E3S Web of Conferences **410**, 05035 (2023) https://doi.org/10.1051/e3sconf/202341005035
*FORM-2023*

# Methods of channel calculations to improve the operational mode of main canals

*A. B.* Saparov[1*], *S. K.* Khidirov[2], *A. B.* Khalimbetov[2], *A. T.* Djumanazarova[1], *Sh. B.* Tolepova[1], and *A. R.* Seitmuratov[1]

[1]Karakalpak Institute of Agriculture and Agrotechnology, Nukus, Uzbekistan
[2]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers", National Research University, Tashkent, Uzbekistan

**Abstract.** The article discusses solutions to improve the operational mode of the canal with an increase in throughput by means of self-washout, while maintaining the morphometric favorable stable cross-section of the canal for further reliable water supply of suspended crop areas. Taking into account the characteristics of the course of channel deformation processes, we have considered the modern dynamics of channel flows for accurate calculation of channel deformations using the systems of equations of one-dimensional flow in the deformable Saint-Venant channel or two-dimensional shallow water equations (planned task), which will give a positive result for the operational mode of the main canals.

## 1 Introduction

The Anasai main canal, which we are studying, takes water from the Takhiatash hydroelectric complex, the right-bank water divider (the head structure), which was put into operation in 1986. The length of the channel is 13.5 km, the design capacity of the canal is 342.0 $m^3$/sec. In the end part of the canal at the picket (PK) 135÷00, a water dividing blocking structure was built.

The canal route passes through the territory (suburb) of the city of Nukus in a densely populated area and has 2 road bridges at PK 94÷50, PK 104+00 and one railway bridge at PK 18÷00 [5-7].

The problems of the object under study are that, in the upper section of the Anasai canal system, silting of the channel is observed, which is caused by the inflow of coarse-grained sands into the channel due to silting of the upper pool of the Takhiatash hydroelectric complex and settling tanks.

Many sections of the canal have not been brought to the design level, banks and slopes are being eroded, silted up along the entire length of the canal, the actual value of the head water flow today is 95.0 $m^3$/s (2021).

During construction, especially during the reconstruction of canals, in some cases it is advisable to use channel deformations artificially induced to form the channel.

Studies by S. T. Altunin, I. I. Levi, S. Kh. Abalyants, T. E. Mirtskhulava, D. R. Bazarov, K. V. Rabkova, Engelund-Hansen, Meyer-Peter, Muller, Akkers-Waig, Brownlee,

*Corresponding author: vohidov.oybek@bk.ru

https://doi.org/10.1051/e3sconf/202341005035

Toffaletti, Young, Van Rijn and many other scientists have shown that various methods for designing channels in earthen channels and for determining the transport capacity of the flow and predicting processes deformations will give positive ways to solve the problems caused.

In the process of mutual exchange of sediments, there is a constant settling of suspended sediments and a compensating process - the uplift of settled suspended sediments and the involvement of temporarily immobile sediment particles in the movement.

All these factors, at present, have received an indirect method, when the characteristics of stable channels are determined from natural data. Such scientific areas are widely developed in the CIS countries, the USA, France and India, and the dependencies that determine the stable shape and size of channels are established on the basis of statistical processing of observational materials on operated channels operating in a stable mode, without erosion and silting.

In modern channel flow dynamics, for accurate calculation of channel deformations, we used systems of equations of one-dimensional flow in a deformable Saint-Venant channel or two-dimensional shallow water equations (planned problem).

Calculation methods in the form of a one-dimensional problem, operating with flow velocities averaged for the entire section, depths, bottom deformations and other indicators based on the Saint-Venant equations, were developed by prominent scientists such as I.I. Levy, M.S. Pakhsraryan and many others in relation to calculations of deformations of reaches and riffles in domestic conditions, general deformations of the channel when the erosion basis changes, deformations of the pools of retaining hydroelectric facilities and reservoirs, etc.

A two-dimensional planned problem operating with local flow characteristics averaged over depth but taking into account their changes along the width of the channel was developed by N.G. Meleshchenko, I.I. Levi, K.I. along the length and width of the flow in domestic rectilinear and curvilinear channels, as well as when the flow moves with whirlpools (lower pools of hydroelectric facilities, local expansion of the channel, the area of operation of transverse protective and regulating structures, etc.). Its foundations were laid by the outstanding scientist hydraulic engineer N.M.Bernadsky.

We are considering the issue of improving the operational mode of canals with an increase in throughput through self-washing, for further reliable water supply of suspended areas, it will retain the morphometrically favorable stable cross section of the canal, it is enough to have an approximate characteristic of the process of channel deformation. Given the above, the methods and calculations we have chosen will give a positive result for the operational mode of the main canals.

## 2 Research methods

The complexity of exact solutions has caused numerous developments of approximate methods for channel calculations. Some of them are used to predict channel deformations in the pools of dam waterworks. Hydrometric, hydraulic and hydrological-morphometric methods are currently used to calculate the elements of a domestic channel.

## 3 Results and discussion

In the modern concept of the channel process as the interaction of a flow with a deformable channel, we mean the interchange of a flow and a channel with sediments. The main active factor of such interchange of sediments is the average velocity field and the turbulent structure of the flow, which depend on the morphometry and roughness of the channel.

With dynamic stability, the limiting state is the channel of dynamic equilibrium, in which complete transit occurs without deposits or additional saturation due to erosion.

In recent years, due to a decrease in the water content of the Amudarya River in the zone of the Takhiatash hydroelectric complex, the actual value of water discharge has sharply decreased, which led to siltation of the channel of the main Anasai canal completely from PK 0 + 00 to PK 135 + 00, that is, along the entire length of the canal. In the process of siltation, a pattern of channel depth decrease is formed, which is accompanied by bank erosion. Due to silting, the depth of the channel decreased from 1.5 to 2.0 m, and their width increased from 1.2 to 1.5 times.

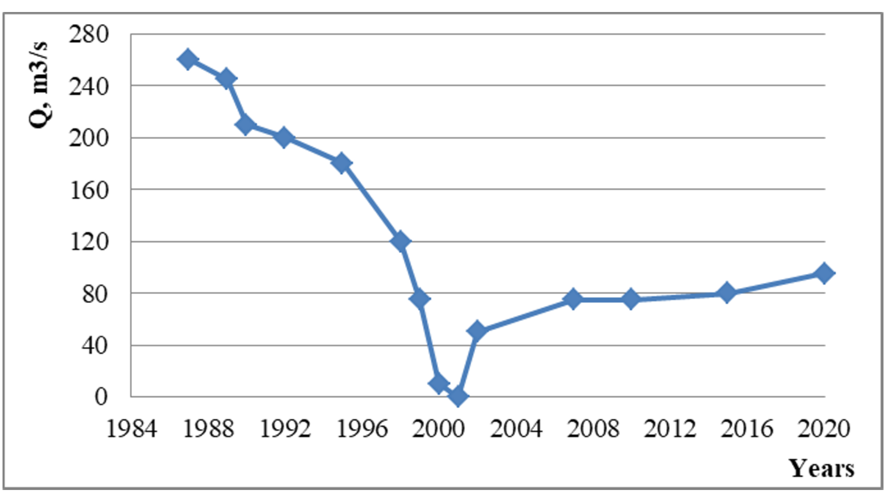
The silting of the channel of the Anasai channel along the entire length increased, the hydraulic resistance of the channels, which led to a decrease in the throughput of the channel to 50-60% of the design indicator, i.e. compared to 1986-1990. The reason for the silting of the canal is the inflow of coarse-grained sands into the canal bed due to silting of the upper pool of the Takhiatash hydroelectric complex and head sedimentation tanks. Especially in the head sections, it did not lead to the rise of water levels, and this process was accompanied by lateral erosion of the channel, which had an extremely negative impact on the normal operation of the canal. When the general slope of the channel has not changed, and accordingly the horizon marks remained at the level of the project. In low-water years and in years of medium water supply, almost all structures operated in a backwater mode; in the upper pool, the water horizon was kept at the level of the corresponding design one, which in turn led to siltation. In high-water years, as a result of the presence of water, the shield regulators operated in an open mode, the channel was washed out and, accordingly, the water horizon decreased.

When it comes to the maximum water flow, it can be noted that this is such a relative value that, depending on the water content of the year, varies over a wide range, i.e. in high-water years, due to erosion, it increases, and in low-water years, on the contrary, due to silting, it decreases.

The magnitude of the maximum water flow and the carrying capacity of the Anasai canal is variable and depends on the water content of the year and the silting of the channel.

**Table 1.** Maximum water flow of the Anasai canal

| Channel name | years | | | | | |
|---|---|---|---|---|---|---|
| | 1987 | 1990 | 2000 | 2015 | 2016 | 2020 |
| Anasai | 260 | 210 | 10 | 75 | 80 | 95 |



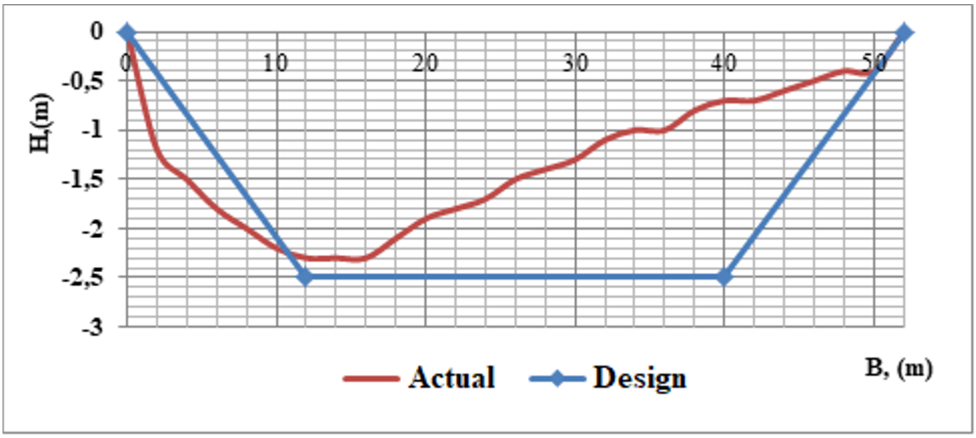
https://doi.org/10.1051/e3sconf/202341005035

**Fig. 1.** Change in the average annual maximum water discharges along the Anasai canal

For our study, we have selected a hydrological-morphometric method - this method uses hydrological-morphological dependencies, refined according to the data of the nearest sections using the hydrometric method. We derive these dependencies of this method based on five equations representing partial expressions of equations (1, 2, 3) and formulas (4, 5, 6). These equations satisfy the conditions for the steady uniform movement of water and sediments, as well as the longitudinal and transverse stability of the channel. At the same time, longitudinal stability is understood as the absence of deformations of the longitudinal profile of the bottom, and transverse stability is the constancy of the cross-sectional area and width along the water's edge. It should be noted that a real channel is considered stable if for a long time it practically retains a constant shape and average characteristics with alternating deformations in separate periods and transverse displacements that do not change the size and shape of the section. In the course of the study, static and dynamic stability were distinguished, corresponding to two limiting states of the channel, at which its deformations are impossible. With static stability, such a state is a channel of static (limiting) equilibrium, in which the flow that does not transport channel-forming sediments flows at maximum speeds without erosion. The limiting state for dynamic stability is the channel of dynamic (mobile) equilibrium, in which complete transit occurs without deposition or additional saturation due to erosion.

Field studies were carried out on the head section of the Anasai Canal in the period 2020-2022, the averaged results of which are shown in Fig. 1-5.


**Fig. 2.** Plan of the head structure of the Anasai canal and the location of the site for the hydrometric measure



 https://doi.org/10.1051/e3sconf/202341005035

**Fig. 3.** Cross-section of the Anasai canal PK 2+00 at Q=21.0 m³/s, (May 2021)

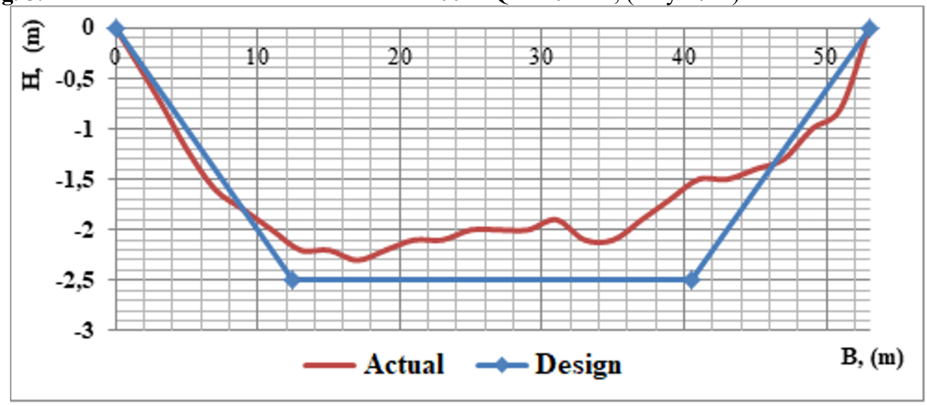



**Fig. 4**. Cross-section of the Anasai canal PK 2+00 at Q=40.5 m³/s (June 2021)

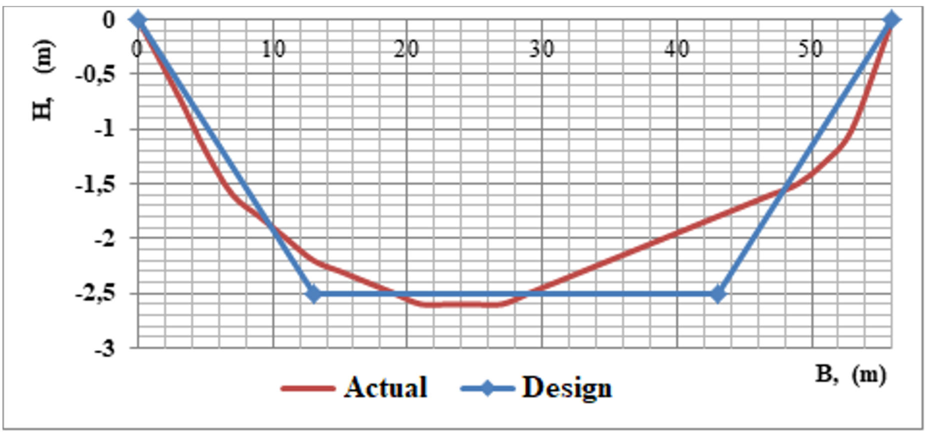



**Fig. 6.** Cross-section of the Anasai canal PK 2+00 at Q=54.3 m³/s, (June 2020)

Analysis of field measurements of the channel cross section shows that, despite the fact that the channel was designed as an engineering structure with clearly regulated velocities, flow rates and depths, their channels were deformed when interacting with the flow, which led to some change in the geometric parameters of the channel. This is due to the fact that when designing a channel, the type of the channel cross section is first selected, and then the elements of the selected section are determined by average determination. Thus, the formation of the channel shape is disrupted, which is proved on the basis of experimental and field data from a number of studies.

From fig. 4-6 it can be seen that in all cases the transverse profiles of the channels acquired a flatter shape, resembling a polygonal or parabolic profile, regardless of the flow rate and soil conditions of the bed.

Thus, field data confirm that earth channels under certain conditions are subject to channel deformations that proceed in the direction of the formation of stable cross sections, in which the velocity characteristics of the flow and the shape of the channel are in a certain dynamic relationship.

The deformation of the canal bed, as well as the deformation of the river bed, is divided into general, covering a section of great length, and local, concentrated on a short section. General deformation is caused by the difference between the actual sediment saturation of the stream and its transport capacity. Local deformations are associated with local changes in the velocity field in the flow sections, as a result of flowing along a channel bent in plan, narrowing by hydraulic structures, etc.

The general channel deformations in the channels were determined by calculations using a system of equations for a one-dimensional flow in a deformable channel, taking into account the flow velocities averaged over the entire section, depths, bottom deformations, and other indicators. The basic equations of this system, called the Saint-Venant equations, are also considered there, additional conditions necessary for closing the system of Saint-Venant equations, as well as the initial and boundary conditions under which it must be integrated [2].

Saint-Venant's equations include [3]:

a) equation of motion

$$-\frac{\partial z_w}{\partial x} = \frac{\upsilon^2}{c^2 H} + \frac{\upsilon}{g}\frac{\partial \upsilon}{\partial x} + \frac{1}{g}\frac{\partial \upsilon}{\partial t} \tag{1}$$

b) continuity equation

$$\frac{\partial Q}{\partial x} + \frac{\partial w}{\partial t} = 0 \tag{2}$$

c) deformation equation

$$\frac{\partial Q_s}{\partial x} + (1-\varepsilon)\cdot\left[B\frac{\partial z_s}{\partial t} + H\frac{\partial B}{\partial t} + \frac{\partial(\mu\cdot\omega)}{\partial t}\right] = 0. \tag{3}$$

To close a system containing six unknowns: $Z_w, C, H, Q, Q_s$ and $B$ add three additional conditions;

d) resistance formula

$$C = f_1(k_1; H) \tag{4}$$

e) sediment flow formula

$$Q_s = f_2(k_2; \partial; \upsilon; B) \tag{5}$$

f) the formula for the relationship between the main dimensions of the cross section of the channel

$$B = f_3(k_3; H) \tag{6}$$

or vertical and lateral deformations

$$\frac{\partial z_s}{\partial t} = f_4\left(k_5\frac{\partial B}{\partial t}\right). \tag{7}$$

In these equations and formulas:

$Z_w$ and $Z_s = Z_w - H$ - ordinates of the water surface and bottom, measured from a horizontal plane coinciding with the axis *O-X;* $Q$ and $Q_s$ - water and sediment costs;

$\upsilon = \dfrac{Q}{\omega}$ - average water flow rate, m/sec; $\omega = B \cdot H$ - free flow area ($B$ - water line width; $H$ - average depth); $\varepsilon$ - sediment porosity; $\mu = \dfrac{\rho}{\tau_n}$ - specific content (turbidity) of sediments; $k_1; k_2; k_3$ and $k_4$ - constants determined by specific characteristics of the soil that make up the bed of the river and sediments (bed roughness, fractional composition of sediments, etc.).
We integrate a closed system under given initial and boundary conditions:

$$Z_{wo} = Z_{wo}(x); H_0 = H_0(x); Q_H = Q_H(t); Q_{sH} = Q_{sH}(t); Z_{wH} = Z_{wH}(t). \quad (8)$$

where the index 0 marks the values corresponding to the beginning of the time reference t=0, and the index n marks the values corresponding to the alignment at the beginning of the section under consideration.
In the case of a two-dimensional planned problem, the number of basic equations increases to four (the equation of motion in the transverse direction is added), and additional conditions must take into account, in addition to the frictional resistance at the bottom, also the resistance along the lateral faces of the selected vertical elements, due to the uneven distribution of longitudinal velocities along the width of the channel. [4]
To obtain such a characteristic, a simplified method for determining the duration of deformation is proposed, based on the assumption of a linear change in the cross-sectional deformation area along the length of the channel section under consideration [6].
In the case of channel channel erosion, this assumption leads to the formula:

$$t\rho = \frac{1.15 \cdot 10^{-5}_{\varphi H}}{\mu_H - \mu_\rho} \cdot K_1\left(w_\rho - w_H\right) + K_2 \cdot ZB_\rho + K_3 H\left(B_\rho - B_H\right) l_x \quad (9)$$

where $t\rho$ is the duration of erosion propagation for the length $l_x$, days; $\mu_H$ *and* $\mu_p$ are the transporting capacities of the flow at the estimated water flow in the initial section before deformation and in the eroded channel, kg/s; $w_p$ *and* $w_H$ - free flow sections at the estimated water flow in the eroded channel in the initial alignment before deformation, m$^2$; Bp and Bн are the widths along the water's edge at the calculated discharge in the eroded channel and in the initial alignment before deformation, m; $l_x$ is the length of the canal section, km; Z is the decrease in the water level in the initial section during the washout time $t\rho$, m; H - the average height of the banks above the water level at the calculated flow rate in the initial alignment before deformation; $K_1= K_2= K_3=0,5$- coefficients that take into account the nature of the change in $w_H$, $Z$ and $H$ along the length $lx$ (with a linear change $K_1= K_2= K_3=0,5$); $\varphi H$ is the volumetric weight of the eroded soil, kg/m$^3$.
The value of the decrease in the water level in the initial alignment, which is included in (9), during the washout period $\Delta t$ can be determined by the formula:

$$\Delta t = Q_\rho^2 l_x l_H \left(1 - \frac{n_H B_H}{B_H n_\rho}\right)^2 \cdot \left(\frac{h_H}{h_{cp}}\right)^{3.67} \quad (10)$$

where: $Q_p$ – design discharge, m$^3$/s; $l_H$ – longitudinal slope of the channel at design

discharge $Q_p$ on the channel length $l_x$; $n_p$ *and* $n_н$ are the roughness coefficients of the eroded channel and the channel by deformation; $h_{cp}$ and $h_н$ is the average depth at the estimated flow rate of the washed-out channel and the initial section before deformation.
In the case of the formation of a stable channel on an extended section of high dams with the help of silting, the time of silting is determined by the formula:

$$t_3 = \frac{1.15 \cdot 10^{-5}_{\varphi H}}{\mu_3} K_4 (w_H - w_3) l_x \quad (11)$$

where: $\mu_3$ is the transporting capacity of the formed silty channel, kg/cm3; w_3 - free section area before siltation and the formed channel at the estimated flow rate Q, m2; φH - volumetric weight of alluvial deposits, kg/m$^3$; $l_x$ is the length of the silting area, km; $K_4$ - correction factor for $l_x < l_{спр}$ (where $l_{спр}$ - straightening length) $K_4$ = 0.5 for $l_x \neq l_{спр}$ calculations are made at $K_4$=0.5 and $K_4$=1.0 (corresponds to complete silting).
When determining the duration of silting by formula (11), in the case of $l_x < l_{спр}$, the width and depth of the silted channel are determined by formulas (12) and (13), assuming *K=0.08*. In the case of limiting silting ($l_x \neq l_{спр}$; $K_4$=1.0), the width of the channel should be determined by formula (14), entering when determining the depth according to (13), the value *K*=0.065

$$B = K\sqrt{\frac{Q}{i}} \quad (12)$$

where: *K* is an empirical coefficient determined on the basis of the development of experimental data.
This formula was proposed specifically for the conditions of r. Amu Darya, irrigation canals of the lower and middle reaches of the river. According to numerous field studies in the conditions of the river. Amu Darya and its irrigation canals, the average depth of the channel does not depend on the longitudinal slope of the water surface and can be determined by the formula [7]:

$$h_{cp} = \left( \frac{n\sqrt{Q}}{K} \right)^{0.6} \quad (13)$$

Based on the processing of field data collected by him, he recommended taking the average value of the coefficient *"K"* for the river bed. Amu Darya. K=0.16, and for outgoing channels *K*=0.10 [8].

$$B = 0.065\sqrt{\frac{Q}{i}} \quad (14)$$

The cross-sectional area of the silted channel in both cases will be $\omega_3 = B_3 \cdot h_3$. The transporting capacity of the flow in the silty channel in the calculations should be taken equal to the average sediment flow rate $\mu_3$=$Q_{cp}$, corresponding to the average water turbidity in the initial alignment of the straightened channel.

When determining the duration of self-erosion according to formula (9), formulas (12) and (13) were used only after a special verification of them according to field data, since these formulas were obtained by processing the data of field measurements in the areas of channel formation with the help of silting. In this case, it is advisable to use other formulas to determine the elements of the formed channel [9].

As a result, the change in cross-section-averaged deformations of the channel along the length of the section under consideration and over time is established, which, in particular, can be used to determine the total volume of canal silting and its distribution along the length by the end of the growing season, specifying the planned volumes of cleaning and arrangement of mechanisms.

However, the practical use of the system of Saint-Venant equations for calculating channel deformations of channels is complicated by the complexity of calculations. The use of computers is hampered by the lack of developed appropriate programs.

Meanwhile, when drawing up projects for the reconstruction of canals with an increase in throughput through self-washout, it is enough to have only an approximate characteristic of the process of channel deformation in time [5].

Taking into account the above problems, they can be solved by our methods and calculations to improve the operating mode of the channel with an increase in throughput up to 40-50% by self-washing, while maintaining a morphometric favorable stable section of the channel and increasing the efficiency up to 84, for further reliable water supply of suspended sowing areas.

## 4 Conclusions

We note that in the practice of calculating channels, when predicting an improvement in the operation mode of channels, they are determined by empirical formulas, since the assumptions and proposals made when deriving theoretical formulas require their serious verification and refinement according to field measurements.

A serious shortcoming of most of the listed works is that the solutions obtained in them poorly reflect the physical essence of the process of interaction between the flowing water flow and soil particles on the bed surface.

1. The field studies carried out for the parameters of the Anasai main canal showed that with unfavorable characteristics of the slopes and dams of the canal, corresponding to a critical state during operation, there will be a high probability of failure of the structure.

2. In the upper section of the Anasai canal system, silting of the channel is observed, which is caused by the influx of coarse-grained sands into the canal channel due to silting of the upper pool of the Takhiatash hydroelectric complex and settling tanks.

3. Do not allow water to be withdrawn from the irrigation source with excess water consumption, i.e. over bandwidth. The value of such flow for the Anasai canal is 95 $m^3/s$ (at the level of 2021). Depending on the water content of the year, the values of this indicator vary.

4. Further development of an increase in the width in the process of silting of the Anasai channel can lead to complete erosion of the bank protection dams, thereby reducing the throughput of the canal and, accordingly, creating a tense critical situation. Given this, it is necessary to clean up the Anasai canal bed and further maintain its design parameters.

5. Their current state does not meet the requirements of operational reliability, in this regard, it is necessary to increase the amount of funding for repair and restoration work.

## References

1. Bazilevich V.A. Calculation of the deformation of the bottom and banks of gravel-pebble channels. Hydraulic engineering, № 11, pp. 31-34. (1976).
2. Jamankaraev S.D., Buzunov I.A. Channel deformations during the operation of

irrigation systems in the lower reaches of the Amudarya. Nukus, p. 154. (1979).

3. Kantorovich V.K., Kuchment L.S. Application of Finite Element Methods to Calculations of Unsteady Water Movement Using the Saint-Venant Equations. Water resources. No. 6. pp. 45-53. Moscow, (1981).
4. 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).
5. 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).
6. Saparov A.B. Technical condition and methods for improving the throughput of the Anasai Canal. International Conference dedicated to the 90th anniversary of the Tashkent State Agrarian University "Actual theoretical and practical problems of agricultural science and ways to solve them" Tashkent, (2020).
7. 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).
8. Bazarov, D., Ahmadi, M., Ghayur, A., & Vokhidov, O. The Kabul River Basin-the source of the Naglu and other reservoirs. In E3S Web of Conferences, Vol. 365, p. 03047. EDP Sciences. (2023).
9. 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.
10. Burlachenko, A., Chernykh, O., Khanov, N., & Bazarov, D. Features of operation and hydraulic calculations. In E3S Web of Conferences, Vol. 365, p. 03048). EDP Sciences. (2023).
11. 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).
12. Bazarov, D., Norkulov, B., Vokhidov, O., Jamalov, F., Kurbanov, A., & Rayimova, I. Bank destruction in the middle section of the Amudarya River. In E3S Web of Conferences, Vol. 274, p. 03006. EDP Sciences. (2021).
13. Bazarov, D., Kan, E., & Atajanova, D. Combined method for calculating the total erosion of channels composed of easily erodible grounds. In IOP Conference Series: Earth and Environmental Science, Vol. 1189, No. 1, p. 012015. IOP Publishing. (2023).
14. Norkulov, B., Khujakulov, R., Kurbanov, I., Kurbanov, A., Jumaboyeva, G., & Kurbanov, A. Regime of deposition of sediments in the head settlement basin of the supply channel of pumping stations. In E3S Web of Conferences, Vol. 365, p. 03045. EDP Sciences. (2023).
15. Norkulov, B., Mamataliev, A., Kurbanova, U., Nazarova, S., Shodiev, B., & Raimova, I. Increasing efficiency of flow energy damping with lateral water intake. In E3S Web of Conferences, Vol. 365, p. 03044. EDP Sciences. (2023).