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Hydraulic mode of operation of the Takhiatash hydroelectric complex

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Abstract. This topic is the design characteristics of the liquid and solid runoff of the Amudarya river in the area of the hydroelectric complex, according to which the average long-term flow of the river at the site of the hydroelectric complex is 46.5 km^3, the discharge is 1470 m^3/s, the maximum is 5760 m^3/s (July) and the minimum is 186 m^3/s (March). The amount of suspended sediment reaches 5 – 6 kg/m^3, and bottom 5 – 8% of suspended sediment. The annual volume of suspended sediment is 120 million tons, and taking into account bottom sediments – 130 million tons. It is noted that due to low water conditions, the Takhiatash dam operated with completely closed gates in all spans for a significant part of the year. The authors of the article provide data comparing the actual flow rates of turbidity and backwater at the Takhiatash hydroelectric complex with the calculated ones. It is proved that sharp fluctuations in the water level in front of the dam and water intake into the canals lead to a change in the hydraulic and alluvial operation of the canals. As shown by the analysis of the river channel cross-sections in the upper reach of the Takhiatash hydroelectric complex, in the initial period of operation, there is a decrease in the level of the river bed bottom. The subsequent years of operation of the hydroelectric complex (after 1982) were characterized by the stability of the ongoing channel processes in the downstream, which is characterized by its own level and discharge regime for each characteristic year. It is noted that the operating mode for dry years, which are characterized by the fact that during periods of chronic low water the gates of the shield dam are almost completely closed and its role in regulating the level regime is almost lost. In this case, the level and flow rates are regulated mainly by end regulators in the right-bank and left-bank systems of main canals, which in turn depend on the demands of limited water consumers. Under these conditions, it is extremely difficult to regulate the water level in the headwater, since it is required to keep at a certain level of the water level. It is noted that there were no difficulties with water intakes in high-water years, and the main difficulties are associated with the passage of flood flows through the shield dam. In recent years, there has been a rapid rise in the water level in the upstream, despite all the open gates of the dam, the navigable lock and water intake structures, which are explained by the influence of the introduced ponds on the throughput of the shield dam. It has been substantiated that without any damage to the water intake during the growing season, it is possible to effectively flush the headwater with a constant decrease in the water intake coefficient below the critical value of the water intake coefficient $K_v < 0.55$. In practice, for the Takhiatash hydroelectric complex, this means that the flushing flow rate should be at least $Q \geq 250 - 300\ m^3/s$. Recommended: for the normal functioning of the Takhiatash hydroelectric complex, taking into account the requirements of all water consumers and sanitary passes to the downstream, it is necessary to clearly link with the operating regime of the Tuyamuyun reservoir.

1. Introduction

The commissioning of any hydraulic structure in the riverbed leads to a change in the hydraulic and alluvial regime of the river. Such a change very often complicates the operation mode of the structure [1, 2].

Therefore, the study of the hydraulic operation of a hydraulic structure is of practical interest. Based on the foregoing, the Takhiatash hydroelectric complex, erected in the lower reaches of the Amudarya, was chosen as the object of study. The Takhiatash hydroelectric complex is located on the flat area of the Amudarya, characterized by a large amount of suspended sediment and an unstable canal. Its main purpose is to regulate water levels in the river in order to ensure guaranteed water intake into the existing main canals in the upper reaches, the reconstruction of which will increase the area of irrigated land in the lower reaches of the Amudarya, in addition, the issues of construction of road and railway bridges are being resolved. When assembling the hydroelectric complex, the principle of sequential two-way water intake on the concave banks of the river was adopted with the location of the dam on the left bank in order to preserve the existing water intakes into the Kyzketken and Suenli canals. The structure of the hydroelectric complex includes: a shield dam, an earthen dam, inlet and outlet channels, head regulators of main canals, navigational locks, right-bank and left-bank sedimentation tanks, systems of stream-guiding dams, fish-pass structures, railway and road bridges. Intensive canal processes in the riverbed complicate the operating conditions for the above-mentioned structures and canals. Effective regulation of the hydraulic and alluvial flow regime in the river in order to ensure a guaranteed and high-quality water intake into the existing main canals in the upper pool always remains relevant.

Many scientists have been and are engaged in solving the problems of channel processes in river beds in the area of hydraulic structures [3–6]. Many of them carried out experimental studies to study the dynamics of the hydraulic and alluvial regime of the river under the influence of damless water intake. A number of studies were devoted to the study of the dynamics of the hydraulic and sediment regime of the Amudarya river after the commissioning of hydraulic structures erected in the river bed. According to the research results, the intensity of the channel morphometry, the relationship between the morphometric elements of the channel and the hydraulic flow parameters were established [7, 8], intensity of planned deformations of the river canal in the area of water intake [9–16]. It should be noted that the nature of channel processes, depending on the degree of regulation of the river channel, the problem of water intake, the conditions for effective flushing of the upper pool of hydroelectric complexes, and the linking of operating modes of successively located reservoirs have not been sufficiently studied. According to the above, the goal and objectives of the study of this scientific work are formulated. The need to analyze the hydraulic operating regime of the Takhiatash hydroelectric complex in conjunction with the operating regime of the Tuyamuyun reservoir is determined as the main goal of this work [16 – 23]. To achieve this goal, the following research objectives have been identified:

- conducting a comparative analysis of the actual hydraulic flow parameters with the calculated ones;
- study of the dynamics of the elevations of the bottom of the upper pool of the Takhiatash reservoir;
- analysis of the dynamics of the water intake coefficient;
- establishment of the nature of management of the hydraulic complex of the Takhiatash hydroelectric complex.

2. Results and Discussion

When designing the hydroelectric complex, the average long-term flow of the river in the section of the hydrosystem was taken as 46.5 km^3, the discharge is 1470 m^3/s, the maximum is 5760 m^3/s (July) and the minimum is 186 m^3/s (March). The amount of suspended sediment reaches 5 - 6 kg/m^3, and bottom 5 – 8% of suspended sediment. The annual volume of suspended sediment is 120 million tons, and taking into account bottom sediments – 130 million tons.

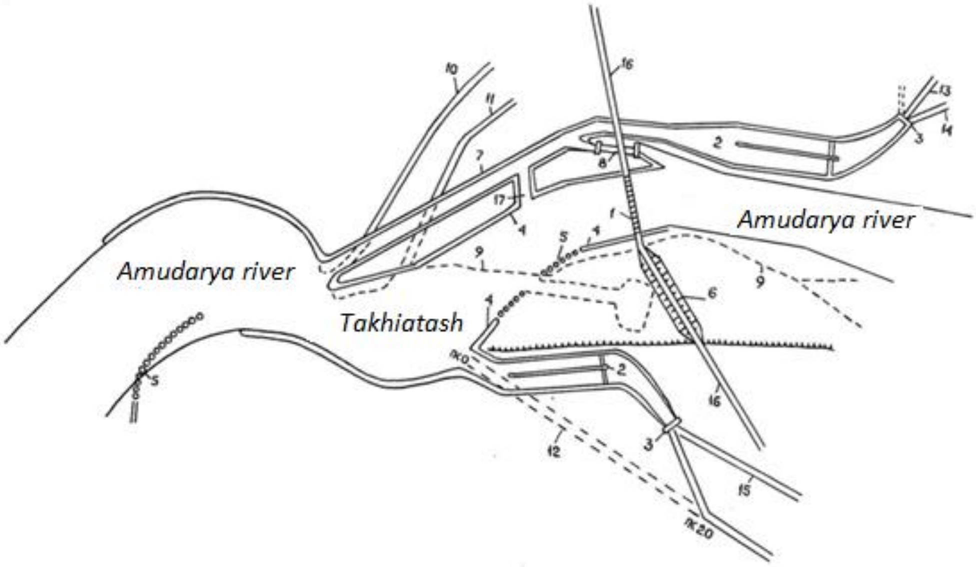

Figure 1. Layout of structures and supply canals of the Takhiatash hydroelectric complex; 1-panel dam; 2-sedimentation tanks; 3-water dividers; 4-channel dams; 5-dams from shell piles; 6 - earthen dam; 7 - unifying supply channel; 8-shipping lock; 9-contour of the left bank of the old river bed. Amudarya; 10-11-old head sections of the Suenli and Parallel canals; 12 of the same Kyzketken channel; 13-new channel of the Suenli Canal; 14-the same Parallel; 15-Feeding parallel channel Kyzketken; 16-highway and railroad; 17-exit for the shipping lock.

In a shield dam with a length of 487.1 m there are 25 spans of 16 m. The total width of the spans of the dam in the clear is 400 m. The maximum height of the dam from the threshold to the top of the bullheads is 16 m. 11000 m^3/s. The elevation of the dam sill is 177.20, the elevation of the water level when the maximum flow is passed is 178.80, the elevation of the top of the dam is 180.0 m. The average elevation of the dam threshold is 172.0 m. and two repair lines. The two leftmost spans of the dam are fish passages and were designed as a sluice, consisting of a lower head with a length of 14 m, a sluice chamber – 52, an upper head – 35 and reinforced concrete box-section trays with a span of 16 m, extended into the lower pool. The earthen dam overlaps the Amudarya bed, has a length of 970, width along the ridge - 31, maximum height - 12, ridge mark - 180 m and is located on the same axis with the shield dam.

The Takhiatash hydroelectric complex was put into operation in 1974. In the initial period (1974 – 1981) of the hydroelectric complex operation, the actual operating conditions of the unit differed greatly from the design ones due to its low water content. During this period, the annual runoff volumes in the upper pool of the node were (km^3): in 1974 y – 11.57, in 1975 y - 15.80, in 1976 y – 16.93, in 1977 y – 10.05, in 1978 y – 24.7, in 1979 y - 14.6, in 1980 y - 14.8, in 1981 y - 8.8. (Transition to the diagram) This is significantly less than the annual volume of 46.5 km3, taken in the calculations of 1966, and the volume of calculations in subsequent years. Due to the strong low water level, the Takhiatash dam operated with completely closed gates in all spans for a significant part of the year. During this period, 100% of the river discharge into the Kyzketken, Suenli and Parallel canals was carried out at the node. Such periods continued: in 1974 y - 17 days, in 1975 y – 178 days, in 1976 y - 97 days, in 1977 y - 154 days. The marks of the highest average daily water levels in front of the dam were 50 – 70 cm higher than those taken in the design assignment of 1962, although the water intake to both banks did not exceed 550 – 580 m^3/s. The high water levels in front of the dam are due to the insufficient flow capacity of the Kyzketken regulator. Another reason for their increase is the desire of the operation service to create a small (40 – 50 million m^3) adjustable tank in the headwater in order to reduce the irregularity of water supply to the canals in spring, short-term flood peaks, which make it possible to accumulate water in the headwater, are replaced by a decline in flow rates that do not provide the planned water supply. In recent years, due to significant siltation of the headwater, this capacity has decreased. The observed insufficient water content of the river and significant level rises in front of the dam significantly changed the operating conditions of the unit in comparison with those adopted in the preparation of forecast channel calculations for 1962 and 1966 (Table 1).

Table 1. Comparison of the actual flow rates (m^3/s), turbidity (kg/m^3) and backwaters (m) at the Takhiatash hydroelectric complex for 1974 - 1981 with the calculations taken in 1962 and 1966

Indicators	Accepted in calculations		According to actual data								
	1962	1966	1974	1975	1976	1977	1979	1981	1982	1983	1984
Average high water discharge											
Upstream	2707	2210	562	1122	1190	725	1091	970	452	651	864
Downstream	2116	1635	242	735	793	649	570	437	19	91	325
Average low water consumption											
Upstream	784	608	152	118	400	380	254	296	120	160	265
Downstream	571	487	96	98	157	-	147	111	-	54	204
Average turbidity upstream											
In the flood	3.53	2.51	1.56	2.46	2.42	2.35	1.55	1.03	0.61	0.54	0.85
In the low water	2.58	1.57	0.73	0.45	1.52	1.01	0.58	0.44	0.16	0.22	0.27
Average backwater during high water											
Curve $Q = f(H)$ 1962	0.51	-	1.91	1.81	1.97	1.90	1.88	1.93	1.79	1.87	1.90
Curve 1966	-	2.28	2.16	2.20	2.42	2.35	2.38	2.41	2.11	2.21	2.07
Backwater in low water											
Curve 1962	1.38	-	1.53	1.76	1.02	1.97	1.81	1.63	1.49	1.66	1.83
Curve 1966	-	1.05	1.70	2.08	1.52	2.47	2.05	1.81	1.59	1.83	2.01

The change in the headwater level depends on the flow rate in the river and on the value of the total water intake. Excessive discharge through the dam (discharge into the downstream) in 1974 low-water year was carried out from 1 to 10 days of June with a flow rate of 10 - 50 m^3/s, with breaks in the II – decade of July, II and III – decades of August. In 1975, the flow of discharge through the dam began from the 3rd - decade of May until the end of the growing season, and the maximum discharge discharge reached 3200 m^3/s. 1978 was a high-water year in comparison with previous years and discharge into the downstream was carried out from April 12 to the end of the season with a discharge from 100 to 4930 m^3/s.

The operating experience of the Takhiatash hydroelectric complex showed that sharp fluctuations in the water level in front of the dam and in the water intake into the canals lead to a change in the hydraulic and alluvial operation of the canals. The retaining levels in front of the dam vary over time in large ranges and the amplitude of level fluctuations reaches 3 m. This disrupts the normal operation of the canals and leads to a decrease in the technical condition indicators, especially the efficiency of the canals.

In the initial periods, when the dam operated at maximum backwater and water intake was carried out with a large forcing of the clarified water flow through the canals, there was a general erosion of the canal bed, a violation of the clogged layer of the canal bed, which led to an increase in the filtration flow, a rise in the groundwater level and waterlogging of lands adjacent the route of the main canals. However, in subsequent years of operation, with the approach of turbid water to the

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hydroelectric complex and its ingress into the canals, the clogging layer was restored - the fluff on the bed of the canals, the filtration losses of water and the size of the swampy areas sharply decreased.

Analysis of survey data of cross-sections in the upper reach of the Takhiatash hydroelectric complex shows that from 1982 to 1988. at the Nietbaytas section, there was a decrease in the level of the river bed bottom. The dynamics of changes in the average bottom marks is as follows: in 1983 - 74.55 m, 1985 - 74.53 m, 1987 - 74/52 m, 1988 - 74.12 m, that is, for 6 years the bottom has dropped almost by 0.5 m, and the bottom was washed out more intensively in 1988 by 0.4 m.

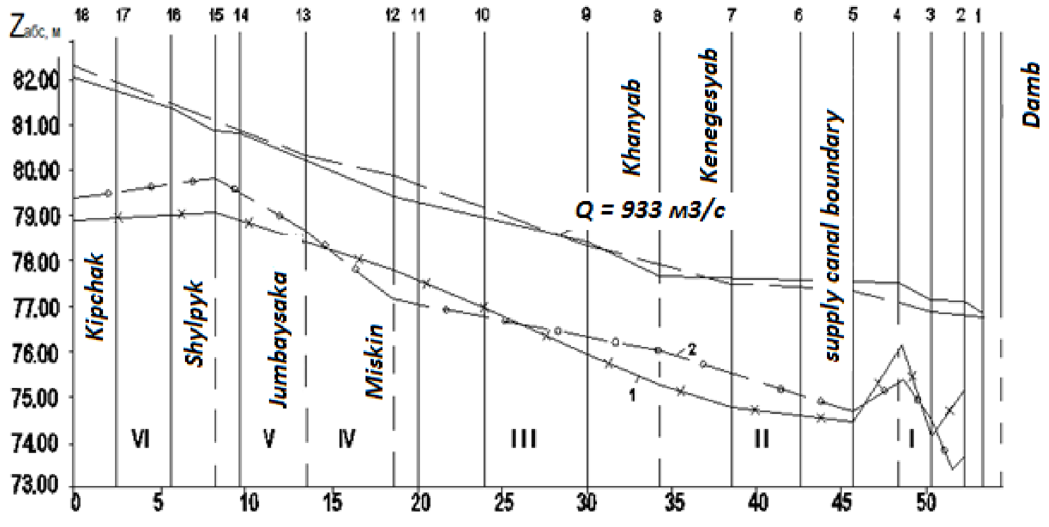

Figure 2. Change in the slope of the water surface and the average elevation of the bottom of the river. Amudarya in the section between the sections of the Kipchak g/s and the dam of the Takhiatash hydroelectric complex: I, II, III, IV, V, VI - numbers of the identified characteristic channel sections. 1 - 1992, 2 - 1999

In figure 2 the longitudinal profile of the Amudarya river channel in the upper reach of the Takhiatash hydroelectric complex between the Kipchak – Takhiatash dam sections is presented. The figure shows that the bottom profile along the length of the river is stepped. The most characteristic is the section between the Kipchak – Zhumabaisak sections, where intensive siltation of the channel is observed, due to its expansion. Further, in the section between the sections Zhumabaisak - Miskinata, the intensity of siltation decreases. This is due to the fact. that the river at the Miskinata section has an indestructible and narrowed channel. Below this section, with the approach to the Takhiatash hydroelectric complex in the upper reach, a gradual rise of the channel bottom is observed. In the initial periods of operation of the Takhiatash hydroelectric complex, the total erosion of the downstream was marked by a rather high intensity of the ongoing processes. The lowering of the bottom during these years averaged 1.10 m.

The subsequent years of operation of the hydroelectric complex (after 1982) were characterized by the stability of the ongoing channel processes in the downstream. The bottom elevation fluctuates towards a decrease or increase by 0.5 m, depending on the water content of the year. During this period, changes in the bottom elevation along the average depth become more stable, the range of level fluctuations becomes less and less and depends on the hydrological regime of the river. The riverbed has become more resistant to flow.

The study of many years of experience in the operation of the Takhiatash hydroelectric complex also showed that the operating mode of the main structures and the conditions of water intakes into the canals mainly depends on the degree of regulation and water content of the Amudarya River, which

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are characterized by the water intake coefficient, which represents the ratio of the total water intake to the river discharge at the Nietbaytas section:

$$K_{w.i} = \frac{\sum Q_{w.i}}{Q_r} \quad (1)$$

where $\sum Q_{w.i}$ - total water withdrawal;

Q_r - river discharge in the Nietbaytas section:

$$Q_r = Q_{w.i} + Q_{s.b} + Q_{HPP} \quad (2)$$

Depending on the water content of the year, the water intake coefficient can also be determined by the water consumption of the right-bank and left-bank water intake:

$$K_{w.i_{\text{right}}} = \frac{Q_{w.i_{\text{right.}}}}{Q_c}; \qquad K_{w.i_{\text{left.}}} = \frac{Q_{w.i_{\text{left.}}}}{Q_r} \quad (3)$$

The degree of flow regulation is determined by the following formula:

$$\eta = 1 - \frac{Q_{\text{average.zareg.}}}{Q_{\text{average domestic}}} \quad (4)$$

Degree of regulation is η f 0.70 – 0.75 for the period 1974 – 1981 and η = 0.80 – 0.85 for the period 1982 – 2015.

Analysis of the operation data of the Takhitash hydroelectric complex and the UGMS show that the nature of the course of canal processes in the headwaters of the node mainly depends on the water content of the rivers and is determined by the hydrological regime of the following characteristic years: high-water (1978, 1988, 1992, 1994, 1998, 2005, 2010, 2015).); low-water (1974, 1977, 1986, 1990, 1995, 1997, 2000, 2002, 2018); medium water (1976, 1979, 1983, 1991, 1993, 1996, 1999, 2003, 2007, 2016).

In figure 3 we have constructed graphs of changes in the values of the water intake coefficients in the intra-annual section for these characteristic years, which are distinguished by three independent straight lines under the slope coefficients characterizing the water content of the year. So, the average value of the water intake coefficient is: $K_v = 0.90$– for dry years; $K_v = 0.55$– for middle-water years; $K_v = 0.25$ – for high-water years.

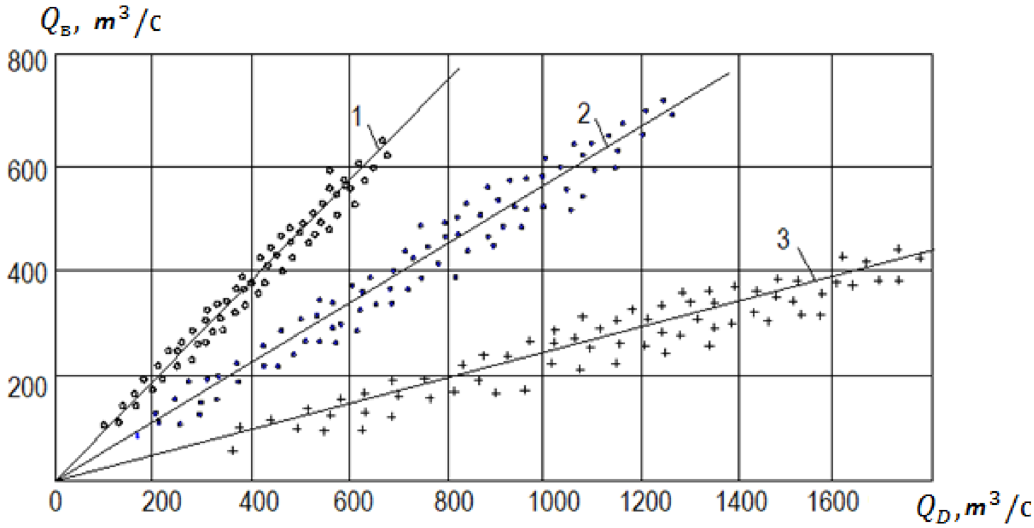

Figure 3. Change in the coefficient of water withdrawals depending on the water content of the rivers: 1-low-water (1980, 1990, 1997, 2000 and 2018); 2-average water years (1976, 1991, 1996, 2003 and 2016); 3-high-water years (1978, 1988, 1992, 1998, 2005, 2010, 2015).

Analysis of these graphs shows that each characteristic year has its own level and expenditure regime. It is especially necessary to note the operating regime in dry years, which are characterized by the fact that during periods of chronic low water the gates of the shield dam are almost completely closed and its role in regulating the level regime is almost lost. In this case, the level and discharge modes are regulated mainly by end regulators in the right-bank and left-bank systems of main canals, which, in turn, depend on the demands of limited water consumers.

Under these conditions, it is extremely difficult to regulate the water level in the headwater, since it is required to keep at a certain level of the water level. However, the need to keep the water level in the headwater not lower than 75.40 m under the operating conditions of the canal at the state district power station, and also in certain cases on the Arnasay canal does not allow this.

In high-water years, there are no problems with water intakes, and the main difficulties are associated with the passage of flood flows through the shield dam. In recent years, there has been a rapid rise in the water level in the upstream, despite all the open gates of the dam, the shipping lock and water intake structures, which are explained by the influence of the introduced ponds on the throughput of the shield dam.

Under the conditions of a regulated river flow, an acceptable condition for the operation of a low-pressure hydroelectric complex is average in terms of water content years with a water intake coefficient $K_v = 0.55$ with the exception of the main shortage within the annual flow (discharge) of water.

Having taken the water intake coefficient as a critical parameter we can characterize the role of the management of the hydraulic complex of the Takhiatash hydroelectric complex as follows:

- the study found that the average value of the water intake coefficient equal to $K_v = 0.55$ assesses the critical state of the control of the hydroelectric complex, while the role of regulation of the level regime at the water intake structures and the shield dam is uniform;

- with an increase in the water intake coefficient from this limit $K_v = 0.55$– the role of regulation of water distribution units of structures increases significantly, and the role of control of a shield dam decreases;

with a decrease of $K_v < 0.55$ – on the contrary, the regulating role of the level regime passes to the shield dam.

The practical number of the water intake coefficient $K_v = 0.55$ makes it possible to plan and carry out not only the design and implementation of automated control facilities, but also other operational measures, among which a special place is occupied by the washing of the supply channel of the hydroelectric complex. This allows us to conclude that, without any damage to the water intake during the growing season, it is possible to effectively flush the headwater with a constant decrease in the water intake coefficient below the critical value $K_v < 0.55$. In practice, for the Takhiatash hydroelectric complex, this means that the flushing flow rate should not be lower $Q \geq 250 - 300\ m^3/s$.

For the normal functioning of the Takhiatash hydroelectric complex, taking into account the requirements of all water consumers and sanitary passes to the downstream pool, it is necessary to clearly link with the operating mode of the Tuyamuyun reservoir. After the construction of the hydroelectric complex, thousands of floating sediments were removed, supplying water to the canals in the spring at a low level in the river, and guaranteed water withdrawal was ensured for all irrigation systems; the volume of cleaning work has greatly decreased, irrigated areas are being intensively developed and crossings across the Amudarya have been made.

3. Conclusions

Analysis of the hydraulic regime of operation of the Takhiatash reservoir made it possible to draw the following conclusions and recommendations:

-analysis of the longitudinal profile of the Amudarya river channel in the upper reach of the Takhiatash hydroelectric complex between the Kipchak - Takhiatash dam sections. He showed that the profile of the channel bottom along the length of the river has a stepped character. The most characteristic is the section between the Kipchak - Zhumabaisak sections, where intensive siltation of the channel is observed, due to its expansion. Further, in the section between the sections of Zhumabaysak - Miskinata, the intensity of siltation decreases. This is due to the fact that the river at the Miskinata section has an indestructible and narrowed channel. Below this section, with the approach to the Takhiatash hydroelectric complex in the upper reach, a gradual rise of the channel bottom is observed;

- insufficient water content of the river and significant level rises in front of the dam significantly changed the operating conditions of the unit in comparison with those adopted in the preparation of forecast channel calculations;

-experience in the operation of the Takhiatash hydroelectric complex showed that sharp fluctuations in the water level in front of the dam and water intake into the canals lead to a change in the hydraulic and alluvial operation of the canals. The retaining levels in front of the dam vary over time in a wide range and the amplitude of level fluctuations reaches 3 m. This disrupts the normal operation of the canals and leads to a decrease in the technical condition indicators, especially the efficiency of the canals.

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