Calculation of planned flows taking into account deformations of bottom sediments in a dam-free water intake

Dilshod Bazarov, *Bekhzod* Norkulov*, *Adkham* Mamataliev, *Ozoda* Vafoeva, and *Shokhida* Nazarova

"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers" National Research University, Tashkent, Uzbekistan

Abstract. The article presents the results of numerical studies carried out by the authors of the existing problems in assessing the intensity of channel processes in the territory of the damless water intake of the Amudarya river. As well as the development of hydraulic regimes and flow regimes of sediment flow for the proposed structures based on experimental and numerical studies for the proposed structures is the main goal of research work. In the course of numerical studies, depths, changes in water flow were determined which elements of flow in straight and curvilinear channels were initially. As part of the numerical studies, the flow spreading conditions (vectors of medium-depth velocities) in specific time intervals and transitions in the water intake area were studied.

1 Introduction

The engineering practice associated with the abstraction of water from river beds dates back millennia and is quite well developed. However, despite such a long practical experience, it is a difficult engineering task to achieve an acceptable balance between the requirements of water transportation systems and the actual water intakes, especially in the conditions of meandering channels composed of easily eroded soils. In this respect, a water intake located in middle and lower reaches of the Amudarya [1, 2]. It should be noted that the choice of the location of the water intake was caused precisely by the fact that in this place the right bank is stable due to the presence of rocky indelible rocks of Cape Pulizindan [3]. In the area of the water intake of the Amudarya river, it is characterized by an exceptionally high transport capacity and has a wide floodplain. The stream bed often changes its location on it and moves away closer to the right bank, then to the left. Islands or a stable shoal are formed near the right bank, moving downstream from Cape Pulizindan in the form of a spit, which are flooded during the flood period [5]. The channel in the water intake area wanders, deviating to the right bank in high-water years, and to the left bank in low-water years. There are practically no channel-regulating and bank protection structures in the area adjacent to the water intake. Water intake and throughput capacity of the head section of the canal are supported by year-round operation of dredgers [6-9].

*Corresponding author: behzod1983@mail.ru

The problem of sustainable water intake in conditions of significant fluctuations in flow rates and water levels is greatly exacerbated by the erosion of river channels. A typical example of such conditions is the damless water intake into the Karshi Main Canal (KMC), where the main flow of the Amudarya continuously moves along a wide floodplain, changing the direction of the currents. As a result, it is very difficult to take the required volume of water from the river into the canal, especially in dry years due to the high instability of the currents at the canal inlet [10-13].

2 Research Method

The research method is to carry out numerical studies to assess the intensity of channel processes in the territory of the damless water intake of the Karshi Main Canal in the Amudarya river. As well as the development of hydraulic and flow regimes of sediment flow for the proposed structures based on experimental and numerical studies for the proposed structures is the main goal of the research work.

3 Results and Discussions

At present, the main flow of the Amudarya river passes mainly along the right-bank channel. The winter level of the water surface at Cape Pulizindan is 243.0 m and creates normal working conditions for the first pumping station (PS No. 1) [14]. The pumping station (NS No. 1) in this case works with three units. In such situations, water intake is provided by water with an area of two channels. During the flood period in winter, the main flow of the Amudarya River above the main water intake has shifted towards the right bank. The main flow was directed to the head of the right-bank channel. During the main flood period in previous years, their values reached 28...30 kg/m^3 against 15...20 kg/m^3 (observed over a long-term period). Cape Pulizindan, created in natural conditions, plays the role of a deaf stable spur [15-17]. Here, the main flow, depending on the current and approach, is reflected at an angle and directed to the opposite erosional bank, where the main stream forms a stall current causing erosion of the coastal area of the Kyzylaak Village. At the head section of KMC, in the earthen channel of the canal from the head water intake to the first pumping station, silting occurred due to insufficient volume of treatment work [18-20]. As a result, there was a rise in the bottom of the channel due to the residual volumes of silting, which has accumulated throughout the years. Here we present the results of residual volumes by years.

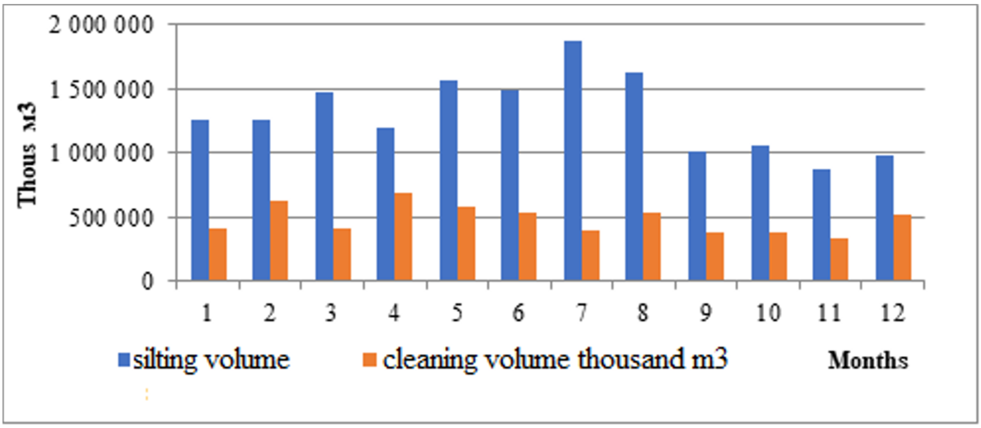


Fig. 1. The volume of silting and cleaning in the Karshi Main Canal

As can be seen from the above factual materials, the residual volume of siltation in the earthen channel in 2020 increased significantly. As a result of the increase in the residual volume, the throughput of the supply channel decreased. An increase in the volume of cleanup works along the earth section of the inlet part of the KMC leads to a decrease in the transporting capacity of the flow on it and, accordingly, the clearing of the flow (Fig. 1-2). With any variant of redistribution of entering sediments between the inlet part of the KMC and the Talimarzhan reservoir, a negative effect is observed: either the cost of cleaning up the inlet part of the KMC increases, or the intensity of silting of the Talimarzhan reservoir increases. It is most cost-effective to design and implement plans and works for reducing the flow of sediments into the canal. The complex of channel regulation works to increase water withdrawal from the Amudarya river should include measures to combat the entrainment of floating bodies into the canal. Such activities may result in a 60% reduction in flow of floating bodies in the Amudarya river upstream of the water intake point in the KMC.


Fig.2. Inflow of bottom and suspended sediments in Karshi Main Canal

During the flood period, a large amount of bottom and suspended sediments entered the head part of the water intake and the supply channel, as a result of which the throughput capacity of the channel significantly decreased and the required flow rate of pumping station No. 1 was not provided.

In the supply channel, the flow rate increased due to the reduction in throughput. As a result, a large amount of sediment entered the concrete section of the canal, which negatively affected the KMC and the Talimarjan reservoir. Based on the field studies and analysis of the available factual materials on the section of the Amudarya River in the area of the KMC damless water intake, changes in the channel processes and the sediment regime on the approach to the water intake point and the operation mode of the water intake at different periods of water content of the year were revealed. Based on the received factual materials, a set of channel and sediment-regulating measures was developed. The main dimensions of the channel adjustment structures were determined and a diagram of their placement was drawn up. The values of the stable channel of the Amudarya River have been established, curvilinear outlines, as well as the scope of work have been developed. At the same time, it should be noted that the construction of large channels and sediment-regulating structures requires large capital funds. In this regard, prior to the construction of large structures, it is necessary to carry out temporary (operational) measures to ensure the required flow rate of water intake with less capture of bottom sediments. Temporary events include:

- clearing and deepening of the channel by dredgers
- making cuts along and across the river floodplain;

- Apply the method of water intake on meandering rivers developed by the authors in the riverbed before the water intake

As part of the numerical studies, the flow spreading conditions (vectors of medium-depth velocities) in specific time intervals and transitions in the water intake area were studied. The results of the study confirmed that it is practically impossible to ensure a stable water intake into the canal without special engineering measures. As a preliminary solution to the problem, it was proposed to make a trench along the right bank in the area of water intake into the canal.

There are 6 pumping stations operating on the 78.4 km section lifting water to a total height of 132.2 m. At the end of this section the Talimarjan reservoir with a useful capacity of 1400 million m^3 is located, which seasonally regulates the flow.

The nearest hydrological station to the KMC damless water intake on the Amudarya River is located 20 km downstream, near the bridge in the city of Kerki. In this work, on hydrological basis, we used the curve of the relationship between the flow rate Q and the water level h in the river, h=F(Q), obtained by recalculating the average long-term relationship between the flow rate and the level at the gauging station h_K and at the KMC damless water intake h_P:

$$h_P = h_K + 242$$

To build a mathematical model of the terrain for hydrodynamic modeling in the KMC water intake area, the following materials were used:

1. Topographic maps.
2. Satellite imagery.
3. Materials of topographic survey.
4. Data of measurements of the diameters of the Amu Darya river.

The functional purpose of this calculation program " Calculation of planned currents taking into account deformations of bottom sediments " is intended for numerical modeling on an uneven rectangular grid of currents in river beds and canals, through consideration of deformation of bottom sediments.

To carry out calculations on a digital hydrodynamic model, the model itself was created in the following way:

- An area for modeling riverbeds and a canal is defined.
- An uneven (or uniform) rectangular grid is superimposed on this area in local or Gauss-Kruger coordinates.
- Interpolation of the available height marks of the terrain and the riverbed and canals to the centers of each grid cell is performed.
- The boundaries of water inflow into the model and outflow from it are determined.
- Parameters are set:
- initial water level;
- bottom surface roughness;
- hydrograph of flow rate and turbidity of water flowing into the model;
- hydrograph of water withdrawal into the canal;
- Q\Z ratio (water discharge from absolute height) of the water flow flowing from the model;
- average size of the predominant fraction of bottom sediments;
- time of initial establishment of the water surface level;
- Courant number;
- limitation on the maximum flow rate;
- limitation on the maximum amount of erosion of bottom sediments

 https://doi.org/10.1051/e3sconf/202340101057

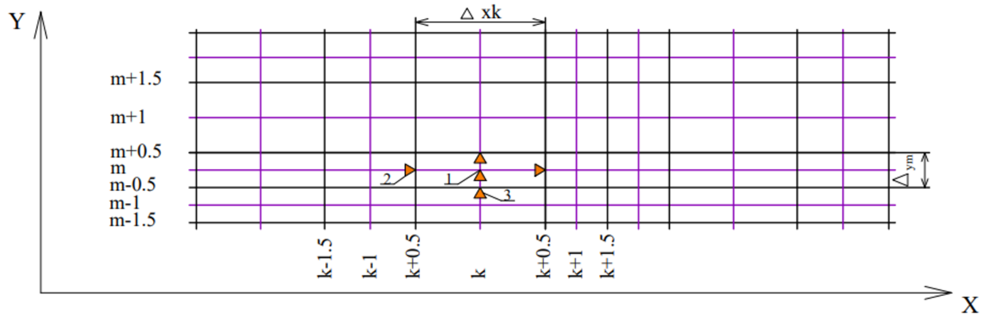


Fig. 3. Staggered finite difference mesh

The use of staggered finite-difference grids makes it possible to ensure the exact fulfillment of the laws of conservation of mass, energy and momentum in the computational fragment (Fig. 3).
The time step (the time simulated in one iterative calculation) is determined automatically by the Courant formula, which ensures the stability of the finite difference scheme:

$$\tau = \min\left(kur\frac{\sqrt{\Delta_{x\ k}^2 + \Delta_{y\ m}^2}}{\sqrt{gh_{k,m}} + \left|V_{k,m}\right|} \right) \text{ for } \forall \text{ k, m, where } \overline{V}_{k,m} = \begin{pmatrix} \dfrac{q_{xk-1/2,m} + q_{xk+1/2,m}}{2h_{k,m}} \\ \dfrac{q_{y_{k,m-1/2}} + q_{y,mk+1/2}}{2h_{k,m}} \end{pmatrix}$$

Where: h –depth; q_x, q_y – specific flow vector components, Δ_x, Δ_y – length steps in x and y direction; 0<kur<1.

The movement of bottom sediments is calculated using the Begnold formula for the specified size of the soil covering the bottom and the turbidity of the water entering the model

$$Q_S = Q\frac{\rho \times \rho_S}{\rho_S - \rho}\frac{C_f V^2}{gh}\left(\frac{0.13}{f - I} + \frac{0.01}{\frac{W}{V} - I}\right)$$

where: Q_S - mass flow conveying capacity, Q – water discharge, ρ - density of water, ρ_S - soil mineral density, C_f- coefficient characterizing the roughness of the channel, V– dynamic velocity, $f = tg(\varphi)$ - sediment internal friction coefficient, φ – sediment friction angle, W – hydraulic sediment size.

In the course of numerical studies, a pioneer ditch was cut in several variants of the direction of water flow into the main channel of the Karshi main canal and the issues of direction of flow into the channel were studied. These studies also considered options for achieving the maximum value of the water level in the head area of the water intake facility in the Karshi main canal. Since the period of low water is considered the most difficult period in a damless water intake, for different periods along the Amu Darya, a plan for the movement of sediments was studied, taking into account deformation processes. This research object presents the results of computational studies at the Amudarya flow rate Q=2600 m^3/s to 300 m^3/s and periods of water inflow into the canal from 40 m^3/s to 180

m^3/s, respectively.

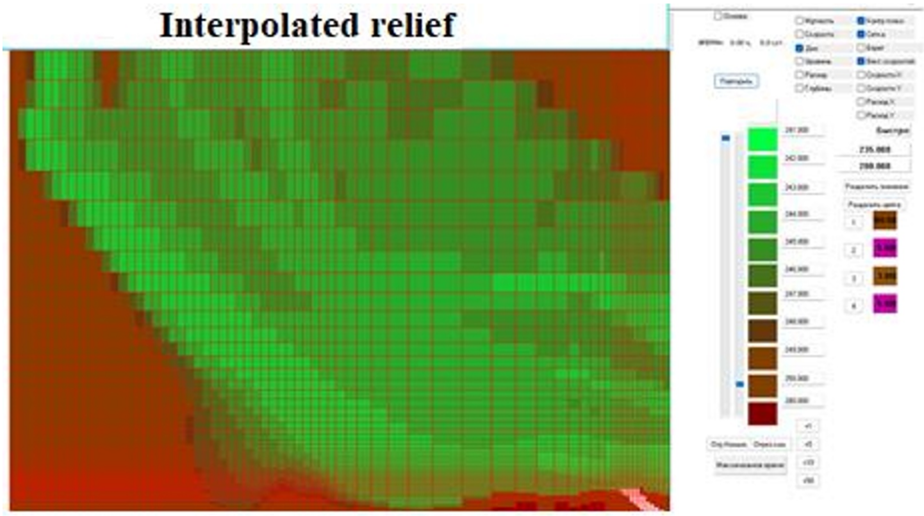
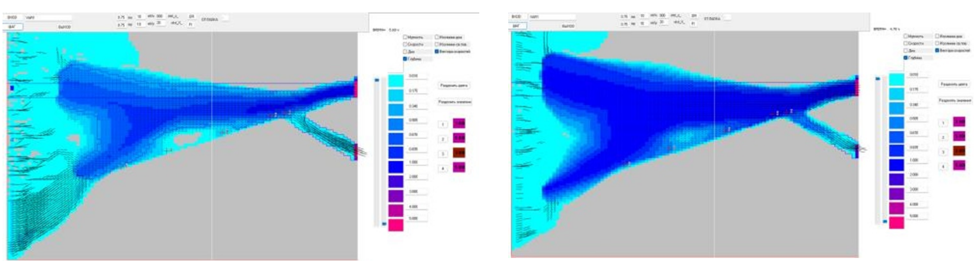


Fig. 4. Steps ΔX and ΔY were increased by 10% when branching from a damless water intake to the main canal

In the case of uneven types, the height of the bottom of the uneven type was not determined from topographic data, and the height of the bed of the uneven type was taken as if the cells were of the flat type. This allowed even and odd type centers to overlap. In the method used to determine the height of the channel, the initial cells of flat types near the water intake of the Karshi main canal were divided into four types, and the height of the channel in each of them was assumed to be equal to the height marks of the original flat type (Fig. 4).



In the river Q= 794 m^3/s. In the canal q=140 m^3/s

In the river Q= 1148 m^3/s In the canal q=144m^3/s

Fig. 5. Changes in depths in the area of the KMC water intake without a dam

In the course of the research, deformation processes in the damless water intake of KMC were studied for different flow rates and months. As a result of the research, the hydraulic parameters of the pioneer dig at Pulizindan were improved. In this case, the depth of the flow and the increase in the number of nanoparticles were substantiated by numerical studies. This increased the level of convenience of obtaining water from the Amu Darya to the Karshi Main Canal (Figure 5-6).

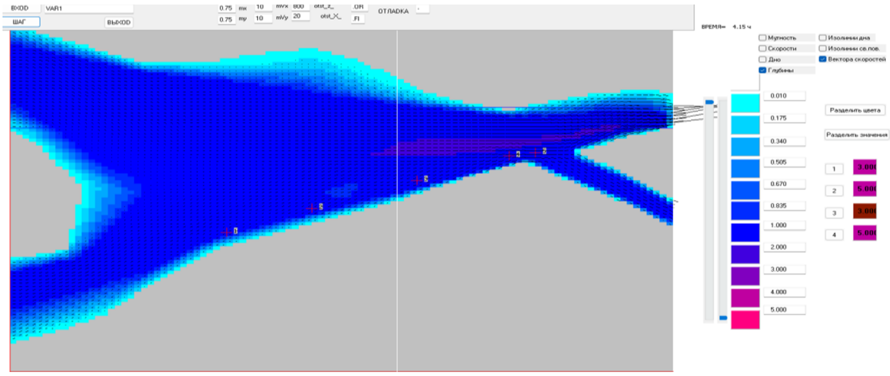
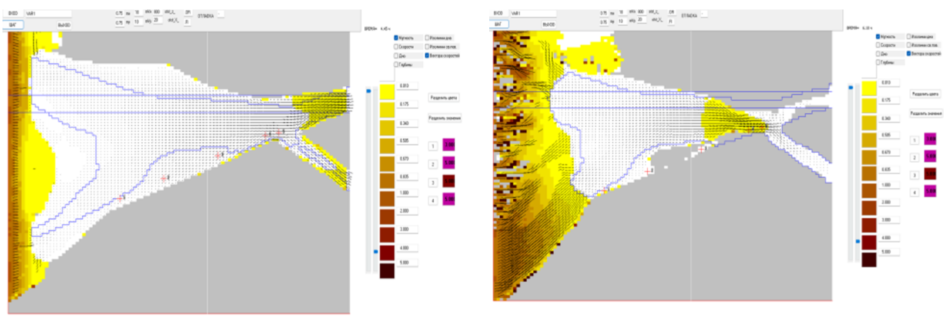


Fig. 6. Changes in depths at Q= 2163 m^3/s in the area of the KMC damless water intake, in channel 180m^3/s

The following figure 7 shows the effect of turbidity distribution in the direction of flow for different water consumption in the water intake canal of KMC. The results of numerical studies to determine the influence of sediments on the flow are presented.



In the river Q= 794 m^3/s, in the canal q=140 m^3/s

In the river Q= 2210 m^3/s, in the canal q=180 m^3/s.

Fig.7. Changes in turbidity in the area of a damless water intake of KMC

The optimal route and boundaries of the location of the pioneer ditch are assigned depending on the location of the main flow of the river relative to the point of the damless water intake. When the main stream departs from this point to the opposite bank of the river, the volume of channel adjustment works increases. It decreases when approaches the point. Timely organization of the production of channel adjustment works on the separation of the pioneer ditch and its systematic cleaning makes it possible to ensure guaranteed water intake during low water levels in the river with intensive wandering of the flow.

The length of the pioneer ditch should be determined based on the planned location of the channels relative to the water intake point. The depth of the development of the pit is determined from the conditions of silting (Fig. 8).

To determine the effective amount of sediments, when they, in accordance with their hydraulic size, settle to the bottom for a length l, the following formula is recommended

$$q_l = q_n \frac{l\bar{u}}{h\vartheta}$$

Where $q_n -$ total suspended sediment, kg; $\vartheta -$ $mean\ water\ flow\ velociy$, m/s; l – ditch length , m; $\bar{u}$ - hydraulic particle size, m/s; h - water depth before excavation,

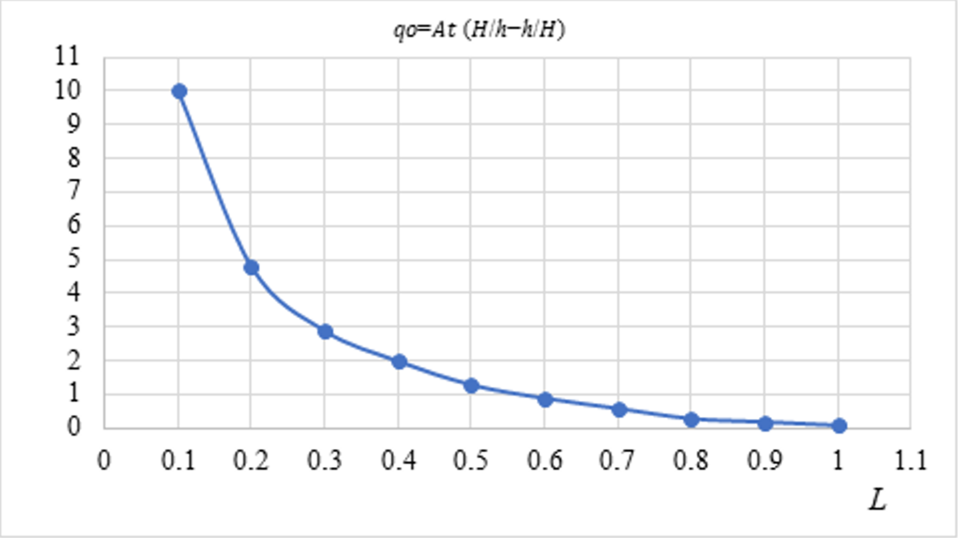


Fig. 8. Calculation scheme for explaining the physical meaning of the concept of "effective amount of sediment"

The total amount of sediments is determined by the formula

$$q_n = B \cdot H \cdot \vartheta \cdot \rho \cdot t$$

Where B - slot width, m; ρ - average sediment concentration, kg/m^3; t - time, s; H - water depth after development, m;

The amount of sediment deposited in the slot can be determined by the formula

$$q_o = kq_c \left(1 - \frac{\vartheta_p^2}{\vartheta_g^2}\right)$$

where k is a coefficient that takes into account the part of the effective amount of sediments involved in siltation; ϑ_g , ϑ_p is the flow velocity in the bottomhole and in the channel, m/s.

Establishing the depth of development from the condition of a given throughput determines the width of the ditch and the average flow velocity

$$B = \frac{Q}{H\vartheta} = \frac{nQ}{H^{\frac{5}{3}}\sqrt{i}}$$

$$\vartheta = \frac{H^{\frac{2}{3}}\sqrt{i}}{n}$$

where Q is the water flow in the tunnel; n - coefficient of roughness of the channel; i - the slope of the bottom or the water surface of the water in the tunnel.

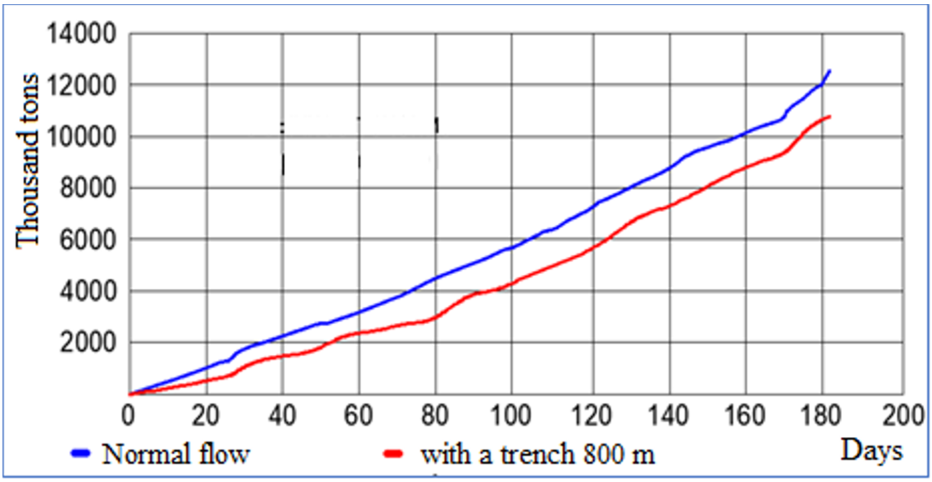


Fig. 9. Sediment inflow into the KMC during a normal flow with a ditch in the period January-June 2022.

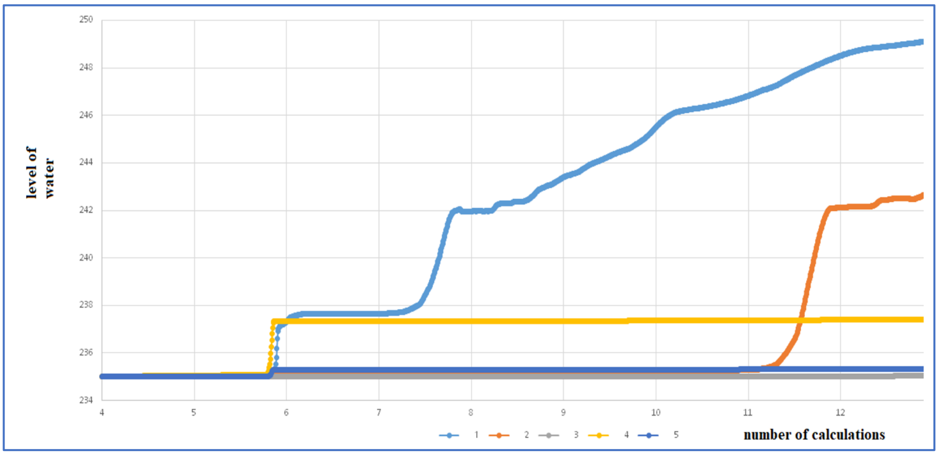


Fig. 10. Change in water level at points on the pioneer ditch

More difficulties with directing water through the water intake arise during the low-water period, when the water level in the river is low. A difficult situation was created with a damless water intake to the Karshi main canal (KMC), in the head part of which there is no regulating structure, and the operation mode of the first pumping station was developed for the conditions of a dam intake in the Kyzylayak alignment. Due to the change in the geopolitical situation in the region, the Kyzylayak dam was not built. Consequently, the water intake to the KMC headworks has become a very difficult task for hydraulic engineers.

In order to study the intensity of riverbed reformation in the area of damless water intake in KMC and develop measures to maintain sustainable water intake during the low-water period with the help of channel adjustment works, during 2014-2023, surveys of the riverbed were carried out 3 km above and 2 km below of the water intake point (Fig. 11).

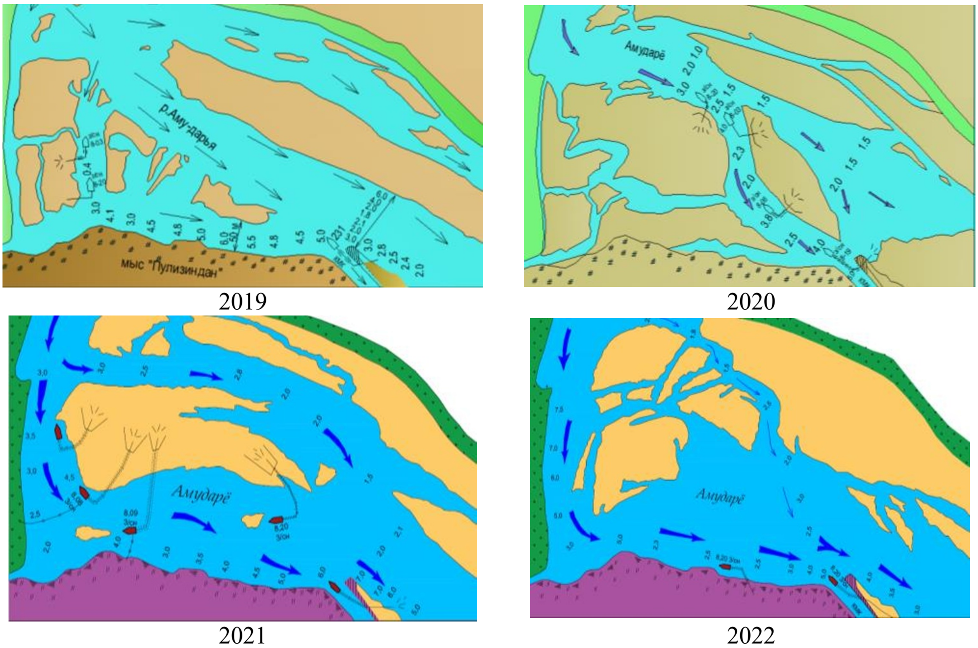


Fig. 11. Dynamics of planned deformations of the Amudarya River in the area of the KMC head works in 2019-2022

The results of the numerical studies have shown that it is possible to ensure guaranteed water intake by carrying out special engineering measures for water intake from the Amudarya to the canal. It is also necessary to develop a scheme for the placement of clearing operations at the pioneer ditch (Fig. 9-10). It is advisable to develop an operating mode depending on the type of dredgers. Because in order to improve the operating mode of the pioneer pit, to reduce the introduction of turbid liquids through the pit, it is necessary to carry out cleaning work even in low-water periods. It is known that this requires a high level of accuracy of the database obtained from the field studies. For this, a more precise level of research is needed in the future. The proposed method of water intake on meandering rivers refers to water intake facilities and contributes to the direction of the main flow by changing the structure of the channel flow. As a result, the required water consumption of the water intake and the head sections of the supply channels is ensured. At the same time, it should be noted that after the transition of the operation mode of the Nurek and Rogun reservoirs from irrigation to energy, it significantly affected the regime of liquid and solid runoff. This equally affected the channel process and the sediment regime in the riverbed and the head sections of water intakes into large irrigation canals. In the river beds in the area of damless water intakes, the flow wandering along a wide floodplain is often observed, forming a meandering channel. In this regard, we recommended measures for a new method of water intake on meandering rivers, which can be used in the channel of the river. Amudarya in the KMC water intake zone. The new method of water intake contributes to the improvement of water intake conditions with less capture of bottom sediments in the head sections of the supply channels.

4 Conclusions

1. The variants of dredging works considered in the paper with the formation of 800 m wide trenches and with a bottom mark of 236 m at a mark in natural conditions of 241÷242 m show that with a sufficient length, such trenches can be effective measures for intercepting sediments.

2. Numerical studies with different configurations and location of semi-dams in the channel on the left bank of the Amudarya River showed that such devices do not allow for a stable water intake into the canal in low water conditions. On the contrary, the construction of a threshold and semi-dams with overflow will not only reduce the amount of sediment entering the canal, but also improve the conditions for water intake even with minimal water flow into the Amudarya rivers.

3. In the course of numerical studies, depths, changes in water flow were determined, which were initially elements of flow in straight and curvilinear channels. As part of the numerical studies, the flow spreading conditions (vectors of medium-depth velocities) in specific time intervals and transitions in the water intake area were studied.

4. According to the recommended method, the route of the ditch should be marked based on the location of its head on a section of the river that is straight in plan with a diversion angle of not more than 300. The development of the ditch must be carried out during the low-water period (September - April), that is, during the period of the least drift of the channel by traction sediments. The length, width and depth of the pioneer ditch should be assigned depending on the planned location of the river channels relative to the point of damless water intake, the alluvial regime of the river and the technical parameters of the dredgers.

References

1. Bazarov, D. R., Norkulov, B. E., Kurbanov, A. I., Jamolov, F. N., & Jumabayeva, G. U. Improving methods of increasing reliability without dam water intake. In AIP Conference Proceedings (Vol. 2612, No. 1). AIP Publishing. (2023).
2. Bazarov, D., Krutov, A., Sahakian, A., Vokhidov, O., Raimov, K., & Raimova, I. Numerical models to forecast water quality. In AIP Conference Proceedings (Vol. 2612, No. 1, p. 020001). AIP Publishing LLC. (2023).
3. Burlachenko, A. V., Chernykh, O. N., Khanov, N. V., & Bazarov, D. R. Damping of increased turbulence beyond a deep and relatively short spillway basin. In AIP Conference Proceedings (Vol. 2612, No. 1). AIP Publishing. (2023).
4. Bazarov, D., Vatin, N., Norkulov, B., Vokhidov, O., & Raimova, I. Mathematical Model of Deformation of the River Channel in the Area of the Damless Water Intake. In Proceedings of MPCPE 2021: Selected Papers (pp. 1-15). Cham: Springer International Publishing. (2022).
5. Eshev, S., Linkevich, N., Rahimov, A., Khazratov, A., Mamatov, N., & Sharipov, E. Calculation of its dynamically stable cross-section in the steady motion of the channel flow. In AIP Conference Proceedings (Vol. 2612, No. 1, p. 050007). AIP Publishing LLC. (2023).
6. Norkulov, B. E., Nazaraliev, D. V., Kurbanov, A. I., Gayratov, S. S., & Shodiyev, B. (2023, March). Results of a study of severe deformation below the damless water intake section. In AIP Conference Proceedings (Vol. 2612, No. 1). AIP Publishing.
7. Eshev, S. S., Gayimnazarov, I. X., Latipov, S. A., Rahmatov, M. I., & Kholmamatov, I. K. Calculation of parameters of subsurface ridges in a steady flow of groundwater

channels. In AIP Conference Proceedings (Vol. 2612, No. 1). AIP Publishing. (2023).

8. Rakhmatullaev, S., Huneau, F., Celle-Jeanton, H., Le Coustumer, P., Motelica-Heino, M., & Bakiev, M. Water reservoirs, irrigation and sedimentation in Central Asia: a first-cut assessment for Uzbekistan. Environmental earth sciences, 68, 985-998. (2013).
9. Babajanova, I., Bazarov, O., Eshev, S., Babajanov, Y., & Isakov, A. Control of flow in the side outflow channel. In E3S Web of Conferences (Vol. 365, p. 03038). (2023).
10. Haghani, S., Leroy, S. A., Khdir, S., Kabiri, K., Naderi Beni, A., & Lahijani, H. A. K. An early 'Little Ice Age'brackish water invasion along the south coast of the Caspian Sea (sediment of Langarud wetland) and its wider impacts on environment and people. The Holocene, 26(1), 3-16. (2016).
11. Mergili, M., Müller, J. P., & Schneider, J. F. Spatio-temporal development of high-mountain lakes in the headwaters of the Amu Darya River (Central Asia). Global and Planetary Change, 107, 13-24. (2013).
12. Atykbekova, F., Jumaboeva, G., Gayur, A., Ishankulov, Z., & Jumanov, O. Operation damless intake of the Amudarya river (Central Asia). In IOP Conference Series: Materials Science and Engineering (Vol. 883, No. 1, p. 012003). (2020).
13. Uralov, B., Berdiev, S., Rakhmatov, M., Vokhidov, O., Maksudova, L., & Raimova, I. Theoretical models and dependences for calculating intensity of hydroabrasive wear of pump working parts. In E3S Web of Conferences (Vol. 365, p. 03019). (2023).
14. Makhmudov, I., Sadiev, U., & Rustamov, S. Basic conditions for determining the hydraulic resistance to friction in a pipeline when a mixture of water and suspended sediments moves. In AIP Conference Proceedings (Vol. 2432, p. 040005). (2022).
15. Schlüter, M., & Herrfahrdt-Pähle, E. Exploring resilience and transformability of a river basin in the face of socioeconomic and ecological crisis: an example from the Amudarya River basin, central Asia. Ecology and Society, 16(1). (2011).
16. Mamajanov, M., Uralov, B. R., Artikbekova, F. K., Vokhidov, O. F., Nazarov, B. U., & Rayimova, I. Influence of cavitation-hydro abrasive wear and wear of vane hydraulic machines on the hydraulic resistance of the suction line of pumping units. In AIP Conference Proceedings (Vol. 2612, No. 1). (2023).
17. Uralov, B., Li, M., Qalqonov, E., Ishankulov, Z., Akhmadi, M., & Maksudova, L. Hydraulic resistances experimental and field studies of supply canals and pumping stations structures. In E3S Web of Conferences (Vol. 264, p. 03075). (2021).
18. Crosa, G., Froebrich, J., Nikolayenko, V., Stefani, F., Galli, P., & Calamari, D. (2006). Spatial and seasonal variations in the water quality of the Amu Darya River (Central Asia). Water Research, 40(11), 2237-2245.
19. Jiang, L., Jiapaer, G., Bao, A., Li, Y., Guo, H., Zheng, G., De Maeyer, P. Assessing land degradation and quantifying its drivers in the Amudarya River delta. Ecological Indicators, 107, 105595. (2019).
20. Bazarov, D., Norkulov, B., Vokhidov, O., Artikbekova, F., Shodiev, B., & Raimova, I. Regulation of the flow in the area of the damless water intake. In E3S Web of Conferences (Vol. 263, p. 02036) (2021).