	104	600	1,914	2,514
40	CDW reuse for irrigation	Mm3	28	16	8	5	59	92	45	83	102	139	120	48	207	536	743
	Including Dashoguz PZ	Mm3	6	0	0	5	26	34	26	25	27	37	39	22	70	176	246
	Khorezm PZ	Mm3	7	0	0	0	19	36	9	14	26	32	27	13	62	121	183
	Karakalpakstan’s PZ	Mm3	15	16	8	0	14	22	10	43	49	70	54	13	75	239	314
41	CDF discharge to lakes	Mm3	195	113	54	33	412	641	313	579	712	971	842	336	1,447	3,754	5,201
	Including Dashoguz PZ	Mm3	39	0	0	32	183	236	179	177	187	258	276	157	490	1,234	1,724
	Khorezm PZ	Mm3	50	0	0	0	131	250	64	101	180	221	192	88	432	845	1,278

	Karakalpakstan's PZs	Mm3	105	113	54	1	97	154	70	301	345	492	375	91	525	1,675	2,200
42	Return flow: discharge to Amudarya	Mm3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	River channel losses in the lower reaches of Amudarya	Mm3	74	40	43	39	134	215	232	406	493	656	570	315	545	2,673	3,218
44	Amudarya River flow: inflow to Prearalie	Mm3	114	37	231	255	29	105	31	60	79	78	58	343	771	649	1,420
45	Water supply to lakes in Prearalie	Mm3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	Water deficit in lake system	Mm3	333	333	333	333	333	333	500	500	500	500	500	500	2,000	3,000	5,000
47	Water losses in Prearalie	Mm3	0.6	0.2	1.2	1.3	0.1	0.5	0.2	0.3	0.4	0.4	0.3	1.7	4	3	7
48	Amudarya River flow: discharge to the Large Aral Sea (Eastern part)	Mm3	113	37	229	254	29	105	31	59	79	78	58	341	767	646	1,413
49	CDF discharge to Prearalie	Mm3	74	79	38	1	68	108	49	211	242	345	263	64	367	1,172	1,540
50	TOTAL SUPPLY TO THE ARAL SEA	Mm3	187	116	267	255	97	212	80	270	320	422	320	405	1,135	1,818	2,953
51	TOTAL WATER INTAKE	Mm3	2,941	2,076	1,535	1,765	2,860	4,566	3,130	4,541	5,233	6,208	5,489	3,050	15,743	27,650	43,393
52	TOTAL SUPPLY FOR ENVIRONMENTAL NEEDS	Mm3	0	0	0	0	0	0	133	133	133	133	133	133	0	800	800
53	TOTAL CDF	Mm3	308	211	129	164	636	843	545	826	1,024	1,310	1,112	440	2,292	5,259	7,550
	% of water intake	Mm3	10	10	8	9	22	18	17	18	20	21	20	14			
54	TOTAL WATER LOSSES	Mm3	169	101	72	63	156	294	370	580	768	1,016	805	545	855	4,085	4,940
	% of Amudarya's flow (5 rivers in total)	%	7	4	3	3	8	14	14	18	17	16	17	16			
55	Limit cuts in the basin	%	0	0	0	0	0	0	30	30	30	30	30	30	0	30	
56	TOTAL DEFICIT	Mm3	0	0	0	0	0	0	1,323	1,892	2,186	2,657	2,424	1,364	0	11,846	11,846

Case 4

Water resources: based on the scenario of continued cycling, including climate change impact (REMO 04-06)
HEPS mode: energy-irrigation (maximum electricity generation throughout a year)
Afghanistan: increased water consumption (reduced flow of the Amudarya River) from 3 cubic km to 6 cubic km by 2050
Turkmenistan: cut of CDW discharge into Amudarya

№	Balance item	unit	Dry year (2042 - 2043). Case 4														
			Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	October-March	April-September	annual
	VAKH RIVER BASIN																
1	Inflow to the Nurek HS	Mm3	949	614	553	487	399	447	706	1,283	1,986	3,213	3,033	1,632	3,448	11,853	15,301
2	Flow regulation by the reservoir: (+) accumulation, (-) drawdown	Mm3	75	0	0	-53	-146	-283	-409	-175	116	950	1	-3	-407	480	73
3	Water releases from the Nurek HS	Mm3	874	614	553	541	545	729	1,115	1,458	1,870	2,264	3,032	1,634	3,855	11,373	15,228
4	Lateral inflow	Mm3	5	3	3	2	2	2	4	6	10	16	15	8	17	59	77
5	Open river channel losses	Mm3	18	12	11	11	11	15	22	29	38	46	61	33	77	229	306
6	Water intake from Vakhsh at Nurek-Tigrovaya Balka section: limit cuts for dry year and limit for average year (Tajikistan)	Mm3	400	364	298	280	300	449	379	620	705	744	727	533	2,089	3,707	5,796
7	Water intake downstream of Tigrovaya balka GS (Tajikistan)	Mm3	15	8	5	5	6	10	8	14	20	23	21	13	50	100	150
8	Deficit	Mm3	71	64	53	49	53	79	95	155	176	186	182	133	369	927	1,295
9	Return flow	Mm3	111	88	89	84	176	155	114	186	211	223	218	160	703	1,112	1,815
10	Vakhsh's flow: mouth	Mm3	558	321	331	331	405	413	823	987	1,329	1,691	2,456	1,224	2,359	8,509	10,868
	PYANJ RIVER BASIN	Mm3															
1	Pyandj River (Khirmanjoy) + Kokcha River (discharge to Pyandj River)	Mm3	1,818	1,275	1,152	1,040	904	1,027	1,431	2,043	3,254	5,463	4,260	2,300	7,216	18,752	25,967
3	Water intake from the Kokcha River (Afghanistan)	Mm3	82	45	28	30	35	58	86	162	227	259	237	147	280	1,120	1,399
5	Kyzylsu and Yakhsu Rivers (natural inflow)	Mm3	100	70	63	57	50	56	79	112	179	300	234	127	397	1,031	1,428

6	Water intake from Pyandj River: limit cuts for dry year and limit for average year (Tajikistan)	Mm3	76	37	23	24	29	37	87	164	229	262	240	149	225	1,133	1,359
7	Water deficit	Mm3	2	6	4	4	5	18	22	41	57	66	60	37	40	283	324
8	Water use of Kyzylsu and Yakhsu River basins (Tajikistan)	Mm3	29	16	10	11	13	21	31	58	81	93	85	53	100	400	500
9	Return flow	Mm3	23	11	7	7	9	11	26	33	69	79	73	45	68	325	392
10	Open river channel losses	Mm3	9	6	6	5	5	5	14	20	33	55	43	23	36	188	224
11	Pyandj River flow: Lower Pyandj	Mm3	1,744	1,252	1,155	1,034	882	973	1,317	1,784	2,933	5,173	3,962	2,099	7,039	17,267	24,306
	KAFIRNIGAN RIVER BASIN	Mm3															
1	Kafirnigan River basin: recorded flow	Mm3	162	137	126	70	75	193	476	710	595	420	244	152	763	2,596	3,359
2	Water supply to Surkhandarya basin (Karatag, Shirkent) through Large Hissar Canal (LHC)	Mm3	18	12	0	0	5	15	23	53	57	52	40	26	50	251	301
3	Water intake of Upper Kafirnigan PZ (Tajikistan)	Mm3	91	71	0	0	25	64	158	401	437	355	247	152	251	1,750	2,000
4	Water intake of Lower Kafirnigan PZ: limit cuts for dry year and limit for average year (Tajikistan)	Mm3	62	35	0	0	14	33	52	100	109	121	115	83	144	581	725
5	Water deficit	Mm3	-1	6	0	0	3	17	13	25	27	30	29	21	25	145	170
6	Return flow	Mm3	54	37	0	0	14	34	63	68	164	143	169	116	138	723	861
7	Accumulation (+) and drawdown (-) of the reservoirs, losses	Mm3	30	30	20	20	0	0	60	60	60	20	0	0	100	200	300
8	Open river channel losses	Mm3	3	3	3	1	1	4	10	14	12	8	5	3	15	52	67
9	Kafirnigan River flow: mouth	Mm3	12	24	104	48	43	111	237	150	84	6	6	3	340	486	827
	SURKHANDARYA RIVER BASIN	Mm3															
1	Surkhandarya River basin: recorded inflow	Mm3	95	74	67	63	60	101	311	508	506	396	194	110	460	2,026	2,485
2	Water supply from Kafirnigan River basin (Varzob River) through LHC	Mm3	18	12	0	0	5	15	23	53	57	52	40	26	50	251	301
3	Water supply from Amudarya: limit cuts for dry year and limit for average year (Uzbekistan)	Mm3	114	95	0	0	43	64	124	150	173	211	199	103	316	960	1,276
4	Water intake of Karatag-Shirkent PZ (Tajikistan)	Mm3	29	11	0	0	11	29	41	50	58	70	66	34	80	320	400

5	Water intake of Surkhandarya PZ (Uzbekistan)	Mm3	290	112	0	0	109	290	441	531	612	747	705	364	800	3,400	4,200
	Including from Amudarya by limit	Mm3	114	95	0	0	43	64	124	150	173	211	199	103	316	960	1,276
6	Water deficit (by supply from Amudarya)	Mm3	20	-43	0	0	8	70	31	37	43	53	50	26	54	240	294
7	CDF: formation	Mm3	87	34	0	0	33	87	132	79	124	224	272	189	240	1,020	1,260
8	Return water	Mm3	95	17	0	0	16	95	56	55	57	195	269	177	223	809	1,032
9	Accumulation (+) and drawdown (-) of the reservoirs, losses	Mm3	0	50	50	50	-70	-80	0	100	50	-50	-100	0	0	0	0
10	Open river channel losses	Mm3	2	1	1	1	1	2	6	10	10	8	4	2	9	41	50
11	Surkhandarya River flow: mouth	Mm3	2	23	16	11	73	34	26	75	63	79	26	15	159	285	444
	AMUDARYA RIVER BASIN	Mm3															
1	Vakhsh River flow: mouth	Mm3	558	321	331	331	405	413	823	987	1,329	1,691	2,456	1,224	2,359	8,509	10,868
2	Pyandj River flow: Lower Pyandj	Mm3	1,744	1,252	1,155	1,034	882	973	1,317	1,784	2,933	5,173	3,962	2,099	7,039	17,267	24,306
3	Natural flow of Kunduz is rehabilitated in the form of discharge to Amudarya + water intake (1.7 km3) at the level of 2000	Mm3	252	254	256	187	276	195	404	776	1,367	918	385	300	1,420	4,151	5,571
4	Water intake from Kunduz River (Afghanistan)	Mm3	118	65	40	43	50	83	170	419	545	509	316	240	400	2,199	2,598
5	Kunduz River: discharge to Amudarya	Mm3	134	190	216	143	226	112	235	357	822	409	69	60	1,021	1,952	2,973
6	Kafirnigan River flow: mouth	Mm3	12	24	104	48	43	111	237	150	84	6	6	3	340	486	827
7	Surkhandarya River flow: mouth	Mm3	2	23	16	11	73	34	26	75	63	79	26	15	159	285	444
8	Water intake from Amudarya to Surkhandarya PZ: limit cuts for dry year and limit for average year (Uzbekistan)	Mm3	114	95	0	0	43	64	124	150	173	211	199	103	316	960	1,276
9	Water deficit in Surkhandarya PZ	Mm3	20	-43	0	0	8	70	31	37	43	53	50	26	54	240	294
10	Return flow to Amudarya	Mm3	0	17	0	0	17	0	76	24	67	29	3	12	33	211	244
11	Pen river channel losses	Mm3	12	9	9	8	8	8	13	17	26	37	33	17	55	142	197
12	Amudarya River flow: inflow to middle reaches	Mm3	2,323	1,722	1,812	1,560	1,594	1,571	2,576	3,210	5,098	7,139	6,292	3,293	10,582	27,607	38,190
13	Water intake to Garagumdarya – Mary, Akhal and Balkan PZs (Turkmenistan): limit cuts for dry year and limit for average year	Mm3	783	513	460	460	376	647	940	1,116	1,140	1,178	1,083	797	3,239	6,254	9,493
14	Water deficit	Mm3	21	31	22	22	184	291	235	279	285	295	271	199	571	1,564	2,135

15	Water intake to Karshi Main Canal – Karshi PZ (Uzbekistan): limit cuts for dry year and limit for average year	Mm3	346	292	228	228	147	204	340	364	380	407	378	290	1,444	2,160	3,604
16	Water deficit	Mm3	2	-7	40	40	26	154	85	91	95	102	95	73	256	540	796
17	Water intake to Amu Bukhara Canal – Bukhara and Navoi PZs (Uzbekistan): limit cuts for dry year and limit for average year	Mm3	210	192	177	395	174	166	303	373	475	587	487	203	1,314	2,428	3,742
18	Water deficit	Mm3	13	10	7	70	54	77	76	93	119	147	122	51	231	607	838
19	Water intake to Lebap PZ(Turkmenistan): limit cuts for dry year and limit for average year	Mm3	227	133	59	84	228	365	314	369	399	410	349	274	1,097	2,115	3,212
20	Water deficit	Mm3	40	23	10	15	40	64	79	92	100	102	87	69	194	529	722
21	Total water intake in middle reaches of Amudarya	Mm3	1,566	1,130	924	1,167	925	1,382	1,898	2,221	2,394	2,582	2,297	1,564	7,093	12,958	20,051
22	Return flow from Lepab PZ(Turkmenistan)	Mm3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	Return flow from Karshi PZ (Uzbekistan)	Mm3	22	24	21	27	52	87	41	48	46	49	45	20	233	249	482
24	Return flow from Bukhara PZ (Uzbekistan)	Mm3	36	21	16	85	97	92	76	92	119	147	122	24	347	579	926
25	Open river channel losses	Mm3	12	9	11	9	11	7	65	86	179	278	242	110	59	960	1,019
26	Amudarya River flow: inflow to TMHS	Mm3	803	628	914	496	808	361	730	1,042	2,689	4,475	3,920	1,663	4,010	14,518	18,528
27	Flow regulation by TMHS reservoirs: (+) accumulation, (-) drawdown	Mm3	0	100	300	0	-200	-1,000	-750	-1,510	-530	220	330	40	-800	-2,200	-3,000
28	Water losses in TMHS reservoirs	Mm3	30	15	5	5	5	10	65	80	110	110	60	110	70	535	605
	Water volume in the reservoir by the beginning of season	Mm3	7,000	7,000	7,100	7,400	7,400	7,200	6,200	5,450	3,940	3,410	3,630	3,960			
	Water volume in the reservoir by the end of season	Mm3	7,000	7,100	7,400	7,400	7,200	6,200	5,450	3,940	3,410	3,630	3,960	4,000			
29	Water releases from TMHS (discharge to river + water intake)	Mm3	773	513	609	491	1,003	1,351	1,415	2,472	3,109	4,145	3,530	1,513	4,740	16,183	20,923
30	Water intake to Dashoguz PZ: limit cuts for dry year and limit for average year (Turkmenistan)	Mm3	194	0	0	277	345	374	584	578	610	843	901	514	1,190	4,030	5,220
31	Water deficit in Dashoguz PZ	Mm3	-83	0	0	0	178	301	146	145	153	211	225	128	397	1,008	1,404
32	Water intake to Khorezm PZ: 90 % of limit for dry year and limit for average year (Uzbekistan)	Mm3	122	0	0	100	319	508	207	330	588	722	626	288	1,050	2,760	3,809
33	Water deficit in Khorezm PZ	Mm3	22	0	0	0	56	208	52	83	147	180	156	72	286	690	976

34	Water intake in Karakalpakstan's PZs: 90 % of limit for dry year and limit for average year (Uzbekistan)	Mm3	306	275	131	2	237	323	230	982	1,127	1,607	1,225	297	1,274	5,468	6,742
35	Water deficit in Karakalpakstan	Mm3	-5	49	23	0	42	116	58	246	282	402	306	74	226	1,367	1,593
36	Total water intake to lower reaches of Amudarya	Mm3	622	275	131	379	901	1,205	1,022	1,891	2,325	3,172	2,751	1,098	3,514	12,258	15,772
37	Water deficit in the lower reaches	Mm3	-66	49	23	0	276	625	255	473	581	793	688	275	908	3,065	3,972
38	Discharge of emergency environmental flow into canals	Mm3	0	0	0	0	0	0	133	133	133	133	133	133	0	800	800
	Including to Dashoguz PZ	Mm3	0	0	0	0	0	0	25	25	25	25	25	25	0	150	150
	Khorezm PZ	Mm3	0	0	0	0	0	0	25	25	25	25	25	25	0	150	150
	Karakalpakstan's PZs	Mm3	0	0	0	0	0	0	83	83	83	83	83	83	0	500	500
39	Collector-drainage flow	Mm3	249	110	52	152	360	482	409	756	930	1,269	1,100	439	1,406	4,903	6,309
	Including Dashoguz PZ	Mm3	78	0	0	111	138	150	234	231	244	337	360	205	476	1,612	2,088
	Khorezm PZ	Mm3	49	0	0	40	128	203	83	132	235	289	250	115	420	1,104	1,524
	Karakalpakstan's PZs	Mm3	122	110	52	1	95	129	92	393	451	643	490	119	510	2,187	2,697
40	CDW reuse for irrigation	Mm3	31	14	7	19	45	60	51	95	116	159	138	55	176	613	789
	Including Dashoguz PZ	Mm3	10	0	0	14	17	19	29	29	31	42	45	26	60	202	261
	Khorezm PZ	Mm3	6	0	0	5	16	25	10	17	29	36	31	14	52	138	190
	Karakalpakstan's PZ	Mm3	15	14	7	0	12	16	12	49	56	80	61	15	64	273	337
41	CDF discharge to lakes	Mm3	218	96	46	133	315	422	358	662	814	1,110	963	384	1,230	4,290	5,520
	Including Dashoguz PZ	Mm3	68	0	0	97	121	131	204	202	214	295	315	180	417	1,411	1,827
	Khorezm PZ	Mm3	43	0	0	35	112	178	73	116	206	253	219	101	367	966	1,333
	Karakalpakstan's PZs	Mm3	107	96	46	1	83	113	81	344	394	562	429	104	446	1914	2,360
42	Return flow: discharge to Amudarya	Mm3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	River channel losses in the lower reaches of Amudarya	Mm3	77	51	61	49	100	135	255	445	560	746	635	272	474	2,913	3,387
44	Amudarya River flow: inflow to Prearalie	Mm3	74	186	417	63	2	11	5	3	92	93	10	9	752	212	964
45	Water supply to lakes in Prearalie	Mm3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	Water deficit in lake system	Mm3	333	333	333	333	333	333	500	500	500	500	500	500	2,000	3,000	5,000
47	Water losses in Prearalie	Mm3	0.4	0.9	2.1	0.3	0.0	0.0	0.0	0.0	0.5	0.5	0.1	0.0	4	1	5
48	Amudarya River flow: discharge to the Large Aral Sea (Eastern part)	Mm3	73	185	415	63	2	11	5	3	91	93	10	9	748	211	959

49	CDF discharge to Prearalie	Mm3	75	67	32	1	58	79	56	241	276	394	300	73	312	1,340	1,652
50	TOTAL SUPPLY TO THE ARAL SEA	Mm3	148	253	447	63	60	90	61	243	367	487	310	82	1,061	1,550	2,611
51	TOTAL WATER INTAKE	Mm3	2,840	1,935	1,376	1,851	2,211	3,170	3,563	5,147	5,935	7,092	6,330	3,531	13,382	31,597	44,978
52	TOTAL SUPPLY FOR ENVIRONMENTAL NEEDS	Mm3	0	0	0	0	0	0	133	133	133	133	133	133	0	800	800
53	TOTAL CDF	Mm3	307	172	89	264	526	661	602	920	1,161	1,493	1,271	495	2,019	5,942	7,962
	% of water intake	Mm3	11	9	7	14	24	21	17	18	20	21	20	14			
54	TOTAL WATER LOSSES	Mm3	120	76	79	63	116	152	384	611	849	1,134	937	493	607	4,409	5,015
	% of Amudarya's flow (5 rivers in total)	%	5	4	4	4	7	10	15	19	17	16	15	15			
55	Limit cuts in the basin	%	0	0	0	0	0	0	30	30	30	30	30	30	0	30	
56	TOTAL DEFICIT	Mm3	102	140	160	201	648	1,396	891	1,287	1,484	1,773	1,582	883	2,648	7,899	10,547

Comparison of cases

Annual volume	Case	2020-21	2021-22	2022-23	2023-24	2024-25	2025-26	2026-27	2027-28	2028-29	2029-30
Amudarya River flow, upstream of water intake to Garagumdarya, km^3	1	56.89	43.86	55.58	49.93	61.16	91.66	56.53	47.38	45.13	67.68
	2	56.92	43.91	55.26	49.22	61.16	92.21	56.26	47.23	44.97	67.70
	3	55.30	42.92	53.96	48.52	59.19	89.24	60.41	53.14	43.92	65.59
	4	55.33	42.74	53.64	47.81	59.19	89.79	60.14	52.99	43.76	65.62
Amudarya River flow at Birata GS (inflow to TMHS), km^3	1	34.30	23.87	33.02	29.66	38.40	66.73	33.28	26.56	24.33	43.74
	2	34.18	23.15	32.56	26.86	38.24	67.10	32.84	25.57	24.11	43.63
	3	32.80	23.65	31.48	28.33	36.54	64.45	36.98	32.04	23.19	41.76
	4	32.67	22.04	31.03	25.53	36.38	64.81	36.54	31.05	22.97	41.66
Water supply to lakes in South Prearalie, km^3	1	5.00	2.00	3.00	4.00	5.00	5.00	5.00	2.00	1.00	5.00
	2	5.00	0.00	3.00	1.00	5.00	5.00	5.00	1.00	0.00	5.00
	3	5.00	2.00	3.00	3.00	5.00	5.00	5.00	5.00	0.00	5.00
	4	4.00	0.00	2.00	1.00	5.00	5.00	5.00	1.00	0.00	3.00
Water supply to the Aral Sea from the Amudarya and collectors, km^3	1	6.30	2.77	4.84	3.50	5.60	32.26	3.40	3.13	2.50	9.38
	2	3.31	2.69	4.88	2.39	6.98	29.08	3.07	2.67	2.83	9.97
	3	5.24	3.22	3.76	3.47	4.29	30.51	6.03	4.32	2.64	8.00
	4	3.07	2.23	3.51	2.60	5.27	27.42	5.71	6.56	3.57	8.77
Water diversion, km^3	1	55.24	49.32	55.24	49.32	55.24	55.24	55.24	49.32	49.32	55.24
	2	55.24	51.29	55.24	55.24	55.24	55.24	55.24	51.29	49.72	55.24
	3	55.24	47.34	55.24	49.32	55.24	55.24	55.24	49.32	49.32	55.24
	4	55.24	51.29	55.24	55.24	55.24	55.24	55.24	51.29	49.72	55.24
Open river channel losses, km^3	1	9.47	6.10	8.63	7.43	9.45	16.50	8.23	6.55	5.92	11.40
	2	8.50	5.85	8.27	6.71	10.06	18.23	8.29	6.46	6.15	11.83
	3	8.94	6.07	8.09	7.05	8.78	15.83	9.48	8.11	5.58	10.69
	4	8.14	5.54	7.62	6.60	9.30	17.47	9.53	8.32	6.21	10.94
Water deficit, km^3	1	0.00	5.92	0.00	5.92	0.00	0.00	0.00	5.92	5.92	0.00
	2	0.00	3.95	0.00	0.00	0.00	0.00	0.00	3.95	5.52	0.00
	3	0.00	7.90	0.00	5.92	0.00	0.00	0.00	5.92	5.92	0.00
	4	0.00	3.95	0.00	0.00	0.00	0.00	0.00	3.95	5.52	0.00

Volume for April-September	Case	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Amudarya River flow, upstream of water intake to Garagumdarya, km^3	1	42.54	30.72	42.45	36.04	45.83	72.85	39.58	32.88	33.00	54.17
	2	46.38	33.33	45.93	38.77	49.75	77.30	43.77	36.67	35.57	57.34
	3	40.86	29.65	40.67	34.47	43.66	70.11	43.22	38.42	31.57	51.81
	4	44.69	32.03	44.16	37.20	47.57	74.56	47.40	42.21	34.14	54.98
Amudarya River flow at Birata GS (inflow to TMHS), km^3	1	27.15	17.92	27.06	22.96	30.28	55.41	23.81	19.52	19.63	37.67
	2	30.79	19.73	30.37	23.57	34.00	59.64	27.79	22.42	21.38	40.68
	3	25.55	17.56	25.38	21.47	28.21	52.82	27.27	24.78	18.27	35.43
	4	29.20	18.49	28.69	22.08	31.93	57.04	31.24	27.68	20.02	38.44
Water supply to lakes in South Prearalie, km^3	1	3.00	0.00	3.00	3.00	3.00	3.00	3.00	1.00	1.00	3.00
	2	3.00	0.00	3.00	0.50	3.00	3.00	3.00	0.00	0.00	3.00
	3	3.00	0.00	3.00	2.00	3.00	3.00	3.00	3.00	0.00	3.00
	4	3.00	0.00	2.00	0.50	3.00	3.00	3.00	0.00	0.00	3.00
Water supply to the Aral Sea from the Amudarya and collectors, km^3	1	3.70	1.68	4.38	2.55	4.44	28.62	2.81	1.91	1.99	8.20
	2	2.59	1.62	4.00	1.96	5.60	25.21	2.68	2.05	2.11	9.60
	3	2.57	2.03	3.18	2.40	2.98	26.63	5.26	3.84	1.93	6.62
	4	2.20	1.80	2.86	2.02	4.14	23.29	5.12	5.78	2.68	8.01
Water diversion, km^3	1	39.49	33.57	39.49	33.57	39.49	39.49	39.49	33.57	33.57	39.49
	2	39.49	35.54	39.49	39.49	39.49	39.49	39.49	35.54	35.54	39.49
	3	39.49	31.59	39.49	33.57	39.49	39.49	39.49	33.57	33.57	39.49
	4	39.49	35.54	39.49	39.49	39.49	39.49	39.49	35.54	35.54	39.49
Open river channel losses, km^3	1	7.60	4.93	7.84	6.37	8.16	14.46	7.01	5.40	5.44	10.20
	2	7.55	5.22	7.70	6.07	8.91	16.33	7.33	5.65	5.50	10.98
	3	7.05	4.88	7.26	5.95	7.45	13.72	8.20	7.02	5.07	9.43
	4	7.26	5.13	7.07	5.94	8.20	15.50	8.52	7.46	5.50	10.21
Water deficit, km^3	1	0.00	5.92	0.00	5.92	0.00	0.00	0.00	5.92	5.92	0.00
	2	0.00	3.95	0.00	0.00	0.00	0.00	0.00	3.95	3.95	0.00
	3	0.00	7.90	0.00	5.92	0.00	0.00	0.00	5.92	5.92	0.00
	4	0.00	3.95	0.00	0.00	0.00	0.00	0.00	3.95	3.95	0.00

Annual volume	Case	2030-31	2031-32	2032-33	2033-34	2034-35	2035-36	2036-37	2037-38	2038-39	2039-40
Amudarya River flow, upstream of water intake to Garagumdarya, km^3	1	38.90	54.24	51.47	52.28	60.31	52.29	49.13	48.20	41.56	51.44
	2	39.30	53.11	51.47	51.90	60.31	51.66	49.05	48.04	41.38	51.36
	3	37.80	52.65	50.16	50.75	58.33	52.43	48.63	50.28	40.45	50.15
	4	38.43	51.51	50.16	50.37	58.33	51.80	48.55	50.12	40.52	49.84
Amudarya River flow at Birata GS (inflow to TMHS), km^3	1	19.83	32.33	29.80	30.52	36.80	30.19	26.44	26.26	21.39	28.61
	2	19.84	29.72	29.64	28.62	36.64	27.24	26.20	25.22	20.78	28.38
	3	18.79	30.83	28.57	29.08	34.93	30.33	25.98	28.25	20.36	28.13
	4	19.71	28.22	28.41	27.18	34.78	27.38	25.73	27.21	20.70	26.95
Water supply to lakes in South Prearalie, km^3	1	1.00	4.00	4.00	4.00	5.00	5.00	2.00	2.00	0.00	4.00
	2	0.00	2.00	4.00	2.00	5.00	1.00	1.00	1.00	0.00	2.00
	3	0.00	3.00	4.00	3.00	5.00	5.00	3.00	3.00	1.00	3.00
	4	0.00	1.00	3.00	1.00	5.00	1.00	1.00	2.00	0.00	1.00
Water supply to the Aral Sea from the Amudarya and collectors, km^3	1	2.71	3.30	3.76	3.65	5.17	3.08	3.16	2.20	3.20	2.12
	2	2.29	2.67	2.99	2.77	5.82	2.68	3.08	2.47	1.98	2.96
	3	2.80	3.15	2.91	3.58	3.88	3.21	1.96	2.77	2.22	2.50
	4	2.86	2.53	2.90	2.67	4.52	2.79	2.78	3.05	2.63	2.88
Water diversion, km^3	1	45.37	51.29	51.29	51.29	55.24	49.32	51.29	49.32	45.37	51.29
	2	46.95	55.24	51.29	55.24	55.24	55.24	51.29	51.29	46.95	51.29
	3	45.37	51.29	51.29	51.29	55.24	49.32	51.29	49.32	45.37	49.32
	4	44.98	55.24	51.29	55.24	55.24	55.24	51.29	51.29	44.98	51.29
Open river channel losses, km^3	1	5.29	7.84	7.60	7.52	9.23	7.45	6.77	6.23	5.46	7.12
	2	4.98	7.54	7.38	7.23	9.59	6.91	6.77	6.36	5.37	7.19
	3	5.09	7.40	7.14	7.06	8.55	7.46	6.47	6.75	5.34	6.88
	4	4.94	7.09	7.16	6.81	8.91	6.93	6.57	6.87	5.29	6.76
Water deficit, km^3	1	9.87	3.95	3.95	3.95	0.00	5.92	3.95	5.92	9.87	3.95
	2	8.29	0.00	3.95	0.00	0.00	0.00	3.95	3.95	8.29	3.95
	3	9.87	3.95	3.95	3.95	0.00	5.92	3.95	5.92	9.87	5.92
	4	10.26	0.00	3.95	0.00	0.00	0.00	3.95	3.95	10.26	3.95

Volume for April-September	Case	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Amudarya River flow, upstream of water intake to Garagumdarya, km^3	1	25.77	41.33	35.84	37.93	45.13	37.28	34.48	34.17	27.82	37.37
	2	28.39	43.85	39.89	41.55	49.05	40.77	38.60	37.96	31.29	41.20
	3	24.40	39.46	34.20	36.07	42.80	37.06	33.61	35.87	26.34	35.68
	4	27.26	41.98	38.25	39.69	46.72	40.54	37.73	39.66	30.05	39.27
Amudarya River flow at Birata GS (inflow to TMHS), km^3	1	14.14	26.85	21.64	23.62	29.09	23.02	19.63	20.07	15.50	22.38
	2	15.25	27.87	25.49	25.69	32.81	24.15	23.55	22.94	17.33	26.02
	3	12.84	25.07	20.08	21.85	26.87	22.81	18.80	21.68	14.09	21.50
	4	14.86	26.10	23.92	23.92	30.59	23.94	22.72	24.55	16.88	24.19
Water supply to lakes in South Prearalie, km^3	1	0.00	3.00	3.00	2.00	3.00	3.00	1.00	0.00	0.00	3.00
	2	0.00	2.00	2.00	1.00	3.00	0.00	1.00	0.00	0.00	2.00
	3	0.00	2.00	2.00	1.00	3.00	3.00	1.00	1.00	1.00	3.00
	4	0.00	1.00	2.00	0.00	3.00	0.00	0.00	1.00	0.00	1.00
Water supply to the Aral Sea from the Amudarya and collectors, km^3	1	1.73	2.48	2.48	2.57	4.33	1.86	2.12	1.73	1.98	1.53
	2	1.58	2.16	1.68	2.31	4.76	2.11	1.95	1.67	1.57	2.06
	3	1.53	2.13	2.28	2.22	2.76	1.70	1.54	1.97	1.51	1.52
	4	1.94	1.80	2.05	1.92	3.19	1.93	2.26	1.92	1.89	1.66
Water diversion, km^3	1	29.62	35.54	35.54	35.54	39.49	33.57	35.54	33.57	29.62	35.54
	2	33.57	39.49	35.54	39.49	39.49	39.49	35.54	35.54	33.57	35.54
	3	29.62	35.54	35.54	35.54	39.49	33.57	35.54	33.57	29.62	33.57
	4	31.59	39.49	35.54	39.49	39.49	39.49	35.54	35.54	31.59	35.54
Open river channel losses, km^3	1	4.27	6.87	6.39	6.39	8.04	6.18	5.68	5.21	4.48	6.16
	2	4.25	6.93	6.24	6.48	8.53	6.11	5.98	5.60	4.88	6.47
	3	4.10	6.36	5.95	5.88	7.27	6.11	5.39	5.66	4.46	5.92
	4	4.15	6.42	6.23	6.01	7.77	6.05	5.79	6.06	4.75	5.93
Water deficit, km^3	1	9.87	3.95	3.95	3.95	0.00	5.92	3.95	5.92	9.87	3.95
	2	5.92	0.00	3.95	0.00	0.00	0.00	3.95	3.95	5.92	3.95
	3	9.87	3.95	3.95	3.95	0.00	5.92	3.95	5.92	9.87	5.92
	4	7.90	0.00	3.95	0.00	0.00	0.00	3.95	3.95	7.90	3.95

Annual volume	Case	2040-41	2041-42	2042-43	2043-44	2044-45	2045-46	2046-47	2047-48	2048-49	2049-50
Amudarya River flow, upstream of water intake to Garagumdarya, km³	1	55.40	49.87	39.57	59.51	67.37	42.01	57.33	56.00	69.57	60.84
	2	55.47	49.84	39.03	59.16	67.24	41.40	57.78	55.51	69.58	60.83
	3	53.51	48.14	38.32	57.51	64.95	40.51	55.24	54.25	66.90	57.82
	4	53.59	48.11	37.78	57.16	64.83	39.90	55.70	53.75	66.92	57.81
Amudarya River flow at Birata GS (inflow to TMHS), km³	1	30.94	27.87	19.48	36.32	42.40	21.81	32.74	33.13	44.55	36.10
	2	30.85	27.73	18.54	34.37	42.15	20.84	33.04	31.04	44.42	35.95
	3	29.17	26.25	19.04	34.44	40.12	21.13	30.78	31.49	42.04	33.25
	4	29.08	26.10	18.10	32.48	39.88	20.16	31.08	29.39	41.91	33.10
Water supply to the in South Prearalie, km³	1	2.00	4.00	0.00	5.00	4.00	1.00	4.00	5.00	5.00	5.00
	2	3.00	1.00	0.00	3.00	5.00	0.00	3.00	3.00	5.00	5.00
	3	2.00	3.00	0.00	5.00	5.00	1.00	4.00	4.00	5.00	5.00
	4	2.00	1.00	0.00	2.00	5.00	0.00	2.00	3.00	5.00	5.00
Water supply to the Aral Sea from the Amudarya and collectors, km³	1	3.60	3.05	2.55	5.49	9.25	2.58	4.57	4.59	11.44	5.45
	2	3.46	3.76	2.17	4.40	9.86	2.77	3.38	3.74	11.54	5.29
	3	2.38	2.83	2.90	4.24	6.77	2.74	3.21	4.37	9.70	3.49
	4	3.14	2.64	2.53	4.03	8.29	2.97	2.93	4.08	8.19	3.30
Water diversion, km³	1	55.24	49.32	45.37	51.29	55.24	45.37	55.24	51.29	55.24	55.24
	2	55.24	49.72	46.95	55.24	55.24	46.95	55.24	55.24	55.24	55.24
	3	55.24	49.32	43.39	51.29	55.24	43.39	55.24	51.29	55.24	55.24
	4	55.24	49.72	44.98	55.24	55.24	44.98	55.24	55.24	55.24	55.24
Open river channel losses, km³	1	7.72	7.06	5.13	8.82	11.04	5.54	8.68	8.21	12.05	9.32
	2	7.93	7.03	4.82	8.69	11.30	5.59	8.32	7.69	11.96	9.46
	3	7.06	6.55	4.97	8.07	10.10	5.32	7.95	7.68	11.12	8.25
	4	7.37	6.42	4.65	8.05	10.46	5.33	7.69	7.59	10.65	8.43
Water deficit, km³	1	0.00	5.92	9.87	3.95	0.00	9.87	0.00	3.95	0.00	0.00
	2	0.00	5.52	8.29	0.00	0.00	8.29	0.00	0.00	0.00	0.00
	3	0.00	5.92	11.85	3.95	0.00	11.85	0.00	3.95	0.00	0.00
	4	0.00	5.52	10.26	0.00	0.00	10.26	0.00	0.00	0.00	0.00

Volume for April-September	Case	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Amudarya River flow, upstream of water intake to Garagumdarya, km^3	1	40.58	35.24	26.47	44.36	50.47	28.66	43.33	37.36	51.30	46.44
	2	44.60	39.09	29.03	48.07	53.57	30.35	47.12	40.91	54.80	49.80
	3	38.26	33.08	24.83	41.88	47.53	26.72	40.76	35.00	48.02	42.94
	4	42.28	36.93	27.40	45.60	50.63	28.41	44.55	38.55	51.52	46.31
Amudarya River flow at Birata GS (inflow to TMHS), km^3	1	23.97	21.09	14.21	29.01	33.37	16.29	26.58	22.37	34.15	29.53
	2	27.79	24.01	15.19	31.09	36.31	16.44	30.18	24.29	37.48	32.73
	3	21.76	19.04	13.38	26.66	30.57	15.17	24.14	20.12	31.03	26.21
	4	25.58	21.96	14.37	28.74	33.51	15.32	27.74	22.04	34.36	29.41
Water supply to the in South Prearalie, km^3	1	2.00	2.00	0.00	3.00	3.00	0.00	3.00	3.00	3.00	3.00
	2	2.00	1.00	0.00	3.00	3.00	0.00	3.00	1.00	3.00	3.00
	3	1.00	1.00	0.00	3.00	3.00	0.00	3.00	2.00	3.00	3.00
	4	0.00	0.00	0.00	2.00	3.00	0.00	2.00	1.00	3.00	3.00
Water supply to the Aral Sea from the Amudarya and collectors, km^3	1	2.35	2.12	1.76	4.76	8.10	1.74	4.04	3.00	10.14	4.65
	2	2.10	2.27	1.53	3.54	7.24	2.11	2.90	2.03	8.06	4.70
	3	1.69	1.57	1.79	3.09	6.12	1.55	2.30	2.31	7.93	2.30
	4	2.34	1.72	1.55	2.77	5.26	1.92	2.06	1.90	5.86	2.35
Water diversion, km^3	1	39.49	33.57	29.62	35.54	39.49	29.62	39.49	35.54	39.49	39.49
	2	39.49	35.54	33.57	39.49	39.49	33.57	39.49	39.49	39.49	39.49
	3	39.49	33.57	27.64	35.54	39.49	27.64	39.49	35.54	39.49	39.49
	4	39.49	35.54	31.59	39.49	39.49	31.59	39.49	39.49	39.49	39.49
Open river channel losses, km^3	1	6.68	5.88	4.34	7.92	9.81	4.56	7.74	6.68	10.61	8.23
	2	6.94	6.14	4.27	7.98	9.78	5.01	7.67	6.33	10.18	8.55
	3	6.02	5.27	4.11	7.11	8.85	4.24	6.90	6.01	9.53	7.09
	4	6.39	5.53	4.05	7.27	8.82	4.69	6.93	6.09	9.11	7.40
Water deficit, km^3	1	0.00	5.92	9.87	3.95	0.00	9.87	0.00	3.95	0.00	0.00
	2	0.00	3.95	5.92	0.00	0.00	5.92	0.00	0.00	0.00	0.00
	3	0.00	5.92	11.85	3.95	0.00	11.85	0.00	3.95	0.00	0.00
	4	0.00	3.95	7.90	0.00	0.00	7.90	0.00	0.00	0.00	0.00

Annual volume	Case	2050-51	2051-52	2052-53	2053-54	2054-55	average	MAX	MIN
Amudarya River flow, upstream of water intake to Garagumdarya, km^3	1	66.63	46.86	49.59	50.27	73.47	54.85	91.66	38.90
	2	65.35	46.83	49.41	49.80	73.47	54.66	92.21	39.03
	3	63.58	44.93	47.57	47.99	70.11	53.58	89.24	37.80
	4	62.30	44.66	47.62	47.75	70.11	53.39	89.79	37.78
Amudarya River flow at Birata GS (inflow to TMHS), km^3	1	41.62	25.68	26.83	29.03	48.16	32.36	66.73	19.48
	2	40.20	25.55	25.06	26.97	48.06	31.58	67.10	18.54
	3	38.74	24.59	25.66	26.89	45.00	31.29	64.45	18.79
	4	37.32	23.51	24.85	25.78	44.90	30.53	64.81	18.10
Water supply to lakes in South Prearalie, km^3	1	4.00	3.00	3.00	4.00	5.00	3.49	5.00	0.00
	2	4.00	2.00	2.00	1.00	5.00	2.57	5.00	0.00
	3	5.00	3.00	3.00	3.00	5.00	3.46	5.00	0.00
	4	4.00	0.00	3.00	1.00	5.00	2.26	5.00	0.00
Water supply to the Aral Sea from the Amudarya and collectors, km^3	1	8.71	2.99	2.58	3.75	12.60	5.41	32.26	2.12
	2	9.12	2.70	2.74	2.92	12.43	5.08	29.08	1.98
	3	5.81	2.90	2.34	3.17	10.40	4.79	30.51	1.96
	4	7.12	3.10	2.96	2.72	10.23	4.76	27.42	2.53
Water diversion, km^3	1	55.24	47.34	51.29	47.34	55.24	51.57	55.24	45.37
	2	55.24	47.74	55.24	51.29	55.24	52.97	55.24	46.95
	3	55.24	45.37	49.32	47.34	55.24	51.23	55.24	43.39
	4	55.24	47.74	51.29	49.32	55.24	52.58	55.24	44.98
Open river channel losses, km^3	1	10.84	6.55	6.80	7.19	12.79	8.23	16.50	5.13
	2	11.15	6.52	6.59	6.68	12.96	8.18	18.23	4.82
	3	9.69	6.14	6.46	6.49	11.64	7.84	15.83	4.97
	4	10.11	5.95	6.47	6.26	11.80	7.84	17.47	4.65
Water deficit, km^3	1	0.00	7.90	3.95	7.90	0.00	3.67	9.87	0.00
	2	0.00	7.50	0.00	3.95	0.00	2.27	8.29	0.00
	3	0.00	9.87	5.92	7.90	0.00	4.01	11.85	0.00
	4	0.00	7.50	3.95	5.92	0.00	2.66	10.26	0.00

Volume for April-September	Case	2051	2052	2053	2054	2055	average	MAX	MIN
Amudarya River flow, upstream of water intake to Garagumdarya, km^3	1	51.61	33.92	36.12	34.37	57.30	40.14	72.85	25.77
	2	55.49	37.26	39.32	37.79	59.78	43.55	77.30	28.39
	3	48.04	31.53	33.61	31.55	53.37	38.49	70.11	24.40
	4	51.92	34.64	37.05	35.21	55.85	41.91	74.56	27.26
Amudarya River flow at Birata GS (inflow to TMHS), km^3	1	34.45	20.56	21.19	20.98	39.86	25.28	55.41	14.14
	2	38.14	23.00	22.77	22.77	42.21	27.88	59.64	15.25
	3	31.05	19.02	19.53	18.30	36.12	23.84	52.82	12.84
	4	34.74	20.51	22.07	21.05	38.47	26.47	57.04	14.86
Water supply to lakes in South Prearalie, km^3	1	3.00	2.00	2.00	2.00	3.00	2.14	3.00	0.00
	2	3.00	2.00	2.00	1.00	3.00	1.70	3.00	0.00
	3	3.00	1.00	1.00	1.00	3.00	1.94	3.00	0.00
	4	3.00	0.00	3.00	1.00	3.00	1.41	3.00	0.00
Water supply to the Aral Sea from the Amudarya and collectors, km^3	1	7.39	1.64	1.59	2.65	10.49	4.27	28.62	1.68
	2	8.53	2.06	1.84	2.14	11.42	4.05	25.21	1.62
	3	4.99	2.11	1.92	1.66	7.84	3.59	26.63	1.51
	4	6.13	2.10	1.64	1.52	8.77	3.61	23.29	1.55
Water diversion, km^3	1	39.49	31.59	35.54	31.59	39.49	35.82	39.49	29.62
	2	39.49	33.57	39.49	35.54	39.49	37.63	39.49	33.57
	3	39.49	29.62	33.57	31.59	39.49	35.48	39.49	27.64
	4	39.49	33.57	35.54	33.57	39.49	37.23	39.49	31.59
Open river channel losses, km^3	1	9.66	5.47	5.85	5.91	11.26	7.08	14.46	4.27
	2	10.41	5.96	5.93	5.97	11.81	7.30	16.33	4.25
	3	8.49	5.06	5.45	5.09	9.97	6.64	13.72	4.10
	4	9.24	5.30	5.73	5.44	10.52	6.93	15.50	4.05
Water deficit, km^3	1	0.00	7.90	3.95	7.90	0.00	3.67	9.87	0.00
	2	0.00	5.92	0.00	3.95	0.00	1.86	5.92	0.00
	3	0.00	9.87	5.92	7.90	0.00	4.01	11.85	0.00
	4	0.00	5.92	3.95	5.92	0.00	2.26	7.90	0.00

Annex 5. GAMS-based model for optimization of the Nurek HEPS operation

The model describes operation of the Nurek HEPS in the Vakhsh cascade. The input data are monthly flow hydrographs (series) of the Vakhsh River for 2015-2055. Those were derived under the PEER project using two scenarios: i) scenario of continued cycling, excluding climate change impact, ii) scenario of continued cycling, with account of climate change impact (REMO 0406 scenario). Output data are parameters of HEPS operation (discharge, head, capacity, and generated electricity). The following boundary conditions are considered in the model: maximum and minimum water level in the Nurek reservoir, maximum and minimum allowable discharge at HEPS, and installed capacity of HEPS. A bathymetric curve (relationship between reservoir water volume and water surface level), relationship between efficiency coefficient and HEPS head, and relationship between water level in the Vakhsh River downstream of HEPS and discharge by HEPS in the tailwater are considered in the model (algorithm). Optimization is made by two criteria (target functions): i) maximizing electricity generation in autumn and winter (October-March), ii) maximizing electricity generation throughout a year.

<u>File structure of the optimization program for the Nurek HEPS</u>

In total, 63 files were created (7 folders / 9 files).
The files are stored in the directory C: / ASBmm / WAM / A in seven folders: 2020=2025, 2025-2030,…2050-2055.
Each folder contains the files that:

1. Realize the algorithm (a.gms, a1.txt, a2.txt, a3.txt);
2. Contain input data on the Vakhsh River flow (riv.txt, riv.csv);
3. Contain output (results of calculation) – water volume in the reservoir and water releases from the Nurek reservoir (wr.csv, wr.xls, test.txt).

The optimization program is started using

GAMS A / GMS.

A.GMS program listing:

```
$title PEER / NUREK / SIC ICWC, D.Sorokin, 1.07.2017
$inlinecom { }
$offlisting
*$offsymxref
*$offsymlist
*$offuellist
*$offupper

$include 'c:\ASBmm\WAm\A\a1.txt'
$include 'c:\ASBmm\WAm\A\a2.txt'

option reslim =10000;
*option reslim =1000;

option iterlim = 20000;
*option iterlim = 5000;

*option domlim =10000;
*option optcr = 0.000001;

option limrow =0;
option limcol =0;

option solprint = off;

model OP6 /E1,E2,E3,Fun6 /;
model OP7 /E1,E2,E3,Fun7 /;
model OP8 /E1,E2,E3,Fun8 /;

FILE CON;
put CON;
put ' ' put /;
put '----------------------------------- ' put /;
put '   Model ASBmm, WAM, 1.07.2017' put /;
put '   SIC ICWC,  D.Sorokin 'put /;

if (xxx('1')=6,
solve OP6 using NLP maximizing Y6;
else
   );
if (xxx('1')=7,
solve OP7 using NLP maximizing Y7;
else
   );
if (xxx('1')=8,
solve OP8 using NLP maximizing Y8;
else
   );
```

```
$include 'c:\ASBmm\WAm\A\a3.txt'

*   PEEE  /  NUREK / SIC ICWC 1.07.2017  /  D.Sorokin
*   Water Allocation Model  /  Amudarya River Basin
*   Sub-program   /   Structural & Input data block
*   File a1.txt

 sets

 t  /  1*60 /
 tt(t)  / 1*5 /
 t0(t)  / 1 /
 tn(t)  /  1*6, 13*18, 25*30, 37*42, 49*54  /
 tv(t)  /  7*12, 19*24, 31*36, 43*48, 55*60  /
 t1(t)     /  1*12  /
 t2(t)     /  13*24  /
 t3(t)     /  25*36  /
 t4(t)     /  37*48  /
 t5(t)     /  49*60  /

 tv1(t)   /  7*12   /
 tv2(t)   /  19*24  /
 tv3(t)   /  31*36  /
 tv4(t)   /  43*48  /
 tv5(t)   /  55*60  /
 tn1(t)   /  1*6    /
 tn2(t)   /  13*18  /
 tn3(t)   /  25*30  /
 tn4(t)   /  37*42  /
 tn5(t)   /  49*54  /

 tt1(tt)  /  1  /
 tt2(tt)  /  2  /
 tt3(tt)  /  3  /
 tt4(tt)  /  4  /
 tt5(tt)  /  5  /

*NEW

 oct (t)  /  1, 13, 25, 37, 49  /
 nov (t)  /  2, 14, 26, 38, 50  /
 dec (t)  /  3, 15, 27, 39, 51  /
 jan (t)  /  4, 16, 28, 40, 52  /
 feb (t)  /  5, 17, 29, 41, 53  /
 mar (t)  /  6, 18, 30, 42, 54  /
 apr (t)  /  7, 19, 31, 43, 55  /
 may (t)  /  8, 20, 32, 44, 56  /
 jun (t)  /  9, 21, 33, 45, 57  /
 jul (t)  /  10, 22, 34, 46, 58  /
 aug (t)  /  11, 23, 35, 47, 59  /
 sep (t)  /  12, 24, 36, 48, 60  /
```

```
J     /   N_1, V_2  /
 N(j)  /  N_1  /
  V(j)  /  V_2  /

  sets { sets for link }
 TTL(tt,t)  /  1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 1.10, 1.11, 1.12
                2.13, 2.14, 2.15, 2.16, 2.17, 2.18, 2.19, 2.20, 2.21, 2.22,
            2.23, 2.24, 3.25, 3.26, 3.27, 3.28, 3.29, 3.30, 3.31, 3.32,
            3.33, 3.34, 3.35, 3.36, 4.37, 4.38, 4.39, 4.40, 4.41, 4.42,
            4.43, 4.44, 4.45, 4.46, 4.47, 4.48, 5.49, 5.50, 5.51, 5.52,
            5.53, 5.54, 5.55, 5.56, 5.57, 5.58, 5.59, 5.60  /
 TL(t,tt)  /  1.1, 2.1, 3.1, 4.1, 5.1, 6.1, 7.1, 8.1, 9.1, 10.1, 11.1, 12.1,
                13.2, 14.2, 15.2, 16.2, 17.2, 18.2, 19.2, 20.2, 21.2, 22.2,
            23.2, 24.2, 25.3, 26.3, 27.3, 28.3, 29.3, 30.3, 31.3, 32.3,
            33.3, 34.3, 35.3, 36.3, 37.4, 38.4, 39.4, 40.4, 41.4, 42.4,
            43.4, 44.4, 45.4, 46.4, 47.4, 48.4, 49.5, 50.5, 51.5, 52.5,
            53.5, 54.5, 55.5, 56.5, 57.5, 58.5, 59.5, 60.5  /

 parameters xxx(tt)
       /
* 1   6
  1   7
* 1   8
       / ;

table W(N,t)
*$include 'C:\ASBmm\WAm\A\riv.txt'
$ondelim
$include 'C:\ASBmm\WAm\A\riv.csv'
$offdelim

*   PEER   /  NUREK  /  SIC ICWC 1.07.2017  /  D.Sorokin
*   Water Allocation Model  /  Amudarya River Basin
*   Sub-program  /  Balance & Objective function, Input limitation block
*   File A 2.txt

positive variables
            WV_out(t)
            VN(t)
            VK(t)
            EG(t)
variables
         Y6
         Y7
         Y8;
Equations
       E1(t)
       E2(t)
       E3(t)
       FUN6
       FUN7
       FUN8;
```

```
E1(t).. W('N_1',t) =e= VK(t) - VN(t) + WV_out(t);

E2(t)$(not t0(t))..VN(t) =e=  VK(t-1);

E3(t)..EG(t)=e= (VK(t)+VN(t))* WV_out(t) / 1000000;

FUN6..Y6 =e= sum(t, EG(t) );
FUN7..Y7 =e= sum(tn,EG(tn));
FUN8..Y8 =e= sum(tv,EG(tv));

*  PEER  /  NUREK  / SIC ICWC 1.07.2017  /  D.Sorokin
*  Sub-program  Output
*  file a3.txt

Parameter WV_S(tt),WV_Sv(tt),WV_Snv(tt) ;
WV_S("1")= Sum(t1, WV_out.l(t1));
WV_S("2")= Sum(t2, WV_out.l(t2));
WV_S("3")= Sum(t3, WV_out.l(t3));
WV_S("4")= Sum(t4, WV_out.l(t4));
WV_S("5")= Sum(t5, WV_out.l(t5));
*
WV_Sv("1")= Sum(tv1, WV_out.l(tv1));
WV_Sv("2")= Sum(tv2, WV_out.l(tv2));
WV_Sv("3")= Sum(tv3, WV_out.l(tv3));
WV_Sv("4")= Sum(tv4, WV_out.l(tv4));
WV_Sv("5")= Sum(tv5, WV_out.l(tv5));
*
WV_Snv("1")= Sum(tn1, WV_out.l(tn1));
WV_Snv("2")= Sum(tn2, WV_out.l(tn2));
WV_Snv("3")= Sum(tn3, WV_out.l(tn3));
WV_Snv("4")= Sum(tn4, WV_out.l(tn4));
WV_Snv("5")= Sum(tn5, WV_out.l(tn5));
*
FILE sor777  /  c:\ASBmm\WAm\A\test.txt  /
PUT sor777
Put ' W '  put  / ;
Put Loop (t1, put w('N_1',t1):8:0)  put  / ;
Put Loop (t2, put w('N_1',t2):8:0)  put  / ;
Put Loop (t3, put w('N_1',t3):8:0)  put  / ;
Put Loop (t4, put w('N_1',t4):8:0)  put  / ;
Put Loop (t5, put w('N_1',t5):8:0)  put  / ;
Put ' VN'  put  / ;
Put Loop (t1, put VN.l(t1):8:0)  put  / ;
Put Loop (t2, put VN.l(t2):8:0)  put  / ;
Put Loop (t3, put VN.l(t3):8:0)  put  / ;
Put Loop (t4, put VN.l(t4):8:0)  put  / ;
Put Loop (t5, put VN.l(t5):8:0)  put  / ;
Put ' VK '  put  / ;
Put Loop (t1, put VK.l(t1):8:0)  put  / ;
Put Loop (t2, put VK.l(t2):8:0)  put  / ;
Put Loop (t3, put VK.l(t3):8:0)  put  / ;
Put Loop (t4, put VK.l(t4):8:0)  put  / ;
```

```
Put Loop (t5, put VK.l(t5):8:0)  put /;
Put ' WV_out'  put /;
Put Loop (t1, put WV_out.l(t1):8:0)  put /;
Put Loop (t2, put WV_out.l(t2):8:0)  put /;
Put Loop (t3, put WV_out.l(t3):8:0)  put /;
Put Loop (t4, put WV_out.l(t4):8:0)  put /;
Put Loop (t5, put WV_out.l(t5):8:0)  put /;
Put ' WV_S'  put /;
Put WV_S("1"):8:0 Put WV_Sv("1"):8:0 Put WV_Snv("1"):8:0 put /;
Put WV_S("2"):8:0 Put WV_Sv("2"):8:0 Put WV_Snv("2"):8:0 put /;
Put WV_S("3"):8:0 Put WV_Sv("3"):8:0 Put WV_Snv("3"):8:0 put /;
Put WV_S("4"):8:0 Put WV_Sv("4"):8:0 Put WV_Snv("4"):8:0 put /;
Put WV_S("5"):8:0 Put WV_Sv("5"):8:0 Put WV_Snv("5"):8:0 put /;
Put ' RULE '  put /;
Put Loop (t1, put (VK.l(t1)/10570):8:2)  put /;
Put Loop (t2, put (VK.l(t2)/10570):8:2)  put /;
Put Loop (t3, put (VK.l(t3)/10570):8:2)  put /;
Put Loop (t4, put (VK.l(t4)/10570):8:2)  put /;
Put Loop (t5, put (VK.l(t5)/10570):8:2)  put /;

** TEST:  Export to Excel / csv
FILE RES48 / c:\ASBmm\WAm\A\wr6.csv /;
RES48.pc=5;
If(xxx('1')=6,
PUT RES48;
  Loop (t,
Put w('N_1',t):8:0 put VN.l(t):8:0 put VN.l(t):8:0
Put WV_out.l(t):8:0 put    put (VN.l(t)/10570):8:2 /;
       );
Putclose;
else
);

** TEST:  Export to Excel / csv
FILE RES49 / c:\ASBmm\WAm\A\wr7.csv /;
RES49.pc=5;
If(xxx('1')=7,
PUT RES49;
  Loop (t,
Put w('N_1',t):8:0 put VN.l(t):8:0 put VN.l(t):8:0
Put WV_out.l(t):8:0 put    put (VN.l(t)/10570):8:2 /;
       );
Putclose;
else
);
```

A.GMS-based program run (searching for optimal solution):

```
GAMS 24.5.4  r54492 Released Oct 15, 2015 WEX-VS8 x86 32bit/MS Windows
08/02/17 12:26:27 Page 1
PEER  /  NUREK  /  SIC ICWC, D.Sorokin, 1.07.2017
Include File Summary

   SEQ   GLOBAL TYPE     PARENT   LOCAL  FILENAME

     1       1 INPUT         0       0  c:\ASBmm\WAM\A\a.gms
     2       9 INCLUDE       1       9  .c:\ASBmm\WAm\A\a1.txt
     3     154 INCLUDE       2     145  ..C:\ASBmm\WAm\A\riv.csv
     4     161 INCLUDE       1      10  .c:\ASBmm\WAm\A\a2.txt
     5     310 INCLUDE       1      51  .c:\ASBmm\WAm\A\a3.txt

COMPILATION TIME     =        0.016 SECONDS      3 MB  24.5.4 r54492 WEX-VS8

GAMS 24.5.4  r54492 Released Oct 15, 2015 WEX-VS8 x86 32bit/MS Windows
08/02/17 12:26:27 Page 2
PEER  /  NUREK  /  SIC ICWC, D.Sorokin, 1.07.2017
Model Statistics    SOLVE OP7 Using NLP From line 301

MODEL STATISTICS

BLOCKS OF EQUATIONS           4     SINGLE EQUATIONS          180
BLOCKS OF VARIABLES           5     SINGLE VARIABLES          241  40 projected
NON ZERO ELEMENTS           569     NON LINEAR N-Z            180
DERIVATIVE POOL              20     CONSTANT POOL              17
CODE LENGTH                 420

GENERATION TIME      =        0.000 SECONDS      4 MB  24.5.4 r54492 WEX-VS8

EXECUTION TIME       =        0.000 SECONDS      4 MB  24.5.4 r54492 WEX-VS8

GAMS 24.5.4  r54492 Released Oct 15, 2015 WEX-VS8 x86 32bit/MS Windows
08/02/17 12:26:27 Page 3
PEER  /  NUREK  /  SIC ICWC, D.Sorokin, 1.07.2017
Solution Report     SOLVE OP7 Using NLP From line 301

               S O L V E      S U M M A R Y

     MODEL   OP7                 OBJECTIVE  Y7
     TYPE    NLP                 DIRECTION  MAXIMIZE
     SOLVER  CONOPT              FROM LINE  301

**** SOLVER STATUS     1 Normal Completion
**** MODEL STATUS      2 Locally Optimal
**** OBJECTIVE VALUE              645.5508

 RESOURCE USAGE, LIMIT          0.016     10000.000
```

```
 ITERATION COUNT, LIMIT        72         20000
 EVALUATION ERRORS             0            0
CONOPT 3         24.5.4 r54492 Released Oct 15, 2015 VS8 x86 32bit/MS Windows

     C O N O P T 3   version 3.17A
    Copyright (C)   ARKI Consulting and Development A/S
                    Bagsvaerdvej 246 A
                    DK-2880 Bagsvaerd, Denmark

    The model has 241 variables and 180 constraints
    with 569 Jacobian elements, 180 of which are nonlinear.
    The Hessian of the Lagrangian has 0 elements on the diagonal,
    120 elements below the diagonal, and 180 nonlinear variables.

                   Pre-triangular equations:   0
                   Post-triangular equations:  61
                   Definitional equations:     1

  Optimal solution. Reduced gradient less than tolerance.

  CONOPT time Total                          0.027 seconds
   of which: Function evaluations              0.000 =  0.0%
            1st Derivative evaluations       0.000 =  0.0%

REPORT SUMMARY :        0     NONOPT
                        0  INFEASIBLE
                        0  UNBOUNDED
                        0  ERRORS

GAMS 24.5.4  r54492 Released Oct 15, 2015 WEX-VS8 x86 32bit/MS Windows
08/02/17 12:26:27 Page 4
PEER  /  NUREK  /  SIC ICWC, D.Sorokin, 1.07.2017
E x e c u t i o n

**** REPORT FILE SUMMARY

CON c:\ASBmm\WAM\A\CON.put
sor777 c:\ASBmm\WAm\A\test.txt
RES49 c:\ASBmm\WAm\A\wr7.csv

EXECUTION TIME       =        0.000 SECONDS      3 MB  24.5.4 r54492 WEX-VS8

USER: GAMS Development Corporation, Washington, DC   G871201/0000CA-ANY
      Free Demo,  202-342-0180,  sales@gams.com,  www.gams.com   DC0000


**** FILE SUMMARY

Input      c:\ASBmm\WAM\A\a.gms
Output     c:\ASBmm\WAM\A\a.lst
```

Example of output / wr.xls file:

Copy in a red framework the data from file 'wr.csv'

mln m3		to Nur	V1	V2	from Nur	Rule
2020/2021	Oct	841	10500	10500	1100	0,99
	Nov	599	10241	10241	1150	0,97
	Dec	512	9690	9690	1320	0,92
	Jan	421	8882	8882	1155	0,84
	Feb	368	8148	8148	1427	0,77
	Mar	611	7089	7089	1700	0,67
	Apr	1325	6000	6000	1164	0,57
	May	2188	6161	6161	1994	0,58
	Jun	3525	6356	6356	3000	0,6
	Jul	4741	6881	6881	2100	0,65
	Aug	3509	9522	9522	2600	0,9
	Sep	1985	10431	10431	1916	0,99
2021/2022	Oct	932	10500	10500	1100	0,99
	Nov	638	10332	10332	1150	0,98
	Dec	544	9820	9820	1320	0,93
	Jan	482	9044	9044	1155	0,86
	Feb	406	8371	8371	990	0,79
	Mar	514	7787	7787	990	0,74
	Apr	855	7311	7311	1111	0,69
	May	1936	7055	7055	1683	0,67
	Jun	2696	7308	7308	1800	0,69
	Jul	3643	8204	8204	2100	0,78
	Aug	2531	9747	9747	2000	0,92
	Sep	1361	10278	10278	1520	0,97
2022/2023	Oct	739	10119	10119	1100	0,96
	Nov	653	9758	9758	1150	0,92
	Dec	501	9261	9261	1320	0,88
	Jan	439	8442	8442	1155	0,8
	Feb	438	7726	7726	990	0,73
	Mar	603	7174	7174	1687	0,68
	Apr	1021	6090	6090	1111	0,58
	May	2322	6000	6000	2086	0,57
	Jun	4536	6236	6236	3000	0,59
	Jul	4044	7772	7772	2600	0,74
	Aug	3884	9216	9216	2600	0,87
	Sep	1744	10500	10500	1744	0,99
2023/2024	Oct	852	10500	10500	1100	0,99
	Nov	586	10252	10252	1150	0,97
	Dec	509	9688	9688	1320	0,92
	Jan	437	8877	8877	1155	0,84
	Feb	380	8159	8159	1051	0,77
	Mar	469	7488	7488	1700	0,71
	Apr	1016	6257	6257	1111	0,59
	May	1521	6162	6162	1683	0,58
	Jun	2924	6000	6000	1800	0,57
	Jul	3667	7124	7124	2100	0,67
	Aug	3613	8691	8691	2168	0,82
	Sep	1884	10136	10136	1520	0,96
2024/2025	Oct	838	10500	10500	1100	0,99

Nov	617	10238	10238	1150	0,97
Dec	554	9705	9705	1320	0,92
Jan	474	8939	8939	1155	0,85
Feb	402	8258	8258	1600	0,78
Mar	640	7060	7060	1700	0,67
Apr	1148	6000	6000	1111	0,57
May	1832	6037	6037	1869	0,57
Jun	3209	6000	6000	2509	0,57
Jul	4818	6700	6700	2600	0,63
Aug	4122	8918	8918	2600	0,84
Sep	1630	10440	10440	1570	0,99

Annex 6. Water consumption in PZs (results of calculation by the Planning zone model)

Total water consumption in PZs (irrigated agriculture, drinking water supply, and industrial water use): demand for 2010-2050, Mm3

PZ	Scenario	2010-2020	2020-2055	2029-30	2054-55
Vakhsh	BAU	3,835	3,222	3,714	2,882
	FSD	3,914	3,704	4,161	3,406
	ESA	3,907	3,472	3,924	3,171
Pyanj	BAU	3,437	2,983	3,346	2,787
	FSD	3,578	3,705	3,981	3,643
	ESA	3,572	3,419	3,751	3,254
Lower Kafirnigan	BAU	1,358	841	935	806
	FSD	1,361	860	943	837
	ESA	1,358	822	908	788
Akhal	BAU	5,571	5,002	4,880	4,573
	FSD	5,562	5,333	5,097	4,946
	ESA	5,556	5,483	5,189	5,140
Lebap	BAU	3,725	3,665	3,905	3,596
	FSD	3,741	4,163	4,303	4,253
	ESA	3,735	4,129	4,241	4,250
Mary	BAU	6,431	5,492	5,844	5,213
	FSD	6,509	6,428	6,680	6,431
	ESA	6,502	6,351	6,573	6,377
Khorezm	BAU	4,158	4,179	4,075	4,270
	FSD	4,210	4,305	4,171	4,466
	ESA	4,208	4,196	4,081	4,321
North Karakalpakstan	BAU	5,176	4,985	4,869	4,995
	FSD	5,196	5,001	4,857	5,064
	ESA	5,219	4,981	4,854	5,012
South Karakalpakstan	BAU	2,012	2,154	2,091	2,202
	FSD	1,975	1,930	1,887	1,952
	ESA	1,974	1,888	1,848	1,904
Dashoguz	BAU	5,748	4,757	4,766	4,490
	FSD	5,878	5,901	5,661	5,972
	ESA	5,876	5,723	5,528	5,715
Surkhamdarya	BAU	4,420	3,387	3,631	3,319
	FSD	4,446	3,358	3,603	3,242
	ESA	4,444	3,323	3,565	3,207
Karshi	BAU	4,527	3,930	4,135	3,884
	FSD	4,494	3,849	4,044	3,773
	ESA	4,492	3,820	4,019	3,735
Bukhara	BAU	5,094	4,753	4,835	4,731
	FSD	5,135	4,890	4,905	4,939
	ESA	5,132	4,841	4,846	4,897

Countries' total water consumption by river reach in the Amudarya basin (irrigated agriculture, drinking water supply, and industrial water use): demand for 2010-2050 against limits, Mm3

1. Total in PZs

PZ	Scenario	Limit, 2009-10	Limit, 2007-08	2010-2020	2020-2055
Tajikistan	BAU	9,670	8,800	8,630	7,046
	FSD			8,853	8,269
	ESA			8,837	7,712
Surkhandarya	BAU	1,570	1,400	4,420	3,387
	FSD			4,446	3,358
	ESA			4,444	3,323
Total, upper reaches	BAU	11,240	10,200	13,051	10,433
	FSD			13,299	11,627
	ESA			13,281	11,035
Turkmenistan: middle reaches	BAU	15,560	13,920	15,727	14,160
	FSD			15,812	15,924
	ESA			15,793	15,963
Uzbekistan: middle reaches	BAU	8,970	8,190	9,622	8,683
	FSD			9,629	8,739
	ESA			9,624	8,661
Total, middle reaches	BAU	24,530	22,110	25,349	22,843
	FSD			25,441	24,662
	ESA			25,417	24,625
Turkmenistan: lower reaches	BAU	6,440	5,810	5,748	4,757
	FSD			5,878	5,901
	ESA			5,876	5,723
Uzbekistan: lower reaches	BAU	13,020	11,650	11,346	11,317
	FSD			11,382	11,235
	ESA			11,401	11,065
Total, lower reaches	BAU	19,460	17,460	17,093	16,074
	FSD			17,260	17,137
	ESA			17,277	16,788
TOTAL	BAU	55,230	49,770	55,493	49,350
	FSD			56,000	53,426
	ESA			55,975	52,447
TAJIKISTAN	BAU	9,670	8,800	8,630	7,046
	FSD			8,853	8,269
	ESA			8,837	7,712
TURKMENISTAN	BAU	22,000	19,730	21,475	18,917
	FSD			21,691	21,825
	ESA			21,668	21,686
UZBEKISTAN	BAU	23,560	21,240	25,388	23,387
	FSD			25,457	23,332
	ESA			25,469	23,049

2. Transboundary water withdrawal

PZ	Scenario	Limit, 2009-10	Limit, 2007-08	2010-2020	2020-2055
Tajikistan	BAU	9,670	8,800	8,630	7,046
	FSD			8,853	8,269
	ESA			8,837	7,712
Surkhandarya	BAU	1,570	1,400	1,562	1,355
	FSD			1,573	1,343
	ESA			1,572	1,329
Total, upper reaches	BAU	11,240	10,200	10,192	8,401
	FSD			10,425	9,612
	ESA			10,409	9,041
Turkmenistan: middle reaches	BAU	15,560	13,920	15,627	14,060
	FSD			15,712	15,824
	ESA			15,693	15,863
Uzbekistan: middle reaches	BAU	8,970	8,190	9,508	8,531
	FSD			9,520	8,602
	ESA			9,515	8,519
Total, middle reaches	BAU	24,530	22,110	25,135	22,591
	FSD			25,232	24,426
	ESA			25,207	24,383
Turkmenistan: lower reaches	BAU	6,440	5,810	5,748	4,757
	FSD			5,878	5,901
	ESA			5,876	5,723
Uzbekistan: lower reaches	BAU	13,020	11,650	11,346	11,317
	FSD			11,382	11,235
	ESA			11,401	11,065
Total, lower reaches	BAU	19,460	17,460	17,093	16,074
	FSD			17,260	17,137
	ESA			17,277	16,788
TOTAL	BAU	55,230	49,770	52,421	47,066
	FSD			52,917	51,175
	ESA			52,893	50,212
TAJIKISTAN	BAU	9,670	8,800	8,630	7,046
	FSD			8,853	8,269
	ESA			8,837	7,712
TURKMENISTAN	BAU	22,000	19,730	21,375	18,817
	FSD			21,591	21,725
	ESA			21,568	21,586
UZBEKISTAN	BAU	23,560	21,240	22,416	21,203
	FSD			22,474	21,181
	ESA			22,487	20,913