MINISTRY OF WATER RESOURCES OF THE REPUBLIC OF UZBEKISTAN
RESEARCH INSTITUTE OF IRRIGATION AND WATER PROBLEMS

Central Asia Nexus Dialogue Project: Fostering Water, Energy and Food Security Nexus and Multi-Sector Investment (Phase II)

TECHNICAL RECOMMENDATIONS: RUSLOVOYE RESERVOIR SEDIMENTATION MANAGEMENT AT THE TUYAMUYUN HYDRO COMPLEX ON THE AMU RIVER AND SEDIMENT CONTROL

Final Report

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This concept was produced with the financial support of the European Union within the "Central Asia Nexus Dialogue Project: Fostering Water, Energy and Food Security Nexus and Multi-Sector Investment (Phase II)" and the technical support of the World Bank within CAWEP "Laboratory of Innovative Solutions for the Water Sector of Central Asia" (S4W Living Lab). Its contents are the sole responsibility of authors and do not necessarily reflect the views of the European Union, World Bank or CAREC.

BACKGROUND

Reservoirs represent one of the most efficient means of ensuring water supply via active regulation (management) and re-distribution of river runoff over time for use in different economic sectors. Today, Uzbekistan is operating over 50 large and numerous small reservoirs, mainly for irrigation. The total volume of regulated runoff amounts to 21 km^3 or about 40% of the total available water resources consumed annually by all the sectors of the national economy.

From the hydrological point of view, reservoirs form relatively quickly and do not render sufficient time for the environment as well as rivers' natural hydrological regime to adapt. The flow regime in reservoirs is sophisticated. Runoff flows can be well traced in reservoir transient zones and upper sections, mainly in flooded main river channels. In the near-dam section, drain currents form as a result of idle water discharge into the tail bay through spillways, through culverts into HPP channels and/or turbines. Water flow dynamics inside reservoirs, current directions, as well as water stream speed arise under the influence of gravity, pressure gradients and friction stress. The distribution of such currents in reservoirs is accompanied by the transfer of suspended and bed sediments, sediment accumulation and scours, i.e. erosion sites in the reservoir basin and coastline alteration.

As currents spread, the dynamic processes inside a reservoir depend on its morphological features, i.e. bed slope, depth, water exchange rate, etc. In lowland reservoirs, the interaction between bottom and surface wave currents manifests itself rather aggressively. Since the mechanisms underpinning the development of such currents remain largely uncertain, numerous experimental and theoretical studies are ongoing to investigate the matter. The theory of runoff regulation has recently become a powerful tool for justifying water management at various levels, although many challenges still require a more detailed inquiry.

At the 1st Regional Steering Committee Meeting (October 27, 2020)[1], the Ministry of Water Resources (MWR) of the Republic of Uzbekistan (RUz) and Turkmenistan's State Committee for Water Resources (TM SCWR) proposed the Tuyamuyun Hydro Complex (TMHC) as the demonstration project site within the framework of the European Union's Central Asia Nexus Dialogue Project: Fostering Water, Energy and Food Security Nexus and Multi-Sector Investment (Phase II). This demo project aimed to assess the sedimentation in the Ruslovoye Reservoir at the TMHC leading to its reduced active (useful) capacity. Sediment accumulation in the Ruslovoye Reservoir curbs the operation of the offstream reservoirs (Sultansanjar, Koshbulak, and Kaparas) covering Uzbekistan's and Turkmenistan's irrigation needs.

[1] The EU has been supporting demo water-energy-food nexus projects in Central Asia (www.carececo.org).

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Project goal: conduct measurements and assess sedimentation scale at the Ruslovoye Reservoir of the Tuyamuyun Hydro Complex; carry out sedimentation forecast calculations and elaborate recommendations for optimizing the reservoir's operation regimes to diminish sedimentation based on innovative solutions in terms of utilizing sediment deposit materials.

To achieve the project goal, the following tasks were completed: investigating the river bed and irrigation canal condition in the Amu Darya River lower reaches over the years of TMHC operation; analyzing the main performance indicators of the TMHC reservoirs for the years of operation, and evaluating the TMHC overall performance; assessing the influence of reservoir operation regimes on non-productive water losses; diagnosing the effect of irrigation-related deposits on farmland productivity in the downstream Amu Darya.

In broad terms, the exercise aimed at designing and proposing enhanced operation regimes for the TMHC reservoir system to eliminate the negative consequences of disrupted natural channel regime of the lower Amu Darya River, including to improve water intake into irrigation canals, bring down filtration water losses, as well as boost agricultural productivity.

Sedimentation measurements at the TMHC's Ruslovoye Reservoir under Task 1 were completed earlier, and described in the submitted Interim Report.

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1. CURRENT STATE OF TMHC RESERVOIRS

1.1 Hydrological and sedimentation regimes of the Amu Darya River approaching TMHC

The Amu Darya's runoff regime close to TMHC was adopted as per the data of the Darganata (155 km above dam site) and Tuyamuyun (5 km below dam site) Hydroposts, and the data in Uzhydromet hydrological yearbooks, water sector hydro reclamation systems (HRS) and Research Institute of Irrigation and Water Problems (NIIIVP) Expedition (Central Asia Irrigation Research Institute, SANIIIRI), as well as Uzbekistan MWR Service. Fig. 1.1. shows the Amu Darya annual runoff approaching TMHC during 1979-2021, and the obvious cyclical nature of the river's water content, i.e. high- and low-water years alternating every 5-7 years. Thus, the mean multi-year medium water content amounts to approx. 35 km^3, and low water – to 20 km^3. Extreme low-water years – with the discharge fluctuating between 12 and 20 km^3 – have been increasingly observed in recent periods.

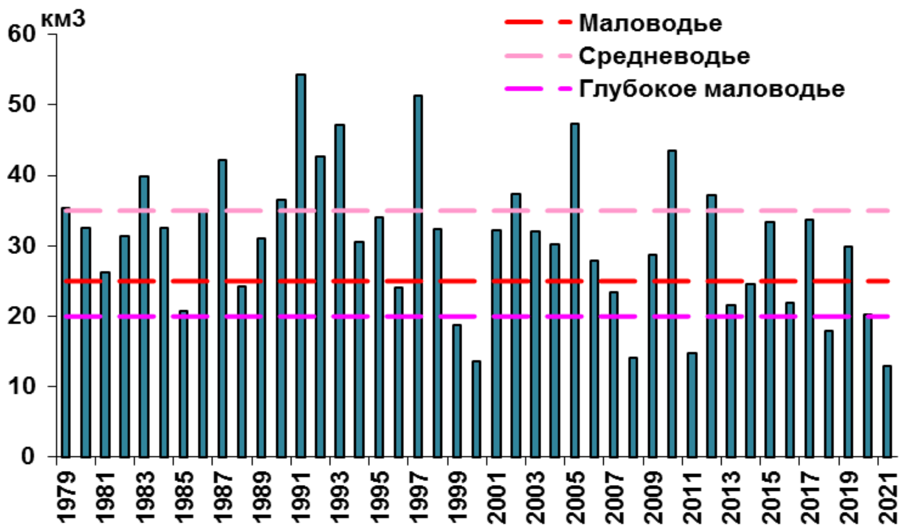

Figure 1.1. Annual river discharge approaching TMHC.

During snow and ice floods (May-September), the runoff may sharply grow and demonstrate significant fluctuations between different 10-day periods. During flood season, 1-2 snow-rain peaks can be distinguished in May-June, and a snow-glacial melt flooding wave peaking in July. A certain growth of mean 10-day runoff in September can be attributed to decreased water withdrawal via irrigation canals in the river's midstream due to irrigation water supply cessation.

The data analysis associated with the river discharge regime at the Darganata Site (42 years of observations) points to the minimum runoff of 13.63 km^3 in 2000/2001 against the mean annual

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of 433 m^3/sec. That water management year was the driest over the span of 42 years of measurements. During other low-water years, the annual runoff ranged from 18.7 to 24.1 km^3. The maximum annual runoff of 54.22 km^3 occurred in 1991-1992. The maximum monthly runoff fluctuates between 560 m^3/sec (January) and 5,640 m^3/sec (July), and the minimum ones between 330 m^3/sec (November) and 2,310 m^3/sec (July). Fig. 1.2. below shows the mean monthly runoff dynamics approaching TMHC during 2004-2021. The data point to the downward trend of water entering the TMHC over these years, averaging minus 50 m^3/sec per year.

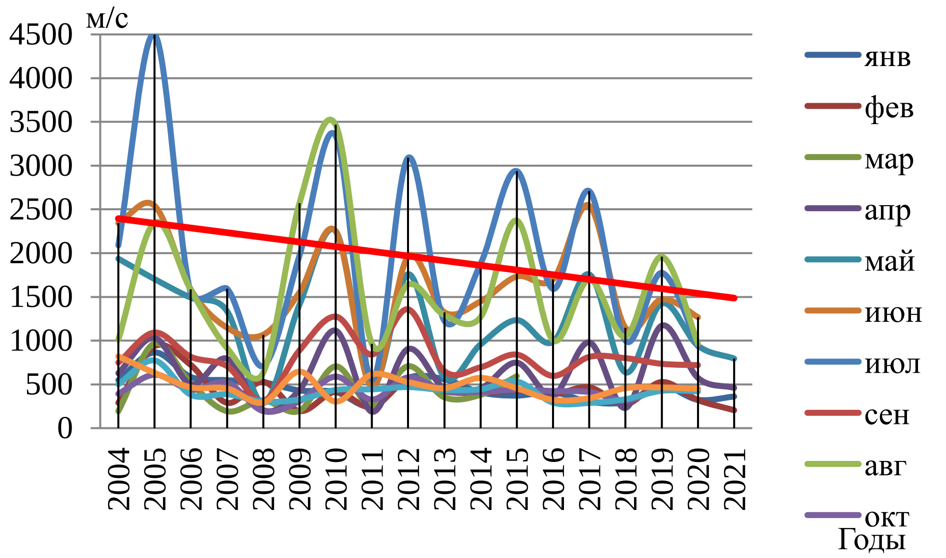

Figure 1.2. The Amu Darya mean monthly runoff approaching TMHC.

Simultaneously, the maximum outlet discharge dropped from 4,500 to 1,900 m^3/sec, mean annual inflow from 2,500 to 1,500 m^3/sec, and the low-water annual inflow ranged between 250 and 750 m^3/sec.

Table 1.1. Mean monthly water discharge at Darganata-Tuyamuyun Reservoir Entry Site (m^3/sec).

Discharge	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**
Q_{mean}	614	478	473	714	1,466	1,911	2,352	1,746	1,018	619	822	704
Q_{min}	279	204	209	230	307	563	702	495	300	238	233	354
Q_{max}	936	811	880	1,403	2,918	3,666	4,499	2,833	1,673	930	6785	990

In the TMHC tail bay, during the observation period the mean annual discharge fluctuated from 317 to 1,691 m^3/sec; and mean monthly discharge from 81 m^3/sec in October to 4,042 m^3/sec in July.

Table 1.2. Mean multi-year monthly tail water discharge at Tuyamuyun Hydro Facility (m^3/sec).

Discharge	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**

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Q_{mean}	449	610	714	586	1,259	1,641	2,017	1,676	791	408	359	519
Q_{min}	110	98	269	124	238	588	524	362	282	81	69	112
Q_{max}	936	2,798	1,300	1,800	2,990	3,666	4,042	2,994	1,565	884	917	990

Sediment regime. Runoff regulation in the Amu Darya River Basin, sediment accumulation in reservoirs, and significant water diversion via canals have significantly impacted the ongoing river's sedimentation regime.

Due to the backwater effect in the Ruslovoye Reservoir and sediment settling in its basin, almost clarified water enters the TMHC's tail bay. During autumn-winter period, turbidity values are minimal ranging between 0.02 and 0.08 kg/m^3, with the maximum turbidity of 1.8 kg/m^3 observed in summer. At the drawdown level of 118 m during vegetation season, the tail bay turbidity reaches 1.10-1.80 kg/m^3. The fluctuations of mean annual discharge of suspended and stream sediment as per the observed data at the TMHC head and tail water hydroposts are presented in Table 1.3. below.

The annual discharge of suspended and stream sediment ranges from 4 to 10 mln tons. This study allowed examining the operation regimes of the TMHC reservoirs, water discharge and sediment transport to the tail bay, as well as the sedimentation taking place in the Ruslovoye Reservoir, and water losses due to evaporation and filtration.

Table 1.3. Mean annual discharge dynamics
of suspended and stream sediment during operation (kg/sec).

Site	Mean monthly discharge of sediment/stream turbidity (kg/m^3)				
	1981	1982-1990	1991-2001	2002-2020	Min and max values
Darganata (155 km)	1,500 1.07	860÷3,460 1.01÷2.48	250÷18000 0.30÷7.0	754÷6,200 1.02÷4.02	88÷9,300 0.33÷6.30
Tuyamuyun (5 km)	890 0.62	80÷340 0.07÷0.187	6.3÷1,400 0.016÷1.8	6.0÷780 0.013÷0.81	1.4÷ 2,600 0.02÷1.30

In 1982-1990, as the result of commissioning the Tuyamuyun Hydro Complex the amount of suspended and stream sediment entering the dam's tail bay had significantly dropped. For instance, in 1981 – as per hydropost data – the mean discharge of suspended and stream sediment amounted to 1,500 kg/sec at the Darganata Site, and 890 kg/sec at the Tuyamuyun Site. During 1982-1998, the mean sediment discharge ranged between 860 and 3,460 kg/sec at Darganata, and from 80 to 340 kg/sec at Tuyamuyun. The max and min values of sediment discharge observed at these hydroposts were 88-9,300 kg/sec (Darganata Site), and 14-2,600 kg/sec (Tuyamuyun Site). Since 2000, no regular observations of the river's sediment regime have been carried out at the aforementioned hydroposts, complicating the assessment of the actual

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sediment regime occurring in recent years. The observed data during this period were as follows: 250-18,000 kg/sec at Darganata, and 63-1,400 kg/sec at Tuyamuyun.

Table 1.4. presents the mean multi-year monthly sediment volume entering the Ruslovoye Reservoir, part of which transiting to the TMHC tail bay. The analysis shows that in the autumn-spring period, sediment inflow ranged from 510 to 750 kg/sec, and tail bay transit from 35 to 75 kg/sec, i.e. only 7-10% of sediment reached the dam's downstream side. In the high-water periods (April-August), sediment inflow amounted to 2,100-6,500 kg/sec, and outflow to 410-570 kg/sec, i.e. 9-20% (Fig.1.3.).

Table 1.4. Mean multi-year discharge of river silt and stream sediment at the Amu Darya River sites (kg/sec).

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Darganata Site											
725.6	513.6	681.2	2,119	6,573	5,092	6,439	3,715	1,854	737.2	954.2	1,243
Tuyamuyun Site											
34.57	50.43	74.87	135.2	417.8	329.2	566.0	531.2	167.3	35.29	29.07	41.43

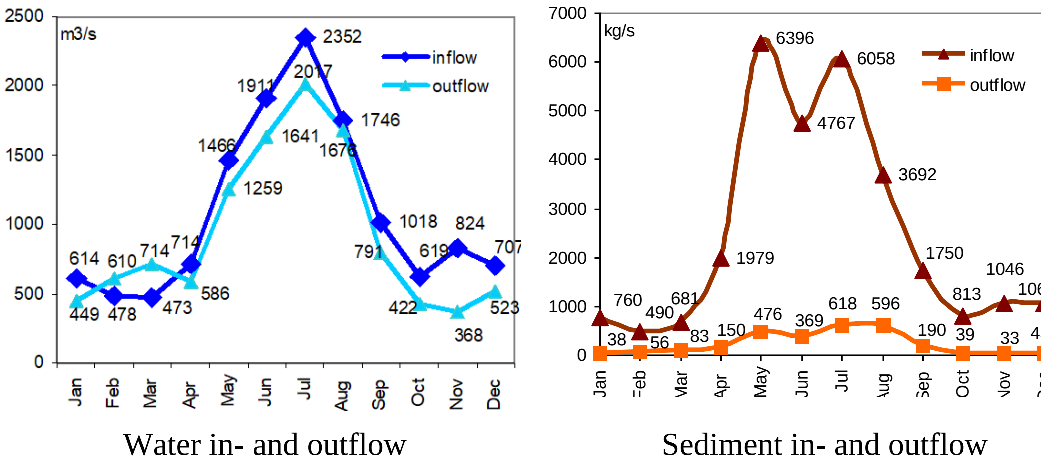

Figure 1.3. River runoff, suspended and stream sediment discharge.

Stream turbidity. The mean annual stream turbidity values – observed since 1981 – fluctuated as follows: at the Darganata Site – 1.07 kg/m^3, and at the Tuyamuyun Site – 0.62 kg/m^3. During 1982-2000, the mean annual stream turbidity varied from 1.01 to 2.48 kg/m^3 at Darganata, and from 0.07 to 0.187 kg/m^3 at Tuyamuyun. The max and min values of the mean monthly stream turbidity were observed within the range of 0.33 to 6.30 kg/m^3 at the Darganata Hydropost, and of 0.02 to 1.30 kg/m^3 at the Tuyamuyun Hydropost. In subsequent 1991-2001, the mean monthly stream turbidity fluctuated between 0.30 and 7.0 kg/m^3 at the former, and between 0.016 and 1.8 kg/m^3 at the latter hydropost.

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As a result of the backwater effect in the Ruslovoye Reservoir and sediment settling in its basin, virtually clarified water enters the TMHC's downstream. Autumn-winter turbidity values are minimal and range between 0.02 and 0.08 kg/m^3, with the maximum value of 1.8 kg/m^3 observed in summer. During vegetation season, at the drawdown level of 118 m the tail bay turbidity reaches 1.10-1.80 kg/m^3. The suspended and stream sediment discharge ranges from 4 to 10 mln tons per year.

Table 1.5. Mean multi-year monthly water turbidity at the Amu Darya River sites (kg/m^3).

I	II	II	IV	V	VI	VII	VIII	IX	X	XI	XII
Darganata Site											
1.36	1.21	1.33	2.08	3.19	2.17	2.12	1.73	1.54	1.30	1.61	1.74
Tuyamuyun Site											
0.074	0.065	0.093	0.160	0.358	0.347	0.369	0.362	0.279	0.122	0.132	0.105

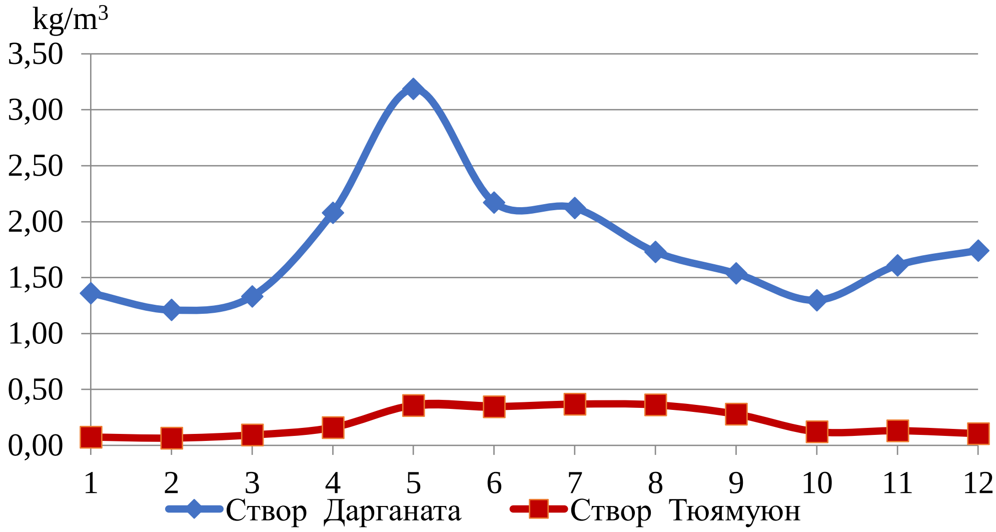

Figure 1.4. Mean monthly water turbidity.

1.2 TMHC design specifications and current condition

The Tuyamuyun Hydro Complex is located on the border of the Amu Darya River mid and lower streams in the Tuyamuyun Gorge, 450 km away from the Aral Sea at the junction of the borders of the Republic of Karakalpakstan and Khorezm Region (Uzbekistan), and Dashkhovuz Region (Turkmenistan). The facility's key functions include the following: ensure in-season regulation of the Amu Darya River runoff benefitting downstream water users; supply water to irrigation systems and reduce sediment inflow during intake into left- and right-bank main canals; accumulate low-mineralized water in the Kaparas Reservoir for further potable water supply to downstream settlements.

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The TMHC includes the Ruslovoye and three offstream reservoirs, namely Kaparas, Sultansanjar and Koshbulak. Their main features and schematic location are presented below (Fig. 1.5.).

Наименование	Ед. изм	Русловое	Капарас	Султансанджар	Кошбулак	Всего
Полный объем	km3	2,34	0,96	2,69	1,81	7,8
Полезный объем	km3	2,07	0,55	1,63	1,02	5,27
Площадь	km2	303	70	149	128	650
НПУ	m	130	130	130	130	130
УМО	m	120	120	116	120	
Протяженность	km	102	15	24	26	167
Ширина максимальная	km	11	9	12	11	

Figure 1.5. The TMHC schematic plan and design specifications.

The entire facility comprises the following: 141 m long concrete spillway dam, earthen dam, hydro power plant (150,000 kW capacity), left-bank water intake (up to 500 m^3/sec), right-bank water intake (200 m^3/sec), control structure with culvert on the main left-bank canal (500 m^3/sec), offstream water intake to fill and operate the Sultansanjar Reservoir (500 m^3/sec), offstream canal to fill and operate the Sultansanjar Reservoir (200 m^3/sec), turbidity-free water intake (250 m^3/sec), turbidity-free water canal (100 m^3/sec), offstream water canal to fill and operate the Koshbulak Reservoir (100 m^3/sec), and offstream water intake to fill and operate the Kaparas Reservoir (400 m^3/sec). All TMHC reservoirs are linked – the Ruslovoye Reservoir is connected with the Kaparas Reservoir via the control structure; the Sultansanjar and Koshbulak Reservoirs communicate via a special canal. The Ruslovoye Reservoir has the following design specifications: total capacity – 2.34 km^3, active capacity 2.07 km^3, mirror – 303 km^2, NRWS (Normal Reservoir Water Surface) – 130 m, TDS (Top of Dead Storage) – 120 m, length 102 km, and max width – 11 km.

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Fig. 1.6. demonstrates the inter-operation of the TMHC component facilities. Water accumulation occurs due to damming of the Amu Darya River channel; the filling of the Ruslovoye Reservoir starts at the utility mark (114 m) and above; water overflow from the Ruslovoye Reservoir to the Kaparas Reservoir via the control structure takes place at 117 m horizon and above; water overflow to the Sultansanjar Reservoir from the duct in the tail part of the Ruslovoye Reservoir begins at 115 m (with open gates); water overflow from Sultansanjar to Koshbulak begins at 120 m water level through the Koshbulak basin inlet neck; reservoirs' drawdown takes place from the Ruslovoye Reservoir to the tail bay and LBC and RBC Canals, from Kaparas to the Ruslovoye Reservoir, from Sultansanjar to the Ruslovoye Reservoir and LBC Canal, and from Koshbulak to the Sultansanjar Reservoir.

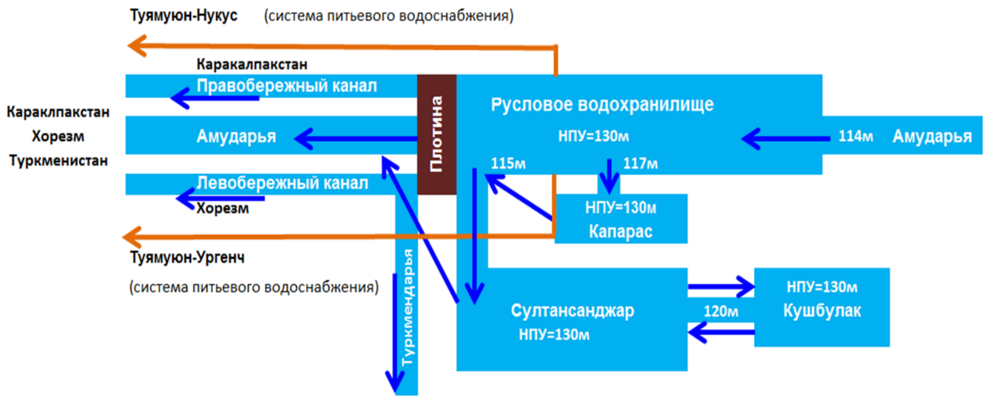

Figure 1.6. Water mass circulation scheme inside TMHC.

The admission and drawdown levels at the reservoirs are recorded at water-metering posts located in the headwater side prior to the Ruslovoye Reservoir Dam, as well as below the water-intake installations in the Kaparas and Sultansanjar Reservoirs. The water level in Koshbulak is considered equal to this in Sultansanjar.

Current condition of the TMHC reservoirs. The 2021 research to examine the capacity and sedimentation of the Ruslovoye Reservoir generated the following findings. The reservoir's total capacity at the near-dam water level (H = 130 m) was calculated to be **863 mln m^3**. The total sediment volume during the entire period of operation until 2021 equaled 2,340-863 = **1,477 mln m^3**. The water mirror at 130 m was 248 km^2 against the design area of 300 km^2. The average slope of the reservoir's basin bed (as per measurements) was **i = 0.00004** against the design i of 0.0002. ***The detailed description of 2021 measurements was presented in the Interim Report.***

1.3 Ruslovoye Reservoir operation regime

The water surface level change at the Ruslovoye Reservoir over the past 15 years shows correlation between its operation regimes and the cyclical water content during the same years (*see*

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Fig. 1.7.). For instance, 2009-2010 were high-water, and the water level in the reservoir remained at 129.5 m almost that entire period. During September-January 2012, the water level also reached 129.5 m. In other years, the water level did not exceed the 129 m mark, and the reservoir never completely filled to the NRWS level of 130 m.

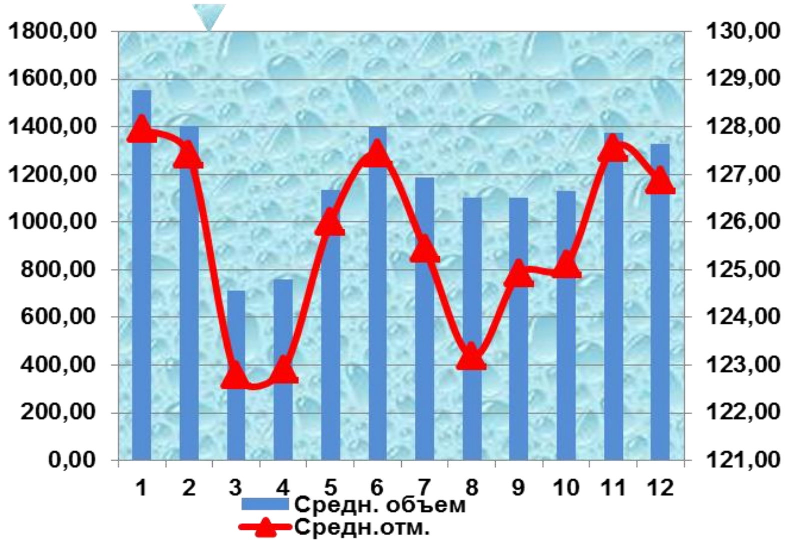

Figure 1.7. Mean multi-year characteristics of Ruslovoye Reservoir (last 15 years).

The analysis of water in- and outflow for 2004-2020 points to the max inflows falling on 2005 (47.3 km^3) and 2010 (43.8 km^3). The min inflows were registered in 2008, 2011 and 2018, amounting to 14.1 and 12.8 km^3, respectively (Fig. 1.8.).

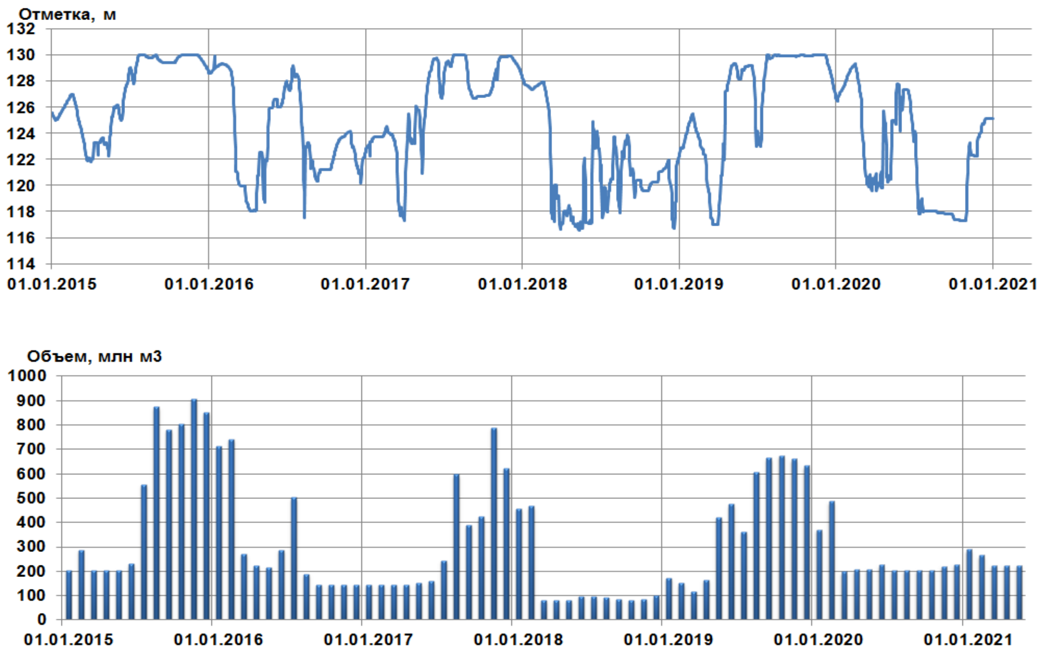

Figure 1.8. Ruslovoye Reservoir operation regime (2015-2021).

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Water losses from reservoirs. The water balance calculations made it possible to identify water losses due to evaporation in the TMHC reservoirs with the account of losses in shallow waters and due to transpiration by aquatic vegetation, as well as to calculate filtration flows along with establishing the hydraulic linkages between the reservoirs and aquifers. The analysis showed that after commissioning the Ruslovoye Reservoir, depending on the actual operation regime the annual evaporation losses reached as much as 250 mln m^2. In low-water years, provided deep drawdown, the losses were minimal. The highest losses occurred during high-water years, when the water levels remained high for a long time. Filtration losses turned out to be significant in high-water years; in low-water years, provided deep drawdown, an influx of filtration flows was observed. The largest filtration flows were observed in the Ruslovoye Reservoir, namely inflow – up to 130 mln m^3, and outflow – up to 280 mln m^3 per year.

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2. SEDIMENTATION VOLUME FORECASTING FOR THE TMHC RUSLOVOYE RESERVOIR (*TASK 2*)

2.1 Assessment of sedimentation dynamics during operation: sediment inflow, settling, flushing and transit

The Ruslovoye Reservoir basin began filling in June 1981. From that moment on, sedimentation has been continual reducing the reservoir's storage capacity. The research carried out by NIIIVP aimed to determine and later refine the main operation water volume curve W = f (H), as based on field measurements of basin water depths the reservoir has been accumulating sediment at various operation stages.

The analysis of sedimentation data for the operation period (1981 through 2008) showed that over the 40-year long operation, the TMHC reservoirs underwent significant changes against their design specifications. These were mainly caused by river mechanics in the Ruslovoye and Koshbulak Reservoirs and the connecting channel; sediment accumulation likewise occurred in the Kaparas and Sultansanjar Reservoirs.

By 1985, the initial design capacity of the Ruslovoye Reservoir (2,340 mln m^3) dropped by 585 mln m^3. The annual reservoir sedimentation during 1985-2005 averaged 22.2 mln m^3, with the most active sediment accumulation in 1991-1992 (222 mln m^3) and 1998 (108 mln m^3), i.e. total of 330 mln m^3. The remaining 17 years of this period gave only 25 mln m^3 of sedimentation. The maximum discharge outflow from the Ruslovoye Reservoir was observed in 1986 (135 mln m^3), 1997 (56 mln m^3), and 2000-2001 (110 mln m^3). The same years' water content amounted to 20.8, 18.3, 18.7, and 13.6 km^3, respectively.

Until 2002, the sedimentation of the Ruslovoye Reservoir basin was determined based on the measurements by NIIIVP (SANIIIRI). In subsequent years, no measurements were done due to the lack of funding. In 2005, the Bathymetric Center (BMC) State Unitary Enterprise executed the measurements, and they showed that the reservoir's total capacity lessened to 1,287 mln m^3 against the design capacity of 2,340 mln m^3; the mirror area values had also changed at different horizons. Due to using the Kaparas Reservoir to accumulate drinking water (156 mln m^3/year), its drawdown is done down to 118 m horizon against the design level of 117 m. In this case, the minimum volume water in the reservoir should be at least 500 mln m^3. Factoring in the evaporation – which for Kaparas amounts to approx. 100 mln m^3/year – it is necessary to fill it up to at least 125 m (630 mln m^3) mark. Water stress during low-water years complicates filling the Kaparas Reservoir. As the result of limited filling of the Sultansanjar Reservoir (up to 127.5 m horizon), the total volume of Koshbulak and Sultansanjar shrank by 640 mln m^3.

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The analysis of field research findings and the data of the TMHC Operational Service allowed identifying the difference in the conditions of sediment advancement, erosion and settling along the entire reservoir's length, and conditionally divide it into three sections.

By 2008, **Section 1** (Sites 71-49) roughly 15 km long features almost complete sedimentation of the original volume (110 mln m^3 design capacity). This section (between 112 and 117 m horizons) is silted up to 95% and serves as the transit zone for sediment washing from the reservoir. The total sediment volume within Section 1 is about 11% of the total sediment volume in the reservoir. It was established that sediment removal from the reservoir in this section occurred during the reservoir operating at lower water levels and significant outflow into the tail bay. The executed measurements confirmed that with a significant drop (from 127 down to 118 m) of water level near the dam, in the near-dam section two processes took place simultaneously, i.e. flushing of sediment that has built up during summer and further sediment erosion. The washing in this section reached up to 30 mln m^3 with the total erosion volume for the entire reservoir amounting to 35-40 mln m^3.

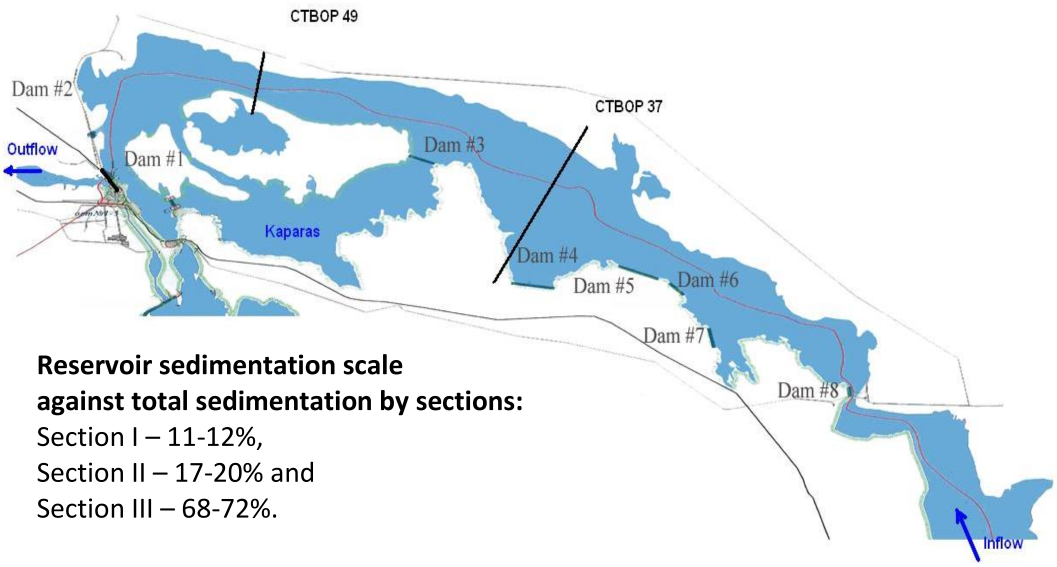

Figure 2.1. Sedimentation distribution by the Ruslovoye Reservoir basin sections.

During reservoir operation, in Section 1 sedimentation and erosion take place at the banked up water level of 118-130 m. In the course of summer flooding with the discharge of 2,700 to 4,500 m^3/sec and reservoir water levels ranging between 126 and 130 m, the sedimentation scale at 118-120 m horizons ranged from 71 to 100% of the total sedimentation in this reservoir section; at 120-124 m horizons, this value reached 30-90%; and at 124-130 m, sedimentation fluctuated between 0 and 44%. In low-water years, sediment erosion was observed at 118-124 m horizons, reducing sedimentation percentage down to 10-50% (versus 50-100%).

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The design capacity of the reservoir's **Section 2** – Sites 49 through 37, 30 km long (15-45 km away from the dam) – is 460 mln m^3. The section features yearly sedimentation volume variability from 27 to 71% against the design capacity (Table 2.1.).

In low-water years, this section's sedimentation amounted to 30-35% of its initial capacity. In meter-scale elevation ranges, the difference in sediment volumes are relatively small. The sediment comes from the superincumbent Section 3; and its advancement closer to the dam or settling depends on the reservoir's level regime, as well as the in- and outflowing discharges, i.e. channel mechanics taking place in this river section.

Table 2.1. Sediment accumulation by depths and its actual and designed volume (mln m^3).

Год / Высотные зоны		1985	1986	1987	1988	1989	1990	1991	1992	1997	2000	2001	2002	2006	2008
I	Объемы отложений до – 117 м	85	71	73	85	89	62	86	90	100	105	110	103	105	107
	% заиления (110 млн.м3)	77	65	66	77	81	56	78	82	91	95	100	94	95	97
II	Объемы отложений От – 117 до – 123 м	155	124	126	155	111	118	136	210	244	270	330	187	223	264
	% заиления (460 млн.м³)	34	27	27	34	24	26	30	46	33	59	71	40	48	57
III	Объемы отложений от – 123 до – 130 м	345	255	329	345	365	379	442	481	523	538	514	608	678	679
	% заиления (1770 млн.м³)	19	14	18	19	20	21	25	27	29	30	29	34	38	38

The Reservoir's **Section 3** (Site 37 and above) over 30 km long – most affected by water level changes – manifests the zone of backwater curve wedging when the reservoir water levels fluctuate above 124 m. It is also the main zone of river silt settling. The constant sediment rearrangements in Section 3 are provoked by periodic drawdowns and fillings of the Ruslovoye Reservoir, and contribute to the overall reservoir's sedimentation intensity and additionally raising the backwater curve upstream. Along Section 3, the erosion zones alternate with sediment settling areas – whereas the erosion scale between Sites 32 and 36 reached 80-100 mln m^3, Sites 31 and 35 demonstrated significant sediment volumes exceeding 100 mln m^3.

The analysis of field measurement data and calculations along the entire length of the reservoir show that the major sedimentation takes place during summer floods with the impounded headwater of the Ruslovoye Reservoir. Moreover, as per the 2008 data, the scale of sedimentation by sections compared to the total reservoir sedimentation was as follows: Section 1 – 11%, Section 2 – 17.7%, and Section 3 – 71.3%. Intensive sediment flushing from the reservoir's upper sections is observed when passing flood water at low reservoir water levels or drawdown. In the course of such flushings, fairway line deepening is observed at all thwart marks (sites).

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Capacity loss for the Ruslovoye Reservoir in the course of the entire operation is presented in Fig. 2.2. Considering the reservoir sedimentation by depth, it deserves noting that between 112 and 117 m the sediment occupied 95% or 104 mln m^3 against the design capacity of 110 mln m^3. Between 117 and 123 m horizons, the sedimentation reached 36% of the design volume and amounted to 166 mln m^3 (design capacity – 460 mln m^3). Between 123 and 130 m marks, the sedimentation reached 38% and amounted to 670 mln m^3 against the design volume of 1,770 mln m^3). Thus, as of 2002 the total reservoir's capacity dropped by 40% down to 1,400 mln m^3, with the sediment volume reaching 940 mln m^3.

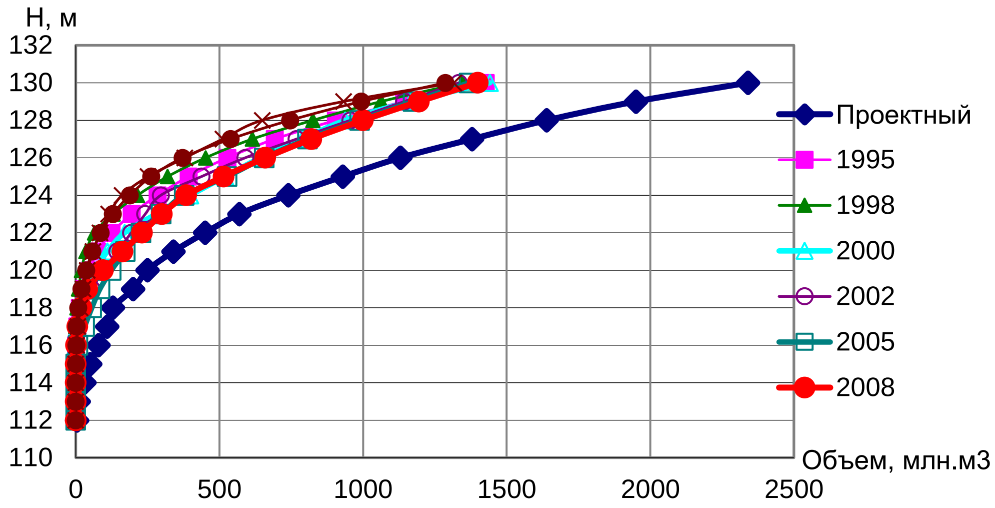

Figure 2.2. Ruslovoye Reservoir volume loss (~28 years).

The 2021 analysis showed that the total capacity of the Ruslovoye Reservoir declined from the design 2,340 down to 863 mln m^3 (at the time of measurements). Accordingly, the mirror area at different horizons had changed also; for instance, at 130 m it was 247.8 km^2. Figures 2.3. and 2.4. depict the dynamics of volume and water surface area changes.

Table 2.2. Ruslovoye Reservoir volume change dynamics during operation (mln m^3).

Water level, m	**Design capacity (1981)**		BMC (2008)	**NIIIVP (2021)**		
	Total capacity	**Available capacity**	**Water volume**	**Water volume**	**Sediment volume**	**Water mirror, km^2**
130	2,340	2,090	1,287	**863**	**1,477**	**247.8**
129	1,950	1,700	994	**539**	**1,411**	211.0
128	1,640	1,390	746	**302**	**1,338**	175.2
127	1,380	1,130	539	**133**	**1,247**	134.9
126	1,130	880	372	**64**	**1,066**	69.7
125	930	680	263	**25**	**905**	8.2
124	740	490	188	**4**	**736**	1.7

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123	570	320	129	0	**570**	0
122	450	200	87	0	**450**	0
121	340	90	58	0	**340**	0
120	250	0	36	0	**250**	0
119	190	0	20	0	**190**	0
118	140	0	9	0	**140**	0
117	110	0	3	0	**110**	0
116	80	0	1.6	0	**80**	0
115	50	0	0.5	0	**50**	0
114	30	0	0.1	0	**30**	0
113	10	0	0	0	**10**	0
112	5	0	0	0	**5**	0

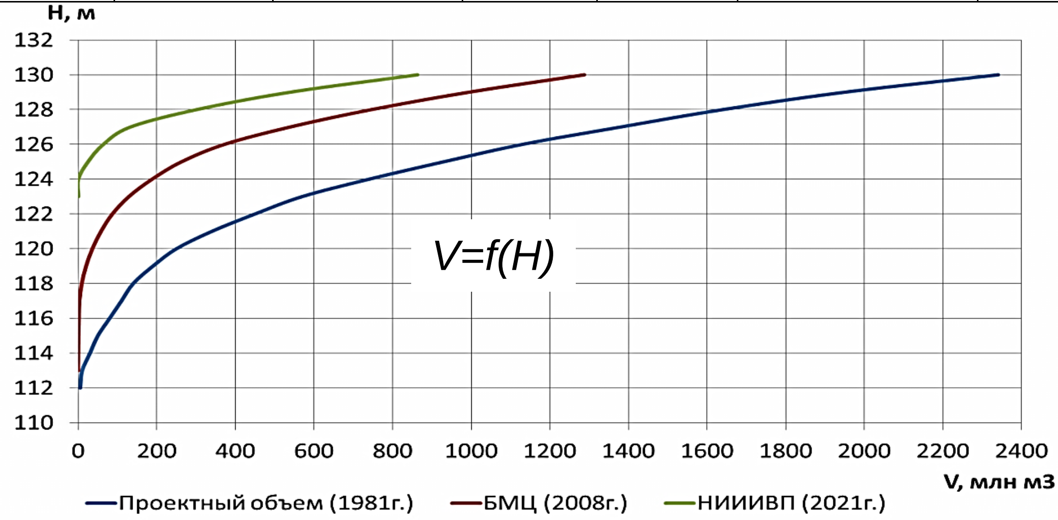

Figure 2.3. Ruslovoye Reservoir volume change dynamics.

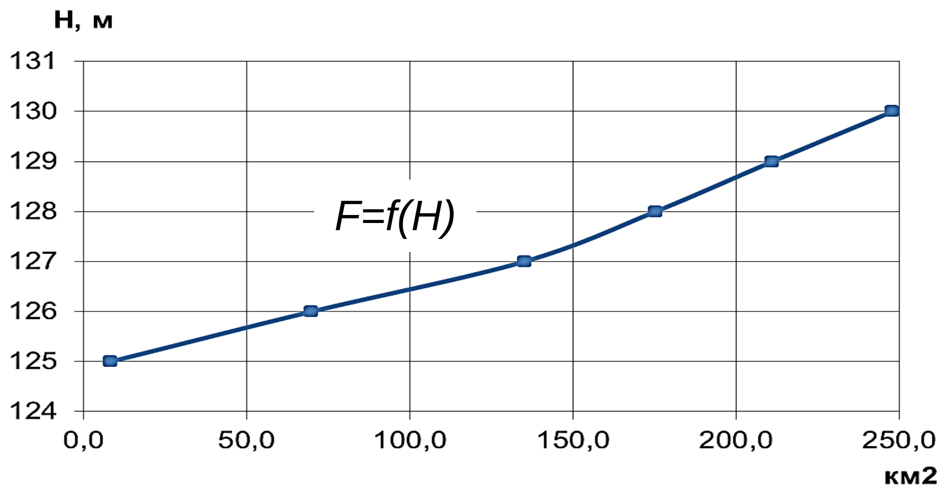

Figure 2.4. Ruslovoye Reservoir water mirror change.

The reservoir basin sedimentation analysis (as per 2021 measurements) pointed to complete coating of the reservoir's bed with sediment up to 125 m, equaling approx. 905 mln m^3 or 38.7%

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of the total sediment volume (Table 2.3., Fig. 2.5.). The remaining sediment volume is distributed as follows:

- between 125-126 m horizons – 161 mln m^3 (7%);
- between 126-127 m horizons – 314 mln m^3 (13.4%);
- between 127-128 m horizons – 260 mln m^3 (11%);
- between 128-129 m horizons – 310 mln m^3 (12.2%);
- between 129-130 m horizons – 390 mln m^3 (17%).

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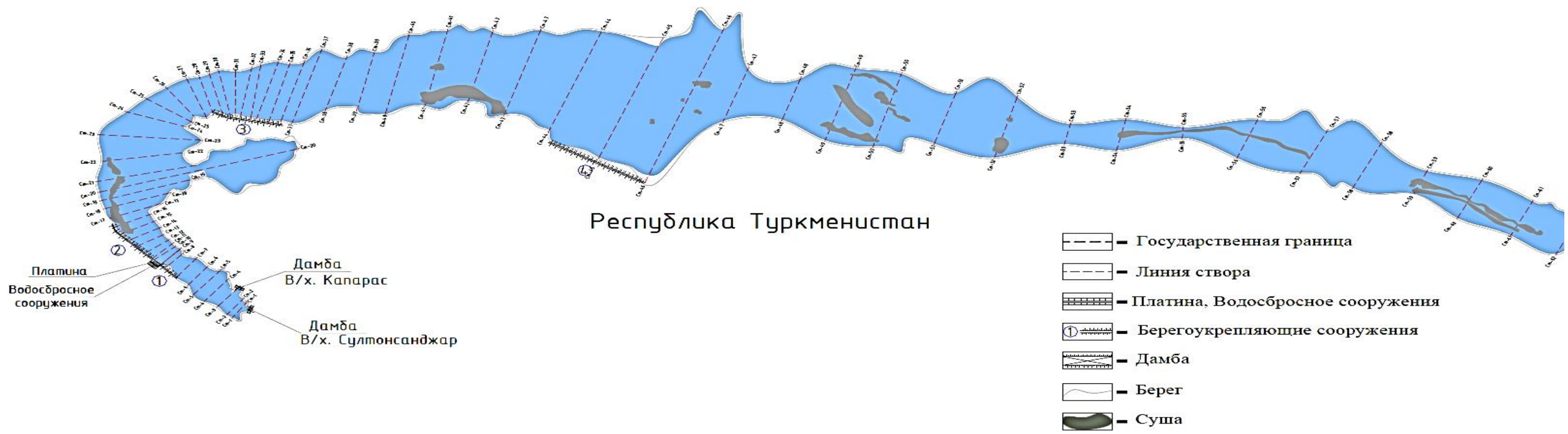

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Figure 2.5. Ruslovoye Reservoir at 124 m (during measurements) and 130 m (NRWS), including dryland zones.

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Fig. 2.6. demonstrates the correlation between sediment volumes and horizons in the Ruslovoye Reservoir basin. The graph shows no major sedimentation between 112 and 118 m (i.e. 180 mln m^3), with most of it (1,050 mln m^3) taking place between 120 and 128 m horizons.

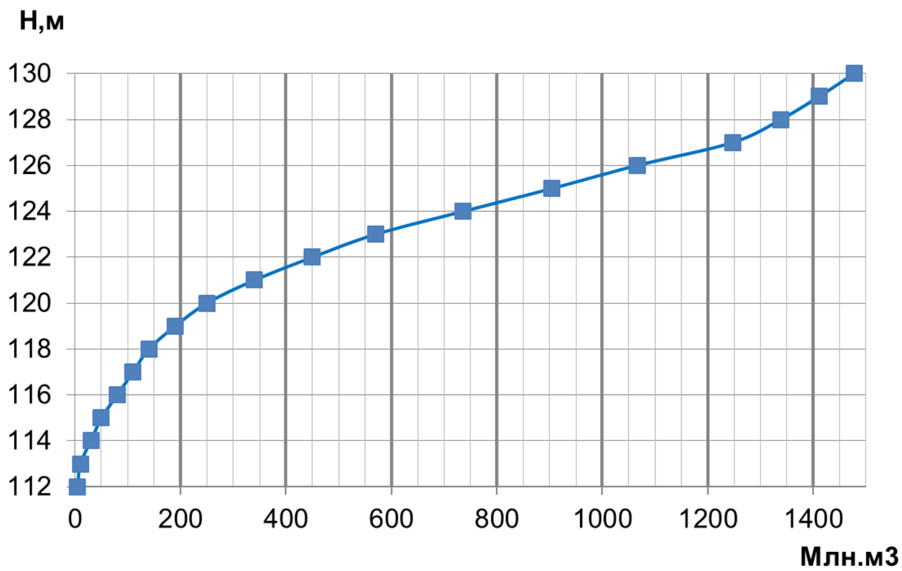
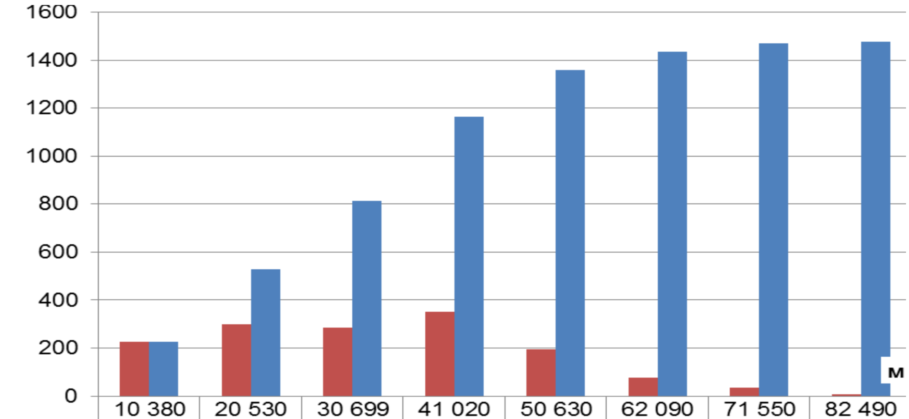


Figure 2.6. Sediment distribution by depth.

The total length of the reservoir basin (81 km) was divided into 8 sections as follows: Section 1 – 10,380 m; Section 2 – 10,150 m; Section 3 – 10,169 m; Section 4 – 10,321 m; Section 5 – 9,610 m; Section 6 – 11,460 m; Section 7 – 9,460 m; and Section 8 – 10,940 m (*see* Fig. 2.7.). Cumulatively amounting to 1,477 mln m^3, sediment distribution by sections in ascending order is presented below.



	10 380	20 530	30 699	41 020	50 630	62 090	71 550	82 490
Объемы заиления по участкам	226,289	300,638	285,366	352,115	193,337	77,082	35,108	7,208
Заиление в порядке возрастания	226,289	526,926	812,292	1164,407	1357,745	1434,827	1469,935	1477,143

Figure 2.7. Sediment location along reservoir basin length.

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Section 1 (10.4 km long) next to the dam contains 226.4 mln m^3, Section 2 (10.2 km long) – 301 mln m^3, Section 3 (10.2 km long) – 285 mln m^3, Section 4 (10.3 km long) – 352 mln m^3, and Section 5 (9.6 km long) – 193 mln m^3, Section 6 (11.5 km long) – 77 mln m^3, Section 8 (11 km long) – 7 mln m^3 of sediment. The main sediment share or 1,164 mln m^3 (79%) along the entire reservoir basin length is located inside the 40 km stretch approaching the dam; and the remaining 312 mln m^3 (21%) along the next 40 km up.

Based on the measurements, the mean slope of the basin bed is i = 0.00004 versus the design i = 0.0002, which means that the sediment deposits that had formed during the initial phase (first 10 years) of operation had gradually moved downstream closer to the dam (Fig. 2.8.).

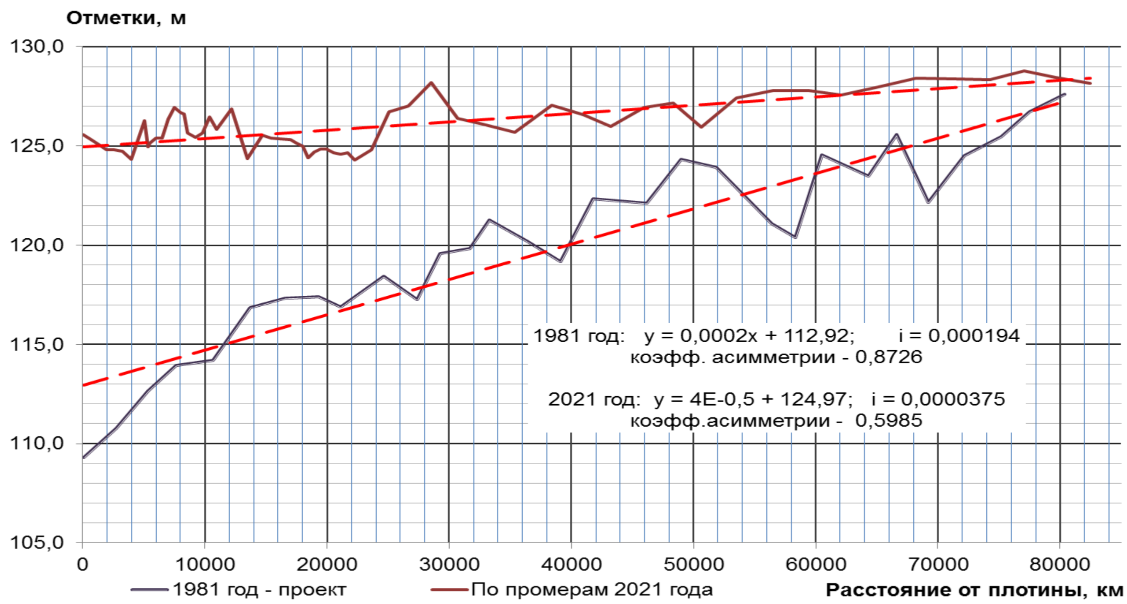

Figure 2.8. Longitudinal slope of Ruslovoye Reservoir basin bed.

The figure above compares the reservoir bed depths – design and these measured in 2021 – and points to a major depth jump observed in the near-dam zone (3-5 m proximity). The field measurements allowed building the Ruslovoye Reservoir GIS-model reflecting basin bed morphology. In its turn, the model made it possible to detect the zones that were previously included in the total reservoir capacity, yet in reality remained backwater spots at water inflow, and thus not used (Fig. 2.9.). The findings of GIS-modelling based on the executed measurements are presented below.

In the near-dam area at 125 m horizon, the movement of turbid flow occupies 1/8 of Site 22 cross-section, as reflected in the site image. The concrete reinforcement slabs in this section demonstrate sediment deposits at 127 m mark; the same deposits are observed on the concrete upstream wall of Dam #3.

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Close to Dam #2, the backwater is completely silted up to 125 m horizon.

Between Sites 51 and 35 at 125 m upstream water level, multiple canals and backwater zones are observed isolated by sediment ridges on all sides, thus representing dead storage.

The same picture is observed in the overlying sections. The left-bank duct close to Site 34 is silted up to 127.5 m. The right-bank section of Site 33 – previously eroded to the depth of 10-18 meters – is currently silted up to 127 m, obviously associated with sediment settling in the underlying section and creation of a sediment bar reducing water stream speed in the upper section.

Upstream of the Lebap Bridge, due to severe sedimentation caused by high horizons in the Ruslovoye Reservoir in previous years – multiple small and large channels had also formed, some of them blocked by causeways in the lower section, thus making it impossible to use the water in them.

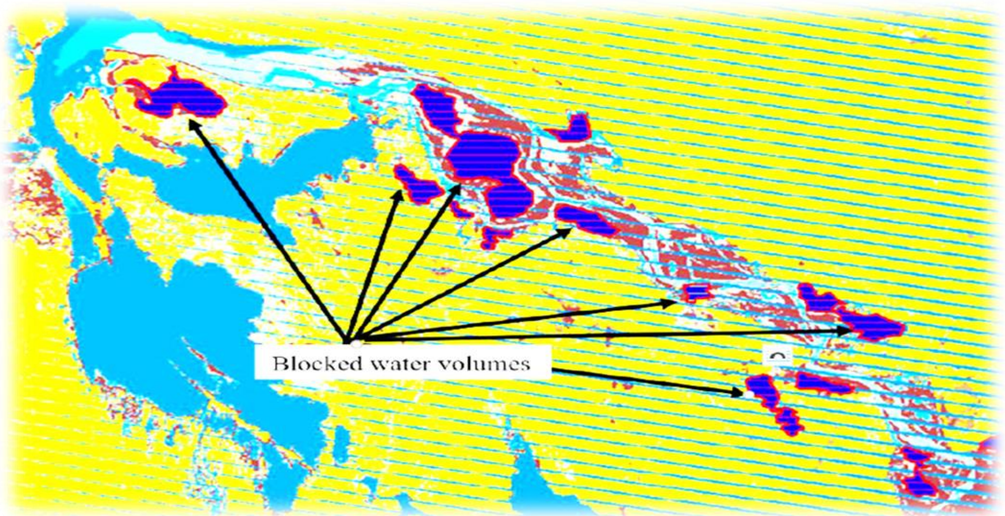

Figure 2.9. Outcomes of GIS-modelling to detect backwater zones in the reservoir basin.

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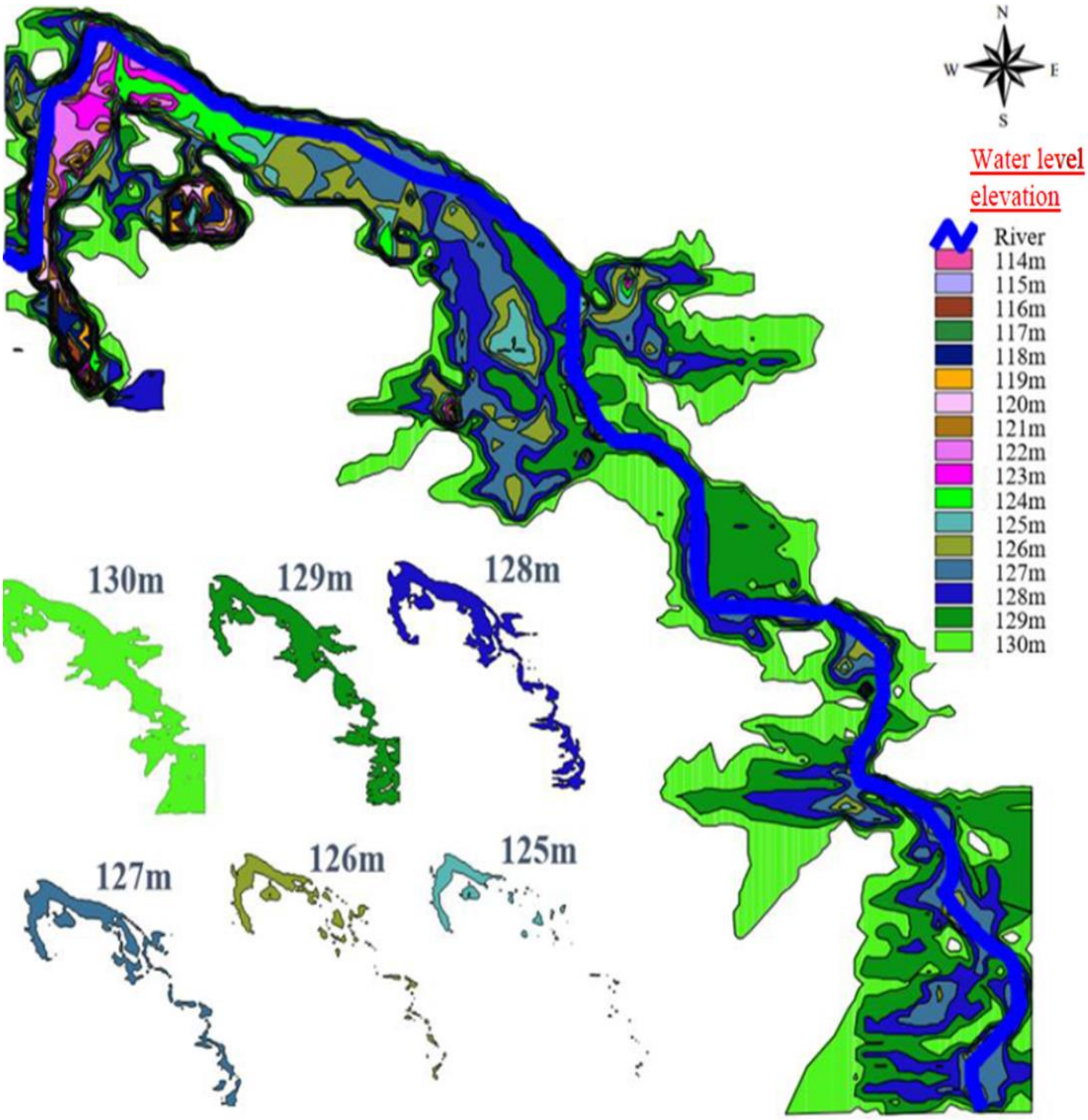

Figure 2.10. Ruslovoye Reservoir GIS-Model.

Elevation, m	130	129	128	127	126	125	124	123	122	121	120	119	118	117	116	115	114	113	112
Design capacity	2340	1950	1640	1380	1130	930	740	570	450	340	250	200	130	110	80	50	30	10	5
BMC	1287	994	746	539	372	263	188	129	87	58	36	20	9	3	1,6	0,5	0,1		
GIS Model	1264	944,7	718,4	512,2	333,4	241,9	158,6	122,5	72,6	56,1	35,2	19,4	8,5	2,8	1,2	0,5	0,1	0	0

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2.2 Assessment of sedimentation growth impacts on water allocation for power generation and irrigation in Uzbekistan and Turkmenistan

Due to sedimentation and capacity loss of the TMHC reservoirs, in particular the Ruslovoye Reservoir, as of today neither Uzbekistan nor Turkmenistan can exploit the Amu Darya water resources fully to meet their irrigation and energy needs.

Uzbekistan. The Tuyamuyun Hydro Complex supplies irrigation water to Khorezm Region and Republic of Karakalpakstan, generates 450 mln kWh per year of electricity, and supplies drinking water to Urgench and Nukus. About 530 thous. ha of farmland in Karakalpakstan get their irrigation supply from the Amu Darya River via TMHC; flow modification is 0.08-0.1 l/sec/ha; outflow per 1 ha amounts to 2.5-3.0 thous. m^3. The irrigated area in Khorezm Region is 255-260 thous. ha. During low-water years, water supply amounts to 2.0-3.5 km^3, 70% of which falls on the growing season.

Turkmenistan. The farmland in Dashoguz Veloyat get irrigated mainly from the Turkmendarya River, with the intake from TMHC and the Khanyab Canal System in the river's lower reaches. The Turkmendarya's discharge of 210-230 m^3/sec is sufficient for supplying irrigation water to five districts comprising Dashoguz Veloyat, namely Akdepe, S. Niyazov, Gorogly, Gurbansoltan Edzhe, and Rukhybelent. 340 thous. ha of farmland in Dashoguz Veloyat get their water from the Amu Darya, including 180 thous. ha via the Turkmendarya irrigation system. Sedimentation, dwindling throughput capacity of the existing irrigation network, as well as water deficit have forced the efforts to rehabilitate the corresponding irrigation systems. The target project provides for their cleaning and/or re-construction to ensure reliable water supply to 425 thous. ha of farmland.

The fluctuation of the Amu Darya River runoff is cyclical, i.e. low- and high-water years repeat every 5-7 years. However, due to climate change low-water cycles have shortened and now occur every 3-4 years (2000-2001 consecutive 2 years; 2008; 2011; 2014; 2018; and 2021) challenging the water needs of different economic sectors, especially agriculture consuming up to 90% of all available water resources. This, in turn, threatens the country's food security.

As a result of global warming and subsequent glacial melt, the available water resources in Central Asia have already shrunk by 25-30%. According to forecasts, a further temperature rise is expected potentially leading to a 40% or greater reduction of glacier area. The preliminary research calculations suggest that by 2050 the Amu Darya River runoff may converge by 15-20%.

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Negative sedimentation impacts. The reduction in the useful capacity of the TMHC Ruslovoye Reservoir due to sedimentation deteriorates the availability of water resources both in Uzbekistan and Turkmenistan. During the design phase, the area allotted to the TMHC inside both countries amounted to 960 thous. hectares. The 1,477 mln m^3 slashing of the reservoir's volume leads to a significant decrease in the operational capacity of the Tuyamuyun Hydro Complex as a whole due to the following:

- reduced possibilities for timely and guaranteed filling of three offstream reservoirs, i.e. Kaparas, Sultansanjar, and Koshbulak;
- provoking intensive sedimentation of three offstream reservoirs, and thus slimming their active capacities;
- low water quality in the Kaparas Reservoir mainly used for drinking purposes;
- impairing irrigation water supply to the farmland in the Amu Darya River lower reaches allotted to TMHC, thus reducing the irrigated land by 76,690 ha (as per current sedimentation status in the Ruslovoye Reservoir), even disregarding the adverse influence on the operating capacity and work of the three offstream reservoirs;
- limited possibilities for regulating the Amu Darya River runoff ranging between 35 and 75 km^3, including flood routing and aftermath;
- degrading the HPP capacity to generate electric power.

The calculations of annual economic losses due to lost capacity of the Ruslovoye Reservoir (without considering the adverse impacts on the TMHC three offstream reservoirs) suggest the following:

A) IRRIGATION – farmland suffering from water shortage – 76,690 ha;

Cotton: i) 2021 – total raw cotton 3.4 mln tons; loss per 1 ha – 1-1.5 tons; total fiber – 25,307.7 tons (330 kg of fiber per 1 ton of raw cotton); price of 1 pound of fiber –1.05 USD in 2021); cotton-related economic losses – 59.051 mln USD (as per 2021 prices);
ii) mean price in the last 10 years (1 pound – 0.65 USD); total cotton-related economic losses – 36.556 mln USD;

Rice: Uzbekistan: 2021, raw rice (*shaly*): Karakalpakstan – 44,000 ha and Khorezm – 30,000 ha; gross planned harvest: 226,000 + 141,091 = 376091 tons (330,115 USD);
Turkmenistan: farmland under rice in Dashoguz Veloyat – 8,100 ha, Lepab Veloyat – 10,200 ha; gross harvest: 35,000 + 47,400 = 82,400 tons (271,096 USD); total rice-related economic losses – 601,211 USD.

B) ENERGY – financial losses – ~ 5.5-16 mln USD per year depending on water content considering the sedimentation of the Ruslovoye Reservoir useful capacity; TMHC HPP capacity – 150 MW, design power generation – 830 mln kWh per year; 6 units of 25 MW; design headwater – 16.4 m; required discharge – 179 m^3/sec.

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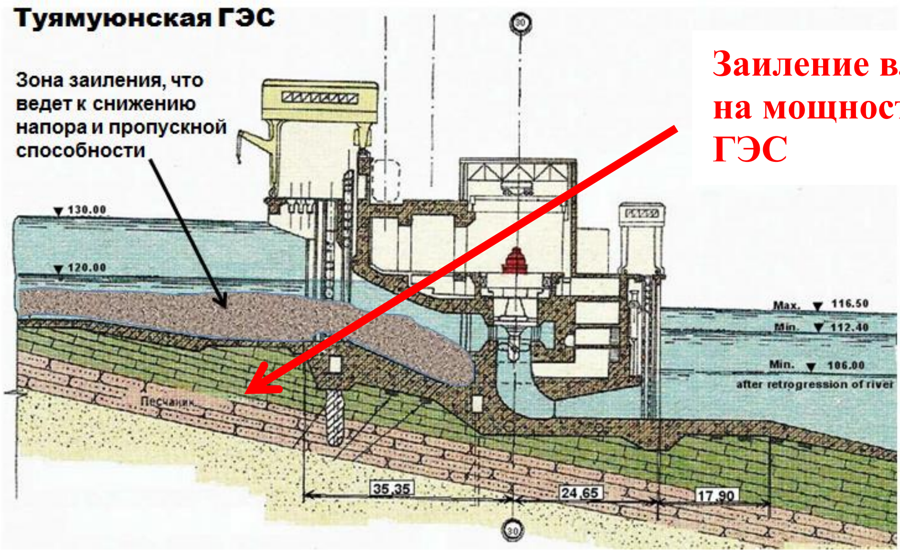
Year	Discharge, m^3/sec	Volume, mln m^3	Depth, m	Working head, m	Actual generation, mln kWh	%	Economic losses, mln USD
2016	692.62	21.842	123.8	7.8	443.404	44.34	**8.04**
2017	1,067.25	33.657	126.5	10.5	604.173	60.42	**5.43**
2018	569.33	17.954	121.2	5.2	136.331	13.63	**15.07**
2019	948.75	29.920	126.9	10.9	571.695	57.17	**7.00**
2020	644.08	20.312	122.4	6.4	213.371	21.34	**14.89**
2021	412.80	13.020	122.2	6.2	1e51.000	15.10	**16.26**

** The cost of 1 kWh in Uzbekistan is 0.018-0.027 USD (2016-2020).*



2.3 Plotting the 50-year expected volume loss dynamics for Ruslovoye Reservoir

The forecast sedimentation calculations for the Ruslovoye Reservoir were carried out based on the actual (current) and the proposed operation regimes considering the water content of each estimated year. The operation regimes were adopted for mid-, low- and high-water years. For calculation purposes, the active capacity of the reservoir (NRWS = 130 m, 1,427 mln m^3) were used (1995). This volume was applied as the starting point for determining the capacity dynamics in the future depending on the modelled operation regime.

The headwater stable channel volume was calculated as per the method of V.A. Skrylnikov and amounted to Wp = Qср. пав/Vp · Lп = 165 mln m^3, where $Q_{ср.пав}$ = 1,800 m^3/sec – mean multi-year water discharge during flood period; V_p = 1.0÷1.2 m/sec – speed of mean-stage river bed for the Amu Darya conditions; Lп = 110 km – headwater length with the account of additional head.

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With the accepted slope of the mean-stage river bed (i = 0.00018) for this river section, the hydraulic elements of the stable channel amounted to Bp = 600 m and Np = 2.5 m. As per design documentation, when the reservoir's useful capacity equals 8,33 Wp, then the Ruslovoye Reservoir will face the second sedimentation phase. In this case (8.33·165 = 1,374 ≈ 1,400 mln m^3) the calculations were done considering this factor. The initial cumulative sediment deposit mark in the reservoir thus was adopted as equaling $\Sigma_{отл}$ = 124.83 m determined based on the design capacity curve for the Ruslovoye Reservoir.

In order to determine the impact of level regimes on basin sedimentation speed, additional predictive calculations were carried out for two scenarios; with Scenario I taking into account the *actual reservoir level regime*; and Scenario II based on the *proposed operation regime* developed for mid-water year with the same inputs.
When calculating the sediment volumes transported to the reservoir with the river stream for real years, the values of river runoff and weighted mean values of stream turbidity at the Darganata Hydropost were used. When calculating the proposed regimes, the values of river runoff were taken as means for high-, mid- and low-water years, respectively.

All sediment volume calculations took account of water clarification index, depending on the water level during the calculated period - ε = F (Wp/Wн).

Since reservoirs are characterized by the variable level regime, during sedimentation volume calculations it becomes necessary to account for the parameters of a particular reservoir corresponding to different drawdown and filling levels. While forecasting the volumes and terms of sedimentation, as well as conducting control calculations – in case of absence of field measurements – the reservoir volume at the calculated level is determined by the following formula:

$$W_{н} = \frac{W_{п} W_{рн} (\nabla НУ - \nabla_{совм})}{W_{р} (\nabla НПУ - \nabla_{совм})}$$

Wрн (volume of channel reservoir) is determined by the curve W = f (H).

During reservoir operation, its level regime changes, and therefore the conditions affecting the sedimentation alter as well. Based on the change range as to correlation of channel capacity (*Wрн*) to the corresponding reservoir capacity (Wн), it is possible to allege the processes occurring in the headwater. Thus, at Wрн/Wн ≤ 0.12 correlation, the reservoir becomes subject to the settling of all sediment coming with the stream. Between 0.12 to 1.0, sedimentation of varying intensity occurs. When the volume correlation becomes 1.0, then the suspended sediment gets transported as well; and if 1.0 is exceeded, the erosion and transit of the settled sediment to the tail bay takes place.

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The forecast sedimentation calculations were executed taking into account the sedimentation stage at the initial calculated time and the accepted actual or recommended operation regime at different water content conditions. The proposed methodology allows long-term forecasting of reservoir sedimentation considering the Amu Darya hydrological regime for different TMHC operation regimes in order to boost the efficiency of the Ruslovoye Reservoir use and decrease the rate of its sedimentation.

To assess the accuracy of calculations based on sedimentation modelling, the calculated and observed sedimentation data were compared against each other (for 10 years). The comparison of the calculated data with the results of field measurements indicated a fairly good convergence, allowing to propose the suggested methodology for forecast calculations.

The analysis of the results of sedimentation calculations for the Ruslovoye Reservoir as per the proposed methodology performed based on the actual operation regime (Scenario I) and the proposed operation regime (Scenario II) is presented below.

Reservoir operation at the levels actually recorded during 1995-2003 (between 124 and 130 m), significant sedimentation was observed. In 1996 (mid-water) and in 1998 (high-water), sediment volumes reached 51 and 151 mln m^3, respectively. In 2002 (mid-water) and 2003 (high-water), sediment deposits amounted to 83 and 143 mln m^3, respectively. Only in low-water years (1997, 2000, 2001), the reservoir's active capacity increased due to bed sediment erosion at low water horizons – by 40, 98 and 79 mln m^3, respectively. However, the subsequent operation regime in 2002-2003 at high horizons again fostered its useful capacity to contract by 83+143 = 226 mln m^3. As per Scenario I, the total sediment volume for the calculated years (1996-2006) amounted to 298 mln m^3, and flushing volume – 217 mln m^3.

The comparison of calculation outputs with the sedimentation and erosion observed data pointed to sufficient correlation of the calculated and field-measured data. This confirms that the methodology can be applied for performing forecast calculations. In addition, the methodology accounts for the potential sedimentation and erosion dynamics occurring in the reservoir at different level and hydrological regimes.

The examination of the calculated values as per the proposed regime pointed to the 81 mln m^3 active capacity growth observed in 1996. Yet, the sediment volume – equaling 189 mln m^3 over the same calculated period – is significantly lower than that under Scenario I (actual operation regime) (*see* Fig. 2.11). The advantage of the recommended regime is explained by the fact that during March-June, at low water levels, it is necessary to route through the highly silted runoff to the TMHC's tail bay. This significantly reduces sedimentation and contributes to partial erosion of bed sediment deposits, as well as their transit outside the reservoir. This operation regime allows utilizing the additional calculated capacity of up to 207 mln m^3.

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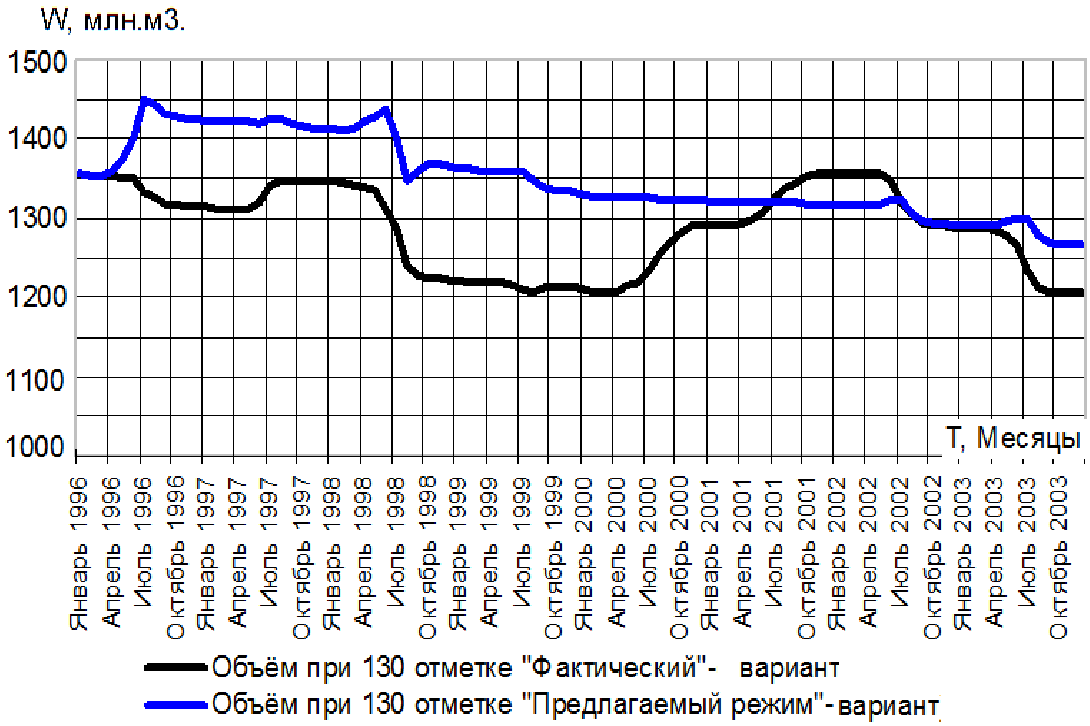

Figure 2.11. Ruslovoye Reservoir available capacity dynamics as per Scenarios I and II.

The preliminary sedimentation forecasting in the Ruslovoye Reservoir for long-term operation covered the period from 1996 to 2040. The calculations showed that under the current regime the reservoir will be completely silted by 2040.

Comparing the calculation outputs to detect the optimal scheme showed that under the proposed regime the sedimentation occurred 1.5 times slower than under the current regime; and that the volume of the Ruslovoye Reservoir would stabilize, i.e. the stable balance between sediment in- and outflow would happen at the reservoir's sediment-free capacity of 700-750 mln. m^3, i.e. by ~ 2025.

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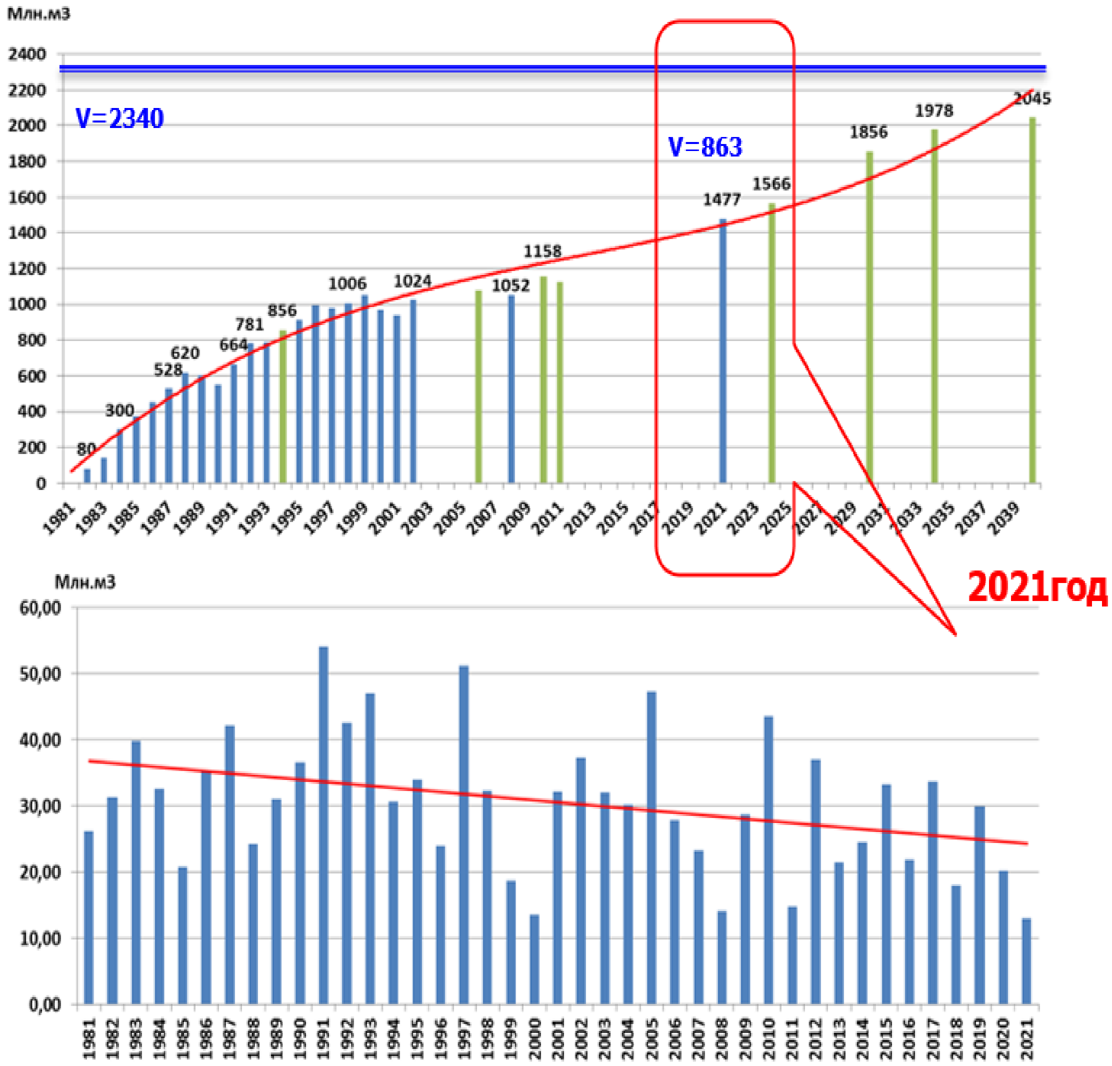

Figure 2.12. Forecasted Ruslovoye Reservoir sedimentation dynamics as per current operation regime.

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2.4 Comparative analysis of actual and proposed operation regimes for Ruslovoye Reservoir

To validate the efficiency of the operation regime proposed for the Ruslovoye Reservoir under this study, it became necessary to consider the operation of all TMHC reservoirs. **In low-water years**, the main task of managing the reservoir is to maximize the use of its active capacity to accumulate water and to subsequently ensure its rational and proportionate allocation for irrigation during runoff-scarce periods. Fig. 2.13. shows the actual and recommended operation regimes of the TMHC reservoirs in a low-water year (23 km^3 runoff), and the corresponding irrigation water supply from them in the same year.

The figures make it obvious that the current TMHC operation regime does not allow a planned accumulation of the required water amount in its reservoirs. For instance, whereas under the ongoing regime the deficit of irrigation water reaches 3.2 km^3, under the proposed regime it is 1.6 km^3. Thus, the proposed scheme allows to determine and utilize its capacity in ensuring proper irrigation water availability to a fuller extent.

The level of water availability was determined as the difference between the actual (or recommended) water supply and required (limited) water supply, i.e. Actual Limit or Recommended Limit. The data analysis showed that in low-water years, the total water undersupply downstream as per the reservoir's current operation conditions was higher than as per the recommended regime. In addition, the proposed regime also allows filling up the Kaparas Reservoir with higher-quality water suitable for drinking in July-August. Mid- and high-water years pose no difficulties in terms of accumulating a sufficient amount of irrigation water.

It deserves noting that the proposed Ruslovoye Reservoir operation scenario provides for choosing an optimal regime allowing to cut water losses due to evaporation and compensate the flooding peaks, as well as to plan for discharging up to 4,000 m^3/sec to the dam's tail bay, which will prevent the potential flooding damage in the Amu Darya lower reaches, as well as inhibit sediment accumulation and transit inside the reservoir.

a)

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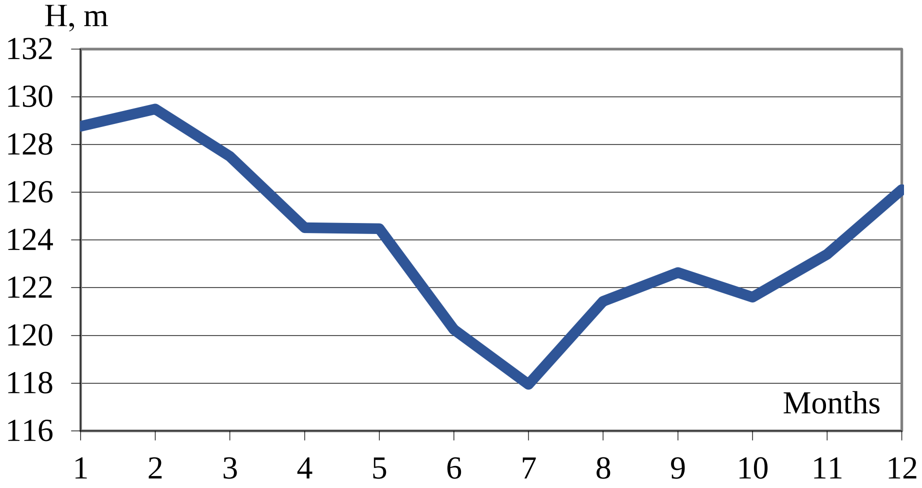

b)

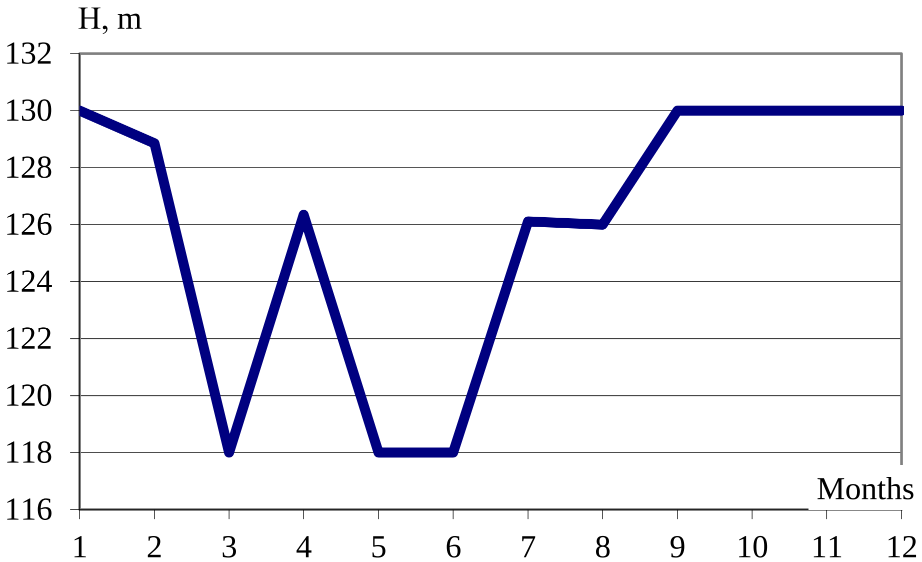

Figure 2.13. Current (a) and proposed (b) Ruslovoye Reservoir low-water year operation regime.

For comparison purposes, Fig. 2.14. features the recommended reservoir operation regime in a low-water year and graphically depicts the calculations of the corresponding irrigation water supply.

a)

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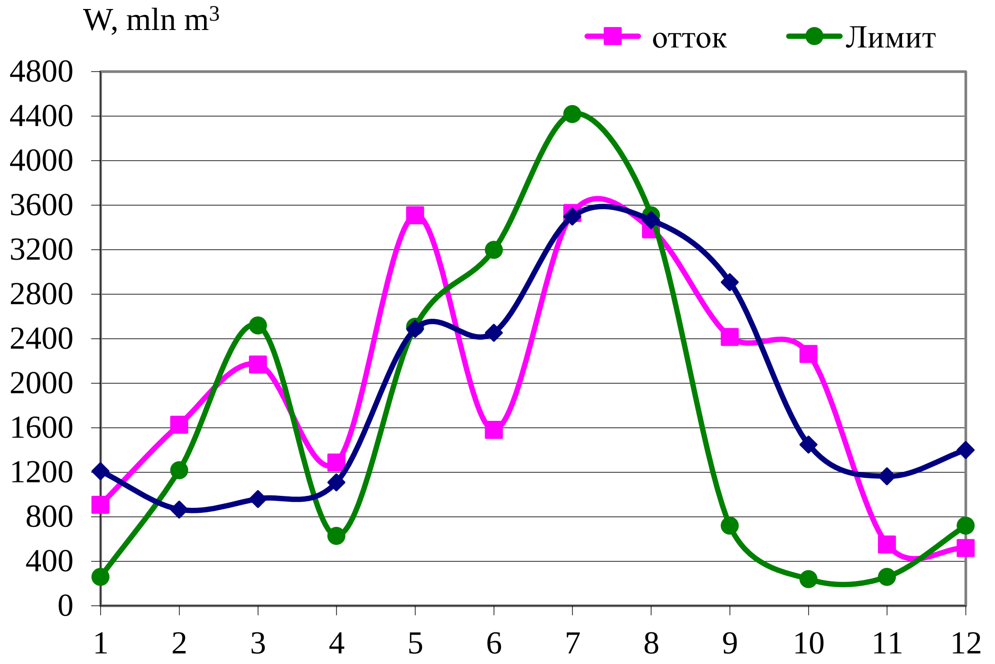

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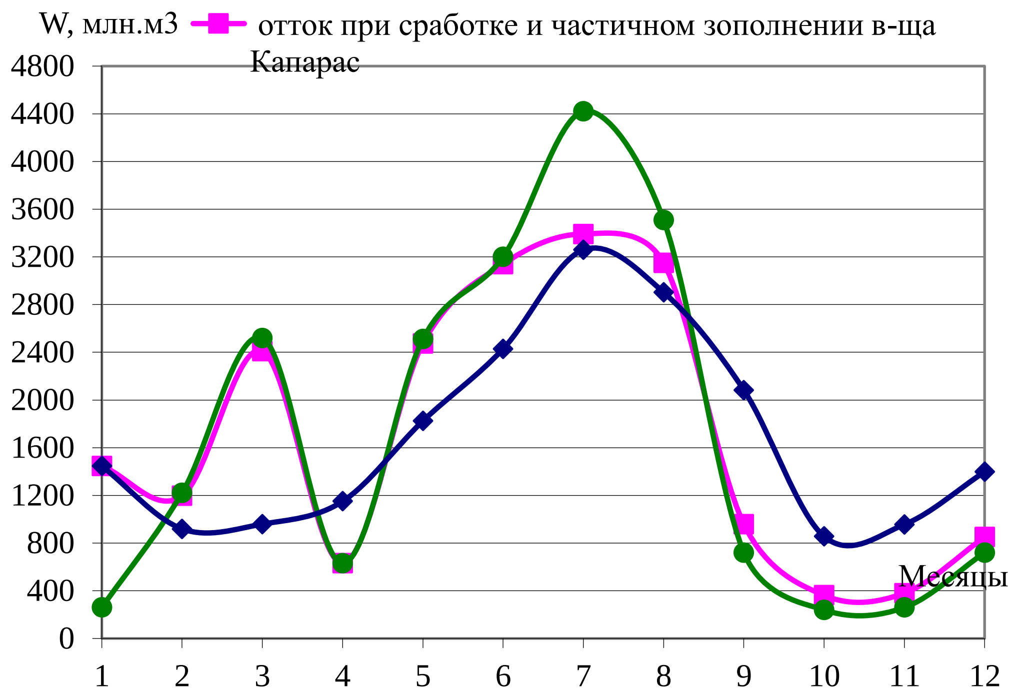

Figure 2.14. Irrigation water supply as per current (a) and proposed (b) Ruslovoye Reservoir low-water year operation regimes.

The analysis of sedimentation calculations in terms of water availability in a particular year showed the following: during the reservoir operation at the levels ranging from 124 to 130 m, severe sedimentation occurs – in mid- and high-water years, sediment volumes average between

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50 and 150 mln m^3, respectively. Only low-water years demonstrated an increase in the reservoir's active capacity due to bed sediment deposit washing at low water horizons (40-98 mln m^3).

The operation at high horizons reduces the reservoir's useful capacity. The advantage of the recommended option is in allowing the highly turbid March-June runoff pass through to the TMHC lower pond. This significantly reduces sediment volume and stimulates partial flushing of bed sediment with its subsequent transfer outside the facility. It is known that certain operation regimes foster flushing of the previously settled sediment in the Ruslovoye Reservoir basin. Favorable conditions for recovering the reservoir's useful capacity by way of flushing a part of bed sediment into the TMHC tail bay do exist.

The efficiency of a reservoir operation regime is determined by the ability to discharge the stream containing suspended sediment into the tail bay at a scale close to the natural flow. It is possible to ensure the removal of sediment in quantities corresponding to the turbidity of non-regulated runoff by operating the Ruslovoye Reservoir at low near-dam water levels during seasonal floods. This will stimulate transporting the stream sediment coming with the river runoff to the tail pond, as well as ensuring the discharge of the bed sediment flushed from the reservoir basin as the result of higher flowage.

The described operation regime is particularly suitable for reservoirs with high water exchange rate. This method is likewise effective in case of drastic water level drop close to dam, as it creates the flushing speeds and is applicable in high-water years, mainly in September due to inadvertent drawdown of large water volumes washing away the sediment.

Table 2.3. Performance indicator comparison for different reservoir operation regimes (2006-2017).

Year dryness (water content)	**TMHC operation regime**	**Water deficit, km^3**	**Sediment flushing, mln m^3**	**Sediment volume arriving in tail bay, mln m^3**	**Capacity increase, mln m^3**
Low water	Actual	6.51-7.42	216.38	319.83	
	Proposed	**4.19-5.4**	**147.12**	**122.91**	**-69.26**
Mid water	Actual	1.89-0.51	8.17	140.54	
	Proposed	**0.67-0**	**281.98**	**412.85**	**273.81**
High water	Actual	0	0	71.12	
	Proposed	**0**	**206.34**	**360.47**	**206.34**
TOTAL	Actual		224.55	531.49	
	Proposed		**635.44**	**896.23**	**410.89**

The following indicators point to the expedience of introducing the study findings:

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- water supply at the recommended regime is 2-2.3 km^3 (36%) higher in low-water years, and in mid-water years it is 0.5-0.67 km^3 (5-6%) higher against the current TMHC operation regime;
- in mid- and high-water years, the flushing of the Ruslovoye Reservoir's falls within the 200-280 mln m^3 range, and the sediment volume entering the tail bay is 250-310 mln m^3 more than under the current TMHC operation regime;
- the freed capacity and reduced evaporation losses under the recommended scheme may supply the lower Amu Darya with an additional 320-400 mln m^3 of water, thus enhancing irrigation of 35-47 thous. ha of farmland.

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3. SEDIMENTATION MANAGEMENT TECHNICAL RECOMMENDATIONS (*TASK 3*)

3.1 Recommendations to reduce sedimentation of Ruslovoye Reservoir: operation regimes allowing maximum silt load transit

The sediment entering the reservoir is distributed along its bottom and forms the corresponding soil profile. The fundamental restructuring of the underwater relief is occurring simultaneously with the reservoir filling. In general, channel basins are prone to bed erosion (washing) and reforming by currents. Erosion due to wave and energy activity usually happens in areas not deeper than 8-10 m. To reduce reservoir sedimentation, it is necessary to maintain the operation regimes allowing maximum transport of incoming solid effluent and sediment erosion; when and if possible, to drawdown the head race to the minimum possible horizon; as well as wash head race sections by creating favorable conditions, and mechanically remove sediment deposits.

Based on the TMHC operation regime model, including the corresponding GIS-model, variants calculations were executed to identify the optimal modes of operating the reservoirs in question, and to assess the efficiency of river runoff exploitation [42, 45, 48, 53, 63, 64]. The task was to select the schemes which satisfy the requirements of minimizing water losses in the TMHC reservoirs and in the river's lower reaches. The calculations took account of water content by yearly river runoff, needs of the downstream irrigation complex, operation regimes of the TMHC reservoirs, level regime of Ruslovoye Reservoir, and its sedimentation regime. The yearly water content was adopted as the main factor limiting the inflow into TMHC. The calculations reflected the following three water content scenarios:

- estimated low-water year at 90% water content;
- medium-water year at 50% water content; and
- high-water year at 10% water content.

Some calculation conditions were adopted, such as downstream water consumption (as per limits) – 20.2 km^3, including during vegetation – 15 km^3, limit cuts downstream in low-water years by 10... 20%, restrictions as to the active capacity of Ruslovoye Reservoir, and restrictions in terms of reservoir filling and drawdown. The following main TMHC functions underwent numerical valuation: seasonal river runoff regulation for irrigation purposes, especially during water scarce years, and flood control in high-water years.

To properly simulate the Ruslovoye Reservoir operation regime, it appeared necessary to factor in the TMHC offstream reservoirs, as well as the following input data and parameters (*see* Annex 2):

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i – calculated month,
Qi – river runoff,
Q_i^L – set water supply limit.

The total capacity W_{total} at ∇NRWS was adopted as per the sedimentation model. The reservoir volume at minimum horizon was also determined based on the same sedimentation model as per the following dependence $W_{min} = f(\nabla_{min})$. The useful capacity of the Ruslovoye Reservoir was taken equal to

$$W_{пз}^{R} = W_{пол}^{R} - W_{min}^{R} \quad (3.1)$$

The calculations algorithm is described below.

1. The reservoir's useful capacity:

$$W_e = W_п - W_m \quad (3.2)$$

2. Total reserve stock to cover deficit during months II-VI:

$$W_3^{II} = W_i^{R_{нач}} + Q_{IV}^{изб} - W_3^1 \quad (3.3)$$

3. River runoff excess over the limit for relevant period:

$$Q_i^{изб} = Q_i - Q_i^L \geq 0 \quad (3.5)$$

4. Cumulative river runoff access during months XI-XII:

$$\sum Q_{IX\text{-}XII}^{изб} = Q_{IX}^{изб} + Q_X^{изб} + Q_{XI}^{изб} + Q_{XII}^{изб} = \sum 20_{IX\text{-}XII} \quad (3.6)$$

5. Ratio of excess in each of the 4 months considered to the excess volume during the same period:

$$\alpha_i = \frac{Q_I^{изб}}{\sum Q_{IX-XII}^{изб}}, \quad (3.7)$$

6. Volume of river runoff withdrawal to fill the reservoir during months IX-XII:

$$W_i^{отб} = (W_{IX\text{-}XII}^{изб} - W_{i\ нач}^{P})\alpha_i \quad (3.8)$$

with river runoff deficit for calculated periods from months II-VI:

$$W_i^{деф} = Q_i - Q_i^L < 0 \quad (3.9)$$

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and values during months VII-XII equaling $W_i^{деф} = 0$

7. Cumulative river runoff deficit during months II-VI:

$$\sum W_{II\text{-}VI}деф = \sum W^{деф}_{i \to II \div VI} \tag{3.10}$$

8. Deficit share during calculated periods of months II-VI:

$$\beta_i = \frac{W_i^{деф}}{\sum W_{II-VI}^{деф}} \tag{3.11}$$

9. Discharge deficit coverage at the expense of reservoir stock and excess inflow during months II-VI with the account of evaporation losses:

$$W_i^{\beta} = \beta_i W_3^{II} \tag{3.12}$$

10. Water horizons in the reservoir at months' beginning H_i^R were calculated based on the capacity curve plotted as per reservoir sedimentation model.

11. Reservoir water mirror at months' beginning:

$$F_i^R = \frac{W_{II} W_{ph}(\nabla НУ - \nabla совм)}{W_p(\nabla НПУ - \nabla совм)} + \frac{W_{ph}(\nabla \sum отл - \nabla НУ)}{\nabla \sum отл - \nabla совм} - \frac{W_{II} W_{p(h-0.1)}[(\nabla НУ - 0{,}1) - \nabla совм]}{\nabla НПУ - \nabla совм} + \\ + \frac{W_{p(h-0.1)}[\nabla \sum отл - (\nabla НУ - 0{,}1)]}{\nabla \sum отл - \nabla совм} : 0{,}1 W_p \tag{3.14}$$

12. Evaporation from the reservoir:

$$W_{\mu_i}^R = \mu_i F_i^R \tag{3.15}$$

,with μ_i as the evaporation water surface layer as per hydrometeorological data.

13. Free reservoir capacity:

$$W^R_{свi} = Wi^R - Wiнач^R - W\mu_i^R \tag{3.16}$$

14. Reservoir drawdown volume:

$$W_{срi}^R = D^R\left(W_i^{\beta} - W_{срi}^R\right) + W_i^R \tag{3.17}$$

15. Reservoir filling volume:

$$W^{Р}_{начVII} = W^{Р}_{\nabla 125} + W^P_{\mu VIII}\ ; \quad W^{Р}_{начVIII} = W^P_{\mu VIII}\ ; \quad W^{Р}_{начII+VI} = Q_{I}^{изб} - W_{\mu I}$$

, provided that if $W_I^{отб} = W_{i}^P - W_{Iнач}^P$ то $W_{Iнач}^P = W_{i}^P - W_{iнач}^P$

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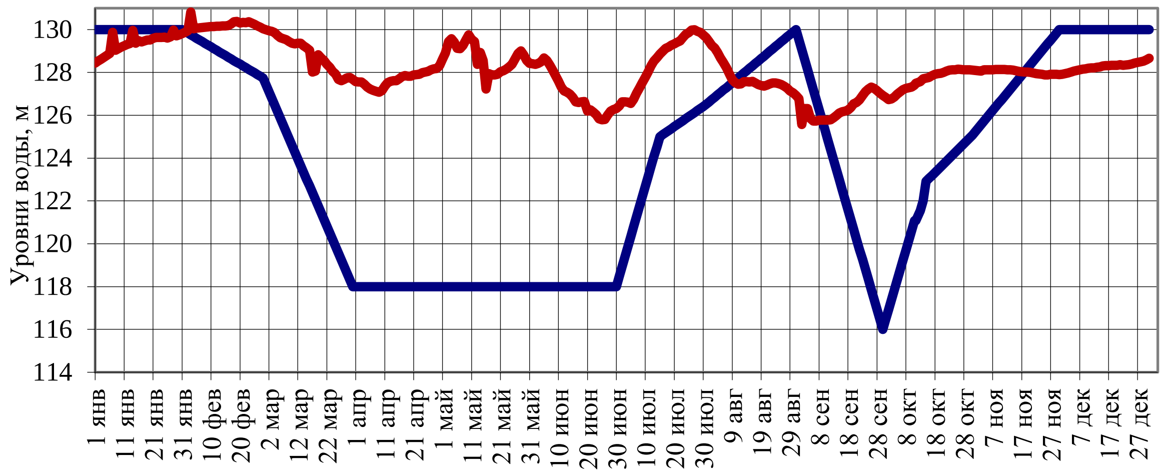
and $W_I^{\text{отб}} < W_{\text{i}}^P - W_{\text{Iнач}}^P$ то $W_{\text{iнач}}^P = W_I^{\text{отб}}$

16. Outflow volume:

$$\sum W_{i\text{от}} = W_{i\text{рек}} + \sum W_{i\text{ср}} - \sum W_{i\text{напол}} \qquad (3.18)$$

The calculation outputs for the TMHC reservoirs' operation regimes based on the proposed methodology are presented in Annex 3 and graphically in Fig. 3.1. below.

a)



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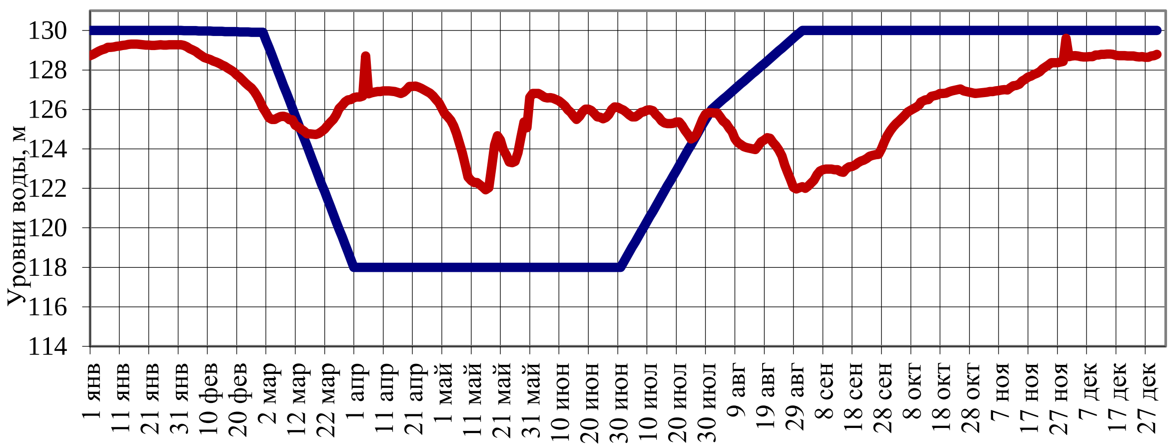

c)

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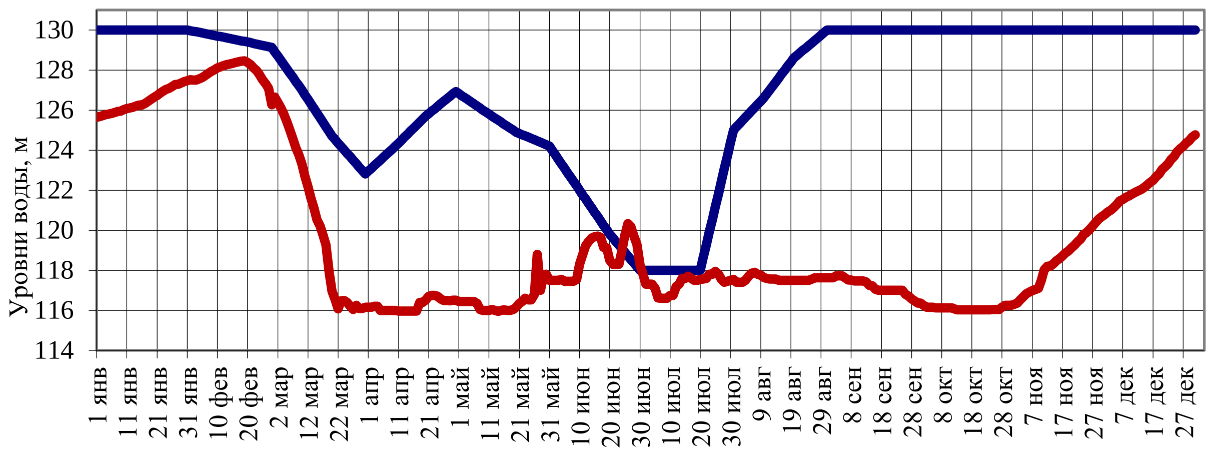
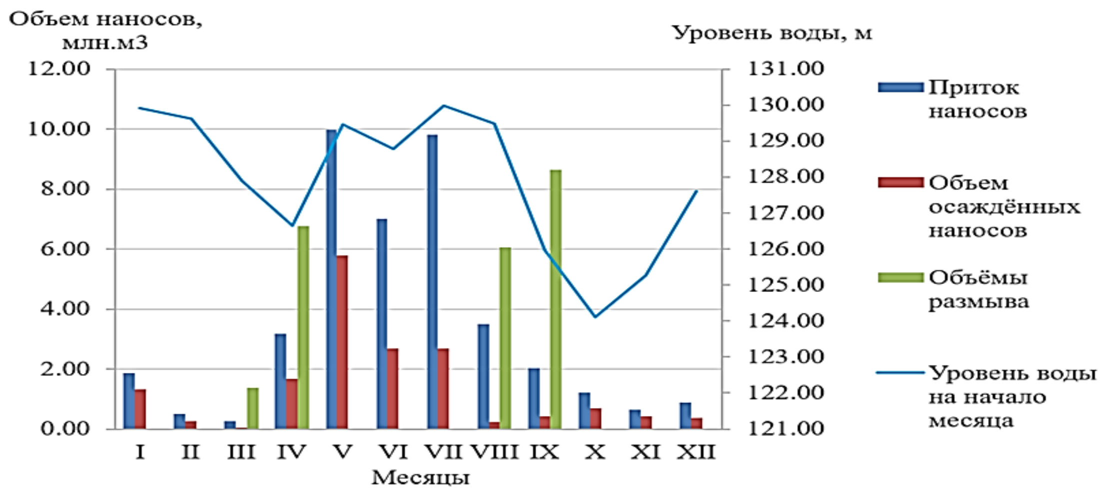


a – high-water, b – mid-water and c – low-water (recommended and actual)

Figure 3.1. Comparison of Ruslovoye Reservoir current and proposed operation regimes for different year dryness.

The elaborated schemes allow utilizing the reservoirs' potential to enhance water supply of the corresponding irrigation systems to the fullest extent. Depending on a particular operation regime, in mid-water year the erosion volumes of the reservoir basin amounted to 10-12 mln m^3, and the deposition volume – 24-26 mln m^3 (*see* Annex 3). According to the calculations, under the optimized recommended operation regime in mid-water year the erosion volume exceeded 25-30 mln m^3, and the deposition volume amounted to 15-17 mln m^3 (Fig. 3.2.). In addition, under Scenario II the deposition process was observed from August through March of the next year – the fall-winter-spring period – on a small scale ranging between 1.5 and 3.8 (August) mln m^3 per month.



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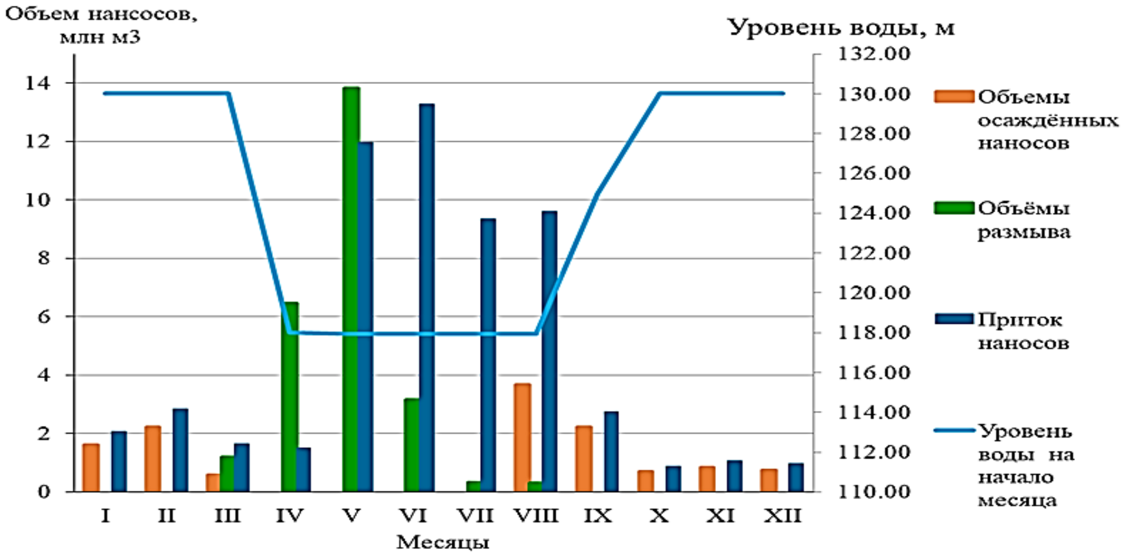

Figure 3.2. Comparison of sediment in- and outflow depending on reservoir water level.

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The analysis of the actual and recommended operation regimes allows recommending the following:

1. The reservoirs of the Tuyamuyun Hydro Complex intended for seasonal runoff regulation should be drawn down and fully filled regardless of a year water content, even if entailing cutting water limits during water-scarce years. In any years, in terms of their water content (excluding severely dry years), excess downstream runoff regularly occurs during October-January and is sufficient for filling the reservoirs in a given calendar year;

2. The Ruslovoye Reservoir passes through itself the entire Amu Darya River runoff and fills the offstream reservoirs. The water reserves from this storage should be used in February-March for irrigated farmland flushing and moisture charging. During April-June, it should be operated without pressure at levels close to DSL (dead storage level), i.e. 118-120 m. This will allow curbing the sedimentation rate in the TMHC head race and, most importantly, filtration and evaporation losses in the Ruslovoye Reservoir per se. Further, in July-August the Ruslovoye Reservoir should be filled up to 125-130 m to ensure the subsequent replenishment of the Kaparas Reservoir, and then – during September-January – of the Sultansanjar and Koshbulak Reservoirs;

3. In high-water years, it is recommended to operate the Ruslovoye Reservoir at low water horizons to boost the volume of eroded and transported sediment reaching the TMHC tail pond, as well as to slow down sediment settling inside the reservoir basin, and water loss due to evaporation and filtration;

4. The application of the river runoff regulation scheme encompassing mandatory drawdown of the Ruslovoye Reservoir in April-June, and additionally in September (during high-water years), to the minimum level possible will contribute to reducing not only the sediment deposits in the reservoir basin, but also the intensity of the growing head race pressure curve in the damming wedging zone, evaporation and filtration losses, as well as will facilitates the erosion and removal of bed sediment from the reservoir, thus ensuring the supply of fertile Amu Darya silt to irrigated farmland;

5. It is necessary to fill the Kaparas Reservoir, intended for creating high-quality potable water stock, which should renew its water annually during the vegetation period of July-August only after filling the Ruslovoye Reservoir up to 125.0-125.5 m level;

6. The Sultansanjar and Koshbulak Reservoirs (filled from the Ruslovoye Reservoir) used to compensate for the irrigation part of the river, should be replenished during September-February and subsequently maintained their regimes at horizons close to NRWS.

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The recommended options for the TMHC Ruslovoye Reservoir operation regimes in mid- and high-water years allow increasing the sediment volumes entering the tail bay and stabilizing downstream water levels, as well as contribute to raising the river bed inside the Tuyamuyun-Biruni Section. The execution of additional measures to boost flushing of bed sediment in the Ruslovoye Reservoir will significantly amplify the efficiency of the proposed reservoir operation regimes.

3.2 Recommendations on hydraulic and hydro-mechanical flushing works for coastal reinforcement

3.2.1 Sediment hydraulic flushing

Reservoir flushing with simultaneous flush stream turbidity control manifests a robust technique of removing the settled sediment deposits. The choice of the washing method is determined by technical and economic analysis, power system capacity, water user requirements and other local factors. ***Hydraulic flushing*** of bed sediment deposits with concentrated water flow at low water levels in reservoir with its subsequent transit through discharge and bed washing galleries (ports) represents the most common method of sediment cleaning. To be able to apply it, it is **first necessary to mechanically clean the bottom holes (sluice ports) in the TMHC concrete dam filled and sealed with sediment over many years**. The concentrated water stream erodes the soil only along its path of movement forming a narrow deep channel at the reservoir bottom. In the future, it will be necessary to regulate the directions of such channels by **mobile dams**.

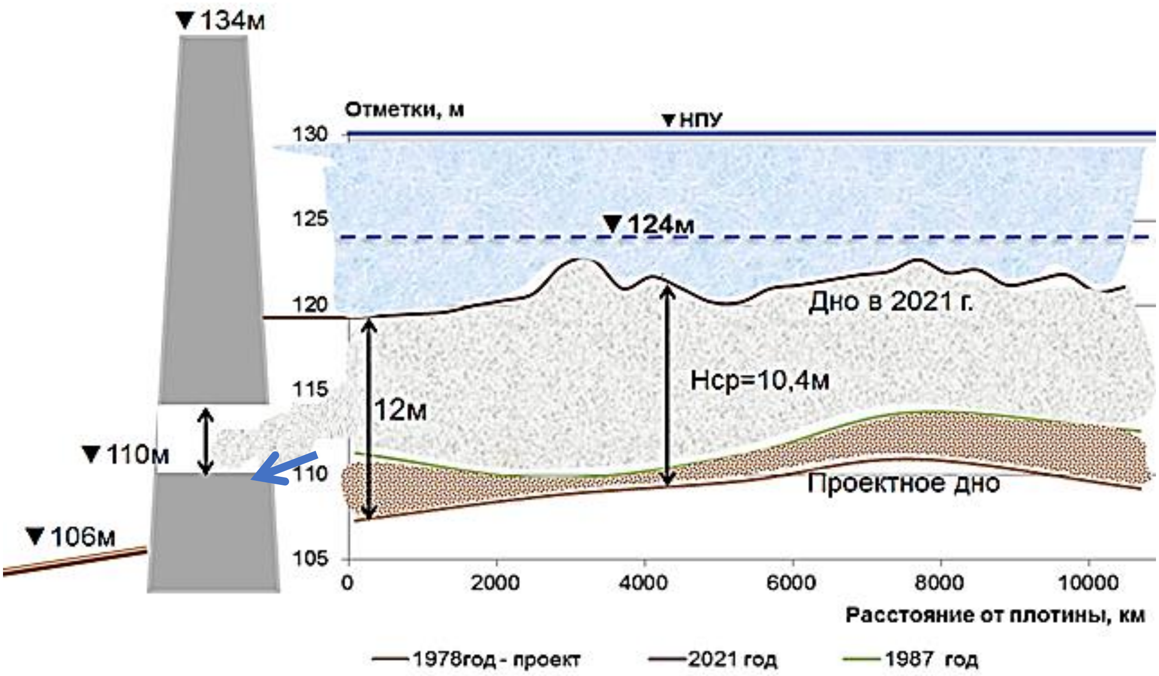

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Figure 3.3. Sediment next-to-dam profile during operation.

Hydraulic washing in the Ruslovoye Reservoir should take account of relief morphological characteristics and dimensions via “shallow” and “deep” schemes with simultaneous regulation of the flow turbidity. The choice of a particular flushing method depends on ***technical and economic calculations***, power system capabilities (in this case, TMHC can ensure the necessary electricity supply), water user requirements and other local factors.

In case of no restrictions as to the head race and tail bay operation regimes, it is recommended to conduct ***deep washing***. In the course of deep flushing, the reservoir is completely emptied (preferably through the ports with the lowest threshold horizons), the TMHC stops operation, and all water users are disconnected. The flushing time and duration are determined based on the hydrological and other local conditions. Deep flushing allows the highest intensity of sediment removal. Due to the significant sediment concentration in the flushing stream, partial sediment deposition in the tail bay is possible and, therefore it is necessary to constantly monitoring the state of the tail pond channel and water intakes in it. The optimal volume of the flushing discharge depends on the basin width and depth, throughput capacity of the bottom ports used for flushing, sediment deposit features, reservoir profile, etc. All the parameters can be validated by table-top (laboratory) model experiments. For calculation purposes, the mean annual discharge can be deemed as the optimal flushing flow rate with 10-15-day duration. The reservoir’s refilling after washing should be carried out in a low-water period (autumn-winter), when the Amu Darya River turbidity is quite low. This will safeguard the reservoir from subsequent sedimentation.

In case of excessive complexity or impossibility to carry out deep flushing with complete reservoir emptying, ***shallow flushing*** represents another option with bringing down the water level and (partially) preserving TMHC operation. It deserves mentioning that in this case the flow saturation with sediment, and thus the efficiency of its removal is lower than with deep flushing. Therefore, the duration of shallow washing should be extended, i.e. approx. up to 1.5-2 months. One must also note that reservoir flushing with controlled washing flow turbidity is justified in cases when it is necessary to provide downstream users with water, the turbidity of which does not exceed the permissible values as per corresponding facility technical requirements (normal operation), or for environmental protection requirements. These factors are not relevant for the Amu Darya River lower reaches, since the river bed had significantly lowered after the TMHC construction, and that had negatively impacted the irrigation water intakes canals.

Turbidity control is done by the stepwise emptying the head race considering the following correlations: the greater the depth and rate of emptying, the higher the turbidity of the washing stream; maintaining the head race at a constant reduced mark allows decreasing the washing flow turbidity over time. The shallow flushing of deposited sediment should be performed as follows:

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Phase I: Identification of the permissible wash stream turbidity threshold, with the maximum turbidity predetermined by the possibility of flushing the tail bay, and the minimum turbidity predetermined by the economic feasibility of flushing. The reservoir should be emptied to the level at which the washing current turbidity corresponds to the maximum permissible threshold. Then, the emptying is suspended and the reservoir water level is maintained at the horizon until the flushing flow turbidity falls to the set minimum value. The turbidity drops due to the gradual sediment erosion and removal, the waterway area – under the condition of maintaining the same water level in the reservoir – increases; along with this, the current's flushing capacity and, consequently, turbidity both decline.

Phase II: After reaching the minimum turbidity value, the water level in the reservoir is again lowered until the turbidity once again reaches the maximum permissible threshold. Further emptying is suspended, and the reservoir's water level is maintained at a given set horizon until the washing current turbidity gradually decreases to the accepted minimum value.

Phase III: The reservoir water level is lowered again, and the cycle repeats over.

To monitor flushing flow turbidity, it is necessary to set up a special observation post fitted with modern turbidity meters in the facility's tail bay. Water samples should be harvested periodically (2-3 times a day), and on an hourly basis during emptying. In the course of flushing, it is required to monitor the condition of the tail pond and corresponding installations, and likewise flushing performance. The efficiency of 1-day flushing is the product of mean daily turbidity and mean daily discharge. The final washing outcome is established instrumentally after completion.

During hydraulic flushing, it is possible that some sediment deposits will not erode due to inaccessibility by the washing stream. Such erosion-resistant zones usually occur along coasts and/or large islands along the main channel. In such cases, it is advisable to combine the mechanical and hydraulic cleaning methods, i.e. dredgers to create canals (curvilinear, if possible) connected to the main washing current, with the convex canal segment directed towards the target sediment deposit zone. This way, part of the main flushing flow will pass the dredger-built canals, and erode them and adjacent sediment deposits. The deposits located in the canal turning zones will be exposed to the most intensive erosion.

Flushing monitoring. To monitor flushing, it is necessary to establish the transit volume at which the inflow rate equals the discharge flow rate through installations, and the reservoir's water level remains constant. The discharge flow rate is increased by ΔQ with the simultaneous measuring of the water level drop in the tail bay (ΔH) and drop duration (Δt). The volume of the reservoir's drawdown is the product of excess discharge and duration ($\Delta W = \Delta Q \Delta t$).

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Taking such measurements in the entire range of pond drawdown makes it possible to plot the dependency between the reservoir's dynamic regulating capacity and water level. The frequency of determining a reservoir's dynamic regulating capacity is established based on sediment deposition rate, reservoir operation regimes, hydrological situation, presence of hydroposts, etc. Regular measurements are advisable to ensure proper operational monitoring of the reservoir and its regulating capacity dynamics.

3.2.2 Sediment hydro-mechanical cleaning

Mechanisms for cutting canals in sediment deposits should be primarily used near spillway dams and water intakes from the reservoir, where sediment complicates normal operation of hydraulic installations and sediment transit to the tail bay.

For this purpose, the research team proposes to use modern machinery, specifically the multi-purpose Watermaster Amphibia Dredger Classic V (2017 latest model) with 900 m^3/h capacity (Classic IV model capacity is 600 m^3/h), 16 m boom length, capable of operating at depths down to 6.5 m and pumping pulp up to 1.5 km.

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Figure 3.4. Watermaster Amphibia Dredger in operation.

Design specifications of the proposed dredger

Engine: Caterpillar C7.1 6-cylinder diesel engine with turbocharger; air-water radiator, 2,100 rpm shaft power, 168 kW (Classic IV) or 205 kW (Classic V); 1,200-liter fuel tank;

Power system: 24V electrical system, 2x170 A/hour batteries, electric fuel pump;

Hydraulics: one axial-piston dragging and propeller pump (345 bar max operation pressure), one axial-piston excavation and stabilizer pump (230 bar max operating pressure);

Excavator: 180° boom turning radius, 83 kN bucket cylinder tearing force, 47 kN handle cylinder digging force, 24.5 kN lifting force at max boom length, quickly replaceable fixtures;

Operation: no winches, cables and/or auxiliary vessels, equipment pre-installation, cranes and/or tugs are required;

Operator cab: comfortable cab with excellent view and FOPS protection against falling objects, additional instructor seat, 10 working lamps, anchoring, independent operation movement and fixing without additional vessels, winches and/or cables;

Body: one-piece body divided into 7 waterproof compartments, external and internal anti-corrosion coating, bottom protective skids, mast signal lights for executing different operations and navigation, two front stabilizers (5.0 m max depth), two rear tilting stabilizers (6.7 m max depth (*see* Fig. 3.5.);

Dimensions and weight during transportation: length without boom 11.00 m, length with boom 16.00 m, width 3.30 m, height 3.15 m, weight approx. 19.5 tons;

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Quality: ISO 9001 Quality Certification, ISO 14001 Environmental Safety Certification, ISO 3449 Safety Certification.

The advantages of the proposed equipment include high capacity, unique universality, water and on-land mobility, independent trailer loading and unloading, independent entry into and exit from water, self-propelling, amphibian in all operating modes.

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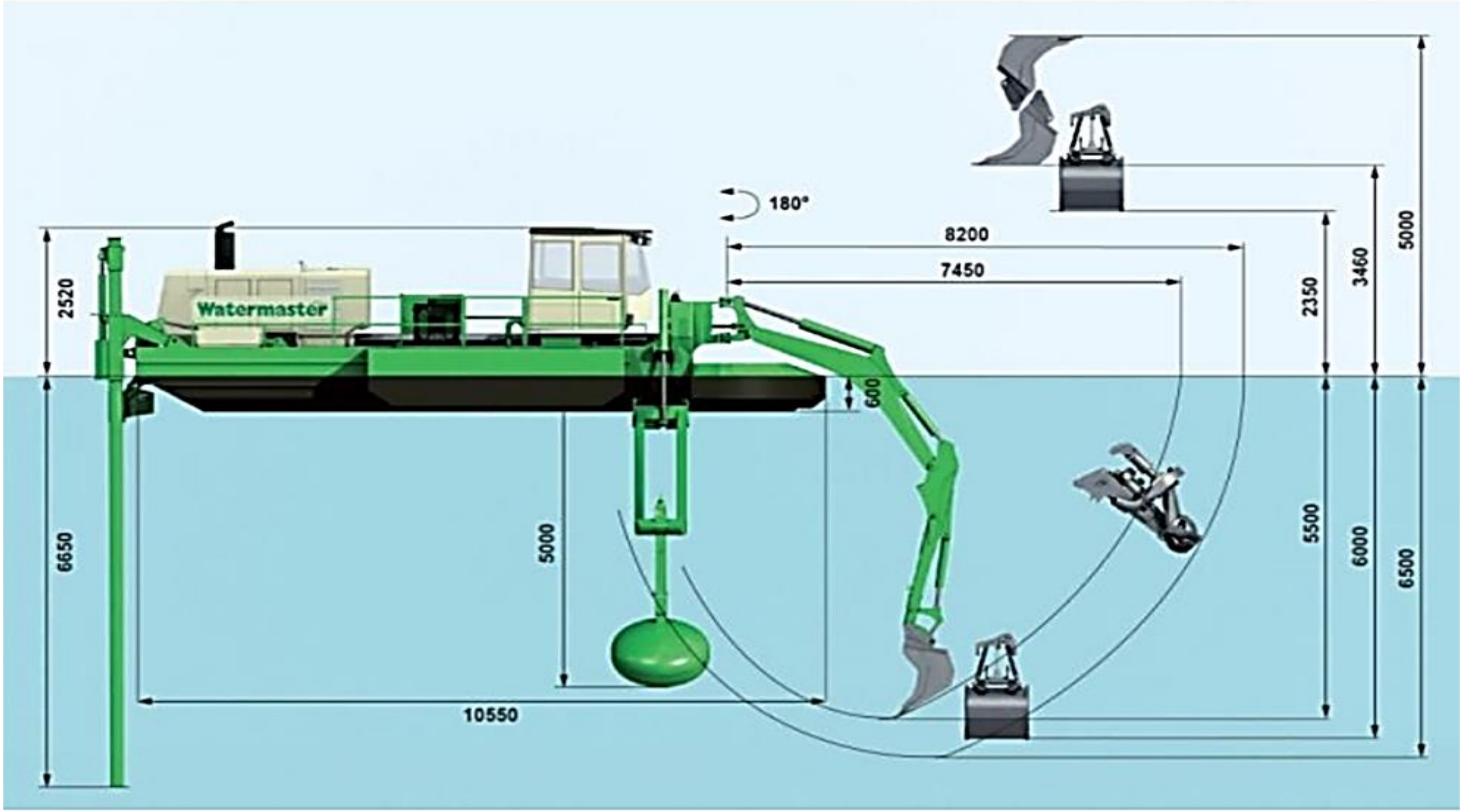

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Figure 3.5. Design specifications of the proposed Watermaster Amphibia Dredger[2].

[2] AQUAMEC Ltd. P.O. Box 260, FI-27801 Säkylä, Finland; ph.: +358 10 402 6400, fax: +358 10 402 6422, e-mail: watermaster@watermaster.fi.

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3.3 Preparation and execution of reservoir sediment cleaning

Prior to commencing works, it is imperative to ensure compliance with all the reservoir sediment cleaning requirements. If any of the conditions are/is not met, the staff shall not commence works regardless of the instructing (authorizing) person. In advance, prior to discharge board opening, it is necessary to check the status of works in the tail bay, and warn the workers there about the time of completing dredging operations, and make sure nobody remains in the pond after completing. The terms of reservoir cleaning shall be agreed with the local office of the Ministry of Water Resource and, via it, with local authorities to warn the downstream communities of the changing water level.

Dredging works in the dam head race shall be authorized only after the water level reaches the lowest horizon specified in the designated cleaning project. The duration of works in the head race shall be consistent with the duration of the head race remaining at low water marks. Prior to raising the water level in the head race, the personnel responsible for filling the bay must personally check the tightness of entry panel(s) closure, lifting mechanism drives, and signs prohibiting to raise panel(s). Upstream communities shall be informed of the reservoir filling and estimated water level.

During flushing, the machinery shall be installed on solid soil. When using dredgers to remove sediment or make canals in sediment deposits, hydromechanics safety rules must be observed.

Hydro-mechanical sediment removal shall be permitted only based on the corresponding ***Activity Management Plan*** describing the sequence of works and necessary auxiliary devices to ensure non-hazardous performance of works. To manage the operations, a responsible person must be allocated from the engineering and technical personnel of the organization executing sediment cleaning works.

The dredger's working zone within one-and-a-half range of its jet action, as well as the zone of possible soil collapse shall be fenced off by safety warning signs. When flushing the bay by alternating water level drops and rises, it shall be forbidden to approach the sediment deposit edge closer than 5 m regardless of its density. Since the washing ports are silted, they shall be cleared in the "away from oneself" direction and only in the head race zone.

After cleaning completion, reservoir depth measurements shall be carried out only after the water level reaches NRWS. While executing depth measurements from boat, the officer shall have on a full-body safety harness with safety cable attached to it, and its other end attached to eye ring or deck rack. Measurements shall be done only in quiet weather, with wind force not exceeding 2 balls (3.3 m/sec wind speed). In case of using an echo sounder for depth measure-

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ments, it is necessary to comply with the following rules: when installing echo sounder on vessel, avoid roll, attach echo sounder transmitter devices to vessel; do not keep the devices suspended in hands; keep the device covers closed at all times during operation; do not adjust equipment under voltage. It is also forbidden to carry out measurement operations from vessels not equipped with rescue and signal means, as well as execute measurements amidst the flushing stream.

All organizational measures to ensure work safety during reservoir cleaning and measurements (procedure(s) for issuing and registering work orders, permitting of work crew(s), supervision during works, etc.) shall be carried out ***in full compliance with operation safety rules*** for water facilities, hydraulic installations and hydro mechanical equipment.

In the conditions of the Ruslovoye Reservoir (82 km length and width ranging between 0.9 and 11 km), cleaning operations shall be executed by dividing the reservoir channel into 8-10 sections depending on morphological and hydrometric characteristics. According to the codes, ***in order to carry out cleaning works of such scale as the TMHC Ruslovoye Reservoir a licensed design organization shall develop the design specifications and estimates indicating the scope of works, required equipment and consumables, work procedure(s) and budget estimates***. The operations shall be carried out by specialized channel workers.

The project specialists have conducted preliminary calculations for the first near-dam reservoir section (10 km long). This section is completely covered with sediment (10-12 m thick), and its volume amounts to approx. 227 mln m3. The schematic plan with bed elevations along the section and cross-sections at the Ruslovoye Reservoir dam site shows the mean bed elevations fluctuating between 124-126 m (*see* Fig. 3.6.). The elevations close to the dam are quite high, which means that despite water discharge/passage into the tail pond, sediment/silt erosion by the ongoing water flow is not very pronounced. In this section, the maximum depth is 12 m (between Sites 11-16) at 118 m horizon. Between Sites 7-9, the bed elevation rises to 120 m. Although in this area, there is a constant water flow moving towards the control structures of the Kaparas and Sultansanjar Reservoirs, significant erosion is not occurring, pointing to the high density of sediment deposits making them resistant to hydraulic erosion.

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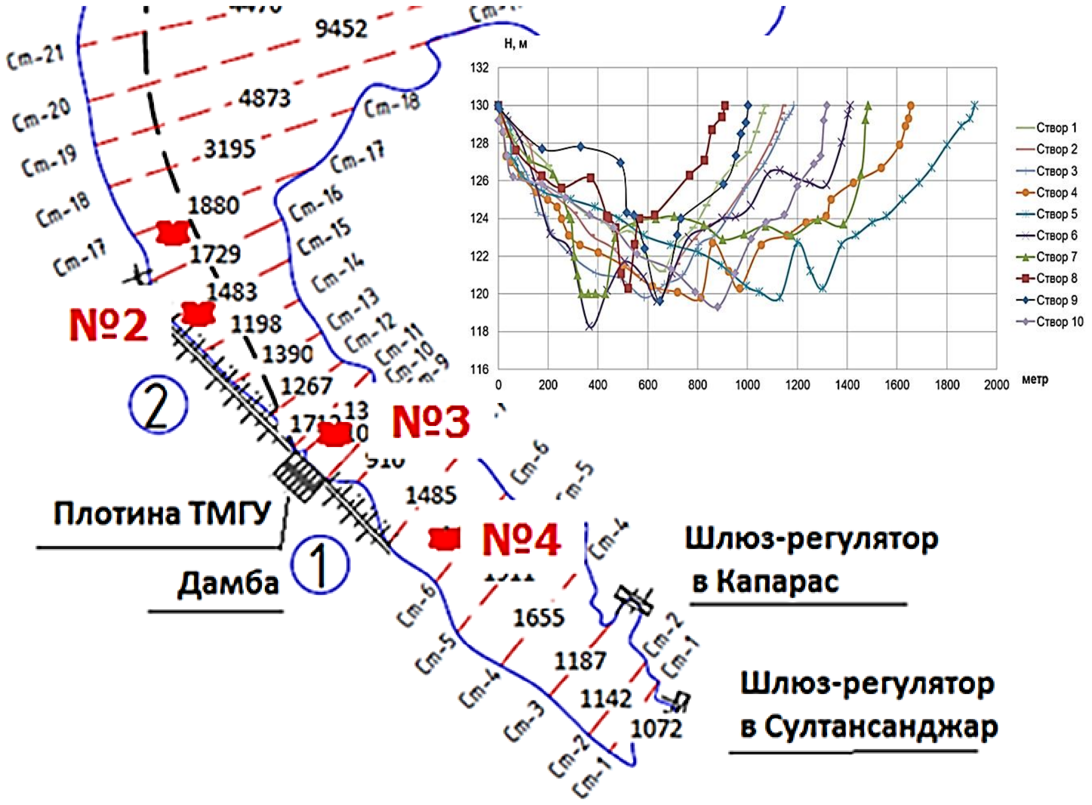

Figure 3.6. Schematic plan and sites of the Ruslovoye Reservoir near-dam section.

The project proposes to start the works with mechanical cleaning to create conditions for hydraulic flushing in this and following upstream areas. Moreover, it is necessary to create conditions for the proper operation of sluice ports (8 ports; 12 x 6 m dimensions) originally designed to allow flushing and passage of bed sediment.

Based on the preliminary calculations, it will take 6.5 years to clean sediment deposits in the near-dam section (10 km long; 227 mln m^3 volume) using 20 Watermaster-Amphibian Classic V Model dredgers. The calculations accounted for the cost of dredgers (specified model), dredger capacity (900 m^3/h), 8-hour work days (20 work days/month), labor and fuel costs. The calculations did not account for hydraulic flushing, although this process will kick in automatically in the course of mechanical cleaning. Thus, the total cost of the cleaning works amounted to approx. 2.38 mln USD[3].

Further, in the following upstream areas, it will become possible to apply the combined sediment cleaning technique, i.e. hydraulic washing mainly in mid reservoir basin areas and backwater zones, and mechanical cleaning in the areas close to shores. To boost the washing effect

[3] Executing the actual design and estimate documentation will give more accurate figures.

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by removing non-washable deposits, it is desirable to (hydro-mechanically) create curvilinear artificial canals directed towards the target deposit sections with their convex parts connected to the main flushing current. Part of the current can be directed into the canals using mobile rubber dams widely used nowadays. The curvilinear canals will aid sediment erosion and will direct the suspension into the main channel for subsequent transit to the tail pond.

3.4 Sedimentation control instructions

Sedimentation control in a particular reservoir depends on local conditions and feasibility studies. ***Sediment control measures shall be specified in the corresponding design documentation, and further adjusted as per the experience of reservoir operation.***

The target measures shall include reservoir operation under regimes ensuring better transit of the incoming solid runoff, necessary reinforcement works to prevent dam destruction and embankment erosion leading to significant sedimentation, mechanical sediment removal, and reservoir flushing.

The sediment control instructions (code) shall be elaborated for each reservoir individually with the account of a water body (river) hydrological regime, technical features of hydraulic installations of a particular hydro complex, and shall include the following:

- Technical characteristics of the hydro complex (waterworks) and its reservoir(s), their purpose and operation functions, water user requirements;
- Reservoir technical condition log to record observation data for solid runoff, embankment and shallow water zone(s) condition, soil and sediment in the tail bay, results of all inspections and reservoir measurements; the corresponding information/data shall be analyzed and summarized every 3-5 years of operation;
- Reports on executed activities and an action plan to preserve the reservoir’s regulation capacity and clean it from sediment, likewise containing data on the efficiency of the works performed, and other operational information;
- Detailed information characterizing liquid and solid runoff;
- Procedure(s) for observing reservoir state;
- Results of the reservoir’s latest bathymetric measurements and volume curves plotted based on these measurements (static and dynamic);
- Reservoir operation regimes for different river water content conditions (low-, mid- and high-water years) and during periods of high sediment inflow;
- Procedure(s) for preparing and executing sediment cleaning works;
- Safety requirements for reservoir cleaning and monitoring works.

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The following principles are recommended for compliance while operating the Ruslovoye Reservoir taking into account the reduced rate of the reservoir basin sedimentation:

1. The management of (one Ruslovoye and three offstream) reservoirs under the recommended regime will allow creating water reserves for irrigation, redistributing them over time to compensate for river runoff shortages in low-water years, and reducing unproductive water losses.

2. The proposed TMHC operation regime will allow scaling down and stabilizing the sedimentation of the Ruslovoye Reservoir, diminishing the river bed erosion overall, as well as raising water level at water intakes. The proposed operation regime is based on the criteria ensuring a uniform year-by-year discharge of eroded sediment to the tail bay, with the bulk of removal occurring in high- and mid-water years to accommodate for smooth water level changes during the growing season.

3. In February-March, the water stock in the Ruslovoye Reservoir should be used for irrigated farmland washing and moisture charging. In April-June, it should be operated in a non-pressure mode at elevations close to NRWS (118-120 m). This will allow curbing the sedimentation rate, filtration and evaporation losses. Further, in July-August the Ruslovoye Reservoir should be replenished up to NRWS to ensure sufficient filling of the Kaparas Reservoir and subsequent (in September-January) filling of the Sultansanjar and Koshbulak Reservoirs.

4. The application of the river runoff regulation scheme entailing mandatory drawdown of the Ruslovoye Reservoir in April-June, and additionally in September (during high-water years), to the minimum level possible will contribute to suppressing not only the sedimentation in the reservoir basin, but also the intensity of the upward head race pressure curve in the damming wedging zone, evaporation and filtration losses, and will likewise facilitate erosion and removal of bed sediments from the reservoir.

3.5 Potential agricultural use of river silt and basin bed sediment

Against the background of almost depleted water resources in terms of irrigation sources, Uzbekistan's agriculture can develop only by boosting the productivity of irrigated farmland by increasing land and water use efficiency, protecting these resources and rehabilitating soil fertility.

One of the reasons for land degradation in the Amu Darya River lower reaches is irrigation with water coming directly from reservoirs and/or river downstream of waterworks virtually devoid of fertile silt, i.e. clarified water.

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The design features of the Tuyamuyun Hydro Complex allow devising and deploying an operation regime for its reservoirs ensuring transportation of suspended river silt to farmland during the growing season in quantities close to watercourse natural content. Building the corresponding mathematical regime models will allow taking account of sediment inflow into irrigation networks.

The enrichment of irrigated land with river silt – coming suspended in irrigation water – would enhance natural soil energy, thus lowering the costs associated with mineral fertilizer application. Natural soil fertility replenishment represents a potent means of maintaining highly efficient agricultural production.

The transit of suspended sediment through the TMHC Ruslovoye Reservoir to the installation's tail bay will facilitate colmatation of both the channel and irrigation network canals. In turn, this will reduce filtration losses of irrigation water, at the same time cutting the amount of sediment entering the tail pond, and over time will stimulate channel bed raising, thus improving water withdrawal conditions in irrigation canals.

The studies of suspended sediment content in the Amu Darya water showed an average of 4.5 g/l of suspended material, more specifically ~ 1.6 g/l in low-water seasons, and 5.6 g/l in flooding conditions. During the vegetation period, the content of sediment grows significantly. The maximum river turbidity is observed during spring flooding usually beginning in mid-May. Mechanically, the suspended silt is mainly dominated by fractions with a particle diameter of <0.01 mm (Amu Darya River ~ 73%, in irrigation canals ~ 50-65%, and in *aryks* (*eng. "irrigation ditch"*) 75-85%). The content of large sand fractures is meager and ranges between decile and centesimal values of the total sediment load. The examined sediments are heavy loam and light clay.

The previous research by NIIIVP (SANIIRI) allowed proposing and justifying the use of the TMHC Ruslovoye Reservoir bed sediment as agricultural fertilizer. The bottom sediment deposits in question form as a result of settling of suspended silt possessing mineral and organic sorbent properties. It was established that the bed sediment includes organic substances (humus generation source), macro elements (nitrogen, phosphorus, sulfur, potassium, magnesium, and calcium) and trace elements (chlorine, copper, iron, manganese, molybdenum, and zinc) necessary for plant nutrition (*see* Table 3.1.), thus making them applicable as fertilizers for various crops.

Table 3.1. Bed sediment chemical profile at Ruslovoye Reservoir.

Component/feature	**Component content**	
	In sediment, g/kg	**In water, mg/l**

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	Max	Mean	Max	Mean
Mineralization	1.3-1.9	1.6	700-1,600	1,000
COD	16-27	19	14.0-3.2	20.4
Total nitrogen	1.8-2.4	2.1	0.33-1.28	0.41
Phosphates	0.1-0.5	0.4	0-0.05	0.01
SSAS	0.03-0.2	0.1	0.01-0.03	0.02
Petrochemicals	0.01-0.3	0.17	0-0.04	0.02
Phenols	0.001-0.02	0.012	0.001-0.004	0.003
Alpha HCCH, mg/kg	0.03-0.06	0.04	$0\text{-}2.6 \cdot 10^{-5}$	$1.0 \cdot 10^{-5}$
Gamma HCCH, mg/kg	0.001-0.02	0.01	$0\text{-}1.4 \cdot 10^{-5}$	$1.0 \cdot 10^{-5}$
Iron, g/kg	0.10-0.30	0.18	0.01-0.03	0.02
Copper, mg/kg	2.6-16.2	6.3	0.001-0.007	0.003
Zinc, mg/kg	5.0-11.2	9.1	0-0.003	0.0015
Molybdenum, mg/kg	7.3-31.0	17.2	-	-
Lead, mg/kg	7.2-23.2	11.3	$0\text{-}27 \cdot 10^{-3}$	$9.3 \cdot 10^{-3}$
Manganese, mg/kg	.01-0.20	0.04	-	-
Chrome 6+, mg/kg	1.0-3.2	2.1	$0\text{-}1.4 \cdot 10^{-3}$	$0.37 \cdot 10^{-3}$
Chrome 3+, mg/kg	0.4-3.1	1.3	$0\text{-}0.5 \cdot 10^{-3}$	$0.17 \cdot 10^{-3}$
Mercury, mg/kg	0.1-0.42	0.26	$0\text{-}0.3 \cdot 10^{-3}$	$0.17 \cdot 10^{-3}$

The transit of suspended (stream) and settled sediment through the Ruslovoye Reservoir will ensure their transfer to farmland in the course of the growing season in amounts corresponding to the runoff turbidity of natural watercourses. As per the preliminary estimates, this would conduce higher crop yields against the baseline, i.e. without fertilizer application: specifically, cotton by 12%, rice by 21%, maize by 19%, wheat by 18%, and potatoes by 31% (*see* Table 3.2.).

Table 3.2. Agricultural crop yield surplus due to evacuation of river silt to farmland (hwt/ha).

Agricultural crop	Cotton	Rice	Maize	Wheat	Potatoes
Standard yield	15	17	22	16	35
Crop surplus due to river silt evacuation to farmland	1.8	3.6	4.2	2.9	11.0

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CONCLUSION

The operation regime calculations for the TMHC reservoirs were executed as per three water content scenarios: low-water (90%), mid-water (50%), and high-water (10%) years. The recommended operation regimes in mid- and high-water years contribute to slowing down the sedimentation in the Ruslovoye Reservoir by eroding and transiting sediment, allow transferring more sediment into the tail bay and stabilizing the water level, as well as raising the river channel bed in the Amu Darya River lower reaches (specifically the Tuyamuyun-Biruni Section), and by that creating better water intake conditions into main irrigation canals within this section.

The transit of suspended sediment through the Ruslovoye Reservoir will furnish transportation of fertile humus material to farmland during the vegetation season in quantities corresponding to natural watercourse turbidity, thus contributing to higher crop yields.

The method used for calculating the Ruslovoye Reservoir sedimentation made allowance of water level change(s), and can be utilized for prediction calculations.

The research aimed at determining the capacity and sedimentation status in the Ruslovoye Reservoir made it possible to draw the following conclusions (*see* Annex 1). The reservoir's capacity at near-dam water level (H = 130 m) amounted to **863 mln m^3**. Considering water losses, the volume of available water reserves amounted to **680 mln m^3**, as shown in the table below.

The reservoir's design capacity (1978/1981) is 2,340 mln m^3.

Sediment volume during the entire period of operation (as of 2021) amounted to **1,477 mln m^3**.

The reservoir's water surface area at 130 m horizon came up to **248 km^2** against the design mirror of 300 km^2.

The mean slope of the reservoir basin bed (as per measurements) was **i = 0.00004** against the design i = 0.0002.

The reservoir's water volume and water surface area values by water horizons are given below.

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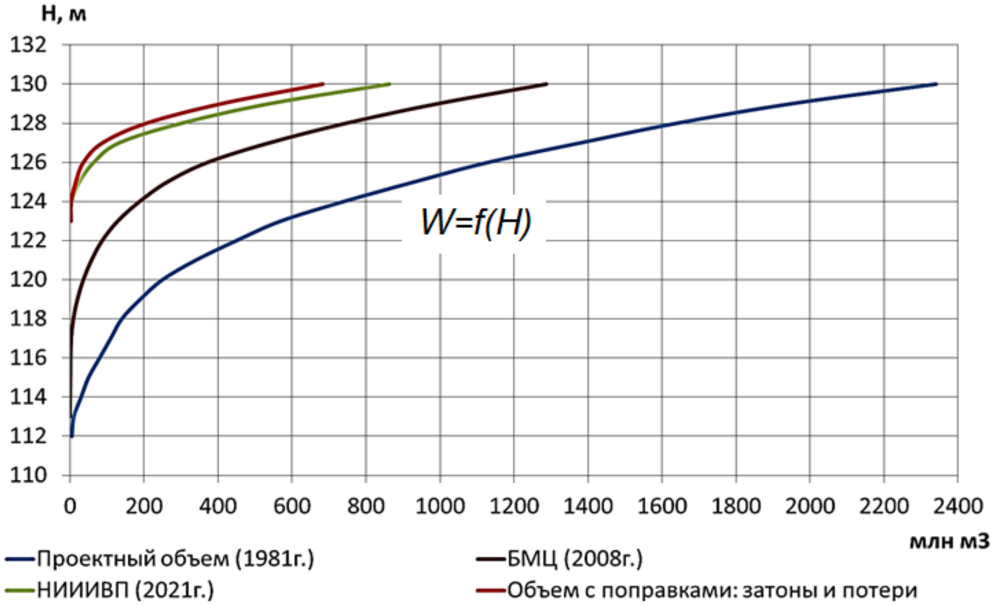

Ruslovoye Reservoir volume curves *W=f(H)*

Ruslovoye Reservoir water volume calculations with the account of losses

Mark	**Measurements (2021)**		**Dead volume (backwater) zones**		**Available water resources (2021)**			
H, m	Area, km^2	Volume, mln m^3	Area, km^2	Volume, mln m^3	Area, km^2	Volume, mln m^3	Loss, mln m^3	Volume, mln m^3
130	247.80	862.70	0.00	0.00	247.80	823.71	143.73	679.98
129	211.00	539.19	0.00	0.00	211.00	500.20	90.73	409.47
128	175.16	301.58	5.58	7.88	169.58	262.59	55.96	206.63
127	134.95	132.86	21.84	10.14	113.11	101.75	26.01	75.74
126	69.72	64.00	17.53	11.84	52.19	43.03	6.79	36.24
125	8.20	25.00	1.33	7.96	6.87	15.87	0.21	15.66
124	1.70	4.00	0.05	1.17	1.65	2.83	0.05	2.78
123	0.65	2.35	0.00	0.00	0.65	2.35	0.02	2.33
122	0	0	0.00	0.00	0.00	0.00	0.00	0.00
121	0	0	0.00	0.00	0.00	0.00	0.00	0.00
120	0	0	0.00	0.00	0.00	0.00	0.00	0.00

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				38.9 mln m^3			143.73 mln m^3	

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REFERENCES

1. Alam, S. (2002). Improving sedimentation management using multiple dams and reservoirs. Hydropower and Dams International Journal, vol. 9, issue 1, p. 63-69;
2. Altunin, S.T. (1964g). Water intake units and reservoirs [*Vodozabornye uzly i vodohranilishha*]. Moscow: *Kolos*, 431 p. [in Russian];
3. Arakelyan, D.G., Nagapetyan, S.A., Zakaryan, B.G., Mkrtchyan, M.K. (2013). GIS modelling of flood events in the Debed River Basin (*GIS modelirovanie javlenij zatoplenija bassejna r. Debed*). Digest of the NAS of the RF, Earth Sciences, 66, vol. 3, p. 24-39 [in Russian];
4. Avakyan, A.B. (1982). Reservoirs and environment [*Vodohranilishha i okruzhajushhaja sreda*]. Moscow: *Znaniye*, 48 p. [in Russian];
5. Becker, L., Yeh, W. (1974). Optimization of real-time operation of a multiple reservoir system. Water Resources Research, vol. 10 (6), p. 1107-1112;
6. Brekhovsky, V.F., Kazmiruk, T.N., Kazmiruk, V.D. (2006). Bed sediment at the Ivankovskoye Reservoir: Condition, composition, properties [*Donnye otlozhenija Ivan'kovskogo vodohranilishha: sostojanie, sostav, svojstva*]. Institute of Water Problems, Moscow: *Nauka*, 173 p. [in Russian];
7. Brooke, N. (2006). Eustis Post-Dam effects on Geomorphology of the Green River. 211 p.;
8. Edelshtein, K.K. (1980). Valley reservoir geometric model [*Geometricheskaja model' dolinnogo vodohranilishha*]. Comprehensive Reservoir Studies, Issue 5, Moscow, p. 11-31 [in Russian];
9. Froebrich, J., Bauer, M., Ikramova, M., Olsson, O. (2007). Water Quantity and Quality Dynamics of the THC-Tuyamuyun Hydro Engineering Complex – and Implications for Reservoir Operation. Environmental Science and Pollution Research, vol. 14, issue 6, p. 435-442;
10. Heydari, M., Othman, F., Taghieh, M. (2016). Optimization of Multiple and Multipurpose Reservoir System Operations by Using Matrix Structure (Case Study: Karun and Dez Reservoir Dams). PLoS One Journal, vol. 11 (6): e0156276, doi: [10.1371], p.18;
11. Ikramova, M. (2016). Estimation of sediment loads: the Tuyamuyun reservoir on Amudarya River. European Science Review. Austria, p. 199-202;
12. Ikramova, M.R. (1996). Calculation of headwater speeds for coastal protection dam [*Raschet skorostej v verhnem b'efe beregozashhitnoj damby*]. Reclamation and Water Management Collection of Research Papers, *NPO SANIIRI*, Tashkent, p. 57-61 [in Russian];
13. Ikramova, M.R. (2007). Improving the efficiency of the Tuyamuyun Hydro Complex reservoirs [*Povyshenie jeffektivnosti raboty vodohranilishh Tujamujunskogo gidrouzla*]. AGROILM Journal, vol. 2 (6), Tashkent, p. 35-37 [in Russian];
14. Ikramova, M.R. (2016). Water losses due to evaporation from the Tuyamuyun Hydro Compex reservoirs [*Poteri vody na isparenie iz vodohranilishh Tujamujunskogo gidrouzla*]. AGROILM Journal, vol. 6 (44), Tashkent, p. 68-69 [in Russian];
15. Ikramova, M.R., Akhmedkhodzhayeva, I., Khodzhiyev, A. (2013). Water balance calculation method for reservoir systems. Certificate of deposit of intellectual property [*Metodika rascheta balansa vody dlja sistemy vodohranilishh. Svidetel'stvo o deponirovanii ob"ektov intellektual'noj sobstvennosti*]. Reg. №0759 [in Russian];

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16. Ikramova, M.R., Khodzhiyev, A. (1998). Tuyamuyun Hydro Complex operation features [*Osobennosti raboty Tujamujunskogo gidrouzla*]. Agriculture of Uzbekistan Journal, vol. 4, Tashkent, p. 29-31 [in Russian];
17. Ikramova, M.R., Khodzhiyev, A.K., Misirkhanov, Kh.I. (2005). Enhancing TMHC operation regime to reduce sedimentation of the Ruslovoye Reservoir [*Sovershenstvovanie rezhima raboty TMGU, napravlennoe na snizhenie inten-sivnosti zailenija Ruslovogo vodohranilishha*]. Reports of the International Scientific and Practical Conference, Taraz, p. 327-332 [in Russian];
18. Itoh, T., Horiuchi, S., Mizuyama, T. & Kaitsuka, K. (2013). Hydraulic model tests for evaluating sediment control function with a grid-type Sabo dam in mountainous torrents. International Journal of Sediment Research, vol. 28, p. 511-522;
19. Li, W., Guo, Sh., Ampitiawatta, A., Liu, P., Guo, F. (2007). A real time dynamic flood prevention storage control model for Qingjiang cascade reservoirs. *IAHS Press*, vol. 315, the Netherlands, p. 41-47;
20. Nikiforov, D. A. (2016). Level regime modeling for the Yenisei River reservoirs [*Modelirovanie urovennogo rezhima vodohranilishh reki Enisej*]. Candidate of Technical Sciences Thesis Paper, Moscow, 335 p. [in Russian];
21. Olsson, O., Bauer, M., Ikramova, M., Froebrich, J. (2008). The Role of Amudarya Dams and Reservoirs in Future Water Supply in The Amu Darya Basin. *Springer*: Science and Business Media, p. 277-292;
22. Olsson, O., Ikramova, M., Sorokin, A. (2011). Modeling scenarios to identify a combined sediment-water management strategy for the large reservoirs of the Tuyamuyun hydro-complex. Irrigation and Drainage Systems, vol. 5, issue 1;
23. Olsson, O., Khodjiyev A., Ikramova M. (2010). Combined reservoir management of water and sediments for the Ruslovoye Reservoir at the Lower Amudarya River. Interstate water resource risk management: Towards a sustainable future for the Aral basin (JAYHUN). London: *IWA Publishing*, p. 87-97;
24. Olsson, O., Ikramova, M., Bauer, M., Froebrich, J. (2010). Applicability of Adapted Reservoir Operation for Water Stress Mitigation Under Dry Year Conditions. Water Resources Management, vol. 24, issue 2, p. 277-297;
25. Potapov, L.V. (1951). Runoff management [*Regulirovanie stoka*]. Vol. 3, Moscow: *Selhozgiz*, 123 p. [in Russian];
26. Potapova, T.M., Fedorov, I.V., Parshina, T.V. (2006). Methods of determining the gras-nulometric and geochemical composition of bottom sediments and suspended sediments [*Metody opredelenija granulometricheskogo i geohimicheskogo sostava donnyh ot-lozhenij i vzveshennyh nanosov*]. Teaching and methodological manual, St. Petersburg: *SPGU Publishing House*, 92 p. [in Russian];
27. Pozdnyakov, Sh. R. (2011). Deposits in rivers, lakes and reservoirs in an expanded range of particle size [*Nanosy v rekah, ozerah i vodohranilishhah v rasshirennom diapazone razmera chastic*]. Doctor of Geographical Sciences Thesis Paper Abstract, St. Petersburg, 40 p. [in Russian];
28. Prytkova, M. Ya. (2011). Hydrological regime and sedimentation of different small reservoirs of the North-West [*Gidrologicheskij rezhim i zailenie malyh raznotipnyh vodoemov Severo-Zapada*]. St. Petersburg: *Nauka*, 194 p. [in Russian];
29. Ran, D.C., Luo, Q.H., Zhou, Z.H., Wang, G.Q. & Zhang, X.H. (2008). Sediment retention by check dams in the Hekouzhen-Longmen Section of the Yellow River. International Journal of Sediment Research, issue 23, p.159-166;

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30. Sabah S. Fayaed, Ahmed El-Shafie, Othman Jaafar (2013). Reservoir-system simulation and optimization techniques. Stochastic Environmental Research and Risk Assessment, vol. 27, issue 7, p. 1751-1772;
31. Sadykov, A.Kh., Gapparov, F.A. (2005). Method of calculating the annual reduction in the volume of the reservoir based on the water balances of the previous years of its explantation [*Metod rascheta ezhegodnogo sokrashhenija ob"ema vodohranilishha na osnove vodnyh balansov predydushhih let ego jekspluatacii*]. Collection of scientific works on SANIIRI 80th anniversary, Tashkent, p. 404-410 [in Russian];
32. Savarensky, A.D. (1951). River runoff regulation by reservoirs [*Regulirovanie rechnogo stoka vodohranilishhami*]. Moscow, 78 p. [in Russian];
33. Shavnina, Yu.N., Maksimovich, N.G., Pyankov, S.V. (2007). Reservoir drawdown modeling and bed sedimentation capacity calculation [*Modelirovanie srabotki vodohranilishha i raschet moshhnosti donnyh otlozhenij*]. Perm: Modern Science and Practice Journal, issue 4 (10), vol. 1, p. 87-93 [in Russian];
34. Shtefan, V.I. (1975). On the calculation of water exchange in valley reservoir [*K raschetu vodoobmena dolinnogo vodohranilishha*]. Moscow State University Bulletin, Geography Series, issue 5, p. 71-75 [in Russian];
35. Shumakov, A.N. (2007). Silting of ponds and reservoirs as elements of erosion channel systems in the agrilandscapes of the Central Black Earth Region [*Zailenie prudov i vodohranilishh kak jelementov jerozionno-ruslovyh sistem v agrolandshaftah Central'no-Chernozemnogo regiona*]. Kursk, 217 p. [in Russian];
36. Sorokin, A.G. (2006). Management of reservoir water and sedimentation regimes in the Amu Darya River Basin: Tools and assessment. Extreme hydrological events in the Aral-Caspian Region [*Upravlenie vodnym i nanosnym rezhimami vodohranilishh bassejna Amudar'i: instrumenty i ocenka. Jekstremal'nye gidrologicheskie sobytija v Aralo-Kaspijskom regione*]. Materials of the international scientific conference (October 19-20, 2006), Moscow, p. 289-293 [in Russian];
37. Stephens, T. (2010). Manual on small earth dams. FAO of the UN, Irrigation and Drainage, vol. 64, Rome, p.127;
38. Taghlavi, S. H. (2010). Improving methods for developing operation management scenarios for reservoirs on rivers with abundant sediment runoff [*Sovershenstvovanie metodov razrabotki scenariev upravlenija jekspluataciej vodohranilishh na rekah s obil'nym stokom nanosov*]. Candidate of Technical Sciences Dissertation, Moscow, 199 p. [in Russian];
39. Van Maren, D.S., Yang, Sh.-L., He, Q. (2013). The impact of silt trapping in large reservoirs on downstream morphology: the Yangtze River. *Springer*, vol. 63, issue 6, p. 691-707;
40. Vlatsky, V.V. (2010). River runoff modeling using GIS-technology [*Modelirovanie rechnogo stoka s ispol'zovaniem GIS tehnologij*]. SHI Bulletin, vol. 9 (115), p. 104-109 [in Russian];
41. Votruba, L., Broža, V. (1989). Water Management in Reservoirs. *Elsevier Science*, p. 441;
42. Vuglinsky, V.S. (1981). On the issue of methodology to account for reservoirs’ impact on river runoff [*K voprosu o metodike ucheta vlijanija vodohranilishh na rechnoj stok*]. SHI Bulletin, vol. 274, Leningrad, p. 73-85 [in Russian];
43. Vuglinsky, V.S. (1991). Water resources and the water balance of large water storages [*Vodnye resursy i vodnyj balans krupnyh vodohranilishh*]. Leningrad: *Hydrometeoizdat*, 223 p. [in Russian].

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ANNEXES

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Annex 1. Ruslovoye Reservoir capacity and sedimentation calculations

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Объем воды - по промерам 2021 года					Объемы отложений - 2021год							
Створы	Расст.между створами,м	Расстояние от плотины, м	Ср. отметки дна, м	Объемы воды, млн м3	Участки	Длина участка, м	Ширина створа, м	Ср. ширина участка ,м	Средн. отметка дна, м	Ср. толщина слоя отложений, м	Объем заиления, млн м3
1	0	0	125,6	2,861	Ств.1-21	10380	1072	2180	125,6	10	226,289
2	570	570	125,4	3,670			1142				
3	660	1230	125,1	5,265			1187				
4	730	1960	124,8	6,218			1655				
5	670	2630	124,8	5,389			1911				
6	620	3250	124,7	5,942			1412				
7	750	4000	124,3	4,528			1485				
8	730	4730	125,6	1,160			910				
9	300	5030	126,3	1,582			1004				
10	300	5330	124,9	1,362			1347				
....											
51	2300	50630	126,0	29,584	Ств.48-51	9610	3350	3353	126,5	6	193,337
52	2850	53480	127,4	30,130	Ств.52-55	11460	2957	1682	127,6	4	77,082
53	3000	56480	127,8	15,503			1238				
54	3000	59480	127,8	10,434			1913				
55	2610	62090	127,6	7,488			618				
56	3010	65100	128,0	7,043	Ств.56-58	9460	1550	1856	128,2	2	35,108
57	3130	68230	128,4	9,755			1913				
58	3320	71550	128,4	10,729			2104				
59	2710	74260	128,4	7,891	Ств.59-62	10940	1470	1318	128,4	0,5	7,208
60	2810	77070	128,8	6,143			1598				
61	2610	79680	128,5	4,991			1217				
62	2810	82490	128,2	5,180			986				
									Объем заиления		**1477**

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Annex 2. TMHF high-water operation regime calculations.

№	Item		Label	Unit	1	2	3	4	5	6	7	8	9	10	11	12	Total
8	Kaparas available capacity		W_e^k	mln m^3	610.0	610.0	610.0	610.0	610.0	610.0	610.0	610.0	610.0	610.0	610.0	610.0	610.0
9	S-s+K-k available capacity (127.5)		$W_e^{S\text{-}s+K\text{-}k}$	mln m^3	2,010.0	2,010.0	2,010.0	2,010.0	2,010.0	2,010.0	2,010.0	2,010.0	2,010.0	2,010.0	2,010.0	2010.0	2,010.0
10	Ruslovoye Reservoir full capacity (H=130.0 m)		W_e^R	mln m^3	1,264.3	1,260.7	1,257.5	1,257.0	1,264.1	1,269.1	1,269.6	1,201.4	1,184.6	1,185.5	1,185.7	1184.0	1,182.6
1	Water discharge		$W_{i\ river}$	mln m^3	2319.1	2,301.1	2,704.6	2,723.8	4,569.8	6,420.2	1,2056.1	6,364.1	2,880.5	1,637.4	2,006.4	1697.1	47,680.3
2	Limit		W_{iz}	mln m^3	260.0	1,220.0	2,520.0	630.0	2,510.0	3,200.0	4420.0	3,510.0	720.0	240.0	260.0	720.0	20,210.0
3	Redundant discharge		W_i^{red}	mln m^3	2059.1	1,081.1	184.6	2093.8	2,059.8	3,220.2	7,636.1	2,854.1	2,160.5	1,397.4	1,746.4	977.1	27,470.3
4	Deficit discharge		W_i^{def}	mln m^3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Limit sum for months I-III and IV-VI		$\sum L_i$	mln m^3	4,000.0	3,740.0	2,520.0	5,235.7	5,235.7	5,235.7	0.0	0.0	0.0	0.0	0.0	0.0	
	Limit percentage		d_i		0.065	0.326	1.000	0.120	0.479	0.611	0.000	0.000	0.000	0.000	0.000	0.000	
7	Evaporation layer		μ_i	mm	19.9	21.5	41.3	67.1	88.1	135.1	154.1	97.2	89.4	62.7	31.9	24.9	
8	Stock volume for calculated period	Ruslovoye	W_s^R	mln m^3	1,198.3	1,116.8	749.3	0.0	0.0	0.0	0.0	1,135.4	1,118.6	0.0	669.6	1027.9	1,116.6
9		Kaparas	W_s^K	mln m^3	323.2	232.2	231.0	229.7	227.3	195.8	82.2	0.0	584.0	564.0	544.7	527.4	512.3
10		Sultansan-jar+ Koshbulak (S-s + K-k)	$W_s^{S\text{-}s+K\text{-}k}$	mln m^3	2,003.3	2,003.3	1,998.2	1,992.7	1982.1	747.0	0.0	0.0	1,206.0	1,849.2	2,010.0	1993.9	1,985.7
33	Initial reservoir volume at calculated period beginning	Ruslovoye	W_{init}^R	mln m^3	1,264.3	1,182.8	815.3	64.4	64.4	64.4	64.4	1,201.4	1,184.6	64.3	735.6	1093.9	1,182.6
34		Kaparas	W_{init}^K	mln m^3	323.2	309.0	294.7	279.3	234.8	108.2	0.0	597.0	577.0	557.7	540.4	525.3	510.6
35		S-s + K-k	$W_{init}^{S\text{-}s+K\text{-}k}$	mln m^3	2,003.3	1,998.2	1,992.7	1,982.1	747.0	0.0	0.0	1,206.0	1,849.2	2,010.0	1,993.9	1985.7	1,979.3
22	Elevation mark at month beginning	Ruslovoye, mln m^3	$\blacktriangledown^R$	m	130.0	129.5	127.2	118.0	117.8	117.8	117.8	130.0	130.0	118.0	127.0	129.4	130.0
23		Kaparas, mln m^3	$\blacktriangledown^K$	M	125.5	125.4	125.2	125.0	123.7	121.2	118.0	129.8	129.4	129.1	128.9	128.6	128.4
24		S-s + K-k, mln m^3	$\blacktriangledown^{S\text{-}s+K\text{-}k}$	m	127.5	127.4	127.4	127.4	120.4	116.0	116.0	120.8	123.4	127.5	127.4	127.4	127.4
25	Water mirror area	Ruslovoye	F_i^R	km^2	300.4	289.5	203.3	8.3	7.3	7.3	7.3	300.4	300.4	8.3	199.3	287.4	300.4
26		Kaparas	F_i^K	km^2	59.0	58.7	58.3	57.8	52.9	45.5	37.0	71.8	70.2	68.6	67.6	66.9	66.3
27		S-s + K-k	$F_i^{S\text{-}s+K\text{-}k}$	km^2	256.7	256.5	256.3	255.9	188.3	166.0	166.0	192.6	215.2	257.0	256.3	256.0	255.8
28	Total water mirror area		$\sum F_i$	km^2	616.1	604.7	517.9	322.0	248.6	218.8	210.3	564.8	585.8	333.8	523.2	610.3	622.4
29	Evaporation	Ruslovoye	$W_{\mu i}^R$	mln m^3	6.0	6.2	8.4	0.6	0.6	1.0	1.1	29.2	26.9	0.5	6.3	7.1	94.0
30		Kaparas	$W_{\mu i}^K$	mln m^3	1.2	1.3	2.4	3.9	4.7	6.1	5.7	7.0	6.3	4.3	2.2	1.7	46.6

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31		S-s + K-k	$W_{\mu i}^{S\text{-}s+K\text{-}k}$	mln m^3	5.1	5.5	10.6	17.2	16.6	22.4	25.6	18.7	19.2	16.1	8.2	6.4	171.6
32	Total evaporation		$\sum W_{\mu i}$	mln m^3	12.3	13.0	21.4	21.6	21.9	29.6	32.4	54.9	52.4	20.9	16.7	15.2	312.1
17	Ruslovoye Reservoir minimum drawdown volume		W_{min}^{R}	mln m^3	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	66.0	
18	Total volume for drinking for month VII		$W_{VII}^{K.drink.}$	mln m^3	91.0	78.0	65.0	52.0	39.0	26.0	13.0	13.0	13.0	13.0	13.0	13.0	
21	Drinking withdrawal from Kaparas		$W_{wthdr}^{.drink.}$	mln m^3	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	
	Maximum capacity н/б		$W_{mcap.}^{\text{н/б}}$	mln m^3	10,720.0	9,720.0	10,720.0	10,360.0	10,720.0	10,360.0	10,720.0	10,720.0	10,360.0	10,720.0	10,360.0	10,720.0	
	Drawdown volume (S-S + K-k)				0.0	0.0	0.0	1,217.9	950.2	89.9	0.0	0.0	0.0	0.0	0.0	0.0	
	Total TMHC drawdown				90.9	377.3	762.3	1,258.5	1,072.2	222.6	13.0	13.0	1,131.6	13.0	13.0	13.0	
	Outflow volume				2,409.9	2,678.4	3,466.9	3,982.4	5,642.0	6,642.7	9,048.0	5,733.9	3,851.3	977.7	1,659.3	1,620.1	
38	Free reservoir capacity	Ruslovoye			0.0	77.9	442.2	1,192.6	1,199.6	1,204.7	1,205.1	0.0	0.0	1,121.2	450.1	90.0	
39		Kaparas			286.8	301.0	315.3	330.7	375.2	501.8	610.0	13.0	33.0	52.3	69.6	84.7	
40		S-S + K-k			6.7	11.8	17.3	27.9	1,263.0	2,010.0	2,010.0	804.0	160.8	0.0	16.1	24.3	
41	Drawdown volumes	Ruslovoye, mln m^3	$W_{draw.}^{R}$	mln m^3	77.9	364.3	749.3	0.0	0.0	0.0	0.0	0.0	1,118.6	0.0	0.0	0.0	2,310.1
		Kaparas, mln m^3	$W_{draw.}^{K}$	mln m^3	13.0	13.0	13.0	40.6	122.0	132.7	13.0	13.0	13.0	13.0	13.0	13.0	412.3
		S-s + K-k, mln m^3	$W_{draw.}^{S\text{-}s+K\text{-}k}$	mln m^3	0.0	0.0	0.0	1,217.9	950.2	89.9	0.0	0.0	0.0	0.0	0.0	0.0	2,258.0
42	Admission volume	Ruslovoye	$W_{adm.}^{R}$	mln m^3	0.0	0.0	0.0	0.0	0.0	0.0	1,205.1	0.0	0.0	672.7	360.1	90.0	1,122.8
		Kaparas	$W_{adm.}^{K}$	mln m^3	0.0	0.0	0.0	0.0	0.0	0.0	610.0	0.0	0.0	0.0	0.0	0.0	610.0
		S-S + K-k	$W_{adm.}^{S\text{-}s+K\text{-}k}$	mln m^3	0.0	0.0	0.0	0.0	0.0	0.0	1,206.0	643.2	160.8	0.0	0.0	0.0	2,010.0
43	Total drawdown		$\sum W_{draw.}$	mln m^3	90.9	377.3	762.3	1,258.5	1,072.2	222.6	13.0	13.0	1,131.6	13.0	13.0	13.0	4,980.4
44	Total admission		$\sum W_{adm.}$	mln m^3	0.0	0.0	0.0	0.0	0.0	0.0	3,021.1	643.2	160.8	672.7	360.1	90.0	4,948.0
45	Reservoir volume at each month end	Ruslovoye		mln m^3	1,182.8	815.3	56.0	64.4	64.4	64.4	1,201.4	1,184.6	64.3	735.6	1,093.9	1,182.6	
		Kaparas		mln m^3	309.0	294.7	279.3	234.8	108.2	0.0	597.0	577.0	557.7	540.4	525.3	510.6	708.3
		S-S + K-k		mln m^3	1,998.2	1,992.7	1,982.1	747.0	0.0	0.0	1,206.0	1849.2	2,010.0	1,993.9	1,985.7	1,979.3	1,731.3
47	Total reservoir capacity		$\sum W$	mln m^3	3,490.0	3,102.7	2,317.4	1,046.2	172.6	64.4	3,004.4	3,610.8	2,632.0	3,270.0	3,604.9	3,672.6	
48	Outflow volume		$\sum W_{out.}$	mln m^3	2,407.6	2,675.4	3,467.4	3,974.7	5,636.4	6,641.3	9,089.4	5,702.8	3,804.4	976.9	1,654.8	1,614.3	47,645.4
49	Total outflow discharge		$\sum Q_{iout.}$	m^3/sec	898.4	1,105.5	1,293.8	1,534.6	2,103.1	2,564.2	3,391.6	2127.9	1468.9	364.5	638.9	602.3	
	Kaparas dead storage		W_{dead}^{K}	mln m^3	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	350.0	
	Koshbulak dead storage		$W_{dead}^{K\text{-}k}$	mln m^3	790.0	790.0	790.0	790.0	790.0	790.0	790.0	790.0	790.0	790.0	790.0	790.0	
	Sultansanjar dead storage		$W_{dead}^{S\text{-}s}$	mln m^3	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	1,060.0	
50	Environmental and sanitary release volumes				2,147.6	1,455.4	947.4	3,344.7	3,126.4	3,441.3	4,669.4	2192.8	3084.4	736.9	1394.8	894.3	
51	River runoff, Darganata Settlement (m^3/sec)		Q_i	m^3/sec	865.3	950.9	1,009.2	1,051.7	1,705.2	2,478.8	4,498.6	2374.7	1112.2	611.0	774.7	633.3	

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Annex 3. TMHF Ruslovoye Reservoir sedimentation calculations (based on 2017 input data).

№	Indicator	Unit	Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	TOTAL
1	Design capacity	mln m^3	2,340.00	2,340.00	2,340.00	2,340.00	2,340.00	2,340.00	2,340.00	2,340.00	2,340.00	2,340.00	2340.00	2340.00	
2	Calculated capacity	mln m^3	1,049.93	1,048.62	1,048.36	1,049.69	1,054.79	1,049.01	1,046.33	1,043.64	1,049.46	1,057.69	1056.98	1056.56	1,056.21
3	Initial capacity	mln m^3	479.26	932.10	813.26	76.89	398.13	651.76	611.85	358.07	82.50	161.71	347.73	695.56	
4	Final capacity	mln m^3	933.37	813.51	76.89	388.93	656.89	614.20	359.83	82.50	151.27	348.18	695.93	609.11	
5	Water volume at joint mark	mln m^3	93.17	93.27	93.29	92.98	91.50	91.93	92.13	92.33	90.99	89.04	89.10	89.13	
6	Water discharge	mln m^3	1,493.88	710.78	518.28	1,944.66	3,617.65	2,957.35	4,280.65	2,486.78	1,838.90	1,416.94	1005.78	1209.89	23,481.55
7	Water discharge (Q^1_p)	m^3/sec	557.4	292.5	193.4	750.8	1350	1142	1597.3	927.9	710	528.71	388.3	451.45	
8	Calculation streamway width (B^1_p)	m	185.81	97.50	64.46	250.28	449.96	380.61	532.42	309.30	236.67	176.24	129.44	150.48	
9	Turbidity	kg/m^3	1.04	0.58	0.40	1.36	2.30	1.98	1.91	1.17	0.92	0.71	0.53	0.61	
10	Additional flushing flow load	kg/m^3	0.00	0.00	9.04	9.04	0.00	0.00	0.00	8.23	8.20	0.00	0.00	0.00	
11	Water level at month beginning	m	126.13	129.31	128.57	119.32	125.25	127.45	127.18	124.91	120.00	122.13	124.58	127.66	127.03
12	Water level at month end	m	129.31	128.57	119.32	125.25	127.45	127.18	124.91	120.00	122.13	124.58	127.66	127.03	
13	Water clarification ratio		0.43	0.54	0.25	0.10	0.31	0.38	0.27	0.09	0.01	0.11	0.30	0.40	
14	Total sedimentation	mln m^3	1,290.07	1,291.38	1,291.64	1,290.31	1,285.21	1,290.99	1,293.67	1,296.36	1,290.54	1,282.31	1283.02	1283.44	
15	Total sedimentation mark	m	126.639	126.645	126.646	126.640	126.619	126.643	126.654	126.665	126.641	126.607	126.610	126.612	
16	Joint marks (initial)	m	121.29	121.31	121.31	121.27	121.09	121.14	121.17	121.19	121.03	120.79	120.80	120.80	
17	Joint marks (final)	m	121.31	121.31	121.27	121.09	121.14	121.17	121.19	121.03	120.79	120.80	120.80	120.81	
18	Sediment inflow	mln m^3	1.86	0.49	0.25	3.16	9.98	7.01	9.81	3.50	2.03	1.20	0.65	0.89	40.83
19	Settled sediment	mln m^3	1.31	0.27	0.05	1.67	5.78	2.68	2.69	0.24	0.43	0.70	0.42	0.35	16.58
20	Flushing volume	mln m^3	0.00	0.00	1.39	6.76	0.00	0.00	0.00	6.05	8.65	0.00	0.00	0.00	22.86

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