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Mathematical model of optimal control of the supply canal to the first pumping station of the cascade of the Karshi main canal

A.J. Seytov, A.R. Kutlimuradov, R.N. Turaev,N.K. Muradov,A.A. Kudaybergenov

PhD, Department of "Mathematics", Chirchik State Pedagogical Institute. Chirchik, Uzbekistan
PhD, Department of "Mathematics", Chirchik State Pedagogical Institute. Chirchik, Uzbekistan
PhD, Department of "Mathematics", Chirchik State Pedagogical Institute. Chirchik, Uzbekistan
PhD, Department of "Mathematics", Chirchik State Pedagogical Institute. Chirchik, Uzbekistan
Doctoral student,t National University of Uzbekistan named after Mirzo Ulugbek, Tashkent, Uzbekistan and Assistant of Department of Algorithmization and Programming Technologies of Karakalpak State University named after Berdakh. Nukus, Uzbekistan

ABSTRACT:Currently, research work is being carried out aimed at improving and developing methods, quality criteria, developing mathematical models of optimal control, using modern information systems, operating modes of water facilities of reservoirs, canals of irrigation systems, main canals and rivers, for supplying water resources to consumers. In this direction, one of the necessary tasks is the development of optimal control based on the methods of projection of the gradient of water distribution in facilities of water management on the basis of optimal control methods, quality criteria, mathematical models and algorithms that ensure water saving.

KEY WORDS: mathematical model, unsteady flow of water, main canals, optimal control problems, fundamental solution, differential equations, hydraulic structures.

I.INTRODUCTION

Some of the largest and most unique systems of pumping water for irrigation in the world are being functioned in the Republic of Uzbekistan, which provide water for more than 2 million hectares of irrigated land. They include various cascades of pumping stations and hydraulic structures, powerful hydro mechanical and electrical equipment, pressure pipelines with various diameters and lengths, inlet and outlet canals, substations and power supply networks of various capacities. Such systems include the Karshi main canal with a cascade of pumping stations, the Amu-Bukhara machine canal with two cascades of pumping stations, the Jizzakh cascade of pumping stations and the Amu-Zangsky pump stations (PS) cascade.

As an object of research, we have chosen the Karshi main canal (KMC) with a cascade of pumping stations, which is one of the largest and most unique of the machine water lifting system for irrigating the republic. Six PS functions as part of the KMC cascade, each of them is equipped with six pumping units with axial pumps of the ARV-11-260 type, EHARV-10-260EHI, with six synchronous electric motors of the D375 / 130-24 type with a capacity of 12.5 mW. The total installed capacity of all pump stations is 450 mW, and the normal capacity of the cascade of pumping stations is forced $-195m^3$ per seconds. The total height of the water rise of the PS cascade is $138.6m$, and the length of the engine section of the Karshi Main Line is 80 km. As part of the KMC, the seventh pumping station also functions to fill the Talimarjan reservoir with a capacity of 1.3 billion m^3 during the low-water period, the water resources of which are additionally used for irrigation of irrigated lands in the Kashkadarya region during the growing season along the gravity-flowing part of the KMC.

Currently, the PS cascade, due to long operation and the presence of a number of reasons, does not function at the proper level. These reasons are:
- changes in the water content of the Amu Darya river due to climatic conditions of recent years affect the level regimes of the supply canal to the first pumping station of the cascade, since the water intake in the Karshi main canal near

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Vol. 8, Issue 3 , March 2021

Cape Pulizindan on the Amu Darya river is damless and this, in turn, affects the level modes in the front chamber of the first pumping station, which determine the working modes of the pumping units of the first pumping station and the operating modes of the entire cascade of pumping stations;
- due to the long-term operation of axial pumps, their hydraulic system for turning the blades out of order and they were welded at various angles of rotation in the pumps. This does not make it possible to maintain the specified performance of the PS and the entire cascade;
- failure to take into account the distribution of water flow parameters in the supply canal to the first pumping station, in the canals between the pumping stations of the cascade in time and in space, gives incorrect values of the parameters and time of transient processes in the canals when the modes of their operation change;
- the absence of automation and telemechanics systems during the operation of the cascade of pumping stations of the Karshi main canal, various types of which functioned in previous years, does not make it possible to maintain at least the specified operating modes of the PS cascade.

During the operation of the PS KMC cascade under these conditions, there are constant losses of water and energy resources. It should be noted that research on improving the operation modes of large PS cascades using modern control methods based on computer technology and new PS equipment in the country has not been carried out in recent years.

II. METHODS

The use of the equations of unsteady water movement to determine the operating modes of the canal section for the implementation of the given planned modes creates certain difficulties in preparing the initial information, initial and boundary conditions for the system of these equations.

Therefore, to set the initial conditions, we can use the equation of the steady-state uneven water movement in the sections of the Karshi main canal. The operating modes of the canal sections are determined on the basis of the specified water flow rates of the side branches and the water level in the end sections of the canal sections, i.e. water levels in the downstream and upstream of pumping stations, and these modes are considered constant throughout for a decade.

Based on the condition that the variable parameters remain constant over time, i.e. in the equations of unsteady water movement in the sections of the canal, the partial derivatives in time are equal to zero and taking into account that the canal bed is prismatic, we obtain the following system of equations for the uneven movement of water on the supply canal to the PS-1 [6,7].

$$\frac{dQ}{dx} = q, \quad (1)$$

$$\frac{dP}{dx} + \frac{d}{dx}\left(\frac{Q^2}{\omega}\right) = -g\omega\left(\frac{dz_0}{dx} + \frac{Q|Q|}{K}\right) + F, \quad (2)$$

Lateral outflows are lumped or distributed. Lateral outflow structures are considered as concentrated outflows, and losses for filtration and evaporation are considered for distributed outflows.

Lateral outflows are set as follows [1,2,8,16]

$$q(x,h) = q_f(x,h) + q_i(x,h) + \sum_{n=1}^{N} q_n(h_a)\delta(x-a_n), \quad (3)$$

where, $q_f(x,h)$, $q_i(x,h)$ is the intensity of losses due to filtration and evaporation, $q_n(h_a)$ is the flow rate of water at the n side outlet, $\delta(x-a_n)$ is the delta function characterizing the location of the outlet of water consumers along the length of the canal section, a_n is the distance to the n side outlet.

The flow rate and water level at the end of the canal section are set as the initial conditions [3,4, 9, 14]

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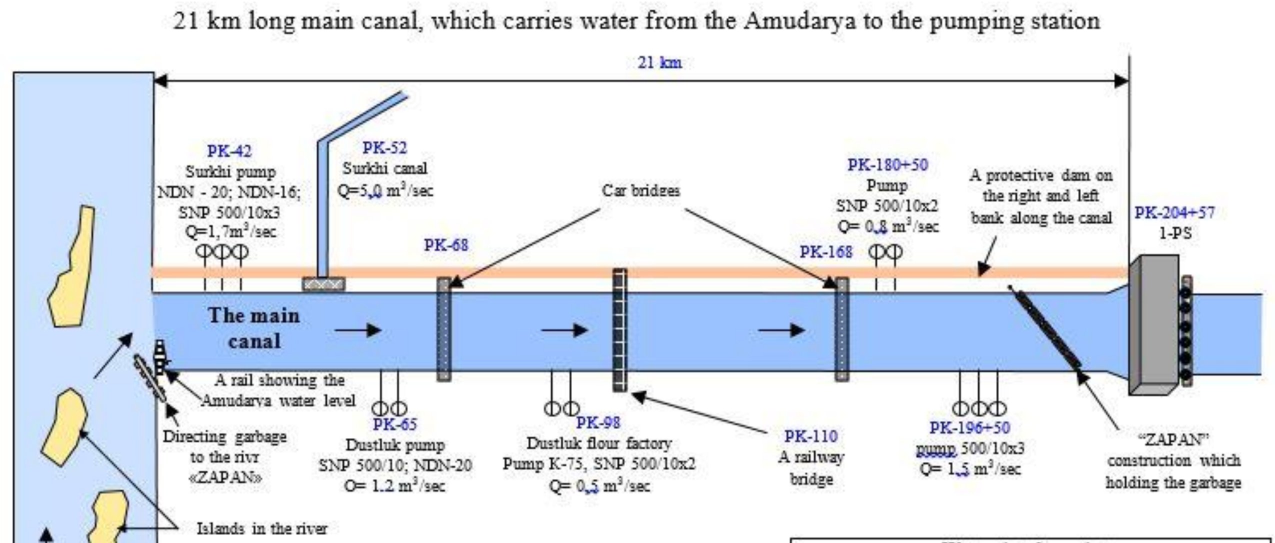
$$Q(l)=Q_k, \quad h(l)=h_k \tag{4}$$

where, Q_k , h_k - flow rate and water level at the end of the canal section.

In the alignment of the canal section, where the lateral outlets are located, appropriate restrictions on the water levels are set, which ensure the specified flow rates as follows

$$h(a_n)\geq h^*_{an}, \quad n=\overline{1,N} \tag{5}$$

where h^*_{an} is the level value required to supply the water flow rate to the outlet; N - the number of outlets.



Length of the main canal::	21 km	Average width:	80 m
Number of hydraulic structures	14 ta	Average canal depth	7 m

Number of employees in the cleaning control service (person)	Normal	According to the current state	The difference (+;-)
	11	11	0

Water intake points					
№	ПК	Name and brand	number	m³/s	
1	42	Surkhi pump SNP500/10, NDN-20, NDN-16	3	1,700	1990
2	52	Surkhi canal	1	5,000	1972
3	65	Dustluk pump SNP500/10,NDN-20	2	1,200	1987
4	98	Dustluk flour factory K-75,SNP500/10	2	0,500	2000
5	180+50	Pump SNP500/10	2	0,800	2005
6	196+50	Pump SNP500/10	3	1,500	2006
		All	13	10,700	

Fig 1. Scheme of the supply canal to the first pumping station of the Karshi main canal cascade

Taking into account that functions of $P(x,h)$ and $\omega(x,h)$ are functions of variables of x and h, equation (2) can be written as follows [10,11]

$$\frac{\partial P}{\partial x}+\frac{\partial P}{\partial h}\frac{dh}{dx}+\frac{2Q\omega\, dQ-Q^2 d\omega}{\omega^2 dx}=-g\omega\left(\frac{dz_0}{dx}+\frac{Q|Q|}{K^2}\right)+F, \tag{6}$$

After simple algebraic transformations and, taking into account (2), we obtain the following equation

$$\frac{\partial P}{\partial x}+\frac{\partial P}{\partial h}\frac{dh}{dx}+\frac{2Qq}{\omega}+\frac{Q^2}{\omega^2}\left(\frac{\partial\omega}{\partial x}+\frac{\partial\omega}{\partial h}\frac{dh}{dx}\right)=-g\omega\left(\frac{dz_0}{dx}+\frac{Q|Q|}{K^2}\right)+F. \tag{7}$$

ISSN: 2350-0328
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Vol. 8, Issue 3 , March 2021

After simple transformations, we finally have [12,13]

$$\left(\frac{\partial P}{\partial h}+\frac{Q^2}{\omega^2}\frac{\partial\omega}{\partial h}\right)\frac{dh}{dx}=-g\omega\left(\frac{dz_0}{dx}+\frac{Q|Q|}{K^2}\right)+F-\frac{\partial P}{\partial x}-\frac{2Qq}{\omega}-\frac{Q^2}{\omega^2}\frac{\partial\omega}{\partial x}. \quad (8)$$

Suppose that the canal bed, flow rate Q, water depth h, for example, at the end of the canal in the section $(N-N)$ and hydraulic parameters of the canal section are given.

The initial conditions for the equations are determined based on the solution of equations (7) under conditions (3) - (5). This problem is also solved algorithmically, determining modes with different values of the water level at the end of the canal section at known values of water flow rates at the end and side water consumers, we calculate the curves of the free surface of the water flow for the corresponding values of the levels.

The boundary conditions are written as follows

$$z_1(0,t)=z_a(t), \qquad Q_i(l_i,t)=Q_{i+1}(l_{i+1},t)=Q_i^{NS}(t)\,,\ \ i=1\,. \quad (9)$$

where $z_a(t)$ is the change in the water level in the Amu Daryariver.

As lateral water intakes of the supply canal to the first pumping station, the water discharge in the Surkhi canal and other water intakes are considered, in total of $10,7\,m^3/s$ for the discharge [13].

III. RESULTS

Results of calculating the problems of optimal control of operation modes of canals and a cascade of pumping stations of the Karshi main canal.

Calculations of individual problems of optimal control of operating modes of canals and a cascade of pumping stations of the Karshi main canal were carried out using this developed software package in the Python language.

Supply canal to the first pumping stations. The channel length is 19.8 km, the bottom width is 35 m, the roughness coefficient is 0.02, the slope coefficient is 4, the slope is 0.00005.

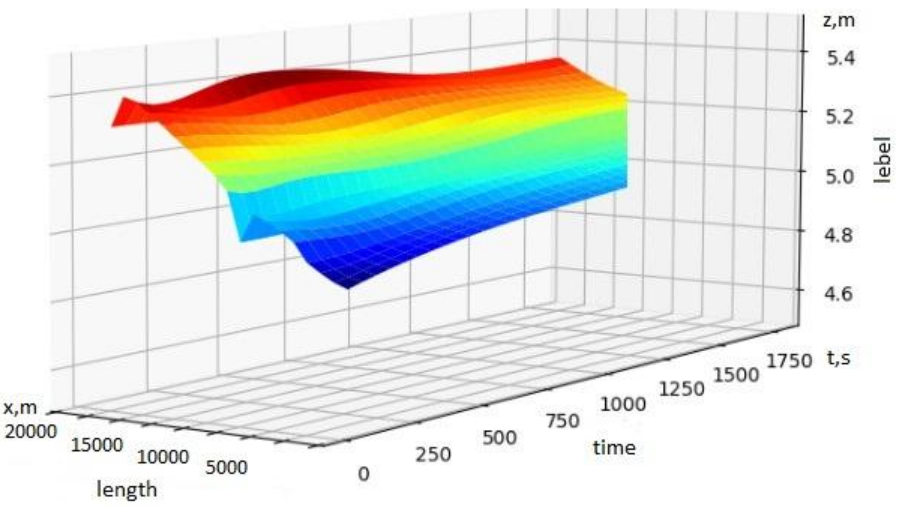

Fig. 2. Change in water level in time and along the length of the supply canal to the first pumping station

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Vol. 8, Issue 3 , March 2021

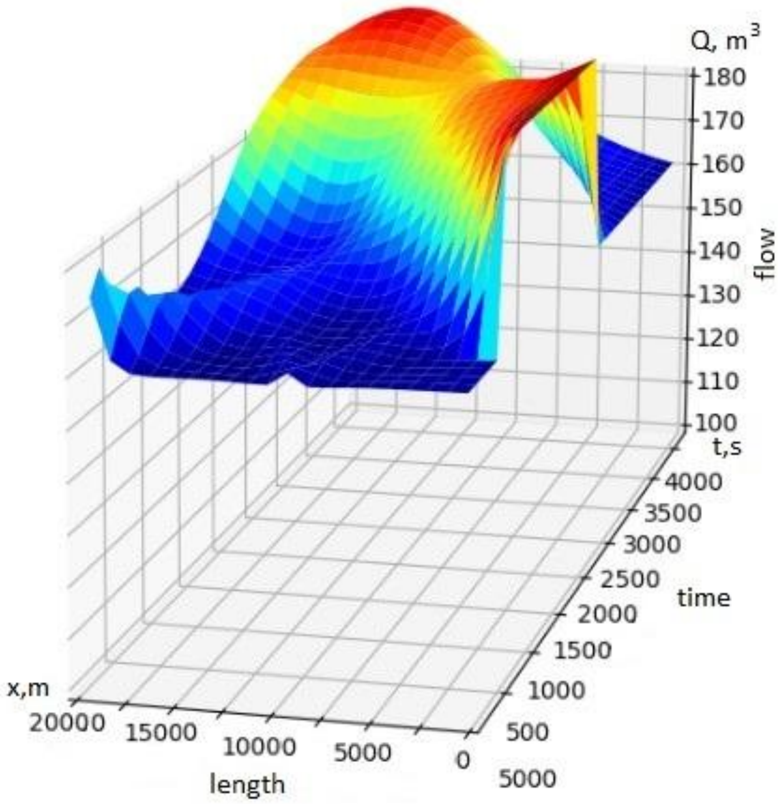

Fig. 3. Change in water consumption over time and along the length of the supply canal to the first pumping station.

In fig. Figures 2, 3 show the results of numerical experiments to determine the change in the level and flow rate of water in the supply canal to the pumping stations.

It can be seen from the figures that the increased flow rate in the supply canal makes it possible to increase the water level along the length of the canal. During t = 29,000 s (8.06 h), the water level at the end of the canal increases by 1.4m.

The obtained results of numerical experiments show that the level and flow rate of water at the end of the canal is stabilized, which is necessary for the first pumping station of the Karshi main canal located there.

IV. CONCLUSION

Based on the research carried out, the following main conclusions and recommendations can be drawn:

1. Mathematical models of optimal control of the supply canal to the first pumping station have been developed, taking into account their modern parameters and operation modes of these canals, as well as mathematical models of optimal control of modern working modes of the pumping stations of the Karshi main canal cascade, taking into account the necessary parameters of objects and equipment of pumping stations.

2. On the basis of the selected algorithms methods, algorithms have been developed for optimal control problems for unsteady water movement in sections of the Karshi main canal and the process of water supply by a cascade of large pumping stations of the Karshi main canal, which make it possible to solve the corresponding optimization problems, as well as on their basis, numerical algorithms have been developed for solving the problems of optimal control of the

canal section, limited by two pumping stations, pumping stations and hydraulic structures on the Karshi main canal section, which solve the problems of unsteady water movement in the canal and process sections water supply of the cascade of pumping stations of the Karshi main canal.

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AUTHOR'S BIOGRAPHY

Seytov Aybek Jumabayevich, was born in 1979, teacher. Author of more than 25 scientific papers. Researcher at the Laboratory "Modern Information Technologies in Water Management and Water Resources Management" Research Institute of Irrigation and Water Problems Ph.D. in technical sciences, received the BachelorDegree in Applied Mechanics-mathematics from National University Uzbekistan, Tashkent, Uzbekistan in 2000. He is pursuing PhD in Management, systems analysis and computer science at Tashkent University of Information Technologies, Tashkent, Uzbekistan. Her research areas include Mathematical modeling, optimal management of distributed parameters, management of water resources in canals, rivers and water facilities, Numerical implementations of nonlinear differential equations, information processing, Programming and Software Engineering.
Address: Laboratory "Modern Information Technologies in Water Management and Water Resources Management" Research Institute of Irrigation and Water Problems Ph.D. in technical sciencesTashkent, Uzbekistan

Kutlimurotov Allanazar Razzakberdievich, was born in 1974, teacher. Author of more than 20 scientific papers. Dean of the Faculty of Mathematics and informathics of the Chirchik State Pedagogical Institute, Tashkent Region, Ph.D. in physical and mathematical sciences, received the BachelorDegree in Applied Mechanics-mathematics from National University Uzbekistan, Tashkent, Uzbekistan in 1996. He is pursuing PhD in Mathematician analysis and mathematical models and control of physical processes at National University of Uzbekistan, Tashkent, Uzbekistan. Her research areas include on the geometric condition of quasiconformality and their application in mathematical modeling and control of physical processes.
Address: faculty Mathematics and informathics of the Chirchik State Pedagogical Institute, Tashkent Region Ph.D. in physical and mathematical sciences Tashkent, Uzbekistan

Turaev Rasul Nortozhievich, was born in 1973, teacher of mathematics and computer science. Author of over 100 scientific papers. Until 2020 senior Researcher of the Laboratory "Mathematical Modeling of Nonlinear Systems" Institute of Mathematics of the Academy of Sciences of the Republic of Uzbekistan. Currently he works as an assistant professor at the Chirchik State Pedagogical Institute. Candidate of Physics and Mathematics, senior Researcher. He is working towards his PhD in Nonlinear Differential Equations and Mathematical Modeling of Nonlinear Systems and Water Resources Management. Research areas include mathematical modeling of nonlinear differential equations and systems, free boundary problems for parabolic equations for water management in canals, rivers and water facilities.

Makhkamov Erkin Musurmanovich, was born in 1983, teacher. Author of more than 12 scientific papers. Head of the Department of Mathematics of the Chirchik State Pedagogical Institute, Tashkent Region Ph.D. in technical sciences, received theBachelor Degree in Applied Mechanics-mathematics from National University Uzbekistan, Tashkent, Uzbekistan in 2005. He is pursuing PhD in Mathematician analysis and mathematical models and control of physical processesat National University of Uzbekistan, Tashkent, Uzbekistan. Her research areas include Application of local residue in problems of restoring holomorphic functions and using them to develop mathematical models and control of physical processes.
Address: Department Mathematics of the Chirchik State Pedagogical Institute, Tashkent Region Ph.D. in physical and mathematical sciences Tashkent, Uzbekistan

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Kudaybergenov Adilbay Abatbaevich, was born in 1979. Researcher at Berdaq Karakalpak State University.Author of more than 15 scientific papers. Received the Bachelor Degree in Applied Mathematics from Karakalpak State University, Nukus, Uzbekistan in 2000and the Marter Degree in Applied Mathematics from Karakalpak State University, Nukus, Uzbekistan in 2002. Her research areas include Artificial Intelligence, Programming, Graph Theory and Software Engineering. At the prensent time he is a PhD student at the National University of Uzbekistan named after Mirzo Ulugbek.
Address: Department of Applied mathematics, Karakalpak State University. Nukus, Uzbekistan