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COMPUTER SIMULATIONS FOR ASSESSING THE WATER REGIME IN IRRIGATION SYSTEMS

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Abstract:

This article discusses computer simulations for assessing the water regime in irrigation systems, solving problems of complex hydrogeological objects, predicting the regime of groundwater in irrigated fields, determining the optimal structure and regime of collector networks, etc., the sweep method for solving the system, the method of alternating directions for solving the equations of planned filtration, a method for the numerical solution of equations.

Keywords: Computer modeling of hydrogeological objects, ground and surface waters, forecasting the regime of ground waters in irrigated fields, determining the optimal structure and regime of collector networks, etc.

INTRODUCTION

In solving many water management problems, computer simulations (systems of mathematical models) of complex hydrogeological objects (forecasting the regime of groundwater in irrigated fields, determining the optimal structure and regime of collector networks, etc.) play an important role. The solution to such problems can be obtained on the basis of a joint consideration of river and soil currents and their interactions. Ground and surface waters are components of the runoff system in the river catchment, where practically all the main processes of the hydrological cycle are present for predicting the water regime of soils and grounds on a regional scale.

If the flow rate in rivers is large compared to the inflow (or outflow from the river) from groundwater, then there is no need for simultaneous modeling of surface and groundwater, and the dynamics of each system can be investigated separately. In this case, it is advisable to construct not one, but two systems of equations (the first for the dynamics of river flows and the second for the dynamics of soil flows).

MATERIALS AND METHODS

In this regard, it is possible to separately solve problems for the river network, and use the calculation results when solving the problem of planned filtration, or vice versa.

These questions are devoted to works [1-4], where mathematical models and algorithms are presented, in which the methods of finite differences and finite elements are mainly used. However, it should be noted that when solving hydrogeological problems, due to the need for a large amount of computer time, they still have a limited scope. Therefore, it is desirable to develop simplified models that would allow the study of hydrogeological objects with an accuracy sufficient for practical purposes.

The main hypothesis for constructing a simplified model is that the processes occurring in the soils of irrigated agriculture are considered as periodic functions of time. This hypothesis is related to the fact that the regime of groundwater in irrigated fields is mainly determined by the regime of irrigation and leaching, which are repeated periodically [6]. In this case, solutions to systems of equations describing processes in soil and soils (planned filtration processes) can be sought in the form of a Fourier series.

Mathematical setting. To describe the processes of planned filtration, the Boussinesq equations are used [1-3]:

$$\mu\frac{\partial H}{\partial t}=\frac{\partial}{\partial x}\left(\mathrm{T}\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(\mathrm{T}\frac{\partial H}{\partial y}\right)+\varepsilon \qquad (1)$$

$$T=\begin{cases}\kappa_{\phi}(a-b),\ H\ge a\\ \kappa_{\phi}(H-b),\ a>H>b\\ 0\ ,H<b\end{cases}$$

in a free-flowing horizon. The uniqueness of the solution (1) of the equation is determined by the presence of boundary and initial conditions in the form

$$\alpha H+(1-\alpha)T\frac{\partial H}{\partial x}=\varphi(x,y,t),\ \ 0\le t\le t_1 \qquad (2)$$

$$H=H_0(x,y) \quad \text{при} \quad t=0. \qquad (3)$$

where t - is time (day); x,y - coordinates in the horizontal plane (m); $H(x,y,t)$ - elevation of the groundwater surface (m); $\mu(x,y,t)$ - coefficient of fluid loss; $\varepsilon(x,y,t)$ -feeding function; k_ϕ - filtration coefficient, (m/day); $a(x,y)$ - elevation of the earth's surface, (m); $\mathrm{b}(x,y)$ - elevation of the bottom of the aquifer, (m). Here is α a coefficient taking the value 0 or 1; $\varphi(x,y,t)$ -assigned functions.

The most commonly used hydrodynamic model of water movement in river channels and flow control systems are the Saint-Venant equations [5]:

$$B\frac{\partial h}{\partial t}+\frac{\partial Q}{\partial s}=d_1 \qquad (4)$$

$$\frac{1}{g\omega}\left[\frac{\partial Q}{\partial t}+\frac{\partial}{\partial s}\left(\frac{Q^2}{\omega}\right)\right]+\frac{n^2Q|Q|}{\omega^2R^{4/3}}+\frac{gh}{\partial s}-i_b=0 \qquad (5)$$

Where n is the roughness coefficient given by

$$\alpha_1 h+(1-\alpha_1)Q=\Phi_1(t),\ \alpha_2 h+(1-\alpha_2)Q=\Phi(t) \qquad (6)$$

$$h=h_0(s),\quad Q=Q(s),t=0,\quad 0\le s\le l \qquad (7)$$

In the case of branching into several channels, the left boundary condition is calculated from the system of equations (4) and (5), and the conjugation conditions;

$$Q_1(l_1,t)=Q_2(O,t)+Q_3(O,t)+\ldots\ldots \qquad (8)$$

$$h_1(l_1,t)=h_2(O,t)=h_3(O,t)=\ldots\ldots \qquad (9)$$

where Q_i is the consumption of the i -th channel; h_i - the depth of the flow of the i -th channel; l_i -is the length of the channel under consideration. With concentrated lateral outflow (pumping stations)

$$Q_2(O,t)=Q_1(l_1,t)-Q_{бок}(t) \qquad (10)$$

$$h_2(O,t)=h_1(l_1,t) \qquad (11)$$

Here t is the time, (sec), S is the distance along the channel, (m); $h(s,t)$ - flow depth, (m); $i_b(s)$ - the slope of the channel bottom; $Q(s,t)$ - flow rate through ω of the cross section, (m³/sec.); B - channel width, (m); g =9,8 m/s²; $d_1(s,t)$ - distributed lateral inflow and evaporation, (m²/sec.), with the help of which water exchange between streams and groundwater is expressed; $k_p(z)=\frac{1}{n}\frac{\omega^{5/3}}{\chi^{2/3}}$ flow modulus determined by Manning's empirical formula; where n is the roughness coefficient, given; R -hydraulic radius, (m); $\alpha_1,\alpha_2=1$ or 0; Φ - known functions.

Main part

The influence of groundwater on the channel flow is carried out through the d_1 term, which depends on its bed, determined by the lithological structure of the under-channel sediments and the clogging of the channel, as well as on the flow rate and speed of water movement in the river, etc. In the presence of a hydraulic connection between the channel current and the movement of water in the saturated zone in the G region with the Γ boundary along the Γ_p tree graph, which is an image of the river network in the x,y plane, the $d_1(s,t)$ value was calculated as follows.

$$d_1=\begin{cases}2\lambda^p(H-Z_p),\ H\ge Z_p\\ 2\lambda^p(Z_p-\mathrm{H}),\ H<Z_p\end{cases} \qquad (12)$$

where H is the elevation of the groundwater surface relative to the comparison plane (m), $\lambda^p(s)$ is the parameter of the relationship of the channel flow with groundwater, characterizing: the heterogeneity of the lithological composition and the colmatation of the channel. In those places where the groundwater level lies below the bottom of the $H < Z_b$ river, the connection between the runoffs and the groundwater will be carried out in only one direction. In these sections of the Γ_p boundary, the discharge d_1 will flow from the river into the groundwater, depending on the depth and width of the river, the coefficient of vertical filtration and the thickness of the clogging layer [3].

$$d_1 = \begin{cases} \dfrac{B\square K_b(h + h_k - h_{kp})}{h_k}, & h > h_{kp} \\ 0 & , h \le h_{kp} \end{cases} \tag{13}$$

Here h_{kp} is the critical depth, below the filtration from the river stops (m); h_k - the thickness of the clogging layer (m); K_b - vertical filtration coefficient (m / day)

To find a solution to problem (1) - (11), it is necessary that the functions $\phi_1(t),\ \phi_2(t),\ \mathrm{h}_0(s),\ Q_0(s),\ I(s),\ w(s,h)$ at $0 \le s \le e,\ 0 \le h \le h_{\max(s)},\ 0 \le t \le t_1$ were specified, where $h_{\max}(s)$ is a given function that exceeds any values for each s from the interval under consideration.

Method for the numerical solution of equations. When combining solutions to the problems of planned filtration and flow through the irrigation network, it is necessary to take into account that the characteristic times of the processes during filtration are significantly longer than when water moves in the irrigation system.

1. To apply the finite-difference method in solving Saint-Venant equations (4), (5), the nonlinear term $Q|Q|$ is expanded by the Taylor formula in the vicinity of node $i + \frac{1}{2} j$ of the computational grid. Then, approximating the derivatives in equations (4) and (5) using implicit difference schemes, we obtain the following grid systems of equations.

$$B_{ij+\frac{1}{2}} \frac{h_{ij+1} - h_{ij}}{\Delta t} + \frac{Q_{i+\frac{1}{2}j+1} - Q_{i-\frac{1}{2}j+1}}{\Delta S} = d_{ij+1}$$

$$Q_{i+\frac{1}{2}j+1} = \frac{Q_{i+\frac{1}{2}j}}{2} + \frac{K^2_{pi+\frac{1}{2}j}}{2\left|Q_{i+\frac{1}{2}j}\right|}\left(I_{i+\frac{1}{2}j} - \frac{h_{i+1j+1} - h_{ij+1}}{\Delta S}\right)$$

The system of equations (4), (5), together with conditions (6) - (11), make it possible to determine the distribution of water depths and flow rate Q, h on layer $j+1$ over time. The sweep method is used to solve this system.

2. *First method.* To solve the equations of planned filtration, the method of alternating directions (or fractional steps) is used, in which, at the first half step along the t axis, an approximation of the derivatives is taken, but by an implicit scheme along the x axis and according to an explicit scheme along the y axis. In the second half step, the opposite is true. In each Δw_{ij} cell on the constructed grid, the planned filtration equations (1) are written in finite-difference form:

$$\mu_{ij}^{l+\frac{1}{2}} \frac{H_{ij}^{l+\frac{1}{2}} - H_{ij}^{l}}{\frac{\Delta t}{2}} = L_{hx} H_{ij}^{l+\frac{1}{2}} + L_{hy} H_{ij}^{l} + \varepsilon_{ij}^{l+\frac{1}{2}}$$

$$\mu_{ij}^{l+1} \frac{H_{ij}^{l+1} - H_{ij}^{l+\frac{1}{2}}}{\frac{\Delta t}{2}} = L_{hx} H_{ij}^{l+\frac{1}{2}} + L_{hy} H_{ij}^{l+1} + \varepsilon_{ij}^{l+1}$$

where

$$L_{hx}H_{ij}^{l+\frac{1}{2}} = \frac{1}{\Delta h^2}\left[T_{i+\frac{1}{2}j}H_{i+1j}^{l+\frac{1}{2}} - \left(T_{i+\frac{1}{2}j} + T_{i-\frac{1}{2}j}\right)H_{ij}^{l+\frac{1}{2}} + T_{i-\frac{1}{2}j}H_{i-1j}^{l+\frac{1}{2}}\right]$$

Similarly expressed $L_{hy}H_{ij}^{l}$.

The sweep method was used to solve the grid equations.

3. *Second method.* When solving equation (1), we replace the partial derivatives with respect to spatial variables by finite-difference analogs. As a result, we obtain a system of ordinary differential equations:

$$\mu_{ij}\frac{\partial H_{ij}}{\partial t} = \frac{1}{h^2}\Big[\left(H_{i+ij} - H_{ij}\right)T_{i-ij} + \left(H_{i-ij} - H_{ij}\right)T_{i-ij} +$$
$$+\left(H_{ij+1} - H_{ij}\right)T_{ij+1} + \left(H_{ij-1} - H_{ij}\right)T_{ij-1}\Big] + \varepsilon_{ij} \qquad (14)$$

where h is the step along the x and y axes.

Since the hypothesis of periodicity is accepted for the investigated object, we will seek the solution of these equations in the form of a Fourier series, limiting ourselves only to the k terms (naturally, the k should not be large, but such that the leading terms are taken into account).

$$H(x,y,t) = \sum_{k=0}^{n} A^{(k)}(x,y)e^{jk\omega t} \qquad (15)$$

$$\varepsilon(x,y,t) = \sum_{k=0}^{n} C^{(k)}(x,y)e^{jk\omega t} \qquad (16)$$

where $A^{(k)}, C^{(k)}$ are the complex amplitudes of the k -th harmonic; $\omega = \frac{2\pi}{Tg}$, Tg -period of the simulated process, t -time.

Substituting expressions (15) and (16) into (14), we obtain

$$jk\omega\mu\, A_{ij}^{(k)} = \frac{1}{h^2}\Big[A_{i+1j}^{(k)}T_{i+1j} + A_{i-1j}^{(k)}T_{i-1j} + A_{ij+i}^{(k)}T_{ij+1} + A_{ij-i}^{(k)}T_{ij-1} -$$
$$-(T_{i+1j} + T_{i-1j} + T_{ij+1} - T_{ij-1})\, A_{ij}^{(k)}\Big] - C_{ij}^{(k)} \qquad (17)$$

Since equation (17) is complex, it can be represented in the form of two real systems of algebraic equations. The complex amplitudes $A_{ij}^{(k)}$ and $C_{ij}^{(k)}$ can be represented as:

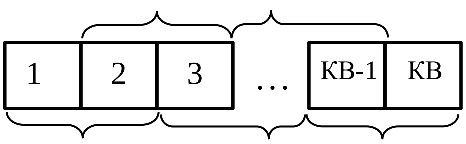
$$A_{ij}^{(k)} = \operatorname{Re} A_{ij}^{(k)} + j \operatorname{Im} A_{ij}^{(k)}$$
$$C_{ij}^{(k)} = \operatorname{Re} C_{ij}^{(k)} + j \operatorname{Im} C_{ij}^{(k)} \qquad (18)$$

Substituting (18) into (17), equating the real and imaginary parts, we obtain a system of algebraic equations. The resulting system of algebraic equations is easily solved by the method of successive approximations.

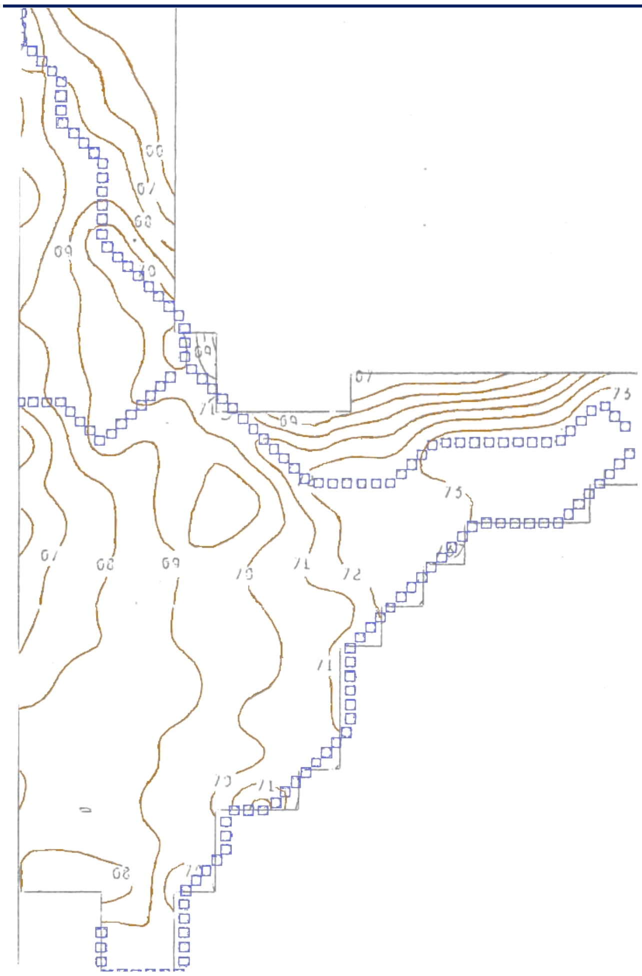
When implementing the solution algorithm, the simulated filtration area is divided into subdomains so that the information about the two subdomains is simultaneously placed entirely in the RAM together with the information contained in the control program (see Picture 1), where KB is the number of subdomains in the simulated filtration area. In this case, the main idea is that the solution process is performed continuously for all subdomains, that is, during the solution, the value of the function at the boundary of each subdomain is not fixed in advance.

It can be noted that in the decision process for each subdomain, the modeled area, the calculation is interconnected with each other. In this case, we have two following advantages. First, when going from one area to another, there is no need to set boundary conditions; secondly, if the solution in each subdomain of the modeled area is made dependently, then when two adjacent subdomains are joined, there will be no accumulation of errors.

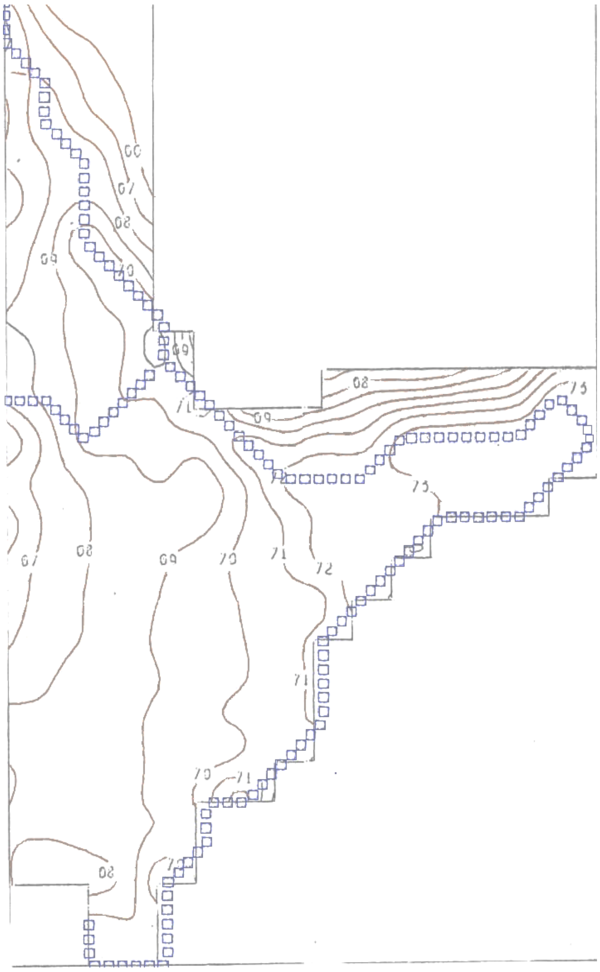
4. Results of calculations. To implement this work, a program has been drawn up. A part of the irrigated areas of the right bank of the lower reaches of the Amu Darya was taken as an example. When calculating, the modeled object is divided into three sections. The calculation was carried out during the growing season with a duration of 90 days.



Picture 1



Picture 2. Map of groundwater hydroisogypsum (0th day of the process).

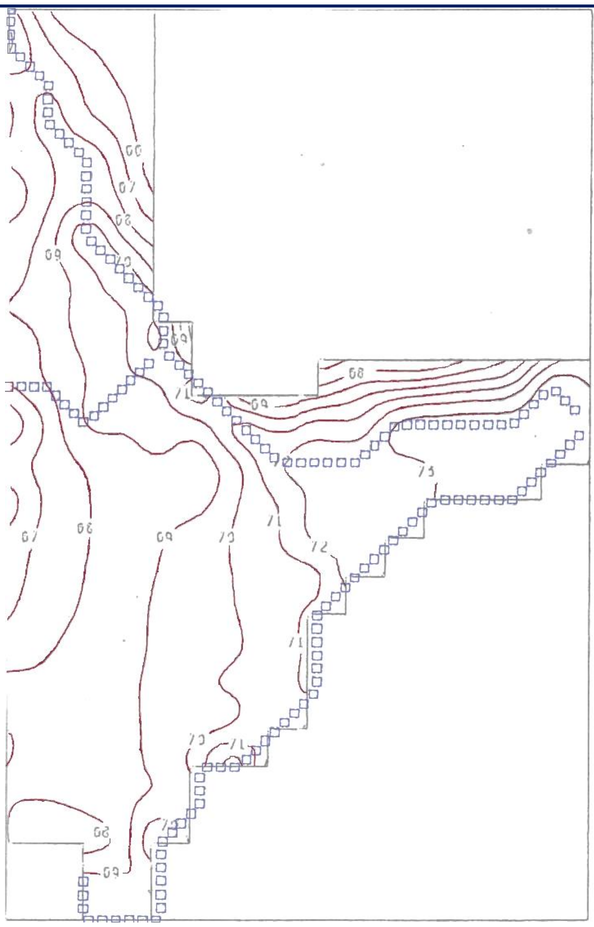


Picture 3. Groundwater hydroisogypsum map (30th day of the process).

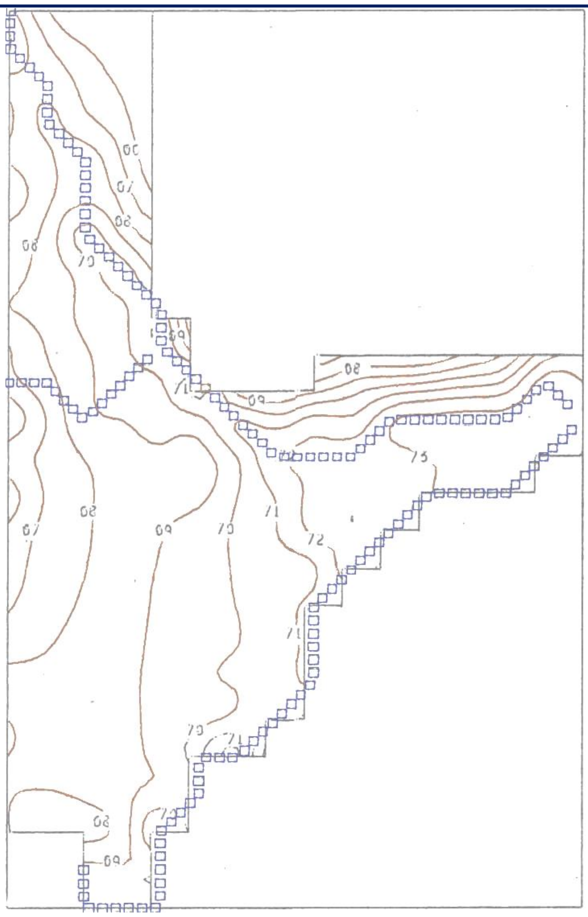
The following initial data were taken: the coefficient of fluid loss μ -was taken to be constant throughout the entire region and equal to 0.1; $T_q = 365$ period of the day; the time step for the river flow problem is 3 hours; the step in x and y is 2 km.

To assess the possibility of using the developed algorithm and practical goals, the calculation results were compared with field observations, with the calculation according to the program, where the harmonic balance method and the alternating direction method are used to solve the planned filtration problem (with the same initial and boundary conditions).

The results are shown in pictures 2 - 5, which shows changes in groundwater isolines at the beginning of the growing season ($t = 0$) and at the end of the growing season $t = 90$



Picture 4. Groundwater hydroisogypsum map (60th day of the process).



Picture 5. Groundwater hydroisogypsum map (90th day of the process).

The results show that at the end of the growing season along the canals, there is a decrease in the level of groundwater due to their diversion through irrigation networks.

Groundwater level from the surface of the earth

Table 1.

Well number	30th day			60th day			90th day		
	Harmonic analysis method	finite difference method	natural observations	Harmonic analysis method	finite difference method	natural observations	Harmonic analysis method	finite difference method	natural observations
23	1,65	1,86	1,13	1,98	2,02	1,91	2,29	2,19	1,91
25	2,10	2,24	1,97	2,06	2,23	1,91	1,96	1,50	1,93
30	1,59	1,75	2,09	1,66	1,71	1,91	1,72	1,42	1,90
38	1,24	1,71	1,79	1,58	1,6	1,78	1,88	1,69	1,78
66	1,38	1,58	1,69	1,66	1,57	1,64	1,87	1,58	1,86
69	1,46	1,76	1,48	1,87	1,88	1,6	2,16	1,45	1,63
26	0,97	1,18	1,51	1,11	1,2	1,46	1,44	1,22	1,35
44	2,40	2,44	1,19	3,21	2,49	1,69	3,31	2,52	1,44
81	0,96	1,28	1,69	1,31	1,37	1,56	1,62	1,46	1,47
40	1,69	1,61	1,43	2,03	1,69	1,44	2,27	1,79	1,33

In the node where well 44 is located (see Table 1), the deviation is greater than in other nodes, both when calculating according to the proposed algorithm, and also by the finite difference method. This happened due to the inaccuracy of the initial information about the object, since linear interpolation was used for unknown parameters. When calculated by the harmonic balance method and the finite difference method, the deviations do not exceed 0.03 + 0.35 m. The results obtained differ from field observations of the groundwater regime by no more than 0.07 + 0.59 m. The harmonic balance method for solving the problem of planned filtering is more economical in terms of the cost of computer time and memory. Thus, it was found that when determining the hydrogeological parameters on irrigated fields, the harmonic balance method can be used.

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