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Optimal Water Management in the Channels of Machine Water Raise Systems

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ABSTRACT: The article studies the problem of water resources management in the channels of machine water lifting systems and developed improved modes of water supply to systems of machine water lifting for irrigation, developed on the basis of the use of modern mathematical models, optimal control methods and algorithms will ensure the saving of water and energy resources in the system of machine water lifting.

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

I. INTRODUCTION

Once the ecological situation has been assessed, it is important to consider how water can be efficiently managed within the pumping station cascade. This may involve assessing the capacity of each station, as well as the amount of water that is being pumped through the system. It may also involve considering the source of the water, including whether it is being drawn from a local river or other waterway, or from an underground aquifer [25,26].

In addition to the strategies mentioned above, it may also be important to consider the potential impacts of climate change on the water resources in the area. This could include changes in precipitation patterns, increased frequency and intensity of extreme weather events, and changes in the timing and amount of snowmelt. By planning for these potential impacts and implementing adaptation strategies, such as increasing water storage capacity or implementing more flexible pumping schedules, it is possible to ensure that water resources can continue to be managed effectively in the face of changing environmental conditions.

Another important aspect of optimal water management is stakeholder engagement. This may involve consulting with local communities, businesses, and other organizations to understand their needs and priorities related to water resources. By engaging with stakeholders in a transparent and collaborative manner, it is possible to build support for water management strategies and ensure that they are implemented in a way that is equitable and inclusive [27].

Finally, it is important to regularly monitor and evaluate water management strategies to ensure that they are achieving their intended goals. This may involve monitoring water quality and quantity, tracking changes in local ecosystems, and assessing the social and economic impacts of water management strategies. By regularly evaluating and adjusting water management strategies based on new information and changing conditions, it is possible to ensure that water resources are being managed in the most effective and sustainable way possible.

Any complex hydrographic scheme of the channels of machine water lifting systems can be divided into several simple structures, which are a graph-tree. The tree graph structure is divided into hierarchies. The hierarchy in the graph is defined using two parameters [1-3]

$$\Omega_I = \left\{ \left[i, \quad K_i^{\Gamma P} \right] \; \forall i \in I \right\} \tag{1}$$

i - hierarchy number; $K_I^{\Gamma P}$ – number of groups in the given hierarchy.

Groups are a set of sections connected to their beginnings. A group can have one or more parcels.

Each group is defined by the following numbers [3,4]

$$\Omega_\Gamma = \left\{ \left[j_{i\Gamma}, \; n_{ij\Gamma}, \; \kappa_{ij\Gamma} \right], \; \kappa_{ij\Gamma} \in N_{ij\Gamma}, \; \forall j_{i\Gamma} \in I_{i\Gamma}, \quad \forall i \in I \right\}, \tag{2}$$

$j_{i\Gamma}$ –group number in the hierarchy; $n_{ij\Gamma}$ –number of the section connected to this group with its end; $\kappa_{ij\Gamma}$ –number of groups in the given hierarchy; $N_{ij\Gamma}$ –set of numbers included in this group of sections of the river; $I_{i\Gamma}$ –set of group numbers included in this hierarchy.

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Vol. 10, Issue 5, May 2023

Each section of the graph is defined as follows [5,6]

$$\Omega_M = \{[m, k_{mB}, k_{m\Pi}, m_y], \ \forall k_{mB} \in K_{mB}, \forall k_{m\Pi} \in K_{m\Pi}, \forall m \in M\}, \qquad (3)$$

m - plot number; k_{mB}, $k_{m\Pi}$ и m_y - respectively, the number of water intakes, tributaries and plots at the end; K_{mB}, $K_{m\Pi}$ и m_y - set of numbers of water intakes, tributaries and numbers of sections located at the end, respectively. Each section of the channel has its own morphological and hydraulic characteristics, which, for example, for trapezoidal prismatic sections, will be written as follows, m –plot number, b_{0m} –bottom width, m_m - slope factor, n_m-roughness factor, i_m -site bottom slope, l_m -section length, η_m -channel section efficiency.

In the case of a non-prismatic section of the channel, the characteristics are given as follows [7,8]

$$\Omega_M^x = \{[m, \ h_{im}, \ B_{im}, \ Q_{im}, \ l_m] \ \forall i \in I_m, \ \forall m \in M\}, \qquad (5)$$

where m – is plot number, h_{im} - depth, B_{im} - width on top of plot in vertical section i, Q_{im} - water consumption corresponding to this mode, i.e. consumption characteristics of the canal sections.

Thus, the structure of the main canal is determined by the knowledge of sets (1) - (5) and they fully characterize its topology and hydraulic characteristics [9]

$$\Omega_K = \Omega_I \cup \Omega_\Gamma \cup \Omega_M \, . \qquad (6)$$

On the basis of the linear scheme of the main canal, hierarchies, groups are determined and all sections, branches, tributaries of the canal are numbered. After that, the sets Ω_I , Ω_Γ , Ω_M are compiled in the form of a table with the corresponding fields, these tables are filled in accordance with the accepted numbering of sections, branches, tributaries, groups and hierarchies. This representation of the structure of the main canal is very convenient for developing a database and solving problems of managing the water resources of the main canal.

Let us consider the record in the given terms of the database of balance relations in the channel sections from the condition of the presence of steady modes in the channel sections.

The water flow at the beginning of the m – section of the canal is determined as follows [10,11]

$$Q_m^H = \frac{Q_m^K + \sum_{j \in J_m^B} Q_{Bmj} - \sum_{j \in J_m^\Pi} Q_{\Pi mj}}{\eta_m}, \quad \forall m \in M \, , \qquad (7)$$

где Q^H_m , Q^H_m - water flow at the beginning and end, Q_{Bmj}, Q_{Bmj} -water consumption of water intakes and tributaries, η_m - is the efficiency of the m - section of the channel.

In the groups $j_{i\Gamma}$ in i - hierarchy of the structure of the main channel, the balance ratios are written as [12]

$$Q_{n_{ij\Gamma}}^K = \sum_{\kappa_{ij\Gamma} \in N_{ij\Gamma}} Q_{\kappa_{ij\Gamma}}^H, \quad \forall n_{ij\Gamma} \in I_{i\Gamma}, \qquad (8)$$

$Q_{n_{ij\Gamma}}^K$ - water flow at the end of the section $n_{ij\Gamma}$-section connected to this group by its end, $Q_{\kappa_{ij\Gamma}}^H$ water flow at the end of section $k_{ij\Gamma}$ - the section of the canal of group $j_{i\Gamma}$.

For end sections in groups, water flow rates are set at the end of these sections [13,14]

$$Q_{m_k}^K = Q_{m_k}, \quad \forall m_k \in M_k \, , \qquad (9)$$

where $Q_{m_k}^K$ - water flow rates at the end of the end sections in the groups of the m_k-section connected to this group by its end, Q_{m_k} - given water flow in the end sections of the main canal, $M_k \in M$ - set of numbers of end sections of the main canal.

Using expressions (7) - (9) with known values of water flow rates at the outlets of water intakes and inflows, as well as at the ends of the final sections of the main canal, starting from the last hierarchy of the canal structure, it is possible to calculate the required water flow rates at the beginning of all sections of the main canal. The resulting water flow rates provide the specified flow rates at the water intakes and end sections of the canals, taking into account the known water flow rates at the inflows at given efficiency values of k.p.d. channel sections.

In the problem of determining water needs in the annual planning of water distribution for the growing season, crop irrigation regimes i are used, in which for each hydromodule region k in each irrigation j, irrigation norms $W_{ikj\Pi}$, irrigation dates, i.e., start t_{ikjH}, end t_{ikjK} and duration of watering $T_{ikj}= t_{ikjH} - t_{ikjK}$. Irrigation rate W_{ikO} for the growing season is determined as the sum of irrigation rates, i.e. $W_{ikO} = \sum_{j=1}^{N_i} W_{ikj\text{П}}$. For planning water resources for each crop, ten-day hydro- and irrigation modules are calculated. The ten-day hydromodule is the required specific water consumption (l/s/ha) supplied evenly for a given decade of the growing season. A ten-day irrigation module is the required specific area (ha/irrigation) irrigated in a given decade of the growing season.

II. SIGNIFICANCE OF THE SYSTEM

The article studies the problem of optimum water resources management of large main canals with cascades of pumping stations. The study of methodology is explained in section III, section IV covers the experimental results of the study, and section V discusses the future study and conclusion.

III. METHODOLOGY

The algorithm for calculating the ten-day hydro - and irrigation module for crop irrigation regimes for the growing season, which is necessary for implementation in the water management database, has the following form:

1. Irrigation regimes for agricultural crops are selected in accordance with the hydromodule area of the region under consideration.

2. For a given hydromodule region of the region, the irrigation regime of the selected crop, starting from the first decade of the growing season, the start and end dates of the decade are compared with the start date of crop irrigation, there may be the following cases:

a. the initial date of irrigation of agricultural crops is outside the decade, in this case, for this decade, the ten-day hydro - $q_{ikjn\text{Д}}$ and irrigation modules $s_{ikjn\text{Д}}$ are equal to zero, i.e. [15,16]

$$q_{ikjn\text{Д}}=0, \tag{10}$$

$$s_{ikjn\text{Д}}=0, \tag{11}$$

where $q_{ikjn\text{Д}}$ is ten-day hydromodule (l/s/ha), $s_{ikjn\text{Д}}$ is irrigation module (ha/irrigation), i – is crop, k -is hydromodule area, j – is irrigation number, n – is current decade number.

b. if the start date of irrigation of agricultural crops is between the start and end dates of the decade, then for this decade the ten-day hydromodule $q_{ikjn\text{Д}}$ and irrigation $s_{ikjn\text{Д}}$ modules are determined by the following dependencies [17,18]

$$q_{ikjn\text{Д}} = \frac{W_{ikjn\text{Д}}(T_{ikj} - t_{ijkH} - 1)}{86{,}4T_{ikj}}, \tag{12}$$

$$s_{ikjn\text{Д}} = \frac{(T_{ikj} - t_{ijkH} - 1)}{T_{ikj}}, \tag{13}$$

t_{nH} is the start date of the decade, n – is the number of the current decade,

c. if the start and end dates of the decade are between the start and end dates of irrigation of crops, then for this decade the $q_{ikjn\text{Д}}$ hydromodule and $s_{ikjn\text{Д}}$ irrigation modules are defined as [19,20]

$$q_{ikjn\text{Д}} = \frac{W_{ikjn\text{Д}}}{86{,}4T_{ikj}}, \tag{14}$$

$$s_{ikjn\text{Д}} = \frac{T_{n\text{Д}}}{T_{ikj}}, \tag{15}$$

where $T_{n\text{Д}}$ is the number of days in a given decade.

.

d. if the end date of irrigation of agricultural crops is between the start and end dates of the decade, then for this decade the ten-day hydromodule is determined as follows [21]

$$q_{ikjn\text{Д}} = \frac{W_{ikjn\text{Д}}(t_{ijkH} - t_{nK})}{86{,}4T_{ikj}}, \tag{16}$$

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$$s_{ikjnД} = \frac{(t_{ijkH} - t_{nK})}{T_{ikj}}, \tag{17}$$

where t_{nK} – is the start date of the decade, n is the number of the current decade.

3. Ten-day hydromodule of agricultural crops is determined by summing ten-day irrigation hydromodules

$$q_{iknД} = \sum_{n=1}^{N_{ik}} q_{ikjnД}. \tag{18}$$

$$s_{iknД} = \sum_{n=1}^{N_{ik}} s_{ikjnД}. \tag{19}$$

In (10) - (19) ten-day hydromodules $q_{ikjnД}$ has the dimension (l/s/ha), ten-day irrigation modules $s_{ikjnД}$ - (ha/irrigation), irrigation duration T_{ikj} and date differences, for example $t_{ikjH} - t_{nK}$ (days).

IV. EXPERIMENTAL RESULTS

Ten-day hydro - and irrigation modules of crops calculated according to the algorithm (10) - (19) are the basis for calculating the water demand of crops for the growing season, depending on the sown areas of the respective crops.

Next, consider the sequence of calculating the needs of the water resources of the main canal consisting of $m \in M$ sections, in each section of the canal there are branches $j \in J_m$, and each branch j irrigates the areas ω_{jmik} where $j \in J_m$ are the numbers of branches in the m- section, J_m are the sets of numbers of branches in the m-section;

$-m \in M$ –numbers of sections of the main canal, M – is the set of numbers of sections of the main canal;

$-i \in I_{mj}$ –types of agricultural crops sown on suspended lands of the j - branch in the section of the canal with the number m; I_{mj} - a set of types of agricultural crops suspended by the lands of the j - allotment in the section of the canal with the number m

$-k \in K_{mjk}$ - types of hydro-modular areas suspended from the lands of the j – branch on the canal section with number m, K_{mjk} - set of types

–hydromodule areas suspended from the lands of the j –branch in the section of the canal with the number .

Thus, ω_{mjik} is the structure of the sown areas of the entire main canal, then for each branch, taking into account the modes of irrigation of crops, the need for water resources is determined as follows [22]

$$Q^{П}_{Omjn} = \sum_{i \in I_{mj}} \sum_{k \in K_{mji}} \frac{q_{iknД}\,\omega_{mjik}}{\eta_{вxmj}}, \tag{20}$$

$$Q^{П}_{mjn} = Q^{П}_{Omjn} + q_{ДПmjn}, \tag{21}$$

where $q_{iknД}$ – ten-day hydromodules of the i –crop of the k –hydromodule region for the n – decade; $Q^{П}_{Omjn}$ is the required flow for irrigation of water, $q_{ДПmjn}$ – is the required flow of non-agricultural consumers, $Q^{П}_{mjn}$ is the total required water flow of the j – outlet of the m –section of the main canal for the n –decade; $\eta_{вxjm}$ is the efficiency factor of the on-farm canals of the j – outlet of the m – section of the main canal..

Irrigated areas by consumers are determined as

$$S^{П}_{mjn} = \sum_{i \in I_{mj}} \sum_{k \in K_{mji}} s_{iknД}\,\omega_{mjik} \tag{22}$$

where $S^{П}_{mjn}$ – irrigated areas of the j –outlet of the m –section of the main canal for the n –decade of the growing season; $s_{iknД}$ - ten-day irrigation modules of the i –crop of the k –hydromodule region for the n – decade.

Similarly, according to formula (20), the required water flow rates at the end outlets of the main canal are determined.

The required costs and irrigated areas suspended by the m –plot in the n – decade of the growing season on the plots are determined as follows

$$Q^{П}_{mn} = \sum_{j \in J_m} Q^{П}_{mjn}, \tag{23}$$

IJARSET
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Vol. 10, Issue 5, May 2023

$$S_{mn}^{П} = \sum_{j \in J_m} S_{mjn}^{П}, \qquad (24)$$

where J_{mj} –are the sets of branch numbers of the m – section of the main canal.

According to expressions (20) - (21), the needs of the canal sections in water resources for the n - decade of the growing season are determined.

The sequence (algorithm) for calculating water flow rates for sections of the main canal is as follows:

1. In accordance with (9) and (20), the required water flow rates are calculated for the n - decade at the end of the final sections of the main canal

$$Q_{nm_k}^{ПК} = Q_{nm_k}^{П}, \quad \forall m_k \in M_k, \quad \forall n \in N_B, \qquad (25)$$

2. Then, starting from the last hierarchy by hierarchy groups in the sections, the required water discharges for the n- decade at the beginning of the sections of the main canal are calculated as follows [23]

$$Q_{mn}^{ПН} = \frac{Q_{mn}^{ПК} + Q_{Bmn}^{П} - Q_{Пmn}^{П}}{\eta_m}, \quad \forall m \in I_{iГ}, \quad \forall n \in N_B, \qquad (26)$$

$$Q_{Bmn}^{П} = \sum_{j \in J_m^B} \left(Q_{OBBmj}^{П} + q_{ДПmjn} \right) = Q_{OBBm}^{П} + q_{ДПmn}, \quad \forall m \in I_{iГ}, \quad \forall n \in N, \qquad (27)$$

$$Q_{Пmn}^{П} = \sum_{j \in J_m^П} Q_{Пmjn}^{П}, \quad \forall m \in I_{iГ}, \quad \forall n \in N_B, \qquad (28)$$

$$Q_{OBmn}^{П} = \sum_{j \in J_m^B} Q_{OBmjn}^{П}, \quad \forall m \in I_{iГ}, \quad \forall n \in N_B, \qquad (29)$$

$$q_{ДПmn} = \sum_{j \in J_m^B} q_{ДПmjn}, \quad \forall m \in I_{iГ}, \quad \forall n \in N, \qquad (30)$$

where $Q^{ПН}_{mn}$, $Q^{ПК}_{mn}$ - water flow at the beginning and end of the site, $Q^{П}_{Bmn}$, $Q^{П}_{Пmn}$ - total water consumption of required water intakes and forecast inflows, $Q^{П}_{OBmn}$, $q_{ДПmn}$ - total water discharges of required water intakes for irrigation and other consumers, J_m^B - set of numbers of water intakes on the site, $J_m^П$ - set numbers of tributaries in the section, $I_{iГ}$ - set of section numbers in the group under consideration, η_m - efficiency of the m – section of the canal, N_B - numbers of the decade of the growing season.

3. In the groups $j_{iГ}$ in the i hierarchy of the structure of the main channel, the balance ratios are written as [24]

$$Q_{n_{ijГ}n}^{ПК} = \sum_{\kappa_{ijГ} \in N_{ijГ}} Q_{\kappa_{ijГ}n}^{ПН}, \quad \forall n_{ijГ} \in I_{iГ}, \ \forall n \in N_B, \qquad (31)$$

where $Q_{n_{ijГ}}^{K}$ is the water flow at the end of the $n_{ijГ}$ section.

4. Next, the calculation is repeated in steps 2 - 3 for the next hierarchy in the structure.

Thus, the planned modes of operation of sections of the main canal are calculated to meet the needs of all consumers, which are characterized by the following set:

$$\Omega_M^{BП} = \left\{ \left[m, \ Q_{mn}^{ПН}, Q_{mn}^{ПК}, Q_{Bmn}^{П}, \ Q_{Пmn}^{П}, \ Q_{OBmn}^{П}, q_{ДПmn}^{П}, \ S_{mn}^{П} \right] \ \forall m \in M, \forall n \in N_B \right\}. \qquad (32)$$

. Here $Q^{ПН}_{mn}$, $Q^{ПК}_{mn}$ – are the water consumption at the beginning and end of the site, $Q^{П}_{Bmn}$, $Q^{П}_{Пmn}$ – are the total water discharges of water intakes and tributaries, $Q^{П}_{OBmn}$, $q^{П}_{ДПmn}$ – are the total water consumption for irrigation and other consumers, $S^{П}_{mn}$ – are the irrigated areas of agricultural crops suspended on the plot m for the decade n of the vegetation period.

The head required (planned) water flow $Q_{m_г n}^{НП}$ corresponding to the initial section of the canals of the machine water lifting system for decades of the growing season is the required flow for all consumers of the canal. Here $m_г$ – is the number of the initial section of the main channel.

Determining the need for water resources by consumers of the main canal in the non-vegetation period is similar to that for the growing season. The only difference is that instead of irrigation regimes for crops, leaching rates of irrigation of saline lands by types of salinization, the irrigation rate of grain and other crops during the non-vegetation period, and the rates of water-charging irrigation are used.

For the non-vegetation period, leaching regimes for saline areas are determined by salinity types *i*, in which leaching rates, irrigation rates for grain crops and the rate of water-charging irrigations $W_{ikjП}$, irrigation periods, i.e. start t_{ikjH} , end t_{ikjK} and duration of irrigation $T_{ikj}= t_{ikjH} - t_{ikjK}$. The leaching rate, irrigation rate for cereals during the non-vegetation period and the rate of water-charging irrigation $W_{ikП}$ are determined as the sum of leaching and irrigation rates, i.e. . $W_{ikП} = \sum_{j=1}^{N_i} W_{ikjП}$.

Appendix 6 to Table A1.2 shows the flushing regimes for saline lands during the non-vegetation period. For planning water resources for each type of saline lands, ten-day flushing hydro and irrigation modules are calculated. A ten-day leaching hydromodule is the required specific water consumption (l/s/ha) supplied evenly for flushing saline lands in a given decade of the non-vegetation period. A ten-day irrigation module is the required specific area (ha/irrigation) irrigated in a given decade of the non-vegetation period. Ten-day hydro and irrigation modules for the non-vegetation period are calculated according to the algorithm (10) - (19) using the data in Table A1.2.

The algorithm for calculating the planned water supply regimes for sections of the main canal for the non-vegetation period, to provide leaching irrigation of saline lands, irrigation of grain water-charging irrigation of all outlet consumers is characterized by the following set [25]

$$\Omega_M^{НВП} = \left\{\left[m,\ Q_{mn}^{НП}, Q_{mn}^{КП}, Q_{Bmn}^{П},\ Q_{Пmn}^{П},\ Q_{OBmn}^{П}, q_{ДПmn}^{П},\ S_{mn}^{П}\right]\ \forall m \in M, \forall n \in N_{HB}\right\}. \quad (33)$$

Here $Q^{ПН}{}_{mn}$, $Q^{ПК}{}_{mn}$ – are the water discharge at the beginning and end of the canal section, $Q^{П}{}_{Bmn}$, $Q^{П}{}_{Пmn}$ – are the total water discharges of water intakes and tributaries, $Q^{П}{}_{OBmn}$, $q^{П}{}_{ДПmn}$ – are the total water discharges for irrigation and other consumers, $S^{П}{}_{mn}$ – are the irrigated areas of agricultural crops suspended on the plot m for a decade n outside the growing season, N_{HB} –the numbers of the decade of the growing season.

The elements of the set (33) are calculated on the basis of saline lands leaching regimes, irrigation of crops during the non-vegetation period, according to the structure of areas of saline lands, the structure of crops of grain and other crops irrigated during the non-vegetation period.

With the calculation of all elements of the sets (32) - (33) according to the above algorithm, the problem of determining the planned needs in the annual planning of irrigation of irrigated lands is solved

V. CONCLUSION AND FUTURE WORK

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 Jizzakh pumping stations has been refined:

- analysis of water intake and water supply regimes of the Amu Zangsky pumping station cascade;
- 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;
- the methodology for calculating the steady-state operating modes of sections of the cascade channels has been refined.

It should be noted that the developed method for calculating the operating modes of the objects of the machine water lifting system for irrigation, using the example of the Jizzakh pumping station cascade, will improve the operating modes of the system objects, reduce the consumption of water and energy resources during water lifting in the system and increase the operational efficiency of the system objects by increasing the speed of obtaining, storage and processing of necessary information.

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