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Satbayev University

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НАЦИОНАЛЬНОЙ АКАДЕМИИ
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IMPROVEMENT OF THE WATER DISTRIBUTION MANAGEMENT SCHEME ON IRRIGATION SYSTEMS USING HYDROLOGICAL INFORMATION

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Abstract. Hydraulic reclamation and water management facilities for regulating or redistributing river flow have a significant impact on the geological environment. To take into account these natural and anthropogenic factors, a detailed study of existing conditions in order to predict their changes due to land reclamation, an important part is engineering-geological, hydrological studies, as well as the regime and operational reserves of groundwater. At the same time, the problem of effective water resources management and water allocation on irrigated lands is one of the most important for human society, since decisions on water resources management occur due to a variety of natural (geological, hydrological) and anthropogenic factors. Considering such issues, the need for which requires the development of a clear concept of water resources management and is determined by the complex role of water, its numerous interrelations and impact on ecosystems, as well as the vital need of the population for water, we come to the conclusion that the creation of a comprehensive structure for the use of water resources in economic sectors is relevant. The improved scheme of water distribution management in irrigation systems, developed by the authors, using hydrological information will solve the problem of improving the principles and methods of balanced water supply management in irrigation systems, taking into account the operating modes of water bodies and possible options for the development of economic sectors both in the Republic of Kazakhstan and in neighboring territories, provided that ecological balance in the environment is preserved.

Key words: hydrological information, improvement, water resources management, irrigation systems, water distribution

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ГИДРОЛОГИЯЛЫҚ АҚПАРАТТЫ ПАЙДАЛАНА ОТЫРЫП, СУАРУ ЖҮЙЕЛЕРІНДЕГІ СУ БӨЛУДІ БАСҚАРУ СХЕМАСЫН ЖЕТІЛДІРУ

Есенкүл Калыбекова — техника ғылымдарының докторы. "Су ресурстары және мелиорация" кафедрасының профессоры. Қазақ ұлттық аграрлық зерттеу университеті, Алматы, Қазақстан
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Нұрлан Балғабаев — ауыл шаруашылығы ғылымдарының докторы. Қазақстан Республикасының Ауыл шаруашылығы Академиясының және ауыл шаруашылық білім беру Халықаралық Академиясының академигі. Қазақ су шаруашылығының ғылыми – зерттеу институтының директоры, Тараз, Қазақстан
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Ермек Әуелбек — "Су ресурстары және мелиорация" кафедрасының ауыл шаруашылық магистры. Қазақ ұлттық аграрлық зерттеу университеті, Алматы, Қазақстан
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Аннотация. Өзен ағынын реттеуге немесе қайта бөлуге арналған гидротехникалық мелиорациялар мен су шаруашылығы құрылыстары геологиялық ортаға айтарлықтай әсер етеді. Осы табиғи және антропогендік факторларды ескеру мақсатында, мелиорация нәтижесінде олардың өзгеруін болжау үшін қолданыстағы жағдайларды егжей-тегжейлі зерттеу үшін инженерлік-геологиялық, гидрологиялық зерттеулер, сондай-ақ жер асты суларының режимі мен пайдалану қорлары маңызды бөлік болып табылады. Сонымен бірге, су ресурстарын тиімді басқару және суармалы жерлерде су бөлу проблемасы адамзат қоғамы үшін ең маңызды мәселелердің бірі болып табылады, өйткені су ресурстарын басқару жөніндегі шешімдер көптеген табиғи (геологиялық, гидрологиялық) және антропогендік факторларға байланысты туындайды. Қажеттілігі су ресурстарын басқарудың нақты тұжырымдамасын әзірлеуді талап ететін және судың күрделі рөлімен, оның көптеген өзара байланыстарымен және экожүйеге әсерімен, сондай-ақ халықтың суға деген өмірлік қажеттілігімен айқындалатын мәселелерді қарай отырып, экономика салаларында су ресурстарын пайдаланудың кешенді құрылымын құру өзекті болып табылады деген пікірге келеміз. Авторлар әзірлеген гидрологиялық ақпаратты пайдалана отырып, суландыру жүйелерінде су бөлуді басқарудың жақсартылған схемасы қоршаған ортада экологиялық тепе-теңдік сақталған жағдайда, Қазақстан Республикасында да, көршілес аумақтарда да су объектілерінің жұмыс режимдерін және экономика салаларын дамытудың ықтимал нұсқаларын ескере отырып, ирригациялық жүйелерде су құбырын теңгерімді басқарудың қағидаттары мен әдістерін жетілдіру жөніндегі міндетті шешуге мүмкіндік береді.

Түйін сөздер: гидрологиялық ақпарат, жетілдіру, су ресурстарын басқару, суару жүйелері, суды бөлу

Қаржыландыру: Бұл зерттеулер 2021–2023 жылдарға арналған "Жаңа суармалы жерлерді енгізу, қолданыстағы ирригациялық жүйелерді реконструкциялау және жаңғырту кезіндегі суару технологиялары мен техникалық құралдары" ғылыми-техникалық бағдарламасы (ҒТБ) шеңберінде Қазақстан Республикасының ауыл шаруашылығы министрлігімен қаржыландырылды (BR10764920).

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УСОВЕРШЕНСТВОВАНИЕ СХЕМЫ УПРАВЛЕНИЯ ВОДОРАСПРЕДЕЛЕНИЕМ НА ОРОСИТЕЛЬНЫХ СИСТЕМАХ С ИСПОЛЬЗОВАНИЕМ ГИДРОЛОГИЧЕСКОЙ ИНФОРМАЦИИ

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Аннотация. Гидротехнические мелиорации и водохозяйственные сооружения для регулирования или перераспределения речного стока оказывают значительное воздействие на геологическую, гидрогеологическую и гидрологическую среду. Для учета этих природных и антропогенных факторов, детального изучения существующих условий с целью прогнозирования их изменений вследствие мелиорации, важной частью являются инженерно-геологические, гидрологичесие исследования, а также режим и эксплуатационные запасы подземных вод. Вместе с тем, проблема эффективного управления водными ресурсами и вододелении на орошаемых землях является одной из самых важных для человеческого общества, поскольку решения по управлению водными ресурсами происходят из-за множества природных (геологических, гидрологических) и антропогенных факторов. Рассматривая такие вопросы, необходимость которых требует разработки четкой концепции управления водными ресурсами и определяется сложной ролью воды, ее многочисленными взаимосвязями и влиянием на экосистемы, а также жизненной потребностью населения в воде, приходим к мнению, что создание комплексной структуры использования водных ресурсов в отраслях экономики, является актуальной. Разработанная авторами улучшенная схема управления водораспределением на оросительных системах с использованием гидрологической информации позволит решить задачу по совершенствованию принципов и методов сбалансированного управления водоподачей на ирригационных системах с учетом режимов работы водных объектов и возможных вариантов развития отраслей экономики как в Республике Казахстан, так и на соседних территориях, при условии сохранения экологического равновесия в окружающей среде.

Ключевые слова: гидрологическая информация, усовершенствование, управление водными ресурсами, оросительные системы, водораспределение

Финансирование: Данные исследования были профинансированы Министерством сельского хозяйства Республики Казахстан (BR10764920) в рамках научно-технической программы (НТП) “Технологии и технические средства орошения при внедрении новых орошаемых земель, реконструкции и модернизации существующих ирригационных систем” на 2021–2023 годы.

Introduction

Water reclamation and hydraulic structures for regulating or redistributing river flow have a significant impact on the geological environment. To account for these impacts, a detailed study of existing natural conditions in order to predict their changes due to land reclamation, engineering-geological and hydrological studies are an important part. The main directions of engineering-geological and hydrological research for reclamation construction differ significantly from those for other types of construction. This is due to the special specifics of the construction of hydro-reclamation and water management systems, their special purpose. The intensity of the impact of hydro-reclamation systems on the natural environment is higher than the effects that many other types of construction have. For example, irrigation of vast territories in the arid zone can change natural landscapes, entail noticeable hydrological studies.

Under modern conditions, the remarkable ability of nature to regulate itself, acquired in the process of evolution, has become disrupted. Now, with the modern development of society, natural processes also occur under the influence of anthropogenic activities. People, introducing artificial changes into the natural environment and biogeocenoses, deprives them of stability, which often leads to radical changes in ecosystems, the progressive destruction of the biosphere (Shiklomanov, 2008; Zauirbek, 2019; Urkumbaev, 2003).

Water is the most important resource of the environment and one of the determinants of the development and distribution of productive forces of the country. The deficit of water resources in the Republic of Kazakhstan will increase more and more as economic sectors develop. This problem arises primarily because of the irrational use of water resources, especially in the irrigation sector and, the gradual reduction of water flow in the basins of trans boundary rivers is another reason.

In the long term, the size of the formed flow will also be affected by global climatic changes. Much attention has been paid to changes in temperature regime and sea level rise of the oceans. However, there has been little research into the magnitude of the potential impacts of impending climate change on water resources at the regional, national or local level.

According to calculations in the next 30 years in the basins of mountain rivers in Kazakhstan, the annual flow may increase to 22.5 % (due to melting glaciers), and in plain rivers — to decrease to 10.3 % (Annual bulletin, 2016). The unevenness of flow distribution during the year is increasing.

At the same time, the water sector in Kazakhstan is characterized by a weak material and technical base and low capital equipment, especially in irrigated agriculture. Traditional provisions of market economy and methodology for assessment of economic efficiency of water sector performance and solving water problems have not been fully formed in the sector, as well as water use strategy linked to available water resources and taking into account requirements of natural complexes has not been developed yet. For the basins of transboundary rivers is not appreciated the growth of water withdrawal for the future in the territories of neighboring states.

Materials and methods

Problems of planning of use and protection of water resources, and also struggle against harmful influences of water, first of all, depend on strategy of development of branches of economy.

Analysis and assessment of water resources use efficiency on the basis of hydrological information in the river basin in question cannot do without clarification of some generally applicable and frequently operated concepts when developing recommendations on rational water resources use for economic sectors and, in particular, for irrigated agriculture as the largest water consumer of the country.

Effective management of water distribution and water supply processes in irrigation systems directly affect the quality of functioning of the agro-industrial complex of Kazakhstan. To solve this problem, it is necessary to ensure the coordinated work of all parts of the irrigation system in the presence of a large number of technological resources and other constraints.

Results and discussion

The primary task of improving the technical level of irrigation systems is to develop a set of measures to minimize or completely eliminate technological losses, as well as the scientific rationale and development of new methodologies for planning and implementing water use processes in irrigation systems, taking into account the current level of digitization, methods of mathematical and physical modeling, computer technology. Modern irrigation strategy should be based on the improvement of both existing and development of new methodologies for planning and implementation of water use processes, providing optimal management decisions in a single technological process, taking into account natural factors and man-made technical means.

Taking I.V. Olgarenko's scheme of irrigation water distribution technological process management in irrigation systems as a basis, a complex structure of water distribution management in the irrigation system, based on hydrological information, taking into account flow formation in river basins presented in Figure 1, (Olgarenko, 2013: 218; Tkachev et al., 2021: 69).

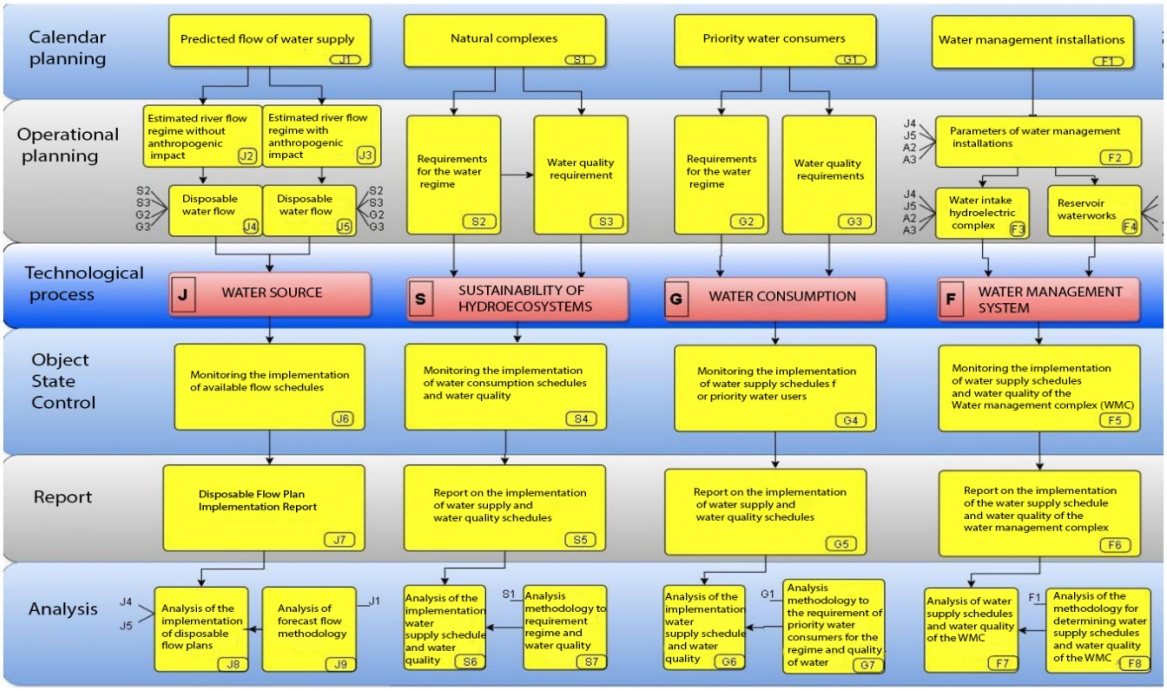

Figure 1. Blocks included in the water management structure

The proposed structure for effective management of irrigation water distribution in irrigation systems took into account and included the following features and factors:

- global climatic changes;
- hydrological information of water source (water source regime, water quality)
- extent to which the irrigation system's water requirements are met;
- combination of river flow regimes and crop water requirements;
- parameters of water management facilities and their operation regimes;
- water requirements of priority water users and natural complexes.

Justification of included blocks in the structure of balanced irrigation water distribution management in irrigation systems is given below.

Water resources (water source). In order to make water management calculations it is necessary to have hydrographic network parameters. Principles of determining the calculated regime of river flow in a certain site depend on the scheme of water and land resources use in the river basin: simple and complex.

They collect materials: hydrographic characteristics of the water source under consideration, possibility of use of the reservoir for the purposes of hydropower, navigation, recreation, fishery value of the river, etc. The study of the river, the annual flow and its intra-annual distribution are established. These materials are given for the multiyear period. Identify the time of freeze-up, opening of the river, duration of freeze-up, ice thickness and ice strength and determine: the water flow rate — Q, m^3 / s; the flow volume — W, m^3; flow module — M, l / (s · km^2); a flow layer — h, mm.

Also their calculated values are determined — Qp, Wp, hp, Mp, with the use of the coefficient of variation; the asymmetry coefficient and the correlation coefficient. In the future, the size of the formed runoff will also be influenced by the onset of the expected global climatic changes. In this regard, development of special measures for adaptation to climate change will be required.

Air temperature in Kazakhstan has started to rise since the early 1960s. Temperature growth rate is 0.028 degrees a year, or 0.28 degrees every 10 years (Kromer, 2002). According to calculations, the annual runoff in mountain river basins in Kazakhstan may increase by up to 22.5 % in the next 30 years (due to melting glaciers). The annual flow of basins of plain rivers may decrease to 10.3 % (Framework Convention, 2015; Rio Declaration, 1992).

The decrease is expected and the more uneven distribution of runoff during the year increases.

With the expected increase in air temperature and unchanged atmospheric precipitation, the specific values of crop irrigation rates will increase by 4–5 % every 10–20 years. Hence, it follows that the rate of implementation of water-saving and innovative technologies in irrigated agriculture should be almost twice as high as they were adopted in the Scenario of Sustainable Development of the State Hydrological Institute (SSD SHI) (Afzal et al., 2016: 40; Zauirbek, 2018: 240; Gleick et al., 2016: 784).

Development of other branches of economy will take place only at the expense of specific water consumption norms reduction.

Provision of irrigation systems with necessary regime and water quality is impossible without water management facilities, which carry out necessary level of river basin water resources use, which use is possible by flow regulation. Therefore, it is necessary to have a special block: "Water management system".

Water management system. Dispatch schedules, which are a set of lines, connecting water and power output of hydro schemes with level or volume of water in the reservoir, are used for reservoirs operation control and allow to manage completely water resources use of isolated hydroschemes reservoirs. For cascades and their associations, the dispatch schedules are supplemented by the system of dispatch rules, which regulate the order of water resources use of reservoirs of different stages.

Operation regime and water release from reservoirs in turn depends on the level of water resources use and water consumption regimes of natural complexes and economic sectors. The task is to meet the water requirements of natural complexes with reliability of p=95 % and priority water consumers p=95 or 97 %–for municipal and agricultural water supply; p=95 %–for industrial water supply of special state significance.

Therefore, there is a need to include special blocks: "Stability of hydroecosystems" and "Priority water consumers".

Water management problems are most rationally solved under integrated water resources use, when it is necessary to meet water requirements of all economic sectors in given region. At the same time, protection of water resources from depletion and pollution is inseparable from their rational use.

Nature protection. Water management problems are solved most rationally under integrated water resources use, when it is necessary to meet water demands of all sectors of economy in given region. Protection of water resources from depletion and pollution is inseparable from their rational use. Another important direction of water management is the control of harmful water impact, which includes development of engineering measures against floods, mudflows, flooding, water erosion, erosion of river banks, channels, reservoirs and seas, formation of ravines, landslides, snow avalanches, engineering protection of territories, etc.

In existing schemes of water resources use, demands of objects of nature to water are taken into account according to the "residual principle". For them, the so-called "environmental flow" is not allocated, their requirements are satisfied as a residual term of the water balance equation.

In addition, a unified methodological approach to establishing the permissible load on the natural environment, including permissible limits of withdrawal of water resources from water bodies that meet social, environmental and economic aspects of environmental protection, i.e. the conditions of environmentally sustainable development, which is the main objective of the Water Code of the Republic of Kazakhstan, is not developed. Thus, sustainable functioning of water sector and preservation of natural complexes in river basins is not achieved.

Dynamics of water and land resources use in river basins of Kazakhstan shows that water needs of water management sectors are increasing from year to year. Until recently these needs are met at the expense of extensive use of surface water volume, which disturbs ecological equilibrium (ecological stability) in lower reaches of rivers. As a result, sectors of the economy as a whole suffer significant damage (Kalybekova et al., 2022: 104).

In order to give special status to natural complexes, to take into account their requirements to water quantity and quality, it is necessary to introduce a special indicator–the level of satisfaction of natural complexes' requirements to water regime and water quality–into statistical reporting. For this purpose it is necessary to establish the state of environment and possibility of coordination of level of technogenic load on ecosphere with "possible endurance of natural environment" already at new level (Litrico et al., 2021: 317; Hashemy et al., 2021; García Villanueva, 2021).

Thus, management of water resources of the river basin with long-term planning of spatial distribution, will allow using resources of the state, business and the population rationally. For this purpose, at the first stage the modern condition of use of water resources and an ecological condition in the river basin at its various water availability is analyzed, level of use of water resources and level of satisfaction of need for water of natural complexes is estimated. At the second stage possibility of economic branches development for perspective taking into account predicted changes of water resources which, in turn, depend on accepted scenarios of global climatic changes in biosphere.

In order to substantiate economic efficiency of water management measures and achieve optimal parameters of water management installations, an improved criterion is proposed (Zauirbek, 2018: 234).

$$SEER_i = I_i - D_i - E_i + EEA \rightarrow max \quad (1)$$

where $SEER_i$, I_i, D_i, E_i, EEA_i — r espectively, socio-ecological and economic result, income of industries, damage from depletion and pollution of water sources, costs of construction of water management and water protection facilities, additional economic effect arising from the increase in value of natural resources at the i – th option of integrated use of water resources of the river basin.

Based on the difference between income and environmental damage, the criterion makes it possible to determine the environmental and economic result for various degrees water resource use (on the example of the Ile river basin) in Figure 2.

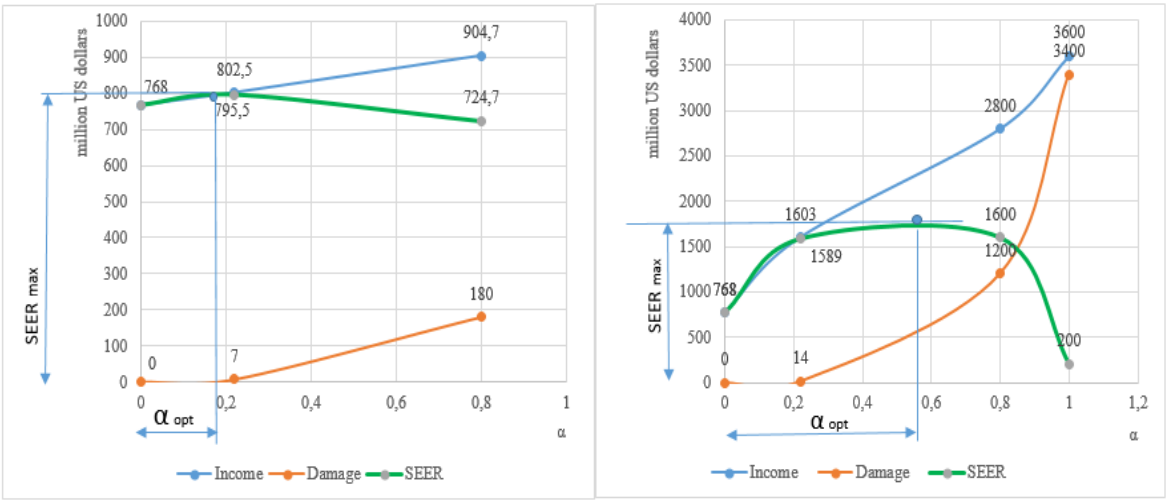

Figure 2. Dynamics of income changes, environmental damage, and criteria of ecological -economic results with varying degrees water resources use (on the example of the Ile River).

As can be seen from the graphs, at the current level of water use technology, the optimal level of water use of a water source is α = 0.18. With an increase in water intake from a water source, the income of economic sectors increases. We see that the negative consequences of depletion and pollution of the water source for the environment also increase, and the first indicator doubles as the second. At the same time, we can see that the socio-environmental and economic indicator, on the contrary, has gradually decreases.

In the case of the use by water consumers of advanced technologies for the use of water resources at α = (0.2–0.4), the incomes of economic sectors and additional economic effects increase, and at the same time the damage to the environment in the river basin increases. However, reaching the level α = (0.55) of water resources use, the socio-ecological and economic indicator begins to decline and tend to zero in the case of full use of the river flow, that is at α = 1.0.

Priority water consumers. When drawing up a water balance, different ratios between its discharge and inflow parts are possible, namely: water resources are sufficient and their distribution in time in all points of the territory provides coverage of water consumption schedules taking into account necessary transit water releases, i.e. the balance is positive. In this case there is no water deficit in this region. In order to increase economic efficiency of water resources use it is possible to develop and expand branches of economy.

Thus developed structure will allow to solve a problem on perfection of principles and methods of balanced management of water distribution on irrigation systems taking into account hydrological information, operating regimes of water facilities and possible variants of economic branches development both on neighboring territories and in the Republic of Kazakhstan under condition of ecological equilibrium preservation in environment.

Conclusions

Currently, as a result of the development of natural resources (including water resources), the gross product of economic sectors is increasing, environmental pollution is increasing at the same time, changes are taking place in the ecological state of the bio- and hydrosphere due to man-made impacts on them. Global climatic changes also affect the size of the formed river flow. Therefore, it is necessary to develop scientific and methodological principles for the rational use and protection of water resources of the river basin, taking into account anthropogenic and climatic impacts.

The proposed scientific and methodological basis for the rational use and protection of water resources of the river basin consists of two stages. At the first stage, the optimal level of use of water resources of the river basin is determined based on hydrological information, taking into account the formation of its resources.

At the second stage, a comprehensive functional structure for the management of technological processes of water use in irrigation systems is being developed, which is the basis for the development of principles and methods of balanced water distribution management in irrigation systems based on hydrological information, taking into account the formation of water resources in river basins.

The existing structure of water resources solves the problems of providing irrigation water to reclamation systems. Yet, it does not take into account the complexity of tasks for the formation of the water regime of the irrigation source at the present level and possible schemes for the use of water resources in the future. Also, it does not solve the issues of providing priority water consumers with water both above and below the intake of the irrigated massif and ensuring environmental safety in the river basin.

The proposed integrated functional structure of water resources management is the basis for the development of principles and methods of balanced water distribution management in irrigation systems based on hydrological information, taking into account the formation of water resources in river basins. It will make it possible to use the resources of a water source, both at the current and prospective level of development of economic sectors, meeting the water needs of all water consumers, including natural complexes, and ensuring the environmental safety of regions.

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