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NEW APPROACHES FOR SOLVING PROBLEMS OF THE SIMULATION OF FLOOD WAVES AND BREAKTHROUGH TO JUSTIFY PROTECTIVE MEASURES

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Abstract: *The article is devoted to the development of river flow modeling methods. This paper discusses possible approaches to modeling fluid flow. The analysis of recent floods and measures to protect agricultural lands from flooding based on computer simulation of the spread of flood and breakthrough waves. Preferred various examples show that the most optimal way to prevent the breakthrough of hydraulic structures is is a constant automated monitoring of water level. This information is used to predict the emergency situation in the future.*

Keywords: *flood, flood and breakthrough waves, computer simulation, turbulent hydrodynamics, monitoring system, protection of the territory from flooding*

ҚОРҒАНЫС ШАРАЛАРЫН НЕГІЗДЕУ ҮШІН СУ ТАСҚЫНЫН ЖӘНЕ СЕРПІНДІ ТОЛҚЫНДАРДЫ МОДЕЛЬДЕУДІҢ МІНДЕТТЕРІН ОРЫНДАУҒА АРНАЛҒАН ЖАҢА ЖОЛДАР

Аңдатпа: *Мақала өзен ағынын модельдеу әдістерін әзірлеуге арналған. Онда ағынды модельдеудің ықтимал тәсілдері қарастырылады. Су тасқынының және серпінді толқындардың таралуын компьютерлік модельдеу негізінде соңғы болған су тасқыны мен ауылшаруашылық жерлерін су басудан қорғау шараларына талдау жүргізілді. Су деңгейіне автоматтандырылған бақылау жүргізу гидротехникалық құрылымдардың серпілісіне жол бермеудің оңтайлы тәсілі болып табылады. Бұл ақпарат болашақта төтенше жағдайды болжау үшін қолданылады.*

Түйінді сөздер: *су тасқыны мен серпінді толқындар, су басу, компьютерлік модельдеу, турбулентті гидродинамика, бақылау жүйесі, аумақты су басудан қорғау*

НОВЫЕ ПОДХОДЫ ДЛЯ РЕШЕНИЯ ЗАДАЧ О МОДЕЛИРОВАНИИ ПАВОДКОВЫХ И ПРОРЫВНЫХ ВОЛН ДЛЯ ОБОСНОВАНИЯ ЗАЩИТНЫХ МЕРОПРИЯТИЙ

Аннотация: *Статья посвящена разработке методики моделирования речного потока. В данной работе рассматриваются возможные подходы моделирования течения жидкостей. Проведен анализ недавних наводнений и мероприятий по защите сельскохозяйственных земель от затопления на основе компьютерного моделирования распространения паводковых и прорывных волн. Приведенные различные примеры показывают, что самым оптимальным способом предотвращения прорыва гидротехнических сооружений является постоянный автоматизированный мониторинг уровня воды. Данная информация впоследствии используется для прогнозирования аварийной ситуации.*

Ключевые слова: *наводнение, паводковые и прорывные волны, компьютерное моделирование, турбулентная гидродинамика, система мониторинга, защита территорий от затопления*

Introduction

In recent years, the world has seen an increase in the number and extent of flooding and the associated social and economic losses. Currently, floods as a natural disaster cannot be entirely prevented everywhere, they can only be attenuated, localized and with timely warning of light to minimize material damage. For example, flooding in different regions of the country in 2018 led to the death of crops on an area of several thousand hectares. The situation was so critical that in the Central and Northern regions of Kazakhstan the authorities were forced to evacuate the population.

The most common methods of protection against flooding are the construction of dams. Due to the considerable length of the protection objects for determining the parameters of protective structures, the use of numerical hydrodynamic modeling is promising. On its basis, the distribution of flood and breakthrough waves is estimated and the calculation of flood zones in the river valley is carried out.

The use of existing software to identify areas of potential flooding as a result of the passage of a flood or a breakthrough wave is possible only by highly qualified specialists using expensive equipment, while their cost is quite high. At the same time, the applied modeling techniques and software products do not offer an operational solution to the problems associated with the assessment of the consequences of catastrophic floods. Development of express technology for modeling flood and breakthrough waves to justify measures to protect agricultural land from flooding is an important area of research.

By express technology we mean scientific activities that allow us to quickly and effectively justify measures to protect agricultural land from flooding.

Currently, there are many examples of emergency situations (ES) associated with flooding caused by the spread of flood and breakthrough waves. At this time in our country there is a task of protection of agricultural lands and settlements from flooding. Flooding of agricultural land occurs when large-scale floods are missed, as well as other natural and man-made factors, such as:

- with the passage of extreme costs, the reservoir may overflow and disrupt the normal operation of the discharge facilities, which leads to water overflow through the dam crest and the formation of a blockage;
- due to the long service life, the main structures of the dam and hydromechanical equipment can wear out, which can lead to the formation of a block in the dam;
- due to personnel errors related to the lack of monitoring of hazardous situations and insufficient forecasting data on floods;

due to a possible terrorist act leading to the destruction of the dam.

We present some cases of flooding that caused significant damage to agricultural land and human settlements.

Dozens of dead, thousands of injured and billions of tenge, “drowned” in the water. In recent years, the arrival of spring in Kazakhstan is marked not only by the awakening of nature, but also by destructive floods. The flood problem is becoming more acute. The situation when in various regions of the country populated areas literally go under water has become the norm. At the same time, budget funds are still used to eliminate the consequences of floods, instead of preventing them. Kazpravda.kz correspondents recalled the most terrible leashes, found out what could happen this year, how to act in case of flooding and what measures are taken by the state to prevent and eliminate floods.

In Kazakhstan, a bus with schoolchildren was washed off the road by a flash flood. Video of the incident appeared on the network. In the video you can see how the bus that has moved down into the ditch is poured over the windows with stormy streams of melt water. Rescuers on the boat rescue the bus passengers through the upper hatch.

The incident occurred on April 16 in Sandyktau district on the Atbasar-Kokshetau highway, between the villages of Balkashino and Maksimovka, reports sputniknews.kz. “The bus of model “PAZ” left Derzhavinsk with 10 children, accompanied by teachers to the event in Kokshetau. On the road, the bus pulled out because of the meltwater overflow, the children were not injured, they were evacuated and placed in the school,” the police said.

Figure 1 - Flood in Kazakhstan (April 2018)

Flooding is a phase of the water regime, which is characterized by an intense, usually short-term increase in discharge and water levels, and is caused by rain or snowmelt during thaws. The spring flood is a seasonal phenomenon, and, in fact, this phenomenon has lately been more or less impossible to avoid.

In 2017, Akmola, Aktobe, East Kazakhstan, Karaganda, Kostanay, Pavlodar and North Kazakhstan regions suffered the most from the water-related hazard. Most of the 4715 evacuated people were taken out of Akmola (1340 people), Karaganda (1850) and Aktobe (1174) regions.

Severe flood damage was caused to the city of Atbasar in the Akmola region. The water flow there was so strong that the dam that defended the city was destroyed by a flood over 5 meters high. The water level on the first floors of Atbasar houses exceeded 1 meter.

Unfortunately, 2018 is no exception. Already in early March, alarming news began to appear: residents of the village Tuzdybastau evacuated the residents of the village of Tuzdybastau in the Almaty region, and the villages of Ornek, Akyrtobe, Teremuzek and Mamai were flooded in the Zhambyl region. There was a difficult flood situation in Akmola, East Kazakhstan, Karaganda and North Kazakhstan regions.

Research methods. Attempts to resolve the conflict between the need to use floodplain and coastal lands and losses from possible floods have been repeatedly undertaken by many specialists. But so far this conflict has not been resolved. In order to solve the problem of the possibility of using coastal lands, it is necessary to analyze the possible damage caused by floods. In agricultural areas, the losses caused by the flooding of agricultural land are especially high due to annual floods. Flooding causes damage to crops, damages various engineering and melioration systems.

Modern problems of land use require control and reliable forecast of the quality of land as a result of possible emergencies associated with flooding.

In the case of a flood or breakthrough wave, the quality of the land deteriorates significantly. Even a short-term rise of water in a river during a flood can cause flooding of coastal lands, which invariably entail significant losses associated with both possible crop loss and deterioration of land quality. In case of destruction of the pressure front of the dam, the most dangerous situation is observed. In this case, the resulting wave of breakthrough will cause huge damage, possibly flooding not only agricultural but also land settlements, which will bring catastrophic damage.

As measures to prevent damage caused by a possible flood, it is necessary to carry out such engineering measures as:

— monitoring and regulation of flood flow of rivers using various engineering structures: weirs, dams, strengthening of river banks, straightening of channels, etc.;

— design and rational placement of infrastructure elements and residential buildings in accordance with the potentially hazardous areas of possible flooding; in areas with frequent floods, it is possible to build houses on stilts, or transfer the first floors of buildings to non-residential premises;

— ensuring the sustainability of work, taking into account the possible occurrence of emergencies, important infrastructure elements: bridges, communication lines, etc.

All of the above flood control measures require precise engineering justification. Often, huge expenditures are required, both material and temporary, to conduct such research. To conduct a qualitative simulation of the breakthrough wave in existing software systems, high-class specialists, expensive equipment are required, the cost of the software itself is also high. All this requires huge financial investments, in turn, the available techniques do not offer a quick solution to the tasks.

It is worth noting that the main way today is the construction of embankment dams. The erection of embankment dams requires precise determination of the size of the dams themselves, since when they overflow through them, the dams turn out to be washed away. It is necessary to accurately determine the construction sites of the embankment dams, in order to prevent further spread of water. Due to the fact that the cost of building embankments directly depends on their length and height, it is necessary to optimize their parameters. The most rational conclusion could be the use in the design and construction of shore protection means, the simulation of river flow to determine possible areas of flooding. Further, based on the obtained simulation results, it is possible to calculate the parameters of embankment dams. Such calculations will allow to select the optimal parameters of bank protection means of protecting territories from the effects of flooding.

The founder of meliorative science in Russia was A.N. Kostyakov. In his fundamental work "Fundamentals of reclamation" [1] he described the ways of reclamation of floodplains and flooded lowlands. The concept of soil degradation, including the influence of anthropogenic factor was described in the works of A.A. Izmailskyi and B.A. Shumakov [2]. In the works of B.A. Brudastov the method of surface water drainage with the help of closed collectors was described. [3] Works of S.F. Averyanov on the management of water regime of reclaimed lands, on the methods of calculation of drainage for water drainage are widely used in the design of land reclamation measures [4].

To solve the problem of modeling flood and breakthrough waves and substantiate measures to protect agricultural land from flooding, the analysis of the literature describing possible approaches to modeling the flow of fluids has been carried out.

Для решения задачи о получении зон затопления в результате паводка возможны следующие способы получения результатов:

1. Physical models;
2. Conduct analytical calculations;
3. Numerical simulation.

To date, it has been shown that it is only possible to determine the propagation parameters of flood and breakthrough waves using numerical computer simulation.

Fluid flows are divided into two strongly different from each other type: laminar (smoothly changing, regular) and turbulent (disordered). In cases of the propagation of flood and breakthrough waves, the fluid flow will be turbulent.

P. Bradshaw (1971) [5] put forward the following definition of turbulence: "this is a three-dimensional unsteady motion in which, due to the stretching of vortices, a continuous distribution of velocity pulsations in the wavelength range from the minimum determined by viscous forces to the maximum determined by the boundary conditions of the flow is created. It is the normal state of a moving fluid, with the exception of flows at low Reynolds numbers".

The existence of laminar and turbulent flow regimes was observed in the first half of the 19th century, but the beginning of the theory of turbulence was described in the works of Osborne Reynolds (1883) [6]. Reynolds established the existence of a general criterion for the dynamic similarity of viscous incompressible fluid flows, the so-called Reynolds number:

$$Re = \frac{UL}{\nu}, \qquad (1)$$

where: U - characteristic speed, м/с; L — characteristic length scale in the current under consideration, m; ν — kinematic viscosity coefficient, m^2/s .

It has been discovered that if the Re number is sufficiently small, then the fluid flow is laminar. When the number Re reaches the critical value, the fluid motion becomes turbulent.

The first attempt to describe the processes of momentum transfer in turbulent flows belongs to

Boussinesq (1877) [6, 7]. These ideas were developed in the work Prandtl (1925) [8]. The modern formulation of the hypothesis of "locality" was defined in the work of LG. Loitsyanskyi (1958) [9]. In Richardson's works, a cascade mechanism of energy transfer in a turbulent flow is described. (1922) [6]. Then in the works of Jeffrey Taylor (1935) [6] the concept of homogeneous and isotropic turbulence was introduced. Later, Russian scientist Andrey Nikolaevich Kolmogorov (1941) [10] made significant results in the creation of a holistic theory of locally isotropic turbulence. Important studies of the semi-empirical theory of near-wall turbulence were made in the 50s in the works of E.Van Drist (1956) [11] and F. Clauser (1956). An important role in the development of the theory of turbulence, based on the use of equations for the second moments, was played by the works of A.N. Kolmogorov (1942) and Prandtl-Weghardt (1945), in which a hypothesis was put forward, which relates the coefficient of turbulent viscosity and the kinetic energy of turbulence. Recently, alternative approaches for modeling turbulence have been actively developed. Thus, direct numerical simulation (DNS — Direct Numerical Simulation) was formulated. Of the works that describe the results obtained by this method are W. Schumann, G. Gretzbach, L. Kleiser (1984), [12]). (1984), [12]). Due to the limitations of the methods of direct numerical simulation (DNS) of turbulent flows, the methods of large eddy simulation (LES-methods) have been developed. The main idea of the LES method is a formal mathematical separation of large and small structures by means of some operation. Main works in this area: F. Durst, B.E. Launder (1982), J. Ferziger (1977)), Smagorinsky (1963, 1971) [6], (D. Lilly, 1967).

Then, a new approach to modeling turbulent flows was the method called - Detached Eddy Simulation (DES), (work of M.H. Streletc, F. Spalart (USA), etc. (1997). Recently, combined LES - DES methods for modeling turbulent flows have also been developed.

Currently there is a wide variety of algorithms and programs. Due to the rapid growth of computer technology, the calculation speed has increased markedly, which allows for high-quality modeling. But it is worth noting that in real-life tasks, it becomes more important to obtain high-quality raw data. Inaccuracy of such data can minimize the advantage of using complex computer models. The most well-known and applied in practice are the programs: MIKE 11, developed by the Danish Hydraulic Institute and HEC-RAS, developed by the US Department of Defense. The HEC-RAS software package allows one-dimensional modeling of river flow and can be applied to rivers and canals. Software product MIKE 11, allows simulation of hydrodynamic processes such as dam destruction, breakthrough and flood waves, sediment transport and others. The MIKE 11 module makes it possible to find solutions to the implicit Abbott finite-difference scheme based on one-dimensional Saint-Venant equations.For two-dimensional modeling of river flow, the software package MIKE 21 was created.

The advantages of software systems are that they have a user-friendly interface, and the models used have a sufficient degree of reliability. The disadvantages include the high cost of software products and the complexity of setting the initial data for the simulation

Among the Russian programsfor river flow modeling should be noted a series of programs: "HYDRA", "WAVE", «Hydro Grash», developed by the CJSC Research and design center of Risk research and Safety Expertise, as well the Programs developed at the Scientific research Institute of energy structures under the guidance of A.N. Militeev, V.V. Belikov, S.Ya. Shkolnikov. Also worth mentioning is the RIVER program developed by A.N. Militeev, V.V. Belikov, V.V. Kochetkov, designed to calculate the costs, levels and zones of flooding on the basis of its own algorithm for the joint solution of the one-dimensional Saint-Venant equation and the continuity equation.

When a wave propagates along a flood plain, the use of one-dimensional Saint-Venant equations is inefficient, and two-dimensional equations need to be solved. A simulation based on solving two-dimensional Saint-Venant equations is represented by the "BOR" program created by V.V. Belikov, which allows for calculations of flood currents in rivers and river valleys.

It should be noted that the use of three-dimensional models is required to obtain an accurate picture of the fluid motion in the simulation of a breakthrough wave or a flood wave near the structures. Numerical simulation requires the solution of three-dimensional Navier-Stokes evolution equations. This approach is implemented in Los Alamos Lab Flow3D software package. It is also possible to carry out numerical 3D modeling in the software package Apsus 14, developed by the American company ANSYS Inc. It is worth noting about the software product Flow Vision from the developed. It allows to solve various hydrodynamic problems, including three-dimensional stationary and unsteady flows of compressible, weakly compressible and incompressible fluid using different turbulence models.

Thus, all existing software systems can be divided into one-dimensional, two-dimensional and three-dimensional. Numerical simulation in the one-dimensional and two-dimensional cases greatly simplifies the model under study and does not provide a complete picture of the processes occurring during the propagation of a breakout wave or a flood wave, which will be shown below. Thus, the use of three-dimensional numerical simulation will be most accurate for the calculation of flood and breakthrough waves.

In most cases, the basic system for hydrodynamic modeling is the three-dimensional system of Navier-Stokes evolution equations. The problem of river flow modeling is an important issue. Currently, there is no single solution for forecasting river flow. The constant aspiration to simplification of methods leads to a loss of quality in results of a research. But more complex models require multiple observations, which are often not available, so we have to simplify the models. One-dimensional models of river flow simulation can be used only for preliminary calculations. For a more accurate study, higher-level models should be used.

Conclusion. The paper shows that it is possible to determine the propagation parameters of flood and breakthrough waves only with the use of numerical computer simulation. All considered methods do not allow to receive quickly initial data for justification of flood control measures and demands considerable material and time resources. Thus, it is obvious that it is necessary to create a simplified technology for engineering substantiations of flood control measures that are comparable in terms of the reliability of obtaining results with existing ones, but at the same time have an advantage in speed of modeling and ease of implementation. The technology should, with a minimum set of initial data, make it possible to simulate the propagation of a flood wave or a breakthrough wave, the results of which provide a two-dimensional map of the study area with flood zones ranked by depth, as well as other parameters characterizing the propagation of waves.

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