Mathematical modeling of the operating mode of the South Golodnostepsk main channel

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Abstract. The article presents the results of a study of operation and considers the application of mathematical modeling to the movement of water flow in the South Golodnostepsk main channel. A convenient, simple and cheap mathematical apparatus is proposed, which gives sufficiently reliable predictive results for making the right decisions in emergency situations during the operation of the South Golodnostepsk main channel. It is also given to apply recommendations for the numerical calculation of other irrigation channel in the region.

1 Introduction

Research on the use of mathematical models to improve the performance of irrigation systems in terms of water conservation and increase the efficiency of the channel was carried out by the South Golodnostepsk main channel. The South Golodnostepsk main channel (SGMCh) according to the project has a capacity of 320 m$^3$/sec. The total length of the channel is 136 km, out of 108.2 km it runs in an earthen channel, 27.8 km of the final part of the channel is lined with concrete. Of the total 136 km, two thirds of the channel was built in a half-cut-semi-fill, and the rest in a cut. The cross profile of the channel on the earthen part has a polygonal outline, the concreted part is trapezoidal. The slope of the channel bottom is 0.0005-0.0007, in the final section 0.0001. The cross-sectional width of the channel at the top with a flow depth in the channel of 6.5 m is 68 meters, along the bottom 6.5 m. According to the project, the efficiency factor of the channel was 0.97 [1].

2 Methodology

According to the results of the study of the authors of this article, the actual throughput is 145 m$^3$/s, and the efficiency is 0.67. Due to the long period of operation, the non-stationarity of the hydrological and hydraulic characteristics of the supplied water and the non-systematic cleaning work in the channel, the roughness coefficient increased to 0.083, and due to a sharp decrease in throughput, the likelihood of hydrodynamic accidents increased. Before the operational service, the task of obtaining predictive data on changes in the hydrodynamic characteristics of the flow moving in the channels of the system, according to the time of flow at any time, according to the volume of water and the amount...
of runoff in the system, in the event of a hydrodynamic accident, becomes more and more complicated (2). This information can be obtained using a convenient and simple “tool” for prediction of the operating mode of SGMCH.

Based on the above laws of conservation of mass and momentum, the system of Saint-Venant differential equations can be written as follows:

{\frac{\partial Q}{\partial s} + \frac{\partial \omega}{\partial t} \pm Q_f = 0}

{\frac{i}{\partial s} = \frac{a}{\partial s} g + \frac{\partial h}{\partial s} + \frac{1}{g} \frac{\partial v}{\partial t} \pm \frac{q_r}{g}}

\frac{\partial h}{\partial s} = \frac{\alpha}{\partial s} g \frac{\partial \varphi}{\partial s} + \frac{1}{g} \frac{\partial \varphi}{\partial t} \pm \frac{Q_f}{g}

The resulting equations are called the system of differential equations of Saint-Venant and represent a mathematical model of this movement. The main purpose of writing this system of equations in two forms is that the soil part of the SGMK Ch is 107.2 km, in which the dependence of the intensity of the filtration process on the properties of the flowing soil is assumed, the remaining 28.8 km are covered with concrete, in which the filtration rate is lower. The pumping station receiving water from this channel is capable of removing 145 m$^3$/s of water.

Assuming that the flow direction in this system of hydrodynamic equations coincides with the Ox axis, and if some mathematical changes are made, then the divergent form of the system of hydrodynamic equations for the flow of water moving in a smooth concrete channel can be written as follows:

{\frac{\partial \omega}{\partial t} + \frac{\partial \omega \nu}{\partial x} = 0}

{\frac{\partial \nu \omega}{\partial t} \pm \frac{\partial \varphi}{\partial \nu} + g \frac{\partial S}{\partial x} = \text{const} + \frac{\lambda}{\nu} \nu \lambda = 0}

Z_{c,\varphi} = \frac{\varphi}{\nu} \lambda

\lambda = \frac{gn}{R}

R = \omega \lambda

\frac{\partial \omega}{\partial t} + \frac{\partial \omega \nu}{\partial x} \pm Q_f = 0
It should be noted that when obtaining the divergent form of the Saint-Venant equations, the distribution of the flow velocity in the rocks limiting the field under study, the distribution of hydrodynamic pressure obeys the laws of hydrostatics, the determination of friction and turbulence in the boundary fields according to the laws of hydraulic resistance with smooth movement, the slope of the bottom of the stream was considered to be extremely small and close to horizontal. For this mathematical model, approximation equations were written by the finite difference method, for which special programs were developed in Delphi.

To establish a forecast in the event of possible problems with the adoption of emergency measures for the operation of the SGMCh, the authors of this work used the method of mathematical modeling, as a method that requires much less material costs and allows a series of calculations of the problems under consideration. The mathematical model is based on one-dimensional equations of hydrodynamics. It has been successfully verified and tested with test problems of flow hydraulics.

A calculation scheme for numerical calculation has been compiled. According to the available hydrological, topographic materials, the soil of the channel part, the water level, the dynamics of water flow in the channel, the hydraulic resistance of the channel, the marks of the channel bottom and the water flow in the initial alignment of the channel and the data of the pumping station associated with the operating mode of the SGMCh were taken according to the results of field studies of the authors of this article.
Fig. 2. The supplied water flow in the channel of the irrigation and drainage system through the Headworks at the beginning of the calculation of SGMCh.

According to the accepted calculation conditions, the calculation results with all hydrodynamic parameters were given every 20 km. In addition, with the help of a special subprogram, it is possible to monitor the dynamics of hydrodynamic parameters in the intermediate sections of the SGMCh [5-7] (Fig. 3).

Fig. 3. Hydrograph of the channel bottom mark, demonstration of calculation data in an arbitrary intermediate alignment.

SGMCh Upper and lower lines, respectively, the water level and bottom marks of the SGMCh, time $T = 5.45$ h, $X$ - distance from the head structure, $Z$ - marks of the free surface of the stream and the bottom of the channel, $H$ - depth in m, $Q$ - discharge in m$^3$/sec, $V$ - average flow rate, $Fr$ - Froude number, $E$ - specific flow energy, $T = 5.45$ h - time from the beginning of the count [13, 14] (Fig. 4).
3 Discussion

The problem of saving water and obtaining high yields of agricultural crops can be solved by developing new techniques and technologies and putting them into practice. Studies on the use of mathematical models to improve the performance of irrigation systems in terms of water saving and increase the efficiency of channel were carried out in 3 different natural and technical conditions - the South Golodnostepsk main canal, Shuruzak and the RK-7 canal, the results of the study were compared. Above, you got acquainted with the mathematical model based on the system of hydrodynamic equations of Saint-Venant, which are the laws of conservation of mass and momentum in a state that takes into account the filtration process of water flow in the South Golodnostepsky main canal [2, 5-7].

4 Results

In conclusion, it should be noted that the calculation using the developed mathematical model practically allows solving a wide range of problems of modeling flows in the South Mining and Metallurgical Company, taking into account daily regulation and lateral flow from the system and into the system due to reverse filtration. This makes it possible to identify and take action in advance:

- determine the time of the flow on the irrigation networks;
- set the characteristics and volume of water flow in an arbitrary section of the network at the required time;
- take emergency measures to regulate the incoming residual volume of water after the cessation of its supply to the network, in case of malfunctions in the equipment of hydroelectric facilities and pumping stations;
- at the request of the operating personnel, it is possible to accept the possibility of possible failures in the SGMCh pumping station and predict the impact of this change downstream and upstream in the network;
- minimize the negative consequences of emergency situations, such as damage to control or head structures.

![Graph of water consumption](image)
Reasonably prevent the development of systemic accidents; to prevent flooding of structures, irrigated areas located in the area of SGMCh; to prevent undermining of supports and damage to power lines, transport routes, water and gas pipelines passing through the SGMCh in question, etc.

In addition, the developed and tested mathematical model of the SGMCh allows, in real conditions and in real time, to help in the operational management of actions in an emergency and the choice of the most effective measures for minimizing the consequences at any given time [3].

And also, the developed mathematical model can be used for numerical calculation of other irrigation channel in the region, taking into account their topography, hydrological and hydraulic modes of their operation. The use of mathematical modeling methods makes it possible to reproduce and predict stationary hydraulic processes and modes in hydropower cascades: release waves, floods, breakthroughs and other emergency situations. Such studies are necessary in the design and construction of channel to improve their reliability and safe operation [4].

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