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Optimal Management Of Water Resources Of Large Main Canals With Cascades Of Pumping Stations

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Abstract: In this article studied the problem of optimal management of water resources of large main canals with cascades of pumping stations and using the methods of system analysis of the process of water supply and water intake, modern methods for calculating the operating modes of pumping stations with long pipelines and calculating the operating modes of canal sections.

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

Introduction

In the process of water distribution management, the values of water discharge are mainly determined, which are set for consumers of canals of machine water lifting systems during a decade of the corresponding period and based on the solution of the problem of calculating the outflow and water discharge. Uzbekistan is considered as one of the largest irrigation farming countries in Central Asia. Proper use of existing water and land resources can increase crop production and yields in the agriculture sector [1]. Applications for head water intakes and canal sections for a decade determine the operating modes of canal sections that implement consumer requests in terms of costs. The choice of operating modes of the canal sections is carried out on the basis that all side water intakes are guaranteed to receive the planned flow rates of water resources with minimal water losses for filtration and evaporation. The choice of the operating mode of the control of canal is carried out on the basis that all lateral water intakes are guaranteed to receive the planned discharge of water resources with minimal water losses for filtration and consumption. When using canals, it is important to assess quantitative indicators of the state of reliability associated with such adverse effects as wear of canal dams under the influence of dangerous filtration currents, subsidence, and elevation of canal sections relative to the area [2].

Side outlets are guaranteed to receive water discharge if they have appropriate water pressure in front of the structure. These necessary pressures determine the values of water levels in the canal sections, which are determined in the process of water distribution.

Let us consider the statement of the problem of calculating the operating modes of the canal sections for the operational management of water distribution.

The calculated planned (limited) costs at the beginning of sections, water outlets and the end of the canal must be implemented at each section of the canal.

Therefore, we use the equation of the steady-state non-uniform movement of water in the sections of the canal. The operating modes of the canal sections are determined on the basis of the given water discharge of the side outlets and the water level in the end sections of the canal sections, i.e., water levels of the upstream of the partitioning structures and these regimes are considered constant during a decade.

Materials and methods

Let's consider the problem on the example of one section of the main canal.

Based on the condition that the variable parameters remain constant over time, i.e., in equations (1) - (2) the partial time derivatives are equal to zero and given that the canal bed is prismatic, we obtain the following system of equations for the uneven movement of water in the canal section [3,4]:

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

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

Lateral outflows and inflows are concentrated or distributed. As concentrated inflows and outflows, lateral water outlets or concentrated inflows are considered, and as distributed outflows - losses due to filtration and evaporation.

Lateral inflows and outflows are set as follows [5]:

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

where: $q_f(x, h)$, $q_f(x, h)$ – intensities of filtration and evaporation losses, $q_n(h_a)$ – water discharge of n-th side outlet, $\delta(x-a_n)$ – delta function characterizing the location of the outlet of water consumers along the length of the canal, a_n – distance to the n-th side outlet.

As the initial conditions, the flow rate and water level at the end of the canal sections are set:

$$Q(l)=Q_k, \quad h(l) = h_k. \quad (4)$$

In the canal section, where the lateral water outlets are located, the corresponding restrictions on water levels are set, which provide the given discharge as follows:

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

where: h^*_{an} - the level value required to supply the water discharge to the water outlet.

The task of determining the operating modes of the canal section in the presence of backwater from the lower barrier structure is reduced to determining such a value of the water level at the end of the canal section h_k, which would minimize seepage and evaporation losses in the canal section. At the same time, the water levels in the canal sections, where the side outlets are located, satisfy the restrictions on the water pressure in front of the outlet structure and side outlets [6,7].

The criterion for minimizing evaporation and filtration losses is written as follows [8]:

$$I = \min_{h_k} \int_0^l [q_f(x,h) + q_i(x,h)]dx \quad (6)$$

The operating modes of the canal section are written by equations (1) - (5).

Restrictions on the implementation of specified limits for lateral and final water consumers are written as:

$$Q(l)=Q_k, \quad q_n(h)= q_{nk}, \quad h(a_n) \geq h^*_{an}, \quad n = 1,\dots,N, \quad (7)$$

To solve the formulated problem, the main point is the calculation of the free water surface in the canal section with side water intakes.

Results and discussions

Currently, there are various methods for calculating the curve of the free surface of the uneven movement of the water discharge, based on the integration of the differential equation of the uneven movement of water in open canals without lateral outflows and inflows.

These techniques are based on the use of graphical dependencies or table functions and are not suitable for use in modern computers.

In general research are presents a numerical algorithm for calculating the free surface curve of uneven water flow in open canals with lateral outflows and inflows, based on the integration of the differential equation for uneven water movement using the finite difference method and the quasi-linearization method for approximating nonlinear dependencies.

Considering that the functions P(x, h)) and ω(x, h) are functions of the variables x and h, the second equation can be written as [8]:

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

After simple algebraic transformations and, taking into account (7), we obtain the following equation

$$\frac{\partial P}{\partial x}+\frac{\partial P}{\partial h}\frac{dh}{dx}+\frac{2Qq}{\omega}+\frac{Q^2}{\omega^2}\left(\frac{\partial \omega}{\partial x}+\frac{\partial \omega}{\partial h}\frac{dh}{dx}\right)=-g\omega\left(\frac{dz_0}{dx}+\frac{Q|Q|}{K^2}\right)+F \quad (9)$$

After simple transformations, we finally have [5]:

$$\left(\frac{\partial P}{\partial h}+\frac{Q^2}{\omega^2}\frac{\partial \omega}{\partial h}\right)\frac{dh}{dx}=-g\omega\left(\frac{dz_0}{dx}+\frac{Q|Q|}{K^2}\right)+F-\frac{\partial P}{\partial x}-\frac{2Qq}{\omega}-\frac{Q^2}{\omega^2}\frac{\partial \omega}{\partial x} \quad (10)$$

Let us assume that the canal bed, discharge Q, water depth h_n, for example, at the end of the canal in the section (N-N) and the hydraulic parameters of the site are given (Fig. 1).

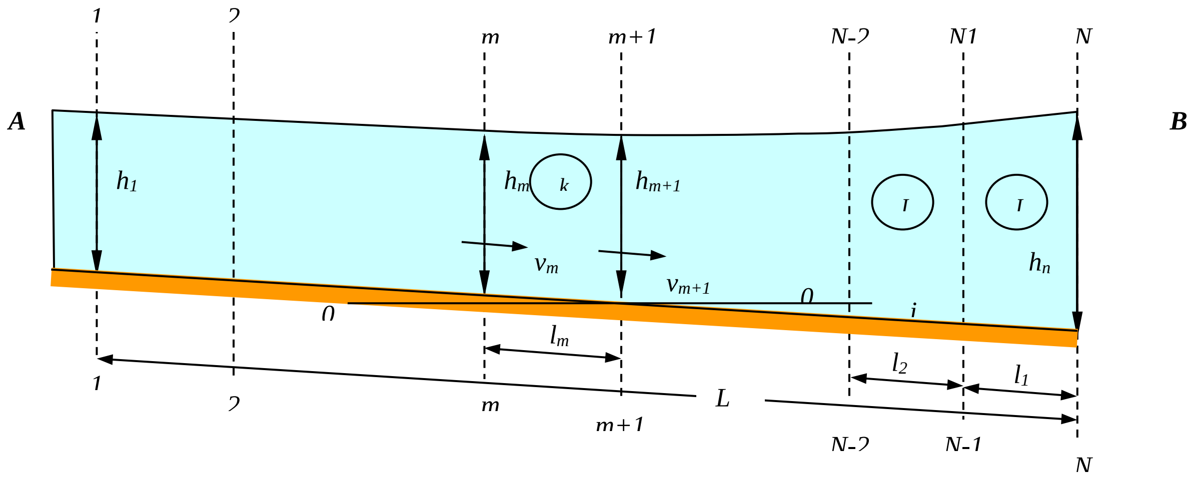

Fig.1. - Scheme of the section of the main canal

We divide the section of the canal, which has a length L, into separate sections of a relatively small length equal to l_m. In this case, each selected section of the canal with a length l_m is considered separately, going upstream: first, we calculate section I, then II, and so on: first, we calculate section I then II, and so on. he calculation of each section consists in determining the depth h_m and discharge Q_m at the beginning of this section, using the known values l_m and h_{m+1}

Applying finite difference methods for equations (1) and (2), we obtain the following difference equations [9,10,11,12]:

$$\frac{Q_{m+1}-Q_m}{l_m}=q_m, \quad (11)$$

$$\left(\frac{\partial P}{\partial h}+\frac{Q_m^2}{\omega_m^2}\frac{\partial \omega}{\partial h}\right)_{m+1}\frac{h_{m+1}-h_m}{l_m}=-g\omega_{m+1}\left(\frac{dz_0}{dx}+\frac{Q|Q|}{K_m^2}\right)_{m+1}+\left(F-\frac{\partial P}{\partial x}-\frac{2Qq}{\omega_m}-\frac{Q_m^2}{\omega_m^2}\frac{\partial \omega}{\partial x}\right)_{m+1}, \quad (14)$$

(12)

where: $(.)_{m+1}$ – means that the corresponding expression is calculated from the known values of Q_{m+1} and h_{m+1} and corresponds to small sections with the number m+1.

The calculation is carried out from the end section of the canal to the beginning, i.e., the unknown quantities are Q_m and h_m which are calculated by formulas (9) and (10), i.e. water discharge Q_m and depth h_m are determined recursively at the boundary sections [13, 14, 15]

(N-1), (N-1),…,(2),(1).

$$Q_m=Q_{m+1}+q_m l_m, \quad (13)$$

$$h_m=h_{m+1}+\left(\frac{-g\omega_{m+1}\left(\frac{dz_0}{dx}+\frac{Q|Q|}{\overline{K}^2}\right)_{m+1}+\left(F-\frac{\partial P}{\partial x}-\frac{2Qq}{\omega}-\frac{Q^2}{\omega^2}\frac{\partial \omega}{\partial x}\right)_{m+1}}{\left(\frac{\partial P}{\partial h}+\frac{Q^2}{\omega^2}\frac{\partial \omega}{\partial h}\right)_{m+1}}\right)l_m$$

where (.)$_m$ and (.)$_{m+1}$ – are the parameters for the section m and m+1, l_m – is the length step.

For a prismatic canal without lateral inflow, the equation has the following form [16,17]

$$h_m = h_{m+1} + \left(\frac{\left(i - \frac{Q|Q|}{\overline{K}^2} \right)_{m+1}}{\left(1 - \frac{Q^2}{g} \frac{B}{\omega^3} \right)_{m+1}} \right) l_m \quad (15)$$

The main empirical variable in dependences (12) and (13) is the discharge modulus of the canal section. In numerical calculations, the approximate formula [18,19,20]:

$$\overline{K} = \frac{1}{2}\left(K(x_{m+1},\ h_{m+1}) + K(x_{m+1},\ h_{m+1} + l_m K(x_{m+1}, h_{m+1})) \right) \quad (16)$$

We have implemented computer calculations using expressions (12), (13) in the form of software modules for calculating the curve of the free surface of the water discharge. An algorithm for determining modes with different values of the water level at the end of the canal section with known values of the 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 level values. Further, according to the curve of the free surface, the conditions for fulfilling the restriction on the pressure in front of the outlets are checked and such a value of the water level at the end of the canal is selected, at which all restrictions on the pressures of the outlets would be met and the values of the total loss for evaporation and filtration in the canal section would be minimal. The described algorithm is implemented as a software module for calculating the parameters of the canal section.

The initial data for the calculation are the morphometric and hydraulic parameters of the canal, the coordinates of the points at which the level values should be calculated, the ranges of changes in the flow rates along the canal and the water horizons in the final section of the site, for which steady state calculations are made. Calculation results of steady-state regimes for the first section of the ПК 239+41 canal with a change in water depth in the upstream of the structure at PK 239+41 from 5.25 m to 6.5 m with a step of 0.25 m and water flow from 5 to 75 $м^3$/с are given in tables 1.

Table 1. Water volume (million m3) in the first section of the canal and PC and PK 239+41

Water dicharge	**Water depth at the end of the canal** (м)					
($м^3$/с)	5,25	5,50	5,75	6,00	6,25	6,50
5,00	3,341	3,608	3,883	4,160	4,462	4,764
10,00	3,345	3,611	3,886	4,170	4,464	4,766
15,00	3,351	3,616	3,890	4,174	4,467	4,769
20,00	3,359	3,623	3,896	4,179	4,471	4,773
25,00	3,369	3,632	3,904	4,186	4,477	4,778
30,00	3,382	3,643	3,913	4,194	4,484	4,784
35,00	3,397	3,655	3,924	4,203	4,462	4,791
40,00	3,414	3,670	3,936	4,214	4,501	4,799
45,00	3,433	3,686	3,950	4,226	4,512	4,808
50,00	3,454	3,704	3,966	4,239	4,523	4,818
55,00	3,476	3,723	3,983	4,254	4,536	4,829
60,00	3,500	3,744	4,001	4,270	5,550	4,841
65,00	3,526	3,767	4,020	4,187	4,565	4,854
70,00	3,553	3,790	4,041	4,305	4,581	4,868
75,00	3,581	4,041	4,063	4,324	4,598	4,883

Table 2. Water depth at the beginning of the first section of the canal and ПК 239+41

Water dicharge	**Water depth at the end of the canal** (м)					
($м^3$/с)	**5,25**	**5,50**	**5,75**	**6,00**	**6,25**	**6,50**

5,00	4,058	4,307	4,557	4,807	5,056	5,306
10,00	4,066	4,314	4,562	4,811	5,060	5,309
15,00	4,080	4,325	4,572	4,819	5,066	5,315
20,00	4,100	4,341	4,585	4,829	5,075	5,322
25,00	4,124	4,361	4,601	4,843	5,087	5,343
30,00	4,153	4,385	4,621	4,859	5,100	5,356
35,00	4,186	4,412	4,644	4,878	5,116	5,372
40,00	4,224	4,444	4,669	4,900	5,134	5,356
45,00	4,265	4,478	4,698	4,924	5,155	5,372
50,00	4,309	4,515	4,730	4,951	5,177	5,389
55,00	4,356	4,555	4,763	4,790	5,202	5,408
60,00	4,406	4,598	4,800	5,010	5,228	5,429
65,00	4,458	4,642	4,838	5,046	5,256	5,451
70,00	4,511	4,668	4,878	5,077	5,285	5,501
75,00	4,566	4,737	4,920	5,112	5,317	5,528

Conclusion

As a result of the research, the methodology for calculating the improved operating modes of the facilities of the machine water lifting system for irrigation - the cascade of the Amu Zang pumping stations has been refined:

- analysis of water intake and supply regimes of the Amu Zang cascade of pumping stations;
- parameters of pumping units and pressure pipelines were determined and specified;
- the methodology for calculating the modes of water intake and water supply of pumping stations based on the theoretical-set approach has been refined;
- algorithms for calculating the planned needs of water resources by agricultural crops by districts and along the canals of the Amu Zang cascade of pumping stations for the growing season were developed;
- the methodology for calculating the steady-state operating modes of sections of the cascade canals has been refined.

The effectiveness of the work lies in the need to equip the facilities of the machine water lifting systems for irrigation with modern information systems based on computer technology, which improve the quality of water distribution management, improve the decision-making process on water supply and water distribution in the system.

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