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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ

Satbayev University

ХАБАРЛАРЫ

ИЗВЕСТИЯ

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НАУК РЕСПУБЛИКИ
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SIMULATION AND OPTIMIZATION MODELING OF WATER USE MANAGEMENT IN IRRIGATION SYSTEMS

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Abstract. In Kazakhstan, agricultural water consumption accounts for more than 65 % of all water consumption in the country. Irrigation of agricultural crops requires 15–16 km3 of water annually. According to the hydrogeological information of the Committee of Geology of the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan, there is a proven reserve of groundwater balance equal to 15.83 km^3/year, of which 8.73 km^3/year is renewable and can be used for irrigation. Sustainable development of the regions is possible on the basis of modern water resources management technologies, which will ensure the optimal use of water resources, high quality of water distribution and efficiency of decisions. The complex functional structure of water use process management in irrigation systems is a practical implementation of the processes and functions of water distribution management. A simulation-optimization model for planning and operational management of water use in irrigation systems is a logical and mathematical description of an object that can be used for experimenting on a computer in order to design, analyze and evaluate the functioning of a water body. The simulation — optimization model has been developed for water

use management at the pilot site of the irrigation system — the Tasotkel main canal. The pilot site is located in the basin of the River Shu. Geological structure is made up of rocks of different ages - from Precambrian to Quaternary deposits. Upper Quaternary deposits in the Shu River valley, as well as in the western part of the Betpak-Dala plateau, are represented by very characteristic yellowish-brown sandy loams and loess-like loams, locally enriched in sandy and pebbly material. An accumulative type of relief is distinguished, characterized by slight surface slopes and the presence of several river terraces, which is associated with the manifestation of various erosion-accumulation formation cycles. The methodology for planning and operational management of water use in irrigation systems, developed on the basis of a simulation-optimization model, is designed to improve the efficiency of managerial decision-making.

Keywords: Agricultural water consumption, management technology, hydrogeological information, geological structure, simulation-optimization model

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СУҒАРУ ЖҮЙЕЛЕРІНДЕГІ СУДЫ ПАЙДАЛАНУДЫ БАСҚАРУДЫ ИМИТАЦИЯЛЫҚ-ОҢТАЙЛАНДЫРУ АРҚЫЛЫ МОДЕЛДЕУ

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Аннотация. Қазақстанда ауылшаруашылық суды тұтыну елдегі барлық су тұтынудың 65 %-дан астамын құрайды. Ауыл шаруашылығы дақылдарын суару үшін жыл сайын 15–16 км3 су қажет. Қазақстан Республикасы Индустрия және инфрақұрылымдық даму министрлігі Геология комитетінің гидрогеологиялық ақпараты бойынша 15,83 км^3/жылына тең барланған жер асты суларының балансы бар, оның 8,73 км^3/жылы жаңартылатын және суаруға пайдалануға

болады. Өңірлердің тұрақты дамуы су ресурстарын оңтайлы пайдалануды, суды бөлудің жоғары сапасын және қабылданған шешімдердің тиімділігін қамтамасыз ететін заманауи су ресурстарын басқару технологиялары негізінде мүмкін болады. Суару жүйелерінде суды пайдалану процесін басқарудың кешенді функционалдық құрылымы суды бөлуді басқарудың процестері мен функцияларын іс жүзінде жүзеге асыру болып табылады. Суару жүйелерінде суды пайдалануды жоспарлау және жедел басқарудың имитациялық-оңтайландыру моделі су объектісінің жұмыс істеуін жобалау, талдау және бағалау мақсатында компьютерде тәжірибе жасау үшін пайдаланылуы мүмкін объектінің логикалық-математикалық сипаттамасы болып табылады. Суару жүйесінің тәжірибелік учаскесі — Тасөткел магистральдық каналында суды пайдалануды басқару үшін имитациялық-оңтайландыру моделі әзірленді. Пилоттық алаң өзеннің алабында орналасқан. Шу, оның геологиялық құрылымы әртүрлі жастағы тау жыныстары — кембрийге дейінгі кезеңнен төрттік шөгінділеріне дейін Шу өзені алқабындағы жоғарғы төрттік шөгінділері, сондай-ақ Бетпақ-Дала үстіртінің батыс бөлігінде өте тән сарғыш-қоңыр құмды саздақтармен және жергілікті құмды және малтатас материалмен байытылған лесс тәрізді саздақтармен ұсынылған. Жер бетінің шамалы беткейлерімен және бірнеше өзен террассаларының болуымен сипатталатын рельефтің аккумуляциялық түрі ерекшеленеді, бұл әртүрлі эрозия-аккумуляциялық қалыптасу циклдерінің көрінісімен байланысты. Имитациялық-оңтайландыру моделі негізінде әзірленген ирригациялық жүйелердегі суды пайдалануды жоспарлау және жедел басқару әдістемесі басқару шешімдерін қабылдау тиімділігін арттыруға арналған.

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ИМИТАЦИОННО-ОПТИМИЗАЦИОННОЕ МОДЕЛИРОВАНИЕ УПРАВЛЕНИЯ ВОДОПОЛЬЗОВАНИЕМ НА ОРОСИТЕЛЬНЫХ СИСТЕМАХ

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Аннотация. В Казахстане сельскохозяйственное водопотребление составляет более 65 % всего водопотребления в стране. Для орошения сельскохозяйственных культур ежегодно требуется 15–16 км^3 воды. Согласно гидрогеологической информации Комитета геологии Министерства индустрии и инфраструктурного развития РК, имеется разведанный запас баланса подземных вод, равный 15,83 км^3/год, из которых 8,73 км^3/год — возобновляемые, их можно использовать на орошение. Устойчивое развитие регионов возможно на основе современных технологий управления водными ресурсами, что обеспечит оптимальное использование водных ресурсов, высокое качество водораспределения и оперативность принимаемых решений. Комплексная функциональная структура управления технологическим процессом водопользования на оросительных системах представляет собой практическое воплощение процессов и функций управления водораспределением. Имитационно-оптимизационная модель для планирования и оперативного управления водопользованием на оросительных системах является логико-математическим описанием объекта, которая может быть использована для экспериментирования на компьютере в целях проектирования, анализа и оценки функционирования водного объекта. Имитационно-оптимизационная модель разработана для управления водопользованием на пилотном участке оросительной системы — Тасоткельский магистральный канал. Пилотный участок расположен в бассейне р. Шу, геологическое строение которой составляют разновозрастные породы – от докембрийских до четвертичных отложений. Верхнечетвертичные отложения в долине реки Шу, а также в западной части плато Бетпак-Дала представлены очень характерными желтовато-бурыми супесями и лёссовидными суглинками, местами обогащенными песчаным и галечным материалом. Выделяется аккумулятивный тип рельефа, отличающийся незначительными уклонами поверхности и наличием нескольких речных террас, что связано с проявлением различных эрозионно-аккумулятивных циклов образования. Методика планирования и оперативного управления водопользованием на оросительных системах, разработанная на основе имитационно-оптимизационной модели, предназначена для повышения эффективности принятия управленческих решений.

Ключевые слова: сельскохозяйственное водопотребление, технология управления, гидрогеологическая информация, геологическое строение, имитационно-оптимизационная модель

Introduction

In Kazakhstan, agricultural water consumption accounts for more than 65 % of all water consumption in the country. Irrigation of crops requires 15–16 km^3 of water annually. Of this, 12 km^3 are used in four regions in the south of the country, where irrigated crops

are grown on an area of 1.25 million hectares (97 % of the water withdrawal). Losses from the volume of water withdrawal, which are primarily associated with the poor technical condition and unsatisfactory operation of irrigation systems, are about 3 km^3 (Water security of Kazakhstan: status, problems and recommendations, 2019).

According to experts, water consumption in Kazakhstan will increase by 56 % by 2040 and amount to about 25 km^3 per year, and the shortage of water resources may reach 12 km^3 per year (How Kazakhstan can avoid a water crisis, 2023).

According to the hydrogeological information of the Committee of Geology of the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan, there is an explored reserve of groundwater balance equal to 15.83 km3/year, of which 8,73 km^3/year can be used for irrigation (Groundwater Resources of Kazakhstan, 2015). However, for the use of groundwater, it is necessary to confirm their reserves, by the protocols of the State Commission on Mineral Reserves, the validity of which has expired almost everywhere and their reassessment is required.

Irrigation of crops on existing irrigation systems is not effective enough due to not only the low technical condition and equipment with modern technologies but also the lack of quality management of water use and water distribution processes along the entire length of irrigation canals (Ibrayev, 2022; Li, 2018; Ibrayev, 2022). Sustainable development of the regions is possible based on modern water resources management technologies, which will ensure the optimal use of water resources, high quality of water distribution, and efficiency of decisions.

Materials and research methods

Evaluation of the efficiency of water resources use and analysis of the technical condition of irrigation systems are based on materials from the operational indicators of irrigation systems, reports from previous studies, and reconnaissance surveys of water bodies (Creation of water allocation management in irrigation systems based on hydrological information, using water resources formation in river basins: Research report (interim), 2021). Based on the research work carried out, a general approach to the development of an integrated functional structure for managing the technological process of water use in irrigation systems was formed, and a method for planning and operational management of water use in irrigation systems was developed based on a simulation optimization model. A methodology for planning and operational management of water use in irrigation systems based on simulation-optimization modeling has been developed, which makes it possible to ensure the reliability and efficiency of managerial decisions and the rational use of water resources.

The main stages in the development of a structure for managing the technological process of water use were: the analysis of information flows; the choice of control criteria. In the first stage, the materials of the conducted studies in the subject area were used (collection of data on the objects of study, collection of hydrological information). In the second stage, possible options for managing the technological process of water use were considered, indicators were determined, according to which various options were compared and the most optimal one was selected.

Widely used methods of scientific research are used, which are well-known ways

to achieve the goal of research work, allowing to obtain specific results clearly and efficiently (Getachew Belaineh, 1999; Ivanova, 2017; Agbortoko Bate Ashu, 2021; Mohammad Reza Nikoo, 2022; Haacker, 2019; Georgiou, 2008).

Main results and analysis

The complex functional structure of water use process management in irrigation systems is a practical implementation of the processes and functions of water distribution management (Figure 1).

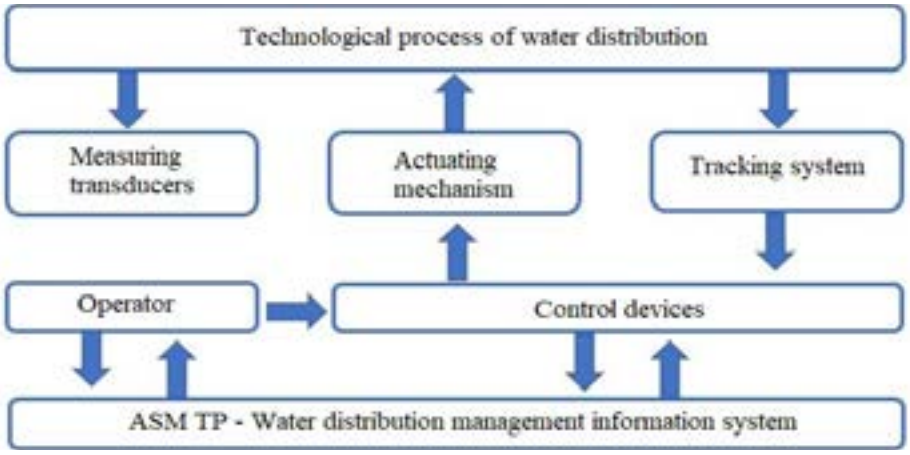

Fig. 1 - Comprehensive functional structure for managing the technological process of water use

The developed structure includes:

– measuring transducers designed to measure the specified parameters and transfer them to the water resources management information system, which is the controlling body of the system;

– an actuator is an electric drive with mechanical units - gearboxes and screws, the task of which is to set the sluice gate mechanisms in motion by a signal from the control system to move the shutoff valve (hydraulic seal) up or down, respectively, opening or closing the gate;

– a tracking system designed to control the position of the shutter, using the information received by the control system to calculate the throughput of the sluice gate at the corresponding position of the shutter;

– control device, which is an electronic device with a processor unit that executes a user program (programmable logic controllers or industrial computers);

– water distribution management information system, which is a software product designed to collect and manage the water distribution system.

The main functions of the information system for managing water resources: collecting information from the control device of the executive mechanism; inputting the calendar plan of water consumption; viewing information about current and accumulated parameters from measuring transducers; viewing diagnostic information

on the health of various equipment. At the same time, a complex functional structure for managing technological processes of water use ensures an increase in the efficiency of the technological process by the chosen optimality criterion for given technological, economic, and other production constraints.

A simulation-optimization model for planning and operational management of water use in irrigation systems is a logical and mathematical description of an object that can be used for experimenting on a computer to design, analyze and evaluate the functioning of a water body (Modeling dynamic management of water distribution in the channels of an open irrigation network, 2015).

A mathematical model is commonly understood as a set of relationships — equations, inequalities, logical conditions, operators, etc., that determine the characteristics of the states of the modeling object, and through them the output values of the reaction parameters, depending on the values of the parameters of the original object, input actions, initial and boundary conditions, as well as time.

The simulation-optimization model (hereinafter referred to as the Model) was developed for water use management at the pilot plot (PP) of the irrigation system - the Tasotkel main canal (TMC), which administratively is part of the land use of the Shuisky district of the Zhambyl region and is located 5–10 km northwest of the city of. Shu (Figure 2).

Fig. 2 - Layout of the plot

The pilot site is located in the basin of the river. Shu, whose geological structure is made up of rocks of different ages - from Precambrian to Quaternary deposits. Upper Quaternary deposits in the Shu River valley, as well as in the western part of the Betpak-

Dala plateau, are represented by very characteristic yellowish-brown sandy loams and loess-like loams, locally enriched in sandy and pebbly material. The thickness of the entire stratum here reaches 50 m. Undivided Upper Quaternary and modern deposits are common on wide plains. Within the Moiynkum desert, these are eolian sands overlying rocks of various ages — from Upper Neogene to modern, which indicates the processes of winding and accumulation over a relatively long period. In addition to eolian sands, in the river valley, as well as on the slopes of the foothills and intermountain depressions, young Quaternary formations are widespread. Genetically, they are more often represented by alluvial, alluvial-proluvial and deluvial-proluvial deposits. Lakeside areas, usually consist of sandy clays and silts (Scheme for the integrated use and protection of water resources of the Shu river basin with tributaries, 2017).

Within the river basin Shu, on the PP, an accumulative type of relief is distinguished, characterized by slight surface slopes and the presence of several river terraces, which is associated with the manifestation of various erosion-accumulation cycles of formation. River floodplains are developed everywhere and rise above the water's edge by 0.5-1.0 m.

The lining of the TMC canal is prefabricated-monolithic, there are 12 water outlets, 8 siphons, and 2 storm drains. At the beginning of the TMC canal and inter-farm canals TBKh-1 and TBKh-2, there are head gauging stations with measurement of water flow along a fixed channel, as well as a hydrometric network of posts, and graduated hydraulic structures.

The basis of simulation modeling is the logical analysis of elementary processes in the system and the imitation of the phenomena that make up the process under study while maintaining their logical structure and sequence in time. In the Model, new algorithms have been developed that implement the functional tasks of water intake for water distribution in conditions of water scarcity in the example of TMC. The model is implemented in the Microsoft Excel spreadsheet program in the VBA macro programming language (Visual Basic for Application) and consists of 1 main and several additional Excel sheets interconnected by links and calculation formulas.

The algorithm for constructing the Model for the existing irrigation system includes the following steps (Figure 3):

1 - Choice of channel, culture;

2 - Determination of the decade distribution of irrigation norms for agricultural crops;

3 - Plotting hydro module;

4 - Construction of a linear scheme of the irrigation network;

5 - Determination of the efficiency of irrigation network channels;

6 - Determination of the values of costs for the calculated sections.

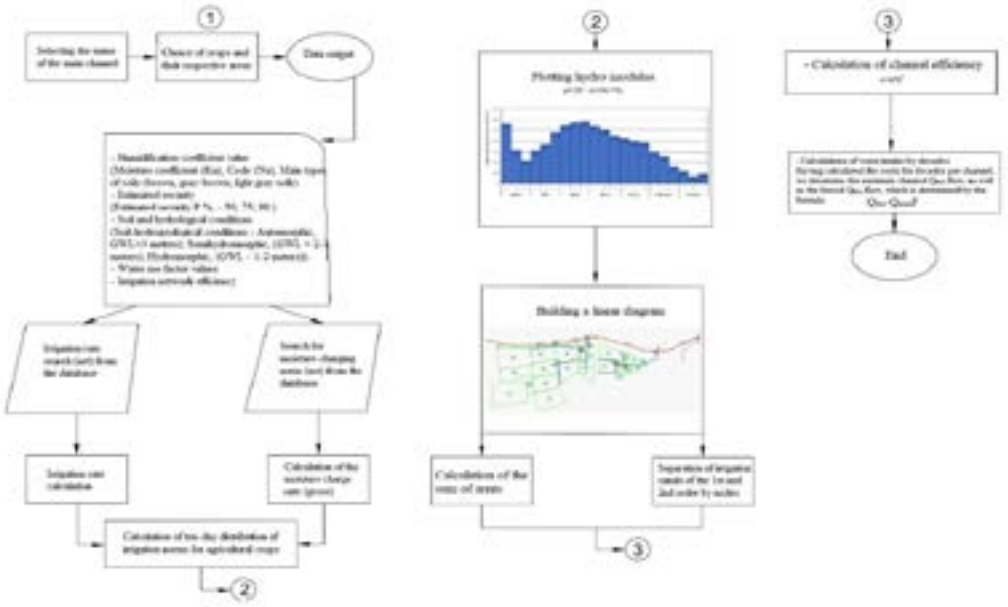

Fig. 3 - Algorithm of computer technology for planning water use

The planned scheme of the irrigation network is the source material for constructing longitudinal profiles and cross-sections of channels of various orders included in it, the number of which is determined depending on the tasks of simulation modeling (Figure 4).

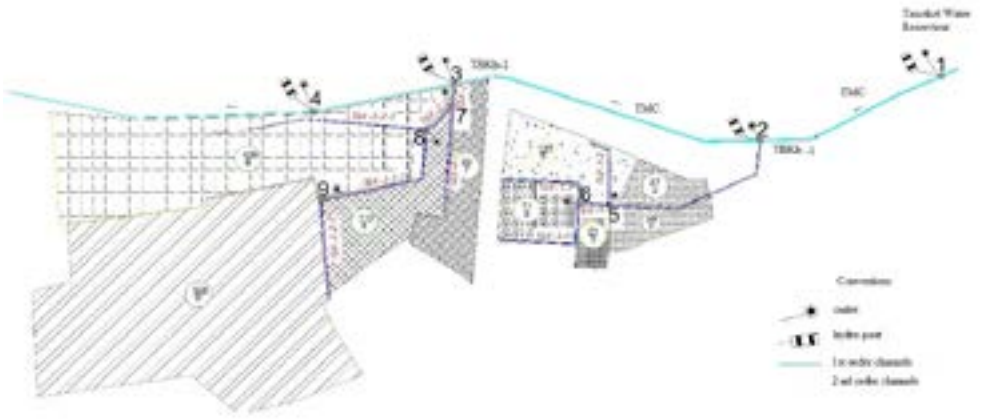

Fig. 4 - Planned scheme of the TMC irrigation network

The final calculation listing of the program is “rashod”, in which the calculations of the ten-day, maximum, and forced water flow for each TMC channel are carried out. The formation of various calculation scenarios is based on water supply schedules for

sections (applications of water consumers), the estimated year of flow availability, and the operating mode of irrigation canals.

Thus, the Model is a computer program implemented using a set of mathematical tools that allow the creation of analogous processes in the computer memory, with the help of which it is possible to conduct a targeted study of the structure and functions of a real irrigation system in its "simulation" mode.

The methodology for planning and operational management of water use in irrigation systems based on a simulation-optimization model is a specialized software package designed for information technology support in solving the following interrelated tasks:

– collection, processing, and storage of the necessary technical data, as well as information about the farms-water users of the irrigation system;

– automation of the technological process of compiling and calculating the intra-seasonal ten-day distribution of the irrigation norm of crops based on the composition of water users, the structure of sown areas;

– automation of the technological process of calculating the efficiency of channels, maximum and forced costs in channels;

– exchange of information on the planned indicators of work with higher, related, or interested organizations;

– collection, processing, and storage of information on the actual performance of the irrigation system;

– automation of operational reporting on the water management activities of the irrigation system.

The considered scenarios for the operation of TMC and its water outlets showed that with an increase in the estimated year of flow supply (50%, 75%, 95%), the main indicators of the Model change automatically depending on the water availability of the year and are:

– Decade irrigation norm for fields - 10490.2 m3/ha - 11588.5 m3/ha - 13598.4 m3/ha, respectively;

– Maximum flow - 19.5 m3/s - 21.1 m^3/s - 24.7 m3/s, respectively.

When a situation arises in the irrigation network, in which one of the channels does not work, the costs transferred to other channels also change automatically, according to the new conditions.

Conclusions

An integrated functional structure for managing technological processes of water use will increase their efficiency, in accordance with the chosen optimality criterion for given technological, economic, and other production constraints.

The developed simulation-optimization model for planning and operational management of water use in irrigation systems, implemented using a set of mathematical tools that allow you to create analogous processes in computer memory, allows you to conduct a targeted study of the structure and functions of a real irrigation system in its "imitation" mode, to optimize some its parameters.

The methodology for planning and operational management of water use in irrigation systems, developed based on a simulation-optimization model, is designed to improve

the efficiency of managerial decision-making. The use of simulation modeling of production activities in the field of water use allows, on the one hand, to evaluate the quality of the decision made on the model, and on the other hand, it can be a means of improving the skills of operational personnel.

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