SIC ICWC Policy brief

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Studying Alternative Operation Regimes of Rogun HPP

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This Policy Brief is prepared by Anatoliy Sorokin based on the work done by the Regional Computing and Analytical Division of SIC ICWC on Theme 2.2 "Study of Alternative Operation Regimes of the Rogun Hydroscheme" of the SIC ICWC Work Plan.

Summary

The Policy Brief summarizes the findings of previous studies on alternative operation regimes of the Rogun Hydropower Project (HPP) and incorporates an analysis of the assessments and recommendations from the 2023 Updated Environmental and Social Impact Assessment of the project.

This Policy Brief also explains results of modeling the alternative operation regimes of Rogun and Nurek HPPs by SIC's models, namely -GAMS-based models for optimization of HPP operation and simulation of water allocation in the Amu Darya River basin, based on water balance calculations for river sections and reservoirs.

The analysis shows that the coupled operation of Rogun and Nurek HPPs, as proposed in ESIA, fails to meet the growing season's flow requirements downstream of Nurek HPP to cover water shortage in low-water years, at over 90% flow probability. .

The policy brief proposes the coupled operation regimes of Rogun and Nurek HPPs that are based on multi-year flow regulation by the reservoir of Rogun HPP to cover water shortages. The output of both HPPs has been calculated for different scenarios of low flow probability (P=90%, P≥95%) and available water supply (fully met water withdrawal limits; limit cuts by 5% and 10%).

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1. Introduction

The aim of this work is to compare alternative operation regimes of Rogun HPP derived from the past and 2024SIC'sresearch and to justify the recommended regime.

This work is of relevance since the existing assessments of operation regimes of Rogun and Nurek HPPs after the commissioning of Rogun HPP at its design capacity (tentatively after 2036) produce quite different results and the recommended operation regimes are not sufficiently justified.

2. Research Tasks

1. Analyze and compare flow regulation by reservoirs of Rogun and Nurek HPPs, as outlined in the Master Plan of Integrated Use of Water Resources of the Amu Darya River [SAO Gidroproyekt, 1971] and the Updated Master Plan of Integrated Use and Protection of Water Resources of the Amu Darya River [Sredazgiprovodkhlopok, Tashkent, 1983].

2. Analyze and present the recommended operation regime from the alternatives produced by ASBMmm simulations. [V. Dukhovniy, A. Sorokin, 2007].

3. Analyze the coupled operation of Rogun and Nurek HPPs, focusing on optimization as part of the feasibility study of Rogun HPP [OJSC “Bakhri Tojik”, 2014].

4. Analyze the regime of Rogun filling during the 1st (2018-2023) and 2nd (2023-2032) construction phases, based on the actual and projected power generation schedule. Source of power generation data: [ESIA, 2023].

5. Analyze three alternative regimes (schemes) of flow regulation of the Vakhsh River by reservoirs of Rogun and Nurek HPPs after Rogun HPP reaches its design capacity (post-2036). Data source: [ESIA, 2023].

6. Model operation regimes of Nurek and Rogun HPPs using GAMS-models of flow regulation by large reservoir hydroschemes, including both optimistic and pessimistic scenarios (GAMS modeling by D. Sorokin).

7. Model energy-irrigation regimes of flow regulation by the reservoirs of Rogun and Nurek HPPs during a low-water year. Give recommendations on schedules of water releases downstream of Nurek HPP that contribute to meeting the established water withdrawal limits in the Amu Darya River basin by discharging water accumulated through multi-year regulation in the Rogun reservoir (model calculations by D. Sorokin).

Present in the form of a comparative table the operation regimes of Rogun and Nurek HPPs derived in the past research, including Master plans, ASBMmm scenarios, and results of modeling conducted as part of given SIC ICWC research theme.

3. Analysis of Research Results

3.1. Comparison of Indicators of Rogun and Nurek HPPs

Table 1 shows a comparison of indicators of Rogun and Nurek HPPs, from which the following conclusions can be drawn:

- If the dam of Rogun HPP is 335 m high, the active storage of the Rogun reservoir will be by 5.8 km³ more than that of Nurek HPP.
- The capacity coefficient (the ratio of active storage to average multi-year river flow) of the Nurek reservoir HPP is estimated at only 0.2, while that of the Rogun reservoir is 0.5. This indicates that only the latter has the potential for multi-year regulation.

The head at Rogun HPP is 25 m higher than at Nurek HPP.

Table 1. Comparison of Indicators of Rogun HPP (with a 335-meter-high dam) and Nurek HPP

Indicator	*Rogun*	*Nurek*	*Difference*
Dam height, m	335	300	35
*Full reservoir level (**FRL**), m*	1,290	910	380
Water volume at FRL (V_{FSU}), km^3	13.3	10.5	2.8
*Dead storage level (**DSL**), m*	1,185	857	
Water volume at DSL (V_{DSL}), km^3	3.0	6.0	-3.0
Active storage (V_{act}), km^3	**10.3**	**4.5**	**5.8**
Silting of active storage (V_{silt}), km^3	–	Approx. 1.0	
*Head at HPP (**H**), m*	**245**	**220**	**25**
Installed capacity of HPP (N_{inst}), MW	3,600	3,000	600
*Average multi-year power generation at HPP – **E**, bln kWh*	13	11	3

3.2. Nurek HPP without Rogun

Tajikistan is currently facing a persistent electricity deficit, estimated at 3-3.5 bln kWh in winter season. The operation regime of Nurek HPP helps mitigate this deficit by accumulating water during the growing season and releasing it during winter months.

Two potential operation regimes of Nurek HPP were analyzed using the GAMS optimization model. The model was designed to maximize the following objective functions:

- Annual power generation
- Power generation from October to March

The operation regime matching the first objective function can be considered as the *"energy regime"*, while the regime corresponding to the second objective function can be termed as *"energy-irrigation regime"* since the latter both maximizes power generation at Nurek HPP and ensures water releases during the growing season, which partially or fully meet the regulated flow requirements of downstream areas along the Vaksh and Amu Darya rivers.

The process of building the operation regimes of Nurek HPP and its reservoir includes selecting such a regime

$$U_{k,t} \qquad k = 1, R \qquad t = 1, T \ldots (1)$$

that meets the planning objective:

$$F \rightarrow max \ldots (2)$$

and system of constraints

$G_{i,t} = 0$, i = 1, n – balance equations defining the relationship between reservoir water volumes, inflow and releases

$P_{j,t} > 0$, j = 1, m – allowable water volume in the reservoir, allowable water releases from reservoirs and HPPs,

where:

k is the index and **R** is the number of reservoirs

i, **j** are indices and **n**, **m** are the number of constraints

t is time step and **T** is calculation period

U is the regulated flow

F is the target function, selection of which depends on the specific scenario adopted (operation regime of HPP).

The diagrams below illustrate the differences in the operation regimes of the Nurek HPP derived through optimization to maximize power generation during the winter season compared to the entire year.

The analysis reveals that the derived HPP water discharge curve closely approximates the actual water discharge in 2003-2004, which was selected just for comparison.

The total annual power generation under "maximized winter generation" is lower than under "maximized annual generation", which is close to irrigation water release schedule.

Figure 1. Discharge at Nurek HPP under alternative operation regimes

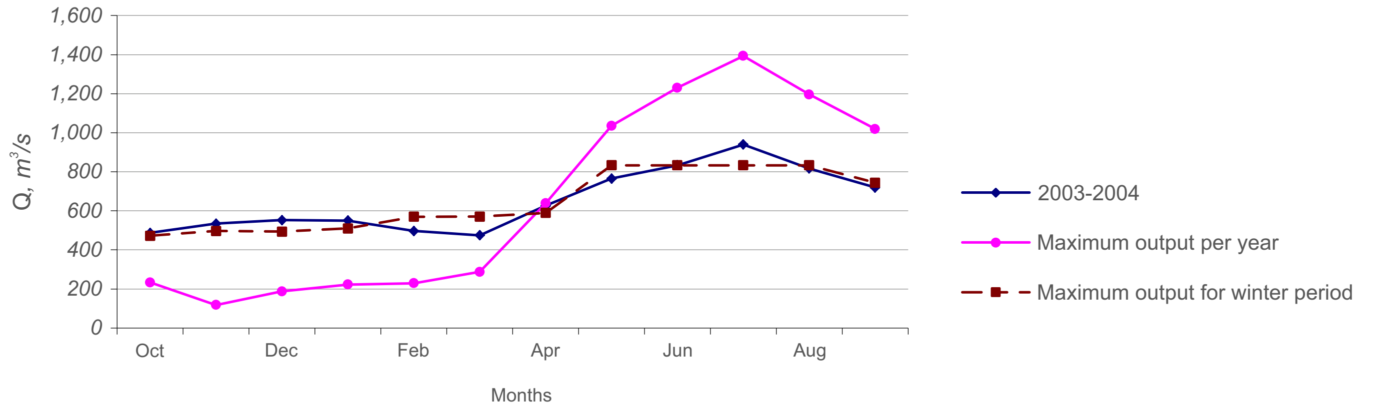


Figure 2. Output of the Nurek HPP under alternative operation regimes

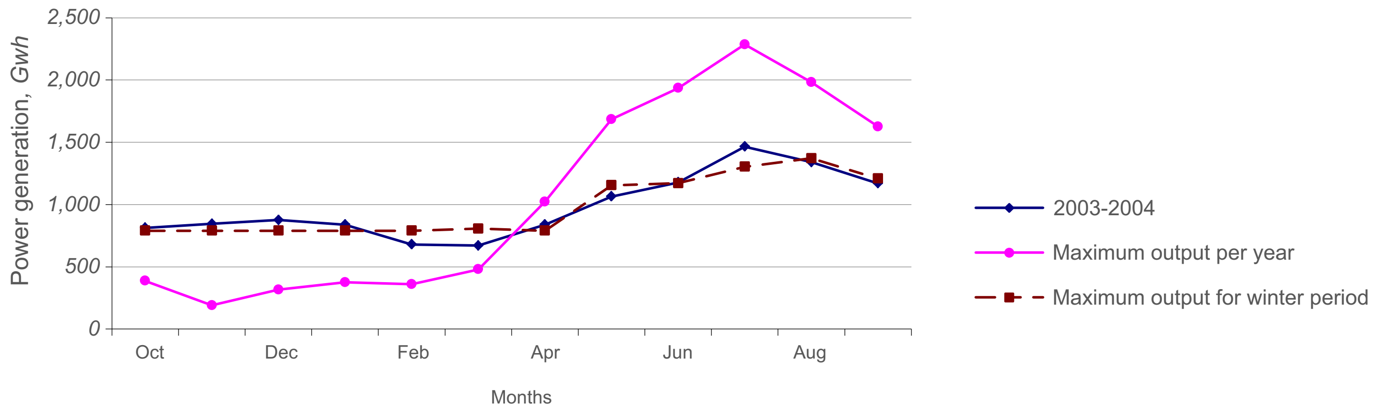
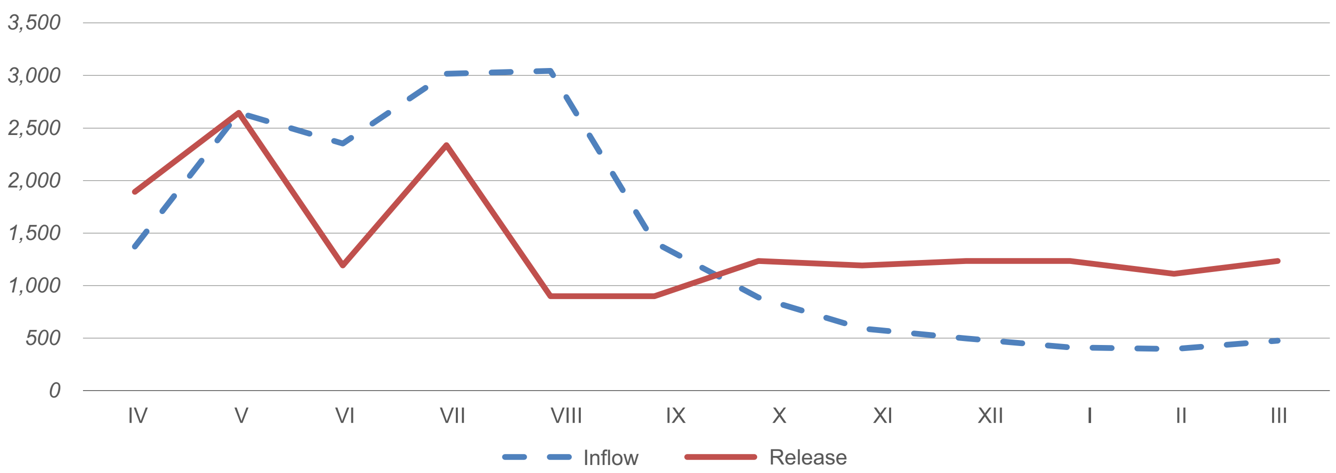


Figure 3. Nurek reservoir operation regime (Mm³). *Source: Amu Darya IWRM Master Plan, 1971*



Conclusion

The operation regime of Nurek HPP, which prioritizes maximum power generation throughout the year (1), results in higher water discharge during the growing season compared to (2), which focuses on maximized power generation during winter. Regime (1) ensures effective water shortage management and maximizes the potential for electricity export in summer.

Specifically, during the growing season of low-water years, the actual water discharge downstream of Nurek HPP averages 650 m³/s, fluctuating between 600-680 m³/s. The inflow into the reservoir during this period is approximately 950 m³/s, varying between 840-990 m³/s. This means that approximately 300 m³/s of water is retained in the Nurek reservoir due to energy-focused regulation

3.3. Filling the Rogun Reservoir

The water surface area of the Rogun reservoir varies within 10 to 25 km² in 2023 and 10 to 30 km² in 2024 (Figures 3 and 4). This corresponds to an accumulated water volume of 0.4-0.5 km³, at the average water level of 1,100 m. Source: SIC ICWC data derived from the processing of Sentinel images of the water surface area (L. Sychugova); water volume calculations based on bathymetric relationships.

The reservoir of Rogun HPP accumulates water in summer and is emptied between September and January increasing water discharge at HPP to generate more power in fall and winter.

Until recently, the inflow to Nurek HPP from the Vakhsh River was measured at the Komsomolabad gauging station. This station is now located within the area of the Rogun reservoir. This means that both inflow to and water releases from Rogun HPP will be determined by the energy operator of this project.

The updated Environmental and Social Impact Assessment (ESIA, 2023) for Rogun HPP emphasizes the need for negotiations between riparian countries regarding the Rogun reservoir filling. It is noted in ESIA that, between 2005 and 2011, Tajikistan did not utilize on average 1.2 km³ of its water withdrawal limit at 9.5 km³ in the river basin (as specified in Protocol No.566). This unused water is now proposed for filling the Rogun reservoir.

However, since 2017, the amount of unused water limit in Tajikistan has decreased, averaging 0.55 km³: dropped to 0.28 km³ in the 2017-2018 hydrological year, to 0.37 km³ in 2021-2022, and to 0.23 km³ in 2022-2023.

Figure 4. Monitoring of the dynamics of changes in the water surface area of the Rogun reservoir (km²) for 2023

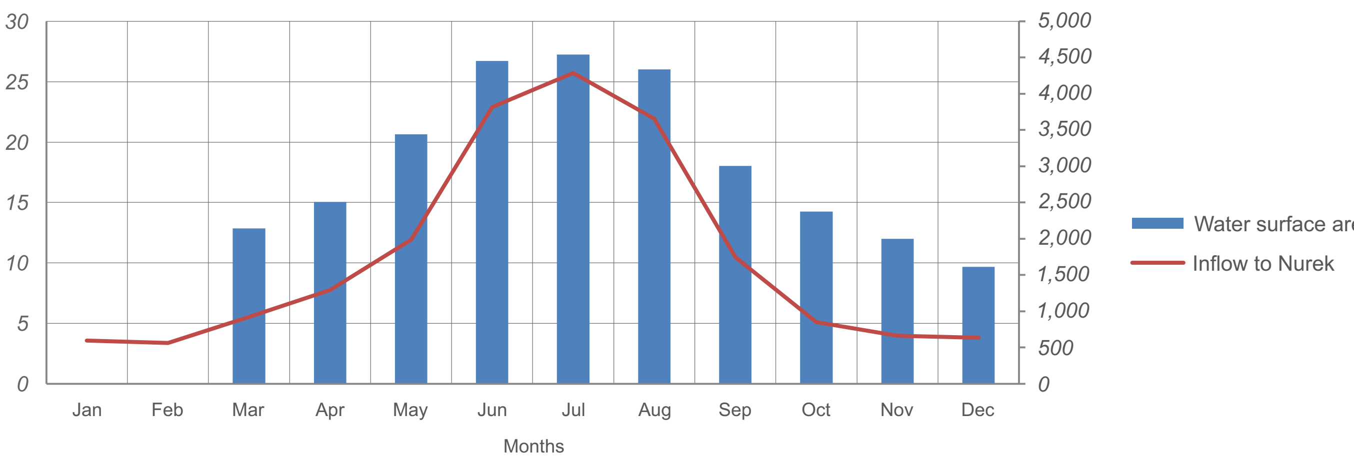


Figure 5. Monitoring of the dynamics of changes in the water surface area of the Rogun reservoir (km²) for 2024

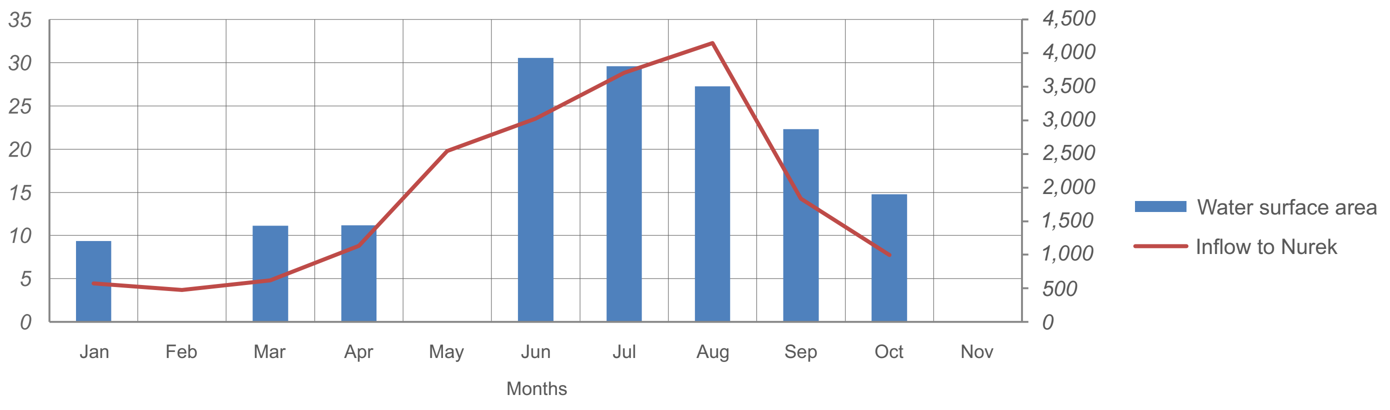


Table 2. Power generation by Rogun HPP from 2018 to 2022
Source: [ESIA, 2023]

Year	2018	2019	2020	2021	2022
Power generation, MkWh	90	847	1,300	1,482	1,654

OJSC "Barki Tojik" source: “It has been decided that the reservoir (Rogun) will be filled only within the water withdrawal limit allocated to Tajikistan.

It is expected that the construction of the Rogun project will be completed in 2029, with full filling (up to a level of 1,290 m) anticipated by 2036. Table 3 shows the projected dynamics of reservoir filling by 2036 (ESIA, 2023).

The ESIA report also provides data on the planned power generation starting since 2024.

By calculating the filling based on this data, it becomes evident that the reservoir (at given generation) would be filled earlier than 2036 – specifically, by 2032 (see Table 4).

Table 3. Option for Rogun reservoir filling from 2024 to 2036
Source: [ESIA, 2023]

Year	2024	2027	2030	2033	2036
Water level in reservoir (m)	1,100	1,185	1,237	1,269	1,290
Water volume in reservoir (km^3)	0.47	3.0	6.67	10.3	13.3

Table 4. Option for Rogun reservoir filling from 2024 to 2032, based on the data on power generation
Source: [ESIA, 2023]

Year	2024	2027	2032
Water level in reservoir (m)	1,100	1,185	1,290
Volume of water in reservoir (km^3)	0.47	3.0	13.3
Power generation at HPP, MkWh	1,745	6,436	14,626

Conclusion

The unused water withdrawal limit for Tajikistan's canals in the past seven years does not allow using this water for filling the Rogun reservoir in the amount of 1.2 km³. If Tajikistan decides to fill the reservoir by this amount of water, water withdrawals into canals observed in recent years will need to be reduced so that together with the filling amount they do not exceed 9.5 km³.

In the 2036 option, the reservoir will be filled at the average annual rate of 1.07 km³, with a maximum filling of 1.22 km³ expected between 2028 and 2033. However, if the reservoir is filled by 2032, the planned average annual filling volume will increase to 1.6 km³, with a maximum filling of 2.06 km³ between 2028 and 2032.

3.4. Coupled Operation of Rogun and Nurek HPPs

Options of coupled operation of Rogun and Nurek HPPs (Source: Phase II Report Techno-Economic Assessment Study for Rogun Hydroelectric Construction Project, 2014):

1. Regulation by the Rogun reservoir, while Nurek HPP accumulates water.

2. Regulation by the Nurek reservoirHPP, with Rogun HPP operating for accumulation.

3. Optimal operation may be in-between (not explained).

In the first and third options of the coupled operation of Rogun and Nurek HPPs, the Rogun reservoir can regulate flow in a multi-year regime. In contrast, the second option, does not allow for multi-year regulation.

According to the report from the Project Management Team for the Rogun Hydropower Project [ESIA, 2023], Tajikistan intends to operate Rogun HPP in a manner that minimizes its impact on the downstream flow pattern of the Nurek dam. This will be achieved by changing the operation of the Nurek reservoir from a water regulating reservoir to a run-of-river operation (i.e. Nurek reservoir maintained at a constant level)".

The 2023 updated Environmental and Social Impact Assessment [ESIA, 2023] considers three alternative options of flow regulation by the Rogun and Nurek reservoirs:

Option 1 – Energy-irrigation regime, maintaining the flow pattern downstream of Nurek HPP at the current level (recommended).

Option 2 – Energy regime assuming maximum power generation in winter.

Option 3 – Energy-irrigation regime that meets the demands of all water consumers and users (not studied).

At the same time, the coupled operation of Nurek and Rogun HPPs is expected to fully meet Tajikistan's electricity needs and enhance opportunities for electricity export. One option being considered is maintaining the current flow pattern (annual volume) of the Vakhsh River, which does not exclude redistributing summer flow to winter flow.

Conclusion

All the options considered, with the exception of Option 3, do not contribute to covering current water shortages in the countries in low-water years, let alone in the future, in the context of increasing water shortage due to climate change and projected diversion of water in Afghanistan through the Qosh-Tepa Canal.

The recommended Option 1, which maintains flow downstream of Nurek HPP at the current level, does not solve the water shortage as well. This is because the areas downstream of Nurek HPP suffer from water shortage in low-water years under the existing water discharge from HPP during the growing season. . Additionally, Option 1 does not utilize the potential of multi-year flow regulation regime of the Rogun reservoir, where the accumulated in wet years water can be used as additional water releases downstream of Nurek HPP during the growing season, thereby reducing water shortage.

Option 3 can be recommended as a basis for discussion and justification of operation regimes of Rogun and Nurek HPPs when negotiating an Agreement for regulation of the operation of HPPs after 2036, but only in case of multi-year flow regulation by Rogun dam.

In the master plans of the SAO Gidroproyekt (1971), the Rogun dam is designed to provide annual flow regulation of the Vakhsh River in two options:

- (a) including counter-regulator (where the counter-regulator is a new reservoir hydro-scheme in the upper reaches of the Amu Darya River).
- (b) no counter-regulator

In option (a), Rogun and Nurek reservoirs operate in energy regime, with the Rogun reservoir receiving 7.9 km³ of water during the growing season in low-water year, and the Nurek reservoir accumulating 2.6 km³ (for a total of 9.5 km³!). During the growing season, the average amount of water discharged from Rogun HPP is 360 m³/s, and only 200 m³/s discharged from Nurek HPP.

In option (b), the Rogun reservoir is operated in energy regime (accumulating 7.9 km³ of water and releasing 360 m³/s), while the Nurek reservoir is operated in irrigation-energy regime (drawdown of 3.5 km³, water releases of **580** m³/s).

Water releases from Nurek HPP in option (b) are 20-60 m³/s less than the actual water releases observed during particularly low-water years (for example, growing season 2020 – 600 m³/s, growing season 2000 and 2001 640 m³/s).

In Master plans of Sredazgiprovodkhlopok, the Rogun reservoir is operated in multi-year regulation regime, releasing 4.55 km³ of water during the non-growing season. It is unclear how the Nurek reservoir operates in this case.

However, if the operation of the Nurek reservoir follows the energy-irrigation regime in low-water years (as outlined in the Master Plan of Integrated Use and Protection of Water Resources of the Amu Darya River, 1971), the average flow in the Vakhsh River downstream of Nurek HPP during the growing season can be assessed at **910** m³/s.

Table 5. Comparison of operation regimes of Rogun and Nurek HPPs for the growing season of a low water year from different sources:
'en' – energy regime, 'ir' – irrigation regime, 'en-ir' – energy-irrigation regime

Information source	Accumulation (+), drawdown (-) of the reservoir, km³		Water discharge at HPP (m³/s)/Water releases (km³, growing season)	
	Rogun	Nurek	Rogun	Nurek
Master Plan of the Amu Darya River, 1971:	*Annual flow regulation*			
(1) available counter-regulator	+ 7.9 en	+ 2.6 en	360 / 5.7	200 / 3.1
(2) no counter-regulator	+ 7.9 en	- 3.5 ir	360 / 5.7	580 / 9.2
Master Plan of the Amu Darya River, 1984:	*Multi-year flow regulation*			
Drawdown of accumulated water	- 4.55 ir	No data	No data	No data
Calculations by ASBmm, 2007:	*Multi-year flow regulation*			
Option 5	+ 1.8 en	- 3.3 ir	600 / 9.5	810 / 12.8

Operation options of Rogun HPP after it reaches its design capacity – water releases downstream of Nurek HPP during the growing season:
*Option of **950** m³/s corresponds to water releases of 15 km³, which is by 15 – 9.5 = 5.5 km³ more than during the growing season in 2020 low-water year.*
*Option of **860** m³/s corresponds to 13.6 km³ of water in April-September (average water release from Nurek HPP for 2010-2023), which is by 13.6 – 9.5 = 4.1 km³ more than during the growing season in 2020 low-water year.*

Results of GAMS model optimization of the operation regimes of Rogun and Nurek HPPs for the inflow data for 2000-2001:

- Energy regime (Scenario 1) assumes that the Rogun reservoir is filled by 3 km³ during the growing season and the Nurek reservoir is filled by 4.5 km³

- Energy-irrigation regime (Scenario 2) assumes drawdown of the Rogun reservoir by 3.5 km³ during the growing season, with the Nurek reservoir operating at a constant level (volume).

Scenario 1

Water content of the Vaksh River: low-water year (analog 2000-2001)

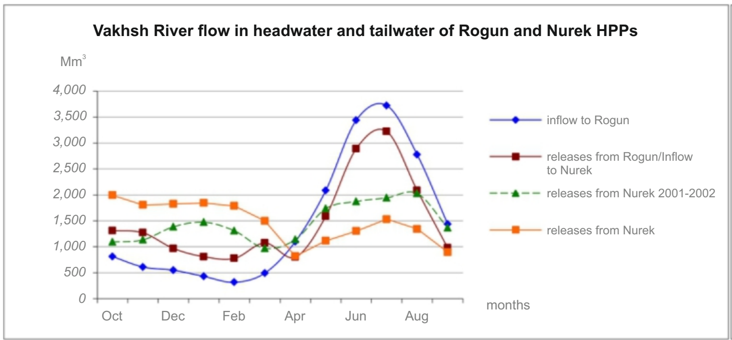
Dam height: **335 m**

FRL 1,290 m Full volume 13,300 Mm^3

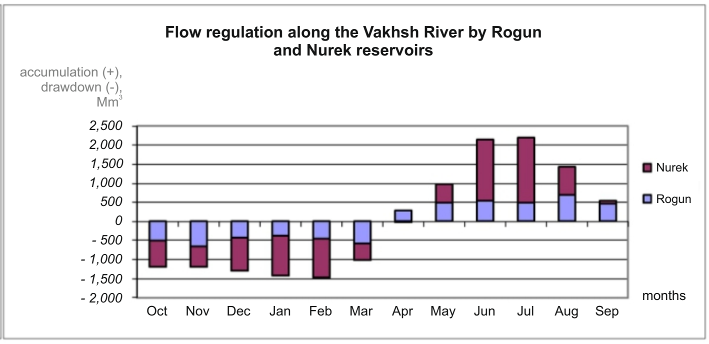
DSL 1,185 m Dead storage 3,000 Mm^3

Operation regime: **Energy** (maximum power generation in winter)

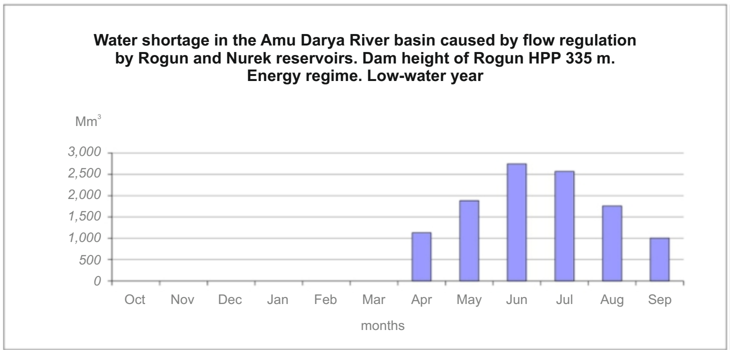
Parameter	*Unit*	*Oct-Mar*	*Apr-Sep*	*Year*
Inflow to Rogun	km^3	3.21	14.57	17.78
Water releases from Rogun	km^3	6.21	11.57	17.78
Inflow to Nurek	km^3	6.21	11.57	17.78
Wate releases from Nurek	km^3	10.76	7.01	17.78
Reservoir filling	km^3	0.00	7.55	7.55
Discharge from reservoir	km^3	7.55	0.00	7.55
Water shortage	km^3	0.00	**15.00**	15.55



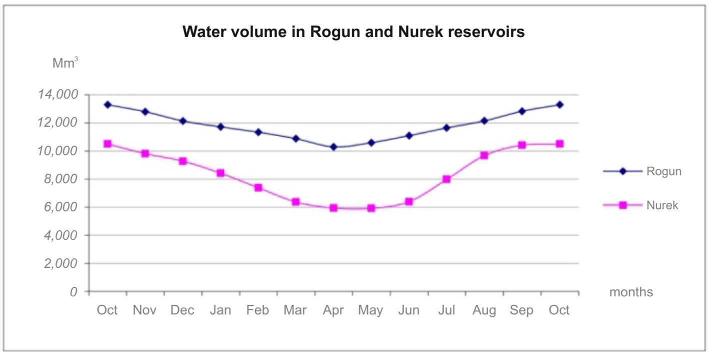
Vakhsh River flow in headwater and tailwater of Rogun and Nurek HPPs



Flow regulation along the Vakhsh River by Rogun and Nurek reservoirs



Water shortage in the Amu Darya River basin caused by flow regulation by Rogun and Nurek reservoirs. Dam height of Rogun HPP 335 m. Energy regime. Low-water year



Water volume in Rogun and Nurek reservoirs

Scenario 2

Water content of the Vaksh River: low-water year (analog 2000-2001)

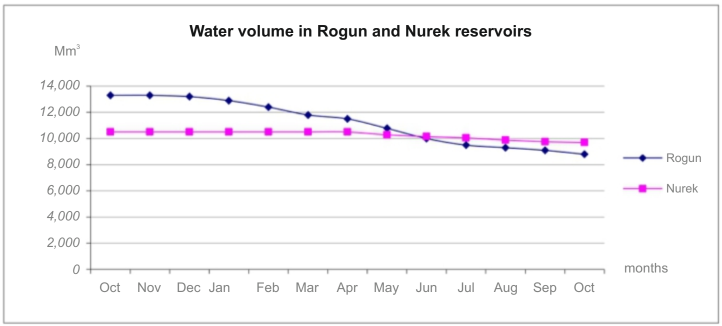
Dam height: **335 m**

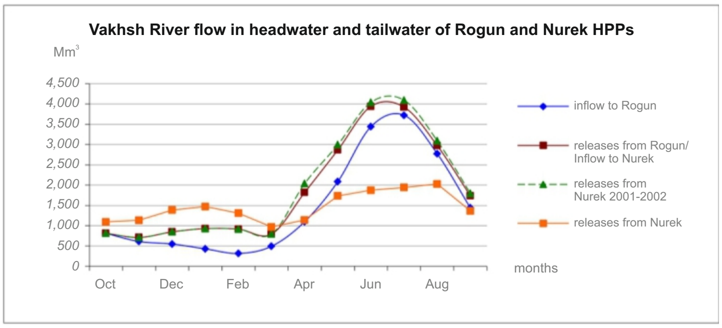
FRL 1,290 m Full volume 13,300 Mm^3

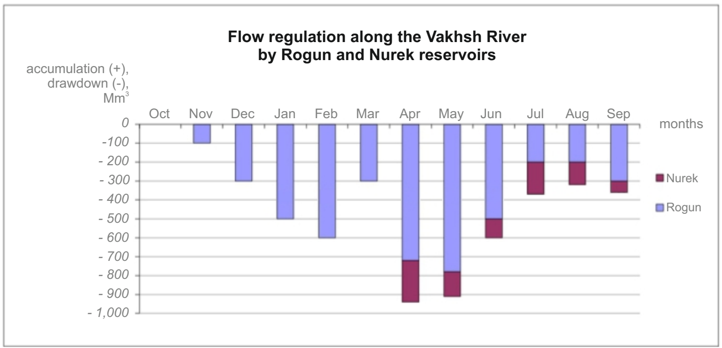
DSL 1,185 m Dead storage 3,000 Mm^3

Operation regime: **Irrigation-Energy**

Parameter	*Unit*	*Oct-Mar*	*Apr-Sep*	*Year*
Inflow to Rogun	km^3	3.21	14.57	17.78
Water releases from Rogun	km^3	5.01	17.27	22.28
Inflow to Nurek	km^3	5.01	17.27	22.28
Wate releases from Nurek	km^3	5.01	17.27	22.28
Reservoir filling	km^3	0.00	0.00	0.00
Discharge from reservoir	km^3	1.80	3.50	5.30
Water shortage	km^3	0.00	0.00	0.00







Conclusion

As none of the regulation options (except for the regulation regime under the "optimistic" scenario simulated for a low-water year similar to 2000-2001) meets the current demand for flow downstream of Nurek HPP in low-water years, (flow probability P ≥ 90 %), a detailed study should be carried out to refine the operation regimes of Rogun and Nurek HPPs. This study should be based on the design hydrograph of discharge from Nurek HPP derived through the river water balance method for different options of flow probability (P = 90 %, P ≥ 95 %) and water availability for canals in the Amu Darya basin (100 %, 95 %, 90 %). Recommendations on energy-irrigation regimes for different cases should be provided as part of this study (new task) as well.

3.5. New Task Modeling Results

SIC ICWC conducted a study on potential regimes of flow regulation by Rogun and Nurek reservoirs based on Option 3 (ESIA, 2023): (1) through the balance method for a low-water year (flow probability P ≥ 90 %) determined water discharges to mitigate or avoid water shortages downstream of Nurek HPP during the growing season; (2) determined volumes of multi-year regulation by Rogun reservoir and annual (seasonal) regulation by Nurek reservoir to ensure needed water discharge downstream of Nurek HPP during the growing season of low-water years.

As analogs of flow in the Amu Darya basin (including inflow to the Rogun reservoir), the following scenarios were selected: (1) 2019-2020 – for a low-water year with flow probability P = 90 %; (2) 2000-2001, 2007-2008, 2010-2011 hydrological years for a ow-water year with flow probability P ≥ 90 %.

In the future (by 2050), water resources of the Amu Darya River basin (mainly summer runoff) are expected to decrease due to climate change. If the runoff decreases by 10%, additional releases of 125 – 150 m^3/s downstream of Nurek HPP will be required during the growing season to cover water shortage. In order to have such discharge, the accumulation by the Nurek reservoir should be reduced by 2-2.4 km^3 during the growing season. To this end, the entire

Table 6. Comparison of alternative operation regimes of Rogun and Nurek HPPs during the growing season (April-September) for a particularly low-water year to cover water shortages by 100, 95 and 90 %

Information source	*Accumulation (+), drawdown (-) of the reservoir, km³*		*Water discharge at HPP (m³/s)/Water releases (km³, growing season)*	
	Rogun	*Nurek*	*Rogun*	*Nurek*
SIC ICWC's options:	*Multi-year regulation*			
1. Flow probability P = 90 %	- 3.0	+ 3.5	1,230 / 20.0	1,050 / 16.5
- limit cut 5 %	- 1.5	+ 3.5	1,170 / 18.5	950 / 15.0
- limit cut 10 %	0	+ 3.5	1,080 / 17.0	850 / 13.5
2. Flow probability P ≥ 95 %	- 5.5	+ 3.5	1,360 / 21.5	1,150 / 18.0
- limit cut 5 %	- 4.0	+ 3.5	1,230 / 20.0	1,050 / 16.5
- limit cut 10 %	- 2.5	+ 3.5	1,170 / 18.5	950 / 15.0

Figure 6. Flow hydrographs in headwater and tailwater of the Vakhsh river in the Rogun and Nurek reservoirs (Mm³). Full coverage of water shortage by releases from the multi-year regulation storage.
Low water year (water availability in 2010-2011)

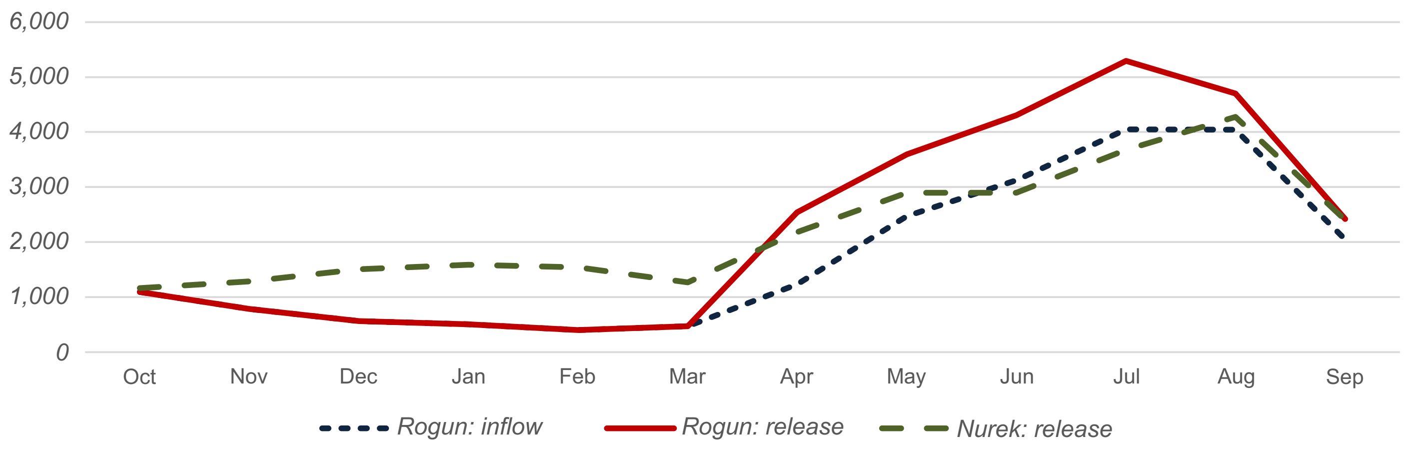
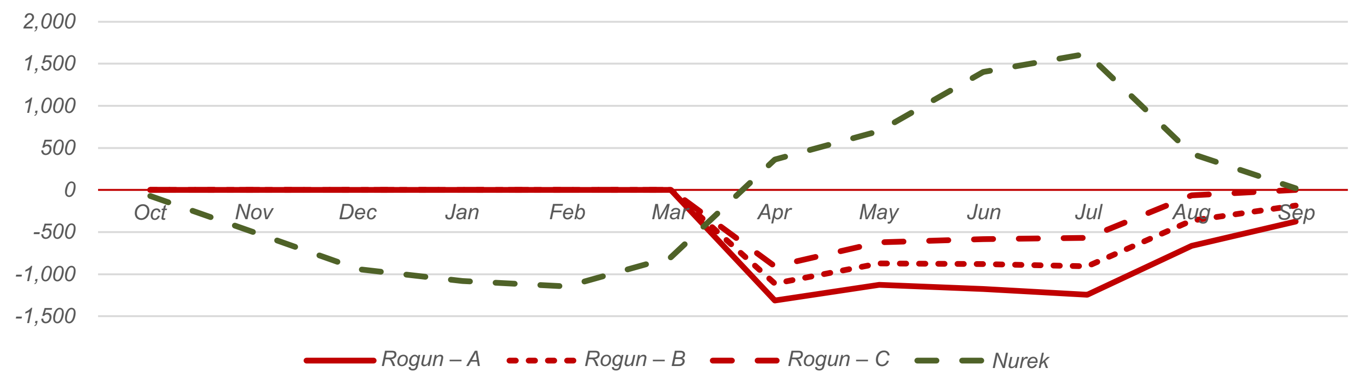


Figure 7. Accumulation (+) and drawdown (-) of the Rogun and Nurek reservoirs, Mm³. Low-water year (2010-2011). Water withdrawal limit cut: A – no cut, B – 5% cut, C – 10% cut



active storage should not be discharged before the start of the growing season.

To compensate for the water shortage caused by water diversion in Afghanistan through the Qosh-Tepa, an additional water discharge of about 250 m³/s will be needed downstream of Nurek HPP during the growing season. However, this is not feasible due to the limited runoff of the Vakhsh River and multi-year regulation of the Rogun dam.

Conclusion

The operation regimes of Rogun and Nurek HPPs in low-water years can cover existing water shortages through multi-year regulation of flow along the Vakhsh River by the Rogun reservoir by discharging water accumulated in high-water years.

The discharge of 3 km³ (years of flow probability P = 90%) and 5.5 км³ (years of flow probability P ≥ 95%) from the Rogun reservoir during the growing season in low-water years and accumulation of 3.3 km³ by Nurek dam during the same period of time would cover water shortages at the current level of water use. Meanwhile, the average water discharge downstream of Nurek HPP should not fall below 1050 m³/s (at P = 90%) and 1150 m³/s (at P ≥ 95%) during the growing season.

The lower water discharge downstream of Nurek HPP during the growing season would cause water shortage, necessitating water withdrawal limit cuts. At a 5% limit cut, the water discharge downstream of Nurek HPP can be reduced to 950 m³/s (at P = 90%) and 1050 m³/s (at P ≥ 95%) during the growing season. At a 10% limit cut water discharge downstream of Nurek HPP can be reduced to 850 m³/s and 950 m³/s, respectively.

4. Recommendations

1. After Rogun HPP is commissioned at its design capacity, the coupled operation of the Rogun and Nurek hydroschemes should ensure water releases along the Vakhsh River downstream of Nurek HPP in low-water years. This will help reduce or avoid water shortages in the Amu Darya River basin. Water releases downstream of Nurek in low-water years should be provided through water accumulation in Rogun in high-water years, i.e. through multi-year regulation regime of this hydroscheme.

2. The schedules of water discharge in the tailwater of Nurek hydroscheme that are to reduce or avoid water shortage in the Amu Darya River basin through the Vakhsh flow regulation by Rogun and Nurek dams can be calculated using the balance method. This includes drafting river water balance for the Amu Darya River for low-water years, with account of environmental flow for different flow probabilities and water withdrawal limit cuts.

3. To mitigate the risks associated with energy-focused regulation of the of the Vaksh River by Rogun and Nurek dams, it is proposed to undertake a thorough study to develop a practical mechanism in support of the earlier mentioned negotiated Agreement. This mechanism would include institutional arrangements and rules of multi-year flow regulation by the Rogun dam. This implies creating a water storage in the reservoir of Rogun HPP and water releases downstream of Nurek HPP, at the expense of accumulated water, during low-water years and a procedure for associated power purchase and sale.

Table 7. Water discharges (Q, m³/s) along the Vakhsh River downstream of Rogun and Nurek HPPs, average for the growing season (April-September) in low-water years, different flow probability (P, %) and available water for country water withdrawal limits in the Amu Darya River basin (W, %)

Water availability for water withdrawal limits, W, %	*Rogun HPP – Q, m³/s*		*Nurek HPP – Q, m³/s*	
	P = 90%	*P ≥ 95%*	*P = 90%*	*P ≥ 95%*
W = 100%	1,230	1,360	1,050	1,150
W = 95%	1,170	1,230	**950**	1,050
W = 90%	1,080	1,170	850	**950**

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