Calculation methods of groundwater backwater in the zone of influence of hydraulic structures

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Abstract. The purpose of the work is to consider methods for calculating the forecast of groundwater backwater in the zone of influence of hydraulic structures. The analysis of the analytical dependencies for calculating the forecast of groundwater backwater for various schemes. A numerical model is proposed and a computational program for calculating the groundwater backwater has been developed for a homogeneous geofiltration structure which allows discretely calculating the groundwater backwater from the canal at any time. To simplify the solution of the problem of calculating the backwater of groundwater, a computer program was created in the Python Version 3.8 programming language, which quickly solves this hydrogeological problem. A possible range of geofiltration parameters is proposed. The results of predictive calculations of groundwater backwater are the basis for assessing the zones of possible flooding - the territory within which the groundwater level rises as a result of backwatering by a hydraulic structure.

1. Introduction

One of the most important practical tasks in the engineering hydraulic structures, artificial reservoirs and reservoirs, as well as irrigation canals on reclamation systems is to predict the water regime in the aeration zone and the regime of groundwater.

A necessary element of the technology for the engineering reclamation systems is the information and methodological support of the design, which includes a system of methods for predicting the water and salt regime of soils and the aeration zone.

The purpose of the work is to consider and analyze the analytical dependencies for calculating the forecast of groundwater backwater near hydraulic structures for various project schemes and the development of a computational program for calculating groundwater backwater, which allows discretely calculating the groundwater backwater from the canal at any time.

The relevance of the problem is associated with the demand for modern computing tools for calculating the backwater of groundwater near hydraulic structures, the results of which allow calculating the zones of flooding and flooding with an assessment of geocological damage [1-2].

2. Materials and methods

Survey materials (geological and hydrogeological maps and sections, maps of lithological and genetic complexes, lithological sections and columns, etc.) serve as initial information for the construction of
design filtration schemes. The construction of filtration schemes should be carried out within a single
geological and genetic complex.

Groundwater backwater is a rise in the groundwater level caused by an increase in the
hydrodynamic head in any section of the flow and accompanied by a decrease in the flow rate.

Secondary permanent or temporary groundwater backwater may occur caused by high water levels
in canals, reservoirs, water basins due to the influence of artificial irrigation structures (figure 1).

![Figure 1. Scheme of the formation of groundwater backwater near the main canal.](image)

The main calculated dependencies should take into account the results of geofiltration
schematization, the nature of the boundary conditions, the types of filtration flows for the main canals,
the length of which is much greater than their width. Typical calculations include the most common
schemes for the contours of aquifers in terms of: open, semi-open, semi-limited flows and limited
filtration flows [3-6].

The main differential equation of stationary planned filtration is described by a nonlinear equation
for a planned-flat flow in the following form [7-8]:

$$\frac{\partial}{\partial x} \left( T \frac{\partial H}{\partial x} \right) + \frac{\partial}{\partial y} \left( T \frac{\partial H}{\partial y} \right) = 0$$

The general solution of equation is presented as [9-10]:

$$H(x; t) = H_0 + \Delta H(x; t)$$

To obtain a solution to equation, the condition of theoretically instantaneous filling of the channel
and instantaneous onset of the stage of supported filtration is adopted, that is, with the following initial
and boundary conditions.

$$\Delta H(x; 0) = 0 \text{ and } \Delta H(0; t) = \Delta H^0$$

The solution has a general form with an instantaneous level change at the boundary:

$$\Delta H(x, t) = \Delta H_0 \times F(x, t)$$

Function depends on the type of flow, conditions at the boundary opposite to the channel and
filtration inhomogeneity of the flow along its length.

For a semi-bounded homogeneous flow, the solution to the equation has the form:

$$F(x, t) = \text{erfc}(\lambda),$$

$$\lambda = \frac{x}{2\sqrt{\alpha t}}$$
To simplify the solution of the problem of predicting groundwater backwater near linear main canals, a computer program has been developed in the Python Version 3.8 programming language, which quickly solves this hydrogeological problem in an automated mode.

To solve the problem, a simple interface was chosen, and a program was written in the Python programming environment that provides a modern graphical environment for modeling groundwater backwater near a linear main canal.

The developed program allows in an automated mode to calculate the forecast of groundwater backwater and present the forecast results in graphical form at any time. The schematic diagram of the program is shown in (figure 2).

![Figure 2. Schematic diagram of the program for the automated calculation of the forecast of groundwater backwater. For automatic calculation of groundwater backwater after entering the required parameters, the values of the function are entered into the programming environment code. The data on the values of the erfλ functions introduced into the code are given in the papers.](image)

The program allows on-line discrete drawing of the forecast graph of groundwater backwater. The advantage of the program is that the problem of calculating the groundwater backwater near the main canal is solved with minimal loss of time, and the specialist only needs to enter the initial data. In addition, the graph is more accurate and there are no unwanted points (when compared to Excel). An important advantage of the program is also a simple and accessible interface.

### 3. Results

The area of construction and operation of the irrigation system, located in the zone of the 5th section of the Big Stavropol Canal (BSC-5), was chosen as the object of research. The watering and irrigation system of the Big Stavropol Canal provides for irrigation on an area of 210.0 thousand hectares and watering an area of 2.6 million hectares [11].

Calculations of groundwater backwater were carried out for the main canal (inter-farm distribution network), designed to supply water for irrigation in Blagodarny and Budennovsky districts. The canal was built in medium and light loamy soils, the length of the canal is 64 km. The most typical scheme of the filtration structure for the territory under consideration is the scheme of a semi-limited reservoir, for which the calculations were carried out.
The channel passes through homogeneous loamy sediments with the following filtration parameters: the thickness of the sediments $m = 6$ meters, the filtration coefficient $K = 0.1$ meters per day, the magnitude of the lack of saturation $m = 0.05$, the value of the instantaneous rise in the level in the channel $\Delta H_0 = 4.0$ meters. The calculation of the backwater value $\Delta H (x, t)$ at various distances from the canal edge was carried out for a stationary period ($t = 3650$ days, or 10 years).

To build a graph of groundwater backwater, it is necessary to enter the initial calculated geofiltration parameters in a given form. The recommended range of parameters is shown in Table 1.

**Table 1.** The range of geofiltration parameters introduced for automated calculation of the forecast of groundwater backwater near the main canal.

| Input parameter name                        | Range of values |
|---------------------------------------------|-----------------|
| Filtration coefficient ($k_0$), meters per day | 0.1-6.0         |
| $\Delta H_0$, meters                        | 1-15            |
| thickness (m), meters                       | 1-15            |
| $\mu$                                       | 0.05-0.15       |
| $T$, day                                    | 0-25000         |
| $X$, meters                                 | 0-5000          |

The results of the development of groundwater backwater from the canal in time using the developed model are shown in (figure 3).

![Figure 3](image-url)  
*Figure 3. Development of groundwater backwater over time using a computer model.*

4. Discussion

To calculate the backwater of groundwater from reservoirs and reservoirs that have nonlinear contours, you can use analytical dependencies, but the complexity of these calculations is obvious. For a homogeneous geofiltration structure, a computer model for calculating groundwater backwater is proposed, which allows discretely calculating groundwater backwater from the canal at any time and at any distance from the canal [12].

The computer program was developed for a computer in the Python Version 3.8 programming language, which for a homogeneous lithological stratum allows you to quickly solve the problems of predicting groundwater backwater during the operation of linear main canals and reservoirs.

The implementation of the software model was carried out for a specific object - the Big Stavropol Canal (BSC-5). The results of predictive calculations of groundwater backwater formed the basis for
assessing the zones of possible flooding - the territory within which the groundwater level rises as a result of its backwatering by a hydraulic structure.

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