Operational Management of Water Distribution Processes in River Basins, Main and Inter-Farm Canals

Tolaniddin Nurmukhamedov, Abdulkhay Azimov, Javlon Gulyamov and Zebo Tulaganova
Tashkent State Transport University, Temiryolchilar Str. 1, 100167 Tashkent, Uzbekistan
ntolaniddin@mail.ru, azimovabdulhay1915@gmail.com, javlonbek1207@gmail.com, tulaganovazebo07@gmail.com

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Abstract: This article addresses pressing issues in the field of water resource management, with a particular focus on the development of mathematical models and quality criteria designed for the efficient and precise management of water distribution systems. These systems include river basins, primary canals, and inter-farm waterways, which are critical for ensuring sustainable agricultural and industrial activities. The article analyzes various challenges encountered in the development and implementation of operational management systems, such as water scarcity, uneven distribution, and technical inefficiencies. It further explores potential solutions and highlights the necessity of adopting advanced mathematical approaches, algorithmic methods, and intelligent software tools to improve system performance. Emphasis is placed on the integration of real-time data processing and predictive analytics to enhance decision-making processes. Additionally, the study presents the design and testing of newly developed algorithms aimed at addressing real-time distribution challenges, supported by custom software applications capable of automating key functions in water management systems.

1 INTRODUCTION

With the growing reliance on computer technologies in the management of water and land resources, alongside increasing demands for the efficiency of resource management within river basins, primary canals, and inter-farm waterways, the necessity arises to develop advanced algorithmic and software tools. These tools aim to address operational management challenges for water resources, enabling the optimal utilization of water management infrastructure. Such solutions are expected to minimize unproductive losses of water and energy, enhance the operational efficiency of facilities, and establish a resource management system that operates effectively within the constraints of limited capital and operational budgets.

At present, the process of operational water distribution management in river basins, main canals, and inter-farm waterways faces significant challenges. These include notable discrepancies between actual and desired water distribution regimes, leading to over-supply in some areas and shortages in others. Additionally, unproductive water losses occur due to inefficiencies in the existing water management system. Consequently, it becomes crucial to analyze and select mathematical models that describe the dynamics of water systems, ensuring compatibility with modern computer technologies and software tools. Developing algorithms and programs for simulating the behavior of water facilities and addressing real-time operational water distribution management tasks holds particular significance.

2 MATHEMATICAL MODELS OF TYPICAL OBJECTS OF WATER MANAGEMENT COMPLEXES FOR OPERATIONAL

Mathematical models designed for sections of a river basin to address operational management tasks must strike a balance: they should accurately represent the key dynamic processes within the system while remaining sufficiently simple to enable efficient computational solutions.

To address operational control challenges, balance differential equations can be employed as a mathematical model for sections of a river [1], [4]:

$$\frac{dW_i^y}{dt} = Q_i^H - Q_i^K + \sum_{j\in N^M} Q_{ji}^{AB} + \sum_{j\in N^{nT}} Q_{ji}^{PR} + Q_i^{PR} - Q_i^P$$
$$W_i^y(0) = W_{i0}^y \quad t\in[0,T], \tag{1}$$

where $W_i^y(t)$ is the volume of water located in section i at time t , Q_i^H and is Q_i^K the water consumption at the beginning and end of the section; Q_{ji}^{B3} and Q_{ji}^{PR} - water flow of the j -th water intake and the j -th concentrated inflow of the i -th section; Q_i^P - intensity of water loss due to filtration and evaporation of the i -th section; Q_i^{PR} forecast water flow of distributed tributaries; $W_{i0}^y(t)$ - initial value of water volume in the i -0 m area; T is the duration of the operational control interval.

In general Q_i^K , Q_{ji}^{B3} , $W_i^y(t)$, Q_i^P depend on the water level H_i^Y in the river section and on the hydraulic and morphometric characteristics of the river section and hydraulic structures [2].

Mathematical models of reservoirs. The variation in reservoir water volumes over time for operational management purposes is represented by the (2) [3].

$$\frac{dW_t^B}{dt} = \sum_{j\in N^M} Q_{ji}^{PR} - \sum_{j\in N_i^Z} Q_{ji}^{B3} - Q_i^P - Q_i^{POP}$$
$$W_t^B(0) = W_{t0}^B, t\in[0,T], \tag{2}$$

where $W_i^B(t)$.is the volume of water in the i -th reservoir at time t ; Q_{ji}^{PR} and Q_{ji}^{B3} - water flows of the j -th inflow and j -th water intake of the i -th reservoir; Q_i^P - intensity of water loss in the reservoir and Q_i^{POP} - flow rate of water passing from the reservoir.

Restrictions on operating modes of sites, reservoirs and control and management points have the form [3]

$$W_i^{Y\min} \le W_i^Y \le W_i^{Y\max}, \tag{3}$$

$$W_j^{B\min} \le W_j^B \le W_j^{B\max},$$

$$Q_{ji}^{\min} \le Q_{ji} \le Q_{ji}^{max},$$

where $W_i^{Y\min}$, $W_j^{B\min}$, $W_i^{Y\max}$, $W_j^{B\max}$ are the minimum and maximum values of water volumes of the river and reservoir sections. These values are determined from the morphometric characteristics of the river section and reservoir.

Mathematical models of pumping stations.

A) Lifting height (static head) - defined as the difference

$$H = H_{vb} + H_{nb}. \tag{4}$$

levels of the upstream and downstream of the pumping station.

B) Characteristics of pressure losses in the pipeline - presented in reference catalogs in the form of functional curves, depending on the flow and lifting height [8], [15]:

$$Q_T^i = \begin{cases} Q_j^i & J=\overline{1,K};\ (i=\overline{1,N}),\quad N\le M \\ H_T^j & J=\overline{1,K} \end{cases}. \tag{5}$$

Where:

1) Q_j^i -argument for the pressure characteristics of the pipeline, i.e. supply of the i-th pumping unit;
2) K - number of points in the pressure characteristic;
3) N is the number of operating pumping units;
4) $H_i^j = H + \Delta H_j$
5) pressure characteristic function;
6) $\triangle H_j$- pressure loss.

C) The performance characteristics of the pumping unit are depicted as a set of curves that illustrate the relationship between the water lift height and various impeller blade angles:

$$\Omega_j^i = \Omega_{H,Q,\varphi} \cup \Omega_{H,m,\varphi},\ i=\overline{1,N}. \tag{6}$$

Where Ω_j^i is the flow characteristic of the pumping unit

$$\Omega_{H,Q,\varphi} = \begin{Bmatrix} Q_j^K & i=\overline{1,N}, & (j=\overline{1,K}) \\ H_i & i=\overline{1,N}, & \\ \varphi_j & j=\overline{1,K}, & \end{Bmatrix}$$

1) energy characteristics of the pumping unit

$$\Omega_{H,\eta,\varphi} = \begin{Bmatrix} \eta_j^i, i=\overline{1,N}, (j=\overline{i,K}) \\ H_i, i=\overline{1,N} \\ \varphi_j, j=\overline{i,K} \end{Bmatrix}.$$

2) φ_j .- corner reversal blades, corresponding j crooked;
3) η_j^i - efficiency i th pumping unit for j - ouch crooked.

D) Acceptable area D of work pumping unit V coordinates $Q-H$ defined by the following external boundaries:

$$\left.\begin{array}{l} D_{1\max}^i = \Omega_T^{i\max} \bigcap \Omega_{H,Q,\varphi}^i \\ D_{1\min}^i = \Omega_T^{i\min} \bigcap \Omega_{H,Q,\varphi}^i \\ D_{2\max}^i = \Omega_{H,Q,\varphi_{\max}}^i \\ D_{2\min}^i = \Omega_{H,Q,\varphi_{\min}}^i \end{array}\right\} \quad (7)$$

g de $\Omega_T^{\max}, \Omega_T^{\min}$ - characteristics of the pipeline at the maximum and minimum geometric height of the modem; $\varphi_{\max}, \varphi_{\min}$ - maximum and minimum angles of rotation of the blades on the pump unit [10]-[12].

If the values Q and H fall within the region D, it is assumed that the unit can supply the required water flow. Otherwise, this operating mode is considered unattainable for the unit. When multiple units are in operation, the permissible area boundaries are defined collectively

$$\Omega_p^i = (\Omega_t^i \bigcap \Omega_{H,Q,\varphi}) \bigcap \Omega_{H,Q,\eta}$$

$$\varphi_i = \varphi_i^p, \Omega_{H,Q,\varphi} \subset \Omega_j^i, \Omega_{H,\eta,\varphi}^i \subset \Omega_j^i \quad (8)$$

by aggregating the flow rates within the defined region boundaries at a fixed lift height.

E) The operation of each pumping unit is described by three key parameters: flow rate, manometric lift height, and efficiency [8], [9]:

$$\left(H_{pb}, H_{vb}, \psi\right),$$

where: φ_p^i is the rotation angle of the blades i of the th operating pump unit. Consequently, the flow rate and efficiency i of the pumping unit are determined from the expressions.

F) The overall flow and power consumption of the pumping station are calculated by summing the individual flows and power consumption of the operating units:

$$Q_{HC} = \sum_{i \in N^P} Q_i , \quad (9)$$

where:

1) $N_i = \gamma_i^H Q_i / 102\eta_i$, / kW/ - power i of the the pumping unit;
2) γ volumetric weight of the pumped liquid [6].

$$N_{HC} = \sum_{i \in N^P} N_i . \quad (10)$$

Mathematical models of the canal section. The condition of the main canal section is defined by variable water flow and is represented by a set of partial differential equations, known as Saint-Venant equations:

$$B\frac{\partial z}{\partial t} + \frac{\partial Q}{\partial X} = q,$$

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q*\omega)}{\partial X} = q\omega\left(\frac{\partial Z_O}{\partial X} + \frac{Q|Q|}{K^2}\right) \quad (11)$$

$$0 < x < l, l > t_0$$

where: $Q = Q\left(x,t\right)$ water consumption; $Z = Z(x,t)$ - ordinate of the free surface; ∂ - gravitational constant; I - bottom slope; $B = B(Z)$- width of the flow along the surface of the living section; $W = W(Z)$- live cross-sectional area of the flow; $C = C(Z)$- speed of propagation of small waves; $K = K(Z)$- flow module.

The system of hyperbolic partial differential equations in (11) includes the mass and momentum conservation equations of the flow, serving as a mathematical model for the unsteady flow of water within an open channel section and free surface ordinate $Z(x,t)$are chosen here as functions that determine the flow $Q(x,t)$. The independent variables are longitudinal coordinate $X$and time t.

The channel is characterized by the bottom elevation $Z_0(X)$ and the cross-sectional width $B(x.t)$ at a vertical distance Z from the channel bed.

Then:

- g flow depth: $h(x,t) = Z(x,t) - Z_0(x)$;
- cross-sectional area of the flow $W(x,h) = \int_0^h B(x,z)dz$;
- average current speed: $U = Q/W$;
- speed of propagation of small waves: $C = \sqrt{\partial W / B}$
- bottom slope: $I = \frac{\partial Z_0}{\partial X}$.

$$K = W * C\sqrt{R}. \quad (12)$$

Flow module $K(X,h)$ characterizes the magnitude of friction forces and is determined by the following formula: where: $R = W/X$- hydraulic radius of the channel; X- wetted perimeter of the channel; C- Chezy coefficient.

To determine the Chezy coefficient, there is a whole series of empirical formulas [7]. Pavlovsky's formula can be accepted as one of them:

$$C = \frac{1}{\eta} R^{\gamma}, \gamma = 2,5\sqrt{n} - 0,13 - 0,75\sqrt{R}(\sqrt{n} - 0,1), \quad (13)$$

where η is the channel roughness coefficient.

To analyze the state of an object using the mathematical model, it is essential to define initial and boundary conditions that describe the solution's domain of determination.

The initial conditions are given as:

$$\begin{matrix} Q(X,0) = Q_0(X) \\ Z(X,0) = Z_0(X) \end{matrix}, \quad (14)$$

where: $Q_0(X), Z_0(X)$ are known functions.

In general, the boundary conditions can be written as follows:

$$\begin{matrix} Q(0,t) = F_1[Z_{vb}(t), Z(0,t), S_0^1(t), ...S_0^N(t)] \\ Q(l,t) = F_2[Z_{nb}(t), Z(l,t), S_l^1(t), ...S_l^N(t)] \end{matrix}, \quad (15)$$

where: $S_0^{\lambda}(t), (i = 1, ...N_0)$, Control parameters of the hydraulic structure located at the initial alignment $X = 0$, $S_l^{\lambda}(t), (i = 1, ...N_2)$, control parameters of the hydraulic structure located at the initial alignment $X = 0, N_1, N_2$ number of control parameters.

The boundary condition expressions vary based on the type of hydraulic flow beneath the gate, and they take the following form [13]:

$$\begin{matrix} Q(0,t) = \mu_1 S_1(t)\sqrt{2g\left[Z_{vb}(t) - Z(0,t)\right]} \\ Q(l,t) = \mu_2 S_2(t)\sqrt{2g\left[Z(l,t) - Z_{nb}(t)\right]} \end{matrix},$$

where: μ_1, μ_2 - cost coefficients of partitioning structures; S_1, S_2 - opening areas of the gates of partitioning structures.

3 ALGORITHMS FOR MODELING DYNAMICS OF TYPICAL WATER MANAGEMENT FACILITIES FOR OPERATIONAL WATER DISTRIBUTION CONTROL

The discrete versions of the balance (1) are formulated as follows

$$\frac{W_i^{YK+1} - W_i^{YK}}{t_K} = Q_i^{HK} - Q_j^{B3K} + \sum_{j \in N_{0,1}} Q_j^{B3K} + \sum_{j \in N^{nj}} Q_j^{nPK} + Q_i^{nPK} - Q_i^{nK} \quad (16)$$

$$W_i^{Y0} = W_{i0}^{Y}; i = 1,2,...N_j; \quad K = 0,1,2,...$$

The superscripts $K+1$and K- mean that the corresponding variables are taken at the moments t_{K+1} and t_K , $\triangle t_K = t_{K+1} - t_K$- time discretization step.

Algorithms for modeling reservoir dynamics. The discrete counterparts of the balance (2), which describe the dynamics of the reservoir filling and drawdown process, are expressed as follows [13], [14]

$$\frac{W_t^{BK+1} - W_t^{BK}}{t_K} = \sum_{j \in N_t^{\beta}} Q_j^{nPK} - \sum_{j \in N_t^{\beta}} Q_t^{B3K} - Q_t^{nK} - Q_t^{nOnK} \quad (17)$$

$$W_t^{B0} = W_{t0}^{B}; \quad i = 1,2,...N_B; \quad K = 0,1,2,...$$

Constraints (3) have the form:

$$W_i^{Y_{min}} \le W_i^{YK} \le W_i^{Y_{max}};$$

$$W_j^{B_{min}} \le W_j^{BK} \le W_j^{B_{\max}};$$

$$Q_n^{B_{min}} \le Q_n^K \le Q_n^{B_{\max}}; \qquad (18)$$

$$i = 1, 2 \ldots N_Y;\ j = 1, 2 \ldots N_B;\ n = 1, 2 \ldots W_{nKY}.$$

Algorithms for modeling the dynamics of a channel section. For the numerical solution of these boundary value problems, it is useful to express the system of (11) in its characteristic form:

$$S\frac{\partial U}{\partial t} + S\frac{\partial U}{\partial x} = F(U, K, t). \qquad (19)$$

The characteristic representation of the system (11) is given by the following form:

$$S = \begin{bmatrix} 1 & -B(\sigma + C) \\ 1 & -B(\sigma - C) \end{bmatrix}; \quad U = \begin{bmatrix} Q \\ Z \end{bmatrix};$$

the finite difference method is applied to numerically solve the boundary value problems (2.90) and (2.91).

In the area we introduce a grid with steps h by X and t by T.

$$\Omega = \{0 \le x \le e, 0 \le t \le T\}$$

$$\varpi_{hr} = \{(x_t, t_j) \div x_t = th;\ t_j = jz;\ i = 0,1, \ldots N;\ j = 0,1, \ldots M;\ h = l/N;\ \tau = T/M\}$$

By approximating the system of (19) with an unconditionally stable implicit difference scheme, which has second-order approximation in space and first-order approximation in time due to linearization, we obtain a system of difference equations for the internal grid points [15-17]

$$-A_P^K \cdot W_{P-1}^{K-1} + B_P^K W_P^{K+1} - C_P^K \cdot W_{P+1}^{K+1} = D_P^K, P = 1, \ldots N. \qquad (20)$$

where (19):

$$W_P^{K+1} = U_P^{K+1}; \qquad U_P^{K+1} = U(x_P, t_{K+1});$$

$$A_P^K = -\frac{\tau}{2h}(\Box S)_P^K; \qquad B_P^K = S_P^K - \tau\left(\frac{\partial F}{\partial U}\right)_P^K;$$

$$C_P^K = \frac{\tau}{2h}(\Box S)_P^K; \qquad D_P^K = \left[S_P^K - \tau\left(\frac{\partial F}{\partial U}\right)_P^K\right]U_P^K + \tau F_P^K;$$

$$\frac{\partial F}{\partial U} = \begin{bmatrix} \partial F / \partial Q \\ \partial F / \partial Z \end{bmatrix}.$$

Next, by utilizing the systems of (11) and the boundary conditions, we derive the difference conditions [18]:

$$B_0^K W_0^{K+1} - C_0^K W_1^{K+1} = D_0^K, \qquad (21)$$

$$-A_N^K W_{N-1}^{K+1} - B_N^K W_N^{K+1} = D_N^K, \qquad (22)$$

where:

$$A_N^K = \begin{bmatrix} a_{11N}^K & a_{12N}^K \\ a_{21N}^K & a_{22N}^K \end{bmatrix}; \qquad B_N^K = \begin{bmatrix} B_{11N}^K & B_{12N}^K \\ B_{21N}^K & B_{22N}^K \end{bmatrix};$$

$$B_0^K = \begin{bmatrix} B_{110}^K & B_{210}^K \\ B_{120}^K & B_{220}^K \end{bmatrix}; \qquad C_0^K = \begin{bmatrix} C_{110}^K & C_{210}^K \\ C_{120}^K & C_{220}^K \end{bmatrix};$$

$$D_0^K = \begin{bmatrix} d_{10}^K \\ d_{20}^K \end{bmatrix}; \qquad D_N^K = \begin{bmatrix} d_{1N}^K \\ d_{2N}^K \end{bmatrix}; \quad .$$

The components of these matrices and vectors, when solving the system of (20) with the boundary conditions (22), are expressed in the following form:

$$a_{11N}^K = 0; \qquad a_{21N}^K = \frac{\tau}{h}(\lambda_{21N}^K \cdot S_{11N}^K + \lambda_{22N}^K \cdot S_{21N}^K);$$

$$a_{12N}^K = 0; \qquad a_{22N}^K = \frac{\tau}{h}(\lambda_{21N}^K \cdot S_{12N}^K + \lambda_{22N}^K \cdot S_{22N}^K);$$

$$B_{11N}^K = 1; \qquad B_{21N}^K = S_{21N}^K + \tau\left(\frac{\partial F}{\partial Q}\right)_N^K + \frac{\tau}{h}\left(\lambda_{21N}^K \cdot S_{12N}^K + \lambda_{22N}^K \cdot S_{21N}^K\right);$$

$$B_{12N}^K = 1; \qquad B_{22N}^K = S_{22N}^K + \tau\left(\frac{\partial F}{\partial Z}\right)_N^K + \frac{\tau}{h}\left(\lambda_{21N}^K \cdot S_{12N}^K + \lambda_{22N}^K \cdot S_{22N}^K\right);$$

$$B_{210}^K = 1; \qquad B_{110}^K = S_{110}^K + \tau\left(\frac{\partial F}{\partial Q}\right)_0^K - \frac{\tau}{h}\left(\lambda_{110}^K \cdot S_{110}^K + \lambda_{120}^K \cdot S_{210}^K\right);$$

$$B_{220}^K = 1; \qquad B_{120}^K = S_{120}^K + \tau\left(\frac{\partial F}{\partial Z}\right)_0^K - \frac{\tau}{h}\left(\lambda_{110}^K \cdot S_{120}^K + \lambda_{120}^K \cdot S_{220}^K\right);$$

$$C_{210}^K = 0 \qquad C_{110}^K = \frac{\tau}{h}\left(\lambda_{110}^K \cdot S_{110}^K + \lambda_{120}^K \cdot S_{120}^K\right);$$

$$C_{220}^K = 0 \qquad C_{120}^K = \frac{\tau}{h}\left(\lambda_{110}^K \cdot S_{120}^K + \lambda_{120}^K \cdot S_{220}^K\right)$$

$$d_{20}^K = U_1^K; \qquad d_{10}^K = \left[S_{110}^K - \tau\left(\frac{\partial F}{\partial Q}\right)_0^K\right]Q_0^K + \left[S_{120}^K - \tau\left(\frac{\partial F}{\partial Z}\right)_0^K\right]Z_0^K + \tau F_0^K;$$

$$d_{1N}^K = U_2^K; \qquad d_{2N}^K = \left[S_{210}^K - \tau\left(\frac{\partial F}{\partial Q}\right)_N^K\right]Q_N^K + \left[S_{220}^K - \tau\left(\frac{\partial F}{\partial Z}\right)_N^K\right]Z_N^K + \tau F_N^K.$$

Therefore, solving the system of partial differential (11) with boundary conditions (14)-(15) is transformed into solving the system of difference (20)-(22) at each time step t_k.

Using the Sweep method, we obtain the solution in the form of the following relationships:

$$W_P^{k+1} = X_P^k W_{P+1}^{k+1} + T_P^K, P = N-1.....1,0. \tag{23}$$

$$W_P^{k+1} = X_P^k W_{P-1}^{k+1} - T_P^K, P = 1,2,....,N-1,N. \tag{24}$$

By transforming (21) into the form of (23) and substituting (22) into (20), we derive the expression for the running coefficients:

$$X_0^K = (B_0^k)^{-1} C_0^K, X_P^K = (B_P^k - A_P^k X_{P-1}^K)^{-1} C_P^K \tag{25}$$

$$T_0^K = (B_0^k)^{-1} D_0^K, T_P^K = (B_P^k - A_P^k X_{P-1}^K)^{-1}(D_P^K + A_P^k T_{P-1}^K) \tag{26}$$

P=1,2.....,N-1

From the above, it can be concluded that the numerical algorithm for solving the difference boundary value problem (20)-(22) follows this sequence:

1) The running coefficients are computed using the recurrence relations (25) and (26):

$$X_0^K, T_0^K, X_P^K, T_P^K.$$

2) The running coefficients are determined by applying the recurrence formulas (25) and (26):

$$X_N^K, T_N^K, X_0^K, T_0^K.$$

3) The numerical values are obtained by applying the recurrence relations (23) and (24):

$$W_P^{K+1}(P = 0,1,....,N).$$

It is important to note that the boundary value problem for the primary variables is solved in the direction of increasing t beginning from t=0.

Using the developed algorithms, software for simulating the dynamics of water management systems in the Syrdarya River basin was created in Python. This program utilizes a database of water management facilities and their interconnection structure.

The mathematical formulation of problems related to the operational management of water distribution in river basins, main canals, and inter-farm waterways is presented as follows. The primary objective of operational water resources management is to ensure that the specified water consumption for consumers is met at every point in time, while also providing the required volumes of water in intra-system reservoirs by the end of the planning period. This can be mathematically expressed as follows [18,19]:

$$W_t^B(T) = W_{in}^B, \ i \in N_{BDX}^B$$

$$Q_{ij}(t) = Q_{ij}^B, \quad j \in N_t^{B3}, i \in N^B, \tag{27}$$

where N_{BDX}^B is the set of numbers inside system reservoirs; N_t^{B3} - set of numbers (codes) of PCU water intakes of the t-th section.

Achieving exact fulfillment of the (27) is not feasible due to the uncertainty in water inflows to the sections and reservoirs, the parameters of the river sections, and the complexity of the transition processes within the river segments. As a result, practical solutions often employ various integral or minimization criteria for the operational management of water resources.

One of the key criteria used in operational management is the volume of water deficit for consumers over the interval [0, T], as well as the amount of water remaining in the reservoir at the end of this period

$$I_1 = \int_0^T \sum_{i \in N_t} \sum_{j \in N_t^{B3}} \eta_{ij}^1(t)dt + \sum_{j \in N_{BDX}^B} \eta_j^2 . \tag{28}$$

While the integral criterion (28) is straightforward, it has a drawback: the deviation of the actual regime from the planned one can be quite significant. As a result, the root-mean-square integral deviation of the actual parameters from their planned values is often used as an alternative, expressed as follows:

$$I_2 = \int_0^T \sum_{i \in N_t} \sum_{j \in N_t^{B3}} (Q_{ji}^B - Q_{ji}(t))dt + \sum_{j \in N_{BDX}^B} (W_{in}^B - W_t^B(T)) . \tag{29}$$

Therefore, the problem of operational water resources management can be framed as the task of minimizing a chosen criterion that evaluates the quality of the system, while describing the movement of water within the basin's water management network, represented as a graph [20].

In addition to integral criteria, the following operational management criterion can be applied.

$$|W_i^B(t) - W_{in}^B| \le \epsilon_1 \ i \in N_{BDX}^B,$$

$$|Q_{ij}(t) - Q_{ij}^B| \le \epsilon_2 \quad j \in N_t^{B3}, i \in N_t^B, \tag{30}$$

here ϵ_1 and ϵ_2 are positive constants that represent the accuracy requirements for operational water resources management. Solving the formulated operational management problems at the river basin level necessitates the application of advanced methods for optimal control of complex dynamic systems, alongside the use of modern computational technologies.

A software suite designed to simulate the dynamics of water management systems for addressing operational water distribution management issues. The software package is intended to model the dynamics of water management systems over a ten-day period within a month, specifically for solving operational water distribution management problems. The software package computes the water volume in reservoirs and river sections over time, utilizing known values of inflows, water withdrawals, and key characteristics of reservoirs, river sections, hydraulic structures, pumping stations, and other related components [4], [21].

Figure 1 illustrates a block diagram depicting the interconnection of software modules for modeling solutions to operational water resource management problems at the river basin level.

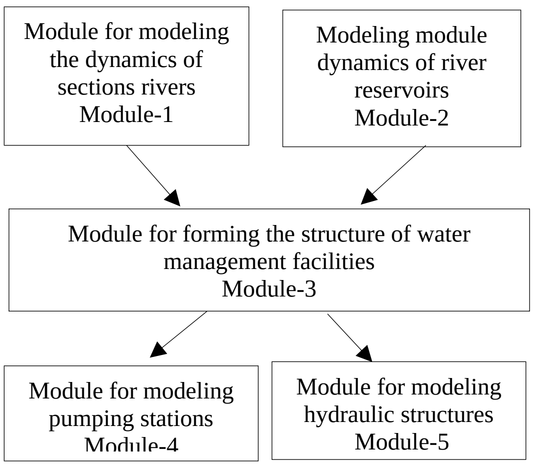

Figure 1: A block diagram of software modules.

Module-1 is responsible for solving equations related to the dynamics of river sections. It calculates the changes in water flow (i.e., water volume transformations) over time within a river section, including total water intake and losses due to filtration and evaporation.

Module-2 is designed to solve equations related to the dynamics of reservoirs. It calculates the variations in water level, surface area, and volume over time, along with total water intake and losses from filtration and evaporation.

Module-3 is intended to simulate the operating modes of hydraulic structures, calculating changes in water flow based on the known gate openings.

Module-4 is responsible for modeling the operating modes of pumping stations, calculating the changes in water flow based on the number of active units and their blade rotation angles.

Module-5 is designed to form the structure of a network of water management facilities.

It is important to note that the modules are developed in Python and utilize a MySQL database. The interaction with the database is managed through importing and exporting data via Excel text files.

Table 1 and Table 2 presents the results of modeling the dynamics of water management systems in the Syrdarya River basin over a ten-day period with daily discretization. It also illustrates changes in the operating modes of partitioning structures within the basin. Table 2 displays the dynamic water balance for the river sections of the Syrdarya River basin. The software package is designed to model the dynamics of water management systems and address operational water resource management issues. It can be applied to any river without modifying the software; only river-specific data needs to be entered. The system's versatility is based on representing water management networks as graphs, where each graph segment corresponds to a river section, and the start and end of each segment represent hydraulic structures, gauging stations, or reservoirs. The modules interpret this graph, utilizing the required morphometric data of river sections and basin objects as input, along with the current state of the river basin and dispatcher recommendations [22]-[24].

Using the developed algorithms, programs were created to simulate the dynamics of pumping stations and canal sections for the operational control of the water distribution process.

The input data includes the characteristics of pumping stations and units, as well as the hydraulic, morphometric, and technological parameters of the main and inter-farm canal sections.

The output data consists of parameter values that describe the dynamic state of the system over time layers (see Fig. 2 and Fig. 3).

Table 1: Modeling the operational balance of the water management facility of the Charvak reservoir for the 1st decade of April 2024.

Name of the structure	Limit per decade	1	2	3	4	5	6	7	8	9	10
Inflow											
m.cub/s		157.0	157.0	157.0	157.0	157.0	157.0	157.0	157.0	157.0	157.0
million cubic meters		135.6	135.6	135.6	135.6	135.6	135.6	135.6	135.6	135.6	135.6
Release											
m.cub/s		207.9	207.9	207.9	207.9	207.9	207.9	207.9	207.9	207.9	207.9
million cubic meters		179.6	179.6	179.6	179.6	179.6	179.6	179.6	179.6	179.6	179.6
Losses											
m.cub/s		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
million cubic meters		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Water intake											
m.cub/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
million cubic meters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Volume											
million cubic meters		1723	1718	1713	1708	1703	1698	1693	1688	1683	1678

Table 2: Modeling the operational balance of the water management facility of the Khojakent reservoir for the 1st decade of April 2024.

Name of the structure	Limit per decade	1	2	3	4	5	6	7	8	9	10
Section No. 6											
Water supply											
m.cub/s	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
million cubic meters	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Inflow											
-small rivers											
m.cub/s		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
million cubic meters		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
- water return											
m.cub/s		58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0	58.0
million cubic meters		50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1	50.1
Losses											
m.cub/s		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
million cubic meters		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Transformation											
m.cub/s		-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2
million cubic meters		-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1
Volume											
million cubic meters		17	17	17	17	17	17	17	17	17	17
Release into the downstream											
m.cub/s		266.1	266.1	266.1	266.1	266.1	266.1	266.1	266.1	266.1	266.1
million cubic meters		229.8	229.8	229.8	229.8	229.8	229.8	229.8	229.8	229.8	229.8

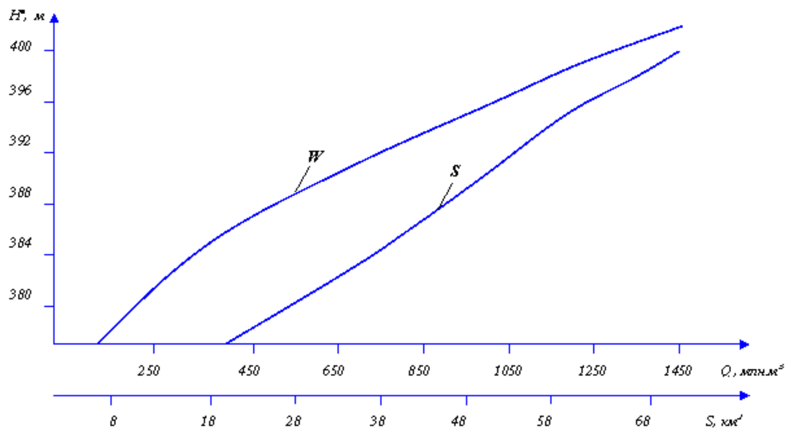

Figure 2: Curves of the dependence of surface areas and water volume on water level in the Charvak reservoir.

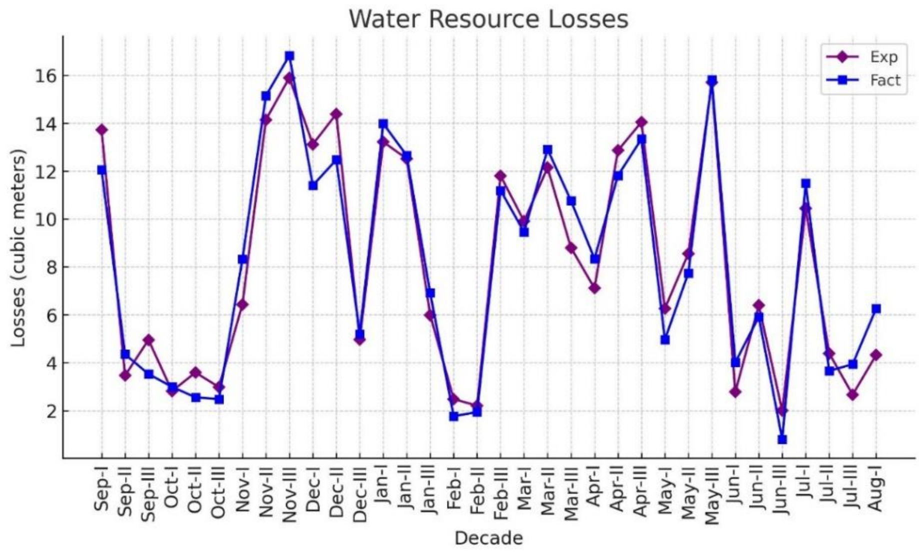

Figure 3: Results of modeling the filling and discharge regimes of the Charvak reservoir.

3 DISCUSSION

This article is based on the foundational project for the state technical program (GNTP)-124, titled of water management facilities and hydraulic structures in the republic." The project was conducted under the contract VA-KHF-5-022, named "Development of scientific foundations for the formation, management, and effective use of surface and groundwater in the Republic of Uzbekistan in the context of climate change," with the Ministry of Innovative Development, and was carried out from 2017 to 2020.

4 CONCLUSIONS

As a result of the research, mathematical models for typical water management facilities were developed to support the operational management of water

"Development of scientifically grounded methods, systems, and management forms, as well as the reliable, safe, and efficient utilization

distribution, considering operational requirements and contemporary technical modeling tools. Algorithms for simulating the dynamics of typical water management facilities—such as reservoirs, river sections, canals, hydraulic structures, and pumping stations—were created to address operational management challenges in water distribution. The developed software package allows for more efficient decision-making in managing the water distribution process. Additionally, mathematical formulations for operational management of water distribution in river basins, main canals, and inter-farm canals were established. Numerical results of modeling the dynamics of water management facilities in the Syrdarya River basin are also presented.

REFERENCES

[1] T. Nurmukhamedov, Zh. Azimov, and Zh. Gulyamov, "Using single factor regression modeling to predict reserve requirements," in Artificial Intelligence, Blockchain, Computing and Security: vol. 2, pp. 719-723, 2023.

[2] T. Nurmukhamedov and Zh. Gulyamov, "Simulation modeling of stock management systems," in Artificial Intelligence, Blockchain, Computing and Security: vol. 2, pp. 706-711, 2023.

[3] T. Nurmukhamedov, M. Hudayberdiev, O. Koraboshev, S. Sodikov, and K. Hudayberdiev, "Algorithms and methods of using intelligent systems in fire safety," in Artificial Intelligence, Blockchain, Computing and Security: vol. 2, pp. 603-610, 2023.

[4] S. Rakhimov, A. Seytov, B. Nazarov, and B. Buvabekov, "Optimal control of unstable water movement in canals of irrigation systems under conditions of discontinuity of water delivery to consumers," IOP Conf. Series: Materials Science and Engineering, vol. 883, p. 012065, 2020, Dagestan, IOP Publishing, [Online]. Available: https://doi.org/10.1088/1757-899X/883/1/012065.

[5] S. Rakhimov, A. Seytov, and A. Kudaybergenov, "Modeling and optimization of water supply processes at large pumping stations," Global and Stochastic Analysis, vol. 8, no. 3, pp. 57-62, 2021.

[6] A. Kabulov, A. Seytov, and A. Kudaybergenov, "Optimal water distribution in large main canals of irrigation system," Global and Stochastic Analysis, vol. 8, no. 3, pp. 45-53, 2021.

[7] A. Seytov, R. Turayev, D. Jumamuratov, and A. Kudaybergenov, "Mathematical Models for Calculation of Limits in Water Resources Management in Irrigation Systems," International Conference on Information Science and Communications Technologies: Applications, Trends and Opportunities (ICISCT 2021), 2021.

[8] Sh. Rakhimov, A. Seytov, M. Sherbaev et al., "Algorithms for solving the problems of optimizing water resources management on a reservoir seasonal regulation," AIP Conference Proceedings, vol. 2432, p. 060023, 2022, [Online]. Available: https://doi.org/10.1063/5.0090412.

[9] S. Rakhimov, A. Seytov, N. Rakhimova, and B. Xonimqulov, "Mathematical models of optimal distribution of water in main channels," 4th IEEE International Conference on Application of Information and Communication Technologies (AICT), 2020, Art. no. 9368798, [Online]. Available: https://doi.org/10.1109/AICT50176.2020.9368798.

[10] A. Kabulov, I. Normatov, A. Seytov, and A. Kudaybergenov, "Optimal management of water resources in large main canals with cascade pumping stations," IEMTRONICS 2020 - International IOT, Electronics and Mechatronics Conference, 2020, Art. no. 9216402, [Online]. Available: https://doi.org/10.1109/IEMTRONICS51293.2020.9216402.

[11] R. Turaev, A. Seytov, B. Hollozov, R. Haydarova, and S. Kuldasheva, "Algorithms for planning water management in irrigation systems," AIP Conference Proceedings, vol. 3045, no. 1, p. 040040, 2024.

[12] A. Seytov, O. Abdurakhmanov, A. Kakhkhorov, D. Karimov, and D. Abduraimov, "Modeling of two-dimensional unsteady water of movement in open channels," E3S Web of Conferences, vol. 486, p. 01023, 2024.

[13] R. Turaev, A. Seytov, S. Kuldasheva, and U. Nortojiev, "Algorithms for calculating limits in water management in irrigation systems," E3S Web of Conferences, vol. 401, p. 02016, 2023.

[14] A. Seytov, L. Varlamova, A. Khudayberdiev, N. Uteuliev, Sh. Yadgarov, and D. Seytimbetov, "Usage of finite element method for modeling two-dimensional unsteady water movement in open channels," AIP Conference Proceedings, vol. 3147, p. 030034, 2024, [Online]. Available: https://doi.org/10.1063/5.0210332.

[15] A. Seytov, A. Khusanov, A. Khudayberdiev, N. Uteuliev, Sh. Yadgarov, and D. Seytimbetov, "Development of algorithms for modelling water management processes on main canals," AIP Conference Proceedings, vol. 3147, p. 030032, 2024, [Online]. Available: https://doi.org/10.1063/5.0210329.

[16] A. Seytov, A. Khusanov, A. Khudayberdiev, N. Uteuliev, Sh. Yadgarov, D. Seytimbetov, O. Ergashev, and O. Abduraxmanov, "Development of algorithms for solving problems of optimisation of water resource management in irrigation systems," AIP Conference Proceedings, vol. 3147, p. 030033, 2024, [Online]. Available: https://doi.org/10.1063/5.0210330.

[17] A. Seytov, L. Varlamova, S. Bahromov, Y. Qutlimuratov, B. Begilov, and S. Dauletyar, "Optimal management of water resources of large main canals with cascades of pumping stations," AIP Conference Proceedings, vol. 3147, p. 030022, 2024, [Online]. Available: https://doi.org/10.1063/5.0210523.

[18] L. Varlamova, A. Seytov, S. Bahromov, Sh. Shokhjakhon, A. Mirzaolimov, and K. Akhmadjon, "Digital Agricultural Ecosystem: Revolutionary," in Advancements in Agriculture, pp. 339-368, Book Chapter, 2024.

[19] A. Ikramov, A. Polatov, S. Pulatov, and S. Zhumaniyozov, "Computer Simulation of Two-Dimensional Nonstationary Problems of Heat Conduction for Composite Materials Using the FEM," AIP Conference Proceedings, vol. 2637, p. 040006, 2022.

[20] A. Polatov, A. Ikramov, and A. Khaldjigitov, "Computer modeling of elastoplastic stress state of fibrous composites with hole," Coupled Systems Mechanics, vol. 8, no. 4, pp. 299-313, 2019.

[21] D. Eshmamatova, A. Seytov, and N. Narziev, "Basins of Fixed Points for Composition of the Lotka–Volterra Mappings and Their Classification," Lobachevskii Journal of Mathematics, vol. 44, no. 2, pp. 558-569, 2023.

[22] S. Seytov and D. Eshmamatova, "Discrete Dynamical Systems of Lotka–Volterra and Their Applications on the Modeling of the Biogen Cycle in Ecosystem," Lobachevskii Journal of Mathematics, vol. 44, no. 4, pp. 1471-1485, 2023.

[23] A. Polatov, A. Ikramov, S. Jumaniyozov, and S. Sapayev, "Computer Simulation of Two-Dimensional Unsteady-State Heat Conduction Problems for Inhomogeneous Bodies by the FEM," AIP Conference Proceedings, vol. 2781, p. 020019, 2023, [Online]. Available: https://doi.org/10.1063/5.0118684.

[24] A. Ikramov and A. Polatov, "Finite Element Modeling of Nonstationary Problems of Heat Conduction under Complex Heat Transfer," Bulletin of Irkutsk State University, Series Mathematics, vol. 45, pp. 104-120, 2023, [Online]. Available: https://doi.org/10.26516/1997-7670.2023.45.104.