Operational efficiency of water damless intake

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Abstract. An improved hydraulic method for increasing the efficiency of operation of a damless water intake is presented. Physical picture of the movement of bottom and surface sediments during flow division in the damless water intake ABMCh (Amu-Bukhara machine channel). Analysis of the distribution of sediment along the channel of the channel showed that clay particles of suspended sediment <0.005 mm increase from the inlet to the main structure of the ABMCh from 15% to 36%. Dusty particles of suspended sediment d = 0.05 also increase from inlet to G.P. ABMCh from 38% to 66%. Sandy sediment particles d = 0.05 to 0.25 mm, on the contrary, decrease from 3% to 71%, and sediment particles d> 0.25 mm decrease from 1.30 to 0.15%. It is substantiated that the angle of the flow outlet to a greater extent influenced the formation of vortex zones at the entrance to the outlet. The size and intensity of the vortices at the inlet, in turn, determined the pressure loss, as well as the amount of sediment deposited at the water inlet, by the amount of sludge entering the outlet. The analysis of the experiments showed that the optimal threshold angle to the shore is β = 30°, 45° 60°.; It is recommended that when setting the water intake mode it is necessary to take into account the fact that the reduction of the discharge angle to reduce the pressure loss at the inlet to the water intake, the latter is more intense carried by precipitating suspensions. It has been established that intense deformations of the Amudarya river channel occur in the area of the ABMCh water intake: Due to dredging of the channel by the dredgers, the pulp is thrown into the river channel, it turns out, as it were, storage of sediment on the right bank. This, in turn, leads to a narrowing of the river channel and siltation of the supply channel, which contributes to the movement of the channel to the left bank and complicates the intake from the river into the channel. Taking into account the complexity of the processes occurring during the division of the flow, it is necessary to consider the qualitative and quantitative aspects of this phenomenon ‘in pure form’, without affecting the moving flow of various anti-ballistic devices. To improve the conditions of water intake and the quality of the incoming stream, an improved scheme with new structural elements is proposed.

1. Introduction
Due to the intensive growth in the volume of water use for agricultural needs, there is a tendency to develop the construction or reconstruction of existing water intake structures. One of the methods of water withdrawal from rivers is the damless water intake, which has significant drawbacks. One of them is the lack of the possibility of guaranteed selection of the volume of water and ensuring the flow of water into the head structure with the lowest turbidity. The problems of protecting the head...
structures of the supply channels of pumping stations during damless water intake from the
entrainment of channel sediments, mainly those from rivers, the channel of which passes on easily
eroded soils transporting a large amount of sediment, is not always successfully solved [1-4]. To date
based on the well-known theoretical studies of many researchers using data from extensive laboratory
and field studies S.T. Altunin, N.F. Danelia, R.J. Julaev, E.A.Zamarin, A.S. Abrazovskiy, M.V.
Potapov, A.M. Mukhamedov, R. Urkinbaev, D.R. Bazarov, H.R. Khdamamov. Others have introduced
a large number of layout schemes of the head structures of damless water intakes with different
operational characteristics into the practice of hydraulic engineering construction [5-8].

Despite the abundance of work on the issue under study, it has not yet been possible to completely
solve the problem of controlling sediment in the head structures of machine channels with damless
water intake. This circumstance is explained, on the one hand, by the complexity and multifactorial
nature of channel processes in time and space, and, on the other hand, by the lack of unambiguity in
the scientific literature on recommendations for the construction and operation of various types of anti-
bearing structural elements as part of the head structures of machine channels of damless water intakes
[9-12]. Since the present scientific work is devoted to solving the second of the above problems, its
relevance is beyond doubt. The development of a method for reducing the inflow of bottom sediments
into the head structure of the intake canal is the main goal of this work.

2. Methods
An analysis of the hydraulic and alluvial regimes of the water flow of one of the muddy water courses
— the Amudarya River — and based on these results, develop calculation justifications for the
structural elements of the head structure, is accepted as a research method for this work.

3. Results and discussion
For damless water intakes, a part of the discharge is separated at household levels of the river, in
connection with which, many researchers have identified here three hydraulic modes of interaction
between the channel stream and the water intake: division mode, water exchange mode and
transitional mode. The division mode is characterized by significant deformations of the river flow
cau sed by relatively large water withdrawals. In the case of passage of flood expenses along the river,
due to the small percentage of water separation, no deformations are observed in the channel stream.
In this case, an intensive water exchange mode is established between the drainage system and the
river flow, as a result of which a certain amount of liquid is transferred to the discharge. This mode is
called the ‘water exchange mode. Some intermediate hydraulic conditions for the interaction of the
channel flow with the drainage system are characteristic of the transitional mode [12-14].

The study of the flow division mode, the interaction of the channel stream with the drainage can be
attributed to the most ancient problems of hydraulic engineering [13, 5, and 15]. At first glance, the
task of separating part of the flow from the main channel and diverting it to the side seems rather
trivial. This assumption is easily refuted by the very number of laboratory and field studies carried out
by domestic and foreign scientists and engineers on this issue, and by the very different and sometimes
conflicting results of experimental studies and the calculated dependences obtained on their basis [16].

In the present work, we consider the flow division mode in the Amudarya River where the damless
intake was located; the damless intake in the Amu-Bukhara machine channel (ABMCh) was located.
The Amu-Bukhara machine channel is the main source of irrigation for the Bukhara and Navoi regions
of the Republic of Uzbekistan of the Farab and Libab region of Turkmenistan.

Over the years of operation, the water flow rates passed through the canal have increased several
times and currently reach up to 400 m³/s. The passage of such a large flow rate of water became
possible due to the multiple reconstruction of the head structure of the ABMCh and the canal with the
widespread use of hydromechanical means. Along with an increase in the volume of water intake, the
volumes of sediment flowing with water increased. A large amount of suspended and entrained
sediment coming from the river, deposited in the channel bed, led to a decrease in the live section and
channel capacity [17].
To maintain the necessary throughput of the canal, the operating service is forced to rent a large number of dredgers of various capacities and types for the timely implementation of treatment and channel adjustment works along the length of the intake channels from the entrance to the main structure of the ABMCh.

The length of the water intake canals, depending on the water content of the year and the location of the channel of the river, varies greatly during the year, from year to year. It is not uncommon for the length of water intake channels during the low water period to increase from hundreds of meters to several kilometers.

Continuous treatment works carried out from the very beginning of the intake into the Amu-Bukhara canal led to the formation of large dumps of sediment along the left bank of channel №1, located on the right bank of the Amudarya river, as well as to a displacement of the flow from the water intake point and the departure of the river fairway to side of the left coast.

Intensive reorganization of the channel at the water intake point and the complexity of sediment deposition along the length of the water intake channels determine the rational use of the existing dredger fleet in organizing sewage treatment works.

Based on the use of research materials, an analysis was made of the intake and sediment deposition into the intake channel №1 of ABMCh.

The measurement data show that in the area from the entrance to the intake channel No. 1 to the head sedimentation tank, there is a sharp decrease in turbidity and an increase in the degree of clarification of the flow. There is also a decrease in the flow rate, and a sharper decrease occurs in the initial sections of the channel. The decrease in flow velocity, turbidity and clarification of the stream along the length of the intake channels mainly depend on the level of discharge, the turbidity of the river and the magnitude of the water discharge passing through ABMCh (figure 1).

![Figure 1. Values of suspended sediment along the length of the intake channel № 1 ABMCh](image)

The changes in the fractional composition of suspended sediment along the length of the intake channel №1, in the context of the main fractions are given in table 1.

As can be seen from this table, clay particles of suspended sediment <0.005 mm increase from the inlet alignment to the main structure of ABMCh from 15% to 36%. Dusty particles of suspended sediment d=0.05 also increase from inlet to ABMCh from 38% to 66%. Sandy sediment particles d = 0.05 to 0.25 mm, on the contrary, decrease from 3% to 71%, and sediment particles d> 0.25 mm decrease from 1.30 to 0.15%.
Table 1. The change in the fractional composition of suspended sediment along the length of the intake channel

| Number observation | Water Sampling Site | Content in% |
|--------------------|---------------------|-------------|
|                    |                    | Clay<0.005 mm | Dusty 0.005-0.05 mm | Sand 0.05-0.25 mm | >0.25 mm |
| Entrance PC 105    |                     | 21,57        | 41,20               | 34,52             | 1,31     |
| 1                  | PC 65               | 24,30        | 50,00               | 25,45             | 0,35     |
|                    | PC 25               | 33,06        | 51,43               | 15,33             | 0,18     |
|                    | PC 10               | 30,41        | 66,00               | 3,44              | 0,15     |
| Entrance PC 105    |                     | 14,8         | 39,60               | 38,84             | 6,84     |
| 2                  | PC 65               | 22,36        | 43,78               | 27,56             | 0,30     |
|                    | PC 25               | 29,34        | 63,34               | 8,14              | 0,18     |
|                    | PC 10               | 36,04        | 41,75               | 21,82             | 0,39     |
| Entrance PC 105    |                     | 18,54        | 38,72               | 42,26             | 0,48     |
| 3                  | PC 65               | 30,40        | 65,80               | 2,92              | 0,88     |
|                    | PC 25               | 2,87         | 5,62                | 70,90             | 0,51     |
|                    | PC 10               | 32,00        | 64,29               | 3,11              | 0,60     |

Thus, analysis of suspended sediment shows that the content of particles of clay sediment fractions tends to increase, while the content of sand sediment decreases in the direction from the entrance to head structure ABMCH.

Figure 2. Transformation of bottom and surface current lines during flow dividing in ABMCh damless intake

According to the classical ideas and the results of field studies, we can state the fact that the transformation of bottom and surface current lines when dividing the flow in the damless water intake ABMCh (Amu-Bukhara machine channel), to the section 1-1 bottom (solid lines) and surface (dashed) current lines do not change their planned geometry relative to the dynamic axis of the main stream. In section 1-2, their noticeable curvature toward the lateral branch begins, and the curvature of the bottom current lines begins somewhat earlier than the surface ones.
In section 2-2, the bottom and surface current lines acquire a pronounced bend in the direction of the outlet channel. The regularity noted above remains - the bottom lines of the currents have a large curvature and are deformed at a much wider width of the main channel than the surface ones.
In section 3-3, there is a rather sharp turn of the surface and bottom current lines into the inlet of the outlet channel. Depending on the magnitude of the selected flow rate, the bottom and surface lines of the fluid currents can go beyond the boundary of the section 3-3, and then turn abruptly to the
branch. The bottom current lines in this case go beyond the boundary of the section 3-3 by a large amount, compared with the surface ones.

In section 4-4, in the input part of the outlet channel, the surface current lines are pressed against the lower edge of the water intake opening and then deviate to the opposite side of the outlet. Bottom lines of currents sharply deviate from the bottom edge of the intake opening in the direction of the top side (figure 2).

At the top edge of the water inlet, the surface current lines, deviating significantly, go far to the opposite side of the branch. Here, the flow is squeezed from the upper ribs and sides of the water intake, the intensity of which largely depends on the amount of flow taken. For small water intake coefficients $\alpha$, the squeezing zone of the liquid jets can occupy more than half the width of the water intake opening. Bottom lines of currents deviate from the upper edge of the water intake, albeit by a smaller, but still significant amount. The described picture explains the formation of a whirlpool zone at the upper edge of the inlet, covering up to 40 ... 50% of the width of the latter. Therefore, eroded channels are characterized by washing of the shore and bottom, at the lower edge of the inlet of the outlet channel and vice versa, the formation of a shallow near the upper side of the entrance.

Section 5-5 is characterized by erosion in the upper side of the discharge channel by surface currents and deposition of transported (bottom) sediments transported by the bottom layers of the liquid on the opposite coast.

In section 6-6 in the direction of the branch, the so-called ‘neutral zone’ is formed. Here, according to the descriptive picture of previous researchers, fluid particles are in a state of unstable equilibrium and, depending on the pulsation of velocities in the flow, can either be entrapped or move down the main channel.

For the shore, from which water is drained, over section 6-6, erosion is characteristic under the influence of surface fluid currents. Near the opposite shore, in turn, a whirlpool is formed - the ‘lull zone’, where intensively deposited sediments form a sandbank.

The described picture of the flow dividing phenomenon is fully confirmed by the experience of operating damless water intake structures with an unprotected entrance to the branch, for earthen outlet channels, which are characterized by meandering and displacement of the channel head downstream [18].

To study the dynamic characteristics of the morphology of the Amudarya river channel in the area of water intake at the ABMCh and the head structure (Table 2), the materials of field observations of the studied object were used [19].

Table 2. Definitions of bottom and surface water withdrawal boundaries at ABMCh

| $q_r$ | $Q_r$ | $b_m$ | $q_s$ | $Q_s$ | $b_p$ | $k$ | $p_p$ | $b_3$ |
|------|------|------|------|------|------|-----|------|------|
| 10,00| 100  | 10   | 2,00 | 1000 | 500  | 5,00| 3,614| 5,382|
| 6,00 | 120  | 20   | 1,83 | 1100 | 600  | 3,27| 2,353| 3,361|
| 4,67 | 140  | 30   | 1,71 | 1200 | 700  | 2,72| 1,951| 2,717|
| 4,00 | 160  | 40   | 1,63 | 1300 | 800  | 2,46| 1,760| 2,412|
| 3,60 | 180  | 50   | 1,56 | 1400 | 900  | 2,31| 1,653| 2,240|
| 3,33 | 200  | 60   | 1,50 | 1500 | 1000 | 2,22| 1,586| 2,132|
| 3,14 | 220  | 70   | 1,45 | 1600 | 1100 | 2,16| 1,541| 2,060|
| 3,00 | 240  | 80   | 1,42 | 1700 | 1200 | 2,12| 1,509| 2,010|
| 2,89 | 260  | 90   | 1,38 | 1800 | 1300 | 2,09| 1,487| 1,973|
| 3,00 | 300  | 100  | 1,36 | 1900 | 1400 | 2,21| 1,577| 2,118|

$b_p$ and $b_s$ – the capture width by the tap of the bottom and surface jets of the stream, respectively, $b$ is the tap width;

$k=q_k/q_p$ – ratio of unit costs in the outlet and main channels;
\[ q_s = \frac{Q_v}{b} \] — specific discharge in the discharge channel equal to the ratio of the amount of discharge taken from the river to the discharge width;

\[ q_p = \frac{Q_p}{B} \] — specific river discharge equal to the ratio of the river discharge above the discharge \( Q_p \) to the width of the river bed \( B \) in the considered section;

\( a_D, a_p, c_D, c_p \) — experimentally obtained coefficients by I.N. Zhulenev and V.A. Shaumyan:

\( a_D = 1.17; \ a_p = 0.73; \ c_D = 0.40; \ c_p = 0.05 \)

According to these materials, dependencies were obtained for determining the boundaries of water with drawal at ABMCH according to the method by I.N. Zhulenev and V.A. Shaumyan (figure 3) and the boundaries of water with drawal at ABMCH were determined by the method of A.S. Abrazovsky (figure 4).

**Figure 3.** Dependence for determining the boundaries of water withdrawal in ABMCh according to the method of I.N. Zhulenev and V.A. Shaumyan

**Figure 4.** Boundary with drawal at ABMCh according to A.S. Abrazovsky
These dependencies are often used to determine the boundaries of water withdrawal when calculating the justification of the layout decisions of water intake waterworks.

When identifying the mechanisms of formation of the boundaries of the division of the flow, during water withdrawal, the determination of the optimal angle of diversion of the flow was important. The latter, as was originally supposed, had an impact both on the spatial geometry of the water intake lines and on the pressure losses in the transit and exhaust flows.

It turned out that the angle of the flow outlet practically does not affect the formation of the boundaries of the division of the stream during water intake due to the beginning of the transformation of the channel stream much higher than the branch. As was already noted, the decisive influence on the nature of the phenomenon under consideration was exerted by the ratio of the transit and discharge flows, as well as the dependence of the distribution of fluid velocities in them.

The angle of the flow outlet to a greater extent influenced the formation of vortex zones at the entrance to the outlet. The dimensions and intensity of the inlets at the inlet, in turn, determined the pressure loss, as well as the amount of sediment deposited at the water inlet, by the amount of sludge entering the outlet. Studies to determine the optimal angle of the flow outlet have shown that pressure losses occur both in the outlet and in the transit stream; losses in the latter were largely determined by the amount of water withdrawal and its boundaries. The angle of tap on the energy loss during flow division practically did not affect [7,11].

To solve the problem of ensuring the flow of a clarified stream into the bowl of the bulk reservoir, the authors of this work proposed a new water intake scheme with fundamentally new structural elements [20]. According to the developed theoretical studies and the geographical location of the head structure at ABMCh, a fundamentally new water intake scheme with new structural elements has been developed. A threshold at the entrance to the head structure is recommended for redirecting bed forms into the riverbed from the water intake, and a clarifier in its channel is proposed for clarifying the flow in the channel (figure 5).

![Figure 5. New water intake scheme in the ABMCh from the Amudarya River](image)

One of the most difficult problems to solve when ensuring high-quality water intake and water supply at ABMCh is the fight against the capture of sediment by the water intake. This in turn contributes to the flow of saturated turbidity to the units of the pumping station. As a result of long operation of pumping units with a constant flow of turbid flow, the impellers of the pumps wear.

It should be noted that such a violation will lead to large operational costs. Despite the large number of theoretical and experimental studies, this method of influencing the hydraulic structure of the flow is not well understood.

To solve problems while ensuring high-quality water intake and water supply, experimental studies were conducted at ABMCh. The analysis of the experiments showed that the value of the optimal threshold angle to the shore is $\beta = 30^\circ, 45^\circ, 60^\circ$ (figure 6).
For all experiments at a value of $P_{\text{on}} > 0.25$, a flow transformation was observed within $(15–20)H_0$ from the threshold site.

**Figure 6.** Schematic diagram of the bottom steam in the damless intake of ABMCH
1-bottom password of variable height; 2-bottom vertical wall; 3-input slot; 4 - inlet channel; 5-oblique planes

The possible calculated dimensions of the sump in the channel channel ABMCh depending on the hydraulic (table 3) and alluvial flow regime (table 4) are given in the following tables.

**Table 3.** Determination of water depths at the beginning of the sump

| h1=Qr/υb | u, m/s | B, m | Qr, m3/s |
|----------|--------|------|----------|
| 2.5      | 0.8    | 40   | 80       |
| 2.4      | 1.0    | 42   | 100      |
| 2.3      | 1.2    | 44   | 120      |
| 2.2      | 1.4    | 46   | 140      |
| 2.1      | 1.6    | 48   | 160      |
| 2.0      | 1.8    | 50   | 180      |
| 1.9      | 2.0    | 52   | 200      |
| 1.9      | 2.2    | 54   | 220      |
| 1.7      | 2.5    | 56   | 240      |

**Table 4.** Determination of the length of the sump for different sediment fractions

| d,мм | w0, sm/s | ϵ | w’ = w0 — ϵ9 | h1 | l=(h1+9)/(w0 — ϵ9) | S = (1.2-1.5) h19/ w0 |
|------|----------|----|---------------|----|---------------------|-------------------------|
| 0,5  | 5,24     | 0,04 | 3,64          | 2,10 | 23                  | 21,32                   |
| 0,30 | 3,00     | 0,04 | 1,4           | 2,10 | 60                  | 37,24                   |
| 0,20 | 1,88     | 0,04 | 0,28          | 2,10 | 300                 | 59,42                   |

4. Conclusions

The performed review of the knowledge of the design and operation of damless water intakes allowed the following main conclusions to be drawn:

- Analysis of the experiments showed that the value of the optimal angle of the threshold to the shore is $\beta = 30^\circ, 45^\circ, 60^\circ$;
- When setting the water intake mode, it is necessary to take into account the fact that reducing the discharge angle in order to reduce the pressure loss at the inlet to the water intake, the latter is more intensively introduced by the precipitated suspensions;
- Intensive deformations of the Amudarya river channel take place in the area of the water intake of the ABMCh: Due to the dredging of the channel by the dredgers, the pulp is thrown into the river channel, it turns out, as it were, storage of sediment on the right bank.
This, in turn, leads to a narrowing of the river channel and siltation of the supply channel, which contributes to the movement of the channel to the left coast and complicates the intake from the river into the channel.

Taking into account the complexity of the processes occurring during the division of the flow, all this initially requires consideration of the qualitative and quantitative sides of this phenomenon ‘in its pure form’, without affecting the moving flow of various anti-carrier devices;

To improve the conditions of water intake and the quality of the incoming stream, an improved scheme with new structural elements is proposed.

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