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Improvement of water distribution management methods for operating modes of machine channels

Oleg Glovatskiy[1,3], *Altingul* Djumanazarova[2], *Amanbay* Saparov[2*], *Naira* Nasirova[3], *Akmal* Sultonov[4] and *Akbarali* Sattorov[4]

[1]"Tashkent Institute of Irrigation and Agricultural Mechanization Engineers", National Research University, Tashkent, Uzbekistan
[2]Karakalpkak Institute of Agriculture and Agrotechnology, X.Abdambetov street n/n, Nukus 230109, Uzbekistan
[3]Research Institute of Irrigation and Water Problems, Karasu-4 Street, Tashkent, 100187, Uzbekistan
[4]Jizzakh Polytechnic Institute, Jizzakh, Uzbekistan

Abstract. The ongoing research aims to improve the reliability of irrigation systems, improve methods for managing the water distribution of the operating modes of machine canals, and increase crop yields in the Nukus and Kegeyli regions of the Republic of Karakalpakstan. At present, increasing the efficiency of the operation of machine channels is associated with the development of energy and resource-saving technologies. Pumps that have been in operation for more than 25-30 years, due to physical and obsolescence, operate with low efficiency, emergencies associated with technological regimes with transients. The article analyzes changes in the processes of the hydrodynamics of control systems with optimization of sediment control on water supply structures, the danger of abrasive wear of the flow path of hydraulic units, and experimentally checks the mathematical model for managing the water distribution of operating modes. In this regard, the improvement of the design of elements and the modernization of individual units of pumping units will increase the efficiency of the entire system of machine water lifting. Recommendations are given on the inclusion of settling tanks in the composition of the head waterworks, carrying a large number of suspended sediments (more than 0.2–0.5 kg/m^3) and systems for their purification.

1 Introduction

An important role in land reclamation is played by pressure water supply systems, including a power source in the form of a pumping station (PS), a network of pressure pipelines, and water consumers. The composition of the PS node includes a water intake structure, a water supply tract, a water intake, pressure pipelines, and water outlet structures [1,2]. Considerable attention is paid to the connecting links and mutual influence in the operation of the main pumping and power equipment and the hydrotechnical complex of

*Corresponding author: irrigator-1986@mail.ru

the PS to improve the methods for managing the water distribution of the operating modes of machine channels [3,4]. This complex in water supply facilities should provide water purification from sediments to exclude abrasive wear of equipment and, on the other hand, preserve the properties of fertilizers for plants. Given the ineffective practice of using sprinkling in the arid zone and subsoil irrigation in meliorative science, there are still no regulatory criteria for assessing the quality of irrigation under these conditions.

2 Methods

The methodological basis of our research is to solve the problem of improving the methods of controlling the water distribution of the operating modes of machine channels by creating favorable hydraulic conditions for the operation of equipment, eliminating unfavorable modes with increased costs for cleaning water supply tracts from sediment and driftwood. In the research process, methods of control and algorithmization of systems with distributed parameters were used according to the principles of system analysis.

3 Results and Discussion

Consideration of the unsteady movement of water is the main one for improving the operating modes of the water supply structures of hydraulic engineering units. The main structures are calculated according to the formulas for open channels. Irrigation canals are objects with distributed parameters, which during operation, change both in time ∂t and distance ∂s [5,6].

The unsteady movement of water in channels can be described by the equations of motion (or dynamic)

$$i_0 - \frac{\partial h}{\partial s} = \frac{\alpha}{2g} \cdot \frac{\partial \upsilon^2}{\partial s} + \frac{\alpha_0}{g} \cdot \frac{\partial \upsilon}{\partial t} + i_f \quad (1)$$

and the continuity equation

$$\frac{\partial \omega}{\partial t} + \frac{\alpha(\omega \upsilon)}{\partial s} = 0 \quad (2)$$

where i_0 is bottom slope; h is the depth of the flow; υ is average flow velocity in the section; i_f is friction slope.

$$\mathrm{i_f} = \frac{\partial h_\omega}{\partial s}$$

Change of depth in the area ∂h_ω of the living section.

When solving equations, it is necessary to know the method for determining energy losses due to friction, which is closely related to the study of the velocity structure of the flow during unsteady motion. Due to the lack of experimental data and the necessary theoretical developments, the energy losses to overcome friction forces for unsteady motion when solving the Saint-Venant equations were determined by the uniform motion formula [7, 8].

$$\mathrm{i_f} = \frac{\upsilon^2}{C^2 R} \quad (3)$$

where C is speed multiplier; R is hydraulic radius.

It is expedient to concentrate the element-by-element analysis of methods for controlling the technological modes of the interface structures of the PS with transient processes on the elements of the water supply structures of the PS.

The state area of their objects is determined by the condition $I_D < I_{pr}$, the failure area - $I_D > I_{pr}$. In this case, the condition for the probability of failure-free operation can be represented as:

$$\mathrm{Pr}ob\{I_{\lim} - I_v = u > 0\} \quad (4)$$

where $I_{\lim}$ is the limiting value of the determining parameter of unsteady unfavorable modes at which failure occurs; I_v - valid parameter value during normal operation.

Calculations of the unsteady movement of water are associated with the satisfaction of the demands of various sectors of the national economy, primarily in the design and reconstruction of irrigation systems.

Thus, when designing hydroelectric facilities, the course of levels and flow rates is calculated over a significant length of the tailwater under various operating modes of the PS, determined by the water content of the year, season, day of the week, and time of day. Operating experience shows the importance of determining for various sections in the "water intake-canal-pumping station" system the values of both maximum water levels (due to the danger of technological regimes) and minimum levels (to ensure the normal functioning of water intakes) as well as water distribution management and operational modes in the intermediate channels of the cascades of the PS.

The complex structures and equipment of the PS, which provides water supply or water disposal following the needs of the consumer, are determined based on the principles of the integrated use of water resources and nature protection.

The main tasks of analyzing the operation of a system with transient processes are:

- identification of changes in the processes of the hydrodynamics of control systems with optimization of sediment control at water supply structures;

-determination of factors that determine the risk of abrasive wear of the flow path of hydraulic units;

- experimental verification of the mathematical model of water distribution control and operating modes in the PS systems;

- creation of a methodology for calculating processes that occur during emergency shutdowns of pumps equipped with new flow-forming systems [9,10]. The method of kinetic averaging used in the flow part of the pumps corresponds to the method of stabilizing cross-sectional average velocities in the water supply structures of the PS [11,12].

All channels, as a rule, should work in a uniform mode or with a small backwater. The operation of the channel in the decay mode requires special justification. When using supply channels as a control vessel, the emptying rate should be selected so as not to destroy the channel slopes by the hydrodynamic effect of water. Hydraulic connections of channels in the system are carried out by boundary conditions.

The construction of a free surface curve is carried out by reducing the equation of non-uniform motion

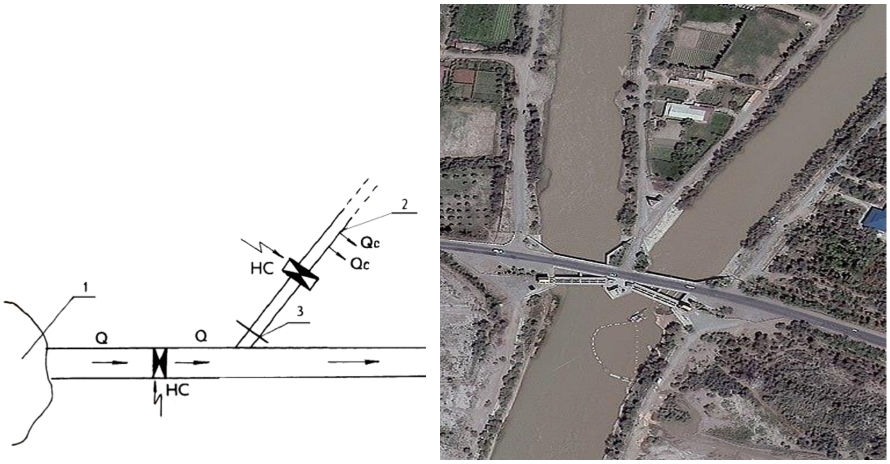
$$\frac{dh}{ds}=\frac{i-\frac{Q^2}{\omega^2 C^2 R}=f(h)}{1-\frac{\alpha Q^2}{q\omega^3}\mathrm{B}} \qquad (5)$$

to the mind

$$S-\int_{h_0}^{h_s} 1/f(h)dh=0 \qquad (6)$$

where h_o is the depth at the beginning of the channel; S is spatial coordinate; h_s is the position of the free surface at a distance S from the beginning of the channel.

At the same time, a different scheme of connecting channels with water withdrawal from the machine channel is considered (Fig. 1a), including a bifurcation of the regulator, for example, to the Anasai channel (left), to the Kyzketken channel (right) (Fig. 1b).



a *b*

a) water intake scheme 1 is water intake; 2 is water extraction from the machine channel; 3 is regulator, b) plan of the head water intake structure of the Anasai and Kyzketken canals

Fig. 1. Connection diagram of PS channels

The solution of equation (5) can be obtained by one of the numerical methods; in this case $\int_{h_0}^{h_s} 1/f(h)dh$, it is considered a function $F(h_s)$ [13, 14]. The interval of integration L is divided into segments $\ell = L/N$, where N is the number of points dividing the alignments. The h_{si} value for section i is found by solving the equation

$$i_l - F(h_{si})=0, i=1,2,...,N.. \qquad (7)$$

Consider some options for connecting channels. The determined parameters here are the flow rate Q = Q (x_o, t) and the water depth in the channel h = h (x_o, t), where x_0 is the boundary point belonging to this node.

Boundary conditions for n = 2.

Connection of channels with sharply different geometric characteristics:

$$Q_1+Q_2 = 0 \tag{8}$$

$$h_1 = h_2 + a \tag{9}$$

where Q_1, h_1 are flow rate and depth of water in the first channel, m^3/s, m; Q_2, h_2 are flow rate and depth of water in the second channel, m^3/s, m; a is difference between the channel bottom marks at the junction point, m.

There is a spillway in the node. Then condition (8) takes the form

$$Q_1 + Q_2 + Q_w = 0$$

where Q_w is the flow rate of water passing through the spillway, which is determined by well-known formula, m^3/s.

Equation (9) remains unchanged.

At the connection point is the PS, the regulator.
Then

$$Q_1 = Q_2 = Q_P$$

where Q_{work} is consumption in the node determined by the work schedule of a particular facility, m^3/s. This scheme corresponds to the "channel-pumping station" system of the PS Anasai.

The hydraulic connections of the channels in the system are carried out by boundary conditions; therefore, the calculation in each section can be carried out independently, starting from the water intake with the head structure and the supply channel (Fig. 2).

Fig. 2. Headwork and supply channel Anasai

The unsteady flow of water in the channel is described by the equations of conservation of mass and momentum. In this case, the divergent form of the equation [15,16] is used

$$\frac{\partial \omega}{\partial t} + \frac{\partial Q}{\partial x} = q \tag{10}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}(P + \frac{Q^2}{\omega}) = q\omega(i - \frac{Q|Q|}{K^2}) + q\int_0^h (h-\xi)(\frac{\partial B}{\partial x})_\xi d\xi \tag{11}$$

$$\omega = \int_0^h B(x,\xi)d\xi; \quad P = q\int_0^h (h-\xi)B(x,\xi)d\xi \tag{12}$$

where x is longitudinal coordinate; t is time; Q is water consumption; h is water depth; i is bottom slope; K is flow module; ω is open area; P is hydrostatic force; B is channel width; q is lateral inflow; p is density of water; ξ is auxiliary quantity.

We will consider P as a function of the arguments h and x. Then equation (11) can be written in a more compact form:

$$\frac{\partial Q}{\partial t}+\left(\frac{\partial \mathrm{P}}{\partial x}\right)_x+\frac{\partial}{\partial x}\left(\frac{Q^2}{\omega}\right)=q\omega\left(i-\frac{Q|Q|}{\mathrm{K}^2}\right) \tag{13}$$

In practice, the boundaries of the regions can be set as follows:
- slowly changing current, if

$$N \le \xi_1 \cap \mathrm{M} \le \eta_1 \cap K \le \xi_2 \cap K \le L \le \eta_2$$

- sharply changing current, if

$$\xi_1 \prec N \le \xi_3 \cap \eta_1 \prec M \le \eta_3 \cap \xi_2 \prec \mathrm{K} \le \xi_4 \cap \eta_2 \prec L \le \eta_4$$

where $N = \max\limits_{x=0.L} \partial Q/\partial t;\quad M = \max\limits_{x=0.L} \partial h/\partial t;$

$$\mathrm{K} = \max_{x=(0.L)} \partial Q/\partial x;\quad L = \max_{x=(0.L)} \partial h/\partial x$$

ξ_i, η_i - setpoints (i = 1,2,3,4).

In some cases, it is known in advance that throughout the entire process, the rate of change of the flow parameters changes insignificantly, then the analysis of the transition conditions can be excluded, and the calculations can be carried out only by the method of calculating the flow rates. The channel connection scheme can be quite detailed and illustrated for the Anasai channel (Fig. 3).

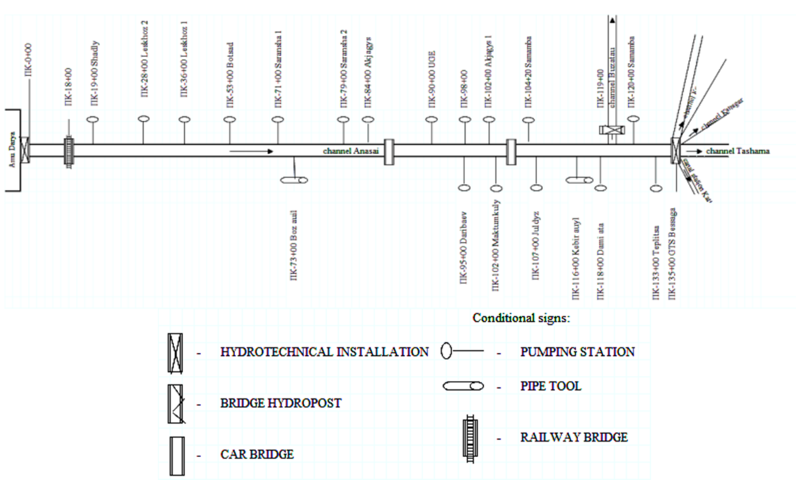


Fig. 3. Connection diagram of channels of main channel "Anasai"

The Anasai channel was put into operation in 1986. At PK 0+00 of the canal, the head water intake facility was operated with a flow rate of 342 m^3/s [17,18]. At 11.9 km of the canal, the head regulator of the Bozatau canal (52.0 m^3/s) is located, the end part of the Anasai canal at 13.698 km there is the Bessaga water divider with regulators to the Kerder canals (80.0 m^3/s), Kattagar (20, 0 m^3/s), Tasharna (180.0 m^3/s).

Water intake to the Anasai canal is carried out from the upper pool of the Takhiatash dam and runs in a south-north direction; its length is 13.698 km to the water divider "Bessaga", of which 11.8 km passes through the territories of the city of Nukus further through the territories of the Nukus region. The canal is bounded from the west by the Amudarya River and from the east by the Dustlik Canal. The total area of irrigated canal lands is 129.98 thousand hectares; for the future, 143.40 thousand hectares will irrigate the lands of the Nukus and Kegeyli regions and partially the city of Nukus. The total length of the canal is 13.698 km.

Throughout its entire length, the channel does not have an impervious lining and runs in semi-dredging. Due to the lack of impervious lining, there are large water losses from filtration from the canal.

During the reconstruction of the canal, the main attention is paid to raising the water level by narrowing the channel and cleaning the canal from sediments to the design sections, which will ensure the passage of the specified design water flow and ensure that the required water level is maintained at these flows.

The Kerder canal regulator has three openings measuring 8x4.0 m separated by a wall 75 cm thick. The openings are blocked by flat, recessed, sliding gates with electric lifts. The Tascharn canal regulator has five openings measuring 8x2.5 m, separated by a wall 75 cm thick. Flat, recessed, sliding gates block the openings with electrically driven lifts. From the side of the upper pool, a reinforced concrete ponur 30 cm thick was made.

The maximum flow rate for the canal is determined by the outcome of the size of the irrigated area and the value of the maximum hydromodulus. The forced flow is defined with a boost factor. The maximum flow rate of the head section of the channel is determined by the formula:

$$Q_{\max} = \frac{q_{\max} x w}{1000} = 152.00 \ m^3/s$$

where q_{max} = 1.06 maximum ordinate of the hydromodule, accepted given reference. W is Net area for the future (143400 ha).

Estimated water flow rates for canal sections are shown in the table 1.

Table 1. Estimated water consumption.

Name channel	Area, (net) ha	Maximum July ordinate hydromodule l/s. ha	Efficiency	Estimated consumption		
				Min. m^3/s.	Max. m^3/s.	Forced. m^3/s.
1	3	4	5	6	7	8
Anasai	143400	1.06	0.76	80.0	200.0	220.0

The total water consumption is determined by the formula:

$$W = Q_{\max} \cdot \tau \cdot 0.0864 \text{ thousand m}^3, \quad (12)$$

where $Q_{\max}$ is maximum flow; τ is amount of days.

The reconstruction of machine channels is currently accompanied by the construction of head-settling tanks [19, 20]. According to the methods of removing settled sediments on irrigation canals, sedimentation tanks are separated with hydraulic flushing, mechanical and hydromechanical cleaning (with the help of dredgers), and a combined cleaning system. In settling tanks, which are non-pressure structures with significantly increased dimensions, the water velocity slows down sharply, due to which suspended sediments are deposited. Settling tanks differ in the principle of operation of the chamber - for periodic and continuous action and in the number of chambers - for single-chamber and multi-chamber (Fig. 4).

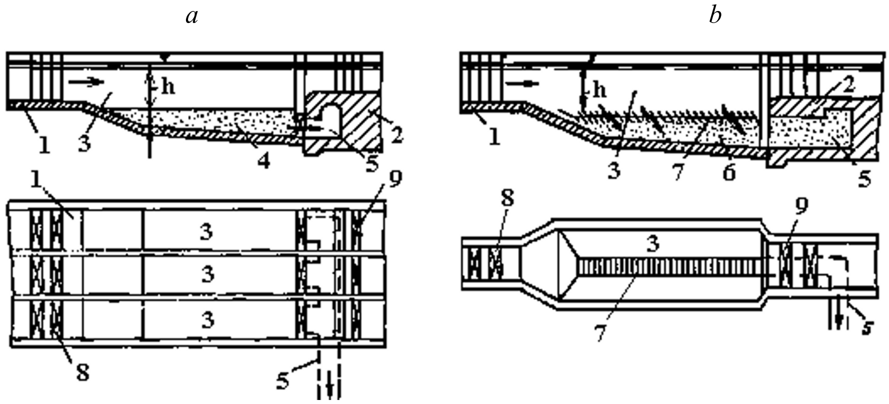


Fig. 4. Irrigation settling tanks: a is intermittent operation with washing of pumps, multi-chamber; b is continuous action with flushing of pumps, single-chamber; 1 is input threshold; 2 is output threshold; 3 is camera; 4 is dead volume; 5 is washing gallery; 6 is collection-flushing gallery; 7 is gratings; 8 and 9 are shutters on the input and output thresholds

In settling tanks with intermittent chambers, when the volume of deposited sediments reaches the calculated one, the chambers are turned off, and the settled sediments are removed. Such settling tanks are usually multi-chambered, with chambers switched off one by one as they are filled with sediments. In settling tanks with continuous chambers, sediment removal occurs without turning off the chambers. Bottom sediments from the washing chamber are washed when the top and bottom gates are opened.

Sedimentation tanks are included in the composition of the head waterworks, carrying a large number of suspended sediments (more than 0.2–0.5 kg/m^3), which, settling in water conduits, reduce their throughput, abrade the metal lining of water conduits, impellers and other elements of pumps. The introduction of the developed designs of sedimentation tanks improves the operating conditions of machine channels.

4 Conclusions

1. Of particular importance in modern conditions are recommendations for reconstructing existing PS to improve their performance. Experience in the operation of the PS shows that the commissioned large machine channels increase attention to water-saving issues, one of the key points of which is to reduce unproductive losses of unsteady water movement at all stages of transportation from the head water intake to irrigated fields.

2. Some options for connecting channels in the connection scheme of the head water intake structure of the Anasai and Kyzketken canals in the considered system are considered. On one of the channels adjacent to the node, there is a head pumping station. The parameters to be determined are the flow and depth of water in the canal. All channels, as a rule, should work in a uniform mode or with a small backwater.

3. The cases of water flow in channels considered by the equations of conservation of mass and momentum are used by the authors for the operating modes of machine channels with an approximate solution of these equations for some selected time t and the total number of days of operation τ *=const.*

References

1. Glovatskiy, O., Ergashev, R., Rashidov, J., Nasyrova, N., & Kholbutaev, B. Experimental and theoretical studies of pumps of irrigation pumping stations. In E3S Web of Conferences, Vol. 263, p. 02030. (2021).
2. Nasyrova N., Tadzhieva D., Krasnalobova D., Shodiev B. Use of Combined Floating Structures at Water Inlets of Pumping Stations. In: Vatin N., Borodinecs A., Teltayev B. (eds) Proceedings of EECE 2020. EECE 2020. Lecture Notes in Civil Engineering, Vol 150. Springer, Cham. (2021).
3. 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).
4. Mamajonov, M., Bazarov, D. R., Uralov, B. R., Djumabaeva, G. U., & Rahmatov, N. The impact of hydro-wear parts of pumps for operational efficiency of the pumping station. In Journal of Physics: Conference Series, Vol. 1425, No. 1, p. 012123. IOP Publishing. (2019).
5. E. Kan and N. Ikramov, "Effect of parallel connection of pumping units on operating costs of pumping station," 2019, 05008, p. 5008.
6. 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). AIP Publishing (2023).
7. 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. EDP Sciences. (2023).
8. Gazaryan, A., & Glovatskii, O. Flow calculations in intake structures of hydropower plants. In E3S Web of Conferences, Vol. 264, p. 03021. EDP Sciences. (2021).
9. 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).
10. Kan E., and Nasrulin A. Technical and economic indicators of reconstructed irrigation pumping stations. In AIP Conference Proceedings (Vol. 2612, No. 1). AIP Publishing (2023).
11. Kan, E. Calculation of Total Erosion in the Lower Reaches of Mezhdurechensk Reservoir Using Empirical Morphometric Dependencies. In E3S Web of Conferences, Vol. 365, p. 03030. EDP Sciences. (2023).
12. Kan, E., & Vatin, N. Consumption of Irrigation Pumps Pumping Water with a High Content of Mechanical Impurities. In E3S Web of Conferences, Vol. 365, p. 03011. EDP Sciences. (2023).
13. Norkulov, B. E., Nazaraliev, D. V., Kurbanov, A. I., Gayratov, S. S., & Shodiyev, B. Results of a study of severe deformation below the damless water intake section. In AIP Conference Proceedings, Vol. 2612, No. 1. AIP Publishing. (2023).

14. Utemuratov M.M. Corrosion of pressure pipelines and concrete structures of large pumping stations in Uzbekistan. Journal "European sciences review". Austria, № 7-8. p.122-126 (2017).
15. 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).
16. 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).
17. Nasyrova, N., Glovatsky, O., Ergashev, R., Rashidov, J., & Kholbutaev, B. Design aspects of operation of water supply facilities of pumping stations. In E3S Web of Conferences, Vol. 274, p. 03008. EDP Sciences. (2021).
18. Kodirov, D., Muratov, K., Davirov, A., Normuminov, J., Mamadjanov, B., Shukuraliyev, A., Musayev, S. Study on the effective use of solar and hydro energy for powering agriculture and water management. In IOP Conference Series: Earth and Environmental Science, Vol. 1142, No. 1, p. 012029. IOP Publishing. (2023).
19. Tkachev A. A., Ivanenko Y. G., Zarubin V. V., & Olgarenko, I. V. Automation of water distribution management during the reconstruction of main irrigation canals. In IOP Conference Series: Materials Science and Engineering, Vol. 537, No. 3, p. 032070. IOP Publishing. (2019).
20. 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).