Improvement of damless water intake methods taking into account the hydraulic and sediment regimes of the river

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Abstract. This article examines the movement of suspended and bottom sediments in a stream, which is considered as a complex problem in the process of water intake from rivers and canals for the needs of energy or the national economy with damless water intakes. The article presents the results of analyzes of experimental and field studies conducted 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 field studies for the proposed structures is the main goal of research work. In the course of experimental studies, measurements of depth, flow and, on this basis, changes in water flow were made, which were initially elements of flow in straight and curved channels.

1 Introduction

One of the most important problems in the world is forecasting the impact of many dam and non-dam water intake structures and other hydraulic structures on flow dynamics and hydrodynamic characteristics. The riverbed processes show that the construction of hydrotechnical and hydropower facilities in the riverbeds will lead to a sharp change in the runoff dynamics. The development of processes in channels with damless water intake is especially important to prevent a negative impact on the reliability and operation of the structure [1-4].

The world pays special attention to conducting targeted research work on the occurrence of channel processes with damless water intake, their negative impact on the operation mode, determining the intensity, direction and duration of channel processes in river channels, including their calculation, aimed at developing guaranteed methods water intake. In this regard, one of the important tasks is the development of measures to prevent

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riverbed processes, including the provision of guaranteed water supply to water intake canals in case of damless water intake [5-7].

At present, large-scale scientific research is being carried out in the republic aimed at ensuring the supply of guaranteed volumes of water with the least sediment in case of damless water intake, especially when water is taken into irrigation canals using pumping stations. In the economic policy of the Republic of Uzbekistan, providing the country with food, providing the population and the economic sector with guaranteed water resources, the construction and reconstruction of hydrotechnical and reclamation networks are considered paramount tasks, the solution of which is one of the most important tasks of the economy in front of the water management and reclamation sectors and hydropower [8-13].

In this regard, it is necessary to prevent flood processes in the water intakes of damless, improve new and existing hydraulic engineering schemes, taking into account the distribution of flow when supplying feed channels to pumping stations with the required volume of water, take various design solutions to improve the operating mode of the head structure, in addition to the necessary measures to water intake facilities, it is necessary to select and recommend for practice the channels of water intake channels that pass the least amount of sediment [14-16].

It is known that the main issue during the intake of the main task is to supply the consumer with a guaranteed volume of water based on a given hydrograph. In the process of water intake, changes in the hydrodynamic characteristics of the water flow occur. These changes, in turn, affect the morphometry of the riverbed. Establishing the regularities of the relationship between water discharge and bottom sediments made it possible to determine the nature of channel processes in the area of construction of a damless water intake [17-19].

In the Amu Darya, channel processes occur in the form of erosion of the banks and washing out of the channel, the emergence of the deigish process, and the migration of deposited sediments. At present, various design solutions for the design and construction of damless water intake structures have been tested in practice and recommendations for their application have been given. Structures with such structural elements in a damless water intake changed the dynamics of the hydraulic parameters of the water flow, making it possible to improve the flow in the impact zone of the structure and reduce the flow of sediment into the canal.

To improve the conditions for water intake without dams, it is necessary to develop structures that lead to the head structure with the least amount of bottom sediments and determine the hydraulic parameters of the flow [20, 21].

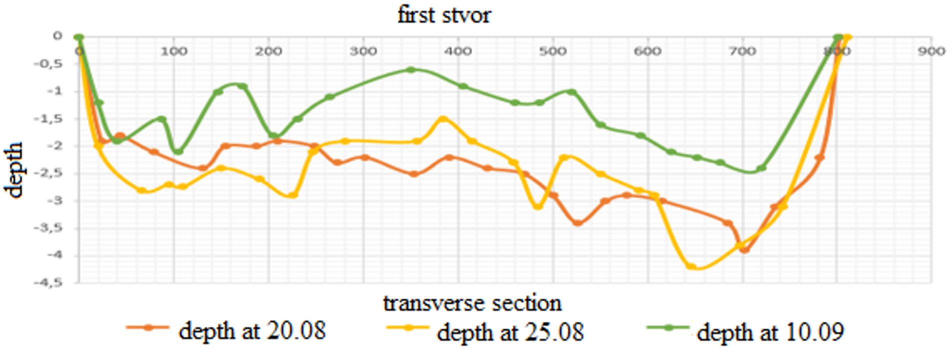
2 Methods

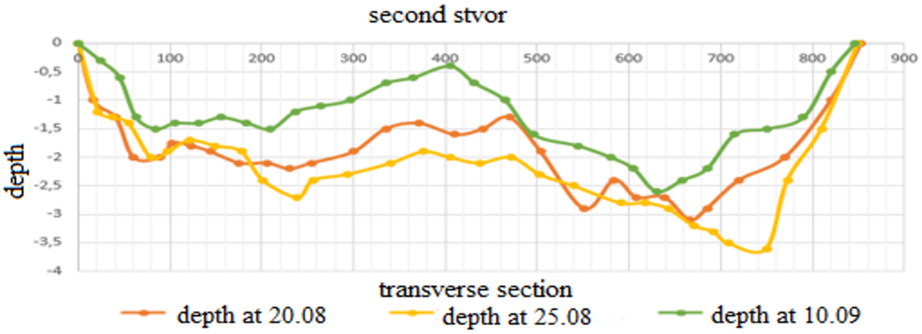
Studying the results of field and experimental studies on the section of the Amudarya River in the area of the damless water intake in the Amu-Bukhara Machine Canal, assessment of the state of the river bed. Amudarya in the zone of water intake and increase the reliability of damless water intake is the research method of this work.

3 Results and discussions

In the conditions of the Amudarya, with a large amount of water withdrawn for irrigation and intensive wandering of the river flow on a wide floodplain, ensuring a guaranteed damless water intake requires the implementation of channel adjustment work to separate the pioneer pit and its systematic cleaning from entry during the operation period.

The optimal route and boundaries of the location of the pioneer pit 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, and decreases as it approaches. Timely organization of the production of channel adjustment work on the separation of the pioneer tunnel 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.





Over the years of operation, the water flow through the Amu-Bukhara machine canal has increased several times and currently reaches 400 m^3/s. As a result of the reconstruction of the head structure and the ABMC canal with the widespread use of hydromechanization devices, it became possible to pass such water flows. As the volume of water intake increased, the volume of sediments coming with water also increased. A large amount of suspended and bottom sediments coming from the river will settle in the canal bed, reducing the clear area and the throughput of the canal.

To maintain the required culvert capacity of the canal, the repair service has to use dredgers at great expense to carry out timely treatment and channel control work along the length of the water intake canals from the entrance to the head structure of the ABMC.

The length of water intake canals varies significantly throughout the year and from year to year, depending on the water content of the year and the location of the fairway of the river.

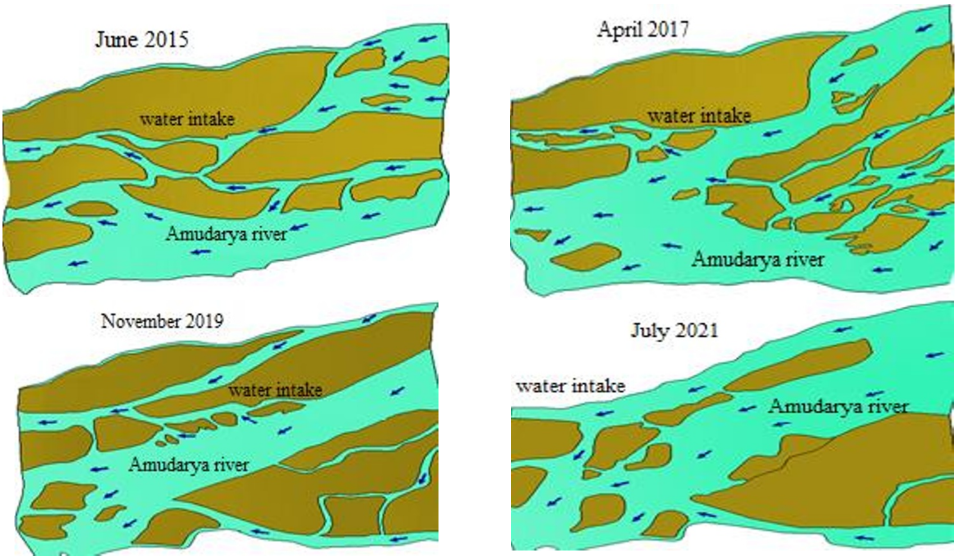


Fig. 1. Channel deformation processes in the area of damless water intake from the Amudarya to the ABMC (2015-2021)

Sand, soil and gravel (1) in their natural state were selected to conduct experimental studies to determine channel processes in the model of a damless water intake. The water supply to the channel was maintained using a pressure tank (2). The control of water supply from the pressure tank through the sump (3) into holes with a diameter of 10 cm was carried out. Research work was carried out on curvilinear (5) and straight (6) channels. The boundary control structure (7), designed to control the flow of water in curvilinear and straight channels, was built by modeling the actual dimensions of a damless water intake channel (8). In the damless water intake model, water flows from the downstream (9) to the discharge channel (11) through the lock (10). The collected water was discharged back to the water source through the outlet channel (12).

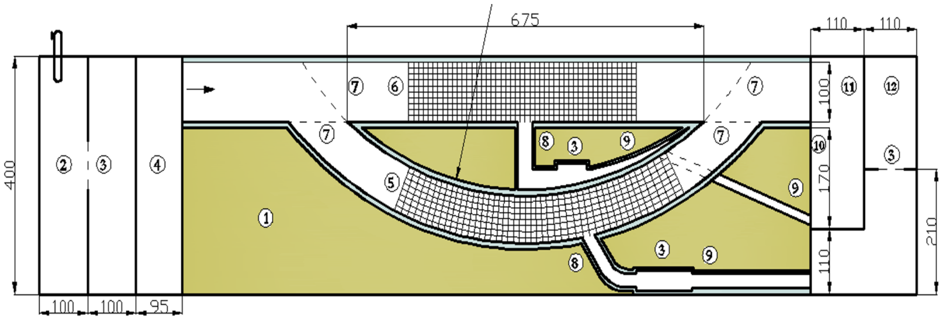


Fig. 2. Model of a damless water intake for the experiment: 1 soil, 2 pressure tank, 3 settling tank, 4 wall, 5 curved channel, 6 straight channel, 7 curved and straight channel boundaries, 8 inlet part of the channel, 9 bottom, 10 lock (gate), 11 discharge, 12 drainage system.

In the initial part of the canal, sediments were distributed mechanically, which allowed the model to reproduce the volumetric distribution and concentration of sediments evenly along the entire length of the channel. The distribution of the amount of sediment sorted with a sieve is analyzed.

Experimental studies were carried out in the laboratory "Hydraulic structures" NRU "TIIAME". In the course of experimental studies, a damless water intake of ABMC was taken as an object. In the course of experimental studies, the following flow parameters were determined:

- water consumption;
- flow rate;
- water level marks.

Table 1. Limits of Reynolds and Froude numbers

A series of experiments	**Type of channel**	Flow rate		Flow depth	$\mathrm{Re}=\frac{\vartheta 4R}{\nu}$		$Fr=\frac{\vartheta^2}{gh}$	
		$\vartheta_{\min},(m/s)$	$\vartheta_{\max},(m/s)$	$h,(m)$	$\mathrm{Re}_{\min}$	$\mathrm{Re}_{\max}$	$Fr_{\min}$	$Fr_{\max}$
1	smooth	0.375	0.48	0.03	41447	53051	0.47	0.78
2	smooth	0.385	0.49	0.04	55446	70562	0.37	0.61
3	smooth	0.39	0.512	0.05	68647	90122	0.31	0.53
4	smooth	0.4	0.52	0.06	82652	107448	0.27	0.45
5	unpaved	0.38	0.57	0.03	41999	62998	0.49	1.11
6	unpaved	0.39	0.59	0.04	56166	84967	0.38	0.88
7	unpaved	0.4	0.6	0.05	70408	105611	0.32	0.73
8	unpaved	0.43	0.61	0.06	88851	126044	0.31	0.63

In the course of experimental studies, measurements of depth, flow and, on this basis, changes in water flow were made, which were initially elements of flow in straight and curved channels. During the study, changes in the depth and speed of the current were observed in 1 section, located at a distance of 200 cm from the water intake on both channels. Based on the data of measurements of depth and discharge, a graph of the change in water discharge by depth in section 1 was constructed (Fig. 3).

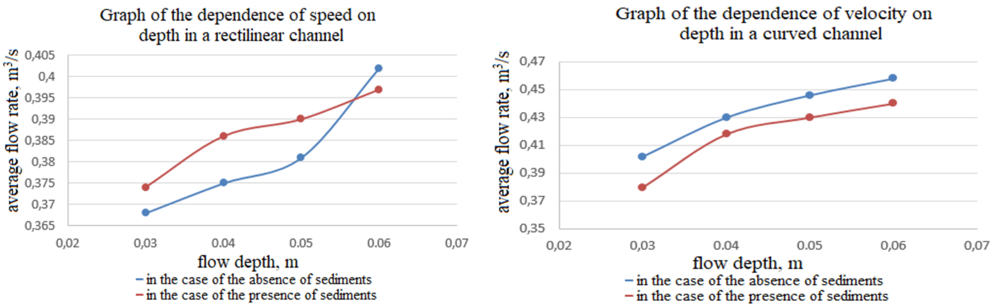


Fig.3. Rate and depth changes during experimental studies

In experimental studies, the change in water flow was carried out through a control structure up to Q=9-25 l/s of water flow, up to v=0.38-0.51 m/s of water velocity and up to 3-6 cm of flow depth. As part of the study, water consumption was measured using a GR-100 hydrometric micro-rotator.

The water supplied to the canal passed through the Chippoletti trapezoidal water meter. The water flow in this type of water meter was determined by the following formula.

$$Q=1.86bH^{3/2} \qquad (7)\cdot$$

Ensuring the flow of water necessary for the survey is made through the regulating structure.

Experimental studies were carried out at different depths, taking into account the boundary conditions, in a flow with moving resistance, represented by sand particles of different fractional composition, with a smooth bottom, outlined by special square cells,

The results of the experimental study were presented in the form of a diagram of the average values of the longitudinal velocity component, standard deviations of the longitudinal, vertical and transverse velocity components, represented by depth distribution graphs.

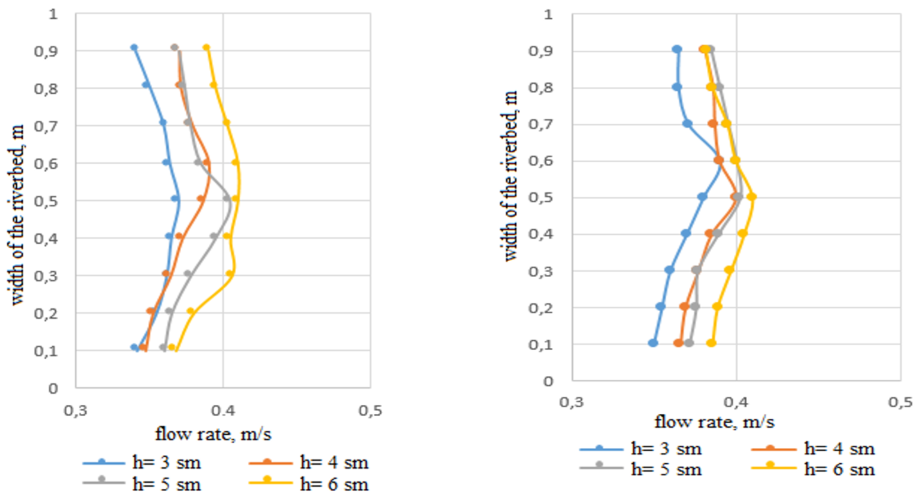


Fig.4. Flow rate in the absence of sediments in the 1st and 2nd sections

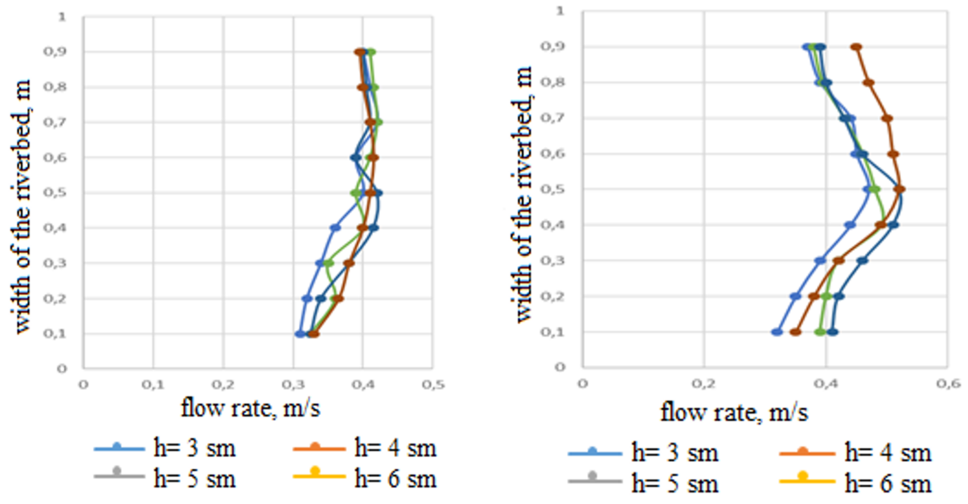


Fig.5. Flow rate in the presence of sediments in the 1st and 2nd sections

The values of flow velocities determined in the mixed state of bottom sediments were compared with the initial case in the absence of bottom sediments.

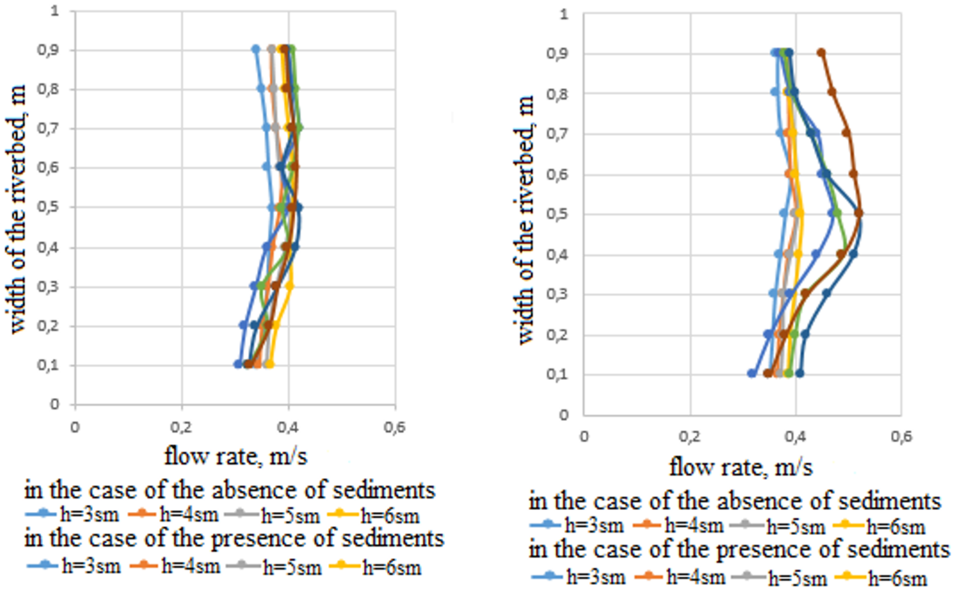


Fig. 6. Flow rate in the presence and absence of sediments in the 1st and 2nd sections

The comparison results show that in the presence of bottom m3/s sediments, the flow velocity changes under the action of hydraulic resistance. The maximum flow velocity was 0.42 m/s in the first section and 0.47 m/s in the second section at a depth of 3 cm with mixing of bottom sediments. Changes in the flow rate were made in 9 verticals along the entire width of the channel. Mixing of bottom sediments into a water jet was carried out using a dispenser. A mixture of light natural gravel and sand was also added. Initially, the sand mixture was laid in a layer 1...2 cm high and 3.5 m long. In the course of experimental studies, channel processes in the territory were studied to determine the water intake boundary. Based on these data, the dynamics of changes in the hydraulic parameters of the channel over time at different water discharges was studied.

As a result of our research, the direction of the trench should be planned at an angle of no more than 300, based on the location of its head on the right side of the river.

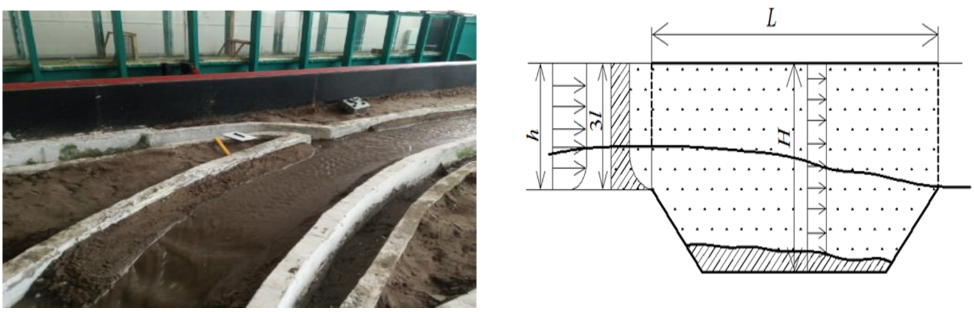


Fig. 7. Experimental studies on the development of a ditch

Experimental studies show that it is necessary to carry out the digging during the low-water period, that is, during the period of the least drift of the channel by traction sediments. The length, width and depth of the pioneer tunnel 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

The length of the pioneer tunnel should be determined based on the planned location of the channels relative to the water intake point. The depth of the excavation of the pit is determined from the conditions of silting (Fig. 4).

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

$$q_l = q_n \frac{l\bar{u}}{h\vartheta} \tag{1}$$

Where is $q_n -$ the total amount of suspended sediment, kg; $\vartheta -$ average water flow velocity, m/s; l - slot length, m; ū - hydraulic particle size, m/s; h - water depth before excavation,

The total amount of sediments is determined by the formula

$$q_n = B \cdot H \cdot \vartheta \cdot \rho \cdot t \tag{2}$$

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

$$q_o = kq_c\left(1 - \frac{\vartheta_p^2}{\vartheta_g^2}\right) \tag{3}$$

where k is a coefficient that takes into account the part of the effective amount of sediments involved in silting; ϑ_g ,$\vartheta_p -$ flow velocities in the bottom and in the channel, m / s. From the flow continuity equation

$$\vartheta_p \cdot h = \vartheta_g \cdot H \tag{4}$$

We have

$$\frac{\vartheta_g}{\vartheta_p} = \frac{h}{H} \tag{5}$$

Hence, substituting (1) into (3), taking into account (5), we obtain

$$q_o = kq\frac{l\bar{u}}{h\vartheta} \cdot \frac{H^2 - h^2}{H^2} \tag{6}$$

Taking into account (2), we reduce equation (6) to the form

$$q_o = kq\bar{u}Blt\left(\frac{H}{h} - \frac{h}{H}\right) \tag{7}$$

Denoting $kq\bar{u}Blt = A_t$, we get

$$q_o = A_t\left(\frac{H}{h} - \frac{h}{H}\right) \tag{8}$$

For the same value A_t, the value $f\left(\frac{H}{h} - \frac{h}{H}\right)$ is determined by a hyperbola (Fig. 4). The value of k in equation (6) was obtained by Indian researchers during the work on deepening the bottom of canals in the river of ports in India and is equal to 0.29. Formula (8) can be used when choosing the depth (H) of development, especially in places where there is a normal supply of sand fractions.

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

$$B = \frac{Q}{H\vartheta} = \frac{nQ}{H^{\frac{5}{3}}\sqrt{i}} \qquad (9)$$

$$\vartheta = \frac{H^{\frac{2}{3}}\sqrt{i}}{n} \qquad (10)$$

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.

The development of the pioneer trench should be carried out during the low water period (September - April), i.e. during the period when there is a minimum amount of moving sediment in the channel. The length, width and depth of the pioneer trench should be determined depending on the planned location of the channels, the alluvial regime of the river, relative to the dam intake point.

The total amount of deposits is recommended to be determined by the following formula

$$q_n = B \cdot H \cdot \vartheta \cdot \rho \cdot t \qquad (13)$$

where B is the width of the pioneer trench, m; ρ - weighted average concentration of sediments, kg/m3; *t* - time, s; *H* is the water depth after the development of the process, m;

Determining the depth of development according to a given permeability condition determines the width of the pioneer trench and the average flow velocity

$$B = \frac{Q}{H\vartheta} = \frac{nQ}{H^{\frac{5}{3}}\sqrt{i}} \qquad (14)$$

$$\vartheta = \frac{H^{\frac{2}{3}}\sqrt{i}}{n} \qquad (15)$$

where Q- water consumption in the pioneer trench, m^3/s; n - channel roughness coefficient; *i* - slope of the bottom or water surface in the pioneer trench.

Difficulties in obtaining water from the Amu Darya to the ABMC arise due to rapid silting and settling of particles in the head part of the canal. Depending on the water content of the year, a runoff of up to 5 kg/m^3 of sediment per year enters the inlet of the canal. Annual deposition ranges from 8 to 12 million tons.

Based on the results of field studies in 2014-2020. and materials of previous years on the study of deformations of the main riverbed in the area of a damless water intake, the optimal mode of operation of the head water intake during low water and drought was determined.

Under the conditions of the Amu Darya, a large amount of water is taken for irrigation, and the rapid flow of the river on wide plains, which ensures guaranteed water intake without dams, requires the channel to be adjusted for digging a pioneer trench and its systematic cleaning. The annual volume of such works is 30...40% of the total head water intake.

4 Conclusions

1. Since the beginning of operation in the area of the main structure of the ABMC damless water intake, the axis of the flow has been variable, and the main fairway has always been on the left bank side. During the low water period, the Amudarya River flows in this area mainly along one channel.

2. Analysis of the studies carried out in the catchment area in the ABMC from the Amudarya shows that the intensity of the shore washout process was observed up to 2 m/h, and the washout circumference was 10-60 m, the depth was 5-10 m. Taking into account the distribution of runoff in the area of the water intake facility the riverbed, a methodology for assessing the main hydrodynamic parameters of the flow and channel processes has been developed.

3. As a result of field studies, the dynamics of the change in depth showed that when the water level rises, the level of the bottom of the channel increases, and decreases during the low water period. A technique has been developed for determining the stages and periods of the formation of channel processes in the area of a damless water intake from a river, taking into account the hydrological regime of the river for the entire period of the season.

4. As a result of theoretical and experimental studies, structural elements of a pioneer trench with a width of B = 50 m, a length of L = 300 m and 750 m, and a depth of H = 5 m were developed, which make it possible to reduce the influx of silt deposits by 20% into the channel diverting runoff from the Amu Darya to ABMC.

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